

PVCON 2018

PHOTOVOLTAIC CONFERENCE

International Conference on Photovoltaic Science and Technologies

Middle East Technical University
4-6 July 2018 | Ankara - Turkey

ABSTRACT BOOK

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Science and Technologies

Book Of Abstracts

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First International Conference on Photovoltaic Science and Technology (PVCon2018) will be organized on July 4-6, 2018, at Middle East Technical University, Cultural and Convention Center in Ankara-Turkey.

PVCon conference series is replacing SolarTR conferences we have been organizing in Turkey since 2010. With the new name and more international perspectives, PVCon conferences will be stronger and more comprehensive with an intensive participation from national and international PV community.

PVCon conference series is intended to be focused solely on scientific and technical issues with high quality oral and poster presentations. Some selected papers will be published at respective international journals.

PVCon2018 coincides with the increased efforts on the usage of solar energy in Turkey. One of the largest solar plant is expected to be built in Turkey in the coming years. A large manufacturing facility for Si wafer, cell and module is being constructed in Ankara, close to PVCon2018 conference venue.

We expect participations both from research institution and industry from Turkey and all over the world.

I hope that you accept our invitation and see you in Ankara at this important event.

With my best regards

Prof. Dr. Raşit TURAN
Conference Chair

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Conference Program

July 4th, 2018 (Wednesday)	
08:30 - 09:00	REGISTRATION
SESSION 1 (09:00 - 10:30)	OPENING & CURRENT PANORAMA OF PV SCIENCE AND TECHNOLOGY (Chair: <i>B. G. Akınoğlu</i>) METUCCC Hall A
09:00 – 09:15	Opening address (<i>R. Turan</i>)
09:15 – 09:45	Keynote Speaker: Dr. W. Sinke (University of Amsterdam, Netherlands) <i>“Photovoltaics towards global impact”</i>
09:45 – 10:15	Keynote Speaker: Dr. S. Kurtz (National Renewable Energy Laboratory, USA) <i>“What is known, unknown, and why we shouldn’t “look the other way””</i>
10:15 – 10:30	F. Es (METU-GÜNAM, Turkey) <i>“Metal assisted texturing routes for low cost, industrial, black c-Si solar cells”</i>
10:30 - 11:00	Coffee Break
SESSION 2 (11:00 - 12:30)	ADVANCED c-Si TECHNOLOGIES - I (Chair: <i>I. Gordon</i>) METUCCC / Hall A
11:00 – 11.30	Keynote Speaker: Dr. S. Glunz (Fraunhofer ISE, Germany) <i>“Carrier-selective contacts for high-efficiency silicon solar cells”</i>
11:30 – 12:00	Keynote Speaker: Dr. S. De Wolf (KAUST, Saudi Arabia) <i>“Passivating contacts for silicon and perovskite solar cells”</i>
12:00 – 12.15	E. Dönerçark (METU-GÜNAM, Turkey) <i>“Single step lithography free inverted pyramids”</i>
12:15 – 12.30	G. Nogay (EPFL, Switzerland) <i>“Passivating contacts with high and low thermal budgets for high-efficiency c-Si solar cells”</i>
12:30 - 14:00	Lunch

<p>SESSION 3 (14:00 - 15:30)</p> 	<p>PEROVSKITE SOLAR CELLS – I (Chair: <i>S. Yerci</i>)</p>  <p style="text-align: right;">METU-CCC / Hall A</p>
<p>14:00 – 14.30</p> <p>14:30 – 14:45</p> <p>14:45 – 15.00</p> <p>15:00 – 15.15</p> <p>15:15 – 15.30</p>	<p>Keynote Speaker: Dr. M. K. Nazeeruddin (EPFL, Switzerland) <i>“Stable perovskite solar cells by compositional and interface engineering”</i></p> <p>M. Carnie (Swansea University, UK) <i>“Recombination and ion migration in triple mesoporous perovskite solar cells”</i></p> <p>S. Sönmezoğlu (Karamanoğlu M. Univ. Turkey) <i>“Strategies for improving the stability of perovskite solar cells”</i></p> <p>S. Rafizadeh (Fraunhofer ISE, Germany) <i>“Evaporation-based perovskite solar cells: Promising methods with reproducible high efficiencies for tandem applications”</i></p> <p>C. Zafer (Ege University) <i>“Performance and stability improvement by interface engineering on triple-cation perovskite solar cells”</i></p>
<p>15:30 - 16:00</p>	<p>Coffee Break</p>
<p>SESSION 4 (16:00 - 17:45)</p> 	<p>ADVANCED c-Si TECHNOLOGIES - II (Chair: <i>M. K. Nazeeruddin</i>)</p>  <p style="text-align: right;">METU-CCC / Hall A</p>
<p>16:00 – 16.30</p> <p>16:30 – 17:00</p> <p>17:00 – 17.15</p> <p>17:15 – 17.30</p>	<p>Keynote Speaker: Dr. I. Gordon (IMEC, Belgium) <i>“Cell and module fabrication options for kerfless, thin epitaxial Silicon foils: Progress and challenges”</i></p> <p>Keynote Speaker: Dr. H. Kuehnlein (RENA, Germany) <i>“Metal-free texturing for diamond-wire-sawn multi-crystalline silicon (DWS-mc)”</i></p> <p>F. Keleş (Niğde Ö. Halisdemir Univ., Turkey) <i>“A smart way of pyramidal silicon properties’ improvement for PV applications by hips technique”</i></p> <p>B. Radfar (METU-GÜNAM, Turkey) <i>“Effects of different laser modified surface morphologies and post-texturing cleanings on Si wafer”</i></p>
<p>18:00 - 20:00</p>	<p>POSTER SESSION</p>  <p style="text-align: right;">METU-CCC</p>
<p>19:00 - 21:00</p>	<p>Welcome reception</p>  <p style="text-align: right;">METU-CCC</p>



July 5th, 2018 (Thursday)	
08:30 - 09:00	REGISTRATION
SESSION 5 (09:00 - 10:30) 	THIN FILM SOLAR CELLS – I (Chair: Ç. Erçelebi)  METU-CCC / Hall A
09:00 – 09:30	Keynote Speaker: Dr. C. Becker (HZB, Germany) <i>“Light management in thin-film silicon and perovskite-silicon tandem solar cells”</i>
09:30 – 10:00	Keynote Speaker: Dr. A. Ennaoui (IRESEN, Morocco) <i>“Ink formulation and inkjet printing as Key Enabling Strategy for low-cost thin film photovoltaic: Application for processing $Cu_2ZnSn(SxSe1-x)_4$ (CZTSS) and $Cu(In,Ga)(SxSe1-x)_2$ (CIGSS) solar cells”</i>
10:00 – 10:15	G. Aygün (Izmir Institute of Technology-IYTE, Turkey) <i>“Investigation of Mo back contact annealing effect on the conversion efficiency of magnetron sputtered Cu_2ZnSnS_4 thin film solar cells”</i>
10:15 – 10:30	Y. S. Ocak (Dicle Univ., Turkey) <i>“Ultrasonically sprayed Cu_2CdSnS_4 solar cells”</i>
10:30 - 11:00	Coffee Break
SESSION 6 (11:00 - 12:00) 	ŞİŞECAM SPECIAL SESSION (Chair: G. Aygün)  METU-CCC / Hall A
11:00 – 11.15	R. Budakoglu (Şişecam, Turkey) <i>“Antireflection coatings on sandy patterned PV cover glass: Optical design, processing and characterization”</i>
11:15 – 11:30	M. Ünal (METU-GÜNAM, Turkey) <i>“Development of textured glass substrates by aluminum induced texturing method”</i>
11:30 – 11:45	Ö. Tuna (Şişecam, Turkey) <i>“In line magnetron sputtering growth and characterization of Ga-doped ZnO thin films”</i>
11:45 – 12.00	L. Kılıç (Şişecam, Turkey) <i>“Sisecam energy glasses: Overview of glass production and the installation of a 6.209 MW roof-top PV system at the Mersin plant”</i>
12:00 - 14:00	Lunch

<p>SESSION 7 (14:00 - 15:30)</p> 	<p>PV MODULE PERFORMANCE AND RELIABILITY – I (Chair: <i>A. Ennaoui</i>)</p>  <p style="text-align: right;">METU-CCC / Hall A</p>	
<p>14:00 – 14.30</p> <p>14:30 – 15.00</p> <p>15:00 – 15.15</p> <p>15:15 – 15.30</p>	<p>Keynote Speaker: Dr. S. Oktik (Şişecam, Turkey) <i>“A brief review of common failures through a life cycle of wafer-based crystalline photovoltaic modules”</i></p> <p>Keynote Speaker: D. Tonini (Applied Materials, Italy) <i>“Shingled modules technology and process integration”</i></p> <p>T. Özden (Gümüşhane Univ., Turkey) <i>“Performance and degradation analyzes of two different PV modules in the Central Anatolia”</i></p> <p>C. Hajjaj (IRESEN, Morocco) <i>“Experimental validation of non-linear empirical model to simulate the photovoltaic production under semi-arid climate. Case study of Benguerir, Morocco”</i></p>	
<p>15:30 - 16:00</p>	<p>Coffee Break</p>	
<p>SESSION 8 (16:00 - 17:30)</p> 	<p>ORGANIC PHOTOVOLTAICS and DSSC (Chair: <i>Ş. Oktik</i>)</p>  <p style="text-align: right;">METU-CCC / Hall A</p>	<p>INDOOR AND OUTDOOR TESTING, SOLAR ENERGY RESOURCE AND PV SOLAR INPUT ASSESSMENT, STORAGE FOR PV APPLICATIONS (Chair: <i>H. Nasser</i>)</p>  <p style="text-align: right;">METU-CCC / Hall B</p>
<p>16:00 – 16.15</p> <p>16:15 – 16.30</p> <p>16:30 – 16.45</p> <p>16:45 – 17.00</p> <p>17:00 – 17.15</p> <p>17:15 – 17.30</p>	<p>G. Günbaş (METU-GÜNAM, Turkey) <i>“New DPP and selenophene based NIR absorbing polymers for organic solar cell applications”</i></p> <p>A. Pockett (Swansea University, UK) <i>“Studying degradation in OPV devices using a combination of frequency and time domain optoelectronic techniques”</i></p> <p>B. Tekin (Karamanoğlu Mehmetbey Univ. Turkey) <i>“Effect of ionic liquids on Cu₂S counter electrode-based quantum dot-sensitized solar cells”</i></p> <p>U. Olgun (Sakarya University, Turkey) <i>“Poly(triphenylamine-thiazolo[5,4-d] thiazole) copolymer dye for bulk-heterojunction organic solar cells”</i></p> <p>M. E. Özser (METU- NCC, T.R. of N. Cyprus) <i>“Synthesis and properties of regioisomerically pure 1,7-disubstituted perylene dyes”</i></p> <p>M. Mazhar (NEDUET, Pakistan) <i>“Dye-sensitized solar cells with graphene counter electrode”</i></p> <p>Keynote Speaker: S. Ransome (SRCL, UK) <i>“Solar PV design, performance and measurement”</i></p> <p>•</p> <p>•</p> <p>•</p> <p>•</p> <p>•</p> <p>A. B. Karaveli (METU-GÜNAM, Turkey) <i>“Determining PV module performance and comparisons”</i></p> <p>S. Kaynak (Sakarya University, Turkey) <i>“GPU-assisted ray-tracing algorithm for solar light analysis on PV panels”</i></p> <p>B. Tuncel (METU-GÜNAM, Turkey) <i>“Thermal modeling of PV module temperature and yield and the verification using the outdoor measurements for Ankara”</i></p> <p>R. Samu (METU- NCC, T.R. of Northern Cyprus) <i>“Techno-economic analysis of PV-hydrogen fuel cell/pumped hydro storage system for micro-grid applications: Case study in Cyprus”</i></p>	
<p>17:40 - 18.00</p>	<p>POSTER AWARDS</p>  <p style="text-align: right;">METU-CCC / Hall A</p>	
<p>19:30 - 21:30</p>	<p>GALA Dinner (*To learn the registration and fee details, please contact Gence Bektaş (gencebektas@gmail.com))</p>  <p style="text-align: right;">METU Vişnelik</p>	



July 6th, 2018 (Friday)	
08:30 - 09:00	REGISTRATION
SESSION 9 (09:00 - 10:30) 	<p>PEROVSKITE SOLAR CELLS – II (Chair: <i>S. Sönmezoğlu</i>) Depart. of Physics / Auditorium-U2</p>
09:00 – 09:30	<p>Keynote Speaker: Dr. A. Agresti (URTV, Italy) <i>“The future of perovskite solar cells between stability and scaling-up: The role of 2D materials”</i></p>
09:15 – 09:30	.
09:30 – 09:45	<p>E. Uğur (KAUST, Saudi Arabia) <i>“Charge carrier dynamics in metal halide perovskite solar cells after humidity and light exposure”</i></p>
09:45 – 10:00	<p>B. Kılıç (Yalova Univ., Turkey) <i>“The application of two-dimensional WS₂ nanomaterials as hole transport layers in perovskite solar cells”</i></p>
10:00 – 10:15	<p>M. Ouafi (Mohammed V Univ., Morocco) <i>“The effect of the halide chemical substitution to improve the UV stability of the MAPbI₃ perovskite”</i></p>
	<p>PV MODULE PERFORMANCE AND RELIABILITY – II (Chair: <i>R. Balog</i>) Depart. of Physics / Auditorium-U3</p>
	<p>F. B. Özkul (Karabük Univ., Turkey) <i>“Investigating the effects of cooling options on photovoltaic panel efficiency: State of the art and future plan”</i></p>
	<p>A. Bouaichi (IRESEN, Morocco) <i>“Evaluation of the crystalline photovoltaic modules: Performance drops affected by snail trails defect”</i></p>
	<p>D. Tolgay (METU-GÜNAM, Turkey) <i>“Daily and monthly module temperature variation for 9 different modules”</i></p>
	<p>S. Moulahoum (University of Médéa, Algeria) <i>“PV module parameters extraction using the flower pollination algorithm”</i></p>
	<p>F. Serttaş (Afyon Kocatepe Univ, Turkey) <i>“An experimental study on the modeling of the PV output”</i></p>
10:30 - 11:00	Coffee Break
SESSION 10 (11:00 - 12:30) 	<p>OPTICS AND PHOTONICS FOR PV APPLICATIONS (Chair: <i>A. Bek</i>) Depart. of Physics / Auditorium-U2</p>
11:00 – 11:15	<p>H. Ş. Kılıç (Selçuk Univ., Turkey) <i>“The effect of Ag plasmonic nanoparticles embedded into the active layer by pulsed laser deposition technique”</i></p>
11:15 – 11:30	<p>S. Yerci (METU-GÜNAM, Turkey) <i>“Exceeding the Shockley Queisser limit via tandem solar cells and spectrum rehaping”</i></p>
11:30 – 11:45	<p>K. Zineb (Mohammed V Univ., Morocco) <i>“Potential of strained SnO₂ as a photo-catalyst for water splitting process”</i></p>
11:45 – 12:00	<p>H. Efeoğlu (Atatürk University, Turkey) <i>“2D power mapping of n⁺⁺/p⁺⁺/a^l crystalline silicon solar cells”</i></p>
12:00 – 12:15	<p>K. Salimi (Ankara Yıldırım Beyazıt Univ., Turkey) <i>“Plasmonic mesoporous Ag@TiO₂ and Ag@Au@TiO₂ nanocomposites for efficient light harvesting in dye sensitized solar cells”</i></p>
12:15 – 12:30	<p>E. Yüce (METU-GÜNAM, Turkey) <i>“Investigation of spectral splitting and solar concentration using diffractive optical elements at oblique angles”</i></p>
	<p>PV POWER PLANTS AND BIPV, ECONOMICS OF SOLAR PV (Chair: <i>R. Sari</i>) Depart. of Physics / Auditorium-U3</p>
	<p>W. Rohouma (Texas A&M University, Qatar) <i>“D-STATCOM for a distribution network with distributed PV generation”</i></p>
	<p>A. Azami (EMU, T.R. of Northern Cyprus) <i>“Modeling and re-designing of Tabriz International Airport in Iran approaching BIPV”</i></p>
	<p>E. Demirezen (METU-GÜNAM, Turkey) <i>“Impacts of a PV power plant for possible heat island effect”</i></p>
	<p>N. Rahman (Dalarna University, Sweden) <i>“Potential use of the solar rooftop photovoltaic system in building energy management under energy efficiency and conservation policies: Economic feasibility analysis”</i></p>
	<p>D. Kilit (Ege Univ., Turkey) <i>“Economic analysis and comparison of 990 kW ground-mounted photovoltaic power plants under Turkey’s regulation scheme”</i></p>
	<p>I. Karadöl (Kilis 7 Aralık Univ., Turkey) <i>“Cost-benefit analysis of the solar power plant: A case study”</i></p>
12:30 - 14:00	Lunch

<p>SESSION 11 (14:00 - 15:30)</p> 	<p>THIN FILM SOLAR CELLS – II (Chair: G. Günbaş)</p>  <p>Depart. of Physics / Auditorium-U2</p>	<p>ADVANCED DEVICE CONCEPTS AND NEW MATERIALS (Chair: M. Özenbaş)</p>  <p>Depart. of Physics / Auditorium-U3</p>
<p>14:00 – 14.15</p> <p>14:15 – 14.30</p> <p>14:30 – 14:45</p> <p>14:45 – 15:00</p> <p>15:00 – 15:15</p> <p>15:15 – 15:30</p>	<p>A. Cantaş (Pamukkale Univ., Turkey) <i>“Effect of precursors’ stacking order on the phase of Cu₂ZnSnS₄ absorber layer for thin film solar cell applications”</i></p> <p>E. Ketenci (Ondokuz Mayıs Univ., Turkey) <i>“Production and characterization of Cu₂SnS₃ absorber layers for photovoltaic solar cell applications”</i></p> <p>H. Yıldırım (Uludağ Univ., Turkey) <i>“Electrochemical properties of cadmium telluride thin films”</i></p> <p>S. Yiğit Gezgin (Selçuk Univ., Turkey) <i>“CZTS solar cell structure produced by pulsed laser deposition technique”</i></p> <p>A. Kıyak Yıldırım (Bilecik Ş.E. Univ., Turkey) <i>“CDS thin films obtained chemical bath deposition for thin film solar cell”</i></p> <p>B. Altıokka (Bilecik Ş.E. Univ., Turkey) <i>“Electrodeposition of CDO thin films for solar cells”</i></p>	<p>V. Kızıloğlu (Gazi Univ., Turkey) <i>“Size dependent intermediate band energy levels and absorption of bound states in box shaped quantum dots”</i></p> <p>M. Barbouche (CRTEEn, Tunisia) <i>“Silicon carbide purification by formation of thin porous layer followed by thermal annealing for silicon passivation”</i></p> <p>C. Dumitru (Politehnica Uni. of Bucharest, Romania) <i>“Electro optical analysis and numerical modeling of Cu₂O layer for advanced solar cells – A review”</i></p> <p>S. Oudjertli (Badji Mokhtar University, Algeria) <i>“Microstructural properties of ZnO powder nanostructures prepared by mechanical alloying”</i></p> <p>N. Ghifari (Paris-Saclay University, France) <i>“Droplet-based self-organized ZnO surfaces for photovoltaic applications”</i></p> <p>L. Souad (Universite Ferhat Abbas Setif 1, Algeria) <i>“Study of the structural, optical and electrical properties of thin layers of ZnO obtained by vacuum evaporation”</i></p>
<p>15:30 - 16:00</p>	<p>Coffee Break</p>	
<p>SESSION 12 (16:00 - 17:30)</p> 	<p>THIN FILM SOLAR CELLS – III (Chair: M. Parlak)</p>  <p>Depart. of Physics / Auditorium-U2</p>	<p>PV MODULE PERFORMANCE AND RELIABILITY – III (Chair: F. Es)</p>  <p>Depart. of Physics / Auditorium-U3</p>
<p>16:00 – 16.15</p> <p>16:15 – 16:30</p> <p>16:30 – 16.45</p> <p>16:45 – 17:00</p> <p>17:00 – 17.15</p> <p>17:15 – 17.30</p>	<p>N. Akçay (Gazi Univ., Turkey) <i>“Investigations on Cu₂ZnSnSe₄ thin films prepared by selenization of RF-sputtered metallic stacks”</i></p> <p>A. B. Gite (SNJB, India) <i>“Electrochemical behavior and effect of reverse potential on electrodeposition of lead telluride thin film on fluorine doped tin oxide substrate”</i></p> <p>M. A. Olgar (Niğde Ö. H. Univ., Turkey) <i>“Influence of Cu and Sn alloy on the properties of Cu₂ZnZnS₄ (CZTS) based thin film solar cells”</i></p> <p>M. Barbouche (CRTEEn, Tunisia) <i>“Effect of argon dilution on the morphological, optical and electrical properties of hydrogenated amorphous silicon carbide thin films grown by plasma enhanced chemical vapor deposition”</i></p> <p>T. Özdal (Çukurova Univ., Turkey) <i>“Elemental analysis of sol-gel spin-coated CZTS thin films for photovoltaic applications”</i></p> <p>Y. Demirhan (IYTE, Turkey) <i>“Controllable deposition of large area roll-to-roll sputtered ITO thin films for photovoltaic applications”</i></p>	<p>M. Çubukçu (Ege Univ, Turkey) <i>“Real-time fault detection of photovoltaic power systems by thermal imaging in Turkey”</i></p> <p>B. Laarabi (Mohammed V Univ., Morocco) <i>“Soiling chemical composition mapping of PV modules in different Moroccan areas”</i></p> <p>F. Serttaş (Afyon Kocatepe Univ, Turkey) <i>“Short term solar power generation forecasting: A novel approach”</i></p> <p>F. B. Özkul (Karabük Univ., Turkey) <i>“Comparison of different cooling options for photovoltaic applications”</i></p>
<p>17:30 - 18:00</p>	<p>Closing Remarks & End of PVCON2018</p>	

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PHOTOVOLTAICS TOWARDS GLOBAL IMPACT

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Photovoltaic solar energy (PV) has demonstrated spectacular cost reduction and performance enhancement over the past decades. Cumulative global installations are expected to reach the terawatt level soon after 2020. This success even causes some people to believe that PV is fully mature and can do without further ambitious innovation programs. However, PV is rather just at the beginning of its life. For big global impact, deployment needs to increase by almost two orders of magnitude and this has to be done as soon as possible. System and generation costs need to, and can be decreased substantially further to allow for large-scale conversion of power to heat and to fuels (P2X). Typical performance levels can be at least doubled, thereby aiding to cost reduction and enhancing installation potential when area is limited or expensive. Moreover, PV has to develop from a “one size fits all” technology to a technology toolbox that offers an attractive and affordable solution for a wide variety of applications. Last but not least, the sustainability profile of PV has to be improved further, a.o. by implementing design-for-sustainability concepts. This presentation will give an overview of the impressive achievements, the main drivers for further development and the technical and socio-economic challenges of PV.

WHAT IS KNOWN, UNKNOWN, AND WHY WE SHOULDN'T “LOOK THE OTHER WAY”

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As the PV industry has grown and prices have dropped precipitously, the question arises: “Will the new, lower priced PV actually work?”. This talk will review some of the technical challenges toward making low-cost PV work for a lifetime and the progress that has been made toward addressing these, including the effects of new (e.g. glass-glass designs) module designs, the importance of controlling the installation process, and simply knowing what questions to ask. Fraudulent (cells replaced by paper replicas) have been found in Africa and should not be allowed into Turkey! The keys to success are to start with a commitment to high reliability and strong quality control, then follow through to ensure that the results are as desired.

CARRIER-SELECTIVE CONTACTS FOR HIGH-EFFICIENCY SILICON SOLAR CELLS

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Traditional crystalline solar cells feature doped junctions like diffused phosphorus emitters or alloyed aluminum back surface fields. Such technologies are well-understood and robust in mass production. However, since the increased doping level within the silicon absorber increases the level of intrinsic charge carrier recombination, i.e. Auger recombination, this technology limits inherently the efficiency potential. Therefore, to allow cell efficiencies closer to the theoretical limit, it is beneficial to spatially separate the carrier separation from carrier generation. This concept is known as carrier-selective or passivated contacts. The best known example is the a-Si/c-Si heterojunction as used by Sanyo/Panasonic or Kaneka successfully for their record cells. Also the highly efficient interdigitated back contact solar cells fabricated by SunPower are utilizing passivated concepts. At Fraunhofer ISE the TOPCon technology based on a thin tunnel oxide and a heavily doped recrystallized PECVD-deposited silicon layer has led to efficiencies of 25.8% and 22.3% on mono- and multicrystalline silicon, respectively. Recently, “silicon-free” approaches based on metal oxide layers like MoOx have shown a very high potential. This talk will give an overview over the different available technologies.

PASSIVATING CONTACTS FOR SILICON AND PEROVSKITE SOLAR CELLS

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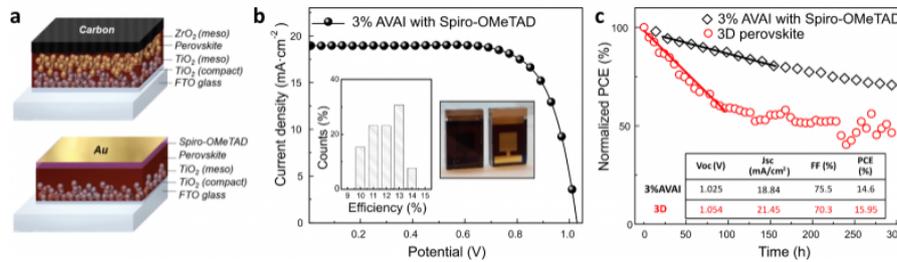
In silicon and perovskite solar cells, carrier recombination at the electrical contacts is increasingly recognized as a key factor limiting device performance. In this presentation we discuss the different available strategies to passive contacts of both types of photovoltaic technologies. Implementing such contacts opens the road to solar cells working in their radiative limit.

STABLE PEROVSKITE SOLAR CELLS BY COMPOSITIONAL AND INTERFACE ENGINEERING

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Despite the impressive photovoltaic performances with power conversion efficiency beyond 22%, perovskite solar cells are poorly stable under operation, failing by far the market requirements.¹ Various technological approaches have been proposed to overcome the instability problem, which, while delivering appreciable incremental improvements, are still far from a market-proof solution. In this talk we show one-year stable perovskite devices by engineering an ultra-stable 2D/3D (HOOC(CH₂)₄NH₃)₂PbI₄ /CH₃NH₃PbI₃ perovskite junction. The 2D/3D forms an exceptional gradually-organized multidimensional interface that yields over 15% efficiency in standard mesoporous solar cells. To demonstrate the up-scale potential of our technology, we fabricate 10×10 cm² solar modules by a fully printable industrial-scale process, delivering 11% efficiency stable for more than 10,000 hours with zero loss in performances measured under controlled standard conditions.



CELL AND MODULE FABRICATION OPTIONS FOR KERFLESS, THIN EPITAXIAL SILICON FOILS: PROGRESS AND CHALLENGES

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Advancement in conventional and kerfless wafering is enabling sub-100 μm wafer thicknesses which necessitates a rethink about how flexible, light-weight and fragile thin Silicon wafers and foils can be handled and processed into solar modules with high mechanical yield. This paper provides a broad overview of the different cell and module fabrication approaches, specifically focusing on the progress and challenges in freestanding processing as well as supported processing of thin Silicon when bonded to a conductive low-cost Silicon substrate or to a glass superstrate, and by extension module-level cell processing on module glass. Kerfless 50 μm -thick epitaxial Silicon foils lifted-off using porous silicon are used as model substrates for this work.

METAL-FREE TEXTURING FOR DIAMOND-WIRE-SAWN MULTI-CRYSTALLINE SILICON (DWS-MC)

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Since diamond-wire-sawing had its break through on Cz-silicon, the price for Cz-silicon and mc-silicon converges. On the one hand because of capacity increase for Cz-silicon, on the other hand it is possible to give the benefit in sawing one-to-one to the end of the value chain. Only minor changes have to be implemented, i.e. the texturing process has to be adapted slightly - the rest of the process chain stays the same.

Typical solutions for the DWS-mc texturing issue are e. g. the Reactive-Ion-Etching (RIE) texturing and the Metal-Assisted-Etching (MAE)-texturing. Both solutions are suffering from extremely high investment costs and extensive subsequent-cleaning steps after texturing process, which increase the machine footprint and the chemistry consumption.

The RENA solution is based on an organic additive optimized for mc-Si Wafers. The additive dw-TEX (diamond-wire texture) yields an effective texture on DWS wafer surfaces. The reflection is similar to slurry sawn wafers with default HF/HNO₃ texture and is typically between 25-27% (weighted average from 400 to 1100 nm). The additive dw-TEX promise slightly higher efficiency of up to +0,1/0,2% compared to slurry wafers. Cell results from industrial production will be shown at EUPVSEC in September 2018. The dosage unit can be integrated in existing InTex tools. The additive dw-TEX promise slightly lower reflectance and higher efficiency from up to +0,1/0,2%. Industrial cell results from production will be shown at EUPVSEC in September 2018.

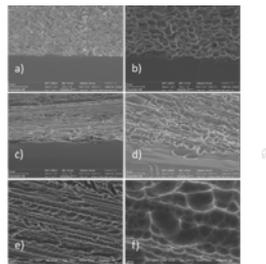


Figure 1: a) SEM-picture of a Slurry-mc wafer as cut. b) SEM-picture of a Slurry-mc wafer, HF/HNO₃ t

LIGHT MANAGEMENT IN THIN-FILM SILICON AND PEROVSKITE-SILICON TANDEM SOLAR CELLS

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Light management is a key element for boosting the efficiency of photovoltaic devices via minimizing optical losses. Tailored nano- and microstructures, which are implemented into the solar cell, have proven to exhibit excellent broadband antireflective as well as light trapping properties. The main technological challenge is the design of nanostructured interfaces enabling efficient light trapping without negatively affecting the electronic absorber material quality or interfaces in the solar cell. Here, we present light management strategies based on nanoimprint-lithography for two different emerging solar cell technologies:

(1) Liquid phase crystallization (LPC) of 5 - 40 μm thick silicon films being grown and crystallized directly on a glass substrate is a promising technology avoiding current challenges of wafer based solar cells, namely high material losses and handling issues particularly arising at very low wafer thicknesses. Scanning a line-shaped laser beam across silicon films on glass leads to the formation of large-grained polycrystalline material comparable with multi-crystalline silicon wafers, which enables solar cells with open-circuit voltages exceeding 650 mV. However, the highest demonstrated efficiency of state-of-the-art LPC silicon solar cells is still only about 14% due to incomplete light absorption, mainly caused by reflection losses at the planar front interfaces of the device. Therefore, we developed a smooth anti-reflective three-dimensional (SMART) texture based on titanium and silicon oxides, leading to a morphologically flat but optically rough layer system. The SMART texture was found to excellently overcome the trade-off between optical gain and texture-induced electronic losses with open-circuit voltage values up to 650 mV and an increased short-circuit current density compared to optimized planar devices, which were simultaneously processed. This paves the way towards efficiencies around 18%.

(2) Perovskite-silicon tandem solar cells are currently one of the most investigated concepts for overcoming the theoretical limit of the power conversion efficiency of silicon solar cells. For a state-of-the-art monolithic device design with planar interfaces, strong reflection and parasitic absorption limit device performance even after optimization of the layer thicknesses. As the realization of perovskite top cells on silicon bottom cells with pyramidal texture is challenging, we investigated shallow two-dimensional sinusoidal nanotextures. In a first attempt, we experimentally realized such sinusoidal structured perovskite solar cells for application in monolithic tandems on nanoimprinted substrates. Numerical simulations reveal that sinusoidal nanotexturing of the perovskite top cell allows current matching to be reached, an increase of current density by more than 1.6 mA/cm² in each sub cell and a power conversion efficiency of 31.8% at the standard perovskite bandgap.

INK FORMULATION AND INKJET PRINTING AS KEY ENABLING STRATEGY FOR LOW-COST THIN FILM PHOTOVOLTAIC: APPLICATION FOR PROCESSING $\text{Cu}_2\text{ZnSn}(\text{SxSe}_{1-x})_4$ (CZTSS) AND $\text{Cu}(\text{In,Ga})(\text{SxSe}_{1-x})_2$ (CIGSS) SOLAR CELLS

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We report on the drop-on-demand (D-O-D) inkjet printing for processing thin films chalcogenide materials and related solar cells. The critical requirement for the formulation of the ink that can be reliably inkjet printed, enabling scalable development of photonic devices is highlighted. Our results based on suitable printable precursor inks obtained either by the synthesis of nanoparticle (NPs) approach or by dissolving suitable metal salts in organic solvents are presented. The standard concept Absorber/Buffer/Window was applied for the fabrication of $\text{Cu}_2\text{ZnSn}(\text{SxSe}_{1-x})_4$ (CZTSS) and $\text{Cu}(\text{In,Ga})(\text{SxSe}_{1-x})_2$ (CIGSS) based solar cells with high efficiencies..

A BRIEF REVIEW OF COMMON FAILURES THROUGH A LIFE CYCLE OF WAFER-BASED CRYSTALLINE PHOTOVOLTAIC MODULES

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The wafer based crystalline silicon photovoltaic module producers guarantee a product output with an annual loss against the initial value up to 25 years. Studies related to a better understanding of performance, failures and degradation throughout a module life time have accumulated a significant number of different mechanisms. Failure processes from macroscopic scale down to a molecular level and the main driving forces are well described in the literature (1,2,3). However, literature relating module failures to the power loss of photovoltaic systems to reduce an uncertainty in the PVPS performance are limited. The degradations mechanisms might be related to technology and materials used in every stage of production as well as quality of balance-of-system components together with design and installation of photovoltaic power systems.

This brief review will be focused on updated literature on the most common failures of wafer-based crystalline photovoltaic modules such as the light induced degradation (LID), the potential induced degradation (PID), junction box failures, defective bypass diodes, glass breakage, loose frame, browning of encapsulants, cell cracks, snail tracks, burn marks, disconnected cell and string interconnect ribbons, corrosion of the cell gridlines or fingers and stringing and tabbing ribbons and also soiling at different stage of the module life cycle.

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SHINGLED MODULES TECHNOLOGY AND PROCESS INTEGRATION

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Shingling technology is an extremely interesting development of cell interconnection in a module is due to higher power densities at same or lower cost, better energy yield, and good reliability. Shingled modules provide lower ohmic losses, better area utilization, lower processing temperature, lower operating temperature resulting in enhanced energy yield, improved aesthetics. In this work we demonstrate the performance gain obtained with shingling interconnection technology in terms of module output power and reliability.

SOLAR PV DESIGN, PERFORMANCE AND MEASUREMENT

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PV power performance is modelled either from indoor (usually matrix, flash test) or outdoor (time series) measurements. PV technologies (e.g crystalline Si, CdTe, CIGS) can depend differently vs. irradiance and module temperature. PV Performance models (e.g. equivalent circuit, curve fitting or empirical/mechanistic fit) derive their coefficients from fitting either IV curves or else just derived points (such as I_{sc} or V_{mp}). For dc energy predictions the power performance vs. plane of array irradiance and module temperature are summed from time series from site climate data (with plane of array calculations and thermal models). For AC performance the balance of systems components are also modelled (e.g. wiring loss, mismatch, inverter efficiency, shading etc.) Detailed data analysis can determine performance losses – tolerances, sensitivities to inputs, seasonal effects and degradation which should be minimised for optimum output.

THE FUTURE OF PEROVSKITE SOLAR CELLS BETWEEN STABILITY AND SCALING-UP: THE ROLE OF 2D MATERIALS

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Recently, the rise-up of perovskite solar cell (PSC) technology has been testified by the rapid increase of power conversion efficiency (PCE) overcoming 23% on small area device.[1] However, the scientific community is now facing up with stability and scalability issues that still prevent the final assessment of perovskite photovoltaics into the market. Indeed, the PSC life time is strongly affected by the operative conditions such as humidity, operating temperature and prolonged light soaking that activate irreversible degradation mechanisms in the bulk of organic/hybrid layers and at the device interfaces. Among them, metal atom diffusion from the counter-electrode toward the perovskite active layer is known to be thermally activated while light soaking induces phase segregation at perovskite/charge transport layer (CTL) interfaces by penalizing the charge injection/extraction at the electrodes and eventually the device PCE stability over time. Moreover, very few works reported about a feasible way to scale-up perovskite technology from lab-scale devices to large area modules, since the PCE falls suddenly down as soon as the active area dimension increases. This is mainly due to i) the increasing of contact series resistance (from the glass/FTO side), ii) the difficulty in controlling perovskite morphology and uniformity on large area substrates, iii) the role of interfacial charge recombination that became prominent as soon as the interfacial surface area increase.

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METAL ASSISTED NANO-TEXTURING ROUTES FOR LOW COST, INDUSTRIAL BLACK SI SOLAR CELLS

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Metal assisted etching (MAE) has been a commonly used method to form micro and nano structures on the surface of the silicon for antireflective and light trapping purposes. As a solution based method, application to large area is possible which is especially a significant problem for nano-structuring. Structures having desired geometry such as nanowires, nano-cones, micro-rods, etc., ranging from nanometer to micrometer sizes with random or periodic distribution can be obtained via MAE by adjusting process parameters. Other than nano-structuring for directly texturing, MAE is becoming a commonly used industrial method to condition the surface of the diamond cut multi-c wafers which cannot be textured via standard iso-texture processes. In this process, MAE is used to form etch pits on the smooth surface of diamond cut wafers that enables the random surface structuring; solving an industrial problem faced with the spread of next generation diamond wire cut wafers.

Keywords

black Silicon, metal assisted etching, nano texturing, solar cells, photovoltaics

SINGLE STEP LITHOGRAPHY FREE INVERTED PYRAMIDS

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Recent researches on Si based solar cells are focused on reducing optical losses and enhancing surface passivation quality [1,2]. Different surface modifications such as random alkaline pyramid texturing, Metal Assisted Etching (MAE) and black silicon (B-Si); which silicon surface reflectance value downs to around 2% [3]. Despite advantages coming from relatively low antireflection properties, B-Si solar cells are suffering from high surface recombination velocities due to the increased surface areas and difficulties on the surface passivation [4]. The obstacle coming from the relationship between surface recombination velocity and reflectance losses could be overcome by inverted pyramid (IP). The most common IP formation belongs to photolithography and wet chemical etch steps, which makes the process costly and challenging for mass production [5]. In contrast to common multi-step process cycle, we have demonstrated the single step lithography-free random IP texturing via $\text{Cu}(\text{NO}_3)_2:\text{HF}:\text{H}_2\text{O}_2$ solution at 50°C.

We are reporting a novel lithography-free, single-step Copper-assisted chemical etching process with controlled reaction temperature yielding randomly distributed, micro-sized IP structures with the star-shaped pyramids resulting in a low reflectance of around 2%. The solution itself assists the Cu nanoparticle to deposition to the surface of c-Si wafer. Depending on molarity of the chemical compounds of the etchant and reaction temperature, various surface morphologies could be achieved such as random IP's, star-shaped IP's and others structures. Furthermore, the electrochemical dependency of etchant will be examined under variation in half-cell reactions and dissociation constants for different reaction temperature resulting in several kind of surface topographies.

Keywords

Copper assisted etching, lithography-free, inverted pyramid

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PASSIVATING CONTACTS WITH HIGH AND LOW THERMAL BUDGETS FOR HIGH-EFFICIENCY C-SI SOLAR CELLS

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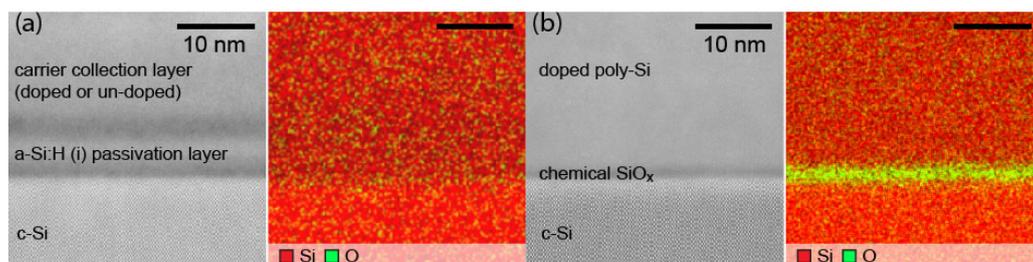
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Industrial c-Si solar cells are limited by recombination losses at the metal-semiconductor interface. This recombination path can be avoided by employing carrier-selective passivating contacts. In this contribution, the application of various passivating contacts with low- and high-thermal-budgets to the c-Si solar cells is presented. SHJ solar cells are studied as representatives for low-thermal-budget [Fig.1 (a)]. The application of the IO:Zr as front TCO in SHJ cells leads to J_{sc} gain due to the broadband transmittance and efficiencies up to 23.4% are attained [1]. Additionally, dopant-free carrier-collection layers are explored by sputtering MoO_x hole-selective layer and MgF_x/Mg electron-selective multilayer using a shadow-mask in back-contacted SHJ design; efficiencies up to 22.4% are achieved. Solar cells with oxide and doped poly-Si are investigated as the cell-concept for high-thermal-budget [Fig.1 (b)]. The in-situ doped SiC_x electron- and hole-selective passivating contacts are developed to attain low surface recombination. After PECVD deposition, the contacts are annealed and hydrogenated. The employed annealing condition is chosen to be compatible with typical solar cell processes, i.e. POCl₃ diffusion or firing. Therefore, our p-type rear-contact represents building blocks for gradual upgrades to existing manufacturing processes. Excellent surface passivation on p-type planar c-Si wafer is evidenced by iV_{oc} values of 735mV and 746mV for the hole and electron contacts, respectively. The performance of the high-thermal-budget SiC_x contacts is demonstrated at device level with a simple patterning-free process reaching an excellent current extraction and surface passivation with FF of 84%, V_{oc} of 727mV on flat cells, and efficiencies up to 22.6% with front-textured-cells.

Keywords

c-Si solar cells, passivating contacts, charge carrier transport, surface passivation, PECVD



STEM-HAADF micrographs of (a) SHJ contact and (b) chemical SiO_x and doped poly-Si contact.

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RECOMBINATION AND ION MIGRATION IN TRIPLE MESOPOROUS PEROVSKITE SOLAR CELLS

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Triple mesoporous layer devices containing a TiO₂ electron transport layer, a ZrO₂ insulating layer and carbon as the hole transporting contact show great promise for scale-up and wide spread implementation. To improve these devices and begin to challenge inorganic PV record efficiencies a deeper understanding of their operation, and in particular sources of performance loss, is needed.

The current state-of-the-art devices use a mixed cation perovskite, consisting of methylammonium and 5-aminovaleric acid (5-AVA). The cells undergo a slow light soaking effect during which time the JV performance of the device is vastly improved. They also show improvement when exposed to a high relative humidity.

A striking feature observed using TPV measurements is the presence of a negative photovoltage transient, comparable to that observed in our previous work on planar TiO₂ devices [1]. This behaviour suggests the presence of high rates of interfacial recombination at the TiO₂ surface. In these cells the phenomena is observed at room temperature and is very slow to disappear under continued illumination. For the planar devices the negative transient was shown to diminish over time as ions in the perovskite redistributed, leading to a reduction in the recombination rate. For the planar devices this effect was only observed at low temperature and disappeared much quicker than in the mesoporous carbon devices at room temperature. Knowledge of this process has allowed us to assess the impact of different treatments and processing conditions on interfacial recombination, which has helped to guide the improvement in device efficiency.

Keywords

perovskite, ion migration, hysteresis, recombination

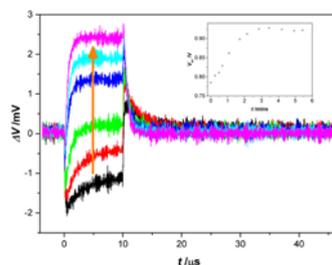


Figure 1. Disappearance of initial negative voltage transient over time as ions redistribute under photo

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STRATEGIES FOR IMPROVING THE STABILITY OF PEROVSKITE SOLAR CELLS

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Although perovskite solar cells (PSCs) have reached an efficiency exceeding 21%, to date, the stability of PSC devices is still unsatisfactory and is the main bottleneck impeding their commercialization. Therefore, long-term stability has been a fundamental challenge for PSC devices. Although strategies have been reported to solve this issue, these methods are introduced during the core-device fabrication processes which will increase the risk of introducing unexpected impurities during the fabrication. Here, we will summarize recent studies on the degradation mechanisms of organometal trihalide perovskites in PSC devices, and will talk about our works, offering a new strategy of simple shelf process to improve the stability and performance of perovskite-based optoelectronic devices.

Keywords

Perovskite solar cells (PSCs), Long-term stability

EVAPORATION-BASED PEROVSKITE SOLAR CELLS: PROMISING METHODS WITH REPRODUCIBLE HIGH EFFICIENCIES FOR TANDEM APPLICATIONS

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Perovskite solar cells became a game changer in the field of photovoltaics by reaching power conversion efficiencies (PCE) beyond 22%.^[1] Different fabrication methods have been suggested so far. Vacuum deposition methods have demonstrated efficiencies above 20% with no need to use toxic and flammable solvents such as dimethylformamide (DMF) and dimethylsulfoxide (DMSO).^[2-3] In this abstract, using a low temperature processed two-step hybrid evaporation-spincoating method, we addressed the challenges of high efficiency perovskite solar cells both in the bulk perovskite material level by compositional engineering of MAPbI₃ and in the solar cell interfaces by optimization of the perovskite-charge carrier interfaces. As a result, highly reproducible 18.2% stabilized PCE's have been achieved. Moreover, we implemented our optimized electron transport bi-layer in the fully evaporated perovskite solar cells yielding a 16% stabilized PCE. The evaporation based methods, promised deposition of a compact perovskite layer on highly efficient silicon solar cells. This enables surpassing the single junction efficiency limit of a silicon solar cell by harvesting the wider light spectrum through perovskite on silicon tandem configuration. Although to reach this goal, still some serious challenges need to be answered.

Keywords

evaporation-based perovskite solar cells, interface engineering, perovskite on silicon tandem

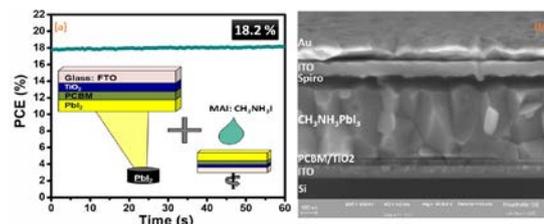


Figure 1. (a) Stabilized PCE of the hybrid deposited perovskite solar cell along with a schematic of the hybrid deposition method (b) cross section SEM image of the fully evaporated perovskite on silicon tandem solar cell.

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PERFORMANCE AND STABILITY IMPROVEMENT BY INTERFACE ENGINEERING ON TRIPLE-CATION PEROVSKITE SOLAR CELLS

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Since their first implementation as light absorbers in thin-film solar cells, Perovskite solar cells now exceed 22% efficiency in converting light to electricity and are set to challenge the performance of traditional silicon solar cells [1]. Given the low technological complexity, ease of fabrication and relatively low cost of production, perovskite technology is particularly attractive for countries, which currently import most of their solar cell infrastructure, but would benefit from cheap, readily accessible solar cell technology. Even though perovskite solar cells have several advantages, such as high efficiency along with a simple and low-cost synthesis, high absorption coefficient, long carrier lifetime, tunable band gap, long diffusion length, they suffer from several drawbacks, such as the relatively low charge carrier mobilities compared to silicon and gallium arsenide and a lack of long-term stability due to environmental moisture sensitivity. Multi cationic structures such as triple cation perovskite system (Cs_{0.05}FA_{0.81}MA_{0.14}Pb(I_{0.85}Br_{0.15})₃) were engineered to overcome the specified problems [2, 3]. Deviations of interfacial charge transfer resistances (R_{ct}) at the TiO₂/Perovskite and Perovskite/Spiro-OMeTAD interfaces were investigated under different annealing temperatures by means of impedance spectroscopy (IS). Photon to current conversion efficiencies (PCE) of over 19% were achieved with improved stability.

Keywords

perovskite solar cell, triple cation, interface

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A SMART WAY OF PYRAMIDAL SILICON PROPERTIES' IMPROVEMENT FOR PV APPLICATIONS BY HIPS TECHNIQUE

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Increment of light absorption while reducing the sheet resistance to effectively collect the photogenerated charge carriers is vital for an efficient photovoltaic device. Nanostructure formation by chemical etching has been applied on pre-patterned silicon in order to improve the light absorption. In this study, we further favored the nanostructure formation on pyramids by an additional ITO layer grown by high-pressure sputter (HIPS) technique before the chemical process. We directly deposited ITO on both pre-patterned pyramidal c-Si and standard glass slides under the high working gas pressure of 24 mTorr (Argon) by using an ITO target by means of RF sputter. We also carried out the annealing after ITO growth on both substrates at 200C for an half-hour under vacuum. We studied the morphology of the nanostructures synthesized on HIPS-ITO by using scanning electron microscopy (SEM). We operated the ellipsometer for the optical characterization and both contactless sheet resistance measurement and four-point probe systems to investigate the electrical properties of the samples, respectively. As a result, we observed that the sample with nanostructures formed on HIPS-ITO presents a more homogenous morphology with an improved optical property; namely, reduced reflection and increased absorption, compared to its counterpart without HIPS-ITO. In addition, it has been shown that the post-annealing improves the optical properties by reducing the sheet resistance from ~ 32 ohm/sq to ~ 7 ohm/sq. We claim that the simple yet novel method presented in this study is likely to open the pathway to improve the performance of the silicon based photovoltaic.

Keywords

optical properties, nanostructure, chemical etching, high pressure sputter

EFFECTS OF DIFFERENT LASER MODIFIED SURFACE MORPHOLOGIES AND POST-TEXTURING CLEANINGS ON SI WAFER

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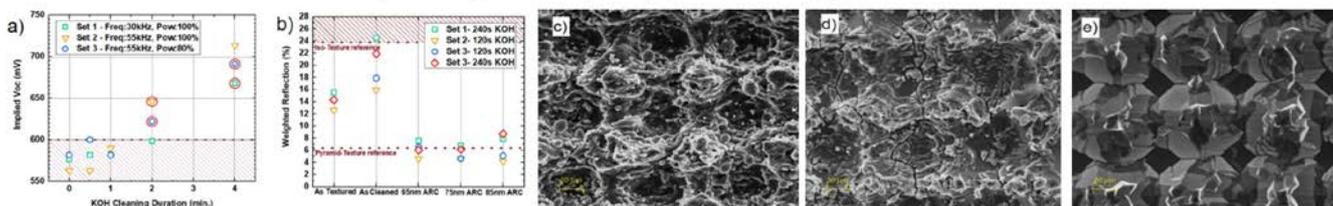
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The surface is one of the crucial parameters affecting the performance of crystalline silicon (cSi) solar cells by influencing both electrical and optical properties. To minimize reflection from the flat surface and consequently, improve the absorption, cSi wafers must be textured. Since using anisotropic alkaline etchants is not feasible for multicrystalline silicon due to the grains of random crystallographic orientations [1], this study utilizes laser texturing [2] to create pits on the cSi surface. After texturing with different laser parameters [3], a chemical cleaning process is performed using KOH solution with different concentrations at 80°C to remove laser-induced damages and other residues from the surface. In order to enhance the optical performance of the process, Si₃N₄, as an antireflection coating layer (ARC), has been deposited with the thickness of 75 nm using PECVD. Moreover, to improve electrical properties, Al₂O₃ has been deposited via ALD system. To assess the proposed process, weighted reflection values are measured, and the results, as seen in Figure a), show weighted reflection can be as low as 4.2% with ARC layer. The iVoc measurements in Figure b) indicate that iVoc as high as 692mV is achievable along with proper weighted reflection value. The scanning electron microscopy (SEM) images of the samples at the different steps, demonstrated in Figure c,d,e), show that the surface morphology develops by increasing KOH cleaning duration.

Keywords

laser texturing, texturing, KOH cleaning, cSi solar cell

FIGURES. a) Weighted reflection after ARC deposition, b) iVoc of sets treated with 20% KOH with different durations. SEM top view images of c) as deposited; d) 60s KOH cleaned; e) 120s KOH cleaned.



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INVESTIGATION OF MO BACK CONTACT ANNEALING EFFECT ON THE CONVERSION EFFICIENCY OF MAGNETRON SPUTTERED $\text{Cu}_2\text{ZnSnS}_4$ THIN FILM SOLAR CELLS

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$\text{Cu}_2\text{ZnSnS}_4$ (CZTS) is a p-type semiconducting absorber layer for thin film solar cells. It has a direct bandgap with large optical absorption coefficient making it an ideal for photovoltaics [1]. Moreover, CdS is one of the most promising buffer layers due to its n-type semiconducting character for thin film solar cells [2]. In this work, Molybdenum was used as back contact on Soda Lime Glass (SLG). Aim of this work is to understand Mo back contact's annealing effect on CZTS solar cell efficiency. Mo coated SLG substrates were annealed for 30 min with an increment of 50 °C from 250 °C to 550 °C. Later, two steps process was used to fabricate CZTS absorber layers on annealed-Mo/SLG. Firstly, CZT metallic precursors were deposited by DC magnetron sputtering on Mo coated SLG [3-4]. Secondly, all precursors were sulfurized for 45 min using sulphur powder at 550 °C under Ar atmosphere. CdS buffer layer was deposited for 45 min at 85 °C by Chemical Bath Deposition (CBD) on CZTS [5]. Finally, ZnO and Al doped ZnO (AZO) were deposited to obtain a full solar cell structure. Systematic search of Mo back contact's annealing effects was examined by XRD, Raman, SEM and EDX techniques. Electrical characterizations were realized to determine annealing effects on the photo-conversion efficiencies of SLG / annealed Mo / CZTS / CdS / ZnO / AZO cells. The evaluation of final results is an ongoing study.

* This research is partially supported by TUBITAK (Scientific and Technical Research Council of Turkey) with project number of 114F341.

Keywords

$\text{Cu}_2\text{ZnSnS}_4$, CZTS, thin film solar cells, CdS buffer layer, AZO window layer

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ULTRASONICALLY SPRAYED $\text{Cu}_2\text{CdSnS}_4$ SOLAR CELLS

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Kesterite phase of $\text{Cu}_2\text{ZnSnS}_4$ (CZTS) occurs in the nature and is the most likely alternative to $\text{Cu}(\text{In,Ga})\text{Se}_2$ (CIGS) thin film solar cells which started to spread increasingly in all over the world. CZTS is very suitable absorber layer material for thin film solar cells due to containing cheap material, has a 1.5 eV band gap that is the most appropriate for theoretical Shockley-Queisser limit values $\text{Cu}_2\text{CdSnS}_4$ (CCTS) is a semiconductor with a band gap of 1.37 eV and has a large absorption coefficient over 10^4 cm^{-1} which makes it a possible photovoltaic material. Its structure is similar to CZTS.

In this work, cheap and abundant material containing $\text{Cu}_2\text{CdSnS}_4$ (CCTS) quaternary semiconductor films were produced on glass substrates by ultrasonic spray pyrolysis method with various substrate temperature. The films were annealed in H_2S atmosphere. The structural features of the thin films were determined by X-ray diffraction (XRD), the molecular structure by Raman spectroscopy, surface morphology by Scanning Electron Microscopy (SEM). Light transmittance and absorbance of the films were used for determining of absorption properties by UV-VIS-NIR as absorber layers in photovoltaic applications. Optical band gaps of the films were determined.

A $\text{Mo}/\text{Cu}_2\text{CdSnS}_4/\text{CdS}/\text{ZnO}/\text{AZO}$ solar cell with 1.14 power conversion efficiency was obtained by using the most appropriate thin film according to optical and electrical properties.

Acknowledgement: This Study is supported by TUBITAK with 115F224 Grand Number

Keywords

quaternary semiconductor, solar cell, $\text{Cu}_2\text{CdSnS}_4$, ultrasonic spray

ANTIREFLECTION COATINGS ON SANDY PATTERNED PV COVER GLASS: OPTICAL DESIGN, PROCESSING AND CHARACTERIZATION

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Commercial photovoltaic panels bear antireflective (AR) coated cover glasses that protect the interior components while letting solar radiation in. Such a coating is also expected to withstand the harsh environmental conditions and remain functional throughout the module life span. Cost reduction concerns dictate the use of a single layer AR solution that should be coated in bulk quantities on a pre-patterned glass substrate.

In this study, we outline Şişecam's experience in producing porous silica based AR coatings on low-iron Sandy patterned glasses. Cross sectional analysis with STEM microscopy reveals that the coating is a homogeneous and porous single layer of ~100 nm thickness. We use porosimetric ellipsometry to verify that the resulting porous network has a closed pore topology; an advantageous feature against performance drops stemming from high ambient humidity.

Keywords

cover glass, antireflective coatings, sol-gel chemistry, porous thin films

DEVELOPMENT OF TEXTURED GLASS SUBSTRATES BY ALUMINUM INDUCED TEXTURING METHOD

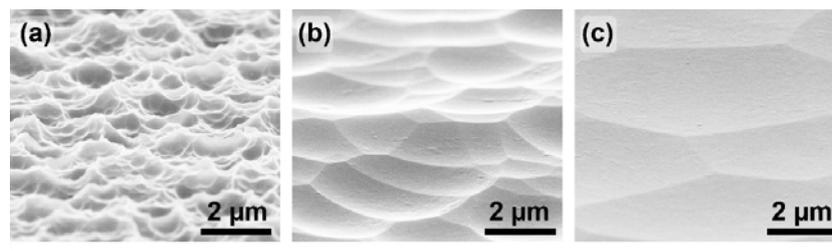
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Light trapping is crucial for thin film solar cells to be able to decrease the cost of produced solar electricity. Texturing transparent conductive oxide and usage of back reflectors are techniques that are applied on the industrial level. To be able to obtain further enhancement, texturing of the substrate is crucial. Among various substrate texturing methods, aluminum induced texturing method is of particular interest due to ability to control surface texture with micron and nano sized structures. Aluminum that is coated on the surface by thermal evaporation or sputtering technique is reacted by soda-lime glass at temperature above 500 °C. This reaction occurs randomly on the surface and SiO₂ is reduced to Si while Al is oxidized to Al₂O₃. Randomization of the reaction creates rough glass-Al₂O₃/Si interface. After removing of reaction products from the surface by suitable chemicals, textured surface can be exposed. Different size of craters can be obtained with different processing conditions. Annealing and etching are the most crucial parameters to obtain an effective texture for light trapping. Annealing conditions affect the aluminum-glass reaction interface while etching could alter the surface structure to obtain larger U-shaped craters. In this presentation, results of aluminum induced texturing studies are summarized. Optical measurements were conducted by integrated sphere spectrometer and texture was investigated by scanning electron microscope.

Keywords

aluminum induced texturing, thin film solar cells, light trapping, haze, glass texturing



AIT surfaces with different process parameters, (a) alkaline, (b) HF (short), (c) HF (long) etching

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IN LINE MAGNETRON SPUTTERING GROWTH AND CHARACTERIZATION OF GA-DOPED ZNO THIN FILMS

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The focus of this study is to investigate Ga-doped Zinc Oxide (GZO) material as an alternative material to Indium Tin Oxide (ITO). GZO with 5% Ga thin films were grown on large area glass substrate (30 cm x 40 cm) by pulsed DC in-line magnetron sputtering. sputtering power and the post annealing temperature on the structural, electrical and optical properties of GZO thin films were investigated. Initially five thin films at five different sputtering power ranging from 0.7 kW to 2.7 kW were grown on glass substrate. While changing the sputtering power, in order to keep the thickness of the layers as close as possible, line speed of the carrier is changed. The sample grown at 1.2 kW power exhibits the best results with regards to sheet resistance of 36 ohm/□, optical transmission of 79% in the visible range. This values are further improved by performing post annealing process. The sheet resistance is decreased down to 11 ohm/□ and the optical transmission is increased to 82-85% by optimizing the post annealing temperature and time.

Keywords

transparent conducting oxides, physical vapor deposition, magnetron sputtering, thin film growth

SISECAM ENERGY GLASSES: OVERVIEW OF GLASS PRODUCTION AND THE INSTALLATION OF A 6.209 MW ROOF-TOP PV SYSTEM AT THE MERSIN PLANT

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In this talk, we will first give an overview of the production of patterned and coated low-iron glasses for energy industry in the Mersin Plant of the Şişecam Flat Glass Group. Şişecam's Mersin Plant is the only integrated production facility in Turkey, which produces patterned glass with a dedicated furnace and houses all the necessary processing capabilities including automated cutting, tempering and AR coating of patterned glasses to meet the demands of the energy industry.

The same plant operates the largest roof-top installed solar system in Turkey comprising 23804 panels distributed over a 79.300 m² roof area yielding a 6,209 MW capacity. In the second part of the talk, we will outline the installation phase of this unique system that utilizes the cover glasses produced by Şişecam and review its operational history so far.

Keywords

roof-top installed systems, grid-connected systems, module performance simulation, energy glasses

PERFORMANCE AND DEGRADATION ANALYZES OF TWO DIFFERENT PV MODULES IN THE CENTRAL ANATOLIA

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Ankara (latitude $\sim 40^\circ\text{N}$) is in Central Anatolia and the climate is dry continental. Due to the rapid transition to renewable energy policies of Turkey [1] it is now a must to reach truthful feasibility analyses for solar power systems countrywide. Long term performance and degradation analyses have been carried out by the authors for three different arrays [2] and many research results appeared in the literature [3]. Present research is on analyzing the outdoor testing results of two PV modules on seasonal and monthly based data. One of the module has multi crystalline (Poly-Si) cells and the other is $\mu\text{-Si/a-Si}$ thin film. The results showed that in five years the yearly efficiency decreases from 14.45% to 11.13% for Poly-Si (14.72% is STC efficiency) and from 8.29% to 6.51% for thin film modules (9.15% is STC efficiency). Our calculations are based on solar irradiance falling on horizontal surface from which we calculated array-in-plane irradiation using anisotropic sky model.

In this work, we present the details of these analyses and degradation rates for the two types of modules to be used in long term feasibility analyses.

Keywords

long term degradation, photovoltaic module, photovoltaic performance analyses

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EXPERIMENTAL VALIDATION OF NON-LINEAR EMPIRICAL MODEL TO SIMULATE THE PHOTOVOLTAIC PRODUCTION UNDER SEMI-ARID CLIMATE. CASE STUDY OF BENGUERIR, MOROCCO

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The investments in large-scale photovoltaic power projects are becoming growth in MENA region [1], which characterized by harsh climate conditions in the sunniest places. In this context, the modeling of photovoltaic performance in such climate is required in order to predict the energy yield with high accuracy. The aim of this study is to adapt a non-linear empirical model to simulate the photovoltaic production under desertic climate. The developed model represents the output power of the PV module as a function of in-plane irradiance and ambient temperature, with a number of semi-empirical coefficients determined by fitting to outdoor measured data. The model has been validated using one year of high accuracy measured data at the ground level of a polycrystalline module (With nominal power 253 Wp) at Green Energy Park research facility [2]. Results of this study show that the proposed model is a good approach to predict the output photovoltaic power under semi-arid climate with an hourly nRMSE of 3.1% in comparison to ground measurements. All the errors and statistical indicators for all time resolution: hourly, daily and monthly will be presented will in the full paper.

Keywords

PV module performance, PV prediction, Semi-Arid climate

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NEW DPP AND SELENOPHENE BASED NIR ABSORBING POLYMERS FOR ORGANIC SOLAR CELL APPLICATIONS

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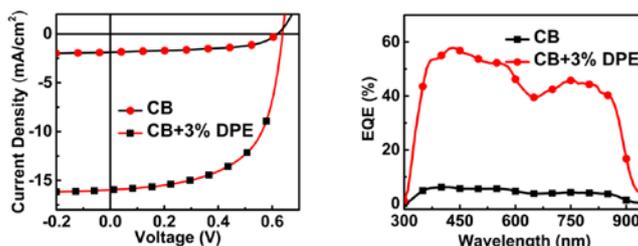
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The broad spectrum of sunlight which spans from 300 nm to 1200 nm cannot be effectively utilized in organic solar cells since most organic polymers have absorption between 300 ve 800 nm range. Recently coppolymers from diketopyrrolopyrrole (DPP) and simple donors such as thiophene and furan was shown to achieve absorption maxima around 800 nm. Here we shown that DPP coupled with selenophene pushes the absorption even futher and a polymer with absorption maxima at 830 nm (absorption onset 930 nm) could be attained. This polymer, under optimized conditions, shown a maximum conversion efficiency of 6.16% with inverted device structure using PC₇₁BM as the electron acceptor. A significant additive effect was also observed where the device efficiencies were improved over 13-fold. EQE studies showed that there is strong contribution in the NIR region with 40% EQE achieved in the range of 700 nm to 850 nm (Figure 1). This material is also one of the rare examples of a high performance NIR absorbing polymer that does not contain any thiophene-based unit in its backbone. Synthetic efforts towards other related derivatives are currently being investigated.

Keywords

NIR polymers, organic solar cells, additive effect



The J-V curves of device with/without additive and the EQE curve of device with/without additive

STUDYING DEGRADATION IN OPV DEVICES USING A COMBINATION OF FREQUENCY AND TIME DOMAIN OPTOELECTRONIC TECHNIQUES

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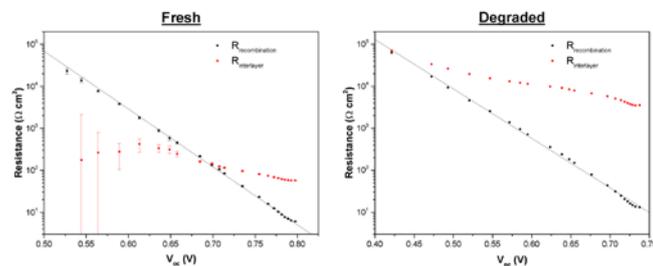
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We show that a more in depth understanding of device operation can be obtained when both time domain (TPV) and frequency domain (EIS) measurements are employed together. The two are in many ways equivalent, and similar information can be obtained from both. However, there are subtle differences between the two which enable certain processes to be studied in more detail using one or the other. The techniques have been combined to study the effect the interlayer between the active layer and metal contact has upon OPV device stability.

The devices under test were based on the non-fullerene acceptor, ITIC, and the donor, PCE10. The interlayers included Ca, LiF, PEIE and PFN. Accelerated aging revealed significant differences in terms of stability, with the most stable device containing the PEIE interlayer and the least stable containing LiF. TPV measurements were used to study the varying levels of degradation and revealed slight differences in terms of trap formation and recombination dynamics for the devices with different interlayers. EIS measurements showed more pronounced differences in terms of the resistance of the different interlayers upon aging. In EIS measurements a small amount of current flows which means it can be used to probe charge transport throughout the entire device and not just recombination as is the case for TPV measurements. Whilst recombination can be observed using EIS measurements, it is obscured by the charge transport through the interlayer. TPV/TPC measurements are therefore more suited to studying recombination and charge accumulation in the active layer.

Keywords

organic PV, interlayer, impedance spectroscopy, TPV



EFFECT OF IONIC LIQUIDS ON Cu_2S COUNTER ELECTRODE-BASED QUANTUM DOT-SENSITIZED SOLAR CELLS

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Copper sulfides (Cu_2S) have drawn much attention as an efficient counter electrode (CE) material in quantum dot-sensitized solar cells (QDSSCs) due to superior catalytic ability towards the sulfide/polysulfide couple as well as their low-cost and low-toxicity. Despite the outperformance of the Cu_2S catalyst material, the Cu_2S CE has some disadvantages, such as low stability and relatively low surface area with poor adhesion and conductivity. To overcome these problems, herein, we focus on preparing the Cu_2S by incorporating 1-butyl-4 methyl imidazolium hydrogen sulfate (BMIMHSO₄) ionic liquid as a dopant with the electropolymerization process. This catalyst material is employed for the first time as CE to fabricate CdSe/ZnS core/shell quantum dots-based solar cells. The ionic liquid-doped CE significantly enhances electrochemical activity and provides a faster charge transfer rate with good adhesion on substrate compared to the bare Cu_2S CE. The QDSSC with the ionic liquid-doped CE exhibits higher energy conversion efficiency (3.68 %) than those with bare Cu_2S (2.68 %) CE. This proof of concept demonstration provides a new path for the development of the quantum dot-sensitized solar cells.

Keywords

BMIMHSO₄ ionic liquid, counter electrode, quantum dot sensitized solar cells (QDSSCs)

POLY(TRIPHENYLAMINE-THIAZOLO[5,4-D] THIAZOLE) COPOLYMER DYE FOR BULK-HETEROJUNCTION ORGANIC SOLAR CELLS

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The polymer-based solar cells (PSCs) are promising due to their simple fabrication procedure, low material cost and flexibility. In recent years, PSCs based on the conjugated polymers as the electron donor materials blended with [6,6]-phenyl-C₇₁-butyric acid methyl ester (PC₇₁BM) have been investigated extensively using a single bulk heterojunction (BHJ) device structure. The semiconductivity and solar cell material properties of thiazolo[5,4-d]thiazoles have been investigated previously [1,2]. In the present work, the photovoltaic properties of conjugated poly(triphenylamine-thiazolo[5,4-d]thiazole) (p-TPTT) alternating copolymer dye were investigated. The p-TPTT copolymer is a red colored dye material with a band gap energy of 1.36 eV. Using the weight ratio of 1:3 for the p-TPTT polymer:PC₇₁BM blend, the OPV device performance values were found as I_{sc}=4.10 mA/cm², V_{oc}= 0.47 V, FF=29% and PCE=0.55%. The p-TPTT solar cell resulted in the maximum IPCE of 14.5% at 470 nm. Therefore, the new copolymer structure can be considered as a promising organic solar cell dye material.

Keywords

organic solar cell, solar energy, band gap , copolymer dye

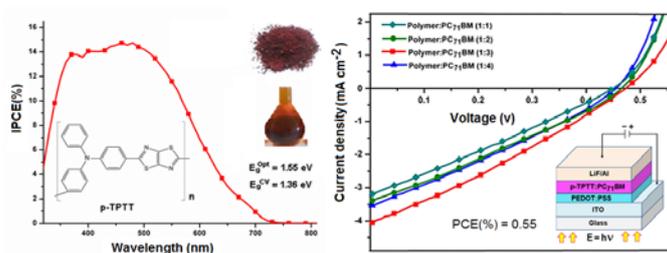


Figure 1. Organic solar cell performance test results.

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SYNTHESIS AND PROPERTIES OF REGIOISOMERICALLY PURE 1,7-DISUBSTITUTED PERYLENE DYES

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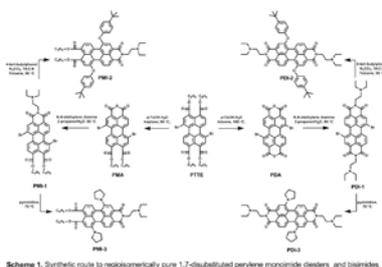
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Perylene moiety provide “peri-”, “bay-” and “ortho-” positions around its core for functionalization, giving the opportunity to control and fine-tune various properties. 1,7-dibromoperylene-3,4,9,10-tetracarboxylic tetrabutyl ester (PTTE) is an excellent starting material for the synthesis of large variety of peri- and bay- decorated regioisomerically pure perylene compounds [1]. Herein, we present the synthesis, electronic absorption and fluorescence properties of regioisomerically pure 1,7-di(tertbutylphenoxy)- and 1,7-di(pyrrolidinyl)- substituted perylene monoimide diester (PMI) and perylene bisimide (PDI) derivatives. Complementary density functional theory (DFT) calculations are also presented. Synthesized compounds have high molar absorptivity coefficients and show broad absorption bands within visible region [2,3]. Nature of bay-substituents has a marked effect on the absorption properties. It is also notable that substituents added at bay-region significantly increase the solubility of compounds in common organic solvents. DFT calculations revealed that the attachment of electron donating groups at 1,7-positions of perylene core results in an increase in frontier orbitals energy levels. Observed energy increase in HOMO level is larger in each case, compared to the energy increase in LUMO levels, due to the higher contribution of side groups to HOMO. Compounds presented here are synthetically accessible and are highly attractive as photo-functional materials.

Keywords

peryene imide, sensitizer, photophysical properties, organic photovoltaic, DFT



Scheme 1. Synthetic route to regioisomerically pure 1,7-disubstituted perylene monoimide diesters and bisimides

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DYE-SENSITIZED SOLAR CELLS WITH GRAPHENE COUNTER ELECTRODE

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Dye sensitized solar cells are fabricated using graphene based counter electrodes. Graphene can be used in any layer of Dye Sensitized Solar Cells DSC, say it be photoanode [1], counter electrode[2], dye [3]or electrolyte [4]. Graphene offers good transparency and conductivity which enhance the characteristic properties of the photovoltaic cell [5]. The highest reported efficiency in DSC is 14% [6] in which the counter electrode was made of graphene[7]. This work is focused on fabrication of counter electrode with graphene ink via spin coating and/or electrodeposition. The deposited layer of graphene over FTO will be characterized by FESEM, AFM, UV-VIS Spectrophotometer, thickness profilometer, 4-probe conductivity measurement. The photoanode will be treated with titanium tetra chloride $TiCl_4$ for efficiency enhancement and dye coated later. The photoanode will be analysed by FESEM and AFM for continuity of mesoporous layer and spread of dye over it. Finally the cells will be assembled and characterized for efficiency, V_{oc} , J_{sc} , FF and resistance and IPCE as well. The electrochemical impedance measurement (EIS) will be made for internal characteristic resistance. The use of graphene enhances the possibility of flexible DSC over polymer substrates. This can be further enhanced for inkjet printing and slot die coating for commercialization [8].

Keywords

dye sensitized solar cells, graphene counter electrode

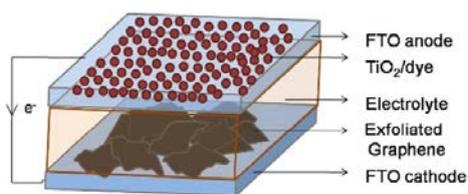


FIG. 1. (Color online) Schematic of thermally exfoliated graphene counter electrode based DSSC.

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DETERMINING PV MODULE PERFORMANCE AND COMPARISONS

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Knowing electricity production potential of a PV system before installation is very beneficial for the investor to see the feasibility of the investment. There are two procedures that can be followed to calculate the potential electricity production of any system under different conditions. These are the use of some database/software to reach the performances and developing a model to make these estimations. It is obvious that installation of PV systems everywhere is neither technically nor economically conceivable. Consequently, there is a need to develop methodology that is able to make accurate estimations. Its accuracy can be controlled by validating the results for some locations with the measured values. So, in this study we initially develop a methodology to calculate efficiency and electricity production performance of some modules in Ankara and compare the results with the measured values owing to the system installed on the roof of Middle East Technical University Solar Energy Research Center. The methodology initially calculates solar irradiation falling on the modules, that is the input. Then the performance of the module is calculated using the developed methodology. There are also some software programs to calculate the performances, such as System Advisory Model [1], EU PVGIS [2] and PV F-Chart [3]. We used these software and compare the results with developed methodology. however, as proven through mean-bias error and root-mean-square error statistical comparison methods, the methodology of this study has given the most accurate results.

Keywords

photovoltaics modules, outdoor testing, module performance

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GPU-ASSISTED RAY-TRACING ALGORITHM FOR SOLAR LIGHT ANALYSIS ON PV PANELS

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Optimal positioning of PV panels on building surfaces requires extensive solar radiation analysis. Efficiency of panels varies with the sun's angle of incidence, the slope of the surface, and the amount of daylight. In order to maximize the benefit, these parameters must be chosen optimal during the installation. It should also be determined if the sunlight encounters an obstacle while moving in the direction of the target surface using the ray-tracing algorithm. In this study, a GPU (Graphics Processing Unit) assisted software tool has been developed to determine the optimal installation parameters and to analyze the dynamic energy efficiency of the PV panels. The developed software tool is based on DSRM (Dynamic Solar Radiation Model) [1] model. The software tool enables analysis on 3D structures which can be either in planning stage or completed at the urban or individual scale. Since the ray-tracing algorithm requires a fairly high computing power for large-scale 3D environments, the algorithm is designed to work on GPU technology. It is shown by experiments that more realistic and sensitive analysis can be done within reasonable time by using GPU technology.

Keywords

solar energy, GPU, ray tracing, photovoltaic panel

THERMAL MODELING OF PV MODULE TEMPERATURE AND YIELD AND THE VERIFICATION USING THE OUTDOOR MEASUREMENTS FOR ANKARA

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Ankara is in the Central Anatolia region where the climate is dry continental with an annual solar insolation of around 1700 kWh/m². In the transition of Turkey to renewable energy, detailed analyses are required to ensure effective exploitation of the solar resource. The essential part of these analyses are estimating power yield and efficiency of photovoltaic solar modules and arrays [1]. The power yield of a solar cells is highly dependent on the module temperature of the solar panels. In this study, a thermal modeling approach [2] is modified using wind speed direction and module temperature dependent power yield to predict the temperature and performance of the module will be presented. The model uses the energy conservation principle and meteorological data that is readily available from most government meteorological services. The analyses can be performed so that the performance of PV systems can be estimated before installing at the location of interest, which is a major advantage and cost savings compared to conducting a long pilot-installation test. In order to verify the model, we used the measured data by METU-GÜNAM Outdoor Test Facility in Ankara [3]. Preliminary analyses showed that the model performs well especially during sunrise and sunsets and the deviations are around a few W/m² for the yield in an hour and around 2 °C for the module temperature. However, the deviations in module temperature becomes as large as 8 °C during noon hours, and for the yield it is around 15 W/m².

Keywords

photovoltaic modules, module efficiency, module temperature, thermal modeling

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TECHNO-ECONOMIC ANALYSIS OF PV-HYDROGEN FUEL CELL/PUMPED HYDRO STORAGE SYSTEM FOR MICRO-GRID APPLICATIONS: CASE STUDY IN CYPRUS

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Fossil fuel resources are under enormous pressure due to the excessive use of it to meet the increasing energy demand of the world which is causing the depletion of these resources. Moreover, the excessive use of fossil fuel resources contributed in the increase in the greenhouse gases emissions in the atmosphere causing the increase in the average surface temperature of the earth or what known as global warming phenomena. Furthermore, the fluctuations in the fossil fuel prices affect significantly the economy of the countries and threat their energy security. Renewable energy resources such as solar resources are a suitable alternative as it is abundant, can be harnessed in affordable ways and are considered environmentally friendly. However, renewable energy resources are less reliable because of their intermittency. To increase the reliability of the renewable energy systems, hybridization of renewable energy resources and the integration of energy storage systems is done. In this study, a techno-economic analysis of PV/Fuel cell system with pumped hydro-storage (PHS) is carried out where Middle East Technical University Northern Cyprus Campus is the case study. The HFC will be integrated to compensate the deficiency in the demand during the lag time of the PHS. The excess energy from the PV power plant will be used to run the electrolyzer to fill the hydrogen tank if there is a space where if it is full it will charge the PHS.

Keywords

Cyprus, energy storage systems, fuel cells, photovoltaic systems, pumped hydro storage, solar energy

CHARGE CARRIER DYNAMICS IN METAL HALIDE PEROVSKITE SOLAR CELLS AFTER HUMIDITY AND LIGHT EXPOSURE

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In a very short time span, metal halide perovskite solar cells (PSCs) showed rapid progress owing to their unique optical and electrical properties. Currently, the power conversion efficiency (PCE) of the PSCs is approaching 23%, a massive improvement for solution-processed solar cells. Towards this end, both surface and bulk recombination of photogenerated charge carriers in the perovskite absorber layer is the major limiting factor for the PCE [1]. In this respect, controlled growth of the film is crucial for the performance of the perovskite solar cells as the crystal growth dynamics are very susceptible to the processing conditions [2]. Some studies report a beneficial effect of water inclusion during the processing, while others claim an adverse effect. Moreover, the effect of humidity and light exposure on the performance of the PSCs is still under debate. In this study, we address how the photophysics change upon exposure to humidity and light in two-step processed MAPbI₃ perovskite thin films. We use time-resolved photoluminescence (TR-PL) spectroscopy before and after humid air exposure under 1-sun illumination, and we correlate the results with solar cell performance. Furthermore, we study the influence of excess lead iodide (PbI₂), which is commonly believed to be a passivation layer for PSCs, on the humidity resistance of MAPbI₃ devices. We discuss how the excess PbI₂ is either accelerating the degradation or increasing the performance of the devices after humid air exposure under illumination.

Keywords

perovskite solar cells, charge carrier dynamics

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THE APPLICATION OF TWO-DIMENSIONAL WS₂ NANOMATERIALS AS HOLE TRANSPORT LAYERS IN PEROVSKITE SOLAR CELLS

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Solar cells based on metal-halide perovskite have investigated to the forefront of photovoltaic research activity [1]. These materials are crystallized from organic halide and metal halide salts to form crystals in the ABX₃ structure, where A is the organic cation, B is the metal cation and X is the halide anion [2]. The power conversion efficiency of perovskite solar cells has risen in just four years from about 3% to over 20% with significant improvements occurring after 2012 [3]. Moreover, stability of perovskite is a big problem in the scientific world. In this study, we produced WS₂ nanomaterials as hole transport layer in perovskite solar cell. Two-dimensional (2D) WS₂ nanomaterials have investigated as a new generation of materials because of their high carrier mobility, high transparency, tunable band gap, low cost, and solution-processable properties. These materials can be fabricated into single layers or few layers through facile processes such as chemical vapor deposition or mechanical exfoliation to unlock their superior electrical and optical properties. The ability to tune the work function enables their application as HTL and electron transport layers in optoelectronic devices. The use of WS₂ nanostructures in perovskite solar cell has been investigated as HTL and as a protective layer. We show that interestingly, the WS₂-based perovskite solar cell was more stable in air than the reference cells without WS₂. Our study suggested that WS₂ are promising candidates as HTLs in perovskite solar cell to replace unstable organic HTLs.

Keywords

perovskite solar cell, WS₂, HTL, nanomaterials

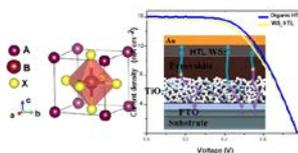


Figure 1. Perovskite ABX₃ crystal structure, illustration of the charge generation processes in a 'perovskite-sensitized' solar cell and J-V characterization

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THE EFFECT OF THE HALIDE CHEMICAL SUBSTITUTION TO IMPROVE THE UV STABILITY OF THE MAPBI₃ PEROVSKITE

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Despite the astonishing progresses reached in the last six years, perovskite thin films still lack some stability. It is well known that UV irradiation and humidity affect strongly perovskite-based solar cell performances. We herein investigate the degradation process of perovskite-based MAPbI₃ thin films without encapsulation in the presence of direct UV light. The UV irradiation effect on structural, morphological and optical properties of the perovskite thin film is investigated. Experimental results show serious degradation of the perovskite proprieties after 12 hours of exposure to UV light. The main objective of this work is to show that it is possible to improve the UV stability of the unencapsulated MAPbI₃ perovskite by the adequate incorporation of the bromide atoms. In fact, it has been found that the MAPb(I_{1-x}Br_x)₃ perovskite exhibits a better stability when the bromide fraction is above 20%. We believe that the observed improvement is linked to the structural transition from the tetragonal phase the more stable cubic structure as shown by the XRD results.

Keywords

perovskite thin films, UV stability, CH₃NH₃Pb(I_{1-x}Br_x)₃

INVESTIGATING THE EFFECTS OF COOLING OPTIONS ON PHOTOVOLTAIC PANEL EFFICIENCY: STATE OF THE ART AND FUTURE PLAN

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Currently, cooling of photovoltaic (PV) panels, a significant issue due the negative effect on panel efficiency, is subjected to intensive researches. For this purpose, numerous researches on cooling methods are performed to keep the panel efficiencies around the design values. In this study, a comprehensive literature review was presented to give the current status of the technological improvement in cooling options. In addition, strong and weak aspects of the studies were discussed, and advantageous methods were emphasized for the further application of PV panels. Finally, future perspective of PV panel cooling studies was explored with proper cooling options in lower operating temperatures for higher operation efficiencies.

Keywords

PV panel, cooling, active cooling, passive cooling, simulation, efficiency

EVALUATION OF THE CRYSTALLINE PHOTOVOLTAIC MODULES PERFORMANCE DROPS AFFECTED BY SNAIL TRAILS DEFECT

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The understanding and quantifying of qualified photovoltaic (PV) module degradation is important to ensure its lifetime and verifying the qualification test at harsh conditions. A test campaign on several p-Si at semi-arid climate has been conducted after 2 years of outdoor exposure. As a result, 50% of modules showed snail trails formation. This defect has been observed increasingly during last decade [1,2] whereas, the performance variation functions of snail trails have not yet been thoroughly investigated [3]. In this work the power drop of PV modules affected by this defect after 3 years of operating was performed. Besides, electrical parameter degradation is quantified by measuring the modules performance parameters under standard test conditions as a function of field exposure time. This has been done using the I-V curve tracer PVPM1040CX. The degradation rate (Rd) for each module has been analytically calculated with discreet data. Results show that the rate of power output drop of affected PV modules could reaches 3%/years. In addition to that, visual evolutions of irregular dark stripes across the cells have been periodically monitored. EL imaging technic also conducted and demonstrates, in contract to some previous work [2], that the snail trails defect not necessary occurs at the micro cracks. The outcome of the study will be of importance to enhance the knowledge of climate specific field PV degradation mechanism and to provide inputs to Morocco/IEC standards.

Keywords

snail trails, photovoltaic , performance drop, micro cracks

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DAILY AND MONTHLY MODULE TEMPERATURE VARIATION FOR 9 DIFFERENT MODULES

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One of the main parameter affecting the efficiency of PV modules is the module temperature. In this respect, outdoor testing of modules is very important to determine the temperature dependent performances and degradation rates [1,2]. In this work, we analyzed the module temperatures of 9 different modules tested in the outdoor testing facility of METU-GUNAM, Ankara (latitude ~40°N, in Central Anatolia and the climate is dry continental). The tested module types are two CIS (identical), one μ c-Si/a-Si, one Poly-Si, three Mono-Si (two identical), one HIT and one bifacial. The module temperatures can reach up to 73 °C while the ambient is around 35 °C during summer days. Monthly average module temperatures can reach up to 33.7°C (CIS) while the monthly average ambient is at 26.0°C and drops down to 1 °C while average ambient temperature is about the same as average module temperature. The results showed that the monthly averages of module temperatures differences are maximum during summer (~3.5°C) and minimum during winter (~1.1°C). It is interesting that the two CIS modules have the highest monthly average module temperature and although they are supposed to be identical their temperatures differ significantly. Bifacial and HIT module temperatures are lower than the Mono-Si modules. One of the two identical Mono-Si modules was not cleaned and its module temperature is always lower than the one that was cleaned periodically, as expected. In this research, we present the details of the module temperature analyses based on daily, monthly and seasonal data.

Keywords

PV modules, module temperature, PV performance analyses

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PV MODULE PARAMETERS EXTRACTION USING THE FLOWER POLLINATION ALGORITHM

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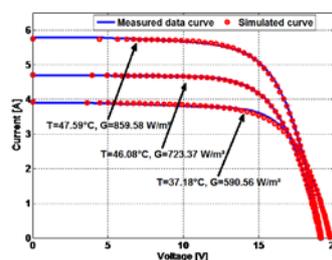
Many systems are provided to exploit the solar energy such as grid connected system, stand-alone system and hybrid system. These systems are based on a PV panels in which the fundamental part is the PV cell. To make the PV system profitable, one must ensure a correct sizing that requires a rigorous study to make the best choice, the best performance and the lowest cost.

The approaches proposed for PV cell modeling are divided into two categories; the first category is non-parametric approach based on the learning that relies on the data, its attributes are the input and the output of the system [1]. The second approach is parametric based on a mathematical model. Several models were proposed in the literature [2]. However, the most common are single and double diode models [3]. These models have unknown parameters to be identified in the purpose to improve their accuracy. Therefore, several optimization algorithms have been proposed for PV cell parameters extraction.

In this paper, PV module parameters extraction by the optimization of the cost function that represents the error between measured data and the model output using Flower Pollination Algorithm (FPA) is proposed [4]. This algorithm inspired from the pollination process of flowers provides a strong solution for the optimization problems, where it presents some advantages such as the independence with the search space and initial conditions. The model with the extracted parameters has been compared with several experimental I-V curves in different weather conditions and for several manufacturing PV cell types.

Keywords

PV modules, outdoor data, flower pollination algorithm, parameters extraction



Measured and simulated I-V curves based on double diode model for Monocrystalline PV module

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AN EXPERIMENTAL STUDY ON THE MODELING OF THE PV OUTPUT

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Accurate calculation of the power outputs of the modules under different solar radiation conditions is an important task to decide if it is feasible to construct a PV plant at the region or not. There are a lot of models that explore more accurate calculation using solar radiation values and the parameters of PV module. Unlike those models, a data based model is proposed in this paper. Before construction of the model, first an experimental setup is built and experiments are performed. During the experiments a pyronometer is positioned on the same angle with a PV module and both the solar radiations fall on the surface of the module and the power output of the module is measured and recorded. Secondly, the data is modeled using regression analysis. Consequently, the regression coefficients are calculated and the performance of the regression on modeling the PV output is examined. To measure the accuracy of the model, correlation of determination parameter and root mean square metric are calculated. It is argued that, it is possible to calculate the power output of the PV module in a good accuracy, in case PV output of the module is measured in a short period of time and the proposed approach is applied. The coefficient of determination value is obtained around 0.9 in experiments.

Keywords

PV generation, solar energy, regression analysis

THE EFFECT OF AG PLASMONIC NANOPARTICLES EMBEDDED INTO THE ACTIVE LAYER BY PULSED LASER DDEPOSITION TECHNIQUE

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The solar cells are manufactured in the form of ultrathin film[1,2] structures to reduce their cost and accelerating the production rate. The number of photons absorbed by the active layers is reduced by the reduction of the thickness of solar cells. The light trapping methods are used to increase the absorbance of the active layer and thus the photo-induced charge numbers in the layer. One of light trapping methods is embedding plasmonic nanoparticles(plasmonicNPs), exhibiting some LSPR properties, into the active layer. The effect of the LSPR formed by the plasmonicNPs, they absorb or scatter photons from UV to IR wavelength region. The number of photo-exciting electrons in the active layer and the accumulation of charges in the joint region can be increased, then efficiency of solar cells can be increased. It has very important advantageous such as simplicity of production of plasmonicNPs and tuning of wavelength region for absorption maxima by adjusting parameters such as the laser energy, background gas pressure and the number of laser pulses of PLD technique[3,4].

The LSPR wavelength and band width of Ag nanoparticles have been moved from the visible region to the NIR region and broaden in solar spectrum, respectively, as laser energy was increased. In addition, it has been reported that an ultra-thin CZTS active layer was produced by PLD and Ag-plasmonicNPs have been embedded in this layer. Optical effect of Ag-NPs have been investigated by UV-vis spectroscopy. CZTS layer absorbs the more photons while the active layer weakly absorbs in NIR region.

Keywords

plasmonic, nanoparticles, thin film, PLD, optic

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EXCEEDING THE SCHOCKLEY QUEISSER LIMIT VIA TANDEM SOLAR CELLS AND SPECTRUM REHAPING

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Crystalline silicon has been dominating the PV industry over decades. The maximum efficiency of any solar cell made up of a single semiconductor such as silicon is limited by the Shockley Quiesseier limit. Additionally, the inherent Auger recombination loss limits the efficiency of silicon solar cells below 30%. Using more than one semiconductors in a tandem solar cell configuration and spectrum reshaping are among the most promising methods to overcome the Shockley Quiesseier limit. While tandem solar cells utilize energy of solar photons more efficiently by two or more semiconductors, upconversion allows the part of the solar spectrum lying above the cutoff wavelength (about 1140 nm for Si) to contribute to photocurrent. In this presentation, I will give an overview of recent developments on tandem solar cell and spectrum reshaping by upconversion. I will also share our recent research activities on both topics, in particular, perovskite/silicon tandem solar cell and upconversion via Er-doped ceramics.

POTENTIAL OF STRAINED SnO₂ AS A PHOTO-CATALYST FOR WATER SPLITTING PROCESS

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Photocatalysis has recently seen a growing interest within researchers as it serves in the most promising technologies in water treatment and energy harvesting such as pollutants degradation, and hydrogen production. Based on Density functional theory (DFT), the present study predicts the energy band structure of SnO₂ under the effect of mis-match strain where it is deposited as a thin film on a foreign substrate. Our results show that tensile strain improves the absorption capability towards visible-light absorption (around 400 nm), and increases its mobility which is a positive factor for photocatalysis. Band edge alignments of unstrained SnO₂ shows that the valence band maximum (VBM) is more positive than the redox potential of O₂/H₂O (1.23V), while the conduction band minimum (CBM) for pH = pH(pzc) lies above the redox potential of H⁺/H₂ (0V), which mean that the pure SnO₂ cannot be used for hydrogen evolution reaction (HER). Applying compressive strain, the CBM edge position decreases gradually as the strain percent increases, in other hand under tensile strain the CBM edge position could be corrected for pH ≥ 10. Which clearly reveals the ability of mechanical strain to modulate the band structure and photocatalytic properties of SnO₂ in order to improve its suitability as a photo-catalyst for water splitting and hydrogen production.

Keywords

SnO₂, uniaxial strain, density functional theory, photo-catalytic properties, hydrogen production

2D POWER MAPPING OF N++/P/P++/AL CRYSTALLINE SILICON SOLAR CELLS

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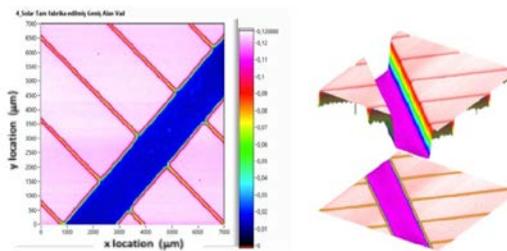
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Silicon based thin film technology for solar cell application is used widely. The quality requirement for efficiency is one of the key factor. Base material is one of the main factor for lower cost without losing performance as well as process technology. However, the most important issue in advances is the efficiency. On that manner life time of photo generated carriers has a major effect. In general, average life time of fabricated wafers is used for characterisation but two dimensional mapping much useful for checking substrate, coated thin film and junction uniformity. The other parameters such as open voltage, short circuit current measured in two dimension by using local illumination are important for uniformity check down two micro scale. In that study 2D mapping of solar cells fabricated on crystalline p-Si is characterised as function of temperature. Our findings shown that designed system with Lab- View based software is capable to carry out performance measurements of any type of solar cell.

Keywords

solar cell, 2D mapping, efficiency, life time



2D open voltage mapping of fabricated solar cell.

PLASMONIC MESOPOROUS Ag@TiO₂ AND Ag@Au@TiO₂ NANOCOMPOSITES FOR EFFICIENT LIGHT HARVESTING IN DYE SENSITIZED SOLAR CELLS

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Dye Sensitized Solar Cells (DSSCs), an important class of third generation solar-cells, have attracted the attention of many researchers due to their low cost, facile fabrication, and relatively high power conversion efficiency (PCE) [1]. Recently, Localized Surface Plasmon Resonance (LSPR) based methods improved the light harvesting efficiency at photoanode based on absorption intensity and the stability of metal (Au and Ag) nanoparticles by controlling the morphology, dimension and composition of the metal nanoparticles and increasing of the absorption intensity of the sensitizer [2, 3]. Herein, we synthesized plasmonic mesoporous Ag@TiO₂ and Ag@Au@TiO₂ nanocomposites for efficient light harvesting in dye sensitized solar cells. Mesoporous TiO₂ nanoparticles (NPs) were synthesized by solvothermal method using Teflon-lined reactor. The primary amine (-NH₂) groups were generated using covalent attachment of 3-aminopropyltriethoxy silane (APTES) via hydroxyl groups of TiO₂ NPs under reflux conditions. Then, Au nanoparticles were obtained by citrate reduction method (15-20 nm in size) and attached onto TiO₂ NPs via their primary amine functionality (Au@TiO₂ NPs). In the next stage, the Ag shell was formed onto the Au@TiO₂ NPs via “seed mediated growth” and the accumulation of Ag nano-islands (10-40 nm in size). The physical and chemical properties of the plasmonic Ag@TiO₂ and Ag@Au@TiO₂ nanocomposites were analyzed using SEM, XRD, XPS, UV-vis, Raman spectroscopy, and BET as well. The anatase crystalline structure, good optical properties, and enhanced LSPR properties of Ag@Au@TiO₂ nanocomposites based DSSCs system demonstrated better PCE value compared to bare TiO₂ nanostructures.

Keywords

dye sensitized solar cells, Ag@Au@TiO₂ nanocomposites, plasmonic nanoparticles, light harvesting

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INVESTIGATION OF SPECTRAL SPLITTING AND SOLAR CONCENTRATION USING DIFFRACTIVE OPTICAL ELEMENTS AT OBLIQUE ANGLES

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Spectral splitting of broadband light is an essential tool for numerous photonic research lines and applications. The efficiency of solar cells is shown to increase by 42% that employ spectral splitting of broadband light [1]. The splitting process can be realized by controlling diffraction of light in such a way that different wavelengths are guided to distinct regions, where materials with optimized efficiency for these distinct wavelengths are located. Spectral splitting can be comprehended by solar concentration using a single diffractive optical element (DOE). Here, we design DOEs using an iterative optimization algorithm in order to demonstrate solar concentration as well as spectral splitting using a single multi-functional layer. Fig. 1(a) shows the height profile of a DOE that we design. The height of the pixels are optimized with 1 μm steps up to a maximum of 10 μm . The output intensity pattern is shown in Fig 1(b). Two selected wavelengths (400 nm and 800 nm) are spectrally split and concentrated to two distinct regions. Using the DOE we design we are able to direct 48% of 400 nm light and 25% of 800 nm light to designated places. Moreover, we investigate the intensity distribution of output light at oblique angles and find that the DOE is able to focus in total of 60 % ans 32% of 400 nm and 800 nm input light to designated positions when the angle of incidence is changed between 0-20o, respectively.

Keywords

spectral splitting, solar concentration, diffractive optical elements

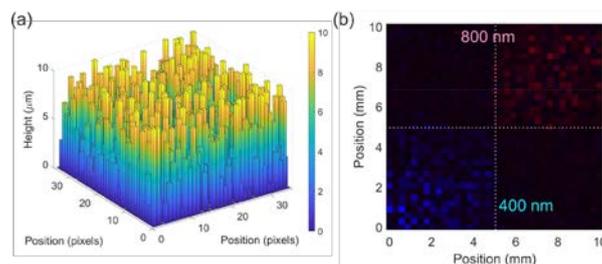


Figure 1. Spectral splitting of of light at wavelengths 400 nm and 800 nm. (a) The height profile of

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D-STATCOM FOR A DISTRIBUTION NETWORK WITH DISTRIBUTED PV GENERATION

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Abstract- Power quality in an ac power distribution system is reduced by nonlinear loads and power electronic enabled devices which draw non-sinusoidal current. When this distorted current interacts with the line impedance of the distribution network, the system voltage becomes distorted which could adversely affect other electrical devices connected to the grid. In the traditional grid, this is compensated at the substation by the utility. Adding PV into the distribution can compliance this when power flow reverses due to excess generation and back feeding. It has been proposed that the photovoltaic inverter should be to improve the power quality by compensating harmonic current. However, this adds complexity and cost to the inverter as well as reduces the inverter reliability.

Keywords

D-STATCOM, distributed PV generation, power quality, harmonic compensation, matrix converter

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MODELING AND RE-DESIGNING OF TABRIZ INTERNATIONAL AIRPORT IN IRAN APPROACHING BIPV

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Airports are one the important characteristics of development of cities in the modern age and play an important key in sustainable development as well. Forecasts shows the double growth of air travelers for Tabriz international Airport in the next 25 years. On the other hand, airports that operates twenty-four hours a day are responsible for maximum energy consumption. This paper discusses on re-design characteristics of existing Tabriz international airport in Iran based on Building Integrated Photovoltaic (BIPV) concept for future development.

Based on Tabriz climatic condition and its solar yield potential, appropriate use of PV types including mono-crystalline, poly-crystalline and thin-film types besides various transparencies according to the form requirements and space function to produce solar electricity to meet maximum energy demands of electricity and heating/cooling demands are some advantages of the proposed airport design utilizing the wing skeleton structure. The research findings show that based on sustainable development and energy efficiency approaches, the proposed design for Tabriz international airport might be altered to the existing airport in the future.

Keywords

solar airport, BIPV, energy efficiency, carbon footprint

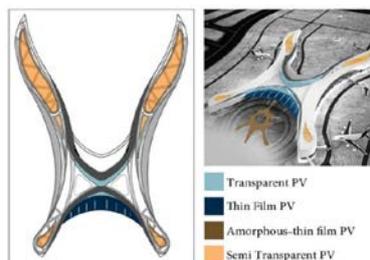


Figure 1: Integration of different PV panels on airport building

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IMPACTS OF A PV POWER PLANT FOR POSSIBLE HEAT ISLAND EFFECT

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Photovoltaic (PV) power plants cover large areas with modules having mostly dark-colored solar cells and therefore an environmental debate arises if they alter the solar reflectivity (albedo) of the surface they are installed. Another fact is the additional heat that the modules radiate while they are running. Urban heat island (UHI) is essentially defined as the air temperature differences between the urbanized area and the neighboring rural areas¹. Many articles appeared in literature on UHI^{2,3}. However, only a few works appeared on the heat island caused by PV power plants (PVHI)⁴. We are conducting a field research with in-situ measurements taken from our two weather stations inside and outside a PV power plant in Tavşanlı, Kütahya. To consider as a reference, we have provided the meteorological data of Tavşanlı station from General Directory of Meteorology; which is the nearest weather station to the PV power plant. These stations have been collecting the data of air temperature, relative humidity, average wind speed and atmospheric pressure every 10 minutes since October 2017. We determined that the differences between the measurements of three stations are statistically significant. We used One-Way Anova method and obtained that the P-value $< \alpha=0,05$ (Significance Level) and $F > F_{crit}$. In addition, the averages of the measurements of the three stations are significantly different as determined by Tukey's HSD test.

This study was supported by "METU Scientific Research Projects Funding" for the 2017 year (Project Number: BAP-07-02-2017-006).

Keywords

photovoltaic power plant, photovoltaic module, heat island, albedo, meteorological parameters

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POTENTIAL USE OF THE SOLAR ROOFTOP PHOTOVOLTAIC SYSTEM IN BUILDING ENERGY MANAGEMENT UNDER ENERGY EFFICIENCY AND CONSERVATION POLICIES: ECONOMIC FEASIBILITY ANALYSIS

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Grid tariff of electricity is quite unstable in Bangladesh. In weekdays, electricity consumption at industrial buildings is at its highest causing 11.98 BDT/ kWh during peak hours however the residential buildings reach its peak on weekends [1]. Electricity distribution authorities have provided policies of using solar PV on consumptions (residential-3%, industries- 7%, if >50kW then 10%) [1]. In this circumstances, using rooftop solar PV system has considered being more effective in the study. The capital cost of solar rooftop PV ranges under 80000 BDT/ kW (without battery) and the Feed-in Tariff Rate is 9.45 BDT/kWh [2]. According to SREDA's energy efficiency and conservation (EE&C) master plan, power consumption in industrial buildings can be reduced by 15% and it could be 36% in the reduction for residential buildings by initiating proper energy management features [3]. The paper proposes an energy management system, which will prove that by controlling peak load of residential or industrial buildings, the unit price of electricity could be reduced substantially. Solar rooftop PV system will be utilized to provide electricity supply in building distribution network during peak hours or only to the individual loads that cause peak consumptions. The system batteries could either be charged directly from the grid (off-peak hours/ after 12 a.m. when the unit price is the lowest) or directly from rooftop panels; depending on solar availability during day hours [1]. According to SREDA's EE&C, the project feasibility was optimized through RETScreen tool using the technical and financial terms into consideration extensively [4].

Keywords

photovoltaic (PV), energy management, feed in Tariff, SREDA, EE&C, BDT, peak consumption, RETScreen

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ECONOMIC ANALYSIS AND COMPARISON OF 990 KWE GROUND-MOUNTED PHOTOVOLTAIC POWER PLANTS UNDER TURKEY'S REGULATION SCHEME

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Today, despite the fossil fuels constitute a large part of the energy production, due to instability and volatility in fossil fuel prices, countries are heading towards alternative energy sources. Therefore, many countries have been placing great importance to R&D activities in the field of renewable energy for years and have made a number of legal regulations in order to increase investment in this area. The regulations made by Turkish government in recent years, have given acceleration the solar energy sector. According to recent research of IRENA (International Renewable Energy Agency), although Turkey has high potential of solar energy among European countries, is ranked seventh place in terms of installed capacity. This result shows that the regulations are still inadequate.

In this paper, the correlation between solar radiation amount and Net Present Value (NPV) of the plants located in different regions was examined by making economic analysis of a 990 kWe ground-mounted photovoltaic power plant under Turkey's regulation scheme. In addition, these simulations were made using the SAM (System Advisor Model) released by NREL (National Renewable Energy Laboratory). As a result, it was determined that there was a direct correlation between the amount of solar radiation - NPV, assuming that the other parameters such as inflation, discount rate, land purchase, logistic costs are fixed, and If the correlation is implemented throughout Turkey, a national incentive model can be created to achieve a homogeneous investment nationwide

Keywords

photovoltaic, energy, renewable, NPV, SAM, economic analysis

COST-BENEFIT ANALYSIS OF THE SOLAR POWER PLANT: A CASE STUDY

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In parallel with the development of industry all over the world, the energy deficit is increasing day by day.[1]Solar energy is the most commonly used renewable energy source to meet growing energy demand.[24] In this study, Kilis 7 Aralık University Vocational School of Technical Sciences has been investigated to meet the energy requirement with solar energy and the solar power plant has been evaluated economically. Due to the fact that the cost of the actual power plant installation is very high, the modeling of plant has been done on the Vocational School of Technical Sciences. With the help of modeling on the simulation programs, the actual solar power plant to be installed has been realized the feasibility study and economic analysis. For this purpose, the PVSYST simulation program is used to model the solar power plant. Thanks to the data obtained from the program, the annual energy production capacity to be established in the Vocational School of Technical Sciences, the efficiency of solar power plant and cost-benefit analysis is calculated.

Keywords

solar energy, solar power plant, cost-benefit analysis

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EFFECT OF PRECURSORS' STACKING ORDER ON THE PHASE OF CU₂ZNSNS₄ ABSORBER LAYER FOR THIN FILM SOLAR CELL APPLICATIONS

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The quaternary compound of Cu₂ZnSnS₄ (CZTS) is a newly explored p-type semiconductor photovoltaic material which attracts so much attention in photovoltaic industry due to its low cost, earth abundant properties as well as consisting of non-toxic elements contrary to other chalcogenide based solar cells such as CuIn(Ga)(S,Se)₂ (CIGS) and CdTe. Although, CZTS studies have been newly started, recently 12.6% efficiency has been achieved which demanding further improvement [1]. The CZTS thin films show p-type conductivity, high absorption coefficient (10⁴ cm⁻¹) and a band gap of 1.45-1.5 eV that is ideal to achieve the highest solar-cell conversion efficiency [2,3]. In this work, CZTS absorber layers were grown on Mo coated soda lime glass (SLG) substrates using two stages which are the magnetron sputtering of metallic precursors, followed by a heat treatment under sulfur vapor atmosphere. Two types of CZT metallic precursors were grown such as SLG/Mo/Cu (55nm)/Sn/Zn/Cu (120nm) and SLG/Mo/Cu (120nm)/Sn/Zn/Cu (55nm). To obtain CZTS absorber films, all precursors were sulfurized using sulfur powder at 550 °C for 45 min under Ar gas atmosphere. For the same stacking order, the effect of Cu thickness sequentially grown with Sn layer on the film quality were investigated. This study revealed a correlation between the CZTS stacking order having different thickness of Cu layer. With the deposition of thick Cu layer below the Sn layer in the stacking order improved the quality of CZTS absorber layer in terms of structural and compositional.

*This research is supported by TUBITAK with the project number114F341.

Keywords

CZTS, magnetron sputtering, XPS, thin film solar cells

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PRODUCTION AND CHARACTERIZATION OF Cu_2SnS_3 ABSORBER LAYERS FOR PHOTOVOLTAIC SOLAR CELL APPLICATIONS

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Next-generation thin film solar cell technologies require earth abundant photovoltaic absorber materials. Various compounds such as CdTe, CuInGaS (CIGS), CIGSSe and $\text{Cu}_2\text{ZnSnS}_4$ (CZTS) have been employed for solar cell fabrication. Nevertheless, the elemental toxicity, complex structure due to more number of elements and rare elements indium and gallium, which are expected to increase in cost restrict them for photovoltaic applications. Recent studies have begun to look towards the synthesis of new ternary semiconductors to reduce the cost and complexity of the synthesis process [1]. Among them, Cu_2SnS_3 (CTS) is an earth abundant, non-toxic material with direct band gap energies of 0.93-1.77 eV. Suitable optical and electrical properties which make it a potential absorber layer for photovoltaic applications [2]. Unfortunately, the material still needs to improve for high efficiency [3]. Depending on the deposition technique, several intermetallic phases may appear [4]. Incomplete conversion of binary sulfides during annealing may lead to the formation of undesirable compounds which affect the crystallization of CTS. In this work, Cu-Sn metallic precursors deposited on glass substrates by Physical Vapour Deposition (PVD) technique. In the second stage, the production of CTS films was completed by applying a sulfurization process in a furnace at different sulfurization temperatures. Structural, optical, surface and electrical properties of the films were investigated in detail with X-ray diffraction, Raman spectroscopy, UV-VIS Spectroscopy, spectroscopic ellipsometry, atomic force microscopy, scanning electron microscopy and four-point probe techniques.

*This work was supported by Scientific Research Projects Coordination Unit of Ondokuz Mayıs University. (Project number: PYO.FEN.1904.18.004)

Keywords

Cu-Sn-S, thin film solar cells, photovoltaics, sulfurization

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ELECTROCHEMICAL PROPERTIES OF CADMIUM TELLURIDE THIN FILMS

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Cadmium telluride thin films were deposited on indium thin oxide (ITO) coated glass substrate by co-electrochemical deposition method. CdTe films were deposited at six different deposition potentials such as -0.4, -0.5, -0.6, 0.7, -0.8 and -0.9 V vs Ag/AgCl reference electrode. Deposition time was kept constant for two min. Deposition electrolyte included aqueous solutions of 10 mM CdSO₄, 20 mM Na₂TeO₃ as precursors, and 200 mM LiCl. HCl was used for pH adjustment of the electrolyte. The effects of deposition potential on characteristics of CdTe thin films were investigated by means of some techniques such as SEM, EDX, XRD, UV-VIS spectroscopy, and electrochemical impedance spectroscopy. Deposition potential dependency of the film surfaces was seen to be high from SEM studies. EDX results show that Cd/Te ratios vary between 0.81 and 1.09. XRD analyses show that the films include hexagonal phase of CdTe, monoclinic phase of CdTeO₃ and CdTe₂O₅. The optical band gaps (E_g) of all the films were derived from Tauc' relation using absorbance data. E_g values change between 1.61 and 1.94 eV depending on deposition voltage. Donor density changes from ~10¹⁷ to 10²⁰ cm⁻³ depending on growth potential according to the Mott-Schottky approximation. Energy level diagrams including valance band, conduction band and fermi level are determined via flat band voltage and the related equations. An equivalent electronic circuit is fitted to Nyquist data for the films, and physical properties of the CdTe films are discussed in terms of the values of circuit elements.

Keywords

CdTe, thin Film, electrodeposition

CZTS SOLAR CELL STRUCTURE PRODUCED BY PULSED LASER DEPOSITION TECHNIQUE

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Cu₂ZnSnS₄ (CZTS) solar cells have non-toxicity, low cost, abundant elements in the nature which have high absorption coefficient and is very attractive material compared to other solar cells materials [1]. Different coating techniques are used for each layer of CZTS thin film solar cells. The certain substrate temperatures can be used to produce these layers in a crystal structure. Pulse laser deposition (PLD) technic has many advantageous for production of thin films in stoichiometric, crystalline and epitaxial structures at low substrate temperatures [1,2,3]. The solar cell can be produced in which all the layers are magnified by the PLD in the same vacuum chamber without requiring a different coating technique.

In this study, we have produced Mo and CZTS thin films on microscopic substrate at room temperature by applying PLD technic. CZTS has been annealed at 400°C in sulphur ambiance after CdS and front contact are deposited on CZTS thin film at room temperature. The morphological and optical properties as well as crystal structure of CdS and CZTS thin films have been analysed by SEM, XRD and UV-vis spectrometry. J-V characteristics of the CdS/CZTS hetero-junction device produced have been obtained under darkness and in illumination conditions. The device has shown diode characteristics in both conditions but exhibited photo-electric behaviour in the illumination conditions. V_{oc} , J_{sc} and Φ_B values of the device have been determined and these values have been interpreted depending on the morphological and crystalline formation in the solar cell structure.

Keywords

solar cell, PLD, CZTS, thin film

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CDS THIN FILMS OBTAINED CHEMICAL BATH DEPOSITION FOR THIN FILM SOLAR CELL

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Photovoltaic devices are becoming increasingly important because of rapidly growing energy crisis today. Among the photovoltaic devices in use at present, CdS/CdTe thin film solar cells have a unique place owing to its relatively low cost of production and high performance in comparison to many such devices [1]. Thin films of CdS is used as buffer layers in Cu(In,Ga)(S) (CIGS) photovoltaic devices. CdS n-type semiconductor is with a band gap of 2.42 eV at room temperature. Thus, thin films of CdS have been used widely as window layers in solar cells with an absorber layer of CdTe, Cu₂S₂ or CuInSe₂ [2]. Chemical bath deposition (CBD) method is known to be a simple, low temperature, and inexpensive large-area deposition technique. This method has been used in the deposition of CdS semiconductor thin films since the 1960s [3].

In this study, CdS thin films have been deposited onto ITO coated glass substrates by using chemical bath deposition method. The effects of bath temperature were investigated at between 60 and 90 °C. The good crystallization was obtained at 80 and 90 °C. It was understood from the absorbance measurements that when films were obtained at 80 and 90 °C, the transmittance increased about two times that of the other films. The energy band gaps of the films varied from the 2,18 to the 2.49 eV. It was estimated from the SEM images that the surface roughness were decreased as bath temperature was increased.

Keywords

CdS, thin films, chemical bath deposition

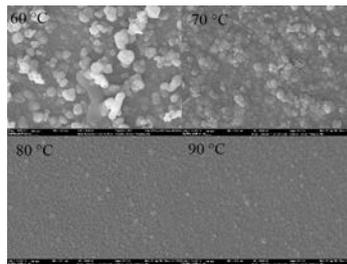


figure 1

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ELECTRODEPOSITION OF CDO THIN FILMS FOR SOLAR CELLS

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Cadmium oxide is transparent conducting oxides thin film materials that possess high optical transparency (>80%) in the visible light region of the electromagnetic spectrum. CdO is an n-type semiconductor with nearly metallic conductivity. It has a direct energy band gap of nearly 2.3 eV [1]. CdO has been used in applications such as photovoltaic cells [2]. CdO thin films is obtained by various physical and chemical deposition techniques such as RF sputtering, sol-gel, spray pyrolysis, metalorganic chemical vapor deposition and electrodeposition Among these techniques electrodeposition is an important method that is suitable for the growth of films and the advantage of this method compared with other techniques includes low process temperature, inexpensiveness and capability of controlling morphology of the films [3].

In this work, thin films of CdO were synthesized by using electrodeposition. End of the electrodeposition, Cd(OH)₂ were precipitated onto ITO coated glass substrates. After the deposition, films were annealed to convert from the Cd(OH)₂ to the CdO. The four annealing temperature were chosen as 200, 300, 400 and 500 °C. The band gap and transmittance were obtained by using absorbance measurements. It was seen from the transmittance plots that when films annealed at 400 and 500 °C, they showed relatively high transmittance according to the other films. The energy band gaps varied between 2.05 and 2.33 eV. XRD patterns showed that the CdO films could be produced. It was estimated from the SEM images that surface roughness was reduced by increasing annealing temperature.

Keywords

CdO, thin Film, electrodeposition

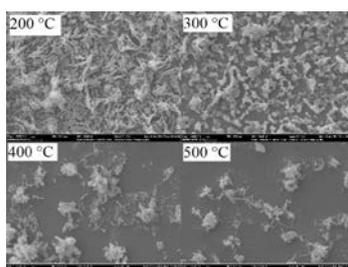


Figure 1

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SIZE DEPENDENT INTERMEDIATE BAND ENERGY LEVELS AND ABSORPTION OF BOUND STATES IN BOX SHAPED QUANTUM DOTS

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The quantum dot intermediate band solar cells (QD-IBSCs) have not reached the expected efficiencies yet, because their sub-bandgap photocurrents are too low. The quantum dot intermediate band solar cells are usually manufactured by forming InAs QDs within a GaAs barrier [1]. The growth by molecular beam epitaxy in Stransky Krasnatov mode is the most common way of producing InAs/GaAs quantum dots and produces truncated quadrangular pyramids [2]. Several works have used different QD shapes for calculations such as spherical, lens or box types [3,4,5]. In this work, single band k.p model is used for calculation of bound state energy levels and absorption coefficients between bound states for box shaped InAs/GaAs quantum dots. In this study, effects of quantum dot parameters on intraband absorption and position of intermediate band energy levels are investigated. The results show that the bound state energy levels decrease with the increase of QD width and conduction band offset value. The QD height has less effect on bound state energy levels and absorption coefficients. Stronger absorption bands have been obtained for smaller quantum dots. The results found in this work will be the first step to design realistic detailed balance model of QD-IBSCs.

Keywords

quantum dot, intermediate band solar cell, absorption coefficient, bound states, energy levels

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SILICON CARBIDE PURIFICATION BY FORMATION OF THIN POROUS LAYER FOLLOWED BY THERMAL ANNEALING FOR SILICON PASSIVATION

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Recently, Silicon carbide (SiC) has generated much interest as a promising material for high-power, high-temperature, high-frequency electronic, optoelectronic devices [1-3] particularly thanks to its wide band gap, its mechanical strength, its thermal stability. During last years, important efforts have been dedicated to the use of SiC in photovoltaic applications. Many techniques can be used to elaborate SiC layers such as Chemical Vapor Deposition (CVD), Pulsed laser Deposition (PLD), sputter deposition and others. As in the case of silicon material, silicon carbide may suffer from the presence of crystallographic defects (dislocations, stacking faults...) and electronic impurities.

Keywords

silicon carbide, gettering, impurities, silicon passivation

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ELECTRO OPTICAL ANALYSIS AND NUMERICAL MODELING OF CU₂O LAYER FOR ADVANCED SOLAR CELLS - A REVIEW

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Research on silicon-based tandem heterojunction solar cells with metal oxides is promising for the development of high performance solar cells. High optical absorptance makes Cu₂O a prospective absorber layer.

The objectives of this work are: experimental analysis of the Cu₂O absorber layer and numerical modeling of its electro optical characteristics.

Results: Cu₂O thin films were synthesized by reactive direct current magnetron sputtering on quartz substrates.

The electro optical and structural properties of the Cu₂O layer are investigated via scanning electron microscopy (SEM), atomic force microscopy (AFM) [1,2], Hall effect measurements, Fourier-transform infrared spectroscopy (FTIR) and spectrofluorometry. Scanning-probe instruments can provide valuable information towards the characterization and optimization [3] of solar cell layers. The SEM analysis revealed an increase in grain size in the sample treated with rapid thermal annealing at 900 °C. AFM analysis shows that the high thermal annealing increases the surface roughness by a factor of 10. FTIR spectrum shows peaks of CuO at the interface of the quartz substrate from oxidation.

Silvaco software was used for electrical modeling, mainly targeting the buffer layer in the simulation, varying its thickness, the doping level and the defect density for several materials. OPAL 2 software was used to model the optical characteristics of the Cu₂O films, respectively optical band gap, reflectance, transmittance and absorptance.

Conclusions: these results are important for optimization of efficient metal oxide tandem solar cells.

The further research will involve specialized software simulation and comparison of experimental data with simulated results.

Keywords

Cu₂O layer, tandem solar cells, electro optical modeling, SEM, AFM, FTIR, spectrofluorometry

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MICROSTRUCTURAL PROPERTIES OF ZNO POWDER NANOSTRUCTURES PREPARED BY MECHANICAL ALLOYING

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ZnO powder nanoparticles mechanically alloyed were doped with iron to investigate their structural and microstructural properties using X-ray diffraction (XRD) and differential scanning calorimetry (DSC) for examined 5% Fe doped ZnO. The ZnO [1,2] starting pure powder exhibited a hexagonal crystal structure with space group p63mc of ZnO, however with the introduction of 5% Fe in the ZnO milled powder, the hexagonal ZnO phase remained unchanged, whereas the microstructural parameters were subject to significant variations due to the introduction of Fe atoms into the ZnO hexagonal matrix to replace oxygen ones [3]. The size of crystallites and microstrains are found milling time dependent.

Keywords

microstructure, ZnO₂, mechanical alloying, DRX, DSC

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DROPLET-BASED SELF-ORGANIZED ZNO SURFACES FOR PHOTOVOLTAIC APPLICATIONS

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There has been a great deal of interest in semiconductor materials based on zinc oxide (ZnO) owing to its excellent properties, which allows for its use in many applications such as solar cells. Thus, the orientation of semiconductor microstructures represents a major challenge, in particular because it paves the way for the formation of functional materials. The originality of our work relies on the combination of droplet-based microfluidics and the sol-gel technique to produce ZnO microspheres, which allows for high flexibility of droplets real time manipulation, as well as for the production of highly monodisperse ZnO droplets. Also, the as-synthesized zinc oxide microspheres self-assemble into highly organized microstructured 2D patterns. Hence, our approach allows for the self-organization of zinc oxide structures without the need to micro and nanotechnologies used to micro-structure materials artificially, or resorting to additional external parameters, like an external electric field or deposition in high vacuum.

Our technique offers many advantages over conventional physical or chemical techniques. As long as it requires a small volume at the microliter scale, a fabrication short time and the control of the formation mechanism.

More specifically, this technique permits the synthesis of zinc oxide microspheres with a well-defined size and shape that enables self-assembly of such microparticles onto glass substrates. It allows also for better optimization of the experimental conditions to produce very effective and inexpensive coatings. It also allows easy control of different parameters, including the size, size distribution, porosity, surface morphology.

Keywords

photovoltaic, microfluidics, ZnO

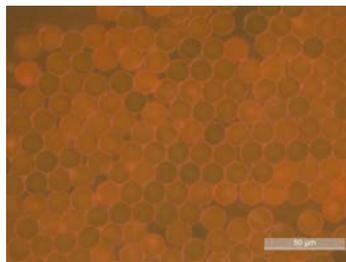


Image of microparticles of zinc oxide obtained by the microfluidic sol-gel route

STUDY OF THE STRUCTURAL, OPTICAL AND ELECTRICAL PROPERTIES OF THIN LAYERS OF ZNO OBTAINED BY VACUUM EVAPORATION

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ZnO thin films were deposited by vacuum evaporation of a Zn powder. The as-deposited films have gray color. Then, these films were annealed in air atmosphere at different temperatures between 300C and 600 C for one hour. Their microstructure and composition were studied using XRD. By increasing the temperature, it was found that film oxidation starts at 300 C. XRD peaks related to ZnO appear and peaks related to Zn decrease. At 500 C, zinc was totally oxidised and the films became totally transparent. The electrical conductivity measurement that were carried out in function of the annealing temperature showed the transition from highly conductive Zn thin film to a lower conductive ZnO thin film. The optical gap (Eg) was deduced from the UV-vis transmittance, and its variation was linked to the formation of ZnO.

Keywords

ZnO, annealed, vacuum, evaporation, thin, film, conductive, optical gap

INVESTIGATIONS ON CU₂ZNSNSE₄ THIN FILMS PREPARED BY SELENIZATION OF RF-SPUTTERED METALLIC STACKS

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Kesterite Cu₂ZnSnSe₄ (CZTSe) thin films have attracted significant interest as promising absorber materials due to its outstanding properties such as optimum direct band gap energy of ~1.0 eV, high absorption coefficient ($> 10^4 \text{ cm}^{-1}$) and earth abundant constituent elements for thin film solar cells [1, 2]. In this work, the CZTSe precursor films with 645 nm thickness were prepared on SLG and Mo-coated SLG substrates by RF magnetron sputtering technique using Cu, Sn and Zn metallic targets in a sequence Cu/Sn/Zn/Mo/SLG. Subsequently, the precursor films were annealed in Se+Sn atmosphere in a quartz container (volume of ~5 cm³) at 560 °C for 15 minutes. The structural, morphological, optical and electrical properties of the films were investigated by using X-ray diffraction (XRD), Raman spectroscopy (RS), Energy dispersive spectroscopy (EDS), Secondary ion mass spectroscopy (SIMS), Atomic force microscopy (AFM), Scanning electron microscopy (SEM), UV-Vis spectroscopy and Hall Effect measurement system. The XRD patterns of the films exhibited the (220)/(204) and (312)/(116) peaks of the kesterite CZTSe along with the intense (112) peak. The formation of kesterite CZTSe was also confirmed from the presence of the major peaks located at 172 cm⁻¹, 194 cm⁻¹ and 234 cm⁻¹ by RS analysis. From the SEM images, it was observed that the selenized CZTSe films had a well crystallized and highly dense microstructure consisting of large grains. The distributions of the elements Cu, Zn, Sn and Se in the structure and sodium diffusion into the CZTSSe film from SLG substrate were analysed by SIMS in detail.

Keywords

Cu₂ZnSnSe₄, CZTSe, RF sputtering, selenization, thin films, solar cell absorber

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ELECTROCHEMICAL BEHAVIOR AND EFFECT OF REVERSE POTENTIAL ON ELECTRODEPOSITION OF LEAD TELLURIDE THIN FILM ON FLUORINE DOPED TIN OXIDE SUBSTRATE

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Lead telluride is listed among the most promising thermo-electric materials thanks to its high thermoelectric figure of merit (ZT) at intermediate temperatures (500-900 K) [1]-[3].

Present paper reports on the voltammetry behavior of Fluorine doped Tin oxide (FTO) substrates in nonaqueous electrolytes containing HTeO^{2+} and Pb^{2+} . Particular cathodic behavior is highlighted and studied by cathodic stripping experiments, demonstrating that the presence of PbTe dendrites induces an additional cathodic peak prior to the dissolution of bulk PbTe. The diffusion coefficients of Pb^{2+} and HTeO^{2+} were measured in order to adjust their respective concentration in the electrolyte. Diffusion of Pb^{2+} being slightly faster than HTeO^{2+} , optimal concentrations were calculated to be 5 mM Pb^{2+} for 5 mM HTeO^{2+} . For steady-state potentiostatic deposition, Pb is under potentially deposited onto over potentially deposited Te from -145mV and its content in the deposit slightly increases with the applied over potential. However, increasing the overpotential also induces different morphologies. In contrast, reverse deposition can lead to the formation of spherical assemblies of hollow nanorods with high specific area [4]. However, it strongly decreases the Pb content in the film.

Keywords

FTO, voltammetry, electrolytes

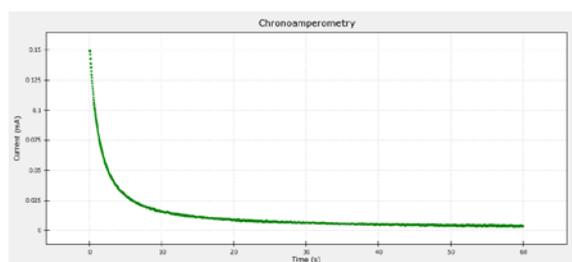


Fig.1 Chronoamperometry of HTeO_2^+ when platinum is used as WE and Pt mesh as CE and Ag/AgCl as RE

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INFLUENCE OF CU AND SN ALLOY ON THE PROPERTIES OF CU₂ZNSnS₄ (CZTS) BASED THIN FILM SOLAR CELLS

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Cu₂ZnSnS₄ (CZTS) has emerged as an alternative material to Cu(In, Ga)Se₂ (CIGS) and sharing the similar crystal structure with this material. Contrary to CIGS and CdTe, CZTS contains earth-abundant and non-toxic elements. Kesterite is the most stable crystal structure of CZTS which has direct band gap around of 1.5 eV, and high absorption coefficient ($\geq 10^4$ cm⁻¹) [1, 2]. In this study, kesterite Cu₂ZnSnS₄ (CZTS) thin films were fabricated by DC magnetron sputtering deposition [3] of Cu, Zn, and Sn metallic layers on Mo coated glass, followed by annealing process in sulfur vapor at high temperature for a particular time. Three kinds of films were prepared and induced pre-annealing treatment in order to obtain Cu-Sn alloy. Chemical composition of the films were checked by X-ray fluorescence (XRF) before and after KCN etching process. Structural characterizations were performed by X-ray diffraction (XRD) and Raman spectroscopy. Glow discharge optical emission spectroscopy (GDOES) was utilized to investigate depth profile of the films. Optical properties of the films were investigated Photoluminescence (PL) and transmission measurements. CZTS thin films were processed to solar cells and characterized.

Keywords

thin film solar cells, Cu₂ZnSnS₄ (CZTS), sputtering, RTP, pre-annealing, kesterite

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EFFECT OF ARGON DILUTION ON THE MORPHOLOGICAL, OPTICAL AND ELECTRICAL PROPERTIES OF HYDROGENATED AMORPHOUS SILICON CARBIDE THIN FILMS GROWN BY PLASMA ENHANCED CHEMICAL VAPOR DEPOSITION

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Nowadays, many efforts are made to improve solar cell performances and to decrease the manufacturing costs. Different studies have demonstrated that a well-passivated surface improve conversion efficiency of silicon-based solar cells [1, 2, 3]. Among different solutions for c-Si surface passivation, amorphous semiconductors deposited by radio frequency Plasma Enhanced Chemical Vapor Deposition (PECVD) at low temperature < 400 °C have revealed excellent results [4, 5, 6].

In this paper, the use of hydrogenated amorphous silicon carbide (a-SiC:H) passivating layers for crystalline silicon solar cell was investigated especially by Photoconductivity decay technique. a-SiC:H thin films were grown by PECVD on silicon single crystal (100) using a gas mixture of pure silane (SiH₄), methane (CH₄) and argon (Ar). The substrate temperature was 300 °C, plasma power is 80 W. The distance between electrodes was 15 mm and total pressure was 1 Torr. Argon flow rate was varied from zero to 10 sccm. Increase of argon flow rate leads to a significant enhancement of a-SiC passivating properties in view of the fact that minority carrier lifetime increased and effective surface recombination velocity decreased. The effect of argon flow rate on the structural, morphological, optical and electrical properties of (a-SiC:H) thin films were also investigated.

Keywords

solar cell, passivation, silicon carbide, PECVD, argon pressure, opto-electrical characterization

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ELEMENTAL ANALYSIS OF SOL-GEL SPIN-COATED CZTS THIN FILMS FOR PHOTOVOLTAIC APPLICATIONS

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CZTS thin film layers consist of naturally abundant and non-toxic materials that show p-type semiconductor properties with a direct band gap of 1.45 eV and are promising for solar cell applications [1-3]. However, it was not possible to increase its efficiency to reach the level of the CIGS alternative due to the difficulty in pure crystal phase preparation [4]. The elemental distribution of copper, zinc, tin and sulphur in CZTS compound is determining the phase structure. This distribution can be varied due to sol preparation and following thermal treatment parameters. In this study, the effect of annealing temperatures on the stoichiometry was analyzed using EDX measurements of the CZTS samples annealed at 300, 400, 500, 525, 550 and 580 °C. The presence of residual elements in the sample that annealed at 300 and 400 °C was attributed to the incomplete evaporation of solvent and stabilizer. Another element of oxygen at the surface of all films due to contact of the film surface with the surrounding air was observed. The increase in the annealing temperature gave rise to the evaporation of solvent residues and better formation of quaternary compound resulting in without Sn and S loss in the composition. The elemental composition of stoichiometric and homogeneous film that annealed at 550 °C was obtained as Cu:Zn:Sn:S = 20.1:9.82:10.49:49.71.

Keywords

CZTS, spin coating, annealing, elemental analysis.

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CONTROLLABLE DEPOSITION OF LARGE AREA ROLL-TO-ROLL SPUTTERED ITO THIN FILMS FOR PHOTOVOLTAIC APPLICATIONS

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Flexible optoelectronic devices such as organic light emitting diodes (OLED), touch-panel displays and flexible polymer solar cells etc. have been substantially growing. Indium tin oxide (ITO) which has a wide bandgap, relatively high work function (WF) is usually preferred for solar cells as an electrode layer. Moreover, among the transparent conducting oxides, ITO films exhibit excellent conductivity and high transparency [1-3]. However, there are a few key limitations like durability of flexible transparent electrode materials, the poor adhesion and low crystalline qualities. In this study, ITO thin films were successfully deposited on polyethylene terephthalate (PET) substrates by a large area roll-to-roll DC magnetron sputtering system. 25 and 75 μm thick PET substrates with a size of 40 cm x 150 m were loaded into the vacuum chamber and rolled one end to the other by a rotational feedthrough. ITO films were deposited with different processing parameters and rolling speed for each ten meters of substrate. Optical emission spectroscopy (OES) analysis have been carried out during the deposition process in a controllable way to study the effect of growth conditions on the film properties. The quality of microstructures and surface roughness were studied by AFM analysis to improve transmission and conductivity. The transmission characteristics were measured by a UV Spectrophotometer. By optimizing the sputtering conditions and controlling the OES results, it would be possible to have very uniform large area ITO films on PET substrates with high transparency (>85%) and low electrical resistivity ($R_s < 50 \text{ ohm/sqr}$). Enhancement of adhesion between a PET-ITO layers has comprehensively investigated to improve the WF.

Keywords

flexible optoelectronic devices, ITO thin films, roll-to-roll sputtering, large area coatings

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REAL-TIME FAULT DETECTION OF PHOTOVOLTAIC POWER SYSTEMS BY THERMAL IMAGING IN TURKEY

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Upon the identification of legal regulations, photovoltaic power systems (PVPS) based on solar energy have been an attractive investment for any investors with small or large scale budgets in Turkey. Approximately 1.8 GWp PVPS was installed in 2017 and a growth which was greater than in any European country has been experienced in the solar energy industry during the year. In this context, the quality and the financial return of the installed systems have gained great importance.

One of the effective method of fault detection of PVPSs is thermal imaging by checking the modules (such as, hot spots, faulty soldering joints, active diodes), cables continuity and terminal connection faults and burned fuses on site. By using infrared imaging, which is an optical inspection method, it is possible to detect abnormal heat radiation caused by defects inside of the modules without touching, harming and interrupting its operation [1, 2]. In this article, the results of real-time fault detections of PVPSs which were installed in different locations of Turkey is examined by self-made aerial craft. Additionally, a comparison of the results between a fixed images and a drone camera images is realized. The experimentation, both in terms of accuracy and processing time, confirms the effectiveness and the efficiency of the thermal imaging approach.

Keywords

photovoltaic power systems, fault detection, thermal imaging, quality check

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SOILING CHEMICAL COMPOSITION MAPPING OF PV MODULES IN DIFFERENT MOROCCAN AREAS

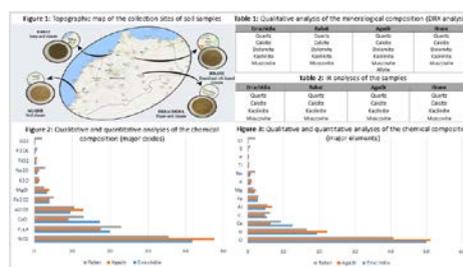
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Photovoltaic power plants development in proper sunny areas is facing to the problem of soiling. The accumulation of dust particles on the surface of PV modules affects largely their efficiency. This phenomenon becomes a serious problem that researchers around the world are trying to control and prevent. In this aim, many studies have been conducted in analyzing dust particles composition [1]-[4]. The present work goes further this objective and presents a mapping of soils naturally deposited on PV modules installed in several Moroccan areas with different climate conditions. To do this, a climatic zoning of Morocco according to the De Martonne index was adopted in order to select representative sites concerned with the collection of soiling samples. For the moment, four samples have been collected from Rabat, Errachidia, Agadir and Ifrane (figure 1). These samples were processed and analyzed. Several analyses were carried out using X-Ray Diffraction (XRD), X-Ray Fluorescence analysis (XF) and Spectroscopy Infrared (IR) to determine the chemical and mineralogical composition of the samples. The results obtained are presented in table 1, table 2, figure 2 and figure 3. They show a variety of chemical constituents of soiling on PV modules. The determination of chemical composition of soiling will be helpful for researchers working on preventive solutions of this phenomenon, especially those who are trying to develop efficient glass coating materials. It will also be useful for researchers working on PV modules surface degradation to well understanding how soiling can damage the front surface of the modules.

Keywords

analyses, soils, PV modules, climatic zoning, XRD, XF, IR



Results

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SHORT TERM SOLAR POWER GENERATION FORECASTING: A NOVEL APPROACH

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Photovoltaics' (PV's) are widely preferred in electricity generation market in our age. However many parameters effect solar power generation such as irradiance, temperature, humidity etc. Therefore solar power generation forecasting is quite significant to plan and manage energy distribution. In this study, a novel methodology called Mycielski-Markov is utilized to forecast solar power generation for short term period. This novel hybrid method based on two different techniques; Mycielski signal processing technique and probabilistic Markov chain. Mycielski investigates the data history and find the repeatness of the solar energy data. It predicts the next data due to this repeatness in a deterministic way. Markov produces the transition probabilities of the solar energy states and forecast new state according to this probabilities. Both techniques completes each other and provide a good forecasting accuracy, approximately 0,85 R² value. The method is tested on data collected from a PV panel placed on ANS campus area of Afyon Kocatepe University and results are presented.

Keywords

solar energy,forecasting,prediction,power

COMPARISON OF DIFFERENT COOLING OPTIONS FOR PHOTOVOLTAIC APPLICATIONS

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The effect of temperature increase plays a significant role on PV panel efficiency. In high operating temperatures, increasing recombination rates decreases the PV panel conversion efficiency. In this study, different cooling options were evaluated under several parameters with different constructions in order to determine the best option for an efficient and simple cooling type. For this purpose, Computational Fluid Dynamics (CFD) simulations were performed in order to investigate the efficiency behavior of a specific Silicon (Si) PV panel while Si PV panel is cooling in operation by using ANSYS-FLUENT: for air cooling and water cooling. For air cooling two different option was suggested: air cooling and air cooling with heat sink. Results of temperature distributions of PV panels for the all cooling options were demonstrated via figures and compared. The influences of temperature difference on Panel efficiency was also investigated.

Keywords

PV panel efficiency, CFD simulation, cooling types

P1

GROWTH OF LOW COST NANOMATERIALS FOR SOLAR CELL DEVICES

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Our objective is to present the synthesis and physical characterization of absorber photovoltaic nanomaterials such as Cu₂ZnSnS₄ (CZTS) and PbS. The development of nanomaterials are made using simple techniques such as chemical spray pyrolysis (CSP) and chemical bath deposition (CBD). Using complementary techniques can improve the performance of devices made from the nanomaterials. Therefore, we studied the effect of various experimental parameters and annealing treatment on the physical properties of nanomaterials. CZTS thin films have been prepared by CSP using both aqueous and alcoholic solution. For the aqueous solution, CZTS material elaborated at a substrate temperature of 280 °C and followed by a thermal treatment in nitrogen at 500 °C, presents the best physical properties [1, 2]. For the CZTS sprayed using methanol as the solvent at a thiourea concentration of 0.04 M, the film exhibited much better crystallinity and has the closest band gap to the theoretical value. Followed by an annealing under nitrogen for an hour at 550 °C, the structural and electrical properties of CZTS showed drastic improvements [3, 4].

PbS thin films are a subject of intense research owing to their technological importance in the field of optoelectronics. PbS has several properties like small direct band-gap (0.4eV) in the bulk. We have grown lead sulfide by CBD and we have shown that we can increase the band gap, by doping it with different elements. PbS material has p-type conductivity and high absorption coefficient in the visible and infrared region [5].

Keywords

nanomaterials, spray pyrolysis, chemical bath deposition, CZTS, PbS; solar cells

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P2

SELF-CLEANING AND HIGHLY TRANSPARENT COATINGS BASED ON END-GRAFTED POLYMERS FOR PHOTOVOLTAIC APPLICATIONS

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Superhydrophobic surfaces show great promise as self-cleaning coatings. The utilization of such coatings in solar cells may prevent the loss of conversion efficiencies due to build-up of water and dust particles. Despite the enormous economic potential of superhydrophobic coatings in photovoltaic applications, the progress has been limited since surfaces that are extremely water repellent (i.e. sliding angles $< 5^\circ$) suffer from reduced transmission of sunlight. In this contribution, we present a two-step coating approach to fabricate surfaces that are simultaneously superhydrophobic and anti-reflective. Our approach is based on interfacial modification of silicon oxide terminated surfaces with end-grafted polymers followed by spray-coating of fluorinated nanoparticles. The end-grafted polymers provide a unique interface for penetration of the hydrophobic nanoparticles leading to a nanostructured film with 4% reduction in the reflection losses and 3.5% increase in the transmittance of the visible light in comparison to a bare glass substrate. The fabricated coatings are extremely water repellent with static contact angles higher than 160° and sliding angles lower than 2° . Application of these coatings on the glass cover of silicon based photovoltaic cells results in increase of the short-circuit current from 8.30 A to 8.44 A with minimal ($<0.2\%$) impact on the power conversion efficiency.

Keywords

photovoltaic applications, superhydrophobic coating,

P3

SURFACE PASSIVATION AND CARRIER SELECTIVITY OF ALD DEPOSITED TiO₂ ON CRYSTALLINE SILICON SUBSTRATES

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In this work we demonstrate the use of atomic-layer-deposited (ALD) ultrathin TiO₂ as a passivating and carrier-selective-contact for c-Si. The optical, structural, and diode quality dependence of TiO₂ on the ALD deposition temperature; varying between 50°C to 300°C, were analyzed using ellipsometry, AFM, XPS, GI-XRD, and CV measurements.

With increasing the deposition temperature, the growth/cycle was found to decrease. An ALD window was determined between 130-150°C. XPS results shows that all the deposited TiO₂ thin films were oxygen deficient. At temperatures lower than the ALD window, O/Ti ratio was the lowest which can be attributed to Ti nanocrystals condensation during ALD processes. In line with Ti condensation at temperatures lower than 130°C, the band gap of the deposited films were high as compared to the band gap of the films deposited at higher temperatures.

The deposition processes were optimized in order to utilize the deposited ultrathin TiO₂ as an effective electron-selective and passivation contact for c-Si. The effective minority carrier lifetime and implied open circuit voltage (iVoc) of the deposited TiO₂ with and without a thin tunneling oxide interlayer between TiO₂ and n-type c-Si were extracted. Our results show that for TiO₂ thin films on top of few angstroms of wet chemical oxide on n-type c-Si, minority carrier lifetime up to 2.3 milliseconds corresponding to an iVoc of ~700 mV were obtained. Finally, the asymmetry in C-V and J-V measurements between the TiO₂/p-type and TiO₂/n-type c-Si heterojunctions was examined and the electron transport selectivity of TiO₂ was revealed.

Keywords

carrier selective contact, ALD, TiO₂, passivation, crystalline silicon

P4

SIMULATION OF SILICON HETEROSTRUCTURE SOLAR CELL FEATURING DOPANT-FREE CARRIER-SELECTIVE MOLYBDENUM OXIDE AND TITANIUM OXIDE CONTACTS

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Dopant-free carrier-selective transition metal oxide (TMO) contacts offer unique electrical properties along with eliminating the issues pertaining to doping-related processes in existent crystalline silicon (cSi) solar cells. In this paper, cSi heterostructure solar cell featuring TMOs of MoOx and TiOx as hole- and electron-selective contacts, respectively, has been realized at the front and rear of the device using Silvaco-TCAD. The photovoltaic performance has been evaluated based on the electron affinity, thickness, band gap of TiOx, interfacial charge density, and operating temperature. Higher work function of MoOx induces significant band bending and Fermi level pinning at the front interface. Low electron affinity of TiOx reduces the Schottky barrier against electrons at the rear that facilitates easier electron transportation. Results show that electron affinity of TiOx affects several PV properties with a relative minimum recombination rate observed for affinity values of 3.6-4.2 eV. The insertion of TiOx reduces the contact resistivity depending on the TiOx thickness. With increase in the interface defects, higher Schottky barrier height obstructs electron transport over the barrier. As a result, more electrons get trapped inside the defects states. For band gap value of 3.1 eV, the proposed device numerically exhibited Voc of 723 mV, Jsc of 39.2 mA/cm², FF of 79.8% and remarkable η of 22.64% with a simulated temperature coefficient of -0.08%/°C. These simulated results validate the applicability of HIT design with fully covered dopant-free carrier-selective contacts that can be useful for industrial applications as it eliminates the need for doped layers with capital-intensive fabrication process.

Keywords

carrier-selective contacts, MoOx, TiOx, cSi, heterojunction

P5

EFFECT OF SUBSTRATE TEMPERATURE ON STRUCTURAL AND OPTICAL PROPERTIES OF ALD GROWN ZNO FOR PHOTOVOLTAIC APPLICATIONS

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Zinc Oxide (ZnO) is a wide bandgap semiconductor, which can be utilized in many application fields such as photovoltaics [1,2], optoelectronics [3] and sensing [4]. Especially, atomic layer deposition (ALD) of ZnO thin films are widely investigated due to the low temperature and atomic scale controllable growth mechanism that ALD provides [5].

In this study, optical, structural and compositional properties of ALD grown ZnO thin films on crystalline silicon (c-Si) with different growth temperatures were characterized by X-Ray Diffraction (XRD), X-ray Photoelectron Spectroscopy (XPS) and Spectroscopic Ellipsometry (SE) methods. Diethylzinc (DEZ) and H₂O were used as precursors and samples with growth temperatures ranging from 70 to 250 °C were prepared to observe the effect of growth temperature. XRD patterns reveal the polycrystalline nature of the deposited films (Fig.1a). From XPS characterization, it is observed that ZnO structures are almost stoichiometric. SE showed that our ALD window is between 170 - 220 °C with 2.1 Å growth/cycle in that region (Fig.1b). The bandgap is 3.3 eV for every sample with different growth temperatures and the refractive index of ALD grown ZnO films increase with growth temperature (Fig.1c).

Keywords

zinc oxide, atomic layer deposition, characterization

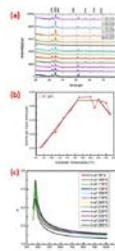


Fig.1: (a) XRD pattern, (b) Growth/cycle vs substrate temp., (c) refractive index vs wavelength

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P6

REFRACTORY METAL BASED CHALCOGENIDES FOR ENERGY CONVERSION APPLICATIONS

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Refractory based chalcogenides have been widely investigated due to their high potential applications in energy industry like hydrogen evolution, membrane fuel cells, solar cells, dye-sensitized solar cells, etc. These chalcogenide materials have been synthesised using hydrothermal, solid-state and high temperature methods [1-2]. Most of these routes requires high pressure and long reaction time[1-4]. However, high-quality nanocrystals can be synthesized with hot-injection method in a short time.

In this study, MWS_x (M= Co, Ni, Mn and Fe) nanostructures in oleylamine (OLA) have been synthesized via hot-injection method. The results showed that MWS_x have amorphous nature and exhibit a rod-like formation. Our study illustrates that hot-injection method are suitable for the synthesis of MWS_x . Moreover, MWS_x nanostructures are promising candidate in the future fabrication of cost-effective and high efficiency energy conversion applications.

Acknowledgements

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Keywords

MWS_x , chalcogenides, nanostructures

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P7

HOT INJECTION SYNTHESIS OF EARTH-ABUNDANT TERNARY COPPER-TUNGSTEN-SULFIDE NANOCUBES AND THEIR PHOTOELECTRICAL PROPERTIES

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The field of copper-based ternary chalcogenides has experienced a recent surge in interest owing to new revelations about the contributions as low-cost alternatives to conventional photovoltaic materials [1-2]. Among the family of chalcogenide based semiconductors, Cu_2WS_4 derivatives are analogous alternative materials with an optimal band gap in the range from 1.7 to 2.2 eV making it well suited for utilization in photonic applications [2-4]. In this study, we reported synthesis of Cu_2WS_4 nanocubes based on colloidal method. XRD, XPS, TEM and SEM techniques were used for characterization. All characterization results show that nanostructures are obtained with good crystallinity and homogeneous atomic dispersivity. In order to analyze the photoelectrical properties of as-synthesized CWS nanocubes, the concentrated toluene solution of nanocubes is spin casted onto ITO surface. The current-potential (I-V) characteristics of the as synthesized CWS films were measured in the dark and under illumination. The tested results show that the photocurrent rise in the IV curves obtained under illumination indicated the potential of the films for photovoltaic applications.

Acknowledgements

The authors would like to thank TUBITAK (P. No:215M309) and Karamanoğlu Mehmetbey University, Scientific Research Council for supporting this work.

Keywords

Cu_2WS_4 nanocubes, solar cells, chalcogenides

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P8

DESIGN OF PBTE QUANTUM DOTS SURFACE PASSIVATION PROTOCOLS: AIMING TO INCREASE STABILITY AND EFFICIENCY OF SINGLET FISSION SENSITIZED SOLAR CELLS

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Characteristic properties such as small band gap and large exciton Bohr radius of the lead chalcogenide nanocrystals make them excellent candidates for photovoltaics. One of the greatest barriers to the use of PbTe QDs in photovoltaic devices is their higher sensitivity towards oxidation and in parallel their less explored surface chemistry. Adsorption of oxygen on the QD surface create acceptor levels near the valence band that are capable of trapping electrons. Therefore, strategies aiming to control the surface states and improve the material quality is an ongoing challenge. We present a detailed understanding on the instability of PbTe QDs and develop surface passivation protocols to provide guidance for future studies on surface engineering. We found that synthesis parameters like size, ligand concentration and catalyst concentration play crucial roles in determining the stability of PbTe QDs. QDs synthesized in the presence of an excess amount of stabilizing ligands are more stable. Increase in stability comes at the cost of a significant drop in yield (%50), which can be increased with the addition of an optimized amount of catalyst. Our results show that catalyst is a key parameter in controlling the yield, but un-optimized concentrations of it decreases the stability of QDs. After revealing the effect of size, ligand concentration and catalyst concentration on the stability, we present a model strategy for optimizing surface engineering protocols. Furthermore, the knowledge gained in this study enabled us to reproducibly fabricate efficient singlet fission sensitized PbTe QD based solar cells with an improved air stability.

Keywords

PbTe quantum dots, surface passivation, singlet fission sensitized solar cells

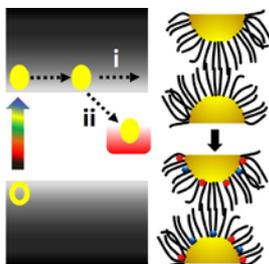


Figure 1

P9

PBSE NANORODS FOR SINGLET FISSION & MEG SENSITIZED HYBRID SOLAR CELLS: OPTIMIZATION OF SYNTHESIS PROTOCOLS AND INVESTIGATION OF SURFACE STABILITY

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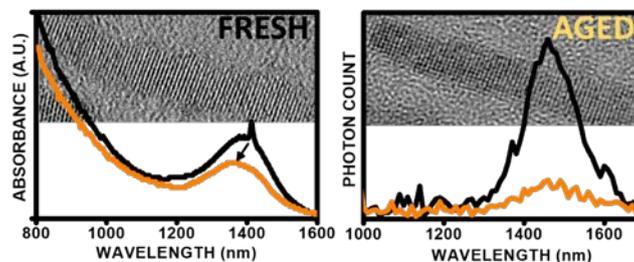
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The successful incorporation of a Singlet Fission (SF) material and a material that have the characteristics of Multiple Exciton Generation (MEG) into the same photovoltaic device has the potential of exceeding theoretical limits. MEG is a process in which multiple charge carrier pairs are generated for a single photon excitation. SF materials on the other hand rapidly converts high-energy singlet excitons into pairs of triplet excitons, which than can be extracted as free charge carriers. Colloidal quantum dots have been of particular interest for inexpensive solar cells due to their high MEG yields. According to the recent reports, 2-D nanostructures are better alternative for MEG compared to dots. We therefore report optimized PbSe nanorods (NRs) synthesis conditions to reach the best performing synthesis protocol. UV-Vis-NIR and photoluminescence measurements were used to determine the band gap and PL intensities of PbSe NRs. TEM was utilized in order to analyse the morphology of PbSe NRs. Preliminary results showed that the transformation of dots to rods starts when the OA/Pb ratio increases from 1.5 to 3.5 together with an increase in both branching and length of the rods. The optimum ratio for the minimum branching and maximum length was found as 2.5. PL measurements indicated that the PL intensity is maximum for the OA/Pb ratio of 2.5. We also report high sensitivity of PbSe nanorods towards oxidation. Surface, being the main suspect of the degradation, plays a crucial role as oxidation starts from surface and proceeds towards core.

Keywords

PbSe quantum dots, PbSe nanorods, multiple exciton generation, singlet fission sensitized solar cell



P10

STUDY OF PECVD-GROWN SILICON NANOWIRES CATALYZED BY INDIUM

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Silicon nanowires (SiNWs) are largely studied thanks to their interesting electrical [1] and optical properties [2]. These nanostructures, with their unique shape, small dimensions and high surface-to-volume ratio, are integrated in many applications such as silicon nanowires field-effect transistor (SiNW-FET), biological sensors and Photovoltaic cells. SiNWs could be elaborated by two approaches: the top-down and the bottom-up approaches. In this work, we propose SiNWs growth by a bottom up technique offering the possibility to tune SiNWs properties. This approach is based on the Vapor-Liquid-Solid process mode where nanowires are catalyzed by metallic particles such as the transition metals. Gold is the most used catalyst but it is known to create deep-level defects in silicon bandgap leading to the electrical properties deterioration [3]. Recently, indium is presented as an interesting catalyst because it forms a low temperature eutectic with silicon (157°C) and induces shallow defects in silicon. In this study, we focus on the elaboration at low temperature of SiNWs obtained by VLS process. SiNWs are formed on indium coated substrates using silane as a precursor gas in plasma enhanced chemical vapor deposition reactor at 400 °C [4]. The obtained nanowires are randomly oriented and tapered (Fig. 1). The nanowires density is quite low attributed to the formation of indium oxide formed during the annealing step. We notice also that SiNWs are composed essentially of amorphous and crystalline silicon. Energy Dispersive Spectroscopy analysis has shown that indium doesn't diffuse into silicon nanowires confirming that this metal is a convenient catalyst.

Keywords

silicon nanowires, PECVD, indium catalyst, VLS process

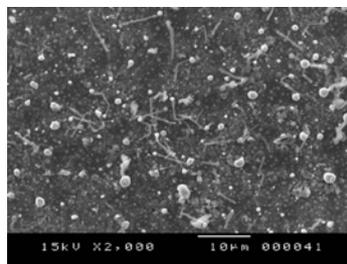


Fig. 1: SEM image of silicon nanowires grown during 15 min

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P11

ENGINEERING OF DENSITY OF STATES TO REVERSE THE EFFECTS OF TEMPERATURE ON PHOTOVOLTAIC EFFICIENCY

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It is well known that the performance of solar-cells degrades with temperature. This is a critical effect as solar-cells are generally exposed to temperatures ranging from 15°C to 50°C in terrestrial applications, or even to higher temperatures in space and concentrated systems. Nevertheless, there is yet no clear guideline for designing materials that can alleviate or reduce the deteriorating effects of the temperature. In this presentation, the theoretical formalism for obtaining the photovoltaic efficiency of a PN junction is revisited and derived without the standard approximations such as the non-degenerate and the usual charge carrier density-of-states. It is shown that for traditional materials, macroscopic parameters, namely, open-circuit voltage, short-circuit current, fill-factor, and efficiency are all affected by temperature. While short-circuit current increases with temperature, which is desirable, open-circuit voltage, fill-factor and efficiency reduce, with the efficiency being dominantly impacted by the open-circuit voltage. We will show that it is possible to engineer the density-of-states such that this trend is reversed. For a specific class of density-of-states, when the material is doped to a degenerate level where the quasi-Fermi levels move inside the energy bands, the open-circuit voltage increases with temperature. Interestingly, this is accompanied by an upsurge in the short-circuit current, which accelerates the increase of the efficiency. The details of the theory and the guidelines to design the desired materials are presented and discussed. In practice, if the effect of temperature were reversed, solar-cells would be more efficient at higher temperatures enabling them to harvest both light and heat.

Keywords

photovoltaic efficiency, temperature effects, density-of-states

P12

USEFULNESS OF ACTIVE CARBON ELECTRODES IN PHOTOVOLTAIC CELLS

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In our daily life we use active carbon in a variety of technological applications due to capability of producibility with a large specific surface area, 500 to 1500 m²/g. Active carbon electrodes give very remarkable results in photovoltaic cells due to high surface area [J Nanosci Nanotechnol, 13(2013)12, 7875]. We focused on to prepare active carbon with high surface are employing wood waste because of being economical material and environmental process. Piece of woods (pine) and compressed woods were collected. Then, first of all, with these samples temperature dependent analysis were performed under argon flow employing differential thermal and thermo gravimetric analyses (DT-TGA) to understand the effects of temperature. According to the thermal analyses, the samples were annealed under argon gas flow at 1200 0C for 6 hours and finally we observed high percent of active carbon. The structural analyses were performed by RAMAN and scanning electron microscopy (SEM) images. We find significant differences between the samples and the best active carbon ratio according to the atmosphere, gas flow ratio, pressure and annealing temperature.

Keywords

active carbon, waste wood

P13

MODIFICATION IN SOL-GEL TECHNIQUE TO GROW (Zn_{100-x-y}Co_xLi_y) NANOPARTICLES

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Nano size oxide semiconductors are widely investigated solar cells due to low cost in production and easy produceability with high surface area. Among the oxide semiconductors, ZnO is an important candidate to produce solar cells with high efficiency because of tunable surface area by changing shape morphology and producable shallow energy levels by either doping atoms or forming point defects. We synthesized Cobalt and Lithium doped ZnO nano particles with a reflux setup under constant Argon gas flow. At the end of chemical route, yellowish color gel was produced. Right after synthesis of gel, temperature dependent structural analyses were performed differential ternogravimetric analyser (TG-DTA) to understand possible chemical reactions by increasing temperature. The particle sizes and structure were determined by scanning electron microscope (SEM) and x-ray prower diffractometer (XRD), respectively.

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Keywords

Zinc oxide, oxide semiconductors, nano particles

P14

EXPERIMENTAL OPTIMISATION OF THE SOLAR CELLS N+-BSF PRE-DEPOSITION PARAMETERS

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In this paper our aim is to optimise the phosphorus (P) pre-deposition (P-D) parameters of n-type monocrystalline silicon solar cells BSF. As a drive-in step, we simulate a co-diffusion of P and boron P-D emitter process previously determined.

The P P-D study concerned two types of as-pre-deposited n-type silicon test-wafers, with PSG and PSG etched.

Temperature P-D optimisation was conducted by studying the passivation quality and contact resistance. Investigations revealed that the effective carrier lifetime (τ_{eff}) is maximal at 900°C for both test-wafers types with a slightly better passivation quality for test-wafers driven-in without PSG. Whereas, temperature of 920 °C produced a slightly lower τ_{eff} but presented the lowest contact resistance. Then, temperature of 920°C was found to be an appropriate trade-off between these two BSF characteristics.

Reduction of P-D duration to 8 minutes while keeping the temperature constant at its optimal value of 920°C and POCl₃/O₂ flow rate ratio at its initial value of 1, we found an increase of 26% of τ_{eff} , reaching a value greater than 200 μ s.

temperature constant at its optimal value of 920°C and duration time at its initial value, reduction of the POCl₃/O₂ flow rate ratio from 2 to 0.4 enhanced the passivation quality. The τ_{eff} increased by 25%, reaching 200 μ s.

However, process conducted with these three optimal parameters yielded a lower τ_{eff} . Finally, the process which gave the τ_{eff} greater than 200 μ s was selected as the optimal. Namely, temperature of 920°C, duration of 8 minutes and POCl₃/O₂ flow rate ratio of 1.

P15

DAMAGE INDUCED BY ELECTRON IRRADIATION ON SINGLE-CRYSTALLINE SILICON SOLAR CELLS PERFORMANCE

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In this study, single-crystalline silicon (c-Si) solar cells samples were exposed to the different doses of electron irradiation with energy of 8 MeV. The current-voltage characteristics of c-Si solar cells under AM1.5 illumination condition and their spectral responses were studied before and after electron irradiation. The results show that the solar cell parameters such as open circuit voltage (V_{oc}), short circuit current (I_{sc}) and efficiency (η) decrease with the increase of the electron irradiation doses. The electron irradiation causes a significant reduction in short circuit current (I_{sc}) and efficiency (η) while the open circuit voltage (V_{oc}) and fill factor (FF) is slightly reduced. The decreases in solar cell parameters are due to displacement damage induced effects. The displacement damage induced by electron irradiation produces defect energy levels in solar cells that can act as trapping and recombination centers [1]. It is the introduction of these defect levels that degrades the performances of a solar cell through a reduction in the minority carrier diffusion length [2]. The spectral responses show that a degradation in EQE has been found for higher wavelength above 600 nm and there is no significant degradation for lower wavelength range. The effect of electron irradiation on EQE for higher wavelength indicating that most of the damage took place at the base region. The decrease of EQE for higher wavelength is related by the decrease in minority carrier diffusion length after electron irradiation.

Keywords

electron irradiation, solar cell, electrical characterization, spectral response

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P16

OPTIMIZATION OF BORON DOPING BY BCL3 FOR N-TYPE BIFACIAL C-SI SOLAR CELL

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Crystalline Si solar cells fabricated on p-type wafers still predominate the PV industry due to advantages in device processing and early focus on p-type cells in the development phase of the industry. Over the years, studies on n-type Cz (Czochralski) substrates have shown that they can be more desirable for the terrestrial applications because of superior material and process advantages such as higher minority carrier lifetime, easier passivation of the surface, absence of light induced degradation (LID) and a low sensibility to metallic impurities. With these advantages, n-type Cz based PERT (passivated emitter, rear totally-diffused) bifacial solar cells with very high efficiency in the ultimate energy conversion have a great potential in the future of the industry. In this study, n-type PERT bifacial solar cells are fabricated by optimization of boron doping, passivation and metallization processes. For boron doping, BCl₃ is used as a gas source with LYDOPTM system designed by SEMCO engineering. Most boron diffusion technologies result in the formation of parasitic layer at the silicon interface which is called as boron-rich layer (BRL). Low Temperature Oxidation (LTO) technique is applied to remove this undesired BRL. For the bifacial PERT solar cell fabrication, one side of the wafer should be protected by a proper masking during the diffusion process. Masking property of SiO₂ is investigated for boron diffusion. In addition, Al₂O₃ passivation is applied to the boron doped surface using atomic layer deposition technique (ALD). Final low contact resistivity is obtained using aluminum deposited by thermal evaporation technique.

Keywords

BCl₃, boron, doping, n-type, photovoltaics

P17

OPTIMIZATION OF OPEN-TUBE FURNACE DIFFUSION WITH BBR₃ LIQUID SOURCE FOR INDUSTRIAL P-TYPE BORON DOPING PROCESS

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In this study, optimization of boron emitter for n-type crystalline Si solar cells has been studied in detail. Industrial open-tube (atmospheric) furnace with BBr₃ as liquid B source was utilized which is a preferred dopant for the diffusion process of n-type wafers in industry [1] [2]. During the processes, full boat (270 wafers) n-type square samples were used to investigate the uniformity from gas zone to door zone and inside the wafer. To achieve uniform boron emitters on large n-type substrates, parameters of the diffusion process such as temperature, BBr₃ flow, BBr₃ flow duration and oxygen flow were varied. Resulting emitters went through a BSG removal step followed by sheet resistance mapping characterization. Especially, the tradeoff between BBr₃ and O₂ flow and their effects on sheet resistance was examined. Additionally, the relation between the borosilicate glass formation and sheet resistance was investigated.

Keywords

BBr₃, diffusion, doping, n-type

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P18

TRAPPING LIGHT WITH PERIODIC MICRO AND NANO HOLES: EFFECT OF ETCHING TYPE ON OPTICAL AND ELECTRICAL PERFORMANCES OF A SOLAR CELL

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Recently much attention has been given to increasing the interaction between incoming light beam and the surface of which is aimed to be used as a solar cell. With regard to the design, the optical and electrical performances of the trapping structure there are many texturing techniques such as; pyramid, wire, rod, and hole patterning. A proper surface texturing can significantly boost the light absorption, and hence electron-hole generation [1,2]. Surface patterning can be done either randomly or periodically [1,4]. For random patterning pyramid texturing is widely applied for standard wafer thicknesses around 150-170 μm , but when we want to go thinner, pyramids are not good candidates. Radial junction solar cells with holes having sizes varying from micron to sub-micron level are promising candidates on relatively thinner wafers for which pyramid texturing is not an option due to high amount of material consumption during pyramid texturing process. In order to obtain a periodic patterning on top of the wafer, we used optical lithography. After pattern transfer reactive ion etching (RIE), and metal assisted etching (MAE) were applied on low-cost Silicon (Si) substrate, which is overwhelmingly dominating photovoltaic (PV) industry. After texturing Si surface with different topology and etching techniques, optical and electrical results were compared.

Keywords

c-Si, texturing, metal assisted etching, reactive ion etching

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P19

OPTIMIZATION OF PHOSPHOROUS DIFFUSION BY SPIN ON DOPING METHOD FOR CRYSTALLINE SILICON SOLAR CELLS

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Thin film crystalline silicon (c-Si) solar cells are becoming popular since the amount of wafer used is decreased and hence the cost/wat peak for the final device is low. However, processing difficulties due to mechanical properties is a drawback. In this study, we optimized a doping process for small-scale c-Si wafers fabricated via laser-assisted etching. The phosphorous dopant was fabricated by using spin-on dopant (SOD) to create the junction. The optimization of coating thickness is obtained by changing the spin-coating speed. Several drops of SOD are placed in the center of the wafer then spun at speeds ranging between 2000-5000 rpm for 15 and 25 seconds to obtain different dopant source thicknesses c-Si surface. Slower spin speeds yield thicker dopant films. The wafer is then pre-baked at 200°C for 15 minutes to harden the film. The coated wafers were placed in an open-tube furnace for thermal diffusion under nitrogen from 850°C to 1050°C for 60 min to obtain different doping depths/profiles. After the thermal diffusion, the formed silica-sol layer and phosphorus silica-glass were removed using diluted HF. The doping profiles were extracted using SIMS while the sheet resistivity values were measured by 4-point-probe (Fig. 1). Finally, c-Si solar cells were fabricated using different SOD and electrical characteristics were compared.

By increasing the temperature, phosphorus dopant atoms penetrate longer distance inside the c-Si while the sheet resistivity decreases. Finally, a complete ultra-thin c-Si solar cell based on laser-assisted silicon slicing will be fabricated according to the obtained doping profiles.

Keywords

thin c-Si, spin on doping, SIMS, doping profiles

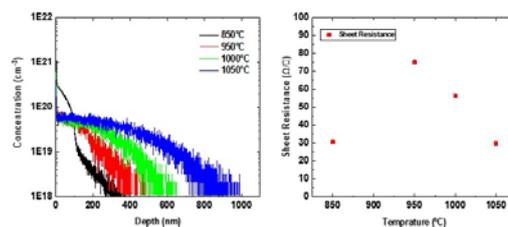


Figure 1 comparison of SIMS profiles of phosphorous at different annealing time and the sheet resistances of the cSi

P20

SIMULATION OF A-SI:H/C-SI HETEROJUNCTION SOLAR CELLS**Fatih Sarıhan¹, Ergi Dönerçark^{2,3}, Mustafa Atmaca¹, Selin Görmez¹, Ertan Arıkan¹,
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The latest developments have proven the ability of Silicon Heterojunction (SHJ) solar cell technology to achieve relatively high efficiencies [1]. The record conversion efficiency is higher than %26 with 180.4 cm² designated area in IBC design [2-3]. The role of thin a-Si:H intrinsic layer at the a-Si:H/c-Si hetero-interface still remains ambiguous [4]. The key factor for defect passivation is the saturation of defect states of the crystalline lattice at the a-Si:H/c-Si interface. Further investigations are still required in understanding of device physics in order to improve efficiency. Simulation studies provide a convenient way to obtain insight in to device physics and to evaluate the role of various parameters[6-7]. Simulation studies of SHJ cells have been carried out via AFORS HET v2.5 simulation program, in order to get more insight into the factors determining the solar cell performance. In order to develop a deeper understanding, we analyzed bulk and interface properties of a-Si:H/c-Si under influence of various density of states, fixed charges. The simulation structure consists of p-doped a-Si:H emitter layer, n-doped c-Si absorber layer, the intrinsic a-Si:H passivation layer on both side and the n-doped a-Si:H BSF layer. For the simulation of the density of states in amorphous layers, it has been assumed that there are both acceptor like states and donor like states. Both of these acceptor and donor like states consist of Urbach tail states and Gaussian mid-gap states [4-5]. The relationship between density of states and surface passivation will be explained in the presentation.

Keywords

Afors-Het, silicon heterojunction, solar cell, simulation

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P21

PASSIVATED TUNNELING OXIDE LAYER WITH P TYPE POLY SILICON

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The main aim of the photovoltaic industry is to increase the efficiencies and thus the power output of solar cells. Tunnel oxide passivated contacts is one of the highest efficiency structures in the field. Tunnel oxide creates an excellent surface passivation between the substrate and poly-Si layer, but it should be extremely thin (~2nm) in order to avoid high contact resistivity. This structure is used in high efficiency solar cells [1], [3], [4] and they are being further improved. Moreover, in various researches, tunnel oxide passivated contacts are used both on front and rear side to improve surface passivation quality and enhance the efficiencies of solar cells [2].

In this study, the concept of tunnel oxide passivated contacts is investigated under various deposition conditions. Temperature dependence of crystallization kinetics of doped amorphous silicon layer is examined. Different furnace temperatures and annealing times are tried to understand the crystallization kinetics and to get better results on the passivation side. Moreover, the role of hydrogenation on the passivation quality of tunnel oxide passivated contact structure is clarified and optimised for p type poly-Si layers. The hydrogenation step of crystallized layer is one of the crucial step to enhance surface passivation. With the help of optimised process parameters, double side tunnel oxide passivated contact layers are used to check the lifetime and implied open circuit voltage values. Also, Raman Spectroscopy measurements are done to check the crystallinity of layers.

Keywords

TOPCon, POLO, crystallization, tunnel oxide, passivation

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P22

OPTIMIZATION OF SILICON NITRIDE (SiNx) ANTI-REFLECTIVE COATING (ARC) AND PASSIVATION LAYERS USING INDUSTRIAL PLASMA ENHANCED CHEMICAL VAPOR DEPOSITION (PECVD) FOR PERC TYPE SOLAR CELLS

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With the introduction of new high-efficiency solar cell concept namely PERC (Passivated Emitter and Rear Cell) in 1989, there has been a growing interest on this cell structure [1]. LONGi Solar recently increased mono-PERC cell conversion efficiency to a world record of 23.6% [2]. Solar cells using the PERC concept is becoming very popular also for high efficiency PV modules in the past decade. In this study, we carried out the optimization studies for SiNx layers which are used on the front side of the cell with the aim of ARC and passivation. These layers were deposited by an PECVD equipment suitable for mass production of PERC cell. This study includes optimization of those SiNx layers on the front to increase the efficiency of industrial p-type monocrystalline PERC solar cells. The capacity of the PECVD tube used for this study is 252 wafers/run. For the optimization, reflectance, transmittance, ellipsometry measurements have been carried out through the PECVD boat to observe uniformity through the boat and within each sample. For the best parameters until now, a set of solar cells were prepared using the SiNx layers from industrial PECVD tool and results were promising. This study will continue with the lifetime results of the SiNx layers to see the passivation ability of these. When optimization is done, a new set of solar cells will be prepared, and characterizations will be done accordingly.

Keywords

SiNx, silicon nitride, PECVD, PERC, mass production, ARC, passivation

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P23

EFFECT OF THE ANOXIC POST DEPOSITION ANNEALING ON OPTICAL AND ELECTRICAL PARAMETERS OF AG/MOO3-X HETEROCONTACT ON C-SI

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As a consequence of the substoichiometric Molybdenum (III) oxide's (MoO_{3-x}) material properties, its fabrication with unsophisticated methods and not requiring toxic gas precursors, thermally evaporated oxygen deficient and electron selective MoO_{3-x} has been implemented on silicon photovoltaics as hole transporting – electron blocking layer (HT – EBL) productively [1-5]. It has been demonstrated with record efficiencies exceeding 20% that MoO_{3-x} can be substituted for p-type a-Si in silicon heterojunction solar cells (SHJ) [1],[6]. Although MoO_{3-x} has superior material properties, there exist studies pronouncedly concerning effect of the post deposition annealing (PDA) as distorted I-V curves (so called S-shaped) and decrease on lateral conductivity [6][7], yet there is no comprehensive study on regarding effect of low temperature anoxic PDA on optical and electrical parameters of thin MoO_{3-x} films and its interface properties with c-Si. This study aims to reveal and tune optical and electrical parameters of MoO_{3-x} heterocontact on n-type c-Si, inclusively. For that reason; effect of the anoxic low temperature - post deposition annealing (PDA) on optical, electrical and morphological parameters of the 10 nm thick MoO_{3-x} thin film on n-type c-Si substrates were investigated. Degradation on optical and morphological parameters was observed whereas interface quality between MoO_{3-x} and c-Si was improved with PDA.

Keywords

hole selcetive, molybdenum tri-oxide, transport layer

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P24

FRONT SIDE METALLIZATION OF SI-HIT SOLAR CELLS BY PHYSICAL VAPOR DEPOSITION

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Reducing the cost and increasing the efficiency are the main study topics in solar cell production. In solar cell production, the most expensive element after the substrate is the metallization process. The front side metallization process is critical for solar cells in terms of both cost and efficiency. The design and method used in the front side metallization process have a direct effect on the efficiency as well as the cost. Among the metallization methods used in solar cell production, screen printing is the most commonly used method with more than 85% utilization rate because it is simple and fast [1]. The biggest disadvantage of screen printing method is that the cost of silver paste is variable and high. In this regard, studies on the search of alternative methods to the screen print continue.

In this study, the use of the PVD technique in the front side metallization process, as an alternative to the screen print, was carried out with the help of a mask. The conversion efficiency value of the first cell produced by this new method was measured as 17.7%. Getting a very high efficiency even without optimization is important in terms of usability of this method in the front side metallization process, but due to some restrictions of the mask, problems arise after a few consecutive applications. As a result, the use of PVD in front side metallization process has been examined in detail, and its advantages and disadvantages are presented.

Keywords

front side metallization, PVD, Si-HIT solar cells

P25

IMPACT OF LIGHT SOURCE ON LIGHT AND ELEVATED TEMPERATURE INDUCED DEGRADATION (LETID) OF IMPLIED-VOC MC-SI SAMPLES

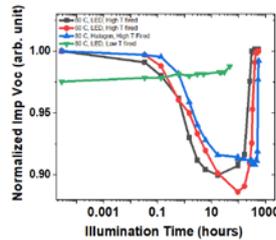
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Light and elevated temperature induced degradation (LeTID) is a phenomenon is known that as a negative effect on solar cells related to temperature and light-induced defect formation in solar cells¹. In this study, different light sources and temperature dependency for the minority charge carrier decay effects were studied. Passivated multicrystalline silicon wafers with the identical silicon wafers were studied. It has been observed that the degradations under different quantified light sources are different.

Keywords

light, elevated, temperature, letid, crystalline, silicon, degradation, solar, cell, lifetime, voc



Characterization of Minority Excess Carrier Lifetime

P26

ANALYSIS OF THE FIRST PERC TYPE CELL FABRICATED IN GUNAM PHOTOVOLTAIC LINE (GPVL)

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PERC concept with an already developed roadmap for 24% production efficiency will be leading the photovoltaics industry in the upcoming years. In a few industrial pilot lines, efficiencies above 22% have already been attained. Pilot lines have important roles in bridging lab scale proven concepts with the products which are ready for mass production. Therefore, GUNAM Photovoltaic Line which is specialized on PERC concepts has been established to overcome the barriers that hinder the performance of c-Si solar cells in PERC concepts in a relevant environment. This article presents the first results of the studies from 6 months ramp up period of GPVL. A batch of standart PERC type solar cells with p-type base and atomic layer deposited Al₂O₃ rear passivation have been fabricated during the ramp up of the line. A detailed gain-loss analysis was performed to adress the optical, electrical and recombination losses in order to increase the cell efficiency.

Keywords

PERC, pilot line, solar cells, photovoltaics

P27

MEASUREMENT OF ECONOMIC FEASIBILITY OF PV POWER PLANTS IN TURKEY

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Photovoltaic (PV) technology has reached a competitive level owing to high learning rate and technological advance. It is now a feasible technology however its feasibility varies with many parameters such as: location where PV power Plant (PV PP) is installed, its technology, economic and social state of the country and even the unpredictable future events. In short, it depends on the cost and revenue and so the legislation, incentives, market situation; climate of the location together with solar irradiation exposure etc. This study questions the differences in the feasibility of PV PP of the two Turkish cities. A 1 MW PV PP is simulated in two cities and its feasibility dependence on the location of interest is determined. Net feasibility analysis that is a concept developed by the authors of this study, includes the calculations of newly defined parameters: levelised revenue of electricity (LROE), levelised profitability of electricity (LPOE) and net feasibility (NF) [1]. They are analyzed together with the well-known parameter levelised cost of electricity (LCOE) [2]. The locations PV PPs are simulated are within Antalya, and Ordu. The results of net feasibility analysis yield NF result of 86 \$/MWh for Antalya while a quite low value of 63 \$/MWh has been determined for Ordu. We discuss the details of the developed techno-economic analysis in the present article.

Keywords

solar PV, LCOE, net feasibility, LROE, LPOE

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P28

THE OUTDOOR ENVIRONMENT INVESTIGATION OF PHOTOVOLTAIC MODULES: EXPERIMENTAL WORK AND REAL-TIME MEASUREMENTS

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In this work, the investigation of the outdoor performances of PV modules and the effects of some environmental variables such as air temperature, wind speed, humidity, on the efficiency of PV modules were aimed. For this purpose, the study includes the data of in-situ measurements taken with the interval of one-hour daily, from May to August 2017 in Bolu, Turkey. The PV modules were produced using different types of connection methods which are connected serial and parallel. The result of this study shows that the efficiency value ($\eta = \% 18.47$) of serial connection PV module is a bit higher than that ($\eta = \% 17.08$) of parallel connection PV module. The results of the statistical analysis show that there is a positive moderate correlation ($r = 0.610$) [1] between the ambient temperature (raise up to 30 °C) and PV modules efficiencies. On the other hand, the efficiencies of the PV modules and increase of the relative humidity also have a moderate negative correlation ($r = -0.575$) [1, 2]. The relationship between wind speed and the efficiency of PV module is found to be weakly positive ($r = 0.247$) [1]. Consequently, as in the previous study for this region [3], the study involves significant results despite its short duration. However, longer-term studies are needed to determine the effects of the environmental variables on the efficiency of PV module in the future.

Keywords

PV module, ambient temperature, wind speed, relative humidity, Bolu (Turkey)

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P29

SIMPLE AND AFFORDABLE PHOTOVOLTAIC CURVE TRACER

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Photovoltaic cells are characterized basically by their current-voltage (IV) curves [1]. Results of these tests can help in improving the efficiency of cells, developing new photovoltaic technologies, and selecting the most efficient spot to place the cell. It can be done by using photovoltaic IV curve tracers. Although they are available in market, they are expensive. Therefore, there are some efforts on creating simple and affordable tracers. Some of those tracers use DC-DC convertor [1] [2] and resistive load [3] to acquire the voltage and current values.

This paper presents a simple, easy to create, and high efficiency tracer that can test and generate IV curves of unspecified number of cells in one step. It uses Keithley 2461 Source Meter along with relay module and MATLAB. The source meter is responsible for generating the voltage sweep and taking the current readings from the solar cell. To test each cell separately, the relay module was added. This gives the user the ability to choose the number of tested cells just by adding more relays. All the instruments are connected to a computer and a MATLAB script is used to control the entire system. It first opens a single relay allowing testing one solar cell. Then, it communicates with the source meter to control its settings in generating the sweep and recalling the volt and current values. Finally, it uses these values to plot the IV curve. After testing the cells, it compares all the curves by combining them in one plot.

Keywords

photovoltaic, IV Curve

References

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P30

SOILING EFFECT OF MINI PV MODULES FOR DIFFERENT TILT ANGLES

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In this study, a PV soiling test system has been constructed at Solar House Garden in Hacettepe University, in order to investigate the effect of tilt angle on the dust accumulation. In the system, ten mini PV modules, which had the same name plate and rating, have been mounted in two rows on an open rack system, for five different tilt angles ranging 6° to 50°. Before every measurement, the first row has been cleaned regularly which labeled as “cleaned modules” whereas second row which is never cleaned manually and labeled as “soiled modules”.

Since the short circuit current (I_{sc}) of the PV module is proportional to the incident irradiance, and due to that PV module becomes soiled the solar radiation reaching the module decreases, the effect of soiling can be determined by comparing the I_{sc} data of the soiled and cleaned modules. All measurements have been done under clear sky and at noon and after the measurement of irradiation, temperature and the I_{sc} data of modules, each I_{sc} values were translated to 1000W/m² and 25°C.

As the tilt angle increases, soiling loss is decreases. In order to see the effect of rain, experimental results have been analyzed dividing the duration of experiment into different periods depending on the rainy days. It is observed that as a results of cleaning effect of rainy days there is a decrease in soiling loss for wet periods, whereas an increase in dry period.

Keywords

photovoltaic module, soiling, soiling loss, short circuit current, tilt angle

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P31

A NOVEL APPROACH FOR MODELING A PV EMULATOR WHICH MINIMIZE THE PARTIAL SHADING EFFECTS

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One of the most commonly used methods for generating electricity from the sun is using photovoltaic (PV) panels. PV panels efficiency is influenced by many parameters. Some of these parameters are the material parameters of the semiconductor cells, the amount of irradiance, air temperature, surface temperature of PV panel and partial shading effect. The partial shading effect from these parameters has a very negative effect on PV panel efficiency. When partial shading occurs on the surface of the PV panel, local and global maximum power points (MPP) of PV panel are observed in the current-voltage (I-V) characteristic. In a photovoltaic solar system, the Maximum Power Point Tracking (MPPT) unit is always required to run the system at the global MPP of the I-V characteristic of the panel. When the MPPT algorithms developed in practical work done in real environment need to be tested comparatively, emulators that can act like a solar panel are needed. It was demonstrated that the design details of a novel approach modeling PV panel emulator the partial shading effects are presented in this study. The characteristics of the emulator are the model of a PV panel with 250W power and three series connected cell arrays. We used dc-dc buck converters in the structure of the emulator's design. The converters were driven by PWM markers generated by a microcontroller in STMicroelectronics' discovery board structure. The microcontroller takes software prepared by an interface program on the serial port to obtain the I-V characteristic with the desired PV panel.

Keywords

photovoltaic emulator, partial shading effects

P32

SILICON SOLAR CELL TOP ELECTRODES WITH SILVER NANOWIRE NETWORKS

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Losses caused by the metal top contacts still remain as an issue in crystalline silicon (Si) solar cells. One approach to eliminate shading losses is to utilise transparent nanostructure networks synthesised through rapid and low cost processes. In this work, the potential of highly conductive silver nanowire (Ag NW) networks as transparent top electrodes for the elimination of metallisation process in Si solar cells was investigated. Ag NW top contact cells were found to possess enhanced conversion efficiencies with respect to conventional metal contact reference cells. Increase in conversion efficiency was attributed to the elimination of shading losses, preferential scattering of light into the substrate by localised surface plasmon resonances (LSPRs) of the Ag NWs and localised and higher charge collection capability with respect to conventional metal contacts.

Keywords

silver nanowires, transparent conductrodes, silicon solar cells

P33

SYNTHESIS OF COGA₂O₄ SEMICONDUCTORS VIA RF MAGNETRON SPUTTERING SYSTEM

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The study include synthesis and understanding the optical response of CoGa₂O₄ semiconductors. CoGa₂O₄ semiconductors are conductive transparent semiconductors, which makes them attractive for photo electrodes to use in photovoltaic cells. The powders were synthesized via solid state reactions and then these particles were used to grow thin films by RF magnetron sputtering. The structural analyses were performed employing x-ray powder diffractometer (XRD), x-ray photoelectron spectrometer (XPS) and scanning electron microscopy (SEM). The point defect amounts in CoGa₂O₄ lattice were modified by annealing the thin films under various gas atmosphere (O₂, Ar, forming gas and vacuum). RAMAN spectra were used to understand the point defect amounts in the lattice. Then the optical response dependent on point defect amount were detected with dc electrical measurements (I-V) curves under illuminations.

Acknowledgement: This work was supported by the Scientific and Technological Research Council of Turkey (TÜBİTAK) with project number 117F156.

Keywords

Co Gallate, point defects, optical response

P34

ORGANIC BULK HETEROJUNCTION SOLAR CELLS BASED ON BENZODITHIOPHENE AND BENZOTHIADIAZOLE CONTAINING CONJUGATED POLYMERS

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Organic photovoltaics (OPVs) or so-called organic solar cells particularly hold promise for manufacturing solar energy due to their advantages in low cost and production processes. In order to understand and improve the performance of OPVs, intense efforts have been dedicated around the world [1]. In particular, conjugated polymers are attractive for OPVs due to the π -conjugated systems in the polymer backbone which generates and transport the charge carriers [2]. Therefore, the design and synthesis of novel conjugated organic polymers play important role to obtain higher photovoltaic properties and improve the power conversion efficiencies (PCEs) of the OPVs.

For this purpose, benzodithiophene and benzothiadiazole containing monomers were independently synthesized, then polymerized via Stille cross-coupling reaction to obtain P1 and P2 polymers. Oxidation and reduction behavior of the polymers were studied by cyclic voltammetry. Measurements indicated that the highest occupied molecular orbital (HOMO) levels were -5.25 eV for P1 and -5.38 eV for P2. The optical band gaps of P1 and P2 were calculated via UV-VIS-NIR spectroscopy as 1.54 eV and 1.64 eV, respectively. Bulk heterojunction solar cells were constructed with these polymers as the donor moieties together with PC₇₁BM as the acceptor in the active layer. The current/voltage measurements showed that the highest PCEs of these photovoltaic devices were recorded as 2.52% for P1: PC₇₁BM (1:4, w/w) in 2% DIO and 1.67% for P2: PC₇₁BM (1:3, w/w) in 3% DIO solution.

This work was funded through TÜBİTAK Project No:115M036.

Keywords

organic solar cell, benzodithiophene, benzothiadiazole

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P35

OPERATIONAL CHARACTERISTIC OF SILICON- BASED PIN PHOTODIODE

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Planar Silicon PIN Photo Diodes which have $3.5 \times 3.5 \text{ mm}^2$, $5.0 \times 5.0 \text{ mm}^2$, and $10 \times 10 \text{ mm}^2$ active areas, have been fabricated and operational characteristics have been carried out. The (100) Si wafers having $2.4 \text{ k}\Omega - 2.8 \text{ k}\Omega$ surface resistivity has been used during the fabrication. The n^+ doped regions were formed by phosphorus diffusion (using POCl_3), while p^+ regions were formed by boron diffusion (using BBr_3). In order to investigate operational characteristics of the PIN photodiode, I-V and C-V measurements were carried out under the dark environment at room temperature. The obtained electrical characteristics are listed in Table 1. As expected, the fabricated PIN photodiodes exhibit high breakdown voltage values. In addition, capacitances are order of Pico farads and currents are order of Nanoamperes at the fully depleted voltage that is -5 V. These results indicate the dark current values are higher than commercial PIN photodiodes but they are convenient for microelectronic applications.

Table 1: Some electrical characteristics of Si- Photo Diode

Active Area	Breakdown Voltage (V)	Leakage Current (nA) at -5V	Capacitance (pF) at -5V
$3.5 \times 3.5 \text{ mm}^2$	-76	-173	23
$5.0 \times 5.0 \text{ mm}^2$	-124	-80	41
$10 \times 10 \text{ mm}^2$	-120	-145	61

Keywords

pin diode, leakage current, capacitance

P36

OPTICAL AND STRUCTURAL PROPERTIES OF SELF-ASSEMBLED THIN FILMS OF MPS-CAPPED CDS QUANTUM DOTS: INFLUENCE OF HEAT TREATMENT

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The colloidal CdS quantum dots (QDs) were synthesized by using 3-mercaptopropyltrimethoxysilane (MPS) molecules as a capping agent. The colloidal QDs were self-assembled directly on a glass substrate by sol-gel spin coating method without introducing any matrix. The QDs were attached to the glass surface by Si-O-Si bonds created by the OH groups of the glass surface and the Si-O groups of MPS [1]. Additionally, SiO₂ network was formed with Si-O-Si bonds between MPS molecules. The films were heat-treated at 225, 250, 275, 300 and 325 °C for 1 hour. The optical and structural properties of the samples were examined by UV-visible spectrometer, NKD spectrometer, atomic force microscope (AFM), scanning electron microscope (SEM), X-ray diffraction (XRD), high resolution transmission electron microscope (HRTEM) and profilometer. The refractive index, extinction coefficient, dielectric constant and thickness of the films were calculated by fitting the measured data to the Drude-Lorentz model. The results showed that the size of CdS QDs changed from 3 to 5 nm with thermal heat treatment due to Ostwald ripening [2]. The thicknesses of the films were found around 200 nm. The refractive index of the films at 550 nm was found in between 1.55 and 1.60. The result showed that the refractive index values of the thin films of MPS capped-CdS QDs are close to the glass substrate. Therefore such films may be a good candidate for the planar luminescent solar concentrators.

Keywords

CdS quantum dots, optical properties, self-assembled, thin film

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P37

SURFACE TEXTURIZATION OF N-TYPE MONOCRYSTAL SILICON WAFER BY NANOSECOND PULSED, 1064 NM FIBER LASER AND INVESTIGATING THEIR OPTICAL AND ELECTRONIC PROPERTIES

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Single crystal n-type silicon wafer with (100) orientation was texturized by using nanosecond pulsed, Ytterbium doped fiber laser with master oscillator power amplifier architecture (MOPA), operating at the peak wavelength of 1064 nm. All texturization processes were done in a repetition frequency range of 40 - 100 kHz, the scanning speed of 50 - 2000 mm/s and average laser power of 10, 15 and 20 W. In this study, focused spot size and laser pulse width were not changed.

The normal incidence reflectivity of the samples was measured by using a 25 cm - focal length spectrometer and FTIR spectrometer operating in visible region [2]. For the electrical measurements, coplanar Al-contacts were evaporated in a high vacuum evaporation system with an ultimate pressure of 1×10^{-6} Torr. The wavelength dependence of spectral absorption coefficient of the samples was measured in Fourier Transform Photoconductivity Spectroscopy (FTPS). The surface morphologies of these samples were observed with scanning electron microscopy (SEM).

The results were discussed and concluded by using the reflection and absorption coefficient spectra. Depending on the laser treatment parameters, the reflectivities of the samples were observed to decrease and also the absorption coefficients were to increase significantly.

Keywords

texturize, laser induced treatment, absorption coefficient, photoconductivity, reflectivity

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P38

IMPROVEMENT OF POLYMER:FULLERENE BULK HETEROJUNCTION MORPHOLOGY VIA INTELLIGENT PROCESSING

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This work present a morphologic optimization to design better performing organic photovoltaic devices via different parameters like solvent additive and temperature processing. Especially the structural order of the polymer phase impacts the charge separation efficiency and transport. In this paper, we report a comprehensive study of the dependence upon the temperature and solvent additive (isopropanol) of the photophysics of a statistical copolymer anthracene containing poly (p-phenylene-ethylene)-alt-poly (p-phenylene-vinylene) (PPE-PPV) copolymers (AnE-PVstat) and phenyl-C61-butyric acid methyl ester (PCBM) in thin films and devices. The photoluminescence and the absorption spectra have been recorded at temperature ranging between 5°C and 65°C in the blend film AnE-PVstat: PC60BM with and without isopropanol (IPA) proving that AnE-PVstat had J - aggregate behaviour linked to stronger intrachain coupling. Our results indicate that the addition of IPA increases the intermolecular interaction between the polymer chains which is consistent with enhanced charge carrier (hole) mobility reaching the value $\mu_h = 10^{-3} \text{ cm}^2 \text{ V}^{-1} \text{ s}^{-1}$

Keywords

bulk heterojunction solar cell, AnE-PVstat, processing temperature, solvent additive aggregation

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THE ROLE OF CARBON NANOTUBES/TIO₂ NANOPOROUS AS EFFICIENT PHOTOANODES FOR DYE-SENSITIZED SOLAR CELLS

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Dye-sensitized solar cells (DSSCs) have been studied extensively in the last years because of their promising solar conversion efficiency, simple fabrication process, low production costs and the use of environmentally friendly materials. Although mesoporous photoanodes offer good performances, largely due to light harvesting of the dye-sensitized nanocrystalline film, there are some drawbacks: while offering an extremely high specific surface for dye loading, mesoporous networks suffer from a high density of grain boundaries, which promote charge recombination in operating devices. Different methods have been investigated to increase charge collection, such as the use of various metal oxide semiconductors, particularly one dimensional (1D) nanostructures like nanorods, nanowires and nanotubes based photoanodes. In this research, CNT/TiO₂ mesoporous photoanode is studied to investigate the effect of CNT based TiO₂ mesoporous on the DSSC performance and the enhancement capability of A-CNT/TiO₂ photoanode on solar conversion efficiency in DSSC is compared with a conventional TiO₂ photoanode. The Influence of CNT/TiO₂ photoanode on solar conversion efficiency of DSSC is compared with a conventional TiO₂ photoanode and result shows that efficiency is increased from 6.51 % to 7.00 % due to the enhanced light absorption and electron transport across the TiO₂ mesoporous based thin films. Structural and optical characterizations are carried out using X-ray diffraction spectroscopy (XRD), scanning electron microscopy (SEM), energy dispersive spectroscopy (EDS), Raman spectroscopy and UV-Vis analyses.

Keywords

dye-sensitized solar cell, carbon nanotube, TiO₂, photoanodes

P40

EFFECT OF SELENOPHENE AND THIOPHENE UNITS ON PHOTOVOLTAIC PERFORMANCE OF FLUORINE SUBSTITUTED BENZOTHIADIAZOLE BEARING CONJUGATED POLYMERS

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In this work, effect of selenophene and thiophene units on photovoltaic performance were investigated. Cells were constructed by spin coating of PEDOT:PSS on ITO as the hole transport layer, spin coating of the active layer including polymer:PC₇₁BM blend inside glove box, and LiF/Al deposition as the cathode layer by vacuum evaporation at 1×10^{-6} mbar. For selenophene containing polymer, P1, and thiophene containing polymer, P2, the optical band gap values were obtained as 1.64 eV and 1.73 eV respectively. For P1, maximum power conversion efficiency was found as 1.60% with 1:3 polymer:PC₇₁BM ratio. Same blend yielded open circuit voltage value of 0.65 V, short circuit current of 3.80 mA/cm² and fill factor of 62.36%. For P2, open circuit voltage, short circuit current, fill factor and power conversion efficiency values were achieved as 0.66 V, 8.23 mA/cm², 66.21% and 3.83%, respectively with 1:3 polymer:PC₇₁BM ratio, annealed by 4% diiodooctane addition. Methanol treatment was also performed for both polymers, however, no improvement was observed.

Keywords

Open circuit voltage, short circuit current, optical band gap

J-V curve of P2

P41

INVERTED TYPE SOLAR CELLS USING ACCEPTOR TYPE MOLECULES

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Solar energy is one of the most promising and viable renewable energy technologies since solar energy is abundant, clean and is for free. Solar energy can be converted into electrical energy by using solar cells. Organic solar cells, which belong to the group of third generation solar cells, have been widely investigated by many scientists throughout the world. Although the efficiencies of organic solar cells from initial values of 2.5 % increased to recent values of 12 %, stability stands as a serious issue to be resolved. One of the reasons for this stability problem in organic solar cells is the use of oxygen sensitive metal electrodes such as Al. Organic solar cells are fabricated in the normal geometry as ITO/Hole Transport Layer(HTL)/Active Layer/Al. One of the ways to replace oxygen sensitive metal electrodes such as Al with less sensitive ones such as Au and Ag is to invert the device geometry as ITO/Electron Transport Layer (ETL)/Active Layer/Au or Ag. Such device configuration is called inverted type solar cells [1].

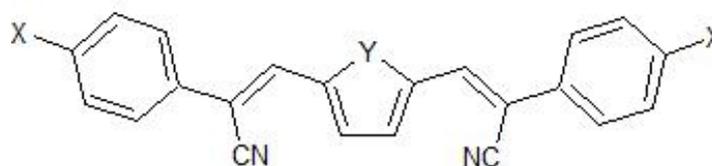
In this study, we have fabricated inverted type organic solar cells using novel cyano (CN) containing acceptor molecules in the active layer [2]. We have compared the device performance of organic solar cells in the normal and inverted geometries. The chemical structure of novel acceptor molecule is given in figure 1.

Acknowledgements

This work is supported by The Scientific and Technological Research Council of Turkey (Project number: TUBITAK-117F079).

Keywords

organic solar cells, CN-containing molecules



X: Br, Cl Y: O, S

Figure 1. Chemical structure of the novel acceptor molecule

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INVERTED ORGANIC SOLAR CELL APPLICATIONS OF BENZODITHIOPHENE AND BENZOTRIAZOLE BEARING ALTERNATING COPOLYMERS

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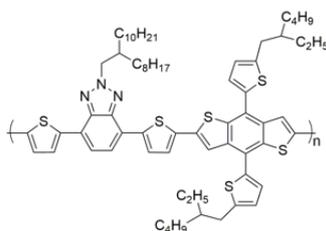
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A novel alternating donor-acceptor copolymer containing benzodithiophene and benzotriazole was synthesized. Thiophene unit was incorporated as a p-bridge into polymer P1. The optical and photovoltaic studies of polymer were investigated. Electronic band gap value of P1 was found as 2.20 eV. On the other hand, optical band gap value was obtained as 1.95 eV. In photovoltaic studies, the polymer was used as the donor material in the fabrication of bulk heterojunction solar cells. The inverted organic solar cell device based on P1:PC₇₁BM (1:3, w/w) with 3% DPE(diphenyl ether) additive exhibited the best power conversion efficiency of 1.30 % with a V_{oc} of 0.52 V, a J_{sc} of 4.51 mA cm⁻² and a FF of 54.97 %.

Keywords

organic solar cell, thiophene, copolymer



Structure of P1

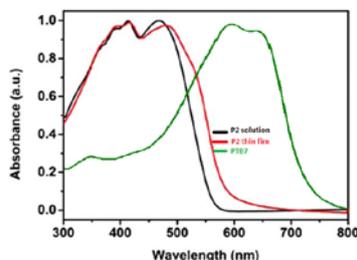
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BISTRIPHENYLAMINE- AND BENZODITHIOPHENE- BASED RANDOM CONJUGATED POLYMERS IN TERNARY BLEND BULK HETEROJUNCTION ORGANIC SOLAR CELLS

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Concept of Ternary organic solar cell is one of the most promising topics in photovoltaic studies. However, because of the complicated phase separation systems, improving the power conversion efficiency is quite compelling. In this study, a ternary organic solar cell with two donors Poly[[4,8-bis[(2-ethylhexyl)oxy]benzo[1,2-b:4,5-b']dithiophene-2,6-diy]] [3-fluoro-2-[(2-ethylhexyl)carbonyl]thieno[3,4-b]thiophenediy]] (PTB7) and benzodithiophene-based random conjugated polymers (P1 and P2) and one fullerene based acceptor (PC₇₁BM) are used to form the active layer. Two donors are complementary with each other in the UV-VIS spectra, in other words, λ_{max} values of PTB7 and P1 were determined as 760 nm and 481 nm, respectively. Photovoltaic performance of the polymers P1 and P2 were examined under the illumination of AM 1.5G, 100 mW.cm⁻². Photovoltaic studies showed that the highest power conversion efficiency of these photovoltaic devices were recorded as 3.50% with open circuit voltage; 0.79 V, short circuit current; 9.45 mA.cm⁻², fill factor; 0.53.



P44

EFFECTS OF SOLVENT AND PH ON POLYSULFIDE ELECTROLYTE FOR HIGH-EFFICIENT QUANTUM DOT SENSITIZED SOLAR CELLS

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Quantum dot sensitized solar cells (QDSSCs) have exhibited a rapid evolution in energy conversion efficiency in the past few years and are now attracting growing research interest. Although much effort has been devoted to the development of QDSSCs, their photovoltaic efficiency is still relatively low. One major challenge in this field is how to selection of an appropriate iodine-free electrolyte, working stably without any significant degradation for QDSSCs. We report an efficient and stable polysulfide electrolyte that has been prepared by different solvents using as methanol and water in different pH media adjusting with NaOH and KCl, for compatibility with CdSe/ZnS core/shell quantum dots in copper sulfide (CuS_x) counter electrode based solar cells. The best efficiency of 3.06% with Voc of 0.50V, Jsc of 2.83 mAcm⁻², FF of 0.63 was achieved using an electrolyte containing methanol in acidic media for QDSSCs due to high wettability and superior penetration capability. Consequently, one of the significant issues for achieving high-efficient QDSSCs is the selection of an appropriate electrolyte.

Keywords

polysulfide electrolyte, quantum dot-sensitized solar cells, methanol/water solvent, pH media

P45

LOW COST PRODUCTION OF DSSCS

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TiO₂/ZnO/FTO working electrode component of DSSCs was obtained by sol-gel and screen printing methods. Low cost chemicals of precursors were preferred to assembly the cells. Natural dyes ((black mulberry, wild jasmine, madder fruits, mahaleb cherry) were used as photosensitizers. The power conversion efficiency was the best for the cells in which black mulberry was used as a photosensitizer estimated under 1 sun.

Keywords

sol-gel spin coating method, screen printing method, natural dyes, dye sensitized solar cells

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CONTROLLING OF MORPHOLOGICAL PROPERTIES OF THE PHOTOANODE OF DSSCS

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Different photoanode structured of dye-sensitized solar cells (DSSCs) were fabricated by applying various additional titanium-layers. The photoanode components were produced by using P25 powder, titanium tetrachloride and titanium isopropoxide. Photoanodes obtained were called S1, S2 and S3. S1 was obtained by applying P25 paste on the bare FTO. S2 was manufactured by applying P25 paste onto FTO immersed in TiCl₄-DI solution. Finally, S3 was obtained by coating extra TTIP solution as a buffer layer under P25 paste application in S2 structure. The morphological properties of the photoanodes were mainly investigated in means of atomic force microscopy. The RMS values of the produced multilayer structures were 28nm, 40nm, and 58nm for S1, S2 and S3, respectively. The best power conversion efficiency of 8.01% conducted under irradiation of 0.3 sun intensity (at 30 mW/cm²) was obtained on the cell composing of S3 photoanode whose RMS value is relatively higher among others. This was further attributed to modifications in surface properties of the photoanode.

Keywords

fluorine doped tin oxide, surface morphology, AFM, RMS

P47

DFT THEORETICAL STUDY OF ORGANIC SEMICONDUCTOR MOLECULES BASED ON TERPHENYL FOR ORGANIC PHOTOVOLTAIC AND SOLAR CELL APPLICATIONS

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In this work, we report a theoretical study by using the DFT method on organic semiconductor molecules 4,4''-bis(diphenylamino)-1,1':3',1''-terphenyl-5'-carboxylic acid (TPA) and 4,4''-di-9H-carbazol-9-yl-1,1':3',1''-terphenyl-5'-carboxylic acid (CAR). These molecules were synthesized and characterized in our previous practical work [1]. Some of their important parameters such as HOMO, LUMO, band gap energy levels etc. have been calculated by DFT method and compared with those ones experimentally obtained in the previous work [1]. Comparison of the parameters of these materials would be helpful to explore other electronic and spectroscopic properties for further studies.

Keywords

Terphenyl, DFT, organic photovoltaic

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P48

MULTILAYER DYE SENSITIZED SOLAR CELL STRUCTURES

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Multilayer dye sensitized solar cells (DSSCs) were fabricated by chemical bath and spin coating methods on FTO coated glass substrates. Structural, optical and electrical properties of the cells were evaluated by XRD, external quantum efficiency and I-V curve measurements, respectively. Crystal size of the TiO₂ layers were estimated from XRD measurements. A larger crystal size was obtained with increasing thickness of photoanode. By adding a new layer, power conversion efficiency of the cells improved ~30%.

Keywords

dye sensitized solar cells, multilayer, efficiency

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ENHANCEMENT OF LIGHT ABSORPTION ABILITY OF DSSCS WITH DESIGNING OF MULTILAYER PHOTOANODE

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Dye sensitized solar cells (DSSCs) fundamentally consist of photoanode, counter electrode, sensitizer and electrode components. Photoanode has a wide-bandgap semiconductor layer on the top of conductive substrate and its properties are vital for the performance of the cell. In this study, multilayer structure of TiO₂ films via spin coating method were proposed. Contributions of added layers were investigated by using UV-Vis spectroscopy measurements. Adding various combination of layers, an improvement in average absorption of 52% was reached in the visible range.

Keywords

dye sensitized solar cells, Absorption

P50

MESO POSITION SUBSTITUTION EFFECT INVESTIGATION OF BODIPY-BITHIOPHENE STRUCTURES AS DONOR MATERIALS FOR ORGANIC SOLAR CELLS

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Bodipy dyes gained interest due to their interesting properties such as high fluorescence quantum yields, high absorption coefficients, ease modification in their structure and good electronic properties [1]. In recent years there is an increase in the amount of research run on new generation solar cells with these dyes, both as dye solar cells (DSC) and organic solar cells (OSC). In OSC, different approaches including as a donor, an acceptor and with novel strategies while forming the cells have been done [2]. We also carried out some studies and used Bodipy as a donor compound with triply connected strong electron donating groups (triphenylamine) and investigated how connectivity in the meso (8-) position altered the efficiency of the cell, while using classical PC₆₁BM as an acceptor [3]. In the present study, we have synthesized two Bodipy structures, this time with doubly and triply substituted with hexyl substituted bithiophene from the 3- and 5- positions of the Bodipy core. Organic solar cells have been constructed with these structures and PCE value of 0.3% was obtained in the preliminary cells constructed with BOD1, further investigations to increase the yield are under study. Thereby, comparative analysis based on the substitution on meso position of Bodipy have been investigated according to the donor group and solid state morphology variation. Computational studies have also been investigated in order to comprehend the electronic effects of the substitutions and the Bodipy dyes as donor materials in general.

Keywords

bodipy, bithiophene, organic solar cells

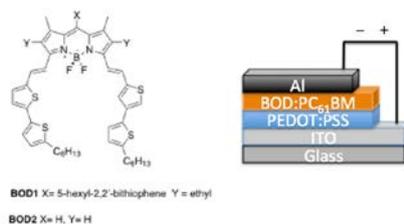


Figure 1. Bodipy dye structures and constructed organic solar cell configuration

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THIENOPYRROLE AND SELENOPYRROLE CONTAINING CONJUGATED POLYMERS FOR ORGANIC PHOTOVOLTAICS

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In recent years, bulk heterojunction organic photovoltaics have a great importance since they are economic, flexible and manufactured easily in a large scale. [1] Moreover, there is a sharp increase in the highest efficiency from 2.5 to 11 %. [2] Based on these results, this study is mainly focused on to develop low band gap polymers which contain electron donor and acceptor units as monomers to design organic solar cell devices.

To accomplish the purpose, 2-(4,8-bis(5-(2-ethylhexyl)thiophen-2-yl)-6-methylbenzo[1,2-b:4,5-b']dithiophen-2-yl)-10,11-didodecyl-8-methyl-10,11-dihydro-[1,2,5]thiadiazolo[3,4-e]thieno[2',3':4,5]pyrrolo[3,2-g]thieno[3,2-b]indole and 2-(4,8-bis(5-(2-ethylhexyl)thiophen-2-yl)-6-methylbenzo[1,2-b:4,5-b']dithiophen-2-yl)-10,11-didodecyl-8-methyl-10,11-dihydroselenopheno[3,2-b]selenopheno[2',3':4,5]pyrrolo[3,2-g][1,2,5]thiadiazolo[3,4-e]indole were synthesized as conjugated polymers with the help of Stille Coupling reaction. Structure of the intermediate materials was investigated by Nuclear Magnetic Resonance Spectroscopy (¹H-NMR and ¹³C-NMR). After the successfully syntheses of these two conjugated polymers, electrochemical and spectroelectrochemical characterization of them will be investigated. The molecular weight and optical band gap of the polymers will be calculated by using GPC and UV-VIS-NIR spectroscopy correspondingly. After optimization of the thickness and morphology of polymer:PCBM blend structure, device will be constructed and current/voltage measurements will be performed in a nitrogen-filled glovebox system.

Keywords

organic photovoltaic , benzotiadiazole, thienopyrrol,selenopyrrol

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LIGHT HARVESTING BASED ON CAGE PROTEINS

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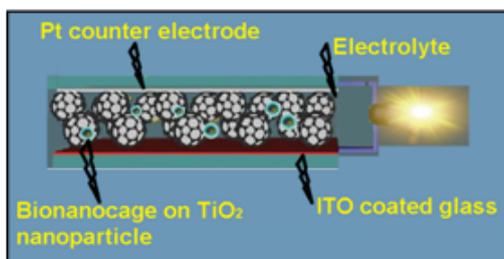
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Protein-sensitized solar cells resemble the design of dye-sensitized solar cells (DSSCs) except that the dye molecules are substituted by light harvesting biomolecules as a sensitizer. They are also called bio sensitized solar cell (BSSC) which is named photon triggered electron ejection by light-activated proteins. On BSSC making have been used natural dyes, cyanobacteria cells, photosynthetic micro-organism, and protein. In contrast to DSSC, BSSC also uses low cost, environment-friendly biomolecules as light harvesters [1].

Bionanoferritin based harvesting devices that have extractable cage metal ions and represent attractive properties of photovoltaic behaviors have been fabricated. In this work, ferritin nanocage based Bio-N-DSSC is synthesized by using ANADOLUCA method, which utilizes photosensitive electron transfer based microemulsion co-polymerization as nanobead form of ferritin. Protein substrate contains metal ions such as silver and copper or metal ion pairs namely, silver-copper (Janus bionanocage) and co-polymeric shell of the photosensitive crosslinker protein. Bionanoferritin has been adsorbed onto the immobilized graphene surface/TiO₂ by covalent bonding. This immobilization has been enhanced the capability of electron transfer between the bionanoferritin layer and graphene/TiO₂ surface owing to the well-designed robust bionanocage structure. In this way, we have developed a novel hybrid and self-assembly bio-dye-approach as a new generation of dye-sensitized solar cells (Scheme). Bionanoferritin/graphene/TiO₂ based Bio-N-DSSC molecules can provide an intriguing and relatively untapped alternative to traditional materials utilized in dye-sensitized solar cells.

Keywords

bionanoferritin, solar cell, light harvesting, DSSC



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EFFECT OF USING BLACKMULBERRY AS PHOTSENSITIZER AND TiO₂ HAVING DIFFERENT THICKNESS ON THE PERFORMANCE OF DYE-SENSITIZED SOLAR CELLS

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This study focuses on power conversion efficiency of dye sensitized solar cells (DSSCs) by using blackmulberry as natural sensitizer and the sol-gel based process applied in the production of TiO₂ photoelectrodes which are produced in different thicknesses (1.25 , 2.5 and 3.75µm). Blackmulberry fruit seems to have ingredients containing anthocyanins which has good chemical bonding with TiO₂ . Specially, cyanine contributing to fruit red pigment from red to purple color which (structure presented herein) is known to contain. In the extracts of natural fruit, the black mulberry extract performed the best photosensitized effect, which was due to the better interaction between the carbonyl and hydroxyl groups of anthocyanin molecule on black mulberry extract and the surface of TiO₂ porous film. Thus, the best power conversion efficiency was obtained in the sample coated with the thickest TiO₂ and synthesized with blackmulberry.

Keywords

blackmulberry, TiO₂ thickness, sol-gel, dye-sensitized solar cells

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OBTAINING DYE-SENSITIZED SOLAR CELLS USING 3 NATURAL DYES AS SYNTHESIZER

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In this study, the effects of different dyes on the efficiency of dye sensitized solar cells (DSSCs) were investigated with applying three different sensitizer dyes which are black mulberry (*morusnigra*), madder (*rubiatinctorum*) fruits, and eosin y . In the process of forming the DSSCs structure,, the electrolyte solution containing redox reactions for the regenerating of the dye was deposited between the working electrode involving TiO₂ and the counter electrode. The photovoltaic conversion performance parameters of the fabricated DSSC were measured under standard test conditions. The best conversion efficiency was obtained with black mulberry dye.

Keywords

low-cost solar cell, natural dyes, dye-sensitized solar cells

P55

SYNTHESES AND CHARACTERIZATION OF BENZOTRIAZOLE CONTAINING CONJUGATED POLYMERS FOR BULK HETEROJUNCTION ORGANIC PHOTOVOLTAICS

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Organic solar cell research is developing day by day in the past half century, but especially in the last decade it has attracted scientifically and economic interest triggered via a rapid increase in power conversion efficiencies. The introduction of new materials, improved materials engineering, and more sophisticated device structures contributed to development of OSC. Today, solar power conversion efficiencies in excess of 25 % have been accomplished with several device concepts.[1] Organic solar cells dragged lot of attention and research interest due to its wide potential and advantages such as low cost, made of abundant earth materials, simple manufacturing techniques and ability to incorporate various technologies.[2] By using organic photoactive materials (e.g. semiconductive polymers) and low-temperature solution processing techniques, they show great potential for low-cost, lightweight, large-area and flexible devices.[3]

1-(5-(7-(5-(4,8-bis((2-ethylhexyl)oxy)benzo[1,2-b:4,5-b']dithiophen-2-yl)thiophen-2-yl)-2-(2-ethylhexyl)-2H-benzo[d][1,2,3]triazol-4-yl)thiophen-2-yl)-5-octyl-4H-thieno[3,4-c]pyrrole-4,6(5H)-dione and 1-(5-(7-(5-(4,8-bis((2-ethylhexyl)oxy)benzo[1,2-b:4,5-b']dithiophen-2-yl)selenophen-2-yl)-2-(2-ethylhexyl)-2H-benzo[d][1,2,3]triazol-4-yl)selenophen-2-yl)-5-octyl-4H-thieno[3,4-c]pyrrole-4,6(5H)-dione were synthesized to be used for potovoltaic applications as conjugated polymers by using Stille Coupling reaction with a suitable catalyst. Structure of the intermediate materials was investigated by Nuclear Magnetic Resonance Spectroscopy (1H-NMR and 13C-NMR). After the successful synthesis of the two conjugated polymers, electrochemical and spectroelectrochemical characterization will be investigated to reveal their properties. The molecular weight and optical band gap of the polymers will be estimated through GPC and UV-VIS-NIR spectroscopy. Additionally, the thickness and morphology of polymer:PCBM blend structure will be optimized and then device construction will be designed. Finally, current/voltage measurements will be done in a nitrogen-filled glovebox system.

Keywords

solar cell, polymer, benzotriazole, thiophene, selenophene

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PHOTOVOLTAIC PROPERTIES OF THIENOPYRROLE AND SELENOPYRROLE FUSED BENZOTHIADIAZOLE CONTAINING POLYMERS

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These days, creating alternative energy sources based on renewable natural resources are gaining considerable importance due to the rise in demand for energy, the reduction of fossil fuel reserves and environmental impacts. For this reason, a significant point is energy recovery and its value rapidly increases with studies in photovoltaic cell and parallel to this, research studies regarding to this subject is a very hot topic for few decades.

In this study, the derivatives of benzothiadiazole fused indole acceptor units which named as the 2,2-dibromo-10,11-didodecyl-10,11-dihydro- [1,2,5] thiadiazolo [3,4-e] thieno [2', 3': 4,5] pyrrolo [3,2-g] thieno [3,2-b] indole and 2,8-dibromo-10,11-didodecyl-10,11-dihydro-selenopheno [3,2-b], 3': 4,5] pyrrolo [3,2-g] [1,2,5] thiadiazolo [3,4-e] indole were synthesized. The brominated acceptor units were polymerized by applying the superiority of the Stille coupling reaction with 2,6-bis (trimethyltin) -4,8-bis (2-ethylhexyloxy) benzo [1,2-b: 4,5-b'] dithiophene. Structural characterization of the materials was carried out by Nuclear Magnetic Resonance Spectroscopy (¹H-NMR and ¹³C-NMR). The HOMO, LUMO, and band gap was calculated via cyclic voltammetry and the UV-VIS-NIR spectroscopy. Organic solar cell devices was constructed by using PCBM:Polymer blend structure under the light of AM 1.5 G which is a standard of polymer solar cell measurements in a nitrogen-filled glovebox system.

Keywords

solar cell, thienopyrrol, selenopyrrol, bulk heterojunction

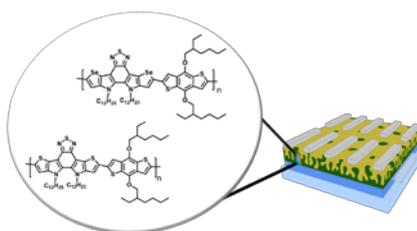


Figure 1

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BENZODITHIOPHENE AND SELENOPHENE BEARING POLYMER FOR INVERTED ORGANIC SOLAR CELL APPLICATIONS

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Inverted organic solar cells have advantages over conventional organic solar cells. Most important advantage is the improved stability of inverted solar cells. In this study, benzodithiophene, quinoxaline and selenophene bearing conjugated polymer was used as donor material in inverted solar cell applications. Device performances were investigated with the device configuration of ITO/ ZnO/ polymer:PC₇₁BM/ MoO₃/ Ag. In order to improve device performance, polymer PCBM ratio, active layer thickness, annealing time and temperature optimizations were carried out. Active layer morphologies were investigated by TEM and AFM analyses. Best performance device showed power conversion efficiency of 2.57 % with V_{oc} of 0.67 V, J_{sc} of 7.68 mAcm⁻² and FF of 50 %.

Keywords

organic solar cells, inverted device architecture

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NATURAL DYES AS PHOTSENSITIZERS FOR DYE-SENSITIZED SOLAR CELLS

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In the last two decades, dye-sensitized solar cells (DSSCs) have attracted more attention as an efficient alternative to economical photovoltaic devices, and the highest efficiency record has increased from ~7% to ~14%. To be more competitive in the solar cell markets, various organic materials are investigated and used in DSSCs to improve the cell efficiency, enhance the cell durability, and reduce the cost of production. The operations of DSSCs are based on the photo-sensitization created by the dyes on wide band-gap mesoporous metal oxide semiconductors; this sensitization is due to the dye absorption over part of the visible light spectrum. There some advantages of using natural pigment as sensitizer in DSSCs are low fabrication cost, easy achievability, low time of energy payback, flexibility, availability of supply of raw materials, non-environmental risk, and great performance at diffuse light and multicolor options. In this study, four natural dyes were extracted from natural fruit which are madder (*rubia tinctorum* fruit), black mulberry (*morus nigra*), wild jasmin (*jasminum fruticans*), mahaleb cherry (*prunus mahaleb*). The extracted dyes were examined using UV-VIS spectroscopy to investigate optical absorbance in the visible region. Even though wild jasmine fruit among others exhibited the highest absorption ability, the madder fruit was the best in terms of optical performance of working electrode.

Keywords

organic photosensitizers, natural dyes, DSSCs

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FLUORESCENT POLY(TRIPHENYLAMINE-THIAZOLO[5,4-D]THIAZOLE) COPOLYMER AND FERROCENE-BASED SCHIFF BASES FOR DYE-SENSITIZED SOLAR CELL (DSSC) APPLICATIONS

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The synthesis, electronic, optical and material properties of triaryl amines have been studied [1,2]. Triphenylamine (N,N-diphenylaniline) (TPA) molecule contains a single nitrogen atom and three phenyl groups. It is widely utilized for donor-acceptor type applications in organic photovoltaics (OPVs) [3,4]. In this study, the photovoltaic properties of poly(triphenylamine-thiazolo[5,4-d]thiazole) (p-TPTT) alternating copolymer and the ferrocene-based schiff base materials in TiO₂ dye-sensitized solar cells were examined. The copolymer is a red colored dye material with high thermal stability, good solubility and low-band gap energy. The electrical conductivity of the p-TPTT was measured as 1.5x10⁻⁵ S/cm. The electrochemical band gap energy, E_g^{CV} was 1.36 eV while the optical band gap energy, E_g^{Opt.} was 1.55 eV. The HOMO and LUMO energy levels of the polymer were found as -5.32 and -3.96, respectively. The ferrocene-based schiff base dyes showed low power conversion efficiencies and the best results were obtained for the p-TPTT copolymer. The DSSC device performance values for p-TPTT were found as V_{oc} = 0.55 V and PCE=1.54%.

Keywords

solar cell, organic dyes, copolymer, solar energy

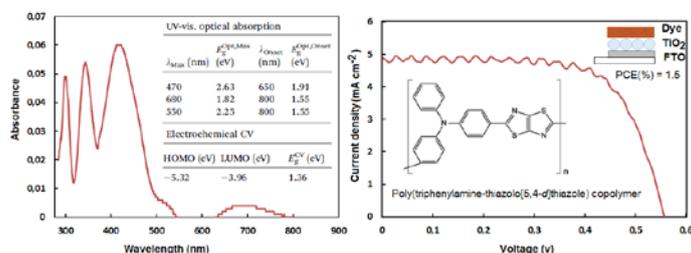


Figure 1. UV-vis optical absorption of copolymer-TiO₂ layer and the solar-cell test results.

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P60

PERFORMANCE ANALYSIS FOR ITO/P3HT:PCBM/AG ORGANIC SOLAR CELLS FOR DIFFERENT P3HT:PCBM MASS RATIOS

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In the last few decades, solar power has gained a significant importance with the improving technology and requesting for clean energy sources. Especially in recent years, the studies of organic solar cell (OSC) technologies have quite large interest. The main reasons for attracting attention in the OSC technologies are easy fabrication techniques to fabricate high-efficiency OSCs, their flexible application potential, lightweight and large area application possibility with solution processed [1,2]. As a result of scientific studies, efficiency values of OSCs reach from 4% in 2001 [3] to 13% in 2018 [4]. P3HT and PCBM are quick miscible materials and they show separation property to preferential electrode interfaces [5]. In order to investigate the effects of P3HT:PCBM mass ratios with reference to these features, glass/ITO/P3HT:PCBM/Ag organic solar cells were fabricated by spin coating method with different P3HT:PCBM mass ratios which are 1:1 and 2:1. The current-voltage (I-V) measurements were performed at room temperature under AM1.5 conditions (100 mW/cm² illumination at 25°C) to investigate the solar cell parameters such as open-circuit voltage (V_{oc}), short-circuit current density (J_{sc}), fill factor (FF) and power conversion efficiency (PCE). The results of solar cell analysis show that P3HT:PCBM mass ratio directly affects the performance of OSCs which were improved by increasing the PCBM concentration for solar cells. Finally, it can be concluded that solar cell parameters are strongly function of the P3HT:PCBM mass ratio for the ITO/P3HT:PCBM/Ag OSCs.

Keywords

organic solar cell, P3HT:PCBM mass ratio, PCE comparison

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THE INVESTIGATION OF DEVICE CHARACTERISTICS OF ITO/PCBM:PCDTBT/AG ORGANIC SOLAR CELLS FOR DIFFERENT PCBM:PCDTBT PERCENTAGE MASS RATIOS

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Organic monomeric and polymeric materials attracted considerable attention due to their potential applications in electronic and optoelectronic devices in recent decades. Among these devices, polymer solar cells (PSCs) have been interested by the photovoltaic community, as proved by the fast increasing number of scientific publications and patent applications. Although the efficiencies of PSCs are not sufficient enough to compete with that of inorganic solar cells, their several unique properties like mass roll-to-roll production capabilities, flexibilities and lightnesses made them a favourable choice. To achieve higher power conversion efficiencies, the researchers concentrated on material combination, besides device architecture, and nanomorphology control. As a results of the investigations, PCBM based PSCs came as a favorable option among others. In this work, we investigated ITO/PCBM:PCDTBT/Ag PSCs with different PCBM:PCDTBT mass percentage ratios. PSCs were produced by spin coating method over ITO coated glass surfaces. The mass percentages were chosen to be 66%:33%, 50%:50% and 33%:66% for PCBM:PCDTBT structure. For the investigation of solar cell parameters, AM1.5 conditions (100 mW/cm² illumination at 25°C) at room temperature were used to perform the current-voltage (I-V) measurements. The results of the experiments were analysed to investigate solar cell parameters like open-circuit voltage (Voc), short-circuit current density (Jsc), fill factor (FF) and power conversion efficiency (PCE). The results of the analysis revealed that change in the percentage mass ratios of PCBM and PCDTBT in PSCs were strongly affected by the variations in mass percentage ratios, and can be used to improve device performance.

Keywords

organic polymers, photovoltaic cells, current-voltage characteristics, power conversion efficiency

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SYNTHESIS AND CHARACTERIZATION OF NOVEL THIENO[3,4-C]PYRROLE-4,6-DIONE (TPD)-BASED RANDOM COPOLYMER AND ITS APPLICATION IN ORGANIC SOLAR CELLS

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An acceptor unit containing thieno[3,4-c]pyrrole-4,6-dione (TPD) was designed with selenophene building blocks since polymers that utilizes with selenophene side units result in polymers with low band gap energy and broad absorptions with covering NIR region. There is only one report of selenophene attached TPD unit being used in organic solar cell and the results do not show the full capacity of this unit. In literature, benzo[1,2-b:4,5-b']dithiophene (BDT) is also known as promising materials for preparing organic solar cells with a high efficiency. Therefore, copolymer including TPD and BDT was designed and synthesized via Stille coupling. However, the resulting copolymer had solubility problem in common organic solvents. To overcome such problem, benzo[d][1,2,3]triazole (BTA) with a longer alkyl chain was also synthesized and used to obtain a novel random copolymer including TPD, BTA and BDT materials via Stille coupling. This time, target polymer showed excellent solubility in common organic solvents. By using TPD-BTA-BDT-based random copolymer, organic solar cells were prepared and followed by performing solar cell studies. Poly(TPD-BTA-BDT) was used as donor whereas PCBM, the common and soluble derivative of fullerene was used as acceptor in preparation of organic solar cells. Thickness and morphological properties of poly(TPD-BTA-BDT):PC71BM were investigated and based on these results suitable solar cell devices (ITO/PEDOT:PSS/poly(TPD-BTA-BDT):PC71BM/LiF/Al) were prepared. After initial optimizations a promising PCE of 4.78% could be reached. Further detailed optimizations are currently underway in our laboratories.

Keywords

organic solar cells, random copolymers, selenophene containing polymers

P63

SYNTHESIS OF NOVEL THIENOTHIOPHENE CONTAINING POLYMERS FOR ORGANIC PHOTOVOLTAIC DEVICE APPLICATIONS

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Thieno[3,4-b]thiophene unit modified with a carboxylate was shown to be one of the most promising acceptor units used for generation of high performance donor-acceptor type polymers as absorbers in organic solar cells. Dithieno[3,2-b:2',3'-d]pyrrole core is used as a donor in variety of polymers that showed high PCEs. These two promising donor and acceptor units were copolymerized successfully for the first time in literature. Cyclic voltammogram was used for investigation of electrochemical behaviors. Oxidation potentials of the polymer were determined to be 0.25 V/ 0.81 V for p-doping and 0.08 V/ 0.52 V for p-dedoping. The materials was found to be a NIR absorber with an absorption maximum at 728 nm. Optical band gap was calculated to be 1.2 eV. The performance of the polymer in organic solar cells is currently being investigated.

Keywords

NIR polymers, thienothiophenes, dithienopyrroles, organic solar cells

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DESIGN AND SYNTHESIS OF A NOVEL 3D NON-FULLERENE ACCEPTOR

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Fullerenes are great electron acceptors and due their unique structure they show notable performance as acceptors in organic solar cells. Almost all of the high performance organic solar cells reported up to date take advantage of fullerene derivatives. However, it is not possible for organic solar cells to be the low-cost energy source of the future if they utilize fullerenes, since synthesis and purification of fullerenes are extremely costly. Hence, design and synthesis of electron acceptor groups other than fullerenes (NFAs) became one of the most important topics in the energy related research. With the success of NFAs, some design principles were offered in the literature. One of the most significant among these guidelines is the necessity to generate 3-D structures. Keeping the guidelines from the literature in mind we designed a novel 3D perylene diimide containing material to be used as acceptors in organic solar cells. Our efforts towards the synthesis of this material will be discussed.

Keywords

non-fullerene acceptors, 3D core structures, organic solar cells

P65

SYNTHESIS OF BORIC ACID DOPED POLYANILINE/CARBON NANOTUBE COMPOSITES AND ITS APPLICATION IN DYE-SENSITIZED SOLAR CELLS AS COUNTER ELECTRODE

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ABSTRACT

In this study, boric acid doped polyaniline (PAni-BA) (1:1) were studied and the polyaniline-doped boric acid (PANI-B)/CNT composites were prepared by coagulation method, and characterized by using SEM, XRD, FTIR, thermal analysis, and electrical conductivity measurements. The coagulation method was applied to produce the PAni-BA and CNTs composites and the various weight percentages of CNTs were used as 5%, 10% and 15% respectively. In the coagulation method, acetonitrile (ACN) was chosen to dissolve the PANI-BA polymer and to permit the dispersion of the CNTs by bath sonication for 10 h.

DSSC based on this CE, prepared in (PAni-BA)/CNT composites 10% shows best photovoltaic performance with conversion efficiency up to 3.62%. Meanwhile, the efficiency of the same photoanode employing a Pt counter electrode was 4.48%. Compared to conventional Pt-based DSSCs, the design of the DSSC fabricated in this work would help to bring down the cost of energy production due to the lower cost of the materials. These promising results highlight the potential application of (PAni-BA)/CNT in cost-effective DSSCs.

Keywords

polyaniline, composites, carbon nanotubes, dye sensitized solar cells, counter electrode

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ORGANIC INORGANIC HYBRID PEROVSKITES FOR PHOTOVOLTAIC APPLICATIONS

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The "perovskite hybrid" materials have attracted a lot of attention in recent years, specifically CH₃NH₃PbI₃. The low cost of synthesis of CH₃NH₃PbI₃ and its high efficiency in photovoltaic application motivated us to do this study. For the calculation of the structural, electronic, optical and thermal properties of CH₃NH₃PbI₃, three approximations were used. The first is LDA, the second is GGA and the third is Vdw. The Vdw approximation gives results comparable to the experimental ones, because it takes into account the intermolecular interactions produced between the organic part and the inorganic part of CH₃NH₃PbI₃. This study showed how the properties of this material can allow less thickness to capture the solar spectrum and how they can weaken its rate of recombination leading to a good efficiency in photovoltaic application. It will also be seen that it may be useful for thermoelectric applications.

Keywords

perovskite hybrid, photovoltaic

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SYNTHESIS AND CHARACTERIZATION OF GRAPHENE OXIDE DERIVATIVES AND THEIR APPLICATION IN PEROVSKITE SOLAR CELLS

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Graphene oxide (GO) has attracted attention in photovoltaic, supercapacitor and biosensor applications due to its physical and electrical properties [1]. Recently, the use of GO in perovskite solar cells (PSCs) has been extensively studied to improve the device efficiency and stability [2]. In this study, graphene oxide (GO) was synthesized via Tour method and then modified with two different amine sources that contain different branched alkyl chain, i.e. dihexylamine (DHA) and 2-Ethylhexylamine (2EHA), and those modified graphene oxides (mGOs) were defined as DHA-GO and 2EHA-GO respectively [3]. The dispersions of them in isopropyl alcohol (1mg/ml) were prepared and then they were implemented as a buffer layer between the perovskite and P3HT layers in PSCs. The structure of devices was FTO/c-TiO₂/mp-TiO₂/perovskite/GO(mGO) /P3HT/Au. Compared to the reference device, solar cells with the additional layer of mGO derivatives present higher efficiency, with the maximum value being achieved in case of 2EHA-GO (13.62 %). The main difference in the efficiency values is related to the increase of J_{sc} of the cells with the additional mGO derivatives, while PSC with GO shows lower J_{sc} value and therefore poor efficiency (7.41 %) (Figure 1). Improved performance of mGO derivatives can be explained by the enhanced transportation of charge carriers via the mGOs that have dot-like morphology compared to the sheet-like morphology of GO.

Keywords

graphene oxide, modified graphene oxide, perovskite solar cells

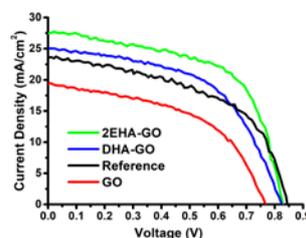


Figure 1. J-V characteristic curves of PSCs

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EFFECT OF DOPING OF HOLE TRANSPORT LAYERS ON ORGANIC AND PEROVSKITE SOLAR CELLS

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Organic and perovskite solar cells are among the third generation solar cells. The low cost, easy fabrication and the easy processability of organic molecules and polymers increase the attention on third generation solar cells by scientists around the world.

Organic solar cells are composed of organic molecules and polymers one of which is an electron donor and the other is an acceptor, sandwiched between two metal electrodes.

Recent efficiencies of organic solar cells reached up to 12% recently.

Perovskite is composed of organic / inorganic components with ABX_3 structure. A perovskite consists of organic components in the cubic-octahedral structure and inorganic components in the octahedral structure. The first perovskite solar cells were prepared by replacing the dye layer of the dye-sensitized solar cell with methylammonium lead iodide ($CH_3NH_3PbI_3$) and using liquid electrolyte and the efficiency was around 7% [1]. Instead of methylammonium lead iodide ($MAPbI_3$), formamidinium lead iodide perovskite solar cells prepared using perovskite material of ($FAPbI_3$) exceeded 20% of yield [2]. In only 5-7 years, the increase of efficiency from modest values to highly competitive ones focused the interest mostly on perovskite solar cells.

In this study, we have fabricated organic and perovskite solar cells and investigated the effect doping of PEDOT:PSS layers with iodine on the device performance and also compared the device performances.

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NUMERICAL STUDY OF THE INFLUENCE OF MAPBI₃ THICKNESS ON ZNO/ MAPBI₃/SPIRO-MEOTAD SOLAR CELL PERFORMANCE

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The highest certificated photovoltaic conversion efficiency (PCE) of perovskite solar cells belongs (PSCs) to the Korean Research Institute of Chemical Technology (KRICT) that has reached 22.7% compared with 3.9 % in 2009, this rapid improvement in photovoltaic conversion efficiency (PCE) makes the perovskite solar cell as a strong rival with silicon and CIGS in photovoltaic field. In this study the performance of such photovoltaic device has been numerically simulated and the thickness of the absorber layer has been optimized to give the optimal photovoltaic conversion efficiency . The solar cells Capacitance Simulator (SCAPS)-1D was the tool that has been used for numerical simulation of this device. In this theoretical study, a PSC FTO/ZnO/CH₃NH₃PbI₃/Spiro-OMeTAD/Au has been modeled of CH₃NH₃PbI₃ layer as absorber layer , ZnO as the electron transporting material (ETM), Spiro-OMeTAD as the hole transporting material (HTM). The effect of CH₃NH₃PbI₃ absorber thickness on different major working parameters like: open-circuit voltage Voc, short-circuit current density Jsc, fill factor FF, photovoltaic conversion efficiency η is studied with a view to optimize CH₃NH₃PbI₃ absorber thickness. This study detects that increasing the thickness of CH₃NH₃PbI₃ absorber layer results in higher efficiency until a maximum value and then decreases slightly. This maximum is found to be 24,917 % at CH₃NH₃PbI₃ optimum thickness close to 5 μ m.

Keywords

perovskite, solar cells, CH₃NH₃PbI₃, absorber thickness, conversion efficiency

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TEMPERATURE EFFECT ON TRIBLE-CATION PEROVSKITE SOLAR CELL PERFORMANCE

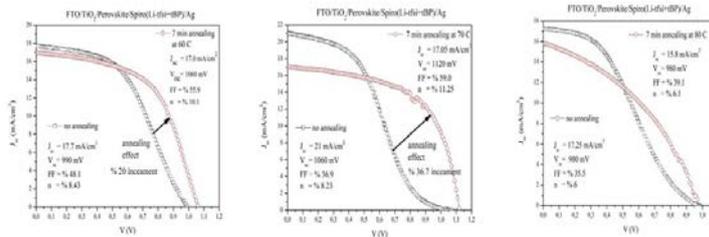
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Perovskite solar cells have raised the power conversion efficiency (PCE) above 22% level in a period of seven years due to their high absorption coefficient, long carrier lifetime, tunable band gap, diffusion length and the ease of fabrication [1]. In this study, we investigated the changes in the electrical parameters of FTO/TiO₂/Cs_{0.05}FA_{0.81}MA_{0.14}Pb(I_{0.852.53}Br_{0.1545})₃/Spiro-MeOTAD(Li-TFSI+4-tBP)/Ag solar cell devices according to the post annealing by using different annealing temperature in the glove box. Compared with the reference device, the post annealed devices exhibited much higher performance in terms of the open circuit voltage (V_{oc}), fill factor (FF) as well as the power conversion efficiency (PCE). The PCE of reference perovskite cells significantly enhanced from 8.43% to 10.1% for 60°C , 8.23% to 11.25% for 70°C without S-shape, respectively. The V_{oc} of the modified devices reach to 1.060 V and 1.120 V, respectively, while the V_{oc} of unmodified devices is 0.99 V and 1.06 V. In addition, the FF of the modified cells increased from 48.1% to 55.9% for 60°C and from 36.9% to 59.0% for 60°C for and 70°C , respectively. This simple process plays an important role to increase efficiency and stability of the films without S-shape.

Keywords

perovskite solar cell, temperature effect, S-shape



Influence of temperature on perovskite solar cells J-V characteristics

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THE STOICHIOMETRIC CONTROL AND STABILITY IMPROVEMENT OF CH₃NH₃PBI₃ FILM FORMED LAYER BY LAYER PROCESS

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The microstructure and phase analysis of perovskite solar cell prepared by two step solution method was characterized. In this study, perovskite solar cell was obtained by spin coating method, which contains PbI₂ and CH₃NH₃I (1,1 and 1 in equal molar ratio) prepared in DMF (dimetilformamid) and 2-propanol, respectively. Operation temperature and relative humidity were controlled to have stable structure. The band gap of MAPbI₃ was determined by UV-visible spectroscopy.

Keywords

perovskite, 2 step solution method, bandgap

P72

FIRST PRINCIPLE CALCULATION OF ELECTRONIC, OPTICAL PROPERTIES AND PHOTOCATALYTIC POTENTIAL OF ARSENENE SURFACES

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Vibrational and thermodynamic properties of LiBH₄ polymorphs from first-principles calculations. Available

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Two-dimensional (2D) materials have shown extraordinary performances as photocatalysts compared to their bulk counterparts. Simulations have made a great contribution to the deep understanding and novel 2D photocatalysts. Ab initio simulations based on density functional theory (DFT) not only show efficiency and reliability in new structure searching, but also can provide a reliable, efficient, and economic way for screening the photocatalytic property space. In this work, The electronic properties of the layered Arsenene are investigated by using the first-principles calculations based on the density functional theory (DFT). The room-temperature electronic transport coefficients are evaluated within the semi-classical Boltzmann theory. The band gap is found to be indirect. Bandgap value obtained with GGA-PBE (1.99 eV). Bond lengths and angles are calculated also. The optical properties are calculated and analyzed. Furthermore, The optical properties are calculated and analyzed. these calculation give a better description of Arsenene as 2D material water-splitting photocatalysts material.

Keywords

photocatalysis, water splitting, first principal calculation, hydrogen production, 2D materials

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TiO₂-Ag-Bi₂S₃ NANOCOMPOSITE AS PHOTOANODE FOR ENHANCED PHOTOELECTROCHEMICAL WATER SPLITTING

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Typically in a photoelectrochemical (PEC) cell, semiconducting photoactive electrodes are responsible for water splitting to produce hydrogen, assisted by solar radiation. TiO₂ is one of the interesting candidates in PEC water splitting owing to its good stability and ability for high charge carrier separation [1]. However various modifications are made to improve the light harvesting response in the visible region as well as higher PEC performance [2, 3]. In this work, TiO₂-Ag-Bi₂S₃ nanocomposite was prepared, characterized and employed as a photoanode for water splitting reaction. The PEC activity of the photoanodes such as TiO₂, TiO₂-Ag NPs, TiO₂-Bi₂S₃ and TiO₂-Ag-Bi₂S₃ were evaluated for water splitting by measuring current density (J)-voltage (V) curves (Fig.1a). Typical photocurrent can be negligible for all samples under dark conditions. Upon light illumination, photocurrent density of TiO₂, TiO₂-Ag, TiO₂-Bi₂S₃ and TiO₂-Ag-Bi₂S₃ composites are 0.36, 1.71, 3.83 and 5.91 mA cm⁻² at 1.23 versus reversible hydrogen electrode (RHE), respectively. Among all, the TiO₂-Ag-Bi₂S₃ composite showed the highest photocurrent which reflects high hydrogen evolution reaction (HER) than other electrodes. Interestingly, current (I)-time (t) curve studies inferred that TiO₂-Ag-Bi₂S₃ composite is highly photostable (Fig.1b). As a result, the better PEC performance of TiO₂-Ag-Bi₂S₃ photoanode is attributed to the synergistic effect between Bi₂S₃ QDs and Ag NPs by extended light absorption in the visible spectrum and also the efficient interfacial charge carrier separation and transfer promoted by the sandwiched Ag NPs between TiO₂ and Bi₂S₃ QDs. Thus, this new composite developed has exhibited superior PEC water splitting performance for HER.

Keywords

PEC water splitting, photoanode, Ag NPs, Bi₂S₃ QDs, surface plasmon resonance, charge separation

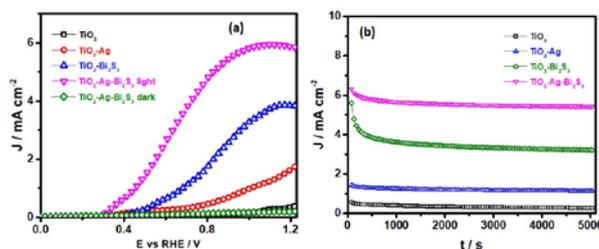


Fig.1 (a) J-V and (b) I-t curves of with and without Ag NPs based photoelectrodes

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PHOTOCATALYTIC SENSITIVITY OF MGO GROWN BY SRAY PYROLYSIS

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The thin layers of magnesium oxide MgO are synthesized by the chemical spraying technique (pyrolysis) "SPRAY" by dissociating 0.2 M magnesium chloride in bi-distilled water as a solvent. Structural, optical and morphological analyzes are performed by XRD, FTIR, spectrophotometry and AFM. They respectively confirm the crystallization of magnesium oxide in the CFC cubic face-centered structure, the presence of native defects on the surface, and a gap energy of the order of magnitude 4 eV. Under solar irradiation, these layers have a photocatalytic activity: the absorbance of methylene blue is observed for the wavelength 665 nm, which corresponds to the total degradation of the dyes of methylene blue for two hours.

Keywords

thin films, magnesium oxide, photocatalytic

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TWO DIMENSIONAL ELECTRICAL MODELING OF HIGH GEOMETRICAL ASPECT RATIO EMITTERS

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High geometrical aspect ratio surface structures have been extensively studied to improve the optical performance of silicon solar cells. These structures provide superior broadband anti-reflection compared to conventional surface textures. Optical performance of high aspect ratio surface structures is well-studied in the literature. However, to our knowledge, a detailed numerical analysis in terms of their electrical performance is missing despite a number of comprehensive experimental studies. In this study, we applied three numerical electrical methods to analyze the performance of the emitters formed on high aspect ratio surface structures. The two dimensional emitter saturation current density was determined by mimicking QSSPC conditions. The spatial carrier collection efficiency profiles were generated from the shift of the minority carrier Fermi level caused by an applied voltage. Lastly, the emitter sheet resistance was obtained from I-V data generated by two-probe measurements in the simulation domain. The methods developed and/or applied in this study can be further extended to other material systems and multi-dimensional structures of any size for similar analyses.

Keywords

solar cell, simulation, emitter

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CHARACTERIZATION OF A-SI:H PASSIVATION LAYER WITH PHOTOLUMINESCENCE IMAGING TECHNIQUE IN HETEROJUNCTION SOLAR CELLS PRODUCTION FLOW

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The Silicon Heterojunction (SHJ) solar cell technology have demonstrated relatively high efficiencies [1] with record conversion efficiency of round %26 [2]. One of the key features of the success is related with excellent surface passivation quality of thin amorphous Silicon (a-Si:H) layer [3,4]. Many research groups are reported effective lifetime values which are higher than 10ms lifetime at a minority carrier density $1 \times 10^{15} \text{cm}^{-3}$ [4,5]. The well-known characterization techniques of passivated samples are QSSPC effective lifetime measurement and photoluminescence (PL) imaging techniques [5,6].

We are reporting step by step analysis of SHJ solar cell process flow by two different effective lifetime measurement techniques, QSSPC [7] and μ -PCD [8]. QSSPC measurements are done by Sinton lifetime tester and μ -PCD lifetime measurements and PL images are measured by Semilab PLI-1001. Phosphorus doped n-type FZ monocrystalline double side polished wafers with resistivity of 1-3 $\Omega \cdot \text{cm}$, (100)-oriented surface and thickness of 200 μm are used as a substrate. Starting from i a-Si:H passivation (Figure1), complete SHJ solar cell structure is analyzed after each deposition step via these two measurement technique. Throughout the study various deposition conditions, Hydrogen plasma treatment, effect of p and n-type a-Si:H deposition and AZO sputtering on the passivation quality are checked and controlled by calibrated PL images. The correlation between two measurements method will be presented under influence of various quality of surface passivation including effect of post-annealing to eliminate sputtering damages. The highest effective lifetime is recorded as 4ms with 740mV implied Voc value with 7nm i a-Si:H passivation.

Keywords

passivation, PL imaging, QSSPC, μ -PCD, lifetime, a-Si:H

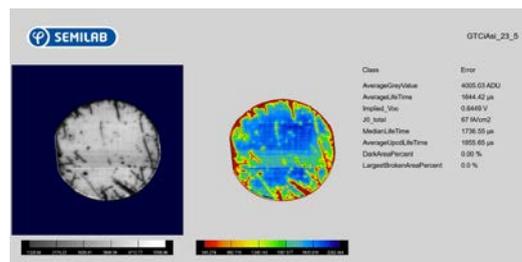


Figure 1. PL image of the passivated sample with 7nm i a-Si:H

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DETERMINATION OF ELECTRICAL PERFORMANCES OF TERRESTRIAL PHOTOVOLTAIC MODULES

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Photovoltaic (PV) modules performance testing and energy rating as described in IEC 61853-1 standard depends on electrical performances of PV modules as a function of temperature. In this work, in order to precisely determine the effects of temperature on the electrical parameters (I_{sc} , V_{oc} , P_{max} , FF) of PV modules the temperature controlled xenon light based Solar Simulator system was used. The Solar Simulator's spectral match, spatial non-uniformity and temporal instability according to the IEC 60904-9 standard's classification requirements corresponds to A⁺ A⁺ A⁺ classes. Moreover, the temperature controlled unit of this system designed in such that it has temperature uniformity of less than $\pm 1\%$ over the 2mx2m area, which is two times better than the IEC 60891 standard requirements ($\pm 2\%$). A mono and a poly crystalline module of 60 cells were respectively placed to the module holder and totally eight PT-100 temperature sensors were attached to their back sides. The temperature inside the thermal chamber was set to be changed from 15 C to 75 C with 5 C intervals. At each temperature level after the desired thermal stability was reached, which was controlled by temperature non uniformity on the whole module area, then the module front surface area was irradiated by flash type simulator with a flashes of 10 ms lengths and 1000 W/m² irradiance levels. After recording the electrical parameters (I_{sc} , V_{oc} , P_{max} , FF) of PV modules the $\alpha(T)$, $\beta(T)$ and $\kappa(T)$ temperature coefficients corresponding to I_{sc} , V_{oc} , P_{max} parameters were calculated.

Keywords

Photovoltaic, Temperature Coefficient, Linearity, Energy Rating

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SPECTRAL EFFECTS ON PV MODULE AND DETERMINING OF THE SUN FOR MUGLA

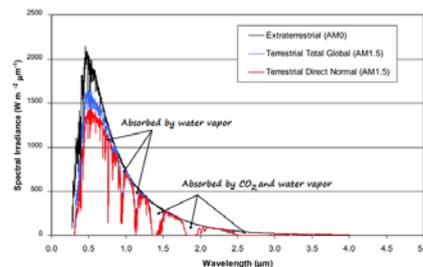
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Not only the theoretical calculation of the amount of solar radiation the characteristics of the light is very important in determining the efficiency of the PV module. There are no theoretical and experimental studies on this subject in our country until now. The amount of incoming radiation varies depending on the wavelength. The amount of radiation and the quality of the light in the atmosphere varies due to many atmospheric effects. One of these effects is air mass. Photovoltaic systems convert solar energy into electricity. The main part in these system are photovoltaic modules which directly convert solar energy into electricity. So the material and the kind of photovoltaic modules are very important. It is therefore important to determine the amount of radiation coming to the surface. The amount of incoming radiation is reduced and the wavelength is changed by atmospheric factors. The determination of these effects is very important in calculating the amount of radiation. SPCTRL 2 calculates the amount of radiation coming from a number of atmospheric effects. In the program, the wavelength-dependent variation of the amount of radiation can be calculated considering the atmospheric effects for a desired region. In this study, the amounts of radiation coming to the surface having horizontal and different slope angles were calculated in Mugla and Ankara. It has been found that the amounts of incoming radiation vary due to regional reasons.

Keywords

solar radition, spectral distribution, solar energy, reference, modelling, SPCTRL2



Standard reference solar spectrum

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P79

REFERENCE CELL AUTOMATED CLEANING SYSTEM FOR BETTER ACCURACY

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With the rapid growth of large scale photovoltaic power systems (PVPS) installations in Turkey, investors expectation of lucriveness on the increase. Especially in Turkey, roughly 1.8 GWp on-grid PVPS was installed the last year at 2017. However with that rush, in a developing country such as Turkey, may lead many workmanship mistakes on the planning, implementation and operation process due to lack of qualified work force. To compensate that faults, it very substantial to put a monitoring devices to plant. Not only for the energy production, also for the incoming irradiance and temperature. Because only that way the performance ratio of the system can be achieved.

The irradiance sensor which is the most important sensor for calculating performance ratio, can heavily effected by soiling, same like the photovoltaic modules [1, 2]. Soiling is very significant factor in Turkey for PVPS. This soiling factor effects the results for the irradiance monitoring element, thus performance ratio. In order to get a good homogeneous results it has to be cleaned in calculated intervals, regarding to soiling intensity. To prove that idea in this article, there is a comparison between 2 irradiance sensor's data. The one which was left as a reference, untouched and the other one was cleaned by the self-made robot in pre-calculated orders. At the end, the results confirmed that there is an observable difference in collected irradiance.

Keywords

photovoltaic power systems, irradiance, soiling, performance ratio.

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P80

THE PREDICTION OF SHORT TIME SOLAR RADIATION BY USING ARTIFICIAL NEURAL NETWORK BASED ON GENETIC ALGORITHM

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Many applications in photovoltaic solar energy research it is very important to analyze the effect of solar radiation. The energy obtained by photovoltaic solar panels depends on the amount of daily radiation [1]. Solar radiation recorded by meteorological methods is difficult to model mathematically, therefore artificial neural networks (ANN) model is preferred in the literature [2]. Besides the amount of solar radiation is done with artificial neural networks is that these data are not linear. In this study the classical ANN model and the optimized ANN model by using genetic algorithm method have been used to model the amount of solar radiation obtained from different types of photovoltaic panels, which are mono-silicon, poly-crystalline, and amorphous silicon. By using 6 months meteorological data solar radiation is analyzed by the classical ANN model and the optimized ANN model by using genetic algorithm method for short-term in Düzce in Turkey. It is aimed to optimize weight and bias coefficients with genetic algorithm in order to correctly model ANN training step. Meteorological data obtained from January to June in 2016 were used 80% for training and 20% for testing. According to these simulation results, the classical ANN and genetic ANN model were compared with each other, and genetic ANN was determined to perform better than the classical ANN.

Keywords

solar radiation, meteorological data, artificial neural networks, genetic algorithm

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PERFORMANCE AND EFFICIENCY ANALYSIS OF THREE DIFFERENT PHOTOVOLTAIC PANELS ACCORDING TO YEARS AND METEOROLOGICAL DATA IN DUZCE

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Photovoltaic panels are important technologies for converting sunlight into electricity. Meteorological data and annual solar radiation vary depending on the region. The efficiency of photovoltaic solar panels and the electricity production capacity affect the amount of solar radiation.. In this study, we have studied the variation in performance and efficiency of different types of photovoltaic (PV) panels, which are single crystalline silicon (sc-Si), polycrystalline silicon (poly-Si) and amorphous silicon (a-Si), for years from 2015 to 2017 for Düzce region in Turkey. The data of PV panels, which were produced energy (kWh), amount of radiation (W/m²), environmental temperature (oC) and panel temperature (oC), have been recorded by data logger with the steps of 5 min for each years. Therefore these values of the panels were calculated for sc-Si (2.35 kW), poly-Si (2.64 kW), a-si (2.40 kW) silicon which were established as on-grid on the roof of Düzce University Scientific and Technological Researches Application and Research Center (DÜBIT) . It is estimated that the performance of the PV panels depends on the environmental factors such as the amount of radiation, the average temperature, and the type of panel. The performance ratios, yields of panels and climate changes at Düzce were analyzed for three different panel types and were compared to each years. The results show that performance ratios and yields of PV panels were decreased from 2015 to 2017 with the ratio of ~0.5% yearly. Additionally, sc-Si has the highest panel efficiency when compared to the other panel types independent to year.

Keywords

renewable energy, PV panel types, effect of aging, performance comparison

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RELIABILITY ASSESSMENT OF SINGLE-PHASE MODULE-INTEGRATED POWER ELECTRONICS BASED ON THE THERMAL MODELING OF PHOTOVOLTAIC MODULES

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The reliability of power electronics is important for photovoltaic (PV) systems as the cost of failure has a significant effect on return on investment (ROI). In this context, a developed thermal model [1] is used to calculate PV module temperature based on measured meteorological parameters specific to the different regions of Turkey. Solar irradiation incident on the module and the module temperature are then used to estimate the PV module output voltage using electrical model. The results are then used in the reliability model to calculate the mean time between failures (MTBF) of various candidate module integrated inverters [2],[3]. The broader impact of this proposed research is to create a methodology and tool in which users, researchers, and manufacturers can evaluate candidate PV technologies for power conversion, energy harvest, and expected reliability specific to the regions of Turkey, without requiring expensive and time-consuming test beds and long-term data logging. The methodology can be applied to other regions of the world. The figure shows the flowchart of the research process.

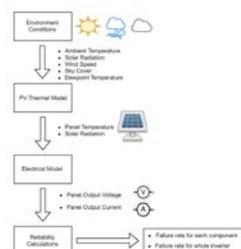


Figure 1

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SOILING IMPACT ON HCPV MODULE PERFORMANCE AND RELIABILITY

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This paper presents several new experimental results obtained from studying the effect of soiling on High Concentration Photovoltaic (HCPV) modules performance. We evaluate the electrical characteristics such as power and energy depending of the variation of dust thickness. The result indicated a 1,610 μm thick fouling layer has decreased the modules performance by 7.64 % for a period of one month. The study is also investigating the effect of module tilt angle on soiling. The results clearly show that soiling effect is present at any tilt angle, but the magnitude is evident: the flatter the solar module is placed, the more energy it will lose. The paper presents also the effect of dust layer thickness on the optical transmittance of Petri dish glass and photo-optical effects and modifications of various materials in the dust on the solar panels.

Keywords

soiling , high concentration photovoltaic , dust effect , efficiency reduction , transmittance

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STUDY AND ANALYSIS OF THE INFLUENCES OF THE UNSTEADY ENVIRONMENTAL CONDITIONS ON THE PERFORMANCE OF THE PV MODULE

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Recently, renewable energies have gained a lot of attention because they are inexhaustible, clean and can be used in a self-directed manner (since they can be used in the same place where they are produced).

The development of the power production from photovoltaic systems consists of the study of the different climate conditions influence, it consists also PV modules internal performance, which is crucial for the understanding of our system also its behavior to optimize its overall performance, operating and lifetime.

The performance of the PV modules is strongly influenced by the environmental conditions: irradiance, temperature, spectral composition of irradiance, angle of incidence of the irradiance and other parameters. This paper propose a study and analysis of the influence of the metrological conditions particularly the unsteady solar irradiation and temperature on the performance of the elaborated photovoltaic module (the power).

In this study, we firstly develop a mathematical model for the PV system based on its characteristic of current-voltage, secondly, we used this model to simulate and analyze the operation of the PV module under two cases: STC and different environmental conditions of irradiance and temperature conditions. We have further imposed a several variations in operating conditions and observed the behavior of the PV module and the variation in its performance. Which illustrates how much the variation of irradiance and temperature of the module usually affects the performance of PV module. Finally, the simulation is done using MATLAB-SIMULINK and the results is discussed.

Keywords

renewable energies, photovoltaic system, performance, climate conditions, irradiance, temperature

P85

APPROACHING NET-ZERO ENERGY BUILDING THROUGH UTILIZATION OF BUILDING-INTEGRATED PHOTOVOLTAICS FOR THREE CITIES IN TURKEY-PRELIMINARY CALCULATIONS

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Due to highly variable topography alternating between low-plains to high-mountains and changes in the proximity to the nearby seas, a wide range of climatic conditions is observed in Turkey. With these conditions, approaching the net-zero energy building target is becoming a challenge for the dynamic Turkish building sector. This research addresses the impact of the building integrated photovoltaic (BIPV) solutions [1,2] on the performance of a residential building with the area of 2247 m². Three coastal cities are chosen with respect to their solar heat gain as the lowest, highest and median. The performance values are calculated hourly using DOE software EnergyPlus. The preliminary results showed that the annual heating and cooling loads for the three locations vary between 1.44 kWh/m² - 9.12 kWh/m² and 22.2 kWh/m² - 56.9 kWh/m², respectively. Preliminary results indicate that a BIPV of 3 kW may be roughly enough to supply the heating load of 1.44 kWh/m² and, a BIPV of 17 kW may be needed for the load 9.12 kWh/m². The cooling load is much higher than the heating load for these coastal locations of Anatolia (as expected). The estimated preliminary results for a BIPV capacity to supply the heating load of 22.2 kWh/m² is roughly 42 kW while for the heating load of 56.9 kWh/m² it is around 100 kW BIPV is needed. As these are preliminary results they can be treated within margins of ± 20 kW depending on the orientation of the building facades and the type of the solar cells.

Keywords

BIPV, energy simulation, net-zero energy building

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P86

ENERGY ANALYSIS OF PHOTOVOLTAIC/THERMAL (PV/T) SYSTEM WITH DIFFERENT LIQUIDS

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Photovoltaic cells have been observed to decrease in power values when their operating temperature increase. This decrease is exacerbated by the increase in temperature and becomes harmful to the system. Solar cells can convert solar energy into electricity with an efficiency about 6% to 25%. Most of the remaining energy is converted into thermal energy, which causes increase in operating temperature of solar cells. Every 1C increase in temperature in the solar cell reduces electricity production by 0.45% depending on the technology of photovoltaic cells. While photovoltaic cell temperatures reach up to 78C in a sunny day well above the testing temperatures. In response to this situation, Photovoltaic /Thermal systems have been developed to take advantage of this heat obtained by the solar cells and also to cool them. At this point, the electricity and the hot water/air are provided at the same time. On the one hand, the reduction in yield is reduced by cooling the solar cell, on the other hand, the temperature that is affected by the system becomes available as thermal energy. Most of the PVT investigations refer to domestic applications, have water as working fluid, use crystalline silicon based photovoltaic cells. In this study energy comparisons of propylene glycol based liquid and water are presented.

Keywords

PVT, collector, energy, exchange, photovoltaic, solar, thermal

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THE FEASIBILITY OF A PHOTOVOLTAIC AND GRID HYBRID POWER PLANT TO SUPPLY ENERGY OF WATER PUMPING STATION TABRIZ-IRAN

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Energy supply to a regional grid for water pumping systems is sometimes difficult. But utilization of solar energy systems may meet energy requirements for such pumping systems. A pumping station with an area of 16290 m² is studied in this research. The station is located in Tabriz city, Iran which has an annual solar insolation of 1884 kWh/m². The energy need for the pumping station is planned to be provided by an 800 kW photovoltaic power plant which uses two-axis sun tracker method to increase the energy generation. The simulations are carried out using both PVSYST and HOMER software. The proposed PV power plant design has a performance ratio of 83.7% and the electrical losses, geographic location of the designed area are considered along with the hardware equipment and environmental profits. Simulation results demonstrated that the land and climatic conditions -as being the main factors- are strongly suggestable for the implementation and construction of aforementioned PV power plant with reduced system losses while around 20% emission reduction for SO₂, NO_x and CO₂ can be achieved.

Keywords

PV power plant, hybrid, water pump, environmental benefits



Location of Water Pump Station and PV Power Plant output

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TRANSFER OF VERTICALLY ALIGNED SILICON NANOWIRES TO TRANSPARENT-CONDUCTIVE AND FLEXIBLE SUBSTRATES FOR REALIZATION OF THIRD GENERATION SOLAR CELLS

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Nowadays, silicon (Si) is still one of the major material for opto-electronic devices including high performance photovoltaic (PV) applications. Although different geometries such as thin film and nanowire are employed for PV technologies, Si nanowires (NWs) based solar cells attract significant attention due to its high light trapping ability and efficient collection of the photogenerated carriers [1]. So far the Si NWs have been commonly fabricated on particular substrates with high cost synthesis processes, high temperature and lack of some significant properties such as flexibility and transparency [2]. Such disadvantages limits applications in their potential research area. So, heterogeneous integration of Si NWs with various substrates which have different physical, optical and electrical characteristics is very significant for low cost and flexible silicon optoelectronics and energy-conversion devices. In this work, we demonstrated that single crystalline silicon nanowires fabricated by Ag-assisted electroless etching technique are transferred from Si wafer onto alien substrates including various glasses and flexible metal foils. This method is based on cut of Si NWs embedded in polymethylmethacrylate (PMMA) on carrier substrate through vertical and lateral applied forces. Therefore, vertically-aligned Si NWs with different length and density are successfully transferred on glass, conducting thin film coated glass (fluorine doped tin oxide (FTO) and indium doped tin oxide (ITO) coated glass), copper foil and silver paste coated glass. The transfer technique enable contact formation between Si NWs and conductive substrates for photovoltaic devices. This approach offer promise to construct highly efficient core-shell solar cell applications for our future study.

Keywords

nanowire transferring method, transparent and flexible substrates, silicon nanowire based solar cells

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ELECTRONIC PROPERTIES OF INDIUM TIN OXIDE THIN FILMS PRODUCED BY RF SPUTTERING

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Physical characterizations of RF sputtered indium tin oxide (ITO) thin film are studied by atomic force microscopy (AFM), field emission electron scanning microscopy (FESEM), UV-Vis spectroscopy, and electrochemical impedance spectroscopy. From AFM measurements, surface roughness of the ITO film is determined to be ~24 nm. FESEM cross-sectional image confirms that ITO layer has nearly 80 nm thickness. Flat band voltages of the ITO thin film are calculated using Mott-Schottky approximation and the $1/C^2$ -voltage variation of the ITO layer/aqueous NaCl electrolyte system. Carrier concentration and work function of the ITO film is $\sim 10^{20} \text{ cm}^{-3}$ and 4.2 eV, respectively. Mott-Schottky approximation and general theoretical equations related with both n-type and p-type semiconductor thin films allow us to determine the relative positions of valance band, conduction band and fermi energy level. In this study, relative positions of valance band, conduction band and fermi energy level are evaluated in eV energy scale vs. vacuum level and represented in an energy band diagram. A model of equivalent electronic circuit is applied to the EIS data of the ITO/electrolyte system and electrical conductivity is explained in terms of charge transfer properties of the ITO thin film.

Keywords

ITO, Mott-Schottky, electrochemical impedance spectroscopy

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EXPERIMENTAL STUDY PERFORMANCE OF COMBINED PHOTOVOLTAIC-THERMAL AIR COLLECTOR WITH BOTTOM REFLECTOR

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This paper presents an experimental study of a combined thermal photovoltaic air collector with bottom reflector (PVTBR). This study has been done in the southern region of Algeria " Ghardaïa ". A prototype of PVTBR is a photovoltaic module with an air cooling system was placed on the rear part of the module, it is a way to increase efficiency and reduce the temperature of the PV module ,on the lower part of the hybrid collector placing a solar reflector plane, we present the results of experimental tests such the temperature of each component of the PVTBR manifold, the fluid temperature at the inlet and the outlet of the channel, the current and voltage of the hybrid collector PVTBR, we compare the results obtained with the results obtained from the photovoltaic module. According to the results obtained from the experiments showed that there is an improvement in the performance of photovoltaic module with the addition of the cooling system and the bottom

Keywords

solar energy, solar collector, hybrid photovoltaic thermal air collector, planer reflector

P91

A NEW SMART PHONE APPLICATION FOR BASIC PHOTOVOLTIC CALCULATIONS - DR. ES PV CALCULATOR

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Ease of use and accessibility are the two most important features of today’s technology. In this scope, smart phones have a twofold role; constituting the means for accessing the knowledge with the quickest way. Therefore, usage of smartphones not only for daily routines but also for research becomes inevitable in order to catch the pace and stay updated. For this purpose, a photovoltaic solar cell parameter calculation application ‘Dr. ES PV Calculator’ has been developed. The application uses Java script programming to calculate cell/module/system level parameters and properties. The functions of the app are:

- Efficiency calculation,
- Wafer area and thickness calculation,
- Resistivity and dopant concentration calculation[1],
- Antireflective index and thickness calculator[2],
- Cell power output calculator,
- Silicon nitrate color generator[3],
- Cell to module loss calculator.

Researchers and industrial people can easily utilize the tool in their daily PV related works. Therefore, the design and the functions were kept as simple as possible as shown in Figure 1.

All the listed calculations can be made through the application in English and Turkish language as chosen by the user. As the PV market grows with increasing number of employees, the app will go on developing with new functions to answer the need of quick calculations in the field.

Keywords

photovoltaic, calculator, application, smart phone

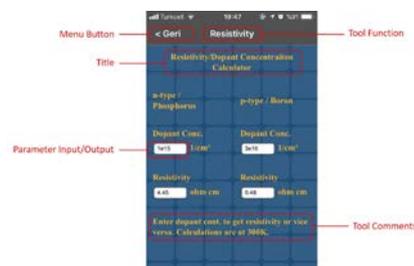


Figure 1: Illustration of the graphical user interface for resistivity/dopant concentration tool

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QUALITY CONTROL OF DIFFUSE SOLAR RADIATION COMPONENT WITH SATELLITE-BASED ESTIMATION HELIOSAT METHOD

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In order to analyze solar energy systems, it is very important to determine the accurate estimation values of solar radiation components belonging to the selected region should be known. Solar radiation components are frequently defined as the beam and diffuse solar radiation¹. Diffuse solar radiation, one of these components, is always unclear since it is mostly affected by many local geographical factors and climatic features in addition to the location parameters. This work aims to compare and evaluate the validity of diffuse estimation methods used to calculate diffuse components of solar radiation on a horizontal surface for Gebze in Turkey^{1,2}. The satellite-based estimation method HELIOSAT, Meteonom and PVGIS in the literature were used to estimate the daily values of diffuse solar radiation on a horizontal surface for the selected region. The diffuse radiation component of all selected methods was tested with ground measured data and methods were analyzed by using statistical errors. According to the data, it could be said that the satellite-based diffuse radiation values are provided by the HELIOSAT method can be used instead of the ground measured data for the selected region when the reliable ground measurements are not available. In addition, the goodness of the fit values (R^2 values equals to 0.98) for the satellite-based HELIOSAT method show very high accurate values of diffuse solar radiation on a horizontal surface.

Keywords

solar energy, diffuse radiation, satellite data

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THE UTILIZATION AND EFFICIENCY LEVEL OF PHOTOVOLTAIC SOLAR ENERGY SYSTEMS IN TURKEY

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Usage of sustainable energy resources has been considerably increasing day by day due to the decline in energy resources. One of the most important sustainable energy resources is undoubtedly photovoltaic solar energy systems. In addition to the need for widespreading of these systems, it is also very important to use these systems effectively and efficiently. Since the initial investment cost of these systems is challenging for many companies, these systems should be used as efficiently as possible. In this study, several applications have been analyzed and interviews have been conducted with various institutions using photovoltaic solar systems in Turkey in order to determine the utilization and efficiency level. In conclusion, significant increase has been observed in the implementation of solar systems in Turkey in recent years. Along with increased use, expertise in this area has also improved. In particular, new legislation and governmental incentives have made considerable contribution in terms of utilization and efficiency level. However, the statistics shows that Turkey has not benefited from solar energy at desired level although the country has a great potential.

Keywords

photovoltaic systems, solar energy , sustainable energy resources, utilization and efficiency level

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LEAD-ACID BATTERY BASED STORAGE SYSTEM PARAMETER ESTIMATION USING GENETIC ALGORITHM WITH FPGA DEVICE

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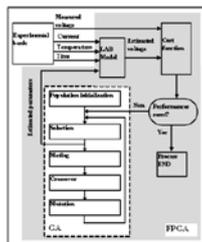
The lead-Acid Battery is largely used in storage systems for PV applications. Therefore, an appropriate mathematic model is very required for an efficient management of storage system that allowing limiting the risk of overcharges and over-discharges and improves the battery lifetime [1-5].

For this end, parameters such the state of charge, the state of health and battery electric parameters should be well known. However, the extraction of such models is a hard task because of the complicated electrical and electrochemical battery behaviors. As a result, in this paper we suggest the use of Genetic Algorithm to estimate the Lead-Acid Battery parameters. It is well known that the GA offers a powerful tool for the identification of complex systems. However the achievement of its iterative process can be expensive in time, especially when the number of estimated parameters grows, when we try to extend the population for better performances and when we use a large experimental data.

For a faster computation we will use an FPGA device to implement the proposed estimation scheme. With its massive parallel processing capabilities, the FPGA can perform several hundreds of Giga operations per second and, therefore, it can easily deal with complex algorithms such as the GA [6-8]. In addition, new FPGA devices give to user many opportunities such dedicated memories and DSP blocs. In this paper, the available memories and DFSP blocks are used to implement the GA. The resulting scheme is very fast and very accurate compared to standard genetic algorithm.

Keywords

lead-acid battery, photovoltaic systems, FPGA, genetic algorithm



The identification process of LAB model with GA using FPGA

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THE ROLE OF GRAPHENE OXIDE ON TiO₂ PERFORMANCE FOR PHOTOVOLTAIC APPLICATIONS

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Abstract

TiO₂ Graphene Oxide (TiO₂-GO) nanocomposite were prepared using the spin coating technique of suspension of Graphene Oxide (GO) nanosheets and Titanium Tetra Isopropoxide (TIP). The prepared nanocomposites samples were characterized by X-ray diffractometer, Scanning Electron Microscope and Atomic Force Microscope to examine their structures and morphologies. UV-vis transmittance and reflectance spectroscopy was employed to estimate band gap energies. From the TiO₂-GO samples, a 0.25 mm thin layer on a pieces of glass 2'2 cm was created.

The X-ray diffraction analysis revealed that the as deposited layers are amorphous in nature. The surface morphology images demonstrate that the layers grew in distributed with some spherical/rod-like and partially agglomerated TiGO on the surface of the composite. The Atomic Force Microscopy indicated that the films are smooth with slightly larger surface roughness. The analysis of optical absorption data of the layers showed that the values of band gap energy decreased from 3.46 eV to 1.40 eV, depending on the grams of GO doping. This reduction might be attributed to electron and/or hole trapping at the donor and acceptor levels in the TiO₂ band structure. Observed results have shown that the inclusion of GO in the TiO₂ matrix have exhibited a significant and excellent properties, which would be promising for application in photovoltaic application.

Acknowledgments:

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Keywords

titanium dioxide, graphene oxide, thin films, spin coating, solar cells

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FE-, NI- AND CO-INDUCED CRYSTALLIZATION OF GE THIN FILMS FABRICATED ON DIFFERENT SUBSTRATES FOR PHOTOVOLTAIC APPLICATIONS

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Metal-induced (Fe-, Ni- and Co-) crystallization of amorphous germanium (a-Ge) thin films were investigated by depositing Ge on c-Si (100) and glass substrates by means of electron beam evaporation. The samples were exposed to post-annealing temperatures of 300, 400 and 500 °C for 1 hour (h). The crystal structure of the Ge films was characterized with a Raman spectrum and X-ray diffraction (XRD) measurements. The Raman spectrum of the samples as-deposited and annealed at a temperature of 300 °C gives broad Raman band with a peak position at around 277 cm⁻¹. The broad and weak peaks observed near 277 cm⁻¹ can be assigned to the amorphous Ge-Ge TO modes. As the annealing temperature increased from 300 °C to 400 °C, the peak intensity of crystalline Ge-Ge mode increased and amorphous Ge-Ge mode decreased due to improvements in the structural order [1,2]. The XRD diffraction patterns of the as-deposited and annealed at 300 °C Ge films show a very broad peak which indicates amorphous structure of films. The samples annealed at 400 °C exhibit three diffraction peaks at 27°, 46° and 53°, corresponding to the diffraction from (111), (220), and (311) planes of the Ge films for both substrates, respectively. When the annealing temperature is increased to 500 °C, the intensity of the Ge (111) peaks increased significantly. Also, the intensity of the Ge (220) and Ge (311) orientations become gradually stronger with the increase of the annealing temperature. These findings could be very useful to realize inexpensive Ge based electronic and photovoltaic applications.

Keywords

thin film, metal-induced crystallization, structural, photovoltaic

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DEPOSITION AND CHARACTERIZATION OF CDZnTE THIN FILMS FOR SOLAR CELL APPLICATIONS

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Cadmium zinc telluride ($Cd_xZn_{1-x}Te$) can be used in many important applications, such as solar cells, photoconductors, light emitting diodes and room temperature gamma ray and X-ray detectors. CdZnTe is a promising candidate for solar cell applications due to its tunable direct band properties. Furthermore, CdZnTe is a good absorber layer thanks to its high absorption coefficient, high quantum efficiency and high atomic number.

In this study, thermal evaporation techniques have been used to fabricate CdZnTe thin films. The deposited CdZnTe thin films have been characterized and its device performance has been investigated. Optical properties is studied using UV-VIS spectrophotometer, crystallographic properties and chemical compositions are analyzed by X-ray Diffraction (XRD) and Energy Dispersive X-ray analysis (EDX). Finally, the rectification properties of ITO/CdS/CdZnTe structure have been also performed using I-V measurements and capacitance-voltage (C-V) measurements. As a result, CdZnTe thin films have shown promising performance for solar cell applications.

Keywords

CdZnTe, CZT, CdS, thin films, solar cells, thermal deposition

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LASER CRYSTALLIZATION OF SILICON THIN FILMS VIA PULSED IR LASER FOR ULTA THIN CRYSTALLINE SOLAR CELLS

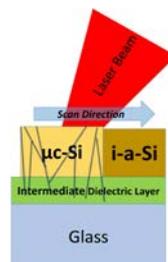
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In this work, a 1064 nm nanosecond pulsed laser was used to crystallize amorphous silicon (a-Si) films with thicknesses in order of micrometer. Laser crystallization (LC) of a-Si layers is an active interest in applied thin film research [1-4]. Great majority of studies on thin-film LC process are mainly focused on utilization of continuous wave lasers. In addition, LC process is typically conducted at elevated temperatures of substrates in order to avoid defects and attain improved crystallinity in device applications such as fabrication of solar cells. The LC process with infrared irradiation is typically sustained with optical power in kW ranges [1,2]. In solar cell related applications, thicknesses of deposited a-Si films reside in the range of tens of micrometers for achieving significant absorption and photo-conversion. In our study, the thicknesses of deposited a-Si layers were decreased down to micrometer range and the LC was performed on room temperature substrates. We were able to control crystallization process by a number of independent laser parameters, since the pulsed lasers provide freedom in adjustment of the pulse-overlap, average irradiation power and scan speed. The influence of pulse overlap, presence and choice of intermediate dielectric layer between glass substrate and a-Si film were investigated in detail. Moreover, various heterojunction solar cell device structures were designed and fabricated on p-type LC Si films by subsequent deposition of n-type a-Si. These devices are found to exhibit promising photo response. *This research is partially supported by TUBITAK (Scientific and Technical Research Council of Turkey) project number 115M061.

Keywords

laser crystallization, liquid-phase crystallization, amorphous silicon, thin film silicon



Laser Crystallization Process

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CHARACTERIZATION OF ULTRASONIC SPRAY PYROLYSED ZNO AND CDO THIN FILMS FOR PV SOLAR CELLS APPLICATIONS

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In this work, ZnO and CdO thin films, belonging to the transparent conducting oxides family and commonly used in photovoltaic solar cells and opto-electronic devices, were deposited onto microscope glass substrates by ultrasonic spray pyrolysis technique at substrate temperature of 400°C and 325°C, respectively. The deposited films were characterized for their electrical, optical, structural, morphological and elemental properties by using current-voltage (I-V) measurements, UV-Vis spectrophotometer, X-ray diffractometer (XRD), scanning electron microscope (SEM) and energy dispersive X-ray spectroscopy (EDS). Electrical measurements at room temperature and in the dark showed both ZnO films and CdO films to have low electrical resistivity values. The optical parameters of the films such as transmission, reflection, absorption and refractive index were investigated, and the optical band gaps were calculated using optical method. The XRD studies confirmed that the films are formed in the polycrystalline structure and that ZnO films have a hexagonal crystal system while CdO films have a cubic crystal system. SEM studies of films showed that all films had an almost homogeneous surface morphology. As a result, it can be said ZnO and CdO films can be used in optoelectronic industry or photovoltaic solar cells due to their suitable electrical, optical and structural properties.

Keywords

ZnO and CdO films; ultrasonic spray pyrolysis, electrical and optical properties, XRD, SEM

P100

ELECTRICAL AND MORPHOLOGICAL STUDY OF CdO:Pb THIN FILMS DEPOSITED BY ULTRASONIC SPRAY COATING TECHNIQUE

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In this work, we reported the effect of Pb doping (0-12 at %) on the some physical properties of cadmium oxide (CdO) thin films which are widely used in photovoltaic thin film solar cells. CdO:Pb thin films were deposited on the microscope glass substrates at a substrate temperature of $300\pm 5^{\circ}\text{C}$ using by ultrasonic spray pyrolysis technique. The electrical, morphological properties and elemental analyses of the films were characterized by Hall Effect measurements, scanning electron microscope (SEM), atomic force microscope (AFM) and energy dispersive x-ray spectroscopy (EDS), respectively. Hall effect parameters of the CdO thin films such as carrier mobility, carrier concentration, electrical resistivity and electrical conductivity were investigated depending on the increasing of Pb doping. SEM and AFM studies confirmed that all films had an almost homogeneous surface morphology with a fine microstructure without holes and cracks. In conclusion, based on the results obtained, it is possible to say that CdO:Pb films can be used in various optoelectronic devices, especially thin film solar cells.

Keywords

CdO:Pb thin films, ultrasonic spray pyrolysis, electrical properties, SEM, AFM, EDS

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THE EFFECTS OF ANNEALING IN AIR, ARGON AND SELENIUM ON OPTICAL PROPERTIES OF $\text{CuGa}_{0.3}\text{In}_{0.7}\text{Se}_2$ THIN FILMS GROWN BY CLOSE-SPACED VAPOR TRANSPORT

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In this work, we present results obtained by annealing $\text{CuGa}_{0.3}\text{In}_{0.7}\text{Se}_2$ (CIGS) thin films absorbers for solar cells applications in various atmospheres (air, Selenium and Argon) using photoacoustic spectroscopy technique [1-2]. Absorbers were deposited on soda-lime glass and Mo/ soda-lime glass substrates by a low cost close-spaced vapor transport (CSVT) technique at various substrate temperatures (440 °C and 500 °C) [3-4]. Solid iodine was used as the transporting agent and it is kept in the lower-temperature region. The schematic drawing of the CSVT system is shown. The zone of reaction consists of a graphite cell placed in a quartz reactor by placing a CIGS graphite source block in close proximity (1mm) to the graphite substrate block. The deposition time was 15 min for all the samples deposited. The resulting films are polycrystalline with a grain size depending on the substrate temperature and iodine pressure in the reactor. Depending on the combination of the growth parameters given above, it was possible to obtain grain sizes between 1 and 3 μm and p-type conductivity. The quality of absorbers is analyzed by XRD, SEM, energy dispersive spectroscopy and electrode probe. The changes in the defect states during the annealing processes are investigated using photoacoustic measurements at temperature. Non-radiative transitions were detected, which are associated with shallow and deep levels. Annealing in various atmospheres confirm the improvement of crystallinity of samples and strong changes in films structure.

Keywords

CIGS, thin film, photoacoustic spectroscopy, optical properties, CSVT

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STRUCTURAL PROPERTIES OF CIGS THIN FILMS GROWN BY CSVT TECHNIQUE

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Polycrystalline thin-film chalcopyrite $\text{CuGa}_x\text{In}_{1-x}\text{Se}_2$ (CIGS) is currently used as an absorber layer for high efficiency photovoltaic (PV) solar cells. The efficiency of record laboratory polycrystalline thin-film solar cells based on CIGS has reached more than 22% [1]. The aim of this work is to analyze the surface morphology, phase structure and chemical composition of the $\text{CuGa}_{0.3}\text{In}_{0.7}\text{Se}_2$ and $\text{CuGa}_{0.2}\text{In}_{0.8}\text{Se}_2$ thin films grown on glass substrate by close-spaced vapor transport low-cost technique with the deposition at short distances (CSVT) at various substrate temperatures (480 °C and 500 °C) [2-3]. The surface morphology is characterized by scanning electron microscopy (SEM) and revealed the good crystalline of layers. The cross-section with SEM was used to estimate the layers thicknesses and the quality of crystallites which are about 2 to 7 μm and confirm that the deposition was homogenous and successful. The energy dispersive spectroscopy (EDS) is performed to control the layers atomic composition, EDS measurements revealed that layers are quasi-stoichiometric, which represents one of the strong point of the CSVT technique. Structural analyses of the grown layers were performed by X-ray diffraction (XRD) and Raman spectroscopy, the layers exhibited highly crystalline chalcopyrite structure, with a preferential orientation in the (112) direction. Raman spectra showed characteristic peaks attributed to chalcopyrite structure. No other secondary phases were detected in the films.

Keywords

thin film, $\text{CuGa}_{0.3}\text{In}_{0.7}\text{Se}_2$, $\text{CuGa}_{0.2}\text{In}_{0.8}\text{Se}_2$, CSVT

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OPTICAL AND ELECTRICAL DESIGN GUIDELINES FOR ZNO NANOROD BASED CDTE SOLAR CELLS

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CdTe is a direct bandgap semiconductor with a near optimum bandgap of ~ 1.5 eV and has a high absorption coefficient near the band edge ($>10^4$ cm⁻¹) making it an excellent material for photovoltaics [1]. Coating an extremely thin absorber (ETA) CdTe layer around randomly oriented ZnO nanorods has been considered as an alternative to planar CdTe solar cell structures. ETA CdTe cells benefit from easier charge separation since charge separation occurs radially. Additionally, randomly oriented ZnO nanorods are good light scatterers, hence, incorporation of ZnO nanorods reduces the need for thick layers of CdTe to a few tens of nanometers. However, the reported efficiencies of ZnO nanorod based CdTe solar cells are much lower than their planar counterparts [2, 3]. A thorough understanding of optical and electrical mechanisms in ETA CdTe solar cells are necessary to overcome low efficiencies.

In this work, we systematically investigated the effect of random geometrical orientations of ZnO nanorods on the optical and electrical performance of the ETA CdTe solar cells through simulations. Finite-difference time-domain simulations (Lumerical FDTD) were made to understand the light trapping effects of ZnO nanorods and enhancement in optical performance. The charge collection efficiency and short circuit current density were simulated with Silvaco ATLAS. The simulation results revealed that averagely tall nanorods ($\sim 1\mu\text{m}$) with moderate rod densities (~ 20 rods/ μm^2) make efficient structures both optically and electrically. With 10^{17} cm⁻³ doping density, the resultant short circuit current density is higher than that of a planar CdTe cell with the same CdTe amount.

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THE INFLUENCE OF ANNEALING TEMPERATURE ON CU₂ZN₂GES₄ THIN FILMS

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Cu₂ZnSnS₄ (CZTS) thin films are one of the members of quaternary chalcogenide semiconductor family, and have attracted much attention as the most potential substitute of CIGS thin films. It has been chosen because of suitable optical band gap and high absorption coefficient. The highest power conversion efficiency for CZTS based solar cell was reported as 12.6% [1]. Therefore other alternative members of quaternary chalcogenide semiconductors should be studied [2,3].

In this study we obtained Cu₂ZnGeS₄ (CZGS) thin films by spin coating of copper, zinc and germanium salt solutions. 10 layers of thin film were obtained and then annealed in H₂S:Ar (1:9) atmosphere. The influence of annealing condition on the optical, structural and morphological properties of these thin films were studied using UV-vis data, X-ray diffraction (XRD), Raman spectroscopy and scanning electron microscopy (SEM).

Keywords

Cu₂ZnGeS₄, thin film, absorber, annealing effect

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SPIN COATED Cu_2MSnS_4 (M=Zn, Ni, Co) THIN FILM ABSORBERS

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$\text{Cu}_2\text{ZnSnS}_4$ (CZTS) based solar cells have attracted extensive attention in recent years because of low cost and nontoxic behavior. The optimal band gap (1.5 eV) and very high absorption coefficient ($>10^4 \text{ cm}^{-1}$) have made CZTS a potential alternate candidate for thin film solar cells. The highest power conversion efficiency of solar cells using CZTS absorber layer was reported as 12.6% using the spin coating technique.

Various methods have been used for the deposition of CZTS thin films including sputtering, thermal evaporation and sol-gel methods. Among all other methods, spin coating technique is currently the predominant technique employed to produce uniform thin films with the thickness of the order of micrometers and nanometers

Beside CZTS, further study of other $\text{Cu}_2\text{BIIICIVX}_4$ compounds may help to achieve a breakthrough in this field. For this purpose, various metals have been replaced in CZTS structure to obtain high efficient solar cells.

In this study, Cu_2MSnS_4 (M=Zn, Ni, Co) thin films were deposited onto soda lime glasses by the spin coating technique. The thin films annealed at 550 °C in $\text{H}_2\text{S}:\text{Ar}$ (1:9) atmosphere. The optical, structural and morphological properties of Cu_2MSnS_4 thin films were analyzed by UV-vis data, X-ray diffraction (XRD), Raman spectroscopy and scanning electron microscopy (SEM).

Keywords

thin film, absorber, CZTS, optical properties

P106

REACTIVELY CO-SPUTTERED $\text{Cu}_2\text{ZnTi}(\text{S:Se})_4$ ABSORBERS FOR THIN FILM SOLAR CELLS

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The demand for energy increases every year all over the world. Because of the limitation of fossil fuel and a considerable amount of CO_2 emission, the interest on alternative energies increases. Solar cells are one of the pollution-free power sources that convert sunlight into electricity.

The thin film solar cells are an exciting topic for low cost and high efficient solar cells. Copper indium gallium diselenide (CIGS) solar cells can be fabricated on various substrates including soda lime glass, stainless steel, and plastics. CIGS has an importance place in the solar market. But the price of Indium metal effects negatively the fabrication cost. Therefore, $\text{Cu}_2\text{ZnSn}(\text{S:Se})_4$ thin films are used in new studies to reduce the cost and increase the efficiency.

In this study, to decrease the fabrication cost and increase the optical absorption of CZTS thin films we successfully used Ti instead of Sn and formed $\text{Cu}_2\text{ZnTi}(\text{S:Se})_4$ thin films. During the sputtering process, the H_2S gas balanced with Ar was used as reactive gas and ZnSe, Cu and Ti targets were used as metals sources. Various H_2S gas flows and substrate temperatures were examined. The films were annealed in a quartz furnace during H_2S gas flows. The optical, structural, morphological and electrical properties of the films were analyzed using UV-vis data, X-ray diffraction (XRD), Raman spectroscopy, scanning electron microscopy (SEM) and Hall effect measurements.

Finally, $\text{Mo}/\text{Cu}_2\text{ZnTi}(\text{S:Se})_4/\text{CdS}/\text{ZnO}/\text{AZO}$ solar cells fabricated and photovoltaic properties of the cells were determined.

Acknowledgment: This study is supported by TÜBİTAK with 114F363 grand number

Keywords

thin film, solar cell, $\text{Cu}_2\text{ZnTi}(\text{S:Se})_4$

P107

FORMATION AND CHARACTERIZATION OF CU₂ZN(SI_XSN_{1-X})S₄ THIN FILMS BY SOL-GEL AND SULFURIZATION METHOD

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The interest on the series of Cu₂-II-IV-VI₄ quaternary chalcogenide semiconductors have increased because of their potential applications in various fields including solar cells, photocatalytic water splitting and pollutant degradation. Cu₂ZnSnS₄ (CZTS) has been used as an absorber layer in the fabrication of thin film solar cells. It has been chosen owing to suitable band gap and high absorption coefficient. The best efficiency for a CZTS based solar cell has been reported as 12.6%. Similar quaternary semiconductors or doping of the CZTS structure have been studied to control physical properties of CZTS films.

In this study, the influence of the substitution of Si atoms instead of Sn atoms on structural, morphological and optical properties of Cu₂ZnSnS₄ thin films has been examined. For this purpose, Cu₂Zn(Si_xSn_{1-x})S₄ thin films with x= 0, 0.25, 0.5, 0.75 and 1% values have been deposited on soda lime glass using spin coating technique at 250 °C temperature. After formation of thin films on glass, the films were annealed in furnace at 30 ccm for 15 and 30 min and 40 ccm for 15 and 30 min in the H₂S environment at 550 °C, respectively. The structural, morphological and optical properties of Cu₂Zn(Si_xSn_{1-x})S₄ thin films were analyzed using X-ray diffraction (XRD), Raman spectroscopy, Scanning Electron Microscopy (SEM) and UV-VIS-NIR data. It was seen that the optical band gap of Cu₂Zn(Si_xSn_{1-x})S₄ thin films increased with the increase of Si ratio in the structure.

Keywords

CZTS, thin film, Si content, annealing

P108

ELECTRICAL AND OPTICAL CHARACTERIZATION OF ZNSE THIN FILMS ON SI DEPOSITED BY PHYSICAL VAPOR DEPOSITION**Hasan Huseyin Gullu^{1,5}, Dilber Esra Yildiz², Ozge Bayrakli^{3,5}, Makbule Terlemezoglu^{4,5,6}, Mehmet Parlak^{4,5}**¹*Department of Electrical and Electronics Engineering, Atilim University*²*Department of Physics, Hitit University*³*Department of Physics, Ahi Evran University*⁴*Department of Physics, Middle East Technical University*⁵*Center for Solar Energy Research And Applications (GUNAM), Middle East Technical University (METU), Ankara, Turkey*⁶*Department of Physics, Namik Kemal University*

Zinc-selenide (ZnSe) is a semiconductor compound composed of II-VI group of elements. It is an intrinsic semiconductor showing a large potential use in thin film devices, especially Schottky barrier diodes, photodetectors and as an n type window layer for thin film heterojunction solar cells. With wide-bandgap characteristics, it has a promising spectral response in the applications of UV-Vis region. In photovoltaic case, ZnSe is an attractive material with allowing transmission of higher energy photons and having a better lattice match with Cu-based chalcopyrite and kesterite thin films absorbers. In addition to these advantages over traditionally used CdS buffer layer, it is Cd free and environmentally friendly; earth-abundant due to Zn and low-cost material in use of device applications. In this work, In/ZnSe/Si/Al heterostructure was fabricated and electrical properties of this device structure were characterized with current-voltage (I-V), capacitance-voltage (C-V) and conductance-voltage (G/w-V) measurements. The forward bias, dark I-V behavior was used to determine the diode parameters and dominant current conduction mechanism, frequency dependence admittance measurements were studied to determine the dielectric parameters, and illuminated I-V measurements under different illumination conditions were performed to evaluate physical mechanism responsible for electrical conduction and optical response of the device proportional to the incident power.

Keywords

thin film, heterojunction

P109

DETERMINATION OF THE DARK AND ILLUMINATED CHARACTERISTIC PARAMETERS OF CU-ZN-SE/SI DIODE STRUCTURE

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Depending on the existence of the constituting elements and their toxic characteristics, the search for suitable band gap materials alternative to the Cu-based chalcogenides and other compound materials for photovoltaic applications have been point of interest to reach the best replacement for the next generation of thin film solar cells. Based on the availability of Cu, Zn, Sn, S and Se, the replacements from Ga/In to Zn/Sn alternatives, can provide low-cost and low-toxic thin film solar cells in the optoelectronic industry. As in the case of well-known chalcopyrite thin film structures, the works have been started to reach a novel compound of the chalcopyrite type by replacing In with Zn. With these initial attempts with Cu doping to the ZnSe structure and therefore fabrication of Cu-Zn-Se (CZSe) ternary alloy have become point of interest as a promising material enabling cost-effective devices. In this work, polycrystalline CZSe film layer in smooth and densely packed morphology was deposited on Si substrate and electrical characteristics of the heterostructure were investigated under dark and illuminated conditions. As a material behavior, being 50% transparent in the visible region, indicates a reasonably good light absorbing behavior for the film layer and tetragonal crystalline structure confirmed to be beneficial for efficient solar energy conversion. Under dark condition, by the help of temperature-dependent current-voltage measurements, main diode parameters were extracted and dominant current transport mechanisms in the diode structure were modeled. Photo-response behavior of the diode was evaluated and photovoltaic characteristics were investigated under different incident illumination intensities.

Keywords

thin film, heterojunction

P110

JUNCTION PROPERTIES OF CU-AU/ZNO/SI SCHOTTKY DIODE UNDER DIFFERENT ILLUMINATION INTENSITIES

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In recent years, transparent conductive oxides (TCOs) have gained attentions among electronic applications mainly in use of photovoltaic, light emitting diodes, and transparent transistors. Among the common TCO film layers, ZnO have become a promising alternative in the case of cost effectiveness and environmental friendliness. It is an ionic wide band gap semiconductor in the family II-VI oxides. Having a direct band gap of about 3.4 eV with a high transparency at visible light and high mobility of conducting electrons provides to be one of the materials dominating TCO technology. In this work, the electrical properties of the Au-Cu/ZnO diode were investigated with the temperature dependent current-voltage and also frequency dependent capacitance-voltage measurements. Assuming thermionic emission model, diode parameters were determined and the strong temperature dependence of these values were modeled by this model modified by Gaussian distribution of the barrier height. The distribution profile of the interface states and series resistance value were evaluated by the capacitance and conductance characteristics. Additionally, opto-electrical response of the device was investigated under different illumination intensities.

Keywords

thin film, heterojunction

P111

DARK AND PHOTO CURRENT MECHANISMS IN CUO/SI HETEROSTRUCTURE

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In recent years, CuO has attracted considerable interests due to its suitable material properties, cost-effective fabrication and constituent materials, non-toxicity and advantageous properties in applications for electronic devices. Among wide range of device applications as a transparent oxide layer, CuO has gained special attention as one of the most promising semiconductor candidates for high performance solar cells. In photovoltaic area, it has been used as a p-type oxide based thin film to fabricate p-n junction. In this work, CuO film layer was deposited on glass and n-Si substrates by direct current sputtering, and after deposition, to obtain crystalline structure, post-annealing was applied. Material properties were investigated by structural, optical and electrical measurements on samples grown onto glass substrate, and diode characteristics of p-CuO/n-Si structure was evaluated under dark and illuminated conditions.

Keywords

thin film, heterostructure

P112

PHOTO-ELECTRONIC PROPERTIES OF MO-O THIN FILMS**Hasan Huseyin Gullu^{1,2}, Ozge Bayrakli^{2,3}, Makbule Terlemezoglu^{2,4,5}, Mehmet Parlak^{2,4}**¹*Department Of Electrical And Electronics Engineering, Atilim University*²*Center for Solar Energy Research And Applications (GUNAM), Middle East Technical University (METU), Ankara, Turkey*³*Department Of Physics, Ahi Evran University*⁴*Department Of Physics, Middle East Technical University*⁵*Department Of Physics, Namik Kemal University*

In this study, physical behavior of electrical current flow in MoO thin film structure under illumination was discussed by considering the nature of the transport of carriers. In order to fabricate MoO thin films, DC-magnetron sputtering technique was used and then post-thermal annealing treatments were applied in order to discuss the possible change in electrical properties of the films on the basis of the change in their structural and physical behaviors. The general behavior of the conductivity and the existent current transport mechanisms were detailed by performing temperature dependent current-voltage measurements under dark and illuminated conditions. These measurements were carried out according to van der Pauw method. The characteristic dependence of current on temperature was investigated by current-voltage measurements under dark condition. Additionally, the variation of the photoconductivity with the input light intensity was discussed by applying five different illuminations in visible spectrum. For all samples, the photoconductivity values were found to be greater than the dark conductivity values with the contribution of the photo-carriers to the conduction. Absorption processes was found to be proportional to the density and energy of absorbing centers involving imperfections in the structure. These imperfections were characterized as a recombination or trapping process of the carriers' recombination center and characteristics activation energies for detrapping were calculated. The obtained power of relation in between photo-current and photoexcitation intensity was explained by the supralinear characteristic which can be explained by the two-center recombination model having two trap levels dominant at both low and high temperature regions.

P113

ENHANCED PHOTOVOLTAIC DEVICE PERFORMANCE OF ZNSE/SI HETEROSTRUCTURES BY HIGH-DENSITY VERTICAL NANOWIRES

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Nanostructured solar cells have shown rising attention on optoelectronic devices and solar cell technologies over the few last decades due to their fascinating properties for solar energy harvesting. Silicon is still the leading material in photovoltaic industry and silicon nanowire structures have become point of interest as a promising material, not only for compatibility with present electronic and photovoltaic technologies, but also for the researches on the fundamental science. In this study, material and device characteristics of ZnSe thin film/silicon nanowire heterojunction diodes were investigated and an enhancement in the device application of the nanowire structure on Si surface with comparing to planar surface was obtained. A simple and cost-effective metal-assisted etching method was applied to fabricate vertically oriented Si nanowires on p-type single crystalline Si wafer. Following the nanostructure synthesis by chemical etching process, ZnSe thin film was deposited on these etched and also planar Si substrates by thermal evaporation of elemental sources. The ideality factor and series resistance values of the ZnSe/Si-nanowire and ZnSe/Si heterojunctions were calculated as 3.12, 461 Ω , and 4.52, 7.26 \times 103 Ω , respectively. As a result, the fabricated nanowire based heterojunction devices exhibit remarkable diode characteristics, enhanced optoelectronic properties and photosensitivity in comparison to the planar reference device.

Keywords

thin film, heterostructure, nanowire

P114

ELECTRICAL PROPERTIES OF CRYSTALLIZED AMORPHOUS SILICON THIN FILMS**Adnan Shariah¹**¹*Physics Dept Jordan University of Science and Technology, Jordan*

The effect of thermal annealing on the electrical and structural properties of aluminum induced crystallized hydrogenated amorphous silicon (a-Si:H) thin films prepared by PECVD and sputtering techniques was studied. The resistivity of the a-Si:H has ranged between 0.06 to 0.16 $\Omega\cdot\text{cm}$. The resistivity of the sputtered a-Si on glass substrates samples has ranged between 0.07 to 0.54 $\Omega\cdot\text{cm}$. Only one of the tested samples that sputtered a-Si on c-Si substrates was crystallized at 350°C for 135 minutes and its resistivity was calculated to be 0.23 $\Omega\cdot\text{cm}$. The carrier's concentration has ranged between $9\times 10^{+15}$ to $1.5\times 10^{+17}$ cm^{-3} for the a-Si:H samples. The carrier's concentration has ranged from $1\times 10^{+16}$ to $8\times 10^{+16}$ for the sputtered a-Si samples on glass substrates. The carrier's concentration for the sputtered a-Si sample on c-Si substrate was about $8\times 10^{+16}$ cm^{-3} . The Hall mobility was calculated, and it was found to be ranging from 319 to 7040 $\text{cm}^2\text{V}^{-1}\text{s}^{-1}$ for the a-Si:H samples, and from 660 to 1750 $\text{cm}^2\text{V}^{-1}\text{s}^{-1}$ for the sputtered a-Si samples on glass substrates. For the sputtered a-Si on c-Si substrates the Hall mobility was calculated to be about $335\text{cm}^2\text{V}^{-1}\text{s}^{-1}$.

Keywords

thin film solar cells, amorphous silicon, crystallization of thin films, electrical properties

P115

THIN FILM SOLAR CELLS BASED ON 3D NANOPILLAR ARCHITECTURE

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The 3D architecture based on nanopillars brought a new valence to the PV solar cells by integrating the geometric factor into the cell design. Also, planar area and mass per area are crucial to determine back reflection. For planar cells, reflection bounces much of the light out of the PV cell before it has a chance to be absorbed and generate electricity. However, back reflection can benefit the planar cell by bouncing the light off of the back of the cell to give the cell two opportunities to absorb photons from the same stream of light. Using a 3D architecture of the cell, the power generated during the day is increased by the fact that the light is reflected in the interior several times and finally absorbed. Nanopillars could be obtained by different methods. Using template synthesis, nanopillars arrays were synthesized in a flexible PCTE membrane. Although any membrane could theoretically be used, a membrane with transversal pores was used to electrochemically deposit a metal inside the pores. The metallic nanopillar array was then used as a base for the deposition of thin films to construct the cell, after the template was removed. Although the CdTe/CdS system was studied, a p-n silicon thin film system can be also used. Electrochemistry is a versatile and inexpensive technique to conformally deposit thin layers. This 3D architecture was proved to reduce considerably the reflection of the light by the cell through trapping the light inside the cell.

Keywords

3D solar cell, nanopillar array, thin films, electrochemical deposition, template synthesis.

P116

ACHIEVING AN IMPRESSIVE HIGH REFLECTANCE HAZE IN CHEMICALLY TEXTURED AL:ZNO BACK REFLECTORS FOR LIGHT MANAGEMENT IN THIN FILM SOLAR CELLS

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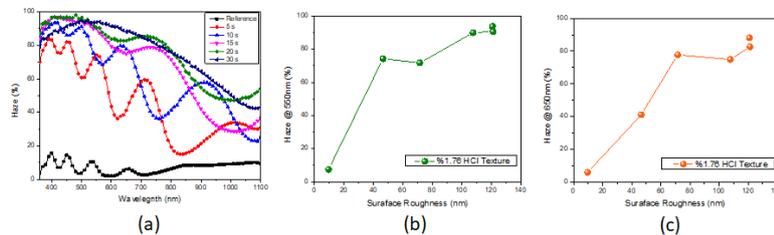
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Enhancement of light absorption in thin film solar cells is achieved by several light management routes. Surface texturing is one of the most common techniques utilized in light management. Transparent conductive oxide (TCO) layer and/or the substrate itself can be textured in order to modulate light scattering and thus enhance optical path length of the incoming light in the absorber layer. Back reflector texturing is used when the solar cell is deposited in substrate configuration to enhance multiple angle back scattering.

Here in this study back reflector texturing is studied for solar cells deposited in substrate configuration. As a back reflector, 600 nm Al:ZnO is deposited on 100 nm silver on ultra-thin flexible glass substrates. Samples were textured in dilute %1.76 HCl solution for 5, 10, 15, 20 and 30 seconds. Optical total and diffuse reflectance were measured by using an integrated sphere while surface morphology and texture features were analyzed by AFM and SEM. Figure:1a shows that at 500 nm more than 95% of reflectance haze can be obtained from the samples textured for more than 15 seconds. Texturing for 15 and 20 seconds resulted in a broad increase in the reflectance haze in the visible and red portion of the spectrum which is desirable for a-Si:H thin film solar cells. The calculated high reflectance haze values of textured surfaces at 550 and 650 nm is correlated to the vast increase in surface roughness with increasing the texturing duration as shown in Figure:1 b and c.

Keywords

light trapping, thin film solar cells, TCO, texturing, Al:ZnO



a) Reflectance haze vs wavelength, effect of surface roughness on haze at b) 550 nm b) 650 nm

P117

THE TEMPERATURE EFFECT ON THE ELECTRICAL PARAMETERS OF CIGS THIN FILMS GROWN BY CSVT

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CuIn_{0.7}Ga_{0.3}Se₂ (CIGS) thin films are deposited on both glass (SLG) substrate, by close-spaced vapor transport technique (CSVt) [1]. Pure copper (Cu) contacts are deposited on the front side of SLG/CIGS thin films by physical vapor deposition (PVD). Hall Effect measurements [2], on these samples, named CIGS1 and CIGS2 and grown at substrate temperature (T_s) of 470 °C and 510 °C, respectively, are performed in the temperature range (300 K - 438 K), in order to investigate the temperature effect on the electrical parameters such as carrier concentration (p), conductivity (σ) and mobility (μ). The bandgap energy (E_g) of about 1.38eV and 1.24 eV are extracted from Arrhenius diagram of (p) and (σ), respectively. Activation energies (E_a) at 563.9 meV and 239.4 meV for CIGS1 thin film and 584.2 meV and 72.7 meV for CIGS2 thin film are also determined. Moreover, average mobilities of 1.83 cm²/Vs and 1.77 cm²/Vs are deduced for CIGS1 and CIGS2 thin films, respectively.

Keywords

CIGS, thin films, CSVt, hall effect

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P118

BORON AND PHOSPHORUS DOPED POLYCRYSTALLINE SILICON THIN FILMS FABRICATED BY ALUMINIUM INDUCED CRYSTALLIZATION AND SOLID PHASE EPITAXIAL THICKENING TECHNIQUES

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High-quality, large-grained polycrystalline silicon (poly-Si) thin films can be fabricated by aluminium induced crystallization (AIC) technique on glass substrate. Thanks to Al, the p⁺-type AIC thin films are fabricated. However, recombination of carriers can be controlled by partial doping through the defects. Phosphorus and boron doping of AIC seed layers may have advantages to improve the film quality by the overdoping induced passivation. On the other hand, for optical confinement, AIC seed layers with thickness of ~200nm need to thicken to ~2µm. In this study, doped AIC thin films were thickened by solid phase epitaxy (SPE) technique at 800°C for 3 hours under N₂ flow in a tube furnace. Optical microscope and electron back scattering (EBSD) diffraction technique used to analyse the structural quality of the films depicted that continuous poly-Si layer with the average grain size value of ~12µm and <100> preferred orientation was formed by AIC+SPE technique. Moreover, the crystallinity of the doped AIC+SPE poly-Si films were studied by the micro-Raman Spectroscopy. The results showed that the crystallinity of AIC+SPE films reach up to 98.55%. The doping efficiency was determined by secondary ion mass spectroscopy (SIMS) for doped AIC+SPE samples. A graded doping profile was obtained by out-diffusion of phosphorus from the overdoped seed layer during the SPE crystallization annealing while boron doping of SPE film has failed with exo-diffusion of boron from AIC seed layer into SPE film. Finally, high-quality n⁺n type poly-Si films were fabricated on glass substrate by using AIC+SPE technique.

Keywords

polycrystalline silicon, aluminium induced crystallization, solid phase epitaxy, glass substrate

P119

A STUDY ABOUT INVESTIGATION THE QUALITY OF DIFFERENT FABRICATION PARAMETERS USED POLY-SI THIN FILMS FORMED BY SOLID PHASE CRYSTALLIZATION

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Low-temperature polycrystalline silicon (poly-Si) thin films are the promising technology for high performance thin film solar cells. Solid phase crystallization (SPC) is a useful technique to realize poly-Si films due to its simplicity and low-cost production. Grain boundaries that have numerous dangling bonds and stained bonds reduce the carrier mobility. To minimize grain boundaries effect, it is necessary to enlarge the size of each grain. Therefore, in this study, the effects of some fabrication parameters, such as crystallization temperature and crucible material used during amorphous silicon (a-Si) deposition, were investigated to enlarge the grain size, i.e. crystallite size, and improve the crystallization. The crystallization of films was carried out using classical tube furnace at 600°C for 8-26 hours. X-ray-diffraction and Raman spectroscopy measurements were carried out in order to control the crystallite size and the crystallinity of the films, respectively. The results show that crystallization duration has a great effect on the quality of film. The crystallinity increases from 10% to 95% by increasing the crystallization annealing duration while the preferential orientation of SPC poly-Si films is $\langle 111 \rangle$ independent of annealing durations. On the other hand, the crystallite size of the films increases from 29.6nm to 36.3nm by the effect of increasing in annealing duration. In addition to these analyses, in this work, the effects of crucible on the crystal quality of SPC poly-Si films were also investigated. The results show that using molybdenum (Mo) crucible instead of graphite gives rise to higher quality poly-Si films formed by SPC technique.

Keywords

thin film, polycrystalline silicon, solid phase crystallization, fabrication parameters

P120

INVESTIGATION OF FULL DEVICE ANNEALING EFFECT ON THE CONVERSION EFFICIENCY OF MAGNETRON SPUTTERED CU₂ZNSNS₄ THIN FILM SOLAR CELLS

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Cu₂ZnSnS₄ (CZTS) as an absorber layer for thin film solar cells is a promising candidate due to its not only low cost but also nontoxic properties contrary to CdTe and Cu(In,Ge)Se₂. CZTS has a direct bandgap of 1.4-1.6 eV and large optical absorption coefficient (10⁴ cm⁻¹). Therefore, it is an ideal absorber layer for photovoltaic devices [1]. Beside these good advantages, components of CZTS are earth abundant and less toxic when compared to those of Cu(In,Ge)Se₂ [2]. In this study, CZTS thin films have been deposited on molybdenum coated soda lime glass following two different processes. Firstly, CZT metallic precursor was deposited using DC magnetron sputtering technique, which is allowed to control thickness of the grown film [3,4]. After deposition of CZT metallic precursor, it was annealed under Ar gas and sulfur vapour atmosphere at 550 °C for 45 min. As a result of these processes, CZTS absorber layer was grown. CdS is an n-type semiconductor which was used as a buffer layer in this work. CdS buffer deposited on CZTS using chemical bath deposition method at 85°C for 45 min. Finally, SLG/Mo/CZTS/CdS/ZnO/AZO solar cell was fabricated. Full device was annealed at 300°C, 400°C and 500°C for 15 minutes. Structural and morphological characterizations of CZTS absorber was done using Raman Spectroscopy, XRD, SEM and EDX analyses. The effect of full device annealing on efficiency of solar cell was investigated using electrical characteristic of solar cell device.

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Keywords

CZTS, magnetron sputtering, CdS, thin film solar cells

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ELECTRICAL PROPERTIES OF KESTERITE ABSORBER LAYER FOR THIN FILM SOLAR CELLS

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Cu₂ZnSnS₄ (CZTS) is a p-type semiconductor compound that is stable having kesterite structure. CZTS has a large absorption coefficient of 10⁴ cm⁻¹ in the visible range of spectrum and high bandgap energy around 1.5 eV [1,2]. Since CZTS contains low cost, non-toxic and earth abundant elements contrary to other chalcopyrite based solar cells such as CuIn_xGa_{1-x}(S,Se)₂ and CdTe, it attracts intense attention in photovoltaic industry. According to Shockley-Queisser theoretical calculations, the conversion efficiency from CZTS solar cells is expected to be about 32% [3]. Despite the fact that CZTS studies have been recently started, 12.6% efficiency was already achieved [4]. This means that more research is needed improve this newly studied material's efficiency. In this work, CZTS thin films were grown on soda lime glass substrates by means of sulfurization of the grown metallic precursors, which were sputtered in the multi-target sputtering system [5,6]. We investigated structural, morphological, electrical, and optical properties of CZTS thin films. Crystallinity and grain formation of the films were determined by scanning electron microscopy. X-ray diffraction and Raman spectroscopy measurements revealed the formation of kesterite structure. Moreover, we focused mostly on temperature dependence of resistivity and Hall coefficient for CZTS samples. Electrical properties were measured by using Van der Pauw technique. CZTS films demonstrated p-type semiconducting material behaviour and the resistivity of the films were measured nearly 0.6 Ω.cm at room temperature.

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Keywords

thin film solar cells, CZTS, sputtering, electrical characterization

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P122

PREPARATION AND CHARACTERISATION OF SPRAYED Fe_2O_3 THIN FILMS TOWARDS FABRICATION OF LOW COST SOLAR CELLS

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Iron oxide (Fe_2O_3) thin films were deposited on ordinary glass substrate by varying substrate temperature (T_{subst}) from 300 to 450°C using chemical spray pyrolysis technique. The effect of T_{subst} on the structural and optical properties of Fe_2O_3 layers was investigated. Samples were characterized using X-ray diffraction and spectrophotometer. The X-ray spectra reveal the formation of α - Fe_2O_3 rhomboedric phase with highly (104) preferential orientation. The best crystallinity is obtained for $T_{\text{subst}}=400^\circ\text{C}$ since the maximum (104) peak intensity and grain size are obtained at this substrate temperature. Optical analysis by means of transmission $T(\lambda)$ and reflection $R(\lambda)$ measurements allow us to know that α - Fe_2O_3 thin films displayed a band gap from 2.07 to 2.16 eV for direct transition and from 1.63 to 2.02 eV for indirect transition. However, it was found that the sprayed α - Fe_2O_3 thin films at 400°C substrate temperature have an excellent characteristic which shows its applicability as a buffer layer in photovoltaic devices such as $\text{CuO}/\alpha\text{-Fe}_2\text{O}_3/\text{ZnO}$. This solar cell has a photovoltaic effect. That the open circuit voltage (V_{oc}) and short circuit current density (J_{sc}) are equal to 0.5 V and 0.43 mA/cm² respectively.

Keywords

chemical spray pyrolysis, substrate temperature, iron oxide, structural and optical properties

P123

CHARACTERIZATION OF ELECTRON-BEAM EVAPORATED CU₂ZNSNS₄ THIN FILMS USING SINGLE CRYSTALLINE POWDER

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In this study, Cu₂ZnSnS₄ (CZTS) thin films, ideal absorber layers for photovoltaic applications, were successfully deposited onto both SLG and Si substrates by e-beam technique. CZTS powder was obtained from CZTS single crystal grown by Bridgman technique. The elemental compositions of the grown crystal were determined through energy dispersive X-ray analysis measurements, which revealed a nearly stoichiometric composition. The (101), (112), (220), (312) and (332) reflection planes were identified using X-Ray diffractometer. The powder was extracted from the grown ingot and evaporated by using e-beam technique. Structural, electrical, optical and morphological properties of the deposited CZTS films were studied and discussed in detail. In order to reveal the annealing effect on properties of CZTS thin films, they were annealed in the temperature range of 200 °C to 400 °C for 30 min. Structural analysis has revealed that the as-grown and 200 °C annealed CZTS films have an amorphous matrix and transform into a polycrystalline form with a kesterite phase having (112) oriented plane direction following the post-annealing process. Surface morphologies of the 200 nm thick CZTS thin films were studied by SEM and AFM measurements. The optical transmittance measurements for both as-grown and annealed CZTS thin films were conducted in the wavelength range of 300-1000 nm. The band gap for 300 °C annealed CZTS film was calculated to be 1.48 eV. Finally, the conducted photo-electrical measurements revealed that CZTS thin films have good sensitivity to the visible light, which is essential for an absorber layer in the solar cell device structure.

Keywords

Cu₂ZnSnS₄, Bridgman, e-beam, absorber

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FABRICATION AND CHARECTERIZATION OF BULK AND THIN FILM FLEXIBLE GAAS SOLAR CELLS GROWN BY MOLECULAR BEAM EPITAXY

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GaAs based III-V solar cells are one of state of the art technology in photovoltaic area with holding numerous efficiency records. Despite its superiority in terms of conversion efficiency III-V cells can be meaningful only in concentrated photovoltaic (CPV) applications in terrestrial use due to high manufacturing cost. Recently, epitaxial lift-off (ELO) process has been standing a most viable method to reduce III-V material cost for large scale applications of these semiconductors, especially for the large area thin film solar cell applications of GaAs which requires huge amount of material consumption in its bulk based technologies.

Epitaxial lift-off (ELO) is used to create thin-film III-V electronic and optoelectronic devices especially large area solar cells without the GaAs wafer [1-3]. The wafer can be reused for subsequent deposition runs thereby reducing the cost of the devices. The thin-film cell can be transferred to any new carrier, e.g. glass, plastic, silicon, or metal foil [4,5].

In this presented study bulk and thin film flexible GaAs based solar cell structures has been designed and simulated. Cell structures with efficiencies of 29.30% and 27.23% have been optimized for bulk and thin film based single junction GaAs cells respectively. Theoretically optimized cell structures have been grown on GaAs substrates by using molecular beam epitaxy (MBE) technique. Thin film active GaAs cell structures have been lifted off from GaAs substrate with lift off speed of about 20 mm/h and transferred on to the flexible plastic carrier.

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Keywords

epitaxial lift off, GaAs thin film, flexible solar cell

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P125

FORMATION AND CHARACTERIZATION OF TWO VOLTAGE REPEATING CHRONOAMPEROMETRY ELECTRODEPOSITED CZTS THIN FILMS

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The $\text{Cu}_2\text{ZnSnS}_4$ (CZTS) thin films have been deposited on ITO (Indium Tin Oxide glass) substrates at room temperature by two different voltage repeating chronoamperometry electrodeposition method. The morphological characteristics with SEM, compositional characteristics with EDX, optical characteristics with UV-vis spectrometer and capacitance-voltage characteristics with Mott-Schottky have been explored. The compositions reveal that the CZTS thin films prepared using the -4V (0,25s), 0V(2,25s) nearly stoichiometric. It is found that the complexing agent tri-sodium citrate affects the quality of CZTS thin films.

Keywords

CZTS, electrodeposition, repeating chronoamperometry, complexing agent

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ALUMINUM INDUCED LASER CRYSTALLIZATION OF THIN AMORPHOUS SILICON

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The thin polycrystalline Silicon (poly-Si) solar cells are one of the promising candidates for relatively cost effective and high efficiency solar cells. In this work, the novel crystallization method will be introduced where aluminum doped poly-Si thin films were fabricated by aluminum induced laser crystallization (AIRC) technique. Amorphous silicon (a-Si) was deposited on glass substrates with different thicknesses of aluminum coatings. Pulsed laser had used to crystallize the a-Si layer. We declare that it is possible to combine two processes of laser induced crystallization [1] and aluminum induced crystallization [2] processes, simultaneously. Crystallization of the a-Si with laser pulses had took place at the interface of the aluminum-silicon layers by the aid of similarity in the eutectic temperature of them. There is a growth of the crystalline silicon from the interface of the layers. By heating up this interface with laser pulse, it is possible to carry this interface to the surface of the a-Si film. It is occurred while aluminum and silicon atoms make and break the bonding between them at the interface and the crystalline grains left behind the interface. Consequently, there were some residual aluminum atoms inside the silicon crystallites. It is possible to trace the interface movement by repeating the pulsing of the laser and perform ToF-SIMS for each step of pulsing. The crystalline quality and aluminum-silicon atoms behavior had studied by Raman spectroscopy and EDS, respectively. The Aluminum thickness has an impact on the crystalline quality and the doping profile of resulted thin poly-Si film.

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P127

SYNTHESIS OF METAL-FREE ORGANIC DYES BASED ON DIBENZONAPHTHYRIDINE STRUCTURE FOR DYE-SENSITIZED SOLAR CELLS

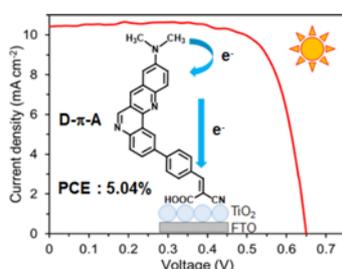
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In today's photovoltaic industry, silicon-based solar cells have been extensively used due to their reasonable and steady energy conversion efficiencies. In recent years, dye-sensitized solar cells (DSSCs) have received significant attention as potential alternatives to traditional silicon-based solar cells, because of their easy production, high energy conversion efficiency, low cost, and environmentally friendly nature. To date, several ruthenium-based sensitizers, such as N719 and N3, have achieved power conversion efficiencies (PCEs) of up to 12% [1]. Compared to the ruthenium or metal-based dyes, metal-free organic dyes have several advantageous features, such as lower material costs, easy synthesis, higher molar absorption coefficient, tunable absorption properties, and environmentally-friendly. The organic dyes are synthesized with the electron donor- π bridge-electron acceptor (D- π -A) configuration, due to the efficient intramolecular charge transfer properties of this molecules [2]. In this work, a series of metal-free organic dyes based on dibenzonaphthyridine as a π bridge structure were synthesized and used in DSSCs for the first time. These dyes consist of a cyanoacrylic acid moiety as the electron acceptor/anchoring group and different electron donor groups such as dimethylamino, trimethoxy and methoxy (Figure). The dye containing dimethylamino group displayed much broader absorption spectrum than the others, which is beneficial to light harvesting capability. When tested in DSSCs, the highest PCE of 5.04% is obtained by dimethylamino containing dye, and this followed by PCEs of 4.02 and 3.60 % for the others. These results indicate that dibenzonaphthyridine is a promising π bridge system to design new metal-free organic dyes.

Keywords

D- π -A, dibenzonaphthyridine, dye-sensitized solar cells



J-V curve of the DSSC based dimethylamino containing dye

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