

PVCON 2020

PHOTOVOLTAIC CONFERENCE

2nd International Conference on Photovoltaic Science and Technologies

Middle East Technical University
30 Nov.-02 Dec. 2020 | Ankara-Turkey

ABSTRACT BOOK

www.pvcon.org



**2nd International Conference on
Photovoltaic Science and Technologies**

Abstract Book

Middle East Technical University
30 Nov.- 02 Dec. 2020 | Ankara-Turkey

Organized by



Financial Sponsor



Supporting Institutions





Today, within the global developing economy and technology, to meet the increased needs of energy, the renewables are at the hub of almost all energy policy transitions. They are the most promising future energy resources as mostly being environmentally friendly, readily available and accessible. In consequence, both the utility-scale and rooftop applications of solar photovoltaic (PV) are becoming widespread with an ever-increasing rate all over the world.



One of the most important reasons of increasing rate of installation of solar energy systems and, in particular solar PV, is the incentives and amendments are regulated by governing bodies of many nations. On the other hand, serious R/D affords are made on reducing the unit prices to reach competitive levels with conventional alternatives. Many research centers all over the world are actively searching to increase the efficiencies and reduce the unit energy prices so that solar PV can compete in the today's dynamic energy market without incentives. In fact, unit energy price of electricity generation of solar PV become already compatible with conventional electricity generating power plants.

In Turkey, in accord with the worldwide development, the interest in solar energy systems is rapidly growing, especially after the implementation of incentives and amendments. Conversely, concerns raised now on possible causes of losses to nationwide economy due to quite high incentives. This can be overcome by the development of Turkey's present R/D infrastructure. In recent years, considerable measures are taken on this issue. To this end, new research infrastructures such as Center for Solar Energy Research and Applications (GÜNAM) have been founded by the financial support provided by Ministry of Development of Turkey.

As the need for R/D is increasing and the steps are taken to improve the infrastructure, we organized the first PVCon in July 2018, METU Campus, Ankara, Turkey. With the hope and willingness for the continuity of this conference while advancing in the future, we are pleased to announce its second organization as PVCon2020. The main aim is to present a well-established scientific and technical forum on solar PV.

We again plan to host international and national invited speakers, researchers, representatives of governmental bodies and private sector. The participants will share the recent researches and developments of the science and technology about solar energy and solar PV, contributing to the development of the related R/D and infrastructure, and in the meantime establishing a fruitful platform of national and international collaborations.

We take this opportunity to thank sincerely in advance of PVCon2020 to all the participants, to the governmental and private sector representatives, to national and international governmental and private organizations supporting us, and to state our best wishes for the success of the second conference like the first one.

With our kind regards,

Prof. Dr. Raşit TURAN
(Chair)

Prof. Dr. Bülent G. Akınoğlu
(Co-Chair)

National Organizing Committee

Dr. Akinoglu, Bulent Gultekin (Co-chair)	Middle East Technical University	Turkey	Modules and Outdoor Testing
Dr. Alagoz, Arif Sinan	TUBITAK Marmara Research Center	Turkey	PV Module Technologies
Dr. Arikan, Bulent	METU GÜNAM	Turkey	Si Solar Cells
Dr. Aygun Ozyuzer, Gulnur	Izmir Institute of Technology	Turkey	CZTS Thin Film Solar Cells
Dr. Bek, Alpan	Middle East Technical University	Turkey	Photonics, Plasmonics, Light Trapping
Dr. Colak, Uner	Istanbul Technical University	Turkey	Solar Energy Systems
Dr. Cubukcu, Mete	Ege University	Turkey	PV Modules and Power Systems
Dr. Eray, Aynur	Hacettepe University	Turkey	PV System Applications
Dr. Es, Firat	Kalyon PV	Turkey	Si Solar Cells
Dr. Gunbas, Gorkem E.	Middle East Technical University	Turkey	Organic Photovoltaics, Perovskite Solar Cells
Dr. Gunes, Serap	Yildiz Teknik University	Turkey	Organic Photovoltaics
Dr. Kesler, Selami	Pamukkale University	Turkey	PV Power Systems
Dr. Nasser, Hisham (Extreme PV Workshop Chair)	METU GÜNAM	Turkey	Silicon Heterojunction (SHJ) Solar Cells and Dopant-free SHJ, Carrier Selective Heterocontacts
Dr. Oktik, Sener	Kadir Has University	Turkey	PV Material Technologies
Dr. Ozden, Talat	Gumushane University	Turkey	PV Electronics, Outdoor Testing
Dr. Parlak, Mehmet	Middle East Technical University	Turkey	Copper Indium Gallium Selenide (CIGS) Solar Cells, New Thin Film Material
Dr. Sonmezoglu, Savas	Karamanoglu Mehmetbey University	Turkey	Dye-sensitized Solar Cells, Perovskite Solar Cells
Dr. Turan, Rasit (Chair)	Middle East Technical University	Turkey	Si Solar Cells
Dr. Unsur, Veysel	Necmettin Erbakan University	Turkey	Si Solar Cells
Dr. Unalan, H. Emrah	Middle East Technical University	Turkey	Nanomaterials and Solar Cells
Dr. Yerci, Selcuk	Middle East Technical University	Turkey	Si Solar Cells, Perovskite Solar Cells, Light Trapping
Dr. Yilmaz, Ercan	Abant Izzet Baysal University	Turkey	Si Device Processing
Besen, Cigdem	GTC Inc. (Photovoltaic Solar Systems)	Turkey	Member of GTC Management Board

Local Organizing Committee

Arikan, Bulent	METU-GÜNAM	Turkey
Bektas, Gence	METU-GÜNAM	Turkey
Çiftınar, Emine Hande	METU-GÜNAM	Turkey
Demirezen, Emre	METU-GÜNAM	Turkey
Kokbudak, Gamze	METU-GÜNAM	Turkey
Zolfaghari Borra, Mona	METU-GÜNAM	Turkey

International Organizing Committee

Dr. Balog, Robert	Texas A&M University	Qatar	Modules, Inverter Technologies
Dr. Ennaoui, Ahmed	Institute of Research in Solar Energy and New Energies (IRESEN)	Morocco	Thin Films, CdTe, CIGS
Dr. Isabella, Olindo	Delft University of Technology	Netherlands	Thin Film Si Solar Cells
Dr. Paulescu, Marius	West University of Timisoara	Romania	Physics of Solar Cells, Quantum Electronics
Dr. Zhou, Lang	Nanchang University	China	Si Solar Cells

Scientific Committee

Dr. Agresti, Antonio	University of Rome Tor Vergata	Italy	Organic and Hybrid Photovoltaics
Dr. Akinoglu, Bulent Gultekin	Middle East Technical University	Turkey	Modules and Outdoor Testing
Dr. Akkurt, Iskender	Suleyman Demirel University	Turkey	Solar Radiation Estimation
Dr. Alptekin, Demet Asil	Middle East Technical University	Turkey	Quantum Dots and Solar Cell Applications
Dr. Aygun Ozyuzer, Gulnur	Izmir Institute of Technology	Turkey	CZTS Thin Film Solar Cells
Dr. Bacioglu, Akin	Hacettepe University	Turkey	Thin Film Solar Cells
Dr. Badescu, Viorel	Politehnica University of Bucharest	Romania	Solar Thermodynamics
Dr. Balog, Robert	Texas A&M University	Qatar	Modules, Inverter Technologies
Dr. Baran, Derya	King Abdullah University of Science & Technology	Turkey	Organic Solar Cells, Hybrid Solar Cells, Transparent Solar Cells
Dr. Becker, Christiane	Helmholtz-Zentrum Berlin	Germany	Silicon Nanostructures for PV and Photonic Applications
Dr. Bek, Alpan	Middle East Technical University	Turkey	Photonics, Plasmonics, Light Trapping
Dr. Campesato, Roberta	Centro Elettrotecnico Sperimentale Italiano – S.p.A.	Italy	Multi-Junction Solar Cells
Dr. Cirpan, Ali	Middle East Technical University	Turkey	Organic Photovoltaics
Dr. Colak, Uner	Istanbul Technical University	Turkey	Solar Energy Systems
Dr. Cubukcu, Mete	Ege University	Turkey	PV Modules and Power Systems
Dr. De Wolf, Stefaan	King Abdullah University of Science & Technology	Saudi Arabia	Si Heterojunction Solar Cells
Dr. Demirci Sankir, Nurdan	TOBB University of Economics and Technology	Turkey	Thin Film Solar Cells
Dr. Dogan, Ilker	TNO/Solliance	Netherlands	Nanomaterials, Perovskite Solar Cells
Dr. Ela Erten, Sule	Ege University	Turkey	Organic Photovoltaics
Dr. Ennaoui, Ahmed	Institut de Recherche en Energie Solaire et Energies Nouvelles	Morocco	Solar Energy Materials & Solar Cells
Dr. Eray, Aynur	Hacettepe University	Turkey	PV System Applications
Dr. Ercelebi, Cigdem	Middle East Technical University	Turkey	Thin Film Materials and Solar Cell Applications
Dr. Glunz, Stefan	Fraunhofer Institute for Solar Energy Systems	Germany	Si Solar Cells
Dr. Gordon, Ivan	Imec R&D, Nano Electronics and Digital Technologies	Belgium	Silicon Photovoltaics
Dr. Gunbas, Gorkem E.	Middle East Technical University	Turkey	Organic Photovoltaics, Perovskite Solar Cells
Dr. Gunes, Mehmet	Mugla University	Turkey	Amorphous-Si Solar Cells, Optical Characterization
Dr. Gunes, Serap	Yildiz Teknik University	Turkey	Organic Photovoltaics
Dr. Hagendorf, Christian	Fraunhofer – Center for Silicon Photovoltaics (CSP)	Germany	Diagnostics of Solar Cells, Indoor and Outdoor Testing, Nanotechnology, Surface Chemistry
Dr. Isabella, Olindo	Delft University of Technology	Netherlands	Thin Film Si Solar Cells
Dr. Kalogirou, Soteris	Cyprus University of Technology	Cyprus	Hybrid Photovoltaic / Thermal Systems, Computational Simulation and Optimization of Solar Systems
Dr. Kaya, Hava Zekiye	Middle East Technical University	Turkey	Perovskite Solar Cells, Perovskite/Silicon Tandem Solar Cells
Dr. Kesler, Selami	Pamukkale University	Turkey	PV Power Systems

Dr. Kodolbas, Alp Osman	TUBITAK Marmara Research Center	Turkey	Amorphous-Si Solar Cells
Dr. Kuhnlein, Holger	RENA Technologies GmbH	Germany	Si Solar Cells
Dr. Kurtz, Sarah	National Renewable Energy Laboratory (NREL) & University of California	USA	Quantification of the Degradation of PV Systems
Dr. Muhtaroglu, Ali	Middle East Technical University (Northern Cyprus Campus)	Cyprus	PV Performance & PV-Thermal
Dr. Nasser, Hisham	Middle East Technical University	Turkey	Silicon Heterojunction (SHJ) Solar Cells and Dopant-free SHJ, Carrier Selective Heterocontacts
Dr. Nazeeruddin, Mohammad Khaja	École Polytechnique Fédérale de Lausanne	Switzerland	Perovskite Solar Cells & Recent Advancements
Dr. Oktik, Sener	Kadir Has University	Turkey	PV Material Technologies
Dr. Ozdemir, Engin	Kocaeli University	Turkey	Inverter Technologies
Dr. Ozdemir Hacioglu, Serife	Middle East Technical University	Turkey	Perovskite Solar Cells, Conjugated Polymers
Dr. Ozden, Talat	Gumushane University	Turkey	PV Electronics, Outdoor Testing
Dr. Ozenbas, Macit	Middle East Technical University	Turkey	Dye-sensitized Solar Cells
Dr. Ozmen, Ozge Tuzun	Duzce University	Turkey	Amorphous-Si Solar Cells
Dr. Parlak, Mehmet	Middle East Technical University	Turkey	Copper Indium Gallium Selenide (CIGS) Solar Cells, New Thin Film Material
Dr. Paulescu, Marius	West University of Timișoara	Romania	Physics of Solar Cells, Quantum Electronics
Dr. Selimoglu, Özgür	TUBITAK Space Technologies Research Institute	Turkey	Concentrator Photovoltaics (CPV)
Dr. Shariah, Adnan	Jordan University of Science and Technology	Jordan	Thin Film Silicon Solar Cells
Dr. Sinke, Wim	Energy Research Centre of the Netherlands & University of Amsterdam	Netherlands	Photovoltaic Energy Conversion
Dr. Soytaş, Ugur	Middle East Technical University	Turkey	Economics of Solar PV
Dr. Sonmezoglu, Savas	Karamanoglu Mehmetbey University	Turkey	Dye-sensitized Solar Cells, Perovskite Solar Cells
Dr. Toppare, Levent	Middle East Technical University	Turkey	Organic Photovoltaics
Dr. Unalan, H. Emrah	Middle East Technical University	Turkey	Nanomaterials and Solar Cells
Dr. Unsur, Veysel	Necmettin Erbakan University	Turkey	Si Solar Cells
Dr. Varlikli, Canan	Izmir Institute of Technology	Turkey	Organic Photovoltaics
Dr. Yaglioglu, Gul	Ankara University	Turkey	Amorphous Thin Films
Dr. Yerci, Selcuk	Middle East Technical University	Turkey	Si Solar Cells, Perovskite Solar Cells, Light Trapping
Dr. Yilmaz, Ercan	Abant İzzet Baysal University	Turkey	Si Device Processing
Dr. Yuce, Emre	Middle East Technical University	Turkey	Optically Functional Surfaces for Solar Applications
Dr. Yucel, Ismail	Middle East Technical University	Turkey	Meteorology, Climate Change, Environmental Impact Assessment
Dr. Zafer, Ceylan	Ege University	Turkey	Organic Photovoltaics
Dr. Zhou, Lang	Nanchang University	China	Si Solar Cells

CONFERENCE PROGRAM

***Please consider that the session and presentation hours are given according to the time zone in Ankara, Turkey.**

**Nov 30, 2020
(Monday)**

OPENING SESSION (08:50 - 10:55)

HIGHLIGHTS AND RECENT DEVELOPMENTS IN SOLAR PV MANUFACTURING

Chair: **Prof. Bülent G. Akınoğlu** (PVCCon2020 Co-chair, METU-PHYS / METU-ESS / METU-GÜNAM, Turkey)

Welcome Speech: **Raşit Turan & Bülent G. Akınoğlu** (PVCCon2020 Chairs, METU-GÜNAM, Turkey)

Keynote Speaker: Ron Sinton (Sinton Instruments, USA)

"Carrier recombination lifetime: Monitoring a critical parameter through the cell process"

Keynote Speaker: A. Buğrahan Karaveli (Ministry of Energy and Natural Resources, Turkey)

"Global trends and solar electricity perspectives of Turkey"

Keynote Speaker: Fırat Es (Kalyon PV, Turkey)

"KalyonPV – Integrated PV Manufacturing and R&D Roadmap"

Break

SESSION 2 (11:00 - 13:10)

ADVANCED C-SI TECHNOLOGIES - I

Chair: **Prof. Raşit Turan** (PVCCon2020 Chair, METU-GÜNAM / METU-PHYS, Turkey)

Keynote Speaker: Radovan Kopecek (ISC Konstanz, Germany)

"PERC and future technologies after"

Keynote Speaker: Hisham Nasser (METU-GÜNAM, Turkey)

"Dopant-free carrier-selective hetero-contacts for efficient crystalline silicon solar cells"

Ergi Dönerçark (METU-GÜNAM, Turkey)

"Bifacial silicon hetero-contact solar cells"

Nabil Khelifati (CRTSE, Algeria)

"Phosphorus and boron co-diffusion in silicon for p-PERT solar cells application"

Gence Bektaş (METU-GÜNAM, Turkey)

"Simplified process flow for the fabrication of PERC solar cells with ion implanted emitter"

Lunch Break

Nov 30, 2020
(Monday)

SESSION 3
(14:00 - 16:10)

ADVANCED C-SI TECHNOLOGIES - II

Chair: **Assist. Prof. Selçuk Yerci** (METU-MNT / METU-EE / METU-GÜNAM, Turkey)

Keynote Speaker: Robby Peibst (ISFH, Germany)

"Passivating poly-Si on oxide contacts – from fundamental investigations towards industrial implementation"

Keynote Speaker: Veysel Ünsür (Necmettin Erbakan University, Turkey)

"Alternative approaches for metallization of silicon solar cells"

Gamze Kökbudak (METU-GÜNAM, Turkey)

"Utilization of MoOx/Ag local rear hole collecting contact in crystalline Si PERC solar cells"

Haris Mehmood (Information Technology University of the Punjab, Pakistan)

"Physical device simulation of dopant-free asymmetric silicon heterostructure solar cell featuring tungsten oxide and ultrathin silicon oxide as a hole-selective and passivation stack layer"

Serkan Erkan (Niğde Ömer Halisdemir University, Turkey)

"The fabrication of silicon based solar cells with graphene and molybdenum doped zinc oxide"

Break

SESSION 4
(16:30 - 18:40)

ADVANCED DEVICE CONCEPTS AND NEW MATERIALS

Chair: **Prof. Ali Çırpan** (METU-CHEM / METU-GÜNAM, Turkey)

Tuğba Hacıfendioğlu (Middle East Technical University, Turkey)

"Design of surface passivation techniques for PbTe quantum dots and application to photovoltaic devices"

Ali Altuntepe (Niğde Ömer Halisdemir University, Turkey)

"Hybrid transparent conductive electrode structure for solar cell application"

Mona Zolfaghari Borra (METU-GÜNAM, Turkey)

"Selective chemical removal of subsurface laser modified silicon for photovoltaics"

Parisa Sharif (Middle East Technical University, Turkey)

"Flexible polymer solar cell with modified multi-layer graphene electrodes"

Nuray Çelebi (Ankara Yıldırım Beyazıt University, Turkey)

"Star-shaped ZnO-CeO₂ Z-scheme heterostructures for photoelectrochemical water splitting"

Laurentiu Fara (Polytechnic University of Bucharest, Romania)

"Optimized Cu₂O/c-Si tandem heterojunction solar cells: Experimental and modeling investigation for defect analysis"

Dec. 01, 2020
(Tuesday)

SESSION 5
(09:00 - 10:35)

THIN FILM SOLAR CELLS - I

Chair: **Prof. Mehmet Parlak** (METU-PHYS / METU-GÜNAM, Turkey)

Keynote Speaker: Mustafa Kulakçı (Eskişehir Technical University, Turkey)

"GaAs based III-V thin film flexible solar cells by epitaxial lift off (ELO) technique"

Ceren Korkut (METU-GÜNAM, Turkey)

"Laser crystallization of α -Ge thin-film via nanosecond pulsed infrared laser"

Hazal Gündoğan Kurtuldu (İzmir Institute Of Technology, Turkey)

"Effect of Ar gas flow rate on growth, structure and optical properties of sputtered Sb₂Se₃ absorber thin films for solar cells"

Teoman Özdal (Çukurova University, Turkey)

"Low cost solution based ZnO/Cu₂O heterostructures for photovoltaic applications"

Break

SESSION 6
(11:00 - 12:40)

THIN FILM SOLAR CELLS - II

Chair: **Prof. Görkem Günbaş** (METU-CHEM / METU-GÜNAM, Turkey)

Gizem Aydın (Şişecam, Turkey)

"Temperable single layer antireflection coatings for solar panel applications based on a dual alkoxy silane precursor chemistry"

Yassine Khaissa (Ibn Tofail University, Morocco)

"A new efficient synthesis of ZnS thin film using mist CVD technique"

Mehmet Ali Oğar (Niğde Ömer Halisdemir University, Turkey)

"Effect of stacking order and reaction temperature on properties of CZTS thin films"

Bünyamin Ümsür (Yozgat Bozok University, Turkey)

"Impact of RbF post deposition treatment on CdS/CIGSe and Zn(O,S)/CIGSe interfaces - A comparative HAXPES study"

Lunch Break

Dec. 01, 2020
(Tuesday)

SESSION 7
(14:00 - 16:00)

PEROVSKITE SOLAR CELLS & ORGANIC AND DYE SENSITIZED PV

Chair: **Dr. Antonio Agresti** (University of Rome Tor Vergata, Italy)

Ümmügülsüm Güneş (Middle East Technical University, Turkey)

"2D perovskite layer based on novel organic cation for increased efficiency and stability"

Hamaneh Zarenezhad (Koç University, Turkey)

"Efficiency enhancement via efficient charge carrier transfer in halide perovskite solar cells fabricated by polymer additives"

Eda Alemdar Yılmaz (Middle East Technical University, Turkey)

"Efficient green OLEDs based on thermally activated delayed fluorescence butterfly-shape emitter"

Caner İldeş (Yozgat Bozok University, Turkey)

"Production and investigation of the flexible dye-sensitized solar cells by using binder-free TiO₂ paste as photoanode material"

Yusuf Çakmak (Konya Food and Agriculture University, Turkey)

"Employing near-IR absorbing bodipy chromophores as donor materials for the active layer of bulk-heterojunction solar cells"

Mustafa Yaşa (Middle East Technical University, Turkey)

"Efficient non-fullerene organic solar cells based on thienopyrroledione comprising random copolymers; effect of alkyl chains"

Break

SESSION 8
(16:30 - 18:45)

OPTICS AND PHOTONICS FOR PV APPLICATIONS

Chair: **Prof. Alpan Bek** (METU-PHYS / METU-GÜNAM, Turkey)

Keynote Speaker: Sener Oktik (Kadir Has University, Turkey)

"Transparent photovoltaic solar cells and solar windows"

Nasim Seyedpour Esmailzad (METU-GÜNAM, Turkey)

"Concentrated photovoltaics with shape controlled nanosphere"

Alim Yolalmaz (Middle East Technical University, Turkey)

"Deep learning-based spectral splitting and concentration of broadband light for solar cells applications"

Mehmet Koç (METU-GÜNAM, Turkey)

"Optical design guidelines for perovskite/perovskite tandem solar cells in a material independent approach"

Berk Nezir Gün (Middle East Technical University, Turkey)

"Control of spatial phase empowering spectral splitting and concentration of solar spectrum"

Tunç Bektaş (METU-GÜNAM, Turkey)

"SnSbSe₂ crystal: Growth by vertical Bridgman technique and investigation of its structural, optical and electrical properties"

18:45

POSTER AWARDS

Dec. 02, 2020
(Wednesday)

SESSION 9
(09:00 - 10:55)

ECONOMICS OF SOLAR PV

Chair: **Prof. Aynur Eray** (Hacettepe University, Turkey)

Keynote Speaker: Huzur Keskin (Middle East Technical University, Turkey)

"Geopolitics of energy"

Yelda Erden Topal (Polytechnical University of Madrid, Spain)

"Review of socio-economic impacts of PV technology development in the developing countries context"

Metin Sever (Middle East Technical University, Turkey)

"Photovoltaic power plants financing models"

Raimon Bawazir (Ege University, Turkey)

"Correcting design of the current off-grid PV system in Aden city-Yemen"

Elşen Aydın (METU-GÜNAM, Turkey)

"A concentrating mini solar power system to overcome the market share"

Break

SESSION 10
(11:00 - 13:20)

SOLAR ENERGY RESOURCE AND PV SOLAR INPUT ASSESSMENT & PV POWER PLANTS AND BIPV

Chair: **Dr. A. Buğrahan Karaveli** (Ministry of Energy and Natural Resources, Turkey)

Deniz Gören (METU-NCC, Cyprus)

"Quality assessment of on-site solar radiation data and estimating global tilted irradiation in METU NCC"

Raimon Bawazir (Ege University, Turkey)

"Investigation of alternative horizontal solar radiation data source in the world"

Deniz Gören (METU-NCC, Cyprus)

"P50/P90 analysis of a solar PV plant in METU NCC using the empirical method and its comparison with my results"

Cihan Karaman (Ege University, Turkey)

"Effects of PV power plant penetrations on frequency and voltage in a distribution grid"

Emre Demirezen (METU-GÜNAM, Turkey)

"Monitoring and assessment of daily and seasonal photovoltaic heat island effect on Sekbandemirli rural region in Kütahya, Turkey"

Ahadollah Azami (Eastern Mediterranean University, Turkey)

"Energy-efficient building form and BIPV performance"

Raimon Bawazir (Ege University, Turkey)

"Designing of an on-grid and off-grid PV system with battery"

Lunch Break

**Dec. 02, 2020
(Wednesday)**

**SESSION 11
(14:00 - 15:50)**

EXtremePV Workshop

Chair: Dr. Hisham Nasser (METU-GÜNAM, Turkey)

Keynote Speaker: Said Ahzi (Hamad Bin Khalifa University, Qatar)

"A multiphysics approach for the computational analysis and prediction of performance and fatigue failure of PV panels"

Keynote Speaker: Klemens Ilse (Fraunhofer CSP, Germany)

"Investigating challenges and solutions for desert PV application"

Bouchra Laarabi (Mohammed V University in Rabat, Morocco)

"Review on modeling and simulation of soiling effects on PV and CSP module performance"

Abdellatif Bouaichi (IRESEN, Morocco)

"Toward the development of a desert PV module by mitigation the aging mechanisms of PV"

Break

**SESSION 12
(16:00 - 17:20)**

PV MODULE PERFORMANCE AND RELIABILITY

Chair: Assist Prof. Mete Çubukçu (Ege University, Turkey)

Beyza Durusoy (Middle East Technical University, Turkey)

"Technical potential of residential rooftop solar photovoltaic for Ankara: A preliminary study"

Nahide Özben Kaya (Şişecam, Turkey)

"Potential utilization of thin patterned glasses in photovoltaic systems through chemical tempering"

Fatemeh Mostofi (Karadeniz Technical University, Turkey)

"Structural performance of an existing building roof subjected to additional PV panel load"

Doğa Tolgay (Middle East Technical University, Turkey)

"Assessment of photovoltaic module temperature estimation for four years in Ankara with four different software"

Break

**SESSION 13
(18:00 - 18:40)**

POWER ELECTRONICS IN PV SYSTEMS

Chair: Prof. Engin Özdemir (Kocaeli University, Turkey)

Mustafa Hasan (Muğla Sıtkı Koçman University, Turkey)

"A new implementing approach for tracking algorithm on photovoltaic systems"

Kamil Okay (Hacettepe University, Turkey)

"Development of prototype battery management system for PV system"

PVCon2020 Closing Remarks: Raşit Turan & Bülent G. Akinoğlu (PVCon2020 Chairs, METU-GÜNAM, Turkey)

INVITED SPEAKERS

	Page
CARRIER RECOMBINATION LIFETIME: MONITORING A CRITICAL PARAMETER THROUGH THE CELL PROCESS Ron Sinton, USA	21
GLOBAL TRENDS AND SOLAR ELECTRICITY PERSPECTIVES OF TURKEY A.Buğrahan Karaveli, Turkey	22
KALYON PV – INTEGRATED PV MANUFACTURING AND R&D ROADMAP Firat Es, Turkey	23
PERC AND FUTURE TECHNOLOGIES AFTER Radovan Kopecek, Germany	24
“DOPANT-FREE CARRIER-SELECTIVE HETERO-CONTACTS FOR EFFICIENT CRYSTALLINE SILICON SOLAR CELLS” Hisham Nasser, Turkey	25
PASSIVATING POLY-SI ON OXIDE CONTACTS – FROM FUNDAMENTAL INVESTIGATIONS TOWARDS INDUSTRIAL IMPLEMENTATION Robby Peibst, Germany	26
ALTERNATIVE APPROACHES FOR METALLIZATION OF SILICON SOLAR CELLS Veysel Ünsür, Turkey	27
GAAS BASED III-V THIN FILM FLEXIBLE SOLAR CELLS BY EPITAXIAL LIFT OFF (ELO) TECHNIQUE Mustafa Kulakçı, Turkey	28
TRANSPARENT PHOTOVOLTAIC SOLAR CELLS AND SOLAR WINDOWS Şener Oktik, Turkey	29
GEOPOLITICS OF ENERGY Huzur Keskin, Turkey	30
A MULTIPHYSICS APPROACH FOR THE COMPUTATIONAL ANALYSIS AND PREDICTION OF PERFORMANCE AND FATIGUE FAILURE OF PV PANELS Said Ahzi, Qatar	31
INVESTIGATING CHALLENGES AND SOLUTIONS FOR DESERT PV APPLICATION Klemens Ilse, Germany	32

ORAL PRESENTATIONS

TOWARD THE DEVELOPMENT OF A DESERT PV MODULE BY MITIGATION THE AGING MECHANISMS OF PV MODULES IN THE MOROCCAN CLIMATE Abdellatif Bouaichi, Zakaria Naimi, Aumeur El Amrani, Abdellatif Ghennioui, Khawla Ettalbi, Choukri Messaoudi	34
ENERGY-EFFICIENT BUILDING FORM AND BIPV PERFORMANCE Ahadollah Azami, Harun Sevinc	35
HYBRID TRANSPARENT CONDUCTIVE ELECTRODE STRUCTURE FOR SOLAR CELL APPLICATION Ali Altuntepe, Serkan Erkan, Mehmet Ali Olğar, Ayse Seyhan, Recep Zan	36
DEEP LEARNING-BASED SPECTRAL SPLITTING AND CONCENTRATION OF BROADBAND LIGHT FOR SOLAR CELLS APPLICATIONS Alim Yolalmaz, Emre Yuce	37
REVIEW ON MODELING AND SIMULATION OF SOILING EFFECTS ON PV AND CSP MODULE PERFORMANCE B. Laarabi, G.J.P. Tevi, W.C. Sinke, A.S. Maiga and A. Barhdadi	38
CONTROL OF SPATIAL PHASE EMPOWERING SPECTRAL SPLITTING AND CONCENTRATION OF SOLAR SPECTRUM Berk Nezir Gun, Emre Yuce	39
IMPACT OF RBF POST DEPOSITION TREATMENT ON CDS/CIGSE AND ZN(O,S)/CIGSE INTERFACES – A COMPARATIVE HAXPES STUDY Bunyamin Umsur, Natalia Maticiuc, Tim Kodalle, Isheta Majumdar, Yajie Wang, Robert Wenisch, Hasan A. Yetkin, Tobias Bertram, Christian A. Kaufmann, Rutger Schlatmann, Iver Laueremann	40
PRODUCTION AND INVESTIGATION OF THE FLEXIBLE DYE-SENSITIZED SOLAR CELLS BY USING BINDER-FREE TiO₂ PASTE AS PHOTOANODE MATERIAL Caner İldes, Hatice Kanbur Cavus	41
LASER CRYSTALLIZATION OF A-GE THIN-FILM VIA NANOSECOND PULSED INFRARED LASER Ceren Korkut, Kamil Cınar, İsmail Kabacelik, Rasit Turan, Mustafa Kulakci and Alpan Bek	43
EFFECTS OF PV POWER PLANT PENETRATIONS ON FREQUENCY AND VOLTAGE IN A DISTRIBUTION GRID Cihan Karaman, Mete Cubukcu	44
P50/P90 ANALYSIS OF A SOLAR PV PLANT IN METU NCC USING THE EMPIRICAL METHOD AND ITS COMPARISON WITH TMY RESULTS Deniz Goren, Onur Taylan	49
QUALITY ASSESSMENT OF ON-SITE SOLAR RADIATION DATA AND ESTIMATING GLOBAL TILTED IRRADIATION IN METU NCC Deniz Goren, Onur Taylan	51

ASSESSMENT OF PHOTOVOLTAIC MODULE TEMPERATURE ESTIMATION FOR FOUR YEARS IN ANKARA WITH FOUR DIFFERENT SOFTWARE	53
Doga Tolgay, Samet Yakut, Talat Ozden, Bulent G. Akinoglu	
TECHNICAL POTENTIAL OF RESIDENTIAL ROOFTOP SOLAR PHOTOVOLTAIC FOR ANKARA: A PRELIMINARY STUDY	54
E.Ceren Kutlu ,Beyza Durusoy, Bulent G. Akinoglu	
EFFICIENT GREEN OLEDs BASED ON THERMALLY ACTIVATED DELAYED FLUORESCENCE BUTTERFLY-SHAPE EMITTER	55
Eda Alemdar Yilmaz, Parisa Sharif, Gorkem Gunbas, Ahmet Oral, Ali Cirpan	
A CONCENTRATING MINI SOLAR POWER SYSTEM TO OVERCOME THE MARKET SHARE	56
Elsen Aydin, Bilge Tuncel, Bulent G. Akinoglu	
MONITORING AND ASSESSMENT OF DAILY AND SEASONAL PHOTOVOLTAIC HEAT ISLAND EFFECT ON SEKBANDEMIRLI RURAL REGION IN KUTAHYA, TURKEY	57
Emre Demirezen, Talat Ozden, Bulent G. Akinoglu	
BIFACIAL SILICON HETERO-CONTACT SOLAR CELLS	59
Ergi Donercark, E.Hande Ciftpinar, Hisham Nasser, Argahavan Salimi, İsmail Kabacelik, Raşit Turan	
REVIEW OF SOCIO-ECONOMIC IMPACTS OF PV TECHNOLOGY DEVELOPMENT IN THE DEVELOPING COUNTRIES CONTEXT	61
Erkan Erdil , Pınar Derin Güre , Ramazan Sarı , Yelda Erden Topal	
DESIGNING OF AN ON-GRID AND OFF-GRID PV SYSTEM WITH BATTERY	62
Eyup Taymur, Raimon O. Bawazir, Numan S. Çetin	
STRUCTURAL PERFORMANCE OF AN EXISTING BUILDING ROOF SUBJECTED TO ADDITIONAL PV PANEL LOAD	63
Fatemeh Mostofi, Onur B. Tokdemir, Vedat Togan	
UTILIZATION OF MOOX/AG LOCAL REAR HOLE COLLECTING CONTACT IN CRYSTALLINE SI PERC SOLAR CELLS	64
Gamze Kokbudak, Mona Zolfaghari Borra, Ahmet Emin Keçeci, Bulent Arikan, Gence Bektas, Hasan Asav, Rasit Turan, Hisham Nasser	
SIMPLIFIED PROCESS FLOW FOR THE FABRICATION OF PERC SOLAR CELLS WITH ION IMPLANTED EMITTER	65
Gence Bektas, Gamze Kokbudak, Ahmet Emin Keçeci, Sumeyye Kocak Butuner, Hasan Asav, Emine Hande Ciftpinar, Rasit Turan	
TEMPERABLE SINGLE LAYER ANTIREFLECTION COATINGS FOR SOLAR PANEL APPLICATIONS BASED ON A DUAL ALKOXYSILANE PRECURSOR CHEMISTRY	67
Gizem Aydin, Refika Budakoglu, Burak Okan, Kürsat Kazmanlı	
EFFICIENCY ENHANCEMENT VIA EFFICIENT CHARGE CARRIER TRANSFER IN HALIDE PEROVSKITE SOLAR CELLS FABRICATED BY POLYMER ADDITIVES	68
Hamaneh Zarenezhad, Timucin Balkan, Navid Solati, Sarp Kaya	

PHYSICAL DEVICE SIMULATION OF DOPANT-FREE ASYMMETRIC SILICON HETEROSTRUCTURE SOLAR CELL FEATURING TUNGSTEN OXIDE AND ULTRATHIN SILICON OXIDE AS A HOLE-SELECTIVE AND PASSIVATION STACK LAYER	69
Haris Mehmood, Syed Muhammad Hassan Zaidi, Tauseef Tauqeer, Rasit Turan, Hisham Nasser	
DEVELOPMENT OF PROTOTYPE BATTERY MANAGEMENT SYSTEM FOR PV SYSTEM	70
Kamil Okay, Sermet Eray, Aynur Eray	
OPTIMIZED CU₂O/C-SI TANDEM HETEROJUNCTION SOLAR CELLS: EXPERIMENTAL AND MODELING INVESTIGATION FOR DEFECT ANALYSIS	72
L. Fara, Ø. Nordseth, I. Chilibon, R. Kumar, I. C. Vasiliu, D. Savastru, L. Baschir, D. Craciunescu, S. Fara, E. Monakhov	
EFFECT OF STACKING ORDER AND REACTION TEMPERATURE ON PROPERTIES OF CZTS THIN FILMS	74
M.A.Olgar, A.O. Sarp, A. Seyhan, R. Zan	
METAL NANOPARTICLES AS REAR TRANSPARENT CONDUCTIVE ELECTRODE WITH TUNABLE LIGHT TRAPPING AND CONDUCTIVITY FEATURES IN TANDEM SOLAR CELL STRUCTURE	75
Mehmet Koc, Selcuk Yerci	
PHOTOVOLTAIC POWER PLANTS FINANCING MODELS	76
Metin Sever, Huzur Keskin, Bulent G. Akinoglu	
SELECTIVE CHEMICAL REMOVAL OF SUBSURFACE LASER MODIFIED SILICON FOR PHOTOVOLTAICS	77
Mona Zolfaghari Borra, Behrad Radfar, Hisham Nasser, Rasit Turan, Ihor Pavlov, Alpan Bek	
A NEW IMPLEMENTING APPROACH FOR TRACKING ALGORITHM ON PHOTOVOLTAIC SYSTEMS	78
Mustafa Hasan, Serra Altinoluk	
NON-FULLERENE ORGANIC SOLAR CELLS BASED ON THIENOPYRROLEDIONE COMPRISING RANDOM COPOLYMERS; EFFECT OF ALKYL CHAINS	79
Mustafa Yasa, Tolga Depci, Eda Alemdar Yilmaz, Serife Ozdemir Hacioglu, Ali Cirpan, Levent Toppare	
PHOSPHORUS AND BORON CO-DIFFUSION IN SILICON FOR P-PERT SOLAR CELLS APPLICATION	81
Nabil Khelifati, Imane Charif, Baya Palahouane, Brahim Mahmoudi, Djoudi Bouhafs	
POTENTIAL UTILIZATION OF THIN PATTERNED GLASSES IN PHOTOVOLTAIC SYSTEMS THROUGH CHEMICAL TEMPERING	83
Nahide Ozben, Gulcan Terzi, İlkay Sokmen, Burcu Ogüt, Turkay Yıldız, Miray Celikbilek Ersundu, Ali Ercin Ersundu, Ersin Gokcen	
CONCENTRATED PHOTOVOLTAICS WITH SHAPE CONTROLLED NANOSPHERE	84
Nasim Seyedpour Esmaeilzad, Ahmet Kemal Demir, Jamileh Hajivandi, Hande Ciftpinar, Rasit Turan, Hamza Kurt, Alpan Bek	

STAR-SHAPED ZNO-CEO₂ Z-SCHEME HETEROSTRUCTURES FOR PHOTOELECTROCHEMICAL WATER SPLITTING	86
Nuray Celebi, Fatih Arlı, Furkan Soysal, Kouroush Salimi	
FLEXIBLE POLYMER SOLAR CELL WITH MODIFIED MULTI-LAYER GRAPHENE ELECTRODES	87
Parisa Sharif, Eda Alemdar Yilmaz, Sevki Can Cevher, Ali Cirpan, Ahmet Oral	
CORRECTING DESIGN OF THE CURRENT OFF-GRID PV SYSTEM IN ADEN CITY-YEMEN	88
Raimon O. Bawazir, Numan S. Cetin	
INVESTIGATION OF ALTERNATIVE HORIZONTAL SOLAR RADIATION DATA SOURCE IN THE WORLD	89
Raimon O. Bawazir, Numan S. Cetin, J. Chakchak	
EFFECT OF AR GAS FLOW RATE ON GROWTH, STRUCTURE, AND OPTICAL PROPERTIES OF SPUTTERED SB₂SE₃ ABSORBER THIN FILMS FOR SOLAR CELLS	93
S. Hazal Gundogan, Gulnur Aygun, Lutfi Ozyuzer, Ayten Cantas	
THE FABRICATION OF SILICON BASED SOLAR CELLS WITH GRAPHENE AND MOLYBDENIUM DOPED ZINC OXIDE	94
Serkan Erkan, Ali Altuntepe, Mehmet Ali Olgar, Ayse Seyhan, Recep Zan	
LOW COST SOLUTION BASED ZNO/CU₂O HETEROSTRUCTURES FOR PHOTOVOLTAIC APPLICATIONS	95
Teoman Ozdal, Merhan Kılıc, Hamide Kavak	
DESIGN OF SURFACE PASSIVATION TECHNIQUES FOR PBTE QUANTUM DOTS AND APPLICATION TO PHOTOVOLTAIC DEVICES	96
Tugba Hacıfendioglu, Taha K. Solmaz, Merve Erkan, Demet Asil	
SNSBSE₂ CRYSTAL: GROWTH BY VERTICAL BRIDGMAN TECHNIQUE AND INVESTIGATION OF ITS STRUCTURAL, OPTICAL AND ELECTRICAL PROPERTIES	97
Tunc Bektas, Makbule T. Bilmis, Ozge B. Surucu, Mehmet Parlak	
2D PEROVSKITE LAYER BASED ON NOVEL ORGANIC CATION FOR INCREASED EFFICIENCY AND STABILITY	98
Ummugulsum Günes, Selcuk Yerci, Gorkem Gunbas	
EMPLOYING NEAR-IR ABSORBING BODIPLY CHROMOPHORES AS DONOR MATERIALS FOR THE ACTIVE LAYER OF BULK-HETEROJUNCTION SOLAR CELLS	99
Yusuf Çakmak	
A NEW EFFICIENT SYNTHESIS OF ZNS THIN FILM USING MIST CVD TECHNIQUE	100
Y. Khaaissa, F. Elguedah, A. Talbi, K. Nouneh	

POSTER PRESENTATIONS

PROPAGATION OF CRACKS IN STANDARD CELL AND HALF-CELL PHOTOVOLTAIC TECHNOLOGY	102
Abdellatif Bouaichi, Eloualid Chakir, Abdellatif Ghennioui, Hassan El Minor, Choukri Messaoudi	
A TECHNO-ECONOMIC STUDY OF ROOFTOP GRID-CONNECTED PHOTOVOLTAIC-ENERGY STORAGE SYSTEMS IN QATAR	103
Abdelrahman Amer, Nabila Elbeheiry, Seif Elgazar, Sawsan Shukri, Morcos Metry, Robert S. Balog	
A GRID CONNECTED PHOTOVOLTAIC POWER CONVERSION SYSTEM WITH SOLID STATE TRANSFORMER	107
Ahmed F. Kasse, Nadir Kabache, Samir Moulahom	
FABRICATION AND CHARACTERIZATION OF EPITAXIAL LIFT-OFF PROCESSED GAAS THIN FILM SOLAR CELLS HETERO-EPITAXIALLY GROWN ON SI SUBSTRATES	108
Ali Buyukpinar, Muhammed Aktas, Burcu Arpapay, Mustafa Kulakci	
OPTICAL AND STRUCTURAL STUDIES OF ZNS:NI FILMS FOR SOLAR CELL APPLICATIONS	109
Ayse Kucukarslan, Barbaros Demirselcuk, Esra Kus, Vildan Bilgin	
EFFECT OF HIGH ILLUMINATION ON INDUSTRY COMPATIBLE SINGLE CRYSTALLINE SILICON PERC SOLAR CELL	110
Behrad Radfar, Rasit Turan	
USING RENEWABLE ENERGY ON ELECTRIC VESSELS IN COASTAL REGIONS	111
Caner Pense, Bulent G. Akinoglu	
DEVICE CHARACTERIZATION OF PHYSICALLY EVAPORATED CDS/CDZNTS THIN FILMS FOR SOLAR CELL APPLICATION	112
C. Dogru, M. Parlak	
DYNAMICS OF SELF-HEALING MECHANISM OF LASER CRYSTALLIZED SI THIN FILMS	113
Ceren Korkut, Kamil Cinar, Alpan Bek	
AIRBRUSH COATED PEDOT:PSS BACK CONTACTS FOR SILICON SOLAR CELLS	114
Deniz Turkay, Batuhan Ülkütasir, Kerem Artuk, Elif Cüce, Konstantin Tsoi, Naser Beyraghi, Milad Ghasemi, Selcuk Yerci	
UTILIZING WET CHEMICALLY GROWN SILICON OXIDES FOR SURFACE PASSIVATION OF SILICON BY PEDOT:PSS	115
Deniz Turkay, Milad Ghasemi, Selcuk Yerci	
A STUDY ON CONTAMINATION DETECTION AND TRACE FOR VARIOUS CELL STRUCTURES FABRICATED IN CLEAN ROOM ENVIRONMENT	116
E. Hande Ciftpinar, Ergi Donercark, Salar H. Sedani, Rasit Turan	

FABRICATION OF BLACK SILICON VIA REACTIVE ION ETCHING: EFFECT OF PRE-ETCHING TREATMENT ON SUPERIOR UNIFORMITY IN LARGE SCALE	118
Elif Sarıgul Duman, Rasit Turan	
FABRICATION AND CHARACTERIZATION OF ZNO NANORODS BASED CZTS SUPERSTRATE SOLAR CELLS	120
Elif Peksu, Hakan Karaagac	
WIDE BAND GAP A-SICX:H PASSIVATION LAYER FOR THE APPLICATION OF SILICON HETEROJUNCTION (SHJ) SOLAR CELLS	121
Ergi Donercark, İsmail Kabacelik, Argahavan Salimi, Salar H. Sedani, Rasit Turan	
AIR AND WATER BASED PHOTOVOLTAIC PANEL COOLING SYSTEMS	123
Ersin Karacabey, Birol Kayisoglu, Levent Taseri	
GROWTH AND CHARACTERIZATION OF MN DOPED ZNS THIN FILMS FOR PHOTOVOLTAIC APPLICATIONS	124
Esra Kus, Ayse Küçükarslan, Barbaros Demirselcuk, Vildan Bilgin	
CHARACTERIZING DC ARCS FOR PHOTOVOLTAIC ARC FAULT DETECTION	125
Fatima Al-Janahi, Sawsan Shukri, Kais Abdulmawjood, Robert S. Balog	
COMPARATIVE EVALUATION OF REAR LOCAL CONTACT PATTERNS FOR P-TYPE MONO CRYSTALLINE SILICON PERC SOLAR CELL	131
Hasan Asav, Gence Bektaş, Ahmet Emin Kececi, Gamze Kokbudak, Bulent Arıkan, Rasit Turan	
THE EFFECT OF AGING ON C-SI SOLAR CELLS EXPOSED TO 8 MEV ELECTRONS IRRADIATION	132
Ismail Kabacelik, Mustafa Kulakci	
DEVELOPMENT OF CVD PROCESS FOR HYBRID PHYSICAL CHEMICAL VAPOR DEPOSITED PEROVSKITE ABSORBERS	134
Kerem Artuk, Thierry Moser, Yan Jiang, Thomas Feuer, Ayodhya N.Tiwari, Fan Fu	
THE ROADMAP OF CELL TO MODULE (CTM) CONVERSION LOSS ANALYSIS OF MONO PERC BIFACIAL GLASS-GLASS MODULES	135
Meric Caliskan, Melis Çetmeli, Betül Şekertekin, Baybars Saica, Mete Gunoven, Firat Es	
CHARACTERIZATION OF GAAS THIN-FILM SOLAR CELL STRUCTURES GROWN BY MOLECULAR BEAM EPITAXY TECHNIQUE ON SI SUBSTRATES FOR FLEXIBLE THIN FILM SOLAR CELL APPLICATIONS	137
Muhammed Aktas, Ali Buyukpinar, Burcu Arpabay, Mustafa Kulakci	
EMITTER FORMATION BY ION IMPLANTATION METHOD FOR N-TYPE BLACK SILICON	138
Mona Zolfaghari Borra, Hande Ciftpinar, Gence Bektas, Ahmet Keçeci, Gamze Kokbudak, Ozan Aydin, Sümeyye Kocak Butuner, Hisham Nasser, Emel Semiz, Ihor Pavlov, Firat Es, Rasit Turan	
SIZING OF DIFFERENTIAL POWER PROCESSING CONVERTERS BASED ON STATISTICAL MODELING FOR NON-PLANAR PHOTOVOLTAIC APPLICATIONS	139
Morcos Metry, Sawsan Shukri, Robert S. Balog	

GREEN AND SUSTAINABLE ENERGY Muratcan Isildak	143
PERIODIC SURFACE TEXTURING OF SILICON BY PHOTOELECTROCHEMICAL ETCHING FOR PHOTOVOLTAICS Nardin Avishan, Alp Akbıyık, Emre Yüce, Alpan Bek	145
SYNTHESIS, CHARACTERIZATION, AND PHOTOVOLTAIC PROPERTIES OF DITHIENYL BENZOOXADIAZOLE BASED POLYMERS FOR HIGH PERFORMANCE ORGANIC SOLAR CELLS Oguzhan Karakurt, Eda Alemdar Yilmaz, Ali Cirpan	146
BUILD A DECISION TREE MODEL FOR MAXIMUM POWER POINT TRACKER BASED ON A FUZZY LOGIC CONTROLLER Rabah Benkercha, Samir Moulahoum	148
IMPROVING MEASURED HORIZONTAL SOLAR RADIATION DATA: THE CASE STUDY- ASIA CONTINENT Raimon O. Bawazir, Numan S. Cetin and J. Chakchak	149
LOW-COST, STAND-ALONE, IN-SITU PV CURVE TRACER Safin H. Bayes, Sawsan Shukri, Robert S. Balog	152
COMPLICATIONS AND ANALYTICAL SOLUTIONS FOR TOF-SIMS CHARACTERIZATION OF SILICON-BASED SOLAR CELLS Salar H. Sedani, Ilker Yildiz, Rasit Turan	156
TAILORED DOPING PROFILE WITH COMMERCIAL NANOSECOND LASER FOR LOW-COST PV INDUSTRIAL APPLICATIONS Salar H. Sedani, Ergi Donercark, E. Hande Ciftpinar, Rasit Turan	158
PARAMETER EXTRACTION TO OPTIMIZE INTERCONNECTIONS OF NON-PLANAR PHOTOVOLTAICS Sawsan Shukri, Safin H. Bayes, Morcos Metry, Robert S. Balog	160
2D-BENZODITHIOPHENE-BENZOTRIAZOLE COPOLYMERS FOR EFFICIENT ORGANIC SOLAR CELLS: EFFECT OF DIFFERENT SIDE GROUPS ON PHOTOVOLTAIC PERFORMANCE Sultan Taskaya Aslan, Duygu Cevher, Ummugulsum Sahin, Soner Ozturk, Ali Cirpan	163
LONG TERM ASSESSMENT OF TWO ON-GRID PV SYSTEMS FOR NINE YEARS Talat Ozden, Ensar M. Ozgun, Bedirhan Keles, Bulent G. Akinoglu	165
VOLTAGE PROFILE ENHANCEMENT USING CAPACITOR-LESS D-STATCOM TO INCREASE PV PENETRATION IN DISTRIBUTION NETWORK UNDER TRANSIENT CLOUD CONDITIONS Wesam Rohouma, Robert S. Balog, Aaqib Ahmad Peerzada, Miroslav M. Begovic	166

Carrier recombination lifetime: Monitoring a critical parameter through the cell process

Ron Sinton

Sinton Instruments, USA

The carrier recombination lifetime in silicon is a critical parameter that can be monitored through the entire cell production process to indicate the material quality and the optimization of every process step. This talk will discuss how this lifetime parameter is related to the IV curve, and how a unified description can be used to interpret data at every step of the process in order to clearly identify the process steps where the most improvement can be made from wafer. This description is valid for each step where the wafer is passivated, at cell test, and at module test. More recently, applications have been reported for studying module-degradation mechanisms after fielding, as well as having the ability to isolate degradation mechanisms and their proposed solutions at the wafer, cell, and module level.

Global Trends and Solar Electricity Perspectives of Turkey

A. Buğrahan Karaveli

Ministry of Energy and Natural Resources, Turkey

World has been proceeding through more digitalised and electrified way of life. The pandemic times we are in has also proven this transition. The energy consumption is targeted to be decarbonised due to the sustainable development goals. Photovoltaics at this point is now accepted as the new king of the electricity sector owing to reasonable cost decline together with positive environmental and social effects. Turkey has also been devoted itself to renewables. Photovoltaics together with hydro and wind has come into prominence for the last 5 years in the country. The trend is revealing that the interest for solar will increasingly be carried out in Turkey in compliance with the global trends.

KALYON PV – INTEGRATED PV MANUFACTURING AND R&D ROADMAP

Firat Es

Turkey

PERC and future technologies after

Radovan Kopecek

ISC Konstanz, Germany

Since 2016, when LONGi began introducing their low-cost Cz-Si wafers to the PV market, mc-Si and homogeneous Al-BSF technologies have been rapidly losing market share. Back then, there was stiff competition between passivated emitter and rear cell (pPERC) and passivated emitter, rear totally diffused (nPERT) technologies, but PERC later prevailed – mostly because of the cheaper price of p-type wafers and associated processing sequences and materials (e.g. Ag and Al pastes). An additional advantage of PERC was the fact that the process sequence was closer to that for p-type standard cells, which facilitated a gradual adaptation of existing production lines.

PERC technology subsequently became, much more quickly than anyone expected, the leading solar cell technology, with the highest production capacity and the lowest cost of ownership (COO). Towards the end of 2019, mono PERC production capacity reached about 100GWp, which corresponds to a total annual solar cell production of more than 120GW, equating to a 75% market share. Standard PERC cell efficiencies, however, are expected to reach their limits soon; scientists in the PV community estimate that this will happen at an average production efficiency value of 22.5–23%. To achieve even higher efficiencies with PERC-like solar cells, new technologies will need to be implemented.

This raises the question of which cell concepts will replace PERC as the leading solar cell technology of the future. Or, more specifically: how can the voltage of low-cost industrial solar cells be increased towards 700mV and beyond in order to obtain efficiencies well above 23%? And how can this be achieved at acceptable costs, i.e. without the addition of too many and too costly new process steps?

The presentation will summarize the state of the art PERC technology and discuss what technologies most likely will follow in 3-5 years and 10-15 years. We believe that in the coming 1-3 years PERC will still improve its efficiency slightly naturally reaching 23%+ (better pastes, better material) and low cost n-type technologies (nPERT, IBC) will be implemented as well, reaching Voc's of around 700mV and more using advanced screen printing. Within 3-5 years so called passivated contact technology will be ready for market implementation and after 10-15 years even c-Si based tandem solar cells will enter the market.

**“DOPANT-FREE CARRIER-SELECTIVE HETERO-CONTACTS FOR EFFICIENT
CRYSTALLINE SILICON SOLAR CELLS”**

Hisham Nasser

Turkey

Passivating poly-Si on oxide contacts – from fundamental investigations towards industrial implementation

Robby Peibst

ISFH, Germany

Passivating poly-Si on oxide contacts and related junction schemes are in the focus of public c-Si PV research over seven years now. The first investigation phase was characterized by basic research on the current transport mechanisms, the evaluation of different manufacturing processes for this junction scheme, and by the experimental demonstration of the high efficiency potential on laboratory cells. As summarized in the talk, new excellent results and valuable insights are still reported for each of these topics. Nevertheless, the current phase focusses on the transfer to industrial mass application. It is not fully clear yet which cell concept can utilize POLO-junctions best in terms of efficiency potential, process flow leanness and low material consumption. Even the most common structure – an n-type frontjunction cell with an n+ POLO junction on the rear – has, despite of demonstrated industrial record efficiencies above 24 %, a hard standing as compared to the existing benchmark PERC. The talk will outline this area of suspense. A new challenger to advanced c-Si technology also appears to be emerging in the form of silicon perovskite tandem cells, which promise much larger leverage. The lecture will also report that POLO junctions are not a dead end but rather can be an essential component of tandem cells based on high temperature processed Si-bottom cells.

Alternative approaches for metallization of silicon solar cells

Veysel Ünsür

Necmettin Erbakan University, Turkey

High living standards all over the world, leading to high energy demand, have resulted in massive consumption of conventional fossil fuels like coal, oil, natural gas etc. In order to make up for this increasing global demand, alternative means to produce energy have been emerging. One of which is solar photovoltaics that is most promising and the fastest growing industry as of to date. Cost and efficiency, however, are the two opposing challenges that must be overcome for cost-effective solar electricity. Metallization, after silicon wafer cost, is not only the second most expensive step in solar cell production but also one of the key steps that can be tailored to increase the overall efficiency.

Screen printed silver (Ag) metal contacts has been the most utilized material because of its excellent conductivity and solder-ability to silicon (Si). Its relatively low diffusion coefficient in Si guarantees good contact with the substrate and longevity of the solar cell. In spite of great electrical advantages, the cost of Ag corresponds to almost 30% of total cost due to availability constraints. There is also the fact that Ag containing metallic pastes include lead oxide (PbO) as well, which is a toxic material that carries health concerns. Therefore, either replacing silver by more readily available and cheaper materials or lowering the amount of Ag usage per cell is crucial for solar cells to penetrate into the energy market.

GaAs based III-V thin film flexible solar cells by epitaxial lift off (ELO) technique

Mustafa Kulakçı

Eskişehir Technical University, Turkey

III-V compounds are not only the basic materials for modern optoelectronic devices but also building blocks for modern record breaking solar cells among the photovoltaic materials by a wide margin. However, high substrate and fabrication costs limit their uses to the specific applications such as Space or concentrator photovoltaics that are more tolerant to cell cost. Recently, exfoliation and transfer of epitaxially grown active cell on to the new carrier platforms (like polyimide and metal foils) by using ELO technique without sacrificing substrate for subsequent growth and cell efficiency has become a very promising approach to effectively reduce the high quality substrate cost which can hold over 80% in III-V cell technology. The talk will be on cost effective GaAs based group III-V lightweight thin film flexible solar cells using ELO and HELO technique.

Transparent Photovoltaic Solar Cells and Solar Windows

Şener Oktik

Kadir Has University, Turkey

Almost 55% of solar energy is in the visible region (380nm-780nm). Contributions of ultraviolet (280nm-380nm) and near infrared (780nm-2500nm) regions are ~ 4% and 41% respectively. Thus at the first glance the idea of “converting solar energy by photovoltaic process via transparent solar cells” might seem to be a bit controversial. However, the most cutting-edge research and technological development efforts on new transparent organic photovoltaic (TOPV) solar cell have shown that this new field has a great potential to change the game in photovoltaic industries. Combining PV solar energy generation and transparency opens up new applications for variety of industries such as; construction, transport, electronics, display technologies etc. Thus progress in (TOPV) has been exponential and dynamically reviewed (1,2). Recently it is demonstrated that transparent organic photovoltaic cells with a power conversion efficiency of 10.8% and visible transparency of ~50% (3).

This work would be concentrated on TOPV and solar windows only. There is a common belief that when TOPV field reaches to technological and commercial maturity, solar windows would replace the most of the traditional glass windows and facades in commercial and domestic buildings. This would overcome problems related to large land parcels or roof spaces for PV conversion. It is estimated that the size of the current glass facades in USA is about 5 to 7 billion square meters and installing transparent solar cells on windows and the facades might provide 40% of energy demand.

References

- 1- Husain, A.A.F., et.al., A review of transparent solar photovoltaic Technologies, Renewable and Sustainable Energy Reviews Volume 94, October 2018, Pages 779-791
- 2- M., et.al., Recent Developments in Solar Energy-Harvesting Technologies for Building Integration and Distributed
- 3- Li et al, Color-neutral, semitransparent organic photovoltaics for power window applications, The Proceedings of the National Academy of Sciences (PNAS) September 1, 2020 117 (35) 21147-21154

Geopolitics of Energy

Huzur Keskin

Turkey

Energy Geopolitics consists of the interrelation of energy, security and international policy. This relationship enables us to better understand the many events we are experiencing today, how energy demand and supply shape international politics. It also defines what are the major challenges for global energy security, and this relationship becomes understandable in the title. Energy geopolitics should focus on both traditional and alternative energies, as it will both affect and be influenced by global geopolitical realities. History shows us how geopolitics of energy has developed as new discoveries are made and institutional, economic and technological changes occur. Today, policy makers, businessmen and researchers are facing a number of new facts in evaluating the energy system.

A Multiphysics Approach for the computational Analysis and Prediction of Performance and Fatigue Failure of PV Panels

Said Ahzi

Texas A&M University, Qatar

Investigating challenges and solutions for desert PV application

Klemens Ilse

Fraunhofer CSP, Germany

An increasing amount of PV installations is taking place in desert environments. In addition to the advantages of high irradiation values, the desert climate entails increased stress factors for PV modules, which could drastically reduce the power output and PV module lifetime. This especially includes high ambient temperatures and temperature changes, increased losses from soiling and degradation caused by high UV doses. Within the presentation, an overview of challenges of desert PV is provided. Advanced laboratory stress tests, extensive outdoor testing and microstructural investigations help to understand the degradation behavior of the different PV materials. This provides the basis for optimizing used components and PV module design to better meet the increased requirements of desert application. In addition, innovative technologies and solutions for desert PV are investigated with respect to their techno-economical feasibility.

PVCON 2020
PHOTOVOLTAIC CONFERENCE

**ORAL
PRESENTATIONS**

Toward the development of a desert PV module by mitigation the aging mechanisms of PV modules in the Moroccan climate

Abdellatif Bouaichi^{1,2*}, Zakaria Naimi¹, Aumeur El Amrani³, Abdellatif Ghennioui¹, Khawla Ettalbi¹, Choukri Messaoudi²

¹ Green Energy Park (IRESEN, UM6P), benguerir, Morocco

² OTEA, Dept. Of Physics, FST, Errachidia, Moulay Ismail University of Meknes, Morocco

³ EST Meknes, Moulay Ismail University of Meknes, Morocco

*bouaichi@iresen.org / a.bouaichi1989@gmail.com

In recent years, PV module performance and durability researchers have focused on the PV aging mechanisms of to save module life and reduce LCOE. In this study, outdoor exposure inspection of c-Si technology in the climate of Morocco has been conducted, which represents particular relevance and can serve in the developing of the qualification tests for like desert condition of MENA region and Africa. The purpose of this work is to develop a desert PV module adapted for arid and semi-arid climate of Morocco. Various characterization techniques such as electroluminescence, infrared imaging and I-V measurement were used in the field for detailed inspection of the modules. The general observation leads us to conclude that the inspection reflects the severity of the climatic conditions not only in terms of the observed aging mechanisms but also in terms of degradation rate values. As a result, we have been able to detect various degradation mechanisms that affect module life, and manifested as hotspots, cracks, encapsulants discolorations, potential induced degradation (PID), delamination and snail tracks. In addition, high annual degradation rates ranging from 2.02% up to 2.73% have been observed experimentally. In addition, and in relation to these severe arid and semi-arid conditions, we opted for a new PV module design (figure 1), based on an approach to mitigate the defects observed, the purpose of which is to save the life of the modules and improve their LCOE.

Keywords: Desert, performance, durability, defect mitigation, new conception,

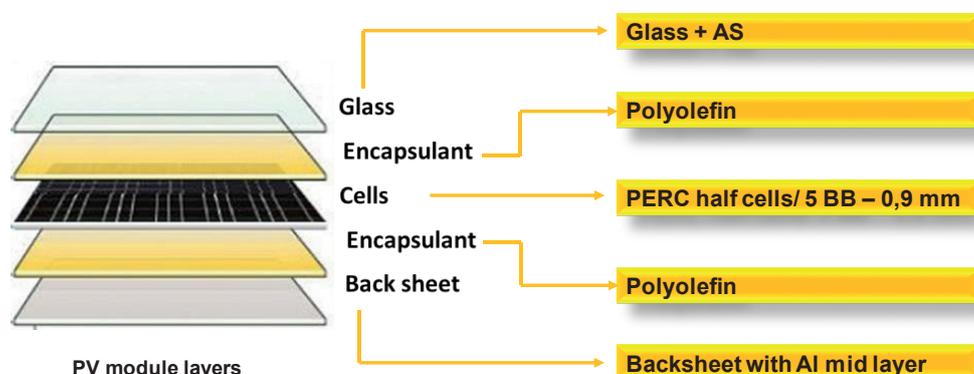


Figure 1. Desert PV module conception for desert climate of Morocco

ENERGY-EFFICIENT BUILDING FORM AND BIPV PERFORMANCE

Ahadollah Azami, Harun Sevinç

Department of Architecture, Eastern Mediterranean University (EMU), Famagusta, North Cyprus

*ahadollah.azami@emu.edu.tr

Building form plays an important role in energy efficiency and solar energy gain as well. Energy-efficient building design is depended on the contextual principles and local climatic conditions of the specific site. However, building envelope plays dual function of energy transition and creation through its surfaces. The compactness (C) which is defined as the relationship of the surface area (A) to the volume (V), is one of the main parameters to optimize the building energy losses. But, in terms of good insulation level for envelope, the effect of reduced surface area would be less for the loss performance. Also, the building shape and its orientation makes significant effect on BIPV solar yield regarding energy creation considered in the early-stage design process.

Different building form types with the same floor area in the mid-latitude climate of Ankara studied to find out the most energy-efficient form by overall balance between the solar gain potential and heat losses through the building envelope. The calculation represents that optimized roof size, orientation and also building form with an appropriate ratio of compactness for the selected form types, resulted in better BIPV performance for energy creation. However due to the seasonal distribution, BIPV performance of facades is higher than flat roofs in winter and transition months.

Keywords: form, solar yield, BIPV performance, energy balance

References

- [1] Wang, Y., Ke, S., Liu, F., Li, J., Pei, G., 2017. Performance of a building-integrated photovoltaic/thermal system under frame shadows, *Energy Build.* 134, 71-79.
- [2] Zomer, C., R  ther, R., 2017. Simplified method for shading-loss analysis in BIPV systems – part 1: Theoretical study, *Energy Build.* 141, 69-82.

Hybrid Transparent Conductive Electrode Structure for Solar Cell Application

Ali ALTUNTEPE¹, Serkan ERKAN^{1,2}, Mehmet ALİ OLĞAR^{1,2}, Ayşe SEYHAN^{1,2}, Recep ZAN^{1,2}

¹Niğde Ömer Halisdemir University, Nanotechnology Application and Research Center, 51200, Niğde, Turkey

²Niğde Ömer Halisdemir University, Department of Physics, 51200, Niğde, Turkey

*Corresponding Author: recep.zan@ohu.edu.tr

Graphene has been one of the most investigated material in recent years because of its remarkable properties such as high optical transmittance (97%), high thermal conductivity (5000 W mK⁻¹), high charge mobility (200.000 cm²V⁻¹s⁻¹) and high durability (1 Tpa Young modules)[1]. Indium Tin Oxide (ITO) is generally used as Transparent conductive oxide (TCO) in Silicon based solar cell. However, ITO has limited resources and some disadvantages for Si based solar cell. Therefore, Al doped Zinc Oxide (AZO) is one of the remarkable alternatives to ITO as AZO has an abundant resource, nontoxicity and good stability [2]. However, AZO has strong absorption in the IR region of the spectrum. Thus, there is a need to improve or modify the optical and electrical behaviors of AZO films [3, 4]. In the present study, AZO/graphene hybrid structure was fabricated to be used as TCO in solar cells. To do this, we first determined the optimum AZO film thickness based on its optical and electrical measurement results. Then, a single layer graphene film was transferred onto AZO films. We found out that a 500 nm AZO/single layer graphene hybrid structure has the best optical and electrical properties. Then, to understand the effect of the graphene film, AZO and AZO/graphene films were applied to Si based solar cell as TCO. As a result, the cell efficiency was improved substantially for each hybrid structure in comparison to that fabricated using only AZO film.

The authors gratefully acknowledge the funding from The Scientific and Technological Research Council of Turkey (TUBITAK-119M032-117M401).

Keywords: graphene, AZO, solar cell, TCO

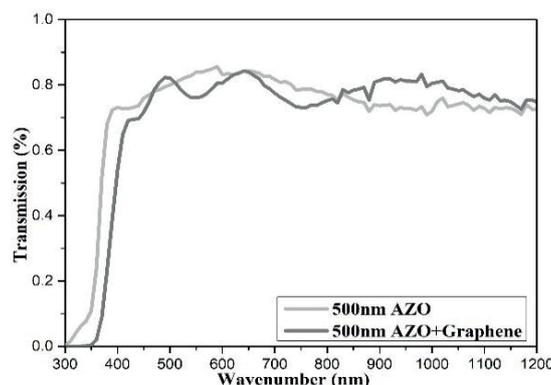


Figure 1. 500 nm AZO and 500 nm AZO+graphene optical transmission graph

References

- [1] A.K. Geim, K.S. Novoselov, The rise of graphene, Nanoscience and technology: a collection of reviews from nature journals, World Scientific 2010, pp. 11-19.
- [2] T.J.T.s.f. Minami, Substitution of transparent conducting oxide thin films for indium tin oxide transparent electrode applications, 516(7) (2008) 1314-1321.
- [3] L. Yin, K. Zhang, H. Luo, G. Cheng, X. Ma, Z. Xiong, X.J.N. Xiao, Highly efficient graphene- based Cu (In, Ga) Se 2 solar cells with large active area, 6(18) (2014) 10879-10886.
- [4] T.T.T. Vo, Y.-H. Ho, P.-H. Lin, Y.J.C. Tai, Control of growth mode and crystallinity of aluminium-doped zinc oxide thin film at room temperature by self-assembled monolayer assisted modulation on substrate surface energy, 15(34) (2013) 6695-6701.

Deep learning-based spectral splitting and concentration of broadband light for solar cells applications

ALİM YOLALMAZ^{1,2,3,*} and EMRE YÜCE^{1,2,3}

¹Programmable Photonics Group, Department of Physics, Middle East Technical University, 06800 Ankara, Turkey

²Micro and Nanotechnology Program, Middle East Technical University, 06800 Ankara, Turkey

³Center for Solar Energy Research and Applications (GÜNAM), Middle East Technical University, 06800 Ankara, Turkey

*alim.yolalmaz@metu.edu.tr

Spectrally bounded absorption of single-junction solar cells limits the amount of converted solar energy^{1,2}. Low overlap between emission spectrum of the sun and absorption spectrum of solar cells causes inefficient use of available energy. A phase plate generated by a spatial light modulator (SLM) which modulates incident light, spectrally disperses and spatially concentrates the broadband light on three different laterally arranged single-junction solar cells. Thus, increased overlap between the emission spectrum of the sun and absorption spectra of two or more solar cells results in better solar energy output³. However, optimization duration of a phase plate is an obstacle to implement it in solar energy. In this study, we used a deep learning architecture to reconstruct a phase plate to disperse and concentrate the broadband light on three targets. We created a training data set to develop our neural network through optimization of a phase plate with the iterative optimization algorithm. Using our neural network, we obtained 96.7% similarity between the iteratively obtained and the reconstructed phase plates. Moreover, the intensity distribution received by the neural network shows 98.9±0.3% accuracy (Figure 1). As a result of this study, we obtained more than an excess of 53.1% light intensity on the targets via the neural network (Figure 1b). Our neural network speeds up optimization duration of a broadband phase plate from 89 days² to 2 seconds.

Keywords: Wavefront shaping, deep learning, spectral splitting, spatial light modulation.

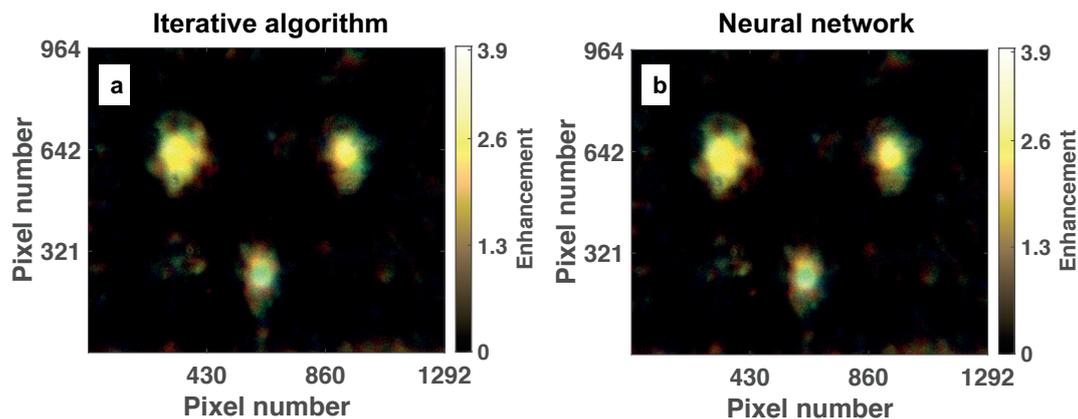


Figure 1. Intensity distribution of the broadband light on the target; (a) Iteratively obtained, (b) reconstructed by the neural network.

References

1. Shockley, W. & Queisser, H. J. Detailed Balance Limit of Efficiency of p-n Junction Solar Cells. *J. Appl. Phys.* **32**, 510–519 (1961).
2. Yolalmaz, A. & Yüce, E. Effective bandwidth approach for the spectral splitting of solar spectrum using diffractive optical elements. *Opt. Express* **28**, 12911 (2020).
3. Uzu, H. *et al.* High efficiency solar cells combining a perovskite and a silicon heterojunction solar cells via an optical splitting system. *Appl. Phys. Lett.* **106**, 013506 (2015).

REVIEW ON MODELING AND SIMULATION OF SOILING EFFECTS ON PV AND CSP MODULE PERFORMANCE

B. Laarabi¹, G.J.P. Tevi², W.C. Sinke³, A.S. Maiga² and A. Barhdadi^{1, *}

¹ Physics of Semiconductors and Solar Energy Research Team (PSES), Energy Research Center (CRE), High College for Education and Research (ENS), Mohammed V University in Rabat (UM5R), Morocco

² Gaston Berger University, Saint Louis, Senegal

³ Institute of Physics, University of Amsterdam, Netherlands

*Corresponding Author's E-mail: abarhdadi@yahoo.fr

The effects of soiling on the performance of solar installations are a subject of rapidly increasing importance and interest. Many researchers around the world work on measurement, analysis, modeling and mitigation of these effects in order to make accurate yield predictions and develop optimal maintenance strategies. This, in turn, is important for risk and uncertainty reduction in large-scale investments. Many reviews of literature in parts of this broad field summarizing the state of the art and supporting researchers in further studies have been published. However, although modeling of soiling effects is addressed in a significant part of the studies published, no systematic review of this part of literature has been performed yet. The review work reported here is entirely focused on the modeling and simulation of soiling effect on PV (Photovoltaics) and CSP (Concentrated Solar Power) module performance. It aims at serving as a reference for future studies.

Highlights

- Summary and analysis of research papers published from 1998 to 2018;
- Published studies have been gathered into groups and the modeling trend has been determined;
- Published papers have been classified and the different parts of modeling of soiling have been identified;
- Interesting perspectives and recommendations for future research works have been presented.

Keywords: Soiling, Modeling, Prediction, PV modules, CSP modules, Performance.

Control of spatial phase empowering spectral splitting and concentration of solar spectrum

Berk Nezir Gun^{1,2,*} and Emre Yuçe^{1,2,+}

¹ Programmable Photonics Group, Department of Physics, Middle East Technical University, 06800, Ankara, Turkey

² The Center for Solar Energy Research and Applications (GÜNAM), Middle East Technical University, 06800, Ankara, Turkey

*gun@metu.edu.tr

+eyuce@metu.edu.tr

Harvesting energy from a broad-spectrum light with high efficiency is a long-standing endeavor given the increasingly important energy source yet to be exploited further: sunlight. No material alone can derive energy from a broadband light with high efficiency. That being the case, the methods benefitting from spectral sub-bands together with concentration are in demand to utilize record level efficiency in photovoltaic cells¹. It is possible to get these sub-bands by portioning a broadband light through spectral splitting². Spectral splitters are generally realized via computational methods. Here, we present an experimental method to spectrally split and concentrate broadband light via controlling the wavefront of the incident light. We have chosen particular concentration spots for red (560 nm - 875 nm), green (425 nm – 620 nm), and blue (420 nm – 535 nm) frequency bands within the broad-spectrum. Encoding different diffractive patterns onto the SLM, we manage to generate dynamic phase plates that enable experimental control on the spatial phase of the incident light. The concentration of light is achieved with a total enhancement factor of 564 %. The spectral splitting ratios that we obtain are 43 %, 37 % and 34 % for red, green, and blue channels, respectively. The method that we offer is faster than the computational methods given the fast response time of the spatial light modulator within 17 ms. This duration is much shorter than the time spent for calculating diffractive optical elements³. We provide an experimental method that can increase the impact of diffractive optical elements (DOE) by providing the means to design efficient and effective DOEs within a very short time. Thereby, the output intensity profile of light that passes through the phase plate is measured and altered within this short duration providing a faster total computational time than a calculation of the output intensity distribution at the target plane. This study is financially supported by The Scientific and Technological Research Council of Turkey (TÜBİTAK), grant no 118F075.

Keywords: wavefront shaping, spectral splitting, spatial light modulator, diffractive optical element

References

- [1] Geisz, J.F., France, R.M., Schulte, K.L. *et al.* Six-junction III–V solar cells with 47.1% conversion efficiency under 143 Suns concentration. *Nat Energy* 5, 326–335 (2020).
- [2] Mojiri, A., Taylor, R., Thomsen, E. & Rosengarten, G. Spectral beam splitting for efficient conversion of solar energy - A review. *Renew. Sustain. Energy Rev.* 28, 654–663 (2013).
- [3] Yolalmaz, A. & Yuçe, E. Effective bandwidth approach for spectral splitting of solar spectrum using diffractive optical elements. *Opt. Express* DOI: 10.1364/OE.381822 (2020).

IMPACT of RbF POST DEPOSITION TREATMENT on CdS/CIGSe and Zn(O,S)/CIGSe INTERFACES – A COMPARATIVE HAXPES STUDY

Bünyamin Ümsür^{1,*}, Natalia Maticiuc², Tim Kodalle², Isheta Majumdar², Yajie Wang², Robert Wenisch², Hasan A. Yetkin², Tobias Bertram², Christian A. Kaufmann², Rutger Schlatmann^{2,3}, Iver Lauermann²

¹ Yozgat Bozok University/Department of Physics and BILTEM, Yozgat, Turkey

² Helmholtz Zentrum Berlin für Materialien und Energie (HZB)/Competence Center Photovoltaics Berlin (PVcomB), Berlin, Germany

³ Hochschule für Technik und Wirtschaft Berlin, Berlin, Germany

*Corresponding Author: bunyamin.umsur@yobu.edu.tr

Thin film solar cells based on Cu(In,Ga)Se₂ (CIGSe) absorbers have reached a record efficiency exceeding 23% on the laboratory scale [1]. Since the first record achievement by using a so-called KF post deposition treatment (PDT) on CIGSe absorbers [2], a lot of effort has been made to understand the beneficial effects of KF as well as the other heavy alkali fluoride PDTs, e.g. CsF [1] or RbF [3].

In conventional CIGSe solar cells a chemical bath deposited CdS thin film is used as a buffer layer. However, it is desired to replace CdS due to the toxicity of cadmium and the rather narrow bandgap energy of CdS. Zn(O,S) is considered to be one of the most attractive candidates as a non-toxic buffer layer with a larger bandgap.

In this work, we aim to compare the properties of the CdS/CIGSe and the Zn(O,S)/CIGSe interfaces depending on the absorber composition and an RbF-PDT. Synchrotron-based hard x-ray photoemission spectroscopy (HAXPES) revealed a strong correlation between Cd diffusion and V_{Cu} concentration in CIGSe before the PDT. Additionally, the RbF-PDT led to an enhanced Cd diffusion into the CIGSe. On the other hand, it was found that Zn atoms are not as easily incorporated into the CIGSe as Cd atoms. As a result, we consider the formation of donor-like Zn_{Cu}⁺ defects at the interface to be less likely than the formation of Cd_{Cu}⁺ defects. In summary, it was observed that the Zn(O,S)/CIGSe interface is less sensitive to changes of the CIGSe composition and to the RbF-PDT compared to the CdS/CIGSe interface. The similarities and the differences will be discussed on the basis of our experimental findings.

Keywords: Thin film solar cells, Cu(In,Ga)Se₂, RbF-PDT, Zn(O,S), CdS, HAXPES, interface

References

- [1] M. Nakamura, K. Yamaguchi, Y. Kimoto, Y. Yasaki, T. Kato, H. Sugimoto, Cd-Free Cu(In,Ga)(Se,S)₂ thin-film solar cell with record efficiency of 23.35%, IEEE J. Photovoltaics. 9 (2019) 1863–1867.
- [2] A. Chirilă, P. Reinhard, F. Pianezzi, P. Bloesch, A.R. Uhl, C. Fella, L. Kranz, D. Keller, C. Gretener, H. Hagendorfer, D. Jaeger, R. Erni, S. Nishiwaki, S. Buecheler, A.N. Tiwari, Potassium-induced surface modification of Cu(In,Ga)Se₂ thin films for high-efficiency solar cells., Nat. Mater. 12 (2013) 1107–1111.
- [3] P. Jackson, R. Wuerz, D. Hariskos, E. Lotter, W. Witte, M. Powalla, Effects of heavy alkali elements in Cu(In,Ga)Se₂ solar cells with efficiencies up to 22.6%, Phys. Status Solidi (RRL). (2016) 1–4.

Production and investigation of the flexible dye-sensitized solar cells by using binder-free TiO₂ paste as photoanode material

Caner İldeş¹, Hatice Kanbur Çavuş²

1 Science & Technology Application and Research Center (BİLTEM), Bozok University, Yozgat, Turkey

2 Department of Physics, Faculty of Arts and Sciences, Bozok University, Yozgat, Turkey

.....

*"CANER İLDEŞ" <caner.ildes@bozok.edu.tr>;

Flexible DSSCs have created a new alternative for solar cells with very important advantages such as lightness, good flexibility, less cost, lower temperature and large scale production etc., and their efficiency is around %12,3 [1]. But flexible substrates deform when the temperature is above 150 degrees. Generally, particle interconnections are not sufficient at such a low temperature and the presence of organic residues will result in more recombination and shorter electron life [2]. Therefore, to solve this problem, a binder-free TiO₂ paste was prepared in this study that could make contact more easily at low temperature, and flexible photo anodes were produced at low temperature using this paste. The low-temperature TiO₂ paste has been prepared using TiO₂ powder, DI water, t-butanol, pH = 4.6 HCl, and ethanol. The low-temperature TiO₂ paste has been coated on flexible PET/ITO substrates. The structural and morphological properties of these flexible films have been characterized by XRD and SEM measurements, respectively. These flexible films have been sensitized with Ruthenizer N719 dye for 48 hours. Pt counter electrode has been prepared using Pt salt and NaBH₄ with a chemical reduction technique on flexible PET/ITO substrates. Then, this flexible photoanode and Pt counter electrode have been combined and electrolyte (AN50) has been applied between two electrodes (Fig.1). The characteristic values of J_{sc}, V_{oc}, FF, and conversion efficiency (η) have been obtained 4.5 mA/cm², 527 mV, 0.46, and 1.1 % respectively for the flexible DSSC with 0.12 cm² active area. This research maybe followed by more studies which is one of our targets to produce photo electrodes that provide better efficiency by preparing TiO₂ pastes with different methods at low temperature.

Keywords: DSSC, Flexible Photoanode, Low temperature TiO₂ paste, efficiency

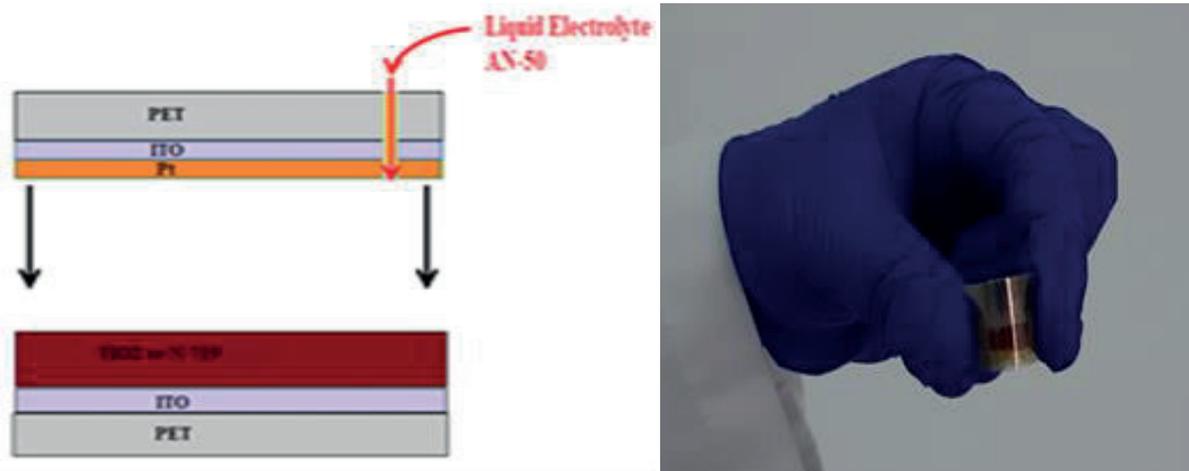


Figure 1. Flexible DSSC Schematic Display, and Produced Flexible DSSC

References

- [1] S. Zhang, J. Jin, D. Li, Z. Fu, S. Gao, S. Cheng, X. Yu, Y. Xiong Increased power conversion efficiency of dye-sensitized solar cells with counter electrodes based on carbon materials RSC Adv., 9 (2019)
- [2] Zhang, P., Wu, C., Han, Y., Jin, T., Chi, B., Pu, J., Jian, L.,., Low temperature preparation of Hierarchical Structure TiO₂ for flexible dye-sensitized solar cell. J. Am. Ceram. Soc., 95(4), 1372-1377 (2012)

Laser Crystallization of α -Ge thin-film via Nanosecond Pulsed Infrared Laser

Ceren Korkut¹, Kamil Çınar², İsmail Kabaçelik^{3,4}, Raşit Turan^{1,4}, Mustafa Kulakcı^{5,6} and Alpan Bek^{1,4}

¹ Physics Department, Middle East Technical University, 06800 Ankara, Turkey

² Faculty of Engineering and Natural Sciences, Maltepe University, Maltepe, 34857, İstanbul, Turkey

³ Department of Medical Services and Techniques, Vocational School of Health Services, Bartın University, 74100, Bartın, Turkey

⁴ Center for Solar Energy Research and Applications (GÜNAM), Middle East Technical University, 06800 Ankara, Turkey

⁵ Department of Physics, Eskişehir Technical University, 26470 Eskişehir, Turkey

⁶ Institute of Earth and Space, Department of Physics, Eskişehir Technical University, 26470, Eskişehir, Turkey

*E-mail: cerenkorkutmetu@gmail.com

Germanium (Ge) has higher carrier mobility and lower contact resistance than silicon (Si); therefore, Ge is one of the most used semiconductors in solar cell technology and production of thin-film transistors. The crystallized semiconductor thin-films on glass substrates offer an opportunity of improving the efficiency and to reduce the material costs [1]. For this reason, different techniques have been applied to produce polycrystalline Ge (pc-Ge) such as ion beam treatment, metal induced crystallization and solid phase crystallization [2]. Unlike these techniques, using nanosecond pulsed lasers is the plausible way of changing the phases of material in short processing times. The main hypothesis to be tested in this project is to understand the dynamics of laser crystallization (LC) by a nanosecond pulsed laser. Nanosecond pulsed infrared laser crystallization of Ge thin films has been studied in ambient. LC was performed to a 300-nm thick α -Ge thin-film utilizing a 200 ns pulsed infrared laser with a wavelength of 1064 nm. The crystallinity of the thin films was examined via Raman spectroscopy, X-ray diffraction and electron backscatter diffraction analyses in a comparative manner. The crystallization and the ablation of surface starts at a fluence of 45 and 115 mJ/cm^2 , respectively. A material has lots of defect in the molten area (see Fig. 1(a)). Defects can be avoided with an optimized power parameter (see Fig. 1(b)). Our work demonstrates the crystallization of ultra-thin α -Ge films into device-quality pc-Ge thin-films that enable solar cells' viable and offer a wide range of substrate.

Keywords: thin film, germanium, laser crystallization, pulsed laser application

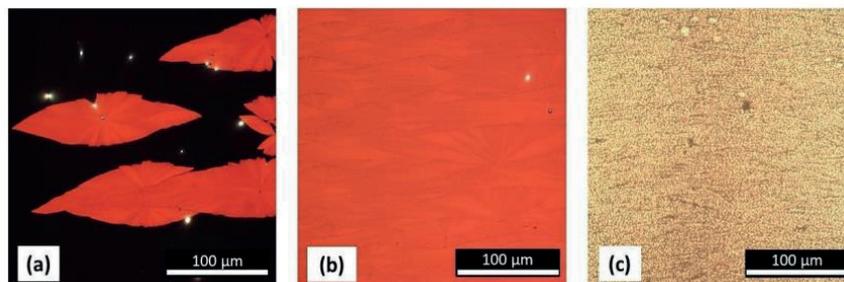


Figure 1. Microscope images of (objective is 63X) LC-Ge performed with a fluences of (a) 45 mJ/cm^2 (b) 110 mJ/cm^2 (c) 115 mJ/cm^2 .

References

- [1] Sakaike, K., Higashi, S., Murakami, H., & Miyazaki, S. (2008). Crystallization of amorphous Ge films induced by semiconductor diode laser annealing. *Thin Solid Films*, 516(11), 3595–3600.
- [2] Kabaçelik, I., Kulakcı, M., & Turan, R. (2015). Investigation of silver-induced crystallization of germanium thin films fabricated on different substrates. *Journal of Crystal Growth*, 419, 7–11.

EFFECTS OF PV POWER PLANT PENETRATIONS ON FREQUENCY AND VOLTAGE IN A DISTRIBUTION GRID

Cihan Karaman¹, Mete Çubukçu²

¹Ege University Solar Energy Institute, Izmir, Turkey

²Ege University Solar Energy Institute, Izmir, Turkey

.....

¹cihan.karaman13@gmail.com

²mete.cubukcu@ege.edu.tr

Grid frequency and voltage as a parameter of a power quality, can be affected seriously by usage of renewable and clean energy sources like solar energy power plants. In this study, consumptions of a district of Izmir located in latitude of 38,49247 and longitude of 27,07185 are created with the help of total energy consumption of Turkey. Radial network model with 20 loads having 200 kW power, is modified by changing line impedances to create strong and weak grid. The grid is feed by a central generator producing 4500 kW/h energy at %3 droop setting constantly. All loads consume energy with changing percentages in minutes and PV power plants are integrated to that load variation in order of 3%, 12%, 24%, 48%, 75% of penetration levels. Simulation is carried out during one year for the day having the most consumption in Digsilent Power Factory Software. Diffuse and global irradiance calculations done with the models Louche et.al. and Adnot-Bourges et.al. and with the integration of cloud and temperature values for selected days, shows the month of May giving the PV production mostly as 790 kWh for selected day, at 75% PV penetration level, minimum and maximum frequency levels increased 0.05 and 0.59 Hz. In strong grid, this variation changed respectively 0.032 and 0.54 Hz. In weak grid, bus voltages increased mostly by 9.5% at 75% PV penetration while 0.4% for strong grid.

Keywords: PV effect on grid, solar energy, PV penetration, radial grids

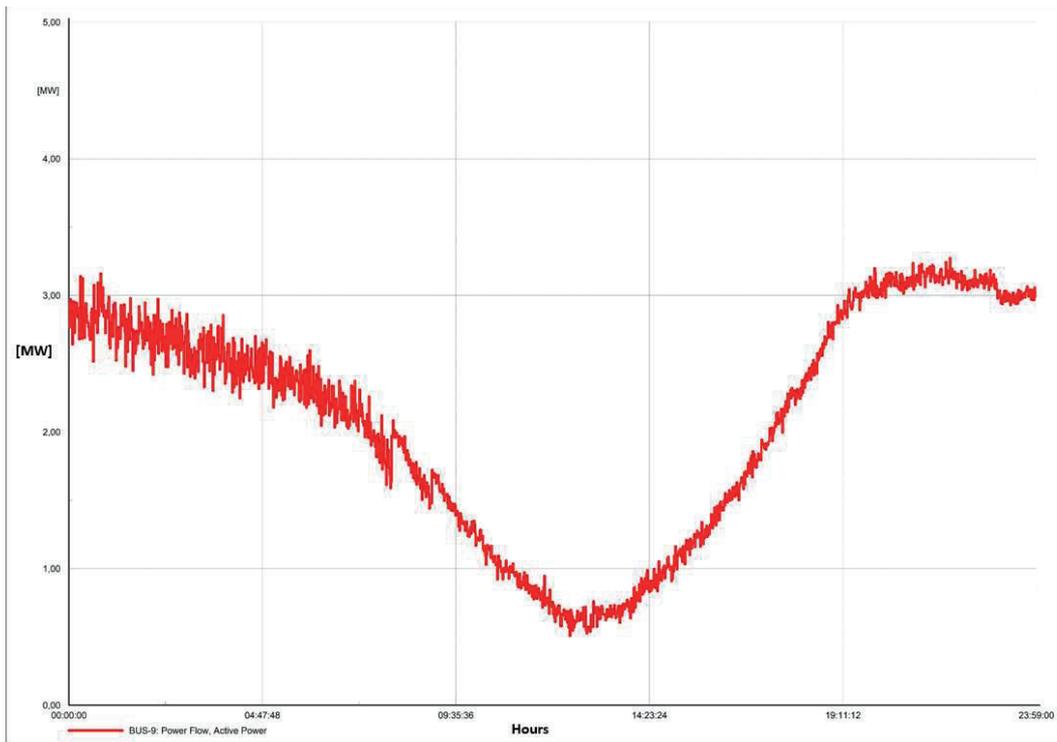


Figure 1. Active Power Flow at 75% PV Penetration for Strong Grid in May

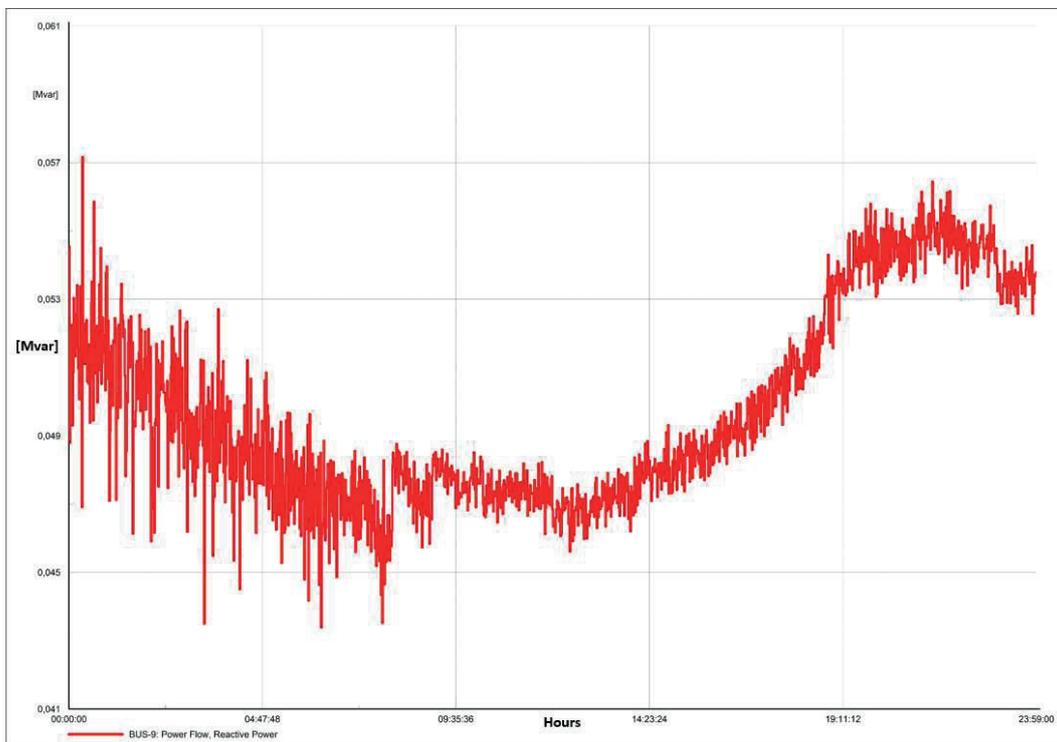


Figure 2. Reactive Power Flow at 75% PV Penetration for Strong Grid in May

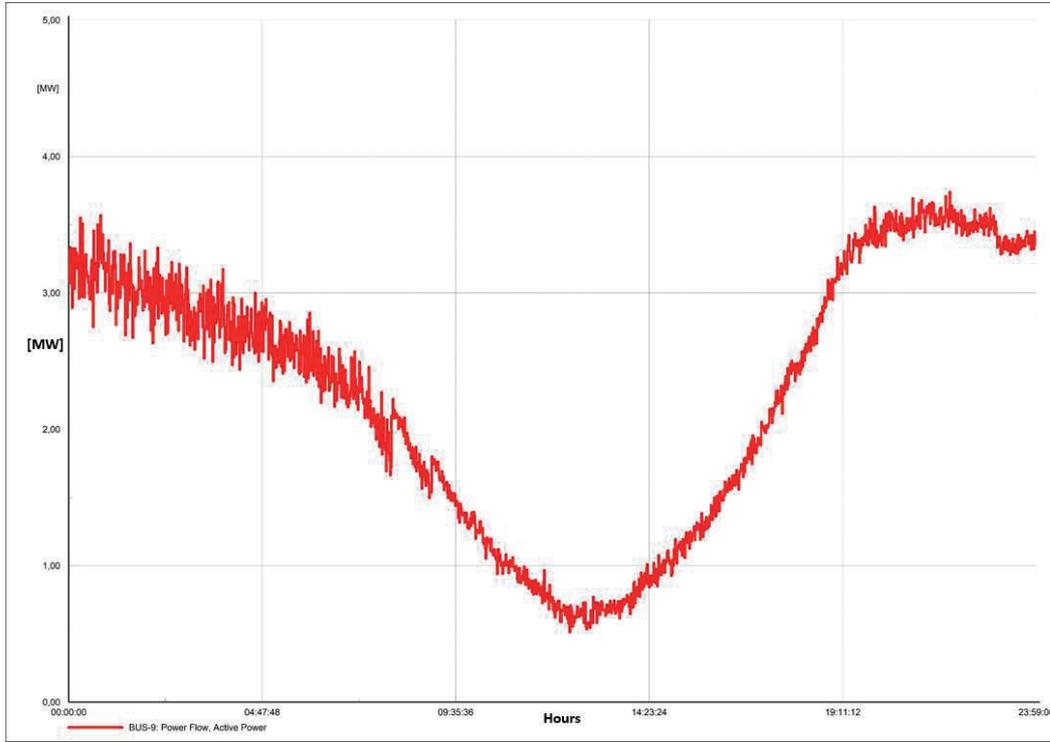


Figure 3. Active Power Flow at 75% PV Penetration for Weak Grid in May

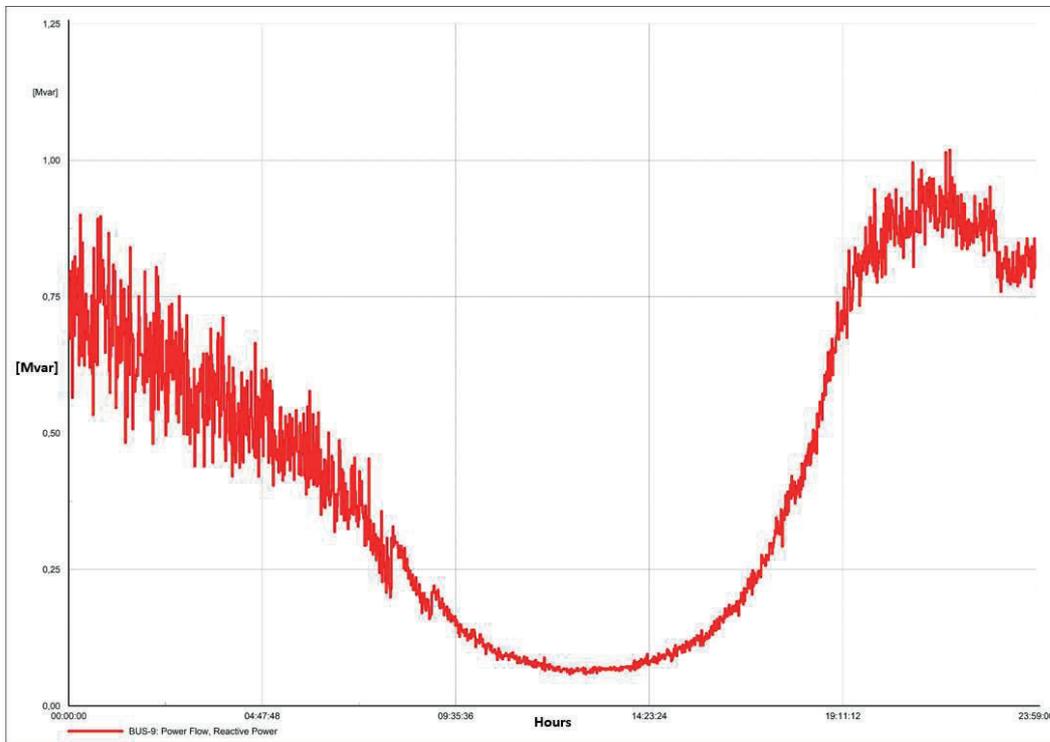


Figure 4. Reactive Power Flow at 75% PV Penetration for Weak Grid in May

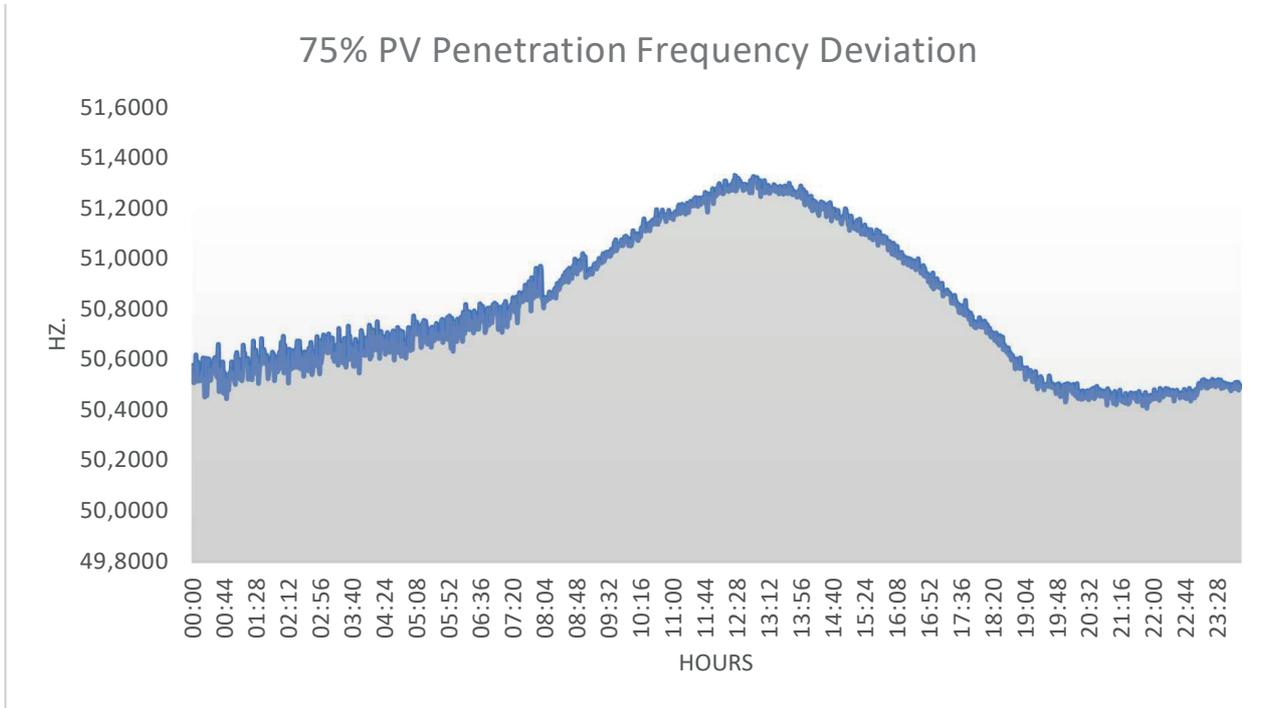


Figure 5. Frequency Deviation at 75% PV Penetration for Strong Grid in May

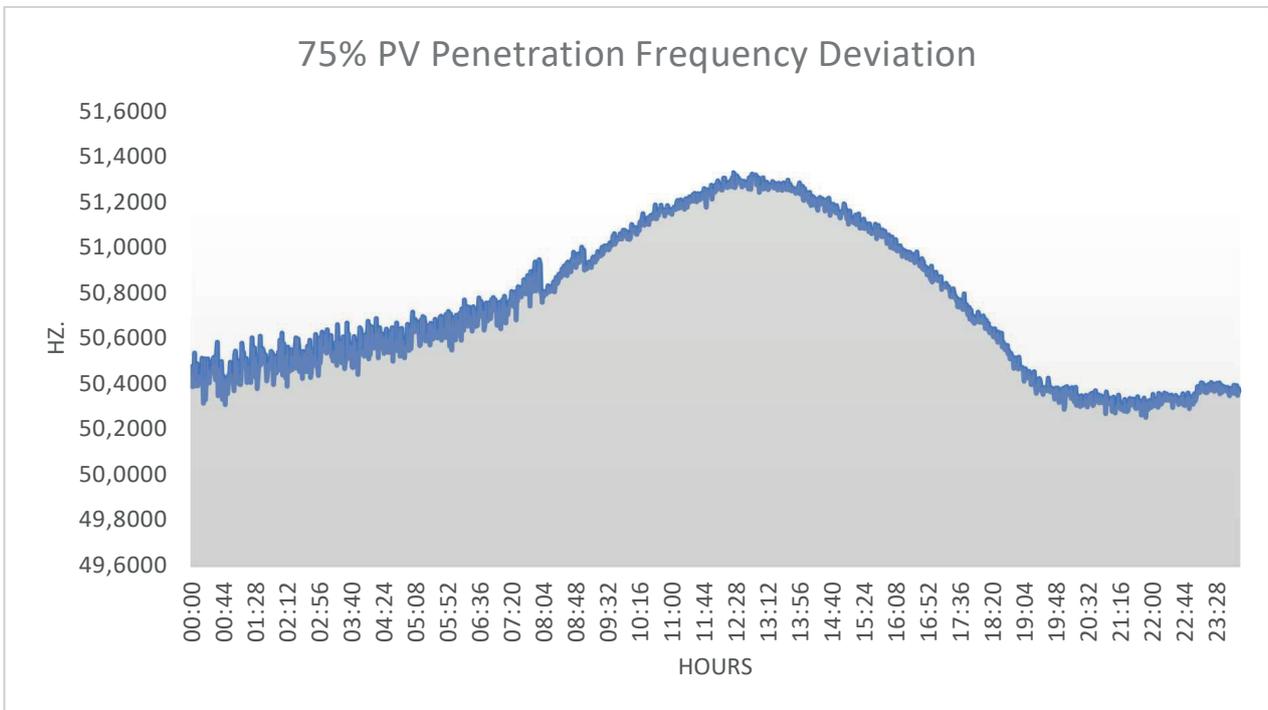


Figure 6. Frequency Deviation at 75% PV Penetration for Weak Grid in May

References

- [1] A. Etxegarai, P. Eguia, E. Torres, A. Iturregi, and V. Valverde, "Review of grid connection requirements for generation assets in weak power grids," *Renew. Sustain. Energy Rev.*, vol. 41, pp. 1501–1514, 2015
- [2] A. Woyte, V. Van Thong, R. Belmans, and J. Nijs, "Voltage fluctuations on distribution level introduced by photovoltaic systems," *IEEE Trans. Energy Convers.*, vol. 21, no. 1, pp. 202–209, 2006
- [3] M. Ebad and W. M. Grady, "An approach for assessing high-penetration PV impact on distribution feeders," *Electr. Power Syst. Res.*, vol. 133, pp. 347–354, 2016
- [4] D. Trudnowski, M. Donnelly, and E. Lightner, "Power-system frequency and stability control using decentralized intelligent loads," *Proc. IEEE Power Eng. Soc. Transm. Distrib. Conf.*, pp. 1453–1459, 2006
- [5] Y. Wang, V. Silva, and M. Lopez-Botet-zulueta, "Impact of high penetration of variable renewable generation on frequency dynamics in the continental Europe interconnected system," *IET Renew. Power Gener.*, vol. 10, no. 1, pp. 10–16, 2016
- [6] S. A. Pourmousavi, A. S. Cifala, and M. H. Nehrir, "Impact of high penetration of PV generation on frequency and voltage in a distribution feeder," *2012 North Am. Power Symp. NAPS 2012*, 2012
- [7] S. Tabatabaee, H. R. Karshenas, A. Bakhshai, and P. Jain, "Investigation of droop characteristics and X/R ratio on small-signal stability of autonomous Microgrid," *2011 2nd Power Electron. Drive Syst. Technol. Conf. PEDSTC 2011*, no. February 2011, pp. 223–228, 2011

P50/P90 ANALYSIS OF A SOLAR PV PLANT IN METU NCC USING THE EMPIRICAL METHOD AND ITS COMPARISON WITH TMY RESULTS

Deniz Gören¹, Onur Taylan^{2,3*}

¹Middle East Technical University Northern Cyprus Campus/ Sustainable Environment and Energy Systems, Mersin 10, Turkey

²Middle East Technical University Northern Cyprus Campus/ Sustainable Environment and Energy Systems, Mersin 10, Turkey

³Center for Solar Energy Research and Applications (GÜNAM), Middle East Technical University, Ankara, 06800, Turkey

*ontaylan@metu.edu.tr

Large investments of renewable energy systems have some financial risks, and energy exceedance probabilities are required to find the expected range of annual energy production (AEP) values. In this study, P50/P90 analysis was done for the 1 MW solar PV power plant in METU NCC using the System Advisor Model (SAM) software for the simulations. Three different transposition models were compared, which are the isotropic sky diffuse model, HDKR model, and Perez model. Photovoltaic Geographical Information System-Surface Solar Radiation Dataset Heliosat (PVGIS-SARAH) [1] database was used as the long-term satellite-based data, which includes the time period 2005-2016 with hourly time resolution, and a typical meteorological year (TMY) data was used to compare the results with P50 values. The interannual variability of global horizontal irradiation (GHI) was found as about 2.21%. For the AEP, the variability values were about 3.21%, 3.31%, and 3.26% for isotropic, HDKR, and Perez models, respectively. According to the comparison of TMY and P50 values, it was found that TMY underpredicted the annual GHI by 1.50%, and the AEP values by 1.28%, 1.26% and 1.37%, respectively. Figure 1 shows that using TMY dataset with the isotropic sky diffuse model leads to the lowest P50 assumption, whereas the anisotropic models estimate a higher probability of exceedance values. Future work includes validation of these results using the actual energy production data, which is measured since 2017.

Keywords: probability of exceedance, annual energy production, typical meteorological year, interannual variability

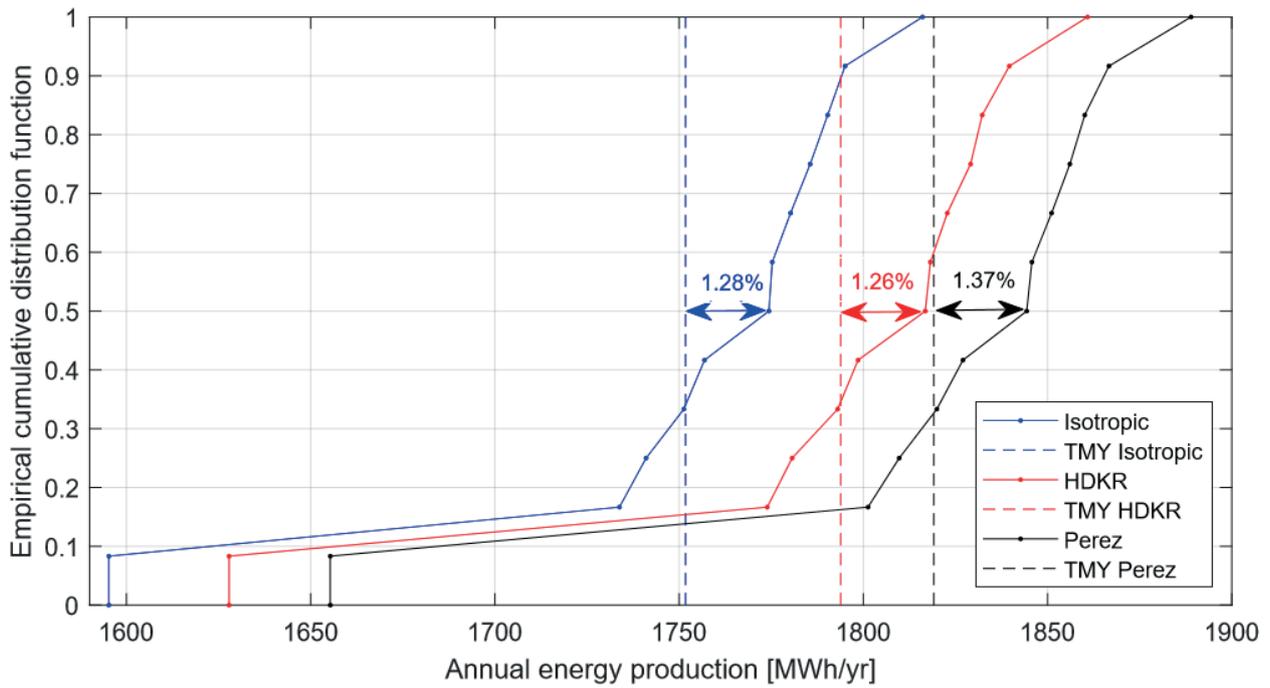


Figure 1. Empirical cumulative distribution functions of the annual energy production (MWh/yr) using isotropic, HDKR and Perez models. Double arrows show the difference between TMY and P50 values.

References

[1] T. Huld, R. Müller, and A. Gambardella, "A new solar radiation database for estimating PV performance in Europe and Africa," *Sol. Energy*, vol. 86, no. 6, pp. 1803–1815, 2012.

QUALITY ASSESSMENT OF ON-SITE SOLAR RADIATION DATA AND ESTIMATING GLOBAL TILTED IRRADIATION IN METU NCC

Deniz Gören¹, Onur Taylan^{2,3*}

¹Middle East Technical University Northern Cyprus Campus, Sustainable Environment and Energy Systems, Mersin 10, Turkey

²Middle East Technical University Northern Cyprus Campus, Mechanical Engineering, Mersin 10, Turkey

³Center for Solar Energy Research and Applications (GÜNAM), Middle East Technical University, Ankara, 06800, Turkey

*ontaylan@metu.edu.tr

Bankable datasets are required by financial institutions to guarantee investments in large-scale solar energy projects, reducing the overall uncertainty of energy yield estimates. Long-term satellite-based data is mostly available globally; however, their systematic errors and bias should be removed by integrating quality-checked ground measurements if available. In this study, a quality assessment was done to detect erroneous/ missing data points using several quality-control tests. In METU NCC, global horizontal irradiation (GHI), direct normal irradiation (DNI), and global tilted irradiation (GTI) were recorded since 2010, 2013 and 2016, respectively. Physical threshold and quality envelope tests revealed that lower-than-expected GHI values were measured in some periods. Thus, erroneous GHI data was estimated using the Erbs model [1] and measured DNI data. While up to 2 hours of missing GHI data were filled by linear interpolation, longer missing data were filled by estimated GHI. Both measured and constructed GHI data were compared with satellite-based GHI data downloaded from PVGIS [2] for the time period 2010-2016. The results indicated that the average relative root-mean-square error (rRMSE) of daily total GHI reduced from 34.63% to 17.77% after the data filing process. The rRMSE decreased to 8.78% for the annual mean daily total GHI data. Additionally, GTI was estimated using the isotropic sky-diffuse model [3], and it was compared with measured GTI. RMSE of daily total estimated GTI was 22.41%, whereas satellite-based GTI had an RMSE of 20.81%. Finally, energy yield was estimated for 1 MWp solar PV plant using satellite-based and estimated GTI in MATLAB.

Keywords: quality control tests, ground measurement, satellite-based data, global tilted irradiation

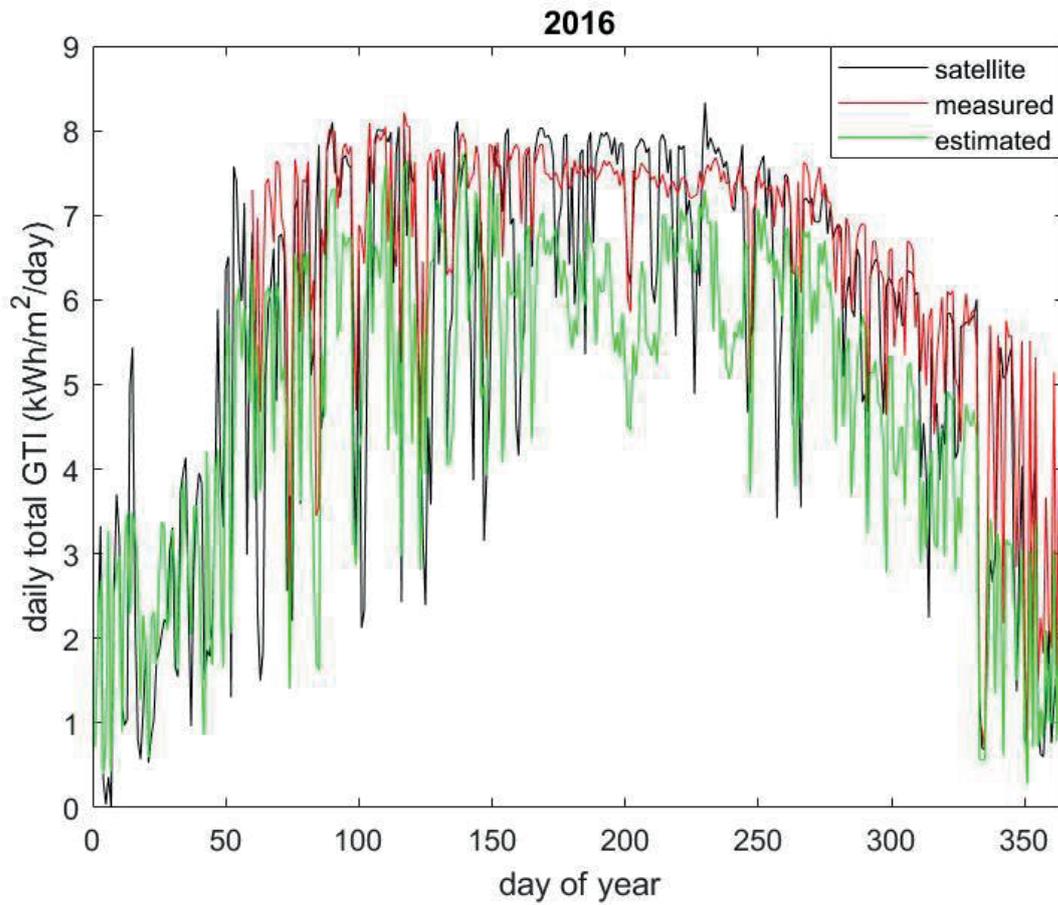


Figure 1. A comparison of daily total global tilted irradiation (GTI) of satellite-based, measured and estimated data.

References

- [1] D. G. Erbs, S. A. Klein, and J. A. Duffie, "Estimation of the diffuse radiation fraction for hourly, daily and monthly-average global radiation," *Sol. Energy*, vol. 28, no. 4, pp. 293–302, 1982.
- [2] T. Huld, R. Müller, and A. Gambardella, "A new solar radiation database for estimating PV performance in Europe and Africa," *Sol. Energy*, vol. 86, no. 6, pp. 1803–1815, 2012.
- [3] J. A. Duffie, W. A. Beckman, and J. McGowan, *Solar Engineering of Thermal Processes*, 4th ed. University of Wisconsin-Madison, 2005.

Assessment of Photovoltaic Module Temperature Estimation for Four Years in Ankara with Four Different Software

Doga Tolgay^{12*}, Samet Yakut², Talat Ozden³⁴, Bulent G. Akinoglu¹⁴⁵

¹Department of Physics, Middle East Technical University (METU), Ankara, Turkey

²Department of Electrical and Electronics Engineering, METU, Ankara, Turkey

³Department of Energy Systems Engineering, Gumushane University, Gumushane, Turkey

⁴The Center for Solar Energy Research and Applications (GÜNAM), METU, Ankara, Turkey

⁵Earth System Science Program, METU, Ankara, Turkey

* Corresponding Author Email : doga.tolgay@metu.edu.tr

The power conversion efficiencies of the photovoltaic modules are dependent on the module temperature. An increase in the module temperature results in a loss of performance for PV systems. In this case, the prediction for module temperatures before installation is very critical for techno-economic reasons. In literature, there are quite many equations that predict cell/module temperatures using environmental conditions and system parameters. Four of them are used very popular photovoltaic power plant design and yield estimation software (HOMER, Helioscope, PVsyst, PVsol) to estimate module temperature. However, there is no comprehensive study that predicts the most accurate formula for each PV technology. In this study, we compared these equations using four years of experimental module temperature data for five different types of modules, Monocrystalline Silicon (Mono-Si), Polycrystalline Silicon (Poly-Si), Copper Indium Selenide (CIS), Micro-crystalline based Amorphous Silicon ($\mu\text{-Si}$ / a-Si), Heterojunction with Intrinsic Thin layer (HIT), in semi-arid climate conditions of Central Anatolia, Ankara/Turkey. In our work, we have developed 16 different categories depending on the ambient temperature and irradiation levels and found the best formula for each PV module technology according to the environmental factors. We have reached important results on which estimation scheme is better for which module. We also discussed the common errors that estimation formulas wrong interpretation according to the irradiation and ambient temperature. Results show that the formula developed by HOMER is not suitable for a semi-arid climate. In other words, it results in larger errors for PV technologies $\mu\text{-Si}$ / a-Si, CIS, Mono-Si, and Poly-Si. When the ambient temperature is approximately lower than 0 °C, in between 0 and -10 °C, all of the formulas resulted in poor estimations, whereas estimations become trustful when the ambient temperature values are between 0°C to 25°C. In addition to that, as the irradiance levels increase, the error also increases. For irradiance levels higher than 800W/m² and an ambient temperature less than 0°C, the errors can reach up to 9.38 and 10.47 for the $\mu\text{-Si}$ / a-Si module for mean bias error (MBE) and root mean square error (RMSE) respectively. This is a clue that, whole temperature estimation formulas fail to estimate temperature accurately at extreme conditions. On the other hand, the best results are attained when the irradiance levels are low. To give an example, when irradiance is lower than 300W/m² and the ambient temperature is between 0°C and 15°C, the MBE and RMSE errors are 1.66 and 2.20 respectively for HOMER temperature model.

Keywords: photovoltaic module, module temperature, temperature variance

TECHNICAL POTENTIAL OF RESIDENTIAL ROOFTOP SOLAR PHOTOVOLTAIC FOR ANKARA: A PRELIMINARY STUDY

E.Ceren Kutlu¹, Beyza Durusoy^{2,4}, Bulent G. Akinoglu^{3,4},

¹ Middle East Technical University/Earth System Science , Ankara, Turkey

² Middle East Technical University/Micro and Nanotechnology , Ankara, Turkey

³ Middle East Technical University/Earth System Science , Ankara, Turkey

⁴The Centre for Solar Energy Research and Applications (GÜNAM), Ankara, Turkey

.....

*Corresponding Author's E-mail: kutlu.ceren@metu.edu.tr

Cities are responsible for over two-thirds of total energy consumption due to the population's externalities. The buildings in the urban areas cause half of this energy consumption. Two hundred fifty cities have a 100% renewable energy target worldwide, including nineteen metropolitans such as London, Los Angeles, Tokyo, and Paris aim at zero emissions in new buildings by 2030 and the existing ones by 2050. As policymakers emphasize, more decentralized solutions as city-wide and municipality-based policies would provide faster and more effective results to reach renewable energy targets.

This study focuses on both building types and roof types by obtaining constants from samples to generalize for all buildings in a city. We develop an accurate methodology to determine the residential rooftop technical PV potential, reliable, and applicable to every type of roof. We categorized residential buildings in Ankara as pitched roof apartments, flat roof apartments, and detached houses. After the manual selection, the presented methodology is into the well-known Helioscope software program. Suitable area constants (access factors) are determined for the three categories due to three sub-types of modules: Mono-Si, Poly-Si, and Bifacial modules. We applied the constant value method to create a generic constant for all buildings. The results indicate that the Mono-Si module application is the optimum for pitched-roof and flat-roof apartments, whereas bifacial modules have better results for detached houses. Further techno economical analysis should be carried out.

Keywords: Rooftop PV, solar energy, solar potential, building solar potential, bifacial

References

1. Nandi A, Mandal S, Ghosh S, Dhar S, Majumdar S, Saha H, et al. Application of hybrid rGO-ITO bilayer TCO on a-Si solar cell for performance enhancement. *IEEE Journal of Photovoltaics*. 2018;9(1):12-7.
2. Yin Z, Zhu J, He Q, Cao X, Tan C, Chen H, et al. Graphene-based materials for solar cell applications. *Advanced energy materials*. 2014;4(1):1300574.
3. Singh E, Nalwa HS. Stability of graphene-based heterojunction solar cells. *Rsc Advances*. 2015;5(90):73575-600.

Efficient Green OLEDs based on Thermally Activated Delayed Fluorescence Butterfly-shape Emitter

Eda Alemdar Yılmaz¹, Parisa Sharif², Görkem Günbaş¹, Ahmet Oral³, Ali Çırpan^{1,2,4,5}

¹ METU/Department of Chemistry, Ankara, Turkey

² METU/Department of Micro and Nanotechnology, Ankara, Turkey

³ METU/Department of Physics, Ankara, Turkey

⁴ METU/ Center for Solar Energy Research and Applications, Ankara, Turkey

⁵ METU / Department of Polymer Science and Technology, Ankara, Turkey

*ealemdar@metu.edu.tr

Luminescent butterfly shape benzophenone derivatives have small energy gaps between their singlet and triplet excited states, and they are used regarding thermally activated delayed fluorescence organic light-emitting diodes. (TADF OLEDs). In this study, benzophenone derivative small molecules were designed and synthesized to achieve efficient TADF OLEDs. These molecules were used in the emissive layer as a guest material. Graphene anodes are promising candidates for replacing indium tin oxide anodes in next-generation flexible organic light-emitting diodes (OLEDs). However, OLEDs with graphene anodes suffer from low luminous efficiency due to their low work function and high sheet resistance. This paper presents a method for the fabrication of flexible OLEDs with graphene anodes on PET substrate for exhibiting high work function, low sheet resistance, low turn-on voltage, and high luminance. After optimizing a single-layer graphene growth process on a flexible substrate, OLEDs are fabricated by stacking 8-layers of optimized graphene films and doped with nitric acid to reduce the sheet resistance. The fabricated anodes are characterized using a conventional Hall Effect Measurement System (HEMS). The device architecture of PET/Graphene/ α -NPD/CBP: SM1/TPBI/LiF/Al has reached 4.8 V turn-on voltage and 14800 cd/m² max luminance value. We believe that these results may be the starting point of next-generation flexible organic optoelectronics where graphene anodes are used.

Keywords: TADF, OLEDs, Graphene anode, benzophenone derivatives

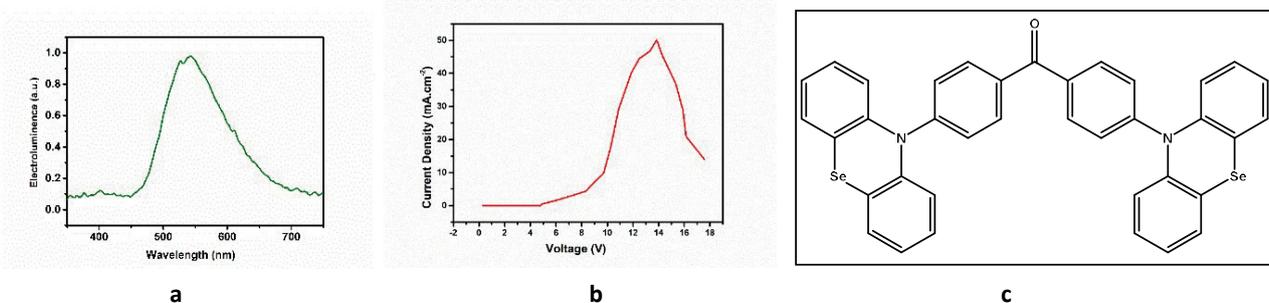


Figure 1. a) Electroluminescence vs. wavelength graph b) Current Density vs. wavelength graph, c) molecular structure of SM1

References
[1] N. J. Turro, V. Ramamurthy, J. C. Scaiano, Modern Molecular Photochemistry of Organic Molecules, University Science Books, Sausalito, 2010.

A CONCENTRATING MINI SOLAR POWER SYSTEM TO OVERCOME THE MARKET SHARE

Elsen Aydın^{1,2}, Bilge Tuncel^{1,3} and Bulent G. Akinoglu^{1,4,5}

¹ Centre for Solar Energy Research and Application, Middle East Technical University, Ankara,

² Archaeometry, Middle East Technical University, Ankara, Turkey

³ Energy Engineering, Ankara University, Ankara, Turkey

⁴ Department of Physics, Middle East Technical University, Ankara, Turkey

⁵ Earth System Science Program, Graduate School of Natural and Applied Sciences, Middle East Technical University, Ankara, Turkey

.....

*bulo@metu.edu.tr

Fresnel lenses are known and used for many years; yet the commercialization, especially in photovoltaic application is not well researched and analyzed. On the other side, although the photovoltaic power plants are rapidly entering the market, the major drawback is still the price of Si cells. In this work, we constructed a Fresnel lens of mini concentrator of around 70 sun with a one cm² standard monocrystalline Si solar cell and conducted various preliminary experiments.

The results that we observed are noteworthy as follows: at medium concentration, if the temperature is not controlled well very rapid degradation or even null-functioning of the cell is un-avoidable. Without a thermal sink structure at the back side of the cell, the temperature can raise up to 350 °C in minutes. With the metal sink structure covering the cell, the temperature rises up to 175 °C within a few minutes. However, with a thermal water-cooling system that we constructed, the equilibrium temperature can be kept at 65 °C, which can further be adjusted by proper thermal sink and cooling design.

Keywords: Renewable energy, Fresnel lens, Si cell, CPV-T system

MONITORING AND ASSESSMENT OF DAILY AND SEASONAL PHOTOVOLTAIC HEAT ISLAND EFFECT ON SEKBANDEMIRLI RURAL REGION IN KUTAHYA, TURKEY

Emre Demirezen^{1,4}, Talat Özden⁴, Bülent G. Akınoglu^{1,2,4}

¹ Middle East Technical University - Earth System Science Department, Ankara, Turkey

² Middle East Technical University - Physics Department, Ankara, Turkey

³ Gümüşhane University - Electrical and Electronics Eng. Dep., Gümüşhane, Turkey

⁴ Middle East Technical University - Center for Solar Energy Research and Applications (GÜSAM), Ankara, Turkey

^{*}denre@metu.edu.tr

Dark-colored solar modules of PhotoVoltaic Power Plants in large numbers cover a rural region's natural land surface. Thus, an artificial albedo (reflectivity) change is expected on that surface. Because of the heat exchange between these modules and the air surrounding them due to this albedo alteration, the region's natural weather conditions may experience PhotoVoltaic Heat Island Effect as a result of external and time-dependent air temperature oscillations caused by the warming-cooling cycles of solar modules. We have been conducting a research project since October 2017 for a PhotoVoltaic Power Plant near the Sekbandemirli rural region to observe and analyze this trend. The weather data, including air temperature and wind (direction and speed) at every 10-minute and hourly intervals, are collected by the three weather monitoring stations placed on the specific locations inside and outside the power plant field. After carrying out statistical, correlational, and graphical analyses, the results show some temporal PhotoVoltaic Heat Island formations at the power plant's center daily and on a seasonal basis. Thus, we can clearly state that the plant center's air temperature tends to be warmer (up to the +4°C difference) during the daytime and colder (up to the -2°C difference) at nighttime. A graphical illustration of the Sekbandemirli rural region and the measured air temperatures for a day hour of November 2019 and a night hour of August 2019 are given in Figure 1. We also visualize the study results by simulating these temporal photovoltaic heat island formations on a microclimate simulation software called ENVI-met.

Keywords: heat island effect, air temperature, photovoltaics, solar power plant, solar module, weather station, wind direction, wind speed

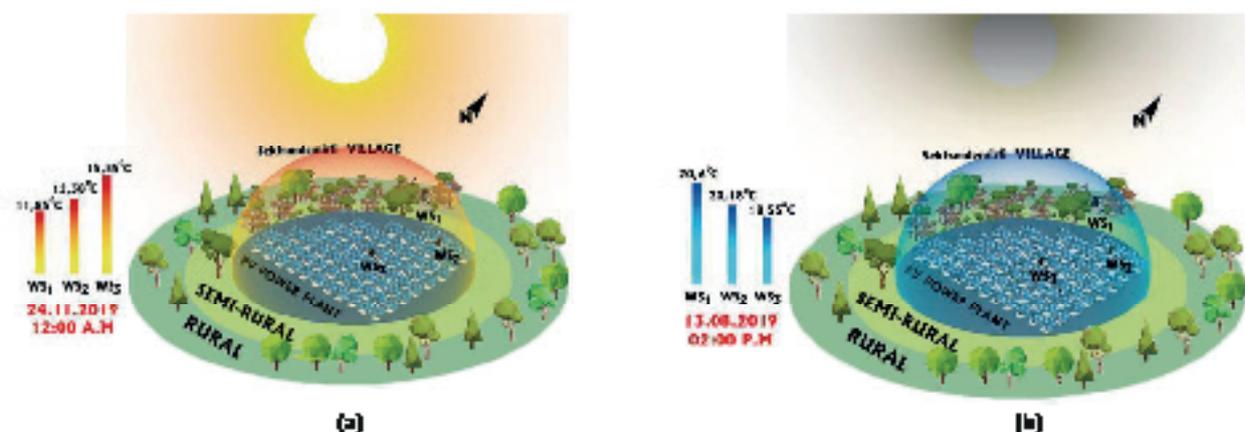


Figure 1. Photovoltaic heat island occurrences on a 2019 November day (a) and 2019 August night (b) in Sekbandemirli

References:

- [1] Ambrosini, D., Galli, G., Mancini, B., Manfà, L., Serra, S. Evaluating Mitigation Effects of Urban Heat Islands in a Historical Small Center with the ENVI-Met® Climate Model. *Sustainability*, 2014, 6 (10), 7013-7028. DOI: 10.3390/su6107013
- [2] Barron-Gaffard, G.A., France-Zackerman, M.A., Miner, B.L. et al. Agrivoltaics provide mutual benefits across the food–energy–water nexus in drylands. *Nat Sustain* 2, 2019, 2, 848–855. DOI: 10.1038/s41893-019-0364-5
- [3] Demirezen, E., Oglak, T., Akınoglu, B. G. Impacts of a Photovoltaic Power Plant for Possible Heat Island Effect, *International Conference on Photovoltaic Science and Technologies (PVCon2018)*, Ankara, Turkey, 2018. DOI: 10.1109/PVCon.2018.8523997
- [4] Wu, W., Yue, S., Zhou, X., Guo, M., Wang, J., Ren, H., Yuan, B. *Observational Study on the Impact of Large-Scale Photovoltaic Development in Oases on Local Air Temperature and Humidity*. *Sustainability*, 2020, 12 (3403). DOI: 10.3390/su12083403

Bifacial Silicon Hetero-Contact Solar Cells

Ergi Dönerçark^{1,2}, E.Hande Çiftpınar^{1,2}, Hisham Nasser², Argahavan Salimi^{1,2}, İsmail Kabaçelik², Raşit Turan^{1,2,3}

¹Middle East Technical University (METU), Micro and Nanotechnology Department, 06800 Ankara, Turkey

²Centre for Solar Energy Research and Applications (GUNAM), Middle East Technical University, 06800 Ankara, Turkey

³Middle East Technical University (METU), Department of Physics, 06800 Ankara, Turkey

* ergidonercark@gmail.com

Silicon Heterojunction (SHJ) solar cells are still a favored technology due to their high conversion efficiency and low-cost process flow [1]. For interdigitated back contact and SHJ solar cells, 26.7% [2] and 25.6% [3] conversion efficiencies were recorded in recent years. The device properties such as minority carrier lifetime, contact resistivity and optical properties should be improved simultaneously to achieve higher conversion efficiencies. In this study, industry compatible processes flow was used to fabricate large-area silicon heterojunction (SHJ) solar cells on n-type CZ wafers. The passivation properties of a-Si:H layer was improved by hydrogen plasma treatment resulting in a lower interface defect density and higher "H" content with $_{imp}V_{oc}$ higher than 735 mV. Beside deposition of standard p-type a-Si:H for the formation of emitter, p-type a-SiC_x:H layer with relatively higher band gap value (1.9-2.0 eV) were tried in SHJ solar cell structure to improve parasitic losses coming from window layer. Furthermore, properties of ITO layer were enhanced by integrating partial oxygen pressure resulting higher mobility and lower carrier density. Ag metal contacts were formed by screen printing method with using mask designed as finger and busbar width; 45 μm and 0.8 mm respectively. Specific contact resistivity (ρ_c) value for screen printed low temperature Ag contacts was decreased down to 0.4 mΩ.cm².

Carrier selective contacts are currently investigating intensively by many research groups where the carrier selective contacts enable to pass one of the carrier from silicon while blocking the other. In this study, MoO_x was used as a hole selective contact and LiF_x/Al was used as an electron selective contact. Stack layer passivation quality of a-Si:H with carrier selective contacts were determined under various thickness for both carrier selective contacts.

In large-area bifacial SHJ solar cells, we have achieved conversion efficiencies of **20.8%** for standard SHJ solar cell, **20.3%** for hole selective contact heterojunction solar cell and **19.8%** for SHJ solar cell with p-type a-SiC_x:H.

Keywords: SHJ solar cell, bifacial, carrier selective contacts, a-Si:H, passivation, MoO_x, LiF_x/Al

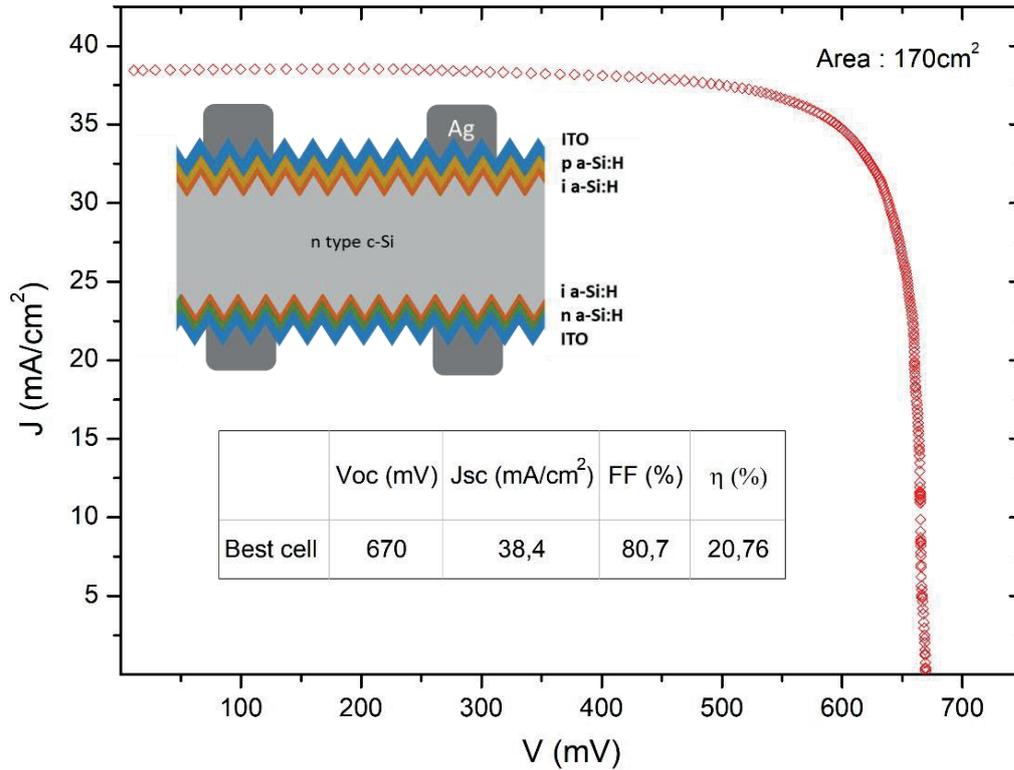


Figure 1. Record SHJ solar cell J-V curve and parameters.

References

- [1] J. Haschke, O. Dupré, M. Boccard, and C. Ballif, "Silicon heterojunction solar cells: Recent technological development and practical aspects - from lab to industry," *Sol. Energy Mater. Sol. Cells*, vol. 187, no. August, pp. 140–153, 2018, doi: 10.1016/j.solmat.2018.07.018.
- [2] M. A. Green, E. D. Dunlop, J. Hohl-Ebinger, M. Yoshita, N. Kopidakis, and A. W. Y. Ho-Baillie, "Solar cell efficiency tables (Version 55)," *Prog. Photovoltaics Res. Appl.*, 2020, doi: 10.1002/pip.3228.
- [3] K. Masuko et al., "Achievement of more than 25% conversion efficiency with crystalline silicon heterojunction solar cell," *IEEE J. Photovoltaics*, vol. 4, no. 6, pp. 1433–1435, 2014, doi: 10.1109/JPHOTOV.2014.2352151.

Review of Socio-Economic Impacts of PV Technology Development in the Developing Countries Context

Erkan Erdil^{1,3}, Pınar Derin Güre¹, Ramazan Sarı², Yelda Erden Topal^{3*}

¹ Middle East Technical University/Department of Economics, Ankara, Turkey

² Middle East Technical University/Department of Business Administration, Ankara, Turkey

³ Middle East Technical University/Science and Technology Policies Research Center, Ankara, Turkey

*Corresponding Author's Email: yeldae@metu.edu.tr

Turkey's 2023 targets, for 100 Anniversary of the Republic, are shaped on fundamental pillars of economic growth, employment and exports. Besides, 11th Development Plan aims to reflect the national sustainable development goals to the sectoral and thematic policy documents, and put special emphasis on solar energy. Moreover, supporting renewable energy production in terms of energy supply security is highlighted, and solar energy has a unique role in the current national energy plan and strategy documents. The fact of energy import dependency frames this tendency. According to the 2015 World Bank data, 75% of Turkey's total energy use is provided by imported sources. 21.55% of the import costs in 2019 is due to the energy sources. In this sense, it is of great importance to reduce energy imports, which constitute a large percentage of our imports and increase our current account deficit problem, and to switch to domestic production. Also, according to IRENA's "Renewable Energy and Employment 2019 Report", while employment decreased in 2019 worldwide, employment in the renewable energy sector increased. Nevertheless, for Turkey employment figures in the renewable energy sector has dropped in 2018. In this sense, it is crucial to the development of new technologies in solar energy to decrease import dependency and increase employment. Considering the energy dependency problem in Turkey, the expansion of domestic production of solar energy and technology will affect economic growth and employment positively. Within the scope of this paper, the analysis of the possible socio-economic impacts of the development of solar energy and related technologies will be carried out by a comprehensive literature review in the context of developing countries as a part of Turkey PV Technology Platform (TFTP) Socio-Economic Impact Assessment.

Keywords: Turkey, PV technology, Export, Employment, Economic Growth, Socio-Economic Impacts

Designing of an on-grid and off-grid PV system with battery

Eyup Taymur¹, Raimon O. Bawazir² and Numan S. Çetin³

¹TemoPower Company, New Jersey, USA

^{2,3}Solar Energy Institute/EGE University, Izmir, Turkey

³raimonengineer@gmail.com

This paper presents a control methodology for small power Photovoltaic (PV) system which can work off-grid and on-grid considering the amount of household energy consumption. The system components are 20 PV panels with 250 W and 8 batteries with 55 Ah. In this study, the design of the PV system is not like classic off-grid or on-grid PV systems. It depends on the grid up to the minimum level due to the different operating characteristics at four different periods of a day. The required battery capacities are also maintained minimum level through improved control method. The control unit of the system measures the consumption of the loads, the charge level of the batteries and grid constantly. So, the batteries are being charged only for a few hours in the morning and they are only being discharged in the evening peak hours. This control unit provides energy management. The Fuzzy logic is implemented to improve this performance of the control unit. As the result, the system cost and payback period are reduced with this approach. It is possible to provide more successful system management according to the classic control method. In this system, the daily energy consumption of the house is nearly 2 kWh and the annual energy production of the PV system is 7600 kWh.

Keywords: PV System, energy management, fuzzy logic control, on-grid and off-grid

STRUCTURAL PERFORMANCE OF AN EXISTING BUILDING ROOF SUBJECTED TO ADDITIONAL PV PANEL LOAD

Fatemeh Mostofi¹, Onur B. Tokdemir², Vedat Toğan³

¹ Karadeniz Technical University, Department of Civil Engineering, Trabzon, Turkey

² Middle East Technical University, Department of Civil Engineering, Ankara, Turkey

³ Karadeniz Technical University, Department of Civil Engineering, Trabzon, Turkey

* togan@ktu.edu.tr

Turkish energy policy is at its crossroads, and the country's national energy strategy is aimed at reducing fuel import volume. Working towards this goal, solar photovoltaic (PV) panels offer clean, sustainable, and renewable solutions, using the most abundant energy resource available throughout the world. In this regard, the rooftop mounted PV panels over existing buildings can significantly contribute towards the broader production of clean energy. However, the direct PV panel installation may not be technically possible, as the additional PV panels load may exceed the allowable load carrying capacity of the existing roof. This study evaluates the structural performance of an existing building roof for carrying the additional loads imposed by PV panels. The structural performance of the roof of a conventional existing building is examined as a case study under the loads of different types of PV panels and layouts to fulfill this purpose.

Keywords: PV panel, roof, existing building, structural performance

UTILIZATION OF MoO_x/Ag LOCAL REAR HOLE COLLECTING CONTACT IN CRYSTALLINE Si PERC SOLAR CELLS

Gamze Kökbudak^{1,2}, Mona Zolfaghari Borra^{1,2}, Ahmet Emin Keçeci^{1,2}, Bülent Arıkan¹, Gence Bektaş^{1,2}, Hasan Asav^{1,2}, Raşit Turan^{1,2,3}, Hisham Nasser¹

¹ The Center for Solar Energy Research and Applications (GÜNAM), Middle East Technical University, Dumlupınar Blvd. 1, 06800 Ankara – Turkey

² Micro and Nanotechnology Graduate Program, Middle East Technical University, Dumlupınar Blvd. 1, 06800 Ankara – Turkey

³ Department of Physics, Middle East Technical University, Dumlupınar Blvd. 1, 06800 Ankara – Turkey

*kgamze@metu.edu.tr

In this study, employing sub-stoichiometric molybdenum oxide (MoO_x) as hole-collecting rear contact in p-type Cz crystalline silicon (c-Si) passivated emitter and rear cell (PERC) is extensively analyzed. PERC design is rapidly gaining more market share and is expected to become the mainstream PV industry in the coming decade [1]. The high efficiency of PERC is due to the improved rear reflectivity and reduced rear-surface recombination by integrating AlO_x/SiN_y together with local aluminum back surface field (Al-BSF). Formation of local Al/Si regions generates highly defective regions and partially reduces the rear reflectivity and passivation limiting the overall cell performance. This issue can be disregarded by incorporating hole-collecting contact, between Si and the subsequent metal contact, such as MoO_x. Only one work, up to now, is reported where hole-collecting MoO_x is utilized in PERC reaching efficiency of 20.4% [2]. This cell features MoO_x/Ag rear dot contacts defined by photolithography which is not compatible with the standard industrial cell processing where laser is used to create local rear openings (LCO) through AlO_x/SiN_y. In this contribution, standard industrial processing and equipment are employed to fabricate PERC with MoO_x/Ag local rear contacts. The use of laser to create LCO slightly damages the Si surface thus different MoO_x thicknesses are considered. PERC PV characteristics as function of MoO_x thickness demonstrate a clear correlation with different features of MoO_x such as surface coverage mainly affecting V_{oc}, contact resistivity affecting FF, and IR parasitic absorption affecting J_{sc}. The attained peak efficiency of batch of PERC, with MoO_x (15 nm)/Ag, fabricated on 90 cm² wafers, is 19.42% with V_{oc} of 626 mV, J_{sc} of 39.4 mA/cm², and FF of 78.8%.

Keywords: molybdenum oxide, hole-collecting contact, PERC solar cells

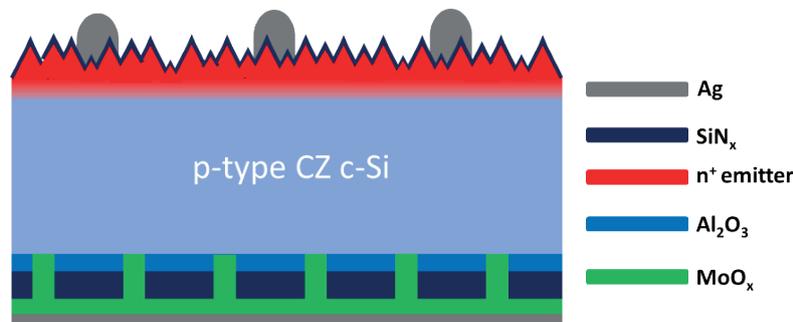


Figure 1. Schematic of the PERC solar cells with MoO_x/Ag hole-collecting local rear contact

References

1- International Technology Roadmap for Photovoltaic Results October 2020, 11th ed., Fig. 38, 2020. [Online]. Available: <http://www.itrpv.net/>

2- J. Bullock, et al., "Proof-of-Concept p-Type Silicon Solar Cells With Molybdenum Oxide Local Rear Contacts", IEEE Journal of Photovoltaics, 5 (6) 1591-1594 (2015).

SIMPLIFIED PROCESS FLOW FOR THE FABRICATION OF PERC SOLAR CELLS WITH ION IMPLANTED EMITTER

Gence Bektaş^{1,2}, Gamze Kökbudak^{1,2}, Ahmet Emin Keçeci^{1,2}, Sümeyye Koçak Bütüner¹, Hasan Asav^{1,2}, Emine Hande Çiftçınar^{1,2}, Raşit Turan^{1,3},

¹The Center for Solar Energy Research and Applications (GÜNAM), Çankaya, 06800 Ankara, Turkey

² Micro and Nanotechnology Graduate Program, Middle East Technical University, Çankaya, 06800 Ankara, Turkey

³ Department of Physics, Middle East Technical University, Çankaya, 06800 Ankara, Turkey

[*gencebektas@gmail.com](mailto:gencebektas@gmail.com)

Emitter formation by ion implantation method is attractive due to its potential to reduce the number of process steps for solar cell fabrication since it allows single side doping. The implanted PERC cells with Al₂O₃/SiN_x rear passivation layers have been reported to achieve power conversion efficiencies of about 20%. The fabrication steps of the solar cells have involved additional processes such as rear surface protection for the front surface texturing and the rear surface polishing [1][2]. In this study, we present a simplified process flow for implanted PERC cells by eliminating rear surface polishing and protection processes. We demonstrate a power conversion efficiency of 19.97% on the implanted PERC solar cell with an area of 244.3 cm².

Keywords: ion implantation, silicon solar cell, phosphorous emitter, PERC, Al₂O₃ rear passivation

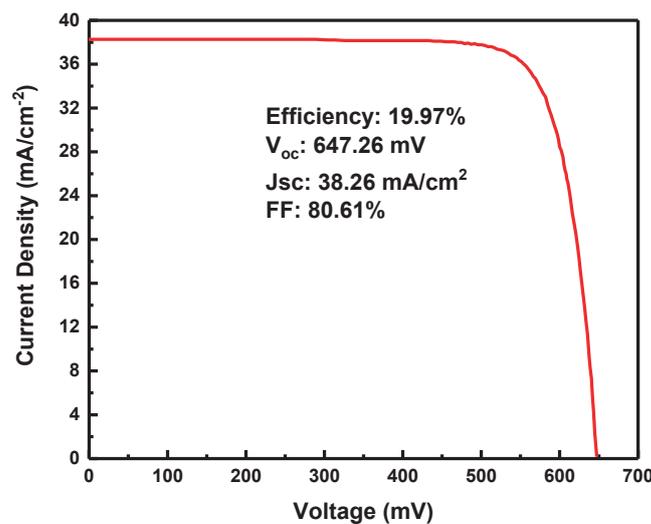


Figure 1. I-V curve of the implanted PERC cell with power conversion efficiency of 19.97%.

References

- [1] T. Dullweber, R. Hesse, V. Bhosle, and C. Dubé, "Ion-implanted PERC solar cells with Al₂O₃/SiN x rear passivation," *Energy Procedia*, vol. 38, pp. 430–435, 2013.
- [2] J. Wu, Y. Liu, X. Wang, and G. Xing, "Application of ion implanted emitter in PERC solar cells," *2015 IEEE 42nd Photovolt. Spec. Conf. PVSC 2015*, 2015.

TEMPERABLE SINGLE LAYER ANTIREFLECTION COATINGS FOR SOLAR PANEL APPLICATIONS BASED ON A DUAL ALKOXY SILANE PRECURSOR CHEMISTRY

Gizem Aydın^{1,2}, Refika Budakoğlu², Burak Okan², Kürşat Kazmanlı¹

¹ Istanbul Technical University/Metallurgical and Material Science, Istanbul, Turkey

² Sisecam Science Technology and Design Center/Kocaeli, Turkey

.....

*giaydin@sisecam.com

In this study, we investigate the production of single layer antireflective coatings using a combination of tetraethyl orthosilicate (TEOS) and methyl triethoxysilane (MTES) precursors. This hybrid chemistry allows us to tune optical properties without using chemical porosity agents. Additionally, we use a dual acidic catalyst system comprising an organic (acetic acid) and an inorganic (nitric acid) acid. This selection enables us to minimize corrosion effects on industrial scale roll-to-roll systems which frequently deploy stainless steel rolls. After the coating process, the coated glasses are cured at 100°C and then calcinate at 700°C. The effects of changing MTES/TEOS mole ratios on the colloidal sol is investigated with dynamical light scattering method and the final properties of solid films are examined in detail through optical spectrophotometry, optical microscopy and electron microscopy (SEM and TEM) techniques. Since the panel glasses are expected to be in contact with the external environment, the mechanical properties of the samples such as hardness, abrasion and scratch resistance are investigated. Finally, we present extensive durability results obtained from accelerated weathering tests. We conclude that the presented dual precursor chemistry can produce coatings which exhibit high mechanical and chemical resistance and retain their antireflection properties in an industrial tempering process.

Keywords: optical thin films, antireflection coatings, sol-gel chemistry

References

- [1] Aydın, Gizem. *Production of Single Layer Antireflective Thin Film Coatings and Investigation of Optical&Mechanical Properties*. Istanbul: Istanbul Technical University, Graduate School of Science Engineering and Technology. Master Thesis, 2020.

Efficiency Enhancement via efficient charge carrier transfer in halide perovskite solar cells fabricated by polymer additives

Hamaneh Zarenezhad¹, Timuçin Balkan^{1,2}, Navid Solati^{1,3,4}, Sarp Kaya^{1,2,3,4*}

¹ Koç University / Tüpraş Energy Center (KUTEM), 34450 Istanbul, Turkey

² Koç University / Department of Chemistry, 34450 Istanbul, Turkey

³ Koç University / Surface Science and Technology Center (KUYTAM), 34450 Istanbul, Turkey

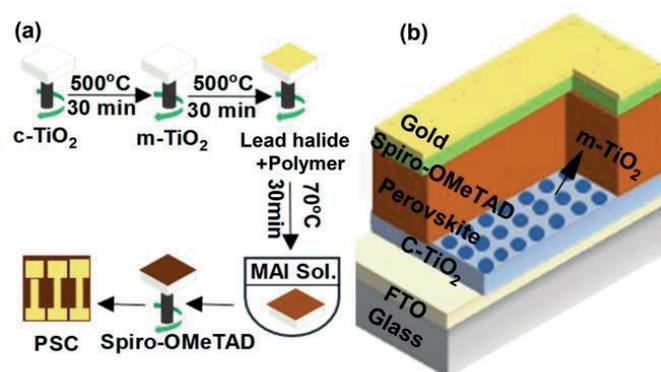
⁴ Koç University / Material Science and Engineering, 34450 Istanbul, Turkey

*sarp.kaya@ku.edu.tr

Inorganic–organic halide perovskite solar cells (PSCs) have recently attracted significant interest due to their considerable photovoltaic performance. Efficient charge carrier extraction-transfer and perovskite layer morphology play a key role in enhancing power conversion efficiency (PCE) of PSCs. Most recently, polymer additives have been used in perovskite precursor solution to modify the morphology of perovskite layer and form compact and uniform layer. In this work, polyvinylidene difluoride (PVDF) and polypyrrole (PPy) were used as ferroelectric and conductive polymer additives, respectively to manufacture PSCs via solution process. PVDF and PPy have had double roles to affect the PCE. Firstly, they caused full coverage and smooth perovskite layers. Secondly, the higher charge carrier transfer and the lower recombination losses were the advantages of using these polymer additives. Conductive pathway provided by PPy facilitates the charge carrier extraction and enhances their transfer to the perovskite layer. Besides, ferroelectric properties of PVDF boosts the charge carrier separation which resulted in the best photovoltaic performance. PCE has been raised from 10.4 % to 16.5% and to 13.2 % in ambient atmosphere with 1.0 wt. % PVDF and PPy respectively, assuring smooth and continuous perovskite layers with higher charge carrier extraction and transfer. Moreover, positive poling induced by external field directed the dipoles of PVDF and resulted in the highest PCE of 18.6 % which reveals the beneficial effect of ferroelectric polymer additive on photovoltaic performance.

Keywords: perovskite solar cells, morphology, polymer additive, PVDF, PPy

Figure 1. (a) schematic of the procedure to fabricate PSC, (b) PSC schematic structure.



Physical Device Simulation of dopant-free asymmetric silicon heterostructure solar cell featuring tungsten oxide and ultrathin silicon oxide as a hole-selective and passivation stack layer

Haris Mehmood^{1,*}, Syed Muhammad Hassan Zaidi², Tauseef Tauqeer¹, Raşit Turan^{3,4}, Hisham Nasser³

¹ Information Technology University of the Punjab (ITU), Lahore, Pakistan

² National University of Sciences and Technology, Islamabad, Pakistan

³ Center for Solar Energy Research and Applications (GÜNAM), Middle East Technical University, Ankara, Turkey

⁴ Department of Physics, Middle East Technical University (METU), Ankara, Turkey

* haris.mehmood@itu.edu.pk

The dopant-related issues are amongst the major performance bottleneck in crystalline Silicon (cSi) solar cells that can be alleviated via implementation of dopant-free layers. This work presents the implementation of tungsten oxide (WO_x) and titanium oxide (TiO_x) as hole- and electron-selective films for heterostructure solar cell design whereby n-type Si has been passivated with ultrathin silicon oxide (SiO_2) layer. Several designs have been investigated including traditional passivated amorphous silicon (*i*-a-Si:H) and results are evaluated separately for each device by primarily focusing on the parameters influencing the charge transport mechanism such as work function, electron affinity, interfacial charge, and layer thickness. The high work function of WO_x induces significant upward band bending to permit holes transportation towards anode, whereas, low electron-affinity for TiO_x reduces the barrier against electrons near the cathode. It has been observed that band offsets appeared to be smaller against minority carriers for devices that employ *i*-a-Si:H as a passivation layer. However, incorporating passivated SiO_2 significantly improves the energy barrier height that lead to improvement in the electric field as well as reduction in the recombination. The best-performance device with an optimum SiO_2 thickness of 1 nm numerically validated V_{oc} of 751 mV, J_{sc} 40.2 mA/cm², FF 79.7%, and η of 24.06%. A comparative analysis with vanadium oxide (V_2O_x) indicates η of 21.73% because of relatively low work function values of V_2O_x .

Keywords: passivating contacts, silicon oxide, titanium oxide, tungsten oxide, vanadium oxide.

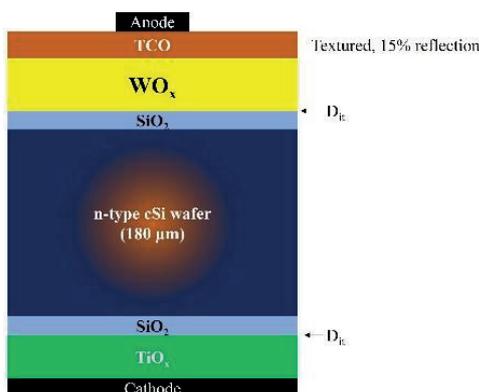


Figure 1. Proposed design of DASH solar cell

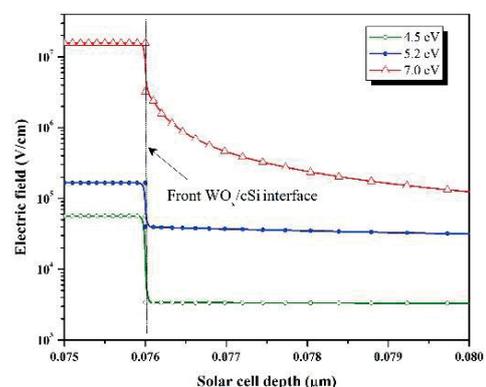


Figure 2. Electric field analysis at front WO_x/cSi interface

References

- [1] H. Mehmood, H. Nasser, T. Tauqeer, R. Turan, Simulation of silicon heterostructure solar cell featuring dopant-free carrier-selective molybdenum oxide and titanium oxide contacts, *Renew. Energy*. 143 (2019) 359–367. doi:10.1016/j.renene.2019.05.007.
- [2] H. Nasser, G. Kökbudak, H. Mehmood, R. Turan, Dependence of n-cSi/MoOx heterojunction performance on cSi doping concentration, *Energy Procedia*. 124 (2017) 418–424. doi:https://doi.org/10.1016/j.egypro.2017.09.267.
- [3] C. Battaglia, S.M. de Nicolás, S. De Wolf, X. Yin, M. Zheng, C. Ballif, A. Javey, Silicon heterojunction solar cell with passivated hole selective MoOx contact, *Appl. Phys. Lett.* 104 (2014) 113902. doi:10.1063/1.4868880.

DEVELOPMENT OF PROTOTYPE BATTERY MANAGEMENT SYSTEM FOR PV SYSTEM

Kamil OKAY¹, Sermet ERAY², Aynur ERAY^{1,3}

¹ Hacettepe University, Renewable Energy Research Center (YETAM), Beytepe, ANKARA

² Hacettepe University, Dept. of Nuclear Engineering, Beytepe, ANKARA

³ Hacettepe University, Dept. of Physics Engineering, Beytepe, ANKARA

*kamilokay@hacettepe.edu.tr

An energy and battery management system (BMS) has a great importance in PV-battery system to increase the system efficiency and battery life.

In this study, a prototype BMS system has been designed and constructed that provides energy and battery management of a grid-connected PV system with lithium-ion battery. The prototype set-up includes (Figure-1);

- 400Wp PV modules,
- battery pack (connected as 7 series 4 parallel block) with 353 Wh (25,2 V, 14 Ah) capacity,
- 300 W power supply and dummy load to get power from the grid and to sale the excess energy to the grid respectively,
- a programmable electronic DC load to simulate the load profile of household consumption by the ratio of 1/15 of the real consumption
- designed control unit (consists of a main board and 4 slave boards. The main board controls all energy flow between PV system, batteries, Household loads and grid. Each slave board has a balancing circuit for 7 serially connected Li-ion batteries).

In the daily experiments, for the 24-hour consumption, so many scenarios have been considered by taking into account of retired and working household consumption profiles on different days on weekdays and weekends. These profiles were loaded into the electronic load, and the operation of the designed battery and energy management circuit was tested on this setup. Due to the energy management system, when the PV-batteries system is not sufficient, the energy is taken from the grid; when the PVs charged batteries fully, the excess energy is sold to the grid, Figure 2.

Keywords: PV system, Battery Management System, Energy Management System, Li-ion Batteries

This study has been supported by Hacettepe University BAP FYL-2018-17425.

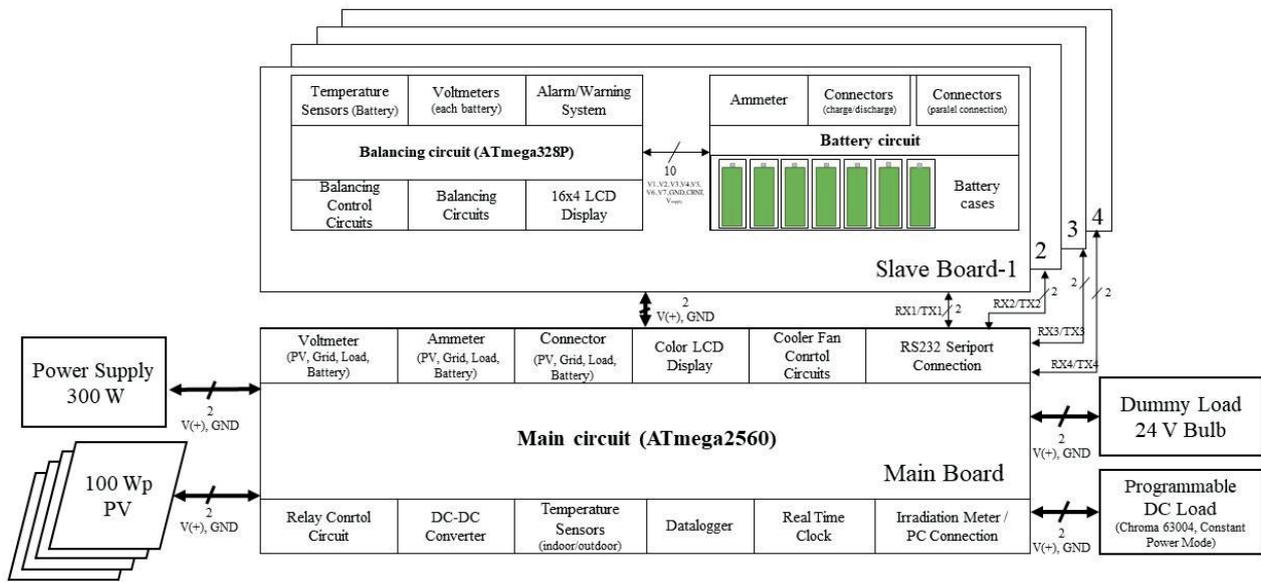


Figure 1. Block Diagram of The Designed System

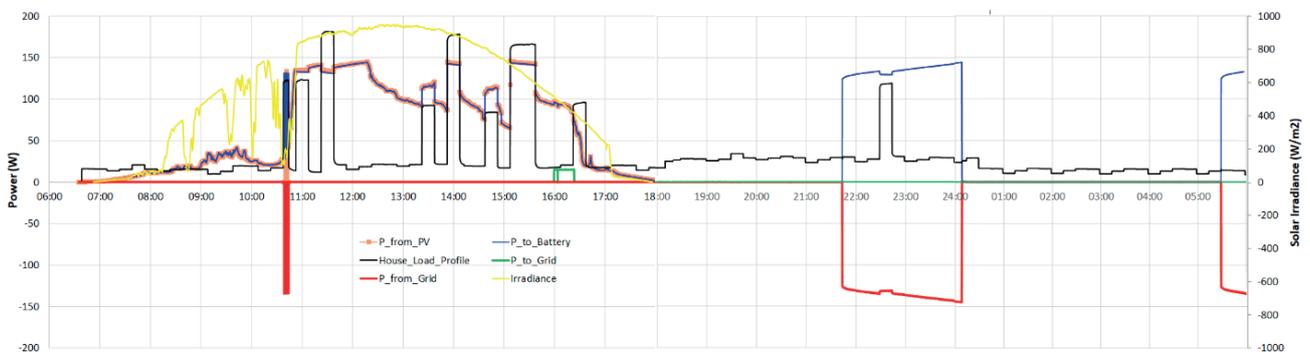


Figure 2. An example from the designed system outputs for selected scenario over 24 hours,

Optimized Cu₂O/c-Si tandem heterojunction solar cells: experimental and modeling investigation for defect analysis

L. Fara^{1,2*}, Ø. Nordseth³, I. Chilibon⁴, R. Kumar⁵, I. C. Vasiliu⁴, D. Savastru⁴, L. Baschir⁴, D. Craciunescu¹, S. Fara¹, E. Monakhov⁵

¹Department of Physics, Faculty of Applied Sciences, Polytechnic University of Bucharest, Romania

²Academy of Romanian Scientists, Bucharest, Romania

³Institute for Energy Technology (IFE), Kjeller, Norway

⁴National Institute of Research and Development for Optoelectronics (INOE-2000), Bucharest-Magurele, Romania

⁵Department of Physics/Center for Materials Science and Nanotechnology (SMN), University of Oslo, Norway

*lfara@renerg.pub.ro

The photovoltaic (PV) market is dominated in present by crystalline silicon solar cells (more than 90%) [1]. Cost reduction of this technology could be obtained by promoting silicon –based tandem solar cells with low cost metal oxide materials [2]. Cuprous oxide (Cu₂O) is considered an attractive material for PV applications since it is a p-type semiconductor with high optical absorption and a direct bandgap of about 2.1 eV.

The electrical and optical characteristics for aluminium doped ZnO (AZO) and un-doped Cu₂O thin film layers synthesized by magnetron sputtering were determined. A four-terminal AZO-Cu₂O/ c-Si tandem heterojunction solar cell was investigated (see Fig.1) I-V curve for the studied heterojunction tandem solar cell shows a rectifying behavior, but its stability and reproducibility has to be solved. Numerical modelling allowed to analyse the main electrical parameters of the two subcells, in order to maximize the performance of the solar device [3]. The influence of the material characteristics of the buffer layer (electron mobility, buffer layer thickness and electron affinity) on the energy performance of the cell (η , FF, J_{sc}, V_{oc}) was analyzed. The effect of interface defects on the electrical characteristics of the AZO/Cu₂O heterojunction was evaluated. The defect analysis based on numerical modeling showed how the interface defects and band offsets of the considered Cu₂O heterojunction tandem solar cell reduce top cell performance. The analysis suggested that the incorporation of a buffer layer could enhance the performance of the heterojunction solar cell.

Keywords: four-terminal, Cu₂O/ c-Si, tandem heterojunction solar cell, AZO, numerical modeling, interface defects

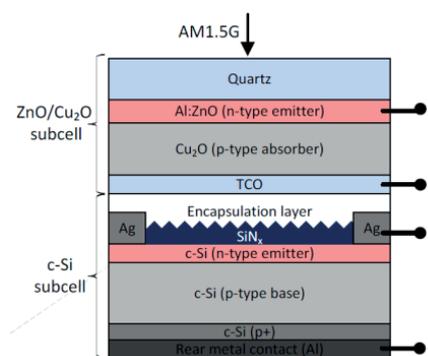


Figure 1. The diagram of the tandem heterojunction solar cell

References

- [1] L. Fara, I. Chilibon, Ø. Nordseth, D. Craciunescu, D. Savastru, C. Vasiliu, L. Baschir, S. Fara, R. Kumar, E. Monakhov and J. P. Connolly, Complex Investigation of High Efficiency and Reliable Heterojunction Solar Cell based on an Improved Cu₂O Absorber Layer, *Energies*, **13**, Issue 18, 4667; doi:10.3390/en13184667 (2020)
- [2] L. Fara, M. Yamaguchi., *Advanced Solar Cell Materials, Technology, Modeling, and Simulation*, IGI Global Publishing House, Hershey (2013).
- [3] C. Dumitru, L. Fara, Ø. Nordseth, I. Chilibon, R. Kumar, B. G. Svensson, F. Drăgan, V. Muscurel, D. Crăciunescu, P. Sterian - Electro optical analysis and numerical modeling of Cu₂O as absorber layer in advanced solar cells, presented at the International Conference on Photovoltaic Science and Technologies PVCON 2018, Ankara, Turkey, published in IEEE Xplore Proceedings of PVCON 2018

Effect of Stacking Order and Reaction Temperature on Properties of CZTS Thin Films

M.A.Olgar^{1,2*}, A.O. Sarp², A. Seyhan^{1,2}, R. Zan^{1,2}

¹ Niğde Ömer Halisdemir University, Department of Physics, Niğde, Turkey

² Niğde Ömer Halisdemir University, Nanotechnology Application and Research Center, Niğde, Turkey

*mehmetaliolgar@ohu.edu.tr

Cadmium telluride (CdTe) and Cu(In, Ga)Se₂ (CIGS) thin films are the main compounds used in thin film solar cell technology. Their photovoltaic conversion efficiencies have already reached over the 20% values [1, 2]; however, rareness of In and Ga and toxicity of Cd may restrict further improvements of such kind of materials in thin film photovoltaic industry. Therefore, Cu₂SnZnS₄ (CZTS) thin film has been emerged as a new and alternative absorber compound to the CdTe and CIGS based solar cells since it has earth-abundant raw materials, high absorption coefficient ($\geq 10^4$ cm⁻¹), suitable optical band gap (~1.5 eV) and p-type conductivity. Additionally, Shockley–Queisser limit predicts that CZTS based p-n junction should have over the 30% conversion efficiency. However, the current record efficiency (12.6%) is still far from the theoretical limit [3, 4]. The reason behind the low conversion efficiency can be attributed to several different reasons, such as secondary phases, film composition, crystalline quality etc. One of the strategies to overcome these issues is employing various stacking order in the precursor films. In the literature, it was shown that the stacking order of the precursor films has a significant impact on the crystalline quality and on the formation of the secondary phases [5]. Therefore, in this study our research group proposed two different stacking order at the first time. Effect of the reaction temperature was investigated for both stacked films. The prepared samples were characterized using different techniques, such as EDX, XRD, SEM, Raman, PL etc.

Keywords: CZTS, Stacking order, Sulfurization temperature, Sputtering

Acknowledgement

This research was supported by The Scientific and Technological Research Council of Turkey (TUBITAK) with the project number of 118F530.

References

- [1] M. Nakamura, K. Yamaguchi, Y. Kimoto, Y. Yasaki, T. Kato, H. Sugimoto, *Ieee Journal of Photovoltaics* 9, 1863-1867 (2019)
- [2] M.A. Green, E.D. Dunlop, J. Hohl-Ebinger, M. Yoshita, N. Kopidakis, X. Hao, *Progress in Photovoltaics: Research and Applications* 28, 629-638 (2020)
- [3] W. Wang, M.T. Winkler, O. Gunawan, T. Gokmen, T.K. Todorov, Y. Zhu, D.B. Mitzi, *Adv Energy Mater* 4, 1301465 (2014)
- [4] W. Shockley, H.J. Queisser, *J Appl Phys* 32, 510-519 (1961)
- [5] M.A. Olgar, J. Klaer, R. Mainz, S. Levenceno, J. Just, E. Bacaksiz, T. Unold, *Thin Solid Films* 615, 402-408 (2016)

Metal Nanoparticles as Rear Transparent Conductive Electrode with Tunable Light Trapping and Conductivity Features in Tandem Solar Cell Structure

Mehmet Koç¹, Selçuk Yerci¹

¹ *The Center for Solar Energy Research and Applications (GUNAM) and Micro and Nanotechnology Department, Middle East Technical University, Ankara, TURKEY.*

*mehmetkoc.ee@gmail.com

Solar cells have presented significant improvements since their first introduction, and every day new developments are still being reported for different solar cell technologies [1]. Conversion efficiency improvements slow down as they become closer to their practical limits and it becomes a more challenging task for researchers to further boost the conversion efficiency. Researchers are continuously searching for alternative routes to surpass fundamental limits. One of the most promising routes is using tandem solar cell structures, which has a long proven success. [2]

Tandem solar cells enable better utilization of available illumination spectrum which leads to a higher conversion efficiency mainly by better spectral matching. However, some major design challenges are waiting to be addressed such as obtaining maximum transmission to the rear sub-cell while having a high carrier collection efficiency. Typically, highly doped metal oxides such as Indium doped tin oxide (ITO), Aluminum doped zinc oxide (AZO), or Fluorine doped tin oxide (FTO) are used as transparent conductive electrodes (TCE) in solar cells regarding their excellent transmission window in the Visible part of the spectrum and low resistivity. The low resistivity is mainly caused by high free carrier density which is a result of high doping concentration. Although parasitic absorption caused by these excess free carriers does not yield significant loss in single-junction solar cells with wider bandgaps such as perovskite, CdTe, it becomes a major optical loss mechanism in tandem configurations for rear subcells with NIR absorbers such as silicon, CIGS. One way of addressing this problem is by using metal nanoparticle-based electrodes. Metal nanoparticles provide a flat transmission window in the Visible and NIR regions with a competitive conductivity. Besides, metal nanoparticles diffract the reflected and transmitted light into more oblique angles. Hence, by careful optical engineering, it is possible to obtain significant light trapping properties. This approach can enable the usage of thinner absorbers in the bot subcell with improved optical absorption and collection efficiency while without having any conductivity cost.

In this work, first, optical response and angular scattering profiles of different metal nanoparticle-based TCEs with various geometries are computed. This provides a better understanding of how to engineer light trapping by changing design parameters such as size, material, and feature size. Subsequently, the full optical response of tandem solar cells with optimized metal nanoparticle-based rear TCEs is analyzed. Finally, how this light trapping technique can be tailored to maximize the performance level of tandem cells with subcells having different bandgap pairs are explored.

[1] Green MA, Dunlop ED, Hohl-Ebinger J, Yoshita M, Kopidakis N, Hao X (2020) Solar cell efficiency tables (version 56). *Progress in Photovoltaics: Research and Applications* 28:629–638. <https://doi.org/10.1002/pip.3303>

[2] Graydon O (2009) Solar success for Sharp. *Nature Photonics* 3:684–684. <https://doi.org/10.1038/nphoton.2009.224>.

PHOTOVOLTAIC POWER PLANTS FINANCING MODELS

Metin Sever¹, Huzur Keskin¹, Bulent G. Akinoglu^{1,2,3}

¹ Earth System Science Program, Graduate School of Natural and Applied Sciences, Middle East Technical University, Ankara, Turkey

² Department of Physics, Middle East Technical University, Ankara, Turkey

³ Centre for Solar Energy Research and Application, Middle East Technical University, Ankara, Turkey

metin.sever@metu.edu.tr

Although renewable energy projects have many benefits, they have some problems such as large land area and appropriate regions for renewable energy technologies. In addition, insufficient network infrastructure, low incentives by governments and financial problems are encountered in realizing the investments of the renewable energy sources. When it comes to financial problems, it is understood that the initial investment costs are relatively high, they are small in comparison with conventional investments, and they have long payback periods [1]. In this context, considering investment difficulties, financing models for renewable energy sources are of great importance and realization of settlements can be realized by solving the financial problem of the investment. In this study, the models used in financing of renewable energy sources in the world, green bonds, crowdfunding, project finance, energy cooperatives, renewable energy fund and examined third-party ownership models, and Turkey has been investigated how the use of these models. As a result, the green bonds issued as financial value in the world, compared to green bonds issued as financial value in Turkey, issued green bonds financial value in Turkey is too low [2]. In addition, crowdfunding model according to the legal regulations in Turkey, will be implemented as an equity-based crowdfunding model, but this model is not yet used in the renewable energy sector. The use of this model will provide a positive contribution to renewable energy investments in Turkey. [3]

Keywords: Photovoltaic modules, renewable energy, financing models

References

- [1] Guajardo, J. A. (2018). Third-party ownership business models and the operational performance of solar energy systems. *Manufacturing and Service Operations Management*. <https://doi.org/10.1287/msom.2017.0687>
- [2] The World Bank. (2019). *Green Bond Impact Report 2019*.
- [3] Burnaz, S., & Demiray, M. (2019). Positioning of crowdfunding platforms: Turkey as an emerging market case. *Pressacademia*, 6(2), 84–94. <https://doi.org/10.17261/pressacademia.2019.1036>

SELECTIVE CHEMICAL REMOVAL OF SUBSURFACE LASER MODIFIED SILICON FOR PHOTOVOLTAICS

Mona Zolfaghari Borra^{1,2}, Behrad Radfar^{1,2}, Hisham Nasser¹, Rasit Turan^{1,2,3}, Ihor Pavlov^{1,3}, Alpan Bek^{1,2,3}

¹ The Center for Solar Energy Research and Applications (GÜNAM), Middle East Technical University, 06800, Ankara, Turkey

² Micro and Nanotechnology Graduate Program, Middle East Technical University, 06800, Ankara, Turkey

³ Department of Physics, Middle East Technical University, 06800, Ankara, Turkey

*mona.zolfaghari Borra@metu.edu.tr, Tel: +903122105095, Fax: +903122105099

Kerf-reduced slicing of bulk crystalline silicon (Si) is of high commercial interest in the photovoltaics industry. Moreover, the industry continues to move towards thinner Si wafers. In this context, novel schemes alternative to wire-cutters for Si wafer slicing are explored for achieving slicing with minimal material loss. In this study, we demonstrate the optimization of a copper nitrate (Cu(NO₃)₂)-based etching solution on the application of subsurface laser modified region [1] in Si. A nanosecond-pulsed fiber laser operating at 1.55 μm wavelength, focused in Si subsurface, induces structural modifications near the focal point due to multiphoton absorption. After laser processing, the modified Si region is then etched by Cu(NO₃)₂-based selective chemical etchant which selectively targets the laser-modified regions. In order to achieve high etch rate, smooth, and defect-free surface, different concentrations of etchant components and etch durations were investigated. The crystalline silicon smoothness is represented by fractal dimensions which obtained from SEM images. The etch rate, selectivity, and surface morphology of subsurface laser modified regions are well controlled during the experiments by varying the concentration of the components.

Keywords: Silicon Slicing, Selective Chemical Etching, Subsurface Laser Modifications

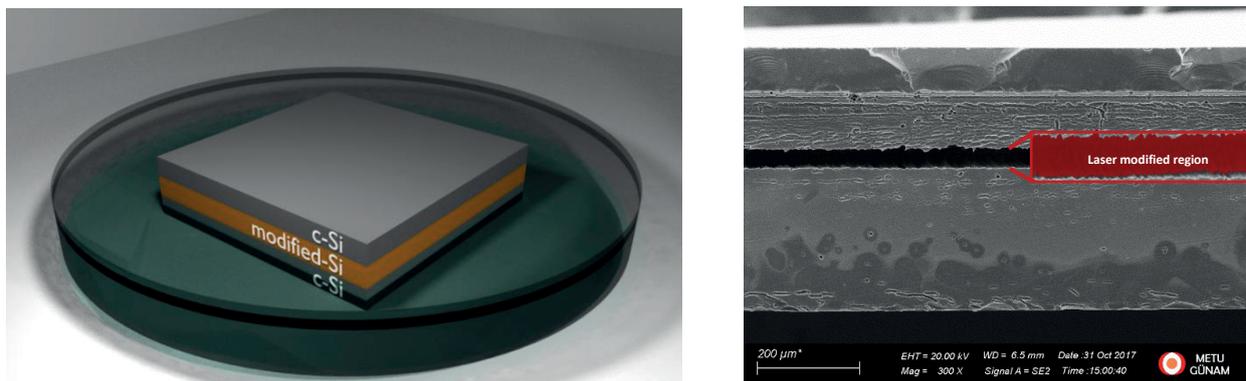


Figure 1. Illustration of the laser process sample in the selective chemical etching

References

- [1] O. Tokel, A. Turnalı, G. Makey, P. Elahi, T. Çolakoğlu, E. Ergeçen, Ö. Yavuz, R. Hübner, M. Z. Borra, I. Pavlov, A. Bek, R. Turan, D. K. Kesim, S. Tozburun, S. Ilday, F. O. Ilday "In-chip microstructures and photonic devices fabricated by nonlinear laser lithography deep inside silicon" *Nature Photonics* 11, 639 (2017)

A NEW IMPLEMENTING APPROACH FOR TRACKING ALGORITHM ON PHOTOVOLTAIC SYSTEMS

Mustafa HASAN ¹, Serra ALTINOLUK ^{1,2}

¹Muğla Sıtkı Koçman Üniversitesi/Electrical & Electronics Engineering, Muğla, Turkey

²The Center for Solar Energy Research and Applications (GÜNAM), Ankara, Turkey

eng.mustafa.lateef@gmail.com

The paper presents an affordable technique for executing a tracking voltage algorithm derived with the second-order transfer function, which is defined for a combined system and used to assure the correct estimation for the proportional integral parameters. The new algorithm is developed with a PIC18F4580 microcontroller implemented on a system consisting of multi input source. Previously studied solar tracking algorithms, mostly considered photovoltaic (PV) system's feeding a load with the pre-existent power of an electronic device, were being able to give the best performance for the system. The designed algorithm suggested in this work includes a Buck Converter providing the possibility to observe the best performance of a PV system in case of disorder, with versatility and scalability. No matter what the order and conditions are, with the developed algorithm the desired output voltage values can be obtained.

Keywords: PV system, buck converter, PI controller, second order transfer function, LabVIEW.

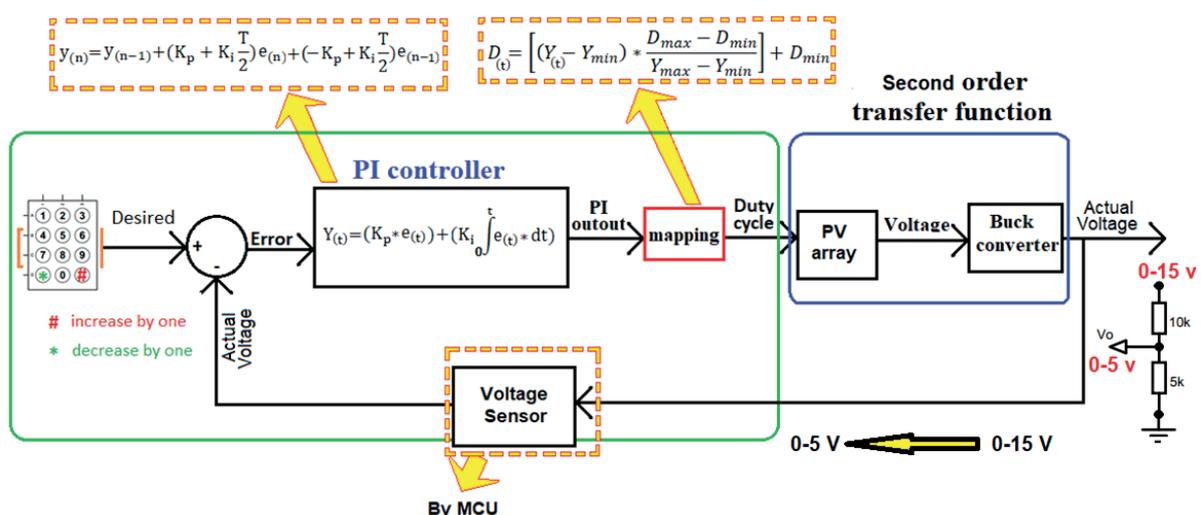


Figure 1. The proposed system for controlling the output voltage by PIC18F4580.

References

- 1- Villalva, M. G. (2008, April). Input-controlled buck converter for photovoltaic applications: modeling and design. In 2008 4th IET Conference on Power Electronics, Machines and Drives (pp. 505-509). IET.

Non-fullerene organic solar cells based on thienopyrroledione comprising random copolymers; effect of alkyl chains

Mustafa Yasa¹, Tolga Depci², Eda Alemdar Yilmaz³, Serife Ozdemir Hacıoglu⁴, Ali Cirpan^{1,3,5,6}, Levent Toppare^{1,3,5,7}

¹ Middle East Technical University / Department of Polymer Science and Technology, Ankara, Turkey

² Iskenderun Technical University / Department of Petrol and Natural Gases Engineering, Hatay, Turkey

³ Middle East Technical University / Department of Chemistry, Ankara, Turkey

⁴ Iskenderun Technical University / Department of Basic Sciences of Engineering, Hatay, Turkey

⁵ Middle East Technical University / Center for Solar Energy Research and Applications, Ankara, Turkey

⁶ Middle East Technical University / Department of Micro and Nanotechnology, Ankara, Turkey

⁷ Middle East Technical University / Department of Biotechnology, Ankara, Turkey

*Corresponding Author's E-mail: toppare@metu.edu.tr

Two new random copolymers, signed as P1 and P2, were designed and synthesized. 5-(2-ethylhexyl)-4H-thieno[3,4-c]pyrrole-4,6(5H)-dione (TPD) was utilized as electron-accepting moiety whereas selenophene was utilized as spacer, 4,8-bis[5-(2-ethylhexyl) thiophen-2-yl]-2,6-bis(trimethylstannyl)benzo[1,2-b:4,5-b'] (BDT(TiC8)), thiophene and alkylthiophene were utilized as donor moieties. Structural analyses of the polymers were carried out by attenuated total Reflectance-Fourier-transform infrared spectroscopy (ATR-FTIR). Weight-average and number-average molecular weights (M_w , M_n) of the polymers were determined via size exclusion chromatography (SEC). Electrochemical and spectroelectrochemical measurements were performed to investigate optoelectronic properties. The polymers were used as donor polymers in active layer to fabricate non-fullerene, bulk heterojunction (BHJ) organic solar cells (OSCs). BHJ solar cells' device structure is ITO/PEDOT: PSS/Active Layer/LiF/Al, where active layer consists of ITIC as acceptor and thienopyrroledione containing donors. Various optimization studies (solvent selection, donor: determination of acceptor ratio, active layer's mass ratio optimizations, determination of the active layer's thickness, additive selection and thermal annealing) were carried out to obtain the best performance from the devices. The device based on P1: ITIC (1:1) blend with a thickness of 161 nm gave the best performance with a power conversion efficiency (PCE) of 7.94 %. The highest PCE obtained from P2 based organic solar cell is 1.96 %. P2 exhibited low solubility attributed to the lack of alkyl groups enhancing polymer solubility, electronic properties, and photovoltaic performances. Our study represents a synthetic approach to exhibit alkyl chains' effect on OSCs' performance based on TPD containing random polymers and non-fullerene acceptors.

Keywords: random copolymers, spacer, thienopyrroledione, benzodithiophene, electrochemistry, organic photovoltaics.

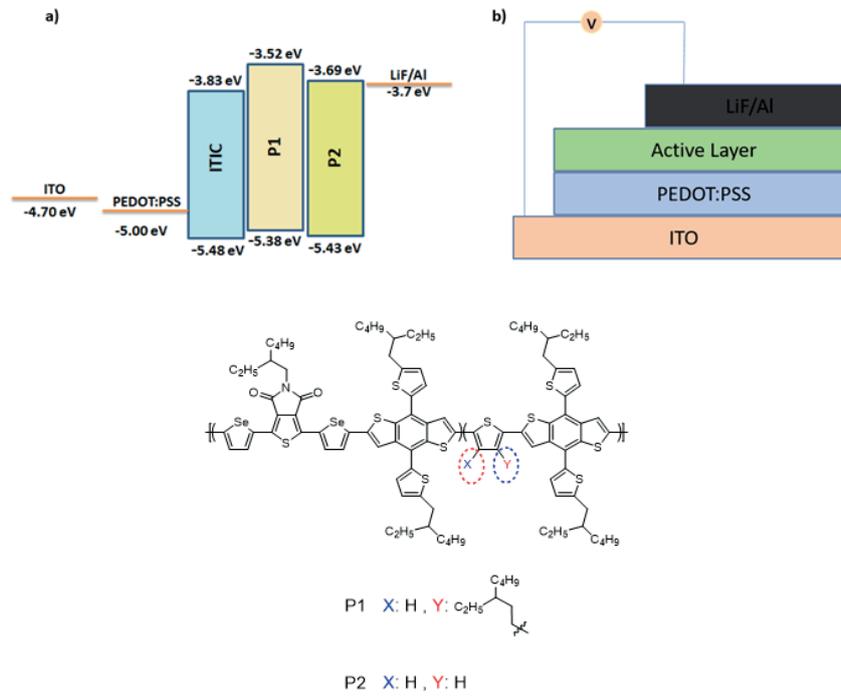


Figure 1. (a) Schematic energy level diagram of acceptor and donor units (ITIC, P1, and P2) and (b) device architecture of OSCs

PHOSPHORUS AND BORON CO-DIFFUSION IN SILICON FOR P-PERT SOLAR CELLS APPLICATION

Nabil Khelifati^{1,*}, Imane Charif², Baya Palahouane¹, Brahim Mahmoudi¹, Djoudi Bouhafs¹

¹ Research Center in Semiconductor Technology for the Energetic (CRTSE), Division DDCS, Bd. 2 Frantz Fanon, les sept merveilles B.P.140, 16038, Algiers, Algeria

² University of Science and technology Houari Boumediene (USTHB), Faculty of Physics, BP 32 El Alia, Bab Ezzouar, Algiers, Algeria

*Corresponding Author's E-mail: khelifatinabil@crtse.dz, n.khelifati@gmail.com

This work is a contribution to the elaboration and the characterization of p⁺pn⁺ bifacial structures destined for passivated emitter rear totally diffused (PERT) solar cell fabrication [1-3]. As a first step, we used spin coating technique to deposit phosphorus and boron dopant sources on the front and the back sides of the wafers. The wafers were divided into three sets A, B and C, and co-diffused at 900°C, 930°C and 960°C, respectively. After SiN_x anti-reflection coating on both sides, the metal contacts were screen printed and co-fired around 750°C. SIMS analysis showed that phosphorus diffuse deeply in silicon than boron. Further characterizations by four-point and Hall-effect techniques allowed us to deduce that the decrease in the sheet resistance of the emitter and the B-BSF (Boron Back Surface Field) with the co-diffusion temperature is due to the increase of active dopants concentration in the surface and/or to the increase of the junction depth. The results obtained by Suns-Voc Tester demonstrate a clear degradation of electrical parameters of samples co-diffused at 930°C. These findings were explained by the electrical losses in the emitter and the B-BSF through the increase of apparent series resistance (R_s^{app}). This interpretation was confirmed by the correlation between the different parameters of the cell on the one hand and the apparent R_s^{app} on the other hand.

Keywords: Silicon, Co-diffusion, Spin coating, p-PERT

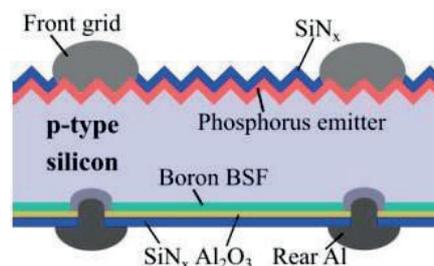


Figure 1. Schematic cross section of bifacial p-PERT solar cell [4].

References

- [1] Zih-Wei Peng , Masahiro Nakahara , Thomas Buck , and Radovan Kopecek, Investigation on Industrial Screen-Printed Aluminum Point Contact and Its Application in n-PERT Rear Junction Solar Cells, IEEE JOURNAL OF PHOTOVOLTAICS, VOL. 9, NO. 6, NOVEMBER 2019

emitters and simplify PERT solar cell processing, Prog Photovolt Res Appl. 2019;2–10.

- [3] Tobias Fellmeth, Sebastian Meier, Florian Clement, Andreas Wolf, Holger Knauss, Holger Haverkamp, Co-diffused bi-facial PERT solar cells, Energy Procedia 124 (2017) 875–880
- [4] Sebastian Meier, Sven Wasmer, Andreas Fell, Nico Wöhrl, Johannes Greulich, Andreas Wolf, Efficiency Potential of p-type PERT vs. PERC Solar Cells, 2018 IEEE 7th World Conference on Photovoltaic Energy Conversion (WCPEC) (A Joint Conference of 45th IEEE PVSC, 28th PVSEC & 34th EU PVSEC)

POTENTIAL UTILIZATION OF THIN PATTERNED GLASSES IN PHOTOVOLTAIC SYSTEMS THROUGH CHEMICAL TEMPERING

Nahide Özben^{1,2}, Gülcan Terzi², İlkay Sökmen¹, Burcu Ögüt¹, Türkay Yıldız¹,

Miray Çelikkbilek Ersundu², Ali Erçin Ersundu², Ersin Gökçen³

¹ Şişecam Science, Technology and Design Center, Çayırova, Şişecam Yolu St., 41420, Kocaeli, Turkey

² Yıldız Technical University, Faculty of Chemical and Metallurgical Engineering, Department of Metallurgical and Materials Engineering, Glass Research and Development Laboratory, Istanbul, 34220, Turkey

³ Trakya Glass Mersin Factory, Mersin Tarsus Organize Sanayi Bölgesi, Atatürk Caddesi No: 1 33400 Akdeniz, Mersin, Turkey

The amount of produced energy in photovoltaic systems significantly depends on the properties of cover glass as well as the efficiency of solar cell. It is always desired that the sun rays passing through the cover glass reach to the cell with the least possible loss. However, cover glass usually decreases the overall solar energy efficiency due to its relatively low visible transmission. Therefore, studies are concentrated in the glass industry to tackle such problems by using different strategies such as, reducing the amount of iron oxide in the glass composition, applying multi-layer coatings (e.g. anti-reflective coating), patterning the glass surface and reducing the glass thickness. Among these strategies, a great deal of prominence is recently given to the utilization of thin patterned glasses to provide higher light transmission in combination with lightness.

The use of thinned glass without losing its mechanical properties is a very intricate process. However, it can now be achieved by chemical tempering method thanks to the advances in glass industry. In this work, the potential utilization of chemically tempered thin patterned glasses with low iron content is investigated in terms of structural, optical, and mechanical properties for their use in photovoltaic systems as panel cover glasses. Our results show that the mechanical strength of thin patterned glasses is increased up to 3x by chemical tempering without resulting any significant alteration in optical and structural properties. It is also tested that the strengthened glasses maintain their resistance against atmospheric effects.

Concentrated Photovoltaics with Shape Controlled Nanosphere

*Nasim Seyedpour Esmailzad^{1,2}, Ahmet Kemal Demir³, Jamileh Hajivandi⁴, Hande Ciftpinar^{1,2}, Rasit Turan^{1,2,5}, Hamza Kurt⁴,
Alpan Bek^{1,2,5,*}*

1. Center for Solar Energy Research and Applications, Middle East Technical University, Ankara 06800, Turkey

2. Micro and Nanotechnology Program of Graduate School of Natural and Applied Sciences, Middle East Technical University, Ankara 06800, Turkey

3. Physics Department, I.D. Bilkent University, Ankara 06800, Turkey

4. Electrical and Electronics Engineering Department, TOBB University of Economics and Technology, Ankara 06560, Turkey

5. Physics Department, Middle East Technical University, Ankara 06800, Turkey

*bek@metu.edu.tr

Dielectric colloidal nanospheres (NSs) can be regarded for light management in photonic devices such as solar cells (SCs). Tighter series of light focus can be obtained due to NS's light concentration effect, which leads to higher photovoltaic conversion efficiency. In addition, NS arrays, which is acting as an effective medium on the SC surface, can reduce reflection and facilitate enhanced forward scattering. Therefore, homogeneous NS arrays located on top of the SC can act as anti-reflective coatings or micro-lenses, and this can be considered a light concentrator in the framework of concentrated photovoltaics. NS-based photonic structures are cost-effective and less complex to manufacture than common alternatives such as vacuum evaporated multi-layer anti-reflective coatings. In this study, we computationally and empirically demonstrate that the optimal shape of NS structures can play a key role in light-harvesting and enhancing light conversion.

Keywords: concentrated photovoltaics, light harvesting, nanospheres, solar cells.

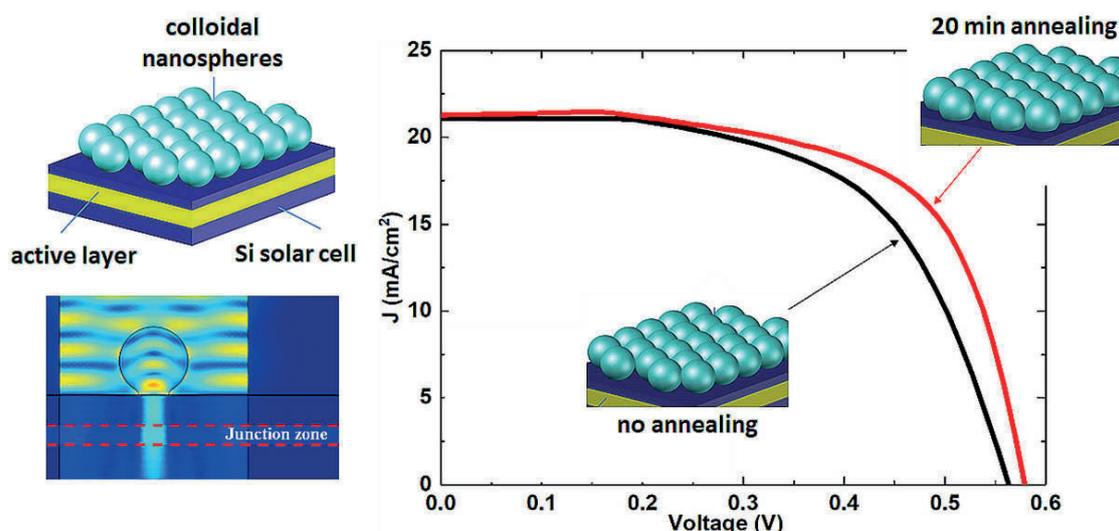


Figure 1. Improved J-V characteristic after shape modification of nanospheres

References

- [1] G. J. Lin, H. P. Wang, D. H. Lien, P. H. Fu, H. C. Chang, C. H. Ho, C. A. Lin, K. Y. Lai, J. H. He, *Nano Energy* **2014**, 6, 36.
- [2] P. Matheu, S. H. Lim, D. Derkacs, C. McPheeters, E. T. Yu, *Appl. Phys. Lett.* **2008**, 93, 113108.
- [3] H. R. Stuart, D. G. Hall, *Appl. Phys. Lett.* **1998**, 73, 3815.

Star-shaped ZnO-CeO₂ Z-scheme heterostructures for photoelectrochemical water splitting

Nuray Celebi¹, Fatih Arlı¹, Furkan Soysal², Kouroush Salimi^{2*}

¹Ankara Yildirim Beyazit University, Department of Energy Systems Engineering, Ankara, Turkey.

²Ankara Yildirim Beyazit University, Department of Chemical Engineering, Ankara, Turkey.

*kouroushsalimi@gmail.com

Semiconductor metal oxides as photocatalyst have paid great attention for energy and environmental fields, mainly demonstrated by producing hydrogen from water splitting. ZnO has been used as photocatalyst thanks to low cost, non-toxicity, high physical and chemical stability [1,2]. Nevertheless, the drawbacks including wide band-gap ($E_g=3.37$ eV) and recombination of charge carriers cause to decrease in catalytic efficiency. Therefore, it is important to construct suitable heterojunction between two semiconductors with appropriate band gap for enhancing charge separation, thus enhancing in photoconversion efficiency. Notably, Z-scheme heterojunction has emerged as more efficient than type II heterojunction for photocatalytic applications [3, 4]. CeO₂, having features like abundant oxygen vacancies, strong redox ability, stability, low cost, has been used as semiconductor for Z scheme heterojunction with ZnO for high photocatalytic activity owing to suitable band gap positions. In this study, Z-scheme heterojunction was established between ZnO and CeO₂ using electron mediator, polydopamine, for H₂ evolution with high photocatalytic performance. The Z-scheme photocatalyst has been performed as a photoanode and linear sweep voltammetry (LSV) measurements were conducted to evaluate photoelectrochemical (PEC) performance. Results showed that PDA had a crucial role as an electron mediator but increased amount of PDA used for shell formation had unfavorable effect because increase in shell thickness might result in obstruction for electron transfer from CeO₂. The Z-scheme photocatalysts represented improvement in PEC performance compared to bare ZnO-CeO₂ thanks to facilitating of charge transfer between ZnO and CeO₂ and suppressing in electron-hole recombination.

Keywords: Z scheme, photocatalysis, water splitting, semiconductor, visible LED light

References

- [1] Murali, A., Sarswat, P. K., & Free, M. L. (2020). Minimizing electron-hole pair recombination through band-gap engineering in novel ZnO-CeO₂-rGO ternary nanocomposite for photoelectrochemical and photocatalytic applications. *Environmental Science and Pollution Research International*.
- [2] Lv, Z., Zhong, Q., & Ou, M. (2016). Utilizing peroxide as precursor for the synthesis of CeO₂/ZnO composite oxide with enhanced photocatalytic activity. *Applied Surface Science*, 376, 91-96.
- [3] Zhu, L., Li, H., Xia, P., Liu, Z., & Xiong, D. (2018). Hierarchical ZnO decorated with CeO₂ nanoparticles as the direct Z-scheme heterojunction for enhanced photocatalytic activity. *ACS applied materials & interfaces*, 10(46), 39679-39687.
- [4] Guo, F., Chen, J., Zhao, J., Chen, Z., Xia, D., Zhan, Z., & Wang, Q. (2020). Z-scheme heterojunction g-C₃N₄@ PDA/BiOBr with biomimetic polydopamine as electron transfer mediators for enhanced visible-light driven degradation of sulfamethoxazole. *Chemical Engineering Journal*, 386, 124014.

Acknowledgement

This study was supported by Scientific and Technical Research Council of Turkey (TUBITAK, Grant No. 119M076).

Flexible Polymer Solar Cell with Modified Multi-layer Graphene Electrodes

Parisa Sharif¹, **Eda Alemdar Yılmaz**², **Şevki Can Cevher**², **Ali Cirpan**^{1,2}, **Ahmet Oral**^{1,3}

¹ METU/Department of Micro and Nanotechnology, Ankara, Turkey

² METU/Department of Chemistry, Ankara, Turkey

³ METU/Department of Physics, Ankara, Turkey

*sharif.parisa@metu.edu.tr

Flexible Organic Solar Cells are promising topics because of their low weight, easy installation, and low-cost price. The presence of a transparent conductive electrode such as indium tin oxide (ITO) limits the reliability and cost price of organic photovoltaic devices as it is brittle and expensive. Graphene is used instead of ITO, commonly used as a transparent electrode, one of the main cost consuming elements in present photovoltaic devices [1], [3]. The second argument for omitting ITO from OPV devices is mechanical flexibility. The brittle ITO layer can be easily cracked, leading to a decrease in conductivity and degradation of the device performance. We first optimized a single-layer graphene growth process on a flexible PET substrate. OLEDs are then fabricated by stacking multi-layers of optimized graphene films and doped to reduce the sheet resistance. This study contains benzochalcogendiazole bearing polymer solar cells with a flexible substrate. The flexible organic solar cells' device structure is PET/MLG/PEDOT: PSS/Active Layer/LiF/Al. The active layer contains PC₇₁BM as an acceptor and PO as a donor. In this study flexible organic solar cells are fabricated with multilayer graphene as bottom transparent electrodes, which show the highest power conversion efficiency of about 4.76% and excellent flexibility. PO based PSCs with ITO substrate were studied before and is found as 8.29% PCE [4]; this work aims to increase the mentioned PCE on flexible electrodes.

Keywords: Flexible Organic Solar Cells, Graphene, Bulk Heterojunction, BDT, Benzochalcogendiazole,

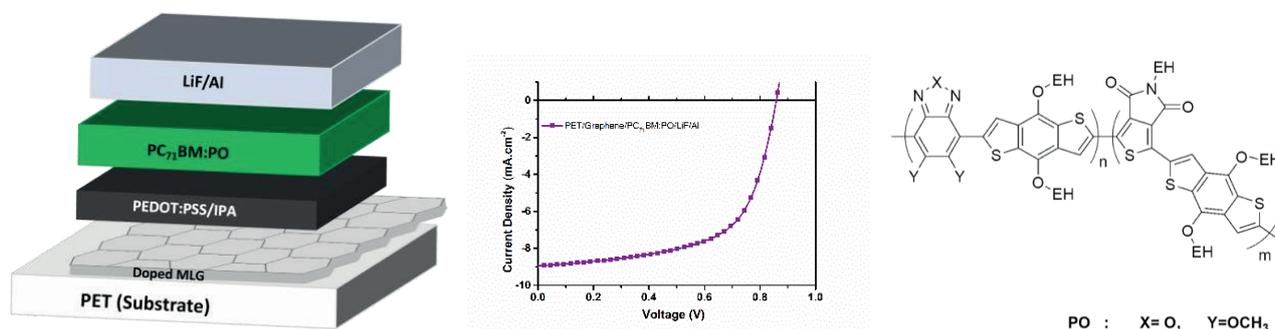


Figure 1. Device structure of flexible PSC with MLG electrode and J-V characteristic

References

- [1] Han, T.-H.; Lee, Y.; Choi, M.-R.; Woo, S.-H.; Bae, S.-H.; Hong, B. H.; Ahn, J.-H.; Lee, T.-W. Extremely efficient flexible organic light-emitting diodes with modified graphene anode. *Nature Photonics* 2012, 6, 105.
- [2] Li, N.; Oida, S.; Tulevski, G. S.; Han, S.-J.; Hannon, J. B.; Sadana, D. K.; Chen, T.-C. Efficient and bright organic light-emitting diodes on single-layer graphene electrodes. *Nature communications* 2013, 4, 1–7.
- [3] Y, Galagan.; J, Rubingh.; R, Andriessen.; Ch, Fan.; P, Blom.; S, Veenstra.; J, Kroon, ITO-free flexible organic solar cells with printed current collecting grids. *Solar energy materials & solar cells* 2011, 95, 1339–1343
- [4] S, Cevher.; G, Hizalan.; E, Yilmaz.; D, Cevher.; Y, Arslan.; L, Toppare.; E, Yıldırım.; A, Cirpan. A comprehensive study: Theoretical and experimental investigation of heteroatom and substituent effects on frontier orbitals and polymer solar cell performances. *Journal of polymer science* 2020, 58, 19, 2792-2806.

Correcting Design of the Current Off-grid PV System in Aden City-Yemen

Raimon O. Bawazir* and Numan S. Çetin

Solar Energy Institute/EGE University, Izmir, Turkey

*raimonengineer@gmail.com

The solar power of the PV system is the highest global capacity used compared with other solar systems. The off-grid/standalone PV system is seen as an alternative electric source in rural areas. Even though Yemen is a rich country of renewable energy resources in particular solar energy, the off-grid PV system is still in the initial stages. This may affect the technical design and economic assessment of the currently used system. Besides, there are few studies that discussed and provide solutions for the off-grid PV system. However, none of these studies give an insight view of the optimal off-grid PV design based on an optimum tilt angle. Therefore, this paper attempts to determine the optimum tilt angle of the PV panel/modules and how that affects a techno-economic assessment for the system. The study is conducted in Aden city, which is the economic and temporary capital in Yemen. Liu and Jordan (LJ)'s model is used to estimate solar radiation incident on a tilted PV panel. Life Cycle Cost (LCC) and Unit Electricity Price (UEP) are the statistical used tools to assess economic performance. The results indicate that the proposed correction in the used fixed off-grid PV system design shows better techno-economic assessment. This study yields a new policy that would help as guidelines for the government and investors to play a bigger role in rural electric projects based on the PV system.

Keywords: diffuse solar radiation, annual optimum tilt angle, techno-economic assessment, life cycle cost, unit electricity price

Investigation of Alternative Horizontal Solar Radiation Data Source in the World

Raimon O. Bawazir*, Numan S. Çetin , J. Chakchak

Solar Energy Institute, EGE University, Izmir, Turkey

*raimonengineer@gmail.com

Solar energy is the second most globally used energy resource after wind energy. Even though solar energy is abundant and within reach, this resource confronts a big challenge in terms of collecting measured data. Solar radiation data is rarely available from uneven distributed ground-based meteorological stations, in particular, developing countries. To overcome this issue, many countries resort to alternatives in obtaining solar radiation data. However, these alternatives are constructed based on such as satellite. Thus, they suffer from disagreement with ground-based meteorological station data. Therefore, this paper attempts to mitigate the differences by proposing the nearest alternative source to measured data. Four different alternative sources of solar radiation data (NASA, PVGIS, Meteonorm, and hybrid) are investigated. Meanwhile, all measured data (used as reference) are collected from the World Radiation Data Centre (WRDC) except for UAE, Iraq, Nigeria, and Tunisia whose were taken from published articles. The comparison is made based on monthly average horizontal solar radiation using statistical methods. In five continents, distributed twenty-eight locations are considered. Due to the Global Performance Indicator (GPI), Meteonorm is a suitable data source for Asia and South American continents with GPI range from 3.185885 to 1.191835 and from 3.477059 to 1.669530 respectively. In Africa, Europe, and North American continents, the alternative solar radiation source depends on the target location.

Keywords: Horizontal solar radiation, NASA, PVGIS, Meteonorm and Global Performance Indicator

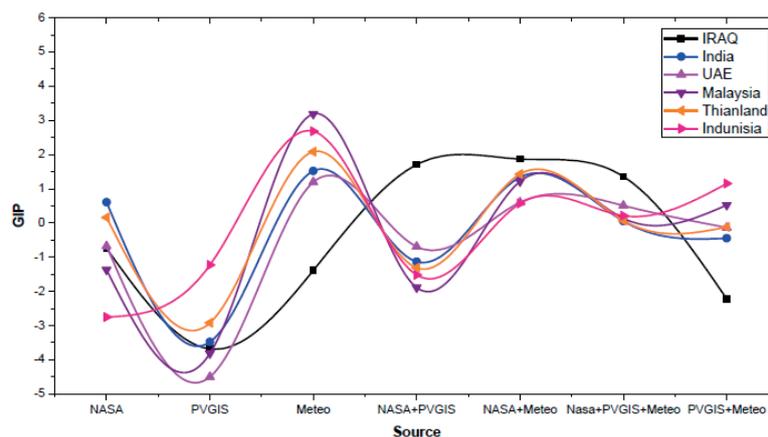


Figure 1. GPI with different solar radiation sources for Asia continent

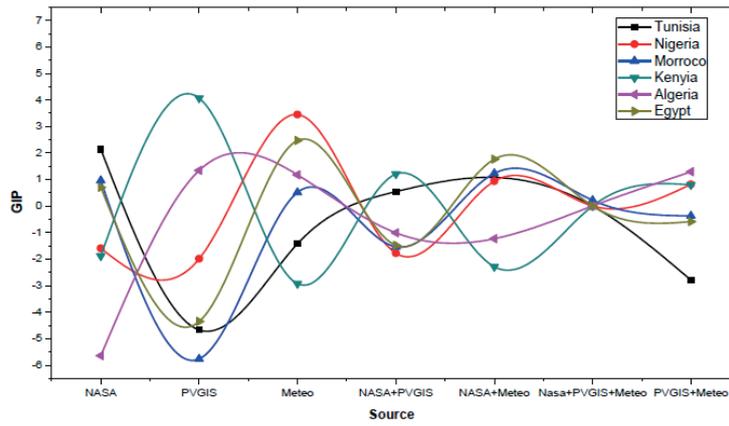


Figure 2. GPI with different solar radiation sources for Africa continent

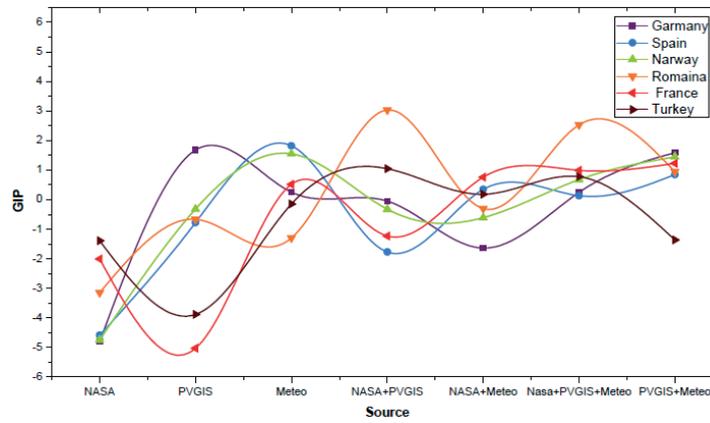


Figure 3. GPI with different solar radiation sources for Europe continent

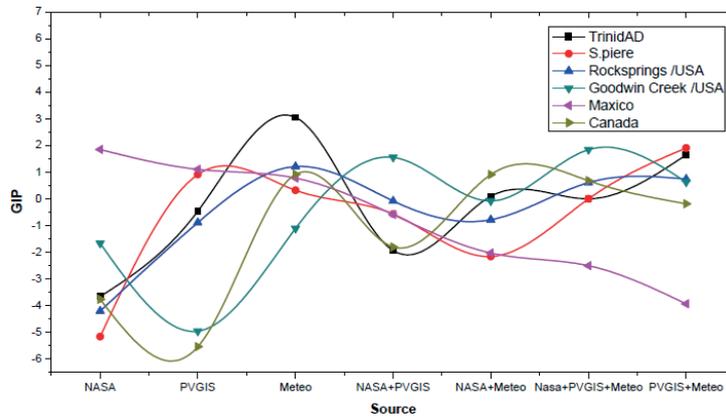


Figure 4. GPI with different solar radiation sources for North American continent

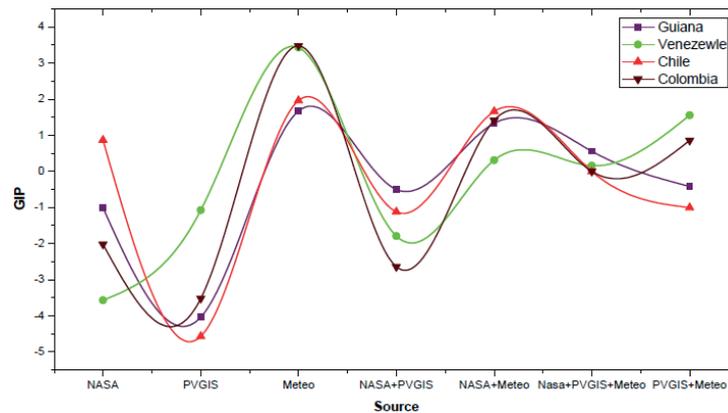


Figure 5. GPI with different solar radiation sources for South American continent

References

[1] REN21, "Renewables 2019: Global Status Report," 2019.

[2] REN21, "Renewables 2018 Global Status Report," 2018.

[3] REN21, "Renewables 2017: global status report," 2017.

[4] REN21, "Renewables 2016 Global Status Report," 2016.

[5] REN21, "Renewables 2015 Global Status Report," 2015.

[6] M. Ernst, A. Thomson, I. Haedrich, and A. Blakers, "Comparison of Ground-based and Satellite-based Irradiance Data for Photovoltaic Yield Estimation," in *Energy Procedia*, 2016, vol. 92, pp. 546–553.

[7] A. G. Amillo, L. Ntsangwane, T. Huld, and J. Trentmann, "Comparison of satellite-retrieved high-resolution solar radiation datasets for South Africa," *J. Energy South. Africa*, vol. 29, no. 2, pp. 63–76, 2018.

[8] C. Budig, J. Orozaliev, and K. Vajen, "Comparison of Different Sources of Meteorological Data for Central Asia and Russia," *EuroSun 2010*, p. 8, 2010.

[9] B. M. Olomiyesan and O. D. Oyedum, "Comparative Study of Ground Measured, Satellite-Derived, and Estimated Global Solar Radiation Data in Nigeria," *J. Sol. Energy*, vol. 2016, pp. 1–7, 2016.

[10] M. A. Alghoul et al., "Effect of Different Solar Radiation Data Sources on the Variation of Techno-Economic Feasibility of PV Power System," *E3S Web Conf.*, vol. 23, no. January, p. 01007, 2017.

[11] K. Abdeladim et al., "Inter-Comparison of Solar Radiation from Different Data Sources: Case of Some Algerian Sites," *Proc. 2017 Int. Renew. Sustain. Energy Conf. IRSEC 2017*, no. October, 2018.

[12] R. Meyer, M. Schlecht, and K. Chhatbar, "Solar resources for concentrating solar power (CSP) systems," in *Concentrating Solar Power Technology: Principles, Developments and Applications*, 2012, pp. 68–90.

[13] L. Wald, "BASICS IN SOLAR RADIATION AT EARTH To cite this version : HAL Id : hal-01676634," 2018.

[14] N. Samuel Chukwujindu, "A comprehensive review of empirical models for estimating global solar radiation in Africa," *Renew. Sustain. Energy Rev.*, vol. 78, pp. 955–995, 2017.

[15] C. Sharma, A. K. Sharma, I. Purohit, S. C. Mullick, and T. C. Kandpal, "Comparison of solar radiation data sources for design and performance appraisal of CSP systems in India," *Int. J. Ambient Energy*, vol. 39, no. 6, pp. 594–605, 2018.

[16] P. Ineichen, "Long term satellite hourly, daily and monthly global, beam and diffuse irradiance validation. Interannual variability analysis," no. March, 2013.

[17] P. W. Stackhouse et al., "POWER Release 8.0.1 (with GIS Applications) Methodology," *NASA Langley Res. Cent.*, vol. 1, 2018.

[18] P. Handbook, R. Authorities, and T. Pvgis, "PVGIS: estimating photovoltaic electricity production at local level," pp. 51–52.

[19] R. K. Tarai and P. Kale, "Development of rasterized map using PVGIS for assessment of solar PV energy potential of Odisha," *Int. J. Renew. Energy Res.*, vol. 6, no. 1, 2016.

[20] Joint Research Centre (JRC), "Pvgis 5 Internet tools for the assessment of solar resource and photovoltaic solar systems," 2017.

[21] E. D. Thomas Huld, Irene Pinedo Pascua, Ana Gracia Amillo, Ruben Urraca, "PVGIS VERSION 5: IMPROVEMENTS TO MODELS AND FEATURES Thomas," in *33rd European Photovoltaic Solar Energy Conference and Exhibition PVGIS, 2017*, pp. 2069–2074.

[22] Meteotest, "Handbook Part I : Meteonorm Software," no. May, 2012.

[23] A. Abdulameer, A. Al-khazzar, and A. Jamal, "Journal of Renewable A Comparative Study of the Available Measured Global Solar Radiation in Iraq," vol. 4, no. 2, pp. 47–55, 2017.

[24] Meteotest, "https://meteonorm.com/en/," 2019. .

- [25] B. Jamil and A. T. Siddiqui, "Estimation of monthly mean diffuse solar radiation over India: Performance of two variable models under different climatic zones," *Sustain. Energy Technol. Assessments*, vol. 25, no. September 2017, pp. 161–180, 2018.
- [26] K. Bakirci, "Models for the estimation of diffuse solar radiation for typical cities in Turkey," *Energy*, vol. 82, pp. 827–838, 2015.
- [27] B. Jamil and N. Akhtar, "Comparison of empirical models to estimate monthly mean diffuse solar radiation from measured data: Case study for humid-subtropical climatic region of India," *Renew. Sustain. Energy Rev.*, vol. 77, no. February, pp. 1326–1342, 2017.
- [28] S. Manju and M. Sandeep, "Prediction and performance assessment of global solar radiation in Indian cities: A comparison of satellite and surface measured data," *J. Clean. Prod.*, vol. 230, pp. 116–128, 2019.
- [29] M. Despotovic, V. Nedic, D. Despotovic, and S. Cvetanovic, "Review and statistical analysis of different global solar radiation sunshine models," *Renew. Sustain. Energy Rev.*, vol. 52, pp. 1869–1880, 2015.
- [30] K. Ulgen and A. Hepbasli, "Diffuse solar radiation estimation models for Turkey's big cities," *Energy Convers. Manag.*, vol. 50, no. 1, pp. 149–156, 2009.
- [31] M. Despotovic, V. Nedic, D. Despotovic, and S. Cvetanovic, "Review and statistical analysis of different global solar radiation sunshine models," *Renew. Sustain. Energy Rev.*, vol. 52, pp. 1869–1880, 2015.
- [32] B. Jamil and N. Akhtar, "Empirical models for estimation of diffuse solar radiation based on measured data for humid-subtropical climatic region of India," *J. Renew. Sustain. Energy*, vol. 9, no. 3, 2017.
- [33] M. D. Islam, I. Kubo, M. Ohadi, and A. A. Alili, "Measurement of solar energy radiation in Abu Dhabi, UAE," *Appl. Energy*, vol. 86, no. 4, pp. 511–515, 2009.
- [34] A. M. AL-Salihi, M. M. Kadum, and A. J. Mohammed, "Estimation of global solar radiation on horizontal surface using routine meteorological measurements for different cities in Iraq," *Asian J. Sci. Res.*, vol. 3, no. 4, pp. 240–248, 2010.
- [35] M. Y. Sulaiman and A. B. Umar, "A Comparative Analysis of Empirical Models for the Estimation of Monthly Mean Daily Global Solar Radiation Using Different Climate Parameters in Sokoto , Nigeria," vol. 5, no. 1, pp. 1–19, 2017.

Effect of Ar Gas Flow Rate on Growth, Structure, and Optical Properties of Sputtered Sb₂Se₃ Absorber Thin Films for Solar Cells

S. Hazal Gundogan¹, Gulnur Aygun¹, Lutfi Ozyuzer^{1,2} Ayten Cantas^{1,3}

¹ Department of Physics, Izmir Institute of Technology, Urla, 35430, Izmir, Turkey

² Teknoma Technological Materials Inc., Izmir Technology Development Zone, Urla, 35430, Izmir, Turkey

³ Department of Electric and Energy, Pamukkale University, Kinikli, 20160, Denizli, Turkey

[*abagdas@pau.edu.tr](mailto:abagdas@pau.edu.tr)

The thin film solar cell technologies gain increasing interest from the photovoltaic industry because of their potential producing low cost electricity. Although CdTe and CIGS are involved in the commercial production of thin-film solar cells, they contain rare and expensive materials like In, Ga, Te and include toxic element like Cd [1,2]. Antimony selenide (Sb₂Se₃) is a newly explored p-type semiconductor material. As an absorber layer, the Sb₂Se₃ compound is composed of Sb and Se elements which are quite low cost, low-toxic and have high surface reserves. Sb₂Se₃ has also favorable photovoltaic properties, such as proper band gap (1.1–1.3 eV), high absorption coefficient (>10⁵ cm⁻¹), intrinsically benign grain boundaries and high theoretical conversion efficiency up to 31% [3]. The properties of the absorber layer vary with deposition parameters such as substrate used, deposition pressure, rate of the inert gas and the growth temperature. In this work, Sb₂Se₃ films have been grown with radio-frequency (RF) magnetron sputtering method onto soda lime glass (SLG) substrates with different Ar flow rates. For the structural characterization of Sb₂Se₃ absorber thin films, the Raman Spectroscopy, X-Ray Diffraction (XRD) and Scanning Electron Microscopy (SEM) were used. The atomic compositional ratio was studied using Energy Dispersive X-ray Spectroscopy (EDX). The evolution of these physical properties of Sb₂Se₃ films as a function of the argon flow rate is discussed. It was found that the physical properties of Sb₂Se₃ depend on coating parameters e.g. Ar flow rate and it can be used as an additional control parameter in setting the value of the band gap energy. The Sb₂Se₃ film grown with 25 sccm has more promising results considering both crystal orientation and optical bandgap energy.

*This research is supported by TUBITAK (Scientific and Technical Research Council of Turkey) project number 118F143. This study was partially supported by Scientific Research Coordination Unit of Pamukkale University under the projects number of HZDP041.

Keywords: Sb₂Se₃, thin film, magnetron sputtering, Ar flow rate

References

- [1] Cantas A., *et al.*, J. Phys. D: Appl. Phys. 51, 275501 (2018)
- [2] Turkoglu F., *et al.*, Thin Solid Films, 670, 6-16 (2019).
- [3] Shongalova, A., *et al.*, Sol. Energy Mater. Sol. Cells, 187, 219-226 (2018).

The Fabrication of Silicon Based Solar Cells with Graphene and Molybdenum Doped Zinc Oxide

Serkan ERKAN^{1,2}, Ali ALTUNTEPE¹, Mehmet ALI OLĞAR^{1,2}, Ayşe SEYHAN^{1,2}, Recep ZAN^{1,2}

¹ Nanotechnology Research and Application Center, Niğde Ömer Halisdemir University, Niğde, Turkey

² Niğde Ömer Halisdemir University, Department of Physics, Niğde, Turkey

*Corresponding Author: recep.zan@ohu.edu.tr

Transparent conductive oxide (TCO) films such as ITO, AZO, MZO etc. are widely used in transparent thin film transistors, solar cells, and optoelectronic devices thanks to their high light transmittance, good electrical conductivity, stability and durability. Graphene, a thin sheet of carbon, has been employed as an alternative to commercial TCOs to enhance the performance of solar cells in the literature (1-3). However, employing only graphene film as TCO does not result in a significant cell efficiency due to its high sheet resistance. To overcome this problem, in this study, we grew molybdenum doped zinc oxide (MZO) thin films and a single layer graphene film to fabricate a hybrid MZO/graphene structure. So, we initially investigated the influence of the film thickness (50-500 nm) of MZO on the structural, electrical, and optical properties of the films by X-ray diffraction (XRD), Scanning Electron Microscope (SEM-EDAX), Four Probe Point (FPP), Atomic Force Microscope (AFM) respectively. The results of the study revealed that with an increase in the film thickness, the crystallinity of the film improved. Among all the films investigated, the MZO film with 500 nm thickness was found to be the best because of its high transmission (Figure 1), low resistivity and high crystallinity. After optimizing the MZO film thickness, a single layer graphene film was transferred onto MZO and thus this hybrid structure was applied to silicon based solar cells. Our study revealed that the efficiency of a solar cell can be increased using hybrid MZO/graphene structure.

The authors gratefully acknowledge the funding from The Scientific and Technological Research Council of Turkey (TUBITAK-119M032-117M401).

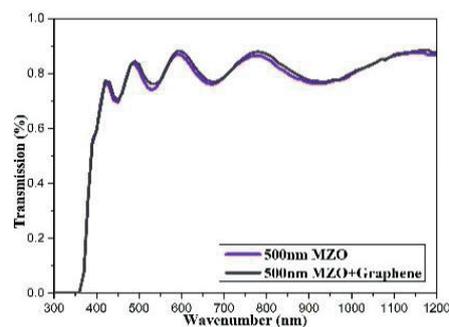


Figure 1 Transmission of 500 nm thickness MZO and MZO+Graphene.

Keywords: TCO, MZO, Graphene, Solar Cell, RF Sputtering

References

1. Nandi A, Mandal S, Ghosh S, Dhar S, Majumdar S, Saha H, et al. Application of hybrid rGO-ITO bilayer TCO on a-Si solar cell for performance enhancement. *IEEE Journal of Photovoltaics*. 2018;9(1):12-7.
2. Yin Z, Zhu J, He Q, Cao X, Tan C, Chen H, et al. Graphene-based materials for solar cell applications. *Advanced energy materials*. 2014;4(1):1300574.
3. Singh E, Nalwa HS. Stability of graphene-based heterojunction solar cells. *Rsc Advances*. 2015;5(90):73575-600.

LOW COST SOLUTION BASED ZnO/Cu₂O HETEROSTRUCTURES FOR PHOTOVOLTAIC APPLICATIONS

Teoman Özdal, Merhan Kılıç, Hamide Kavak
Physics Department, Çukurova University, Adana, Turkey
teமானozdal@hotmail.com

ZnO/Cu₂O thin film solar cells are promising structures due to their abundance in nature and high theoretical efficiency. However, defects in thin films and interface limit the efficiency which can be increased with the optimisation of the ZnO thin film layer and therefore the hetero-interface. In this study, sol-gel spin coated n-ZnO thin film is highly optimized to improve the efficiency of previously studied solar cell device. Solution and thermal treatment parameters were optimized to increase the structural and opto-electronic properties. Simple two electrodes cell was utilized to grow p-type Cu₂O thin film electrochemically on the top of ZnO. Indium thin oxide coated glass substrate was used as a bottom electrode and silver paste used as a top electrode. The V_{OC} and I_{SC} of our champion cell were 202 mV and 0.24 mA with 31% FF. The future work should focus on improving the ZnO-Cu₂O interface.

1. Fabrication and characterization of ZnO/Cu₂O heterostructures for solar cells applications, Teoman Özdal, Hamide Kavak, Superlattices and Microstructures, 146 (2020) 106679.
2. Cu₂O/ZnO heterojunction thin-film solar cells: the effect of electrodeposition condition and thickness of Cu₂O, Man Hieu Tran, Jae Yu Cho, Soumyadeep Sinha, Myeng Gil Gang, Jaeyeong Heo, Thin Solid Films 661 (2018) 132–136.
3. High-Efficiency Oxide Solar Cells with ZnO/Cu₂O Heterojunction Fabricated on Thermally Oxidized Cu₂O Sheets, Tadatsugu Minami, Yuki Nishi, Toshihiro Miyata, Jun-ichi Nomoto, Applied Physics Express 4 (2011) 062301.

DESIGN OF SURFACE PASSIVATION TECHNIQUES FOR PbTe QUANTUM DOTS AND APPLICATION TO PHOTOVOLTAIC DEVICES

Tuğba Hacıfendioğlu¹, Taha K. Solmaz¹, Merve Erkan¹, Demet Asil^{1,2,3,4} *

¹ Department of Chemistry, Middle East Technical University (METU), 06800, Turkey

² The Center for Solar Energy Research and Application, METU, 06800, Turkey

³ Department of Micro and Nanotechnology, METU, 06800, Turkey

⁴ Department of Polymer Science & Technology, METU, 06800, Turkey

* E-mail: adem@metu.edu.tr

Limited air stability circumvents the outstanding properties of the PbTe quantum dots (QDs) and hinders its utilization in the field of optoelectronics.^[1] In this respect, we present a detailed understanding on the instability of the PbTe QDs and develop a combinatorial passivation protocol based on engineering the QD surface during the growth phase and solid state ligand exchange process.^[2] The dual passivation approach yields thin films and solar cells with outstanding stabilities under ambient conditions. Prioritization of the effects of the synthetic conditions with a systematic approach discloses the crucial roles of the size, shape and stabilizing ligand/catalyst concentration on the stability. Our findings show that the stability diminishes beyond a critical size (3.6–3.9 nm) where the shape changes from octahedron to truncated octahedron. We illustrate that the mid gap state formation (MGS), indispensable for any ligand exchange processes, can only be inhibited by using QDs whose capacity to withstand the severe conditions of the exchange process is improved by passivating *in-situ*. *In-situ* growth phase passivation not only control the shape by dictating the {111}/{200} facet ratio but also controls the ligand exchange rate, packing direction and MGS formation. The combinatorial passivation strategy yields air stable solar cells with a 100% increase in the efficiency and up to a fivefold increase in the short circuit current.

Keywords: Lead telluride, PbTe, quantum dot, solar cell, surface passivation, mid gap states

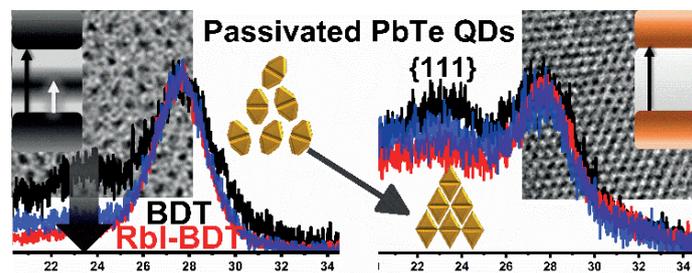


Figure 1. Thin film XRD patterns of the unpassivated PbTe QDs (left) and passivated PbTe QDs (right). Introducing metal halides to the UP-QD surface promotes the packing along the <200> direction as indicated by the disappearance of the (111) diffraction. However, PbTe QDs preserve their packing preferences upon metal halide treatment, when passivated.

References

- [1] D. E. Bode, H. Levinstein, *Phys. Rev.* **1954**, *96*, 259.
- [2] T. Hacıfendioğlu, T. K. Solmaz, M. Erkan, D. Asil, *Sol. Energy Mater. Sol. Cells* **2020**, *207*, 110362.

SnSbSe₂ Crystal: Growth by Vertical Bridgman Technique and Investigation of Its Structural, Optical and Electrical Properties

Tunc Bektas¹, Makbule T. Bilmis,^{1,2,4} Ozge B. Surucu,³ Mehmet Parlak^{1,4}

¹ Middle East Technical University/Physics, Ankara, Turkey

² Namik Kemal University/Physics, Tekirdag, Turkey

³ Atilim University/Electrics and Electronics Engineering, Ankara, Turkey

⁴ The Centre for Solar Energy Research and Applications, Ankara, Turkey

*parlak@metu.edu.tr

SnSe and SbSe compounds are crucial materials for optoelectronic and photovoltaic device applications [1-2]. SnSbSe is a promising candidate to maximize the performances of SnSe and SbSe crystals. The aim of this study was the growth of the SnSbSe₂ crystal using the vertical Bridgman technique and the investigation of the structural, optical and electrical properties of grown crystal. Energy Dispersive X-ray spectrum (EDS) analysis verified the stoichiometric ratio is close to the desired ratio that is around 1:1:2 and Scanning Electron Microscopy (SEM) analysis exhibited that the crystal is composed of two-dimensional layers. The crystal structure was confirmed by X-Ray Diffraction (XRD) analysis resulting in an intense and sharp peak. The optical modes of crystal were described by Raman Spectroscopy. In spectroscopic ellipsometry measurement, the crystal was observed to obey the Cody-Lorentz dispersion model. According to this model, optical constants n and k , at 632.8 nm, were 4.9 and 2.4 respectively and energy band gap of the crystal was 1.37 eV. For electrical characterization, the Indium (In) contacts was coated by thermal evaporation technique and the I - V behavior of the crystal is analyzed in both dark and illuminated conditions. According to the I - V analysis, SnSbSe₂ crystal was found to be in the ohmic nature.

Keywords: SnSbSe₂ crystal, characterization, vertical Bridgman growth

References

- [1] K. Patel, G. Solanki, K. Patel, V. Pathak, and P. Chauhan, "Investigation of optical, electrical and optoelectronic properties of SnSe crystals," *Eur. Phys. J. B*, 2019, doi: 10.1140/epjb/e2019-100306-8.
- [2] Y. Zhang, E. Skoug, J. Cain, V. Ozoliņ, D. Morelli, and C. Wolverton, "First-principles description of anomalously low lattice thermal conductivity in thermoelectric Cu-Sb-Se ternary semiconductors," *Phys. Rev. B - Condens. Matter Mater. Phys.*, 2012, doi: 10.1103/PhysRevB.85.054306.

2D Perovskite Layer based on Novel Organic Cation for Increased Efficiency and Stability

Ummugulsum Gunes¹, Selçuk Yerci^{*2,3,4}, Gorkem Gunbas^{*1,2,4}

¹ METU, Department of Chemistry, Ankara, Turkey

² Center for Solar Energy Research Center and Applications (GUNAM), Ankara, Turkey

³ METU, Department of Electrical and Electronics Engineering, Ankara, Turkey

⁴ METU, Department of Micro and Nanotechnology, Ankara, Turkey

*syerci@metu.edu.tr, *qgunbas@metu.edu.tr

Low dimensional perovskites have attracted a great attention due to their remarkable stability. However, their efficiencies are not on par with their 3-dimensional counterparts, which hinders their commercialization. In this study, we inserted a 2-dimensional perovskite layer using a novel cation (TT), between the 3D perovskite film and the hole transport layer. 3D-2D perovskite devices fabricated in this study exhibited a performance enhancement, resulting in an increase in their power conversion efficiencies (PCE) from 17% to over 19%, by improving hole extraction. Furthermore, devices showed promising stability as a result of hydrophobic nature of the TT-based 2D layer. 3D-2D PSCs retained 92% of its initial PCE at 15% humidity for 25 days without encapsulation while the reference devices maintained only 39% of its initial efficiency.

Keywords: 3D-2D PSCs, stability, novel organic spacer

Employing Near-IR Absorbing Bodipy Chromophores as Donor Materials for the Active Layer of Bulk-Heterojunction Solar Cells

Yusuf Çakmak¹

¹ Konya Gıda ve Tarım Üniversitesi, Biyomühendislik Bölümü, Melikşah Mh. Beyşehir Cd. No: 9, Meram, Konya, Türkiye

* E-mail: yusuf.cakmak@gidatarim.edu.tr

Organic solar cells are among the new generation solar cells and due to their superior properties they have received significant attention in the recent decades. Some of these properties include low-cost, lightweight, easy preparation and flexible structure.¹ Since the power conversion efficiencies (PCE) of these types of cells have exceeded 13%, strategies among commercialization are also in progress. In our lab designing and synthesizing BODIPY based donor small molecules to be used in the active layer of these types of cells have been performed.^{2,3} In order to use the enhanced absorption capability of these compounds injecting electrons from the donor to the acceptor part (PCBM based) of the cell efficiently after absorption of light from the solar simulator and complete the circuit after traveling from other layers has been investigated. Accordingly, designing and synthesizing two novel donor molecules where Bodipy unit has been used as electron deficient part and bithiophene units as electron rich part have been accomplished. Their applicability by characterizing the HOMO-LUMO energy levels computationally and experimentally has been completed. The photophysical characterizations relating to these have also been accomplished. In order to determine the optimized efficiencies, and the current/voltage characteristics under the solar simulator, solar cells was set up in the configuration of ITO/PEDOT:PSS/BODIPY:PCBM/LiF/Al. Different configurations and optimization studies such as donor to acceptor ratio, annealing temperature and time, use of additive have been elaborated. As a result of different configurations it has been shown that the chromophore with the higher amount of solubilizing groups is more efficient with a maximum PCE of 1.3%. Based on the current results, studies have been under consideration where different units have been attached to yield better results.

Keywords: : BODIPY, organic solar cells, organic synthesis, near IR dyes

References

- 1) Bucher, L., Desbois, N., Harvey, P. D., Gros, C. P., & Sharma, G. D. (2017). Porphyrin antenna-enriched BODIPY–thiophene copolymer for efficient solar cells. *ACS applied materials & interfaces*, 10(1), 992-1004.
- 2) Bura, T., Leclerc, N., Fall, S., Lévêque, P., Heiser, T., Retailleau, P., ... & Ziessel, R. (2012). High-performance solution-processed solar cells and ambipolar behavior in organic field-effect transistors with thienyl-BODIPY scaffoldings. *Journal of the American Chemical Society*, 134(42), 17404-17407.
- 3) Kolemen, S., Çakmak, Y., Ozdemir, T., Erten-Ela, S., Buyuktemiz, M., Dede, Y., & Akkaya, E. U. (2014). Design and characterization of Bodipy derivatives for bulk heterojunction solar cells. *Tetrahedron*, 70(36), 6229-6234.

Acknowledgements: TÜBİTAK Project Number 118Z392. Mutahire Tok, Büşra Can (Konya Food and Agriculture Uni.); Derya Öncel Özgür, Yavuz Dede (Gazi Uni.); Gamze Dölek, Mahmut Kuş, Çisem Kırbıyık Kurukavak (Konya Technical Uni.) were acknowledged.

A NEW EFFICIENT SYNTHESIS OF ZnS THIN FILM USING MIST CVD TECHNIQUE

Y. KHAAISSA^{1,*}, F. ELGUEDAH¹, A. TALBI¹, K. NOUNEH¹

¹ Ibn Tofail University, Faculty of Science / Department of Physics, Kenitra, Morocco

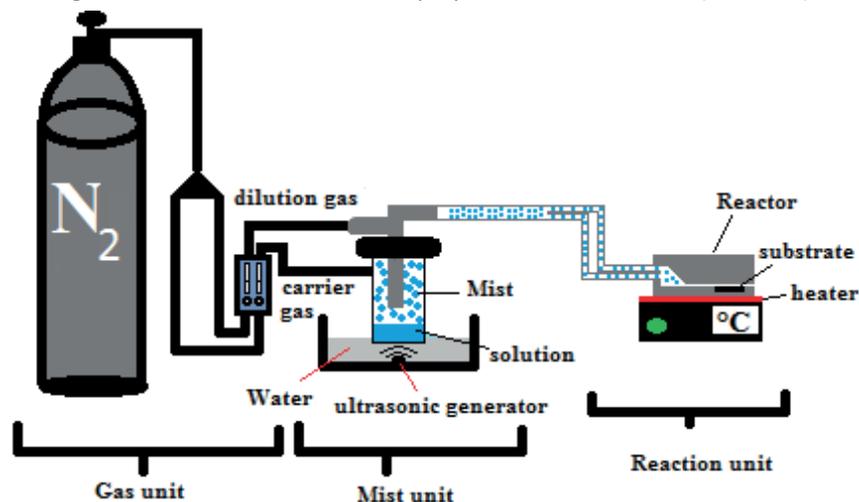
.....

*yassine.khaaissa@uit.ac.ma

Zinc Sulphide (ZnS) thin films have been successfully synthesized using Mist CVD method [1] as a buffer layer for photovoltaic applications [2]. The films were deposited on glass substrates. The solution was prepared using Zinc Chloride and Thiourea as zinc source and sulfur source respectively. First, the effect of the solvent has been investigated and optimized, then we have studied the effect of the temperature on structural, morphological and optical properties of ZnS films. The characterizations have been carried out using X-ray diffraction technique (XRD), UV-vis spectrophotometry and scanning electron microscopy (SEM). XRD results showed that ZnS films were crystallized in the zinc blende (ZB) structure with (111) orientation. Optical measurements have shown that all films exhibit, along the visible range, a high transmittance and that optical band gap depends on both solvent and temperature. The scanning electron microscopy shows that the microstructures of ZnS are homogeneous mainly for 450°C using 25% distilled water and 75% methanol.

Keywords: ZnS, Buffer Layer, thin films, Ultrasonic Spray Assisted CVD, solar cells, photovoltaic applications.

Figure 1. Fine Channel Ultrasonic Spray Assisted CVD method (Mist CVD)



References

- [1] Y. Khaaissa, K. Fathi, A. Talbi, K. Nouneh, K. El Mabrouk, A. Taleb, *Surface Review and Letters*, (2020)
doi: 10.1142/S0218625X20500249
- [2] J. Hong, D. Lim, Y.-J. Eo, C. Choi, *Applied Surface Science*, Volume 432, Part B, 28 February 2018, Pages 250-254

PVCON 2020
PHOTOVOLTAIC CONFERENCE

**POSTER
PRESENTATIONS**

Propagation of cracks in standard cell and half-cell photovoltaic technology

Abdellatif Bouaichi^{1,2*}, Eloualid Chakir³, Abdellatif Ghennioui¹, Hassan El minor³, Choukri Messaoudi²

¹ Green Energy Park (IRESEN, UM6P), benguerir, Morocco

² OTEA, Dept. Of Physics, FST, Errachidia, Moulay Ismail University of Meknes, Morocco

³ ENSA – Université Ibn Zohr, Agadir – Maroc

*bouaichi@iresen.org/ a.bouaichi1989@gmail.com

The inspection of five PV systems installed in the green Energy Park platform, Morocco indicates that the cracks of solar cells, detected by EL thermography, represent a dominant degradation mode under these operating conditions. This is because solar cells are subjected to bending forces under the effect of wind in desert conditions. To better understand the propagation of this phenomenon in standard cell and half-cell technology, under different mechanical loads, we used a 3D simulation. This allowed us to understand the response of each cell type and select the most resistant to mechanical stress as well. Two 3D finite element models were created. Each model represents a mini PV module. In this simulation, different load intensities have been applied. The applied mechanical loads are 2500 Pa then 5000 Pa with embedding of the mini-modules on their ends. The result show that, under standard cell module the crack propagation is proportional to the applied mechanical load, which is not obvious for the half-cell module. The results obtained also show that the cracks propagate less in the half-cells. This is why the half-cell technology can be an alternative to increase the lifespan of PV module in arid and semi-arid regions of Morocco.

Keywords: Cracks, standard cell, half-cell, propagation.

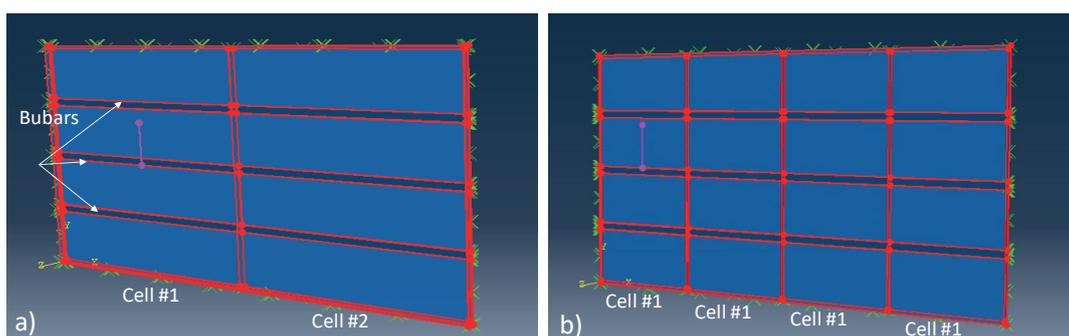


Figure 1. a) Standard cell mini module and b) Half-cell mini module models

A Techno-Economic Study of Rooftop Grid-connected Photovoltaic-Energy Storage Systems in Qatar

Abdelrahman Amer², Nabila Elbeheiry², Seif Elgazar², Sawsan Shukri², Morcos Metry², Robert S. Balog^{1,2}

¹ Renewable Energy & Advanced Power Electronics Research Laboratory, Texas A&M University, College Station, TX 77843, USA

² Department of Electrical and Computer Engineering, Texas A&M University at Qatar, Doha, Qatar

abdelrahman.amer@qatar.tamu.edu

nabila.elbeheiry@qatar.tamu.edu

seif.elgazar@qatar.tamu.edu

sawsan.shukri@qatar.tamu.edu

morcos.m.metry@ieee.org

robert.balog@ieee.org

Gulf Corporation Countries (GCC) are exposed to high levels of solar insolation throughout the majority of the year. Therefore, the use of photovoltaics (PV) is a clean and viable source of energy for applications in the GCC region. This paper presents a detailed techno-economic study for the implementation of a grid-connected rooftop photovoltaic and energy storage system (PV-ESS) in the State of Qatar as seen in *Figure 1*. This study aims to present a detailed cost analysis as well as sizing information for a house in Qatar. A multi-objective optimization taking into account generation and load profiles, cost of grid consumption, cost of materials and house size is presented in form of pareto frontier curves as seen in *Figure 2*. Load modulation is considered in this study to lower capital expenditure and operation costs as seen in *Figure 3*. The benefit to a developed country like Qatar is to improve the resilience of the electrical supply and reduce the carbon footprint. The benefit to a developing country is that it brings electricity to individual homes without needing an expensive utility grid. Although this paper is not an energy policy paper, the techniques used throughout the paper can be used to set energy policy in the state of Qatar. Results of this study are presented in the form of implementation steps to make rooftop PV-ESS systems feasible in Qatar based on factual information and detailed analysis as seen in *Tables 1* and *2*.

Keywords: Photovoltaic, Energy Storage Systems, Residential Rooftop Installations, Renewable Energy Systems, Cost Analysis, Multi-objective Optimization.

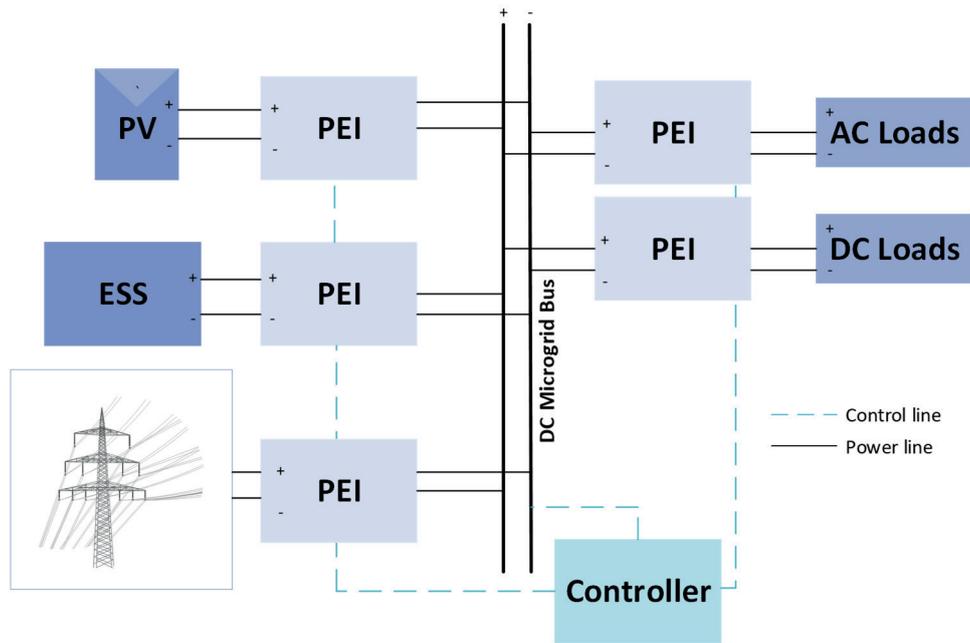


Figure 1. A system topology that integrates solar energy generation and uses power electronic interfaces (PEI) to interface various system components to the common DC bus. The system includes photovoltaic modules (PV), energy storage system (PEI + ESS), grid connection through the point of common coupling (PCC) and loads. The objective for the control of this system is to economically satisfy the load demand while maximally relying on the renewable energy from the solar PV modules.

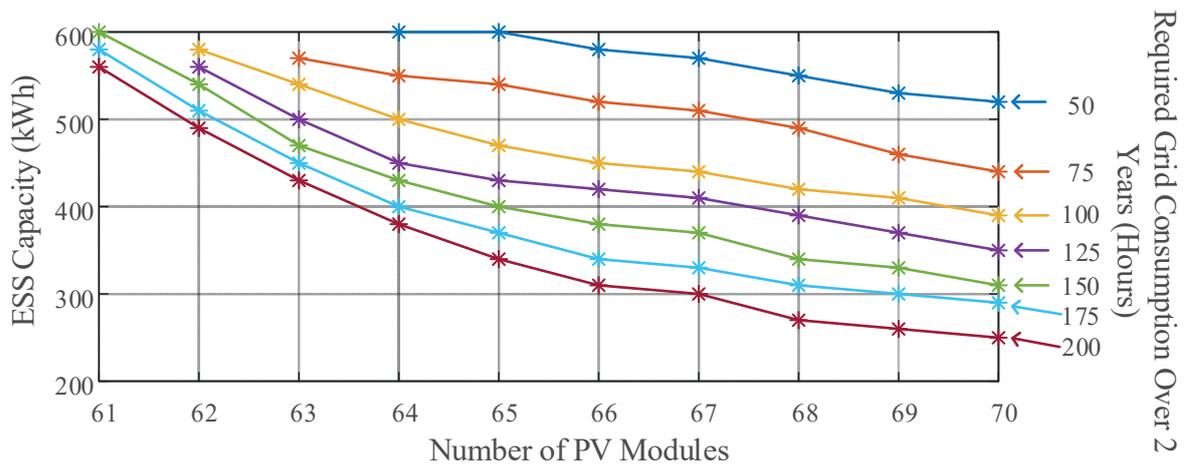


Figure 2. A selection tool to properly size the PV-ESS system based on the Pareto Frontier curves. A tradeoff exists between PV/ESS parameter values given the same grid hours since each curve represents a family of designs with the same number of required grid hours within two years.

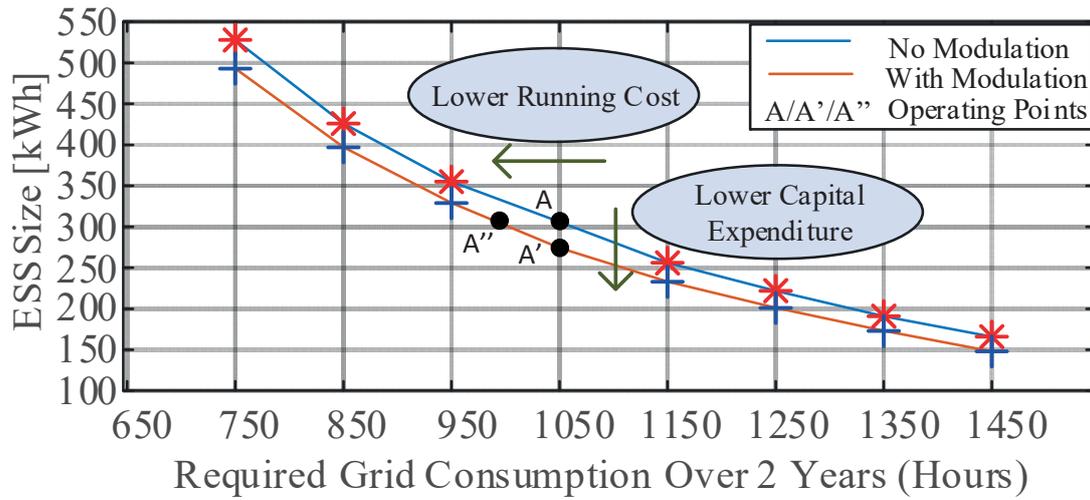


Figure 3. Effect of load modulation on ESS sizing. The integration of Load Modulation: 1- Lowers ESS size (Capital Expenditure) while maintaining required Grid Hours (A to A'). 2- Reduces required Grid Hours (Running Cost) while maintaining the same ESS size (A to A'').

Table 1. Utility Power Grid Electric Energy Consumption Rates

Location	Average Utility Power Grid Electric Energy Rate per kWh (USD)
Qatar	0.0300 [1]
Texas, USA	0.1185 [2]
Jamaica	0.3100 [3]
Germany	0.3400 [4]
US Virgin Islands	0.3985 [5]
California, USA	0.5500 [6]
Vanuatu	0.6000 [5]
Solomon Islands	0.9900 [5]

Table 2. Cost Difference between System Implementation (300 Grid Hours) and total Power Grid Reliance in 18 years with varying rate implementations in Qatar

Country Rate	100% Grid Reliance (\$)	System Implementation Cost (\$)	Net Benefit (\$)
Qatar	24,945.27	228,507.53	-203,562.27
Texas, USA	82,995.78	230,160.42	-147,164.64
Jamaica	217,119.77	233,979.36	-16,859.59
Germany	238,131.36	234,577.63	3553.73
U.S Virgin Islands	279,103.96	235,744.25	43,359.71
California, USA	385,212.49	238,765.50	146,446.99
Vanuatu	420,231.81	239,762.61	180,469.20
Solomon Islands	693,382.49	247,540.10	445,842.39

References

- [1] Km.com.qa. (2019). Qatar General Electricity & water Corporation -المؤسسة العامة القطرية للكهرباء والماء. [online] Available at: <https://www.km.com.qa/Customerservice/Pages/Tariff.aspx> [Accessed 31 Dec. 2019].
- [2] Chooseenergy.com, 2020. [Online]. Available: <https://www.chooseenergy.com/electricity-rates-by-state/>. [Accessed: 26-Jan- 2020].
- [3] GlobalPetrolPrices.com. (2019). Jamaica electricity prices, June 2019 | GlobalPetrolPrices.com. [online] Available at: https://www.globalpetrolprices.com/Jamaica/electricity_prices/ [Accessed 31 Dec. 2019].
- [4] Ec.europa.eu. (2019). Electricity price statistics - Statistics Explained. [online] Available at: https://ec.europa.eu/eurostat/statistics-explained/index.php/Electricity_price_statistics [Accessed 31 Dec. 2019].
- [5] B. Reality, "Countries With The Most Expensive, & Cheapest Electricity Prices (Electricity Prices Around The World) - Better Meets Reality", Better Meets Reality, 2020. [Online]. Available: <https://www.bettermeetsreality.com/countries-with-the-most-expensive-cheapest-electricity-prices-electricity-prices-around-the-world/>. [Accessed: 26- Jan- 2020].
- [6] Sdgc.com. (2019). High Usage Charge | San Diego Gas & Electric. [online] Available at: <https://www.sdgc.com/high-usage-charge> [Accessed 31 Dec. 2019].

A GRID-CONNECTED PHOTOVOLTAIC POWER CONVERSION SYSTEM WITH SOLID-STATE TRANSFORMER

AHMED F. KASSE¹, NADIR KABACHE¹, SAMIR MOULAHOM¹

¹ Laboratory of Electrical Engineering and Automatic / University of Medea, Algeria

.....

*nadir.kabache@gmail.com

This paper presents a grid-connected photovoltaic (PV) system. The grid integration of the PV system is carried out via a solid-state transformer (SST) (Fig. 1). The SST consists of three main stages: medium voltage stage, isolation stage, and low voltage stage. When the power flows from the MV side to the LV side, the input power-frequency ac voltage is converted into a medium voltage dc voltage by the three-phase ac/dc converter, which in such case works as rectifier. The isolation stage includes a high frequency transformer (HFT) and the two corresponding MV- and LV-side converters. Finally, the output LV-side comprises three-phase dc/ac converter. In order to integrate the photovoltaic system as main source, we use transformer multi-port. Furthermore, to allow maximal power conversion into the grid, Maximum Power Point Tracking (MPPT) algorithms, have been incorporated. To control the inverter a voltage oriented control (VOC) method has been applied. The model developed for this work has been implemented in MATLAB/Simulink, and its behavior has been tested. The simulation results show the control performance and dynamic behavior of grid-connected PV system.

Keywords: Solid-state transformer (SST), Photovoltaic power systems, voltage oriented control (VOC), maximum power point tracking (MPPT).

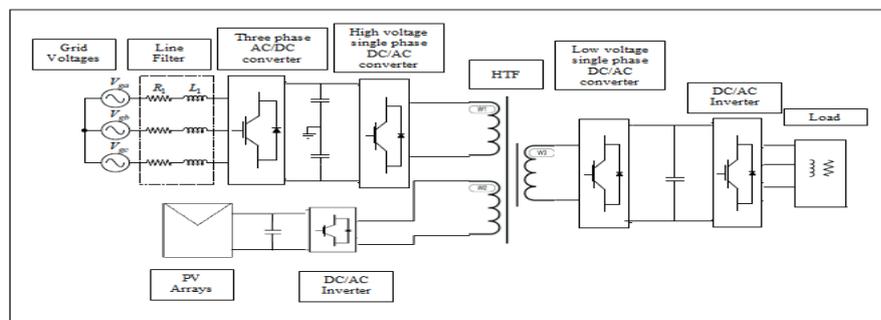


Fig. 1. Schematic configuration of the used SST.

References

- [1] M. Ebrahim Adabi , Juan A. Martinez-Velasco , Salvador Alepuz.2018.Modeling and simulation of a MMC-based solid-state transformer.Electrical Engineering 100.375–387
- [2] Mohammad Rashidi, Adel Nasiri, Robert Cuzner. 2016. Application of multi-port solid state transformers for microgrid-based distribution systems.5 th IEEE International Conference on Renewable Energy Research and Applications (ICRERA)
- [3] Jaime Alonso-Martínez, Joaquín Eloy-García, Santiago Arnaltes .2010 .Direct power control of grid connected PV systems with three level NPC inverter.Solar Energy 84, 1175–1186
- [4] Rym Marouani, Abdelkader Mami.2010.Voltage Oriented Control Applied to a Grid Connected Photovoltaic System with Maximum Power Point Tracking Technique.American Journal of Applied Sciences 8.1168–1173

FABRICATION AND CHARACTERIZATION OF EPITAXIAL LIFT-OFF PROCESSED GaAs THIN FILM SOLAR CELLS HETERO-EPITAXIALLY GROWN ON SI SUBSTRATES

Ali Buyukpinar^{1*}, Muhammed Aktas², Burcu Arpapay², Mustafa Kulakci^{2,3}

¹ Eskisehir Technical University/Materials Science and Engineering, Eskisehir, Turkey

² Eskisehir Technical University/Physics Department, Eskisehir, Turkey

³ Eskisehir Technical University/Institute of Earth and Space Sciences, Eskisehir, Turkey

*abuyukpinar@eskisehir.edu.tr

GaAs based III-V group solar cells are the most efficient and radiation resistant cell technologies in the photovoltaic technologies at present. The high cost of single crystal III-V wafers limits the use of GaAs in photovoltaic applications. The epitaxial lift-off (ELO) technique can be used to reduce the substrate cost by re-using the substrate to grow solar cell multiple times in sequential way. ELO technique allows for the separation of an epitaxial grown GaAs thin film solar cell structure from its underlying substrate using selective wet etching of a thin film AlAs release layer using an aqueous HF solution. Hetero epitaxial growth of group III-V materials and devices on cheaper Si substrate has been attracting huge interests recently. This work describes the fabrication processes to separate and transfer of GaAs based thin film solar cell structures on to the flexible polyimide carriers by using ELO technique. Cell structures was grown on Si substrates in a hetero-epitaxial way using different dislocation filter layer approximations. A flexible and lightweight GaAs thin film solar cells have been fabricated and characterized in a comparative way to investigate effects of dislocation filter layers.

Keywords: GaAs, hetero-epitaxy, ELO, flexible thin film, solar cell

Optical and Structural Studies of ZnS:Ni Films for Solar Cell Applications

Ayşe Kucukarslan¹, Barbaros Demirselcuk², Esra Kus³, Vildan Bilgin¹

¹ Canakkale Onsekiz Mart University/Department of Physics, Canakkale, Turkey

² Canakkale Onsekiz Mart University/Department of Electricity and Energy, Canakkale, Turkey

³ Uludag University/Department of Physics, Bursa, Turkey

*akucukarslan@comu.edu.tr

ZnS are very important semiconductor II-VI compounds used in different fields such as filters, photovoltaic cells due to their optical and electronic properties. ZnS contributes significantly to opto-electronics technology by adding transition elements to semiconductor films. In this work, un-doped and Ni-doped zinc sulfide (ZnS:Ni) thin films were prepared by spray pyrolysis technique using from aqueous solution of zinc chloride ($ZnCl_2$) and thiourea ($SC(NH_2)_2$) as sources of zinc and sulphur ions respectively. We used hexahydrated nickel chloride ($NiCl_2 \cdot 6H_2O$) as the dopant. The films were deposited onto heated glass substrates at $300^\circ C \pm 5$. The effects of Ni doped on optical and structural properties of ZnS thin films were investigated by UV-VIS spectrophotometer and X-ray diffractometer (XRD), respectively. From UV-VIS spectrophotometer measurements, it was determined that optical transmittance of ZnS films decreases in the visible region with Ni doping. The absorption edge analysis revealed that the optical band gap energies for the films were between 3.73-3.96 eV. X-ray diffraction (XRD) studies revealed that all the deposited films (un-doped and Ni-doped ZnS) were polycrystalline with hexagonal structure and exhibited (002) preferential orientation. As a result of analyzes, it has been determined that the Ni doping have influences on the optical and structural properties of ZnS thin films. In this study, usability of undoped and Ni doped ZnS thin films in opto-electronics industry and photovoltaic solar cells were investigated. As a result of analyzes, it is possible to say that ZnS:Ni films can be used in various optoelectronic devices, especially thin film solar cells, due to their structural and optical properties especially the suitability of the band gap..

Keywords: ZnS:Ni thin films; Ultrasonic spray pyrolysis technique; optical properties, UV-Vis, XRD

Acknowledgements: This work was supported by the Canakkale Onsekiz Mart University Scientific Research Projects Committee under the Project Number FBA-2019-3039.

Effect of High Illumination on Industry Compatible Single Crystalline Silicon PERC Solar Cell

Behrad Radfar^{1,2,*}, **Rasit Turan**^{1,2,3}

¹ Center for Solar Energy Research and Applications (GÜNAM), Middle East Technical University, Ankara, Turkey

² Micro and Nanotechnology Graduate Program, Middle East Technical University, Ankara, Turkey

³ Department of Physics, Middle East Technical University, Ankara, Turkey

*behrad.radfar@metu.edu.tr

Solar cells are rapidly growing in both efficiency and widespread utilization. A way to increase the efficiency is increasing illumination on solar cells using sun light concentrator like mirrors or lenses which is called concentrated photovoltaic (CPV). However, the effects of high illuminations on electrical properties of the solar cells requires further investigation [1]. In the following study, the effects of high illumination up to 60 Suns on an efficient fabricated solar cell ($\eta=19.86\%$) are inspected. In addition to fabricated solar cell, an optimal solar cell with enhanced (but not ideal) parameters is examined. The results indicate that various parameters are contributing to the performance; specifically, finger sheet resistance and number of fingers have huge effects on the outcome. Figure 1 shows the effect of illumination on (a) the normalized I-V curve; (b) the Efficiency and Fill Factor; and (c) the I_{sc} and V_{oc} . All the effects are simulated using Griddler Solar software [2].

Keywords: Concentrated Photovoltaic, CPV, Crystalline Silicon Solar Cell

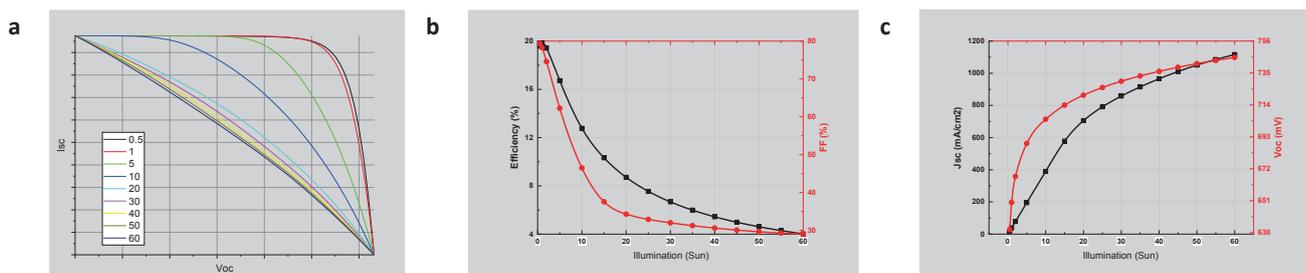


Figure 1. Effect of illumination on a. the normalized I-V curve; b. on the Efficiency and Fill Factor; c. on the I_{sc} and V_{oc} .

References

- [1] G. Paternoster, M. Zanucoli, P. Bellutti, L. Ferrario, F. Ficorella, C. Fiegna, P. Magnone, F. Mattedi, E. Sangiorgi, "Fabrication, characterization and modeling of a silicon solar cell optimized for concentrated photovoltaic applications", *Solar Energy Materials and Solar Cells*, Volume 134, 2015, Pages 407-416, DOI: 10.1016/j.solmat.2014.12.026.
- [2] J. Wong, "Griddler: Intelligent computer aided design of complex solar cell metallization patterns", *Proc. 39th IEEE Photovoltaic Specialists Conference*, Tampa, 2013, DOI: 10.1109/PVSC.2013.6744296.

USING RENEWABLE ENERGY ON ELECTRIC VESSELS IN COASTAL REGIONS

Caner Pense^{1,2,*}, Bulent G. Akinoglu^{2,3,4}

¹ Department of Engineering and Natural Sciences, Bandırma Onyedi Eylül University, 10200, Balıkesir, Turkey.

² Earth System Sciences, Graduate School of Natural and Applied Sciences, Middle East Technical University, 06800, Ankara, Turkey.

³ Department of Physics, Faculty of Art and Science, Middle East Technical University, 06800, Ankara, Turkey.

⁴ Center for Solar Energy Research and Application (GÜNAM), Middle East Technical University, 06800, Ankara, Turkey.

*pense@metu.edu.tr, cpense@bandirma.edu.tr

Today, electric drive technologies have become feasible alternatives to systems running on fossil fuels. Electric vehicles are not only gaining popularity in road transportation, railways, maritime and aviation; they are also promising on reducing the ever-increasing anthropogenic pressure and effects of global warming on the Earth System as well. Today, even though all control mechanisms enforced by the IMO, the global maritime industry's Greenhouse Gas input to the atmosphere is so deeply extensive that it is comparable to the total emissions of industrialized nations. Therefore, electric vessels that offer significantly reduced or even nil emissions could become major contributors in the IMO's GHG emission reduction effort.

Electric drive systems carry much fewer risks for the global causes compared to fossil fuel drive systems and therefore can make shipping safer while also making it more cost-effective. In this talk, the opportunity to use renewable resources in the maritime sector will be discussed, and it is an underrated opportunity that has immense potential in terms of sustainability and global warming. To conclude, when combined with renewable energy sources such as the Solar power, full electric drive systems may become a massive step towards a safer, greener and more sustainable shipping in the age of Intelligent Transportation Systems.

Keywords: Renewable energy, solar power, electric ships, electric vessels, intelligent transportation systems

DEVICE CHARACTERIZATION OF PHYSICALLY EVAPORATED CdS/CdZnTe THIN FILMS FOR SOLAR CELL APPLICATION

C. Dogru^{1,2}, M. Parlak^{1,2}

¹Department of Physics, Middle East Technical University (METU), Ankara 06800, Turkey

²Center for Solar Energy Research and Applications (GUNAM), METU, Ankara 06800, Turkey

Abstract

The aim of this study is to investigate the effect of CdS and CdZnTe thin film thicknesses and annealing on the electrical properties of CdS/CdZnTe thin-film heterojunction devices. Polycrystalline CdS-CdZnTe thin films were prepared by thermal evaporation method to optimize the thickness of the CdS and CdZnTe which is a critical factor affecting device performance. Three different CdS thicknesses of 100 nm, 120 nm and 150 nm have been studied. Additionally, CdZnTe thicknesses of 800 nm and 1500 nm have been deposited on the 120 nm CdS thin films. Finally, CdCl₂ treatment has been performed for all CdS/CdZnTe devices which is a vital process in fabrication of high efficiency and good quality solar cell devices. The highest short-circuit current density was obtained in CdS/CdZnTe devices using the 120 nm CdS film as window layer with 800 nm CdZnTe as an absorber layer. Finally, annealing process was applied after contact deposition in order to investigate the effect of temperature on the device parameters. Hall effect measurements have been conducted to determine the type of the charge carriers, carrier concentration, electrical conductivity, and resistivity. Additionally, I-V measurements under dark conditions were carried out to determine the rectification properties such as ideality factor (n), saturation current (I_0), and potential barrier height (Φ_{B0}). Similar measurements under illumination were performed to obtain device parameters such as series resistance (R_s), shunt resistance (R_{sh}), open circuit voltage (V_{oc}), short circuit current density (J_{sc}), and fill factor (FF).

Dynamics of Self-Healing Mechanism of Laser Crystallized Si Thin Films

Ceren Korkut¹, Kamil Çınar², Alban Bek¹

¹ Department of Physics, Middle East Technical University, Cankaya, 06800, Ankara, Turkey

² Faculty of Engineering and Natural Sciences, Maltepe University, Maltepe, 34857, İstanbul, Turkey

*E-mail: cerenkorkutmetu@gmail.com

In this work, we demonstrate the effects of the laser pulses on improving crystallization dynamics based on our past work [1-2]. A nanosecond pulsed infrared laser was employed at the wavelength of 1064 nm, and the 650 nm thick a-Si film is made to be crystallized partially. Firstly, at the edge of the damage threshold, fluence was applied via a spot focus scan with no or a bit overlapping pulse. Secondly, the damaged region over the partially crystallized regions was observed that the partially damaged regions were cured by the increasing overlapping pulse ratio even if the applied fluence was high enough to damage the surface like the previous experiment. Our aim is to show the dynamics of the self-healing mechanism of laser crystallization by exploiting the benefits of the nanosecond pulsed IR laser to improve the laser crystallization applications. Increasing the overlapping factor improves the crystal quality on Si-based thin films during processes of laser crystallization, and the damage zones are in-situ healed. The quality of polycrystalline silicon structures can be improved to fabricate the efficient silicon thin-films solar cells.

Keywords: silicon thin films, laser crystallization, overlapping pulse, self-healing mechanism

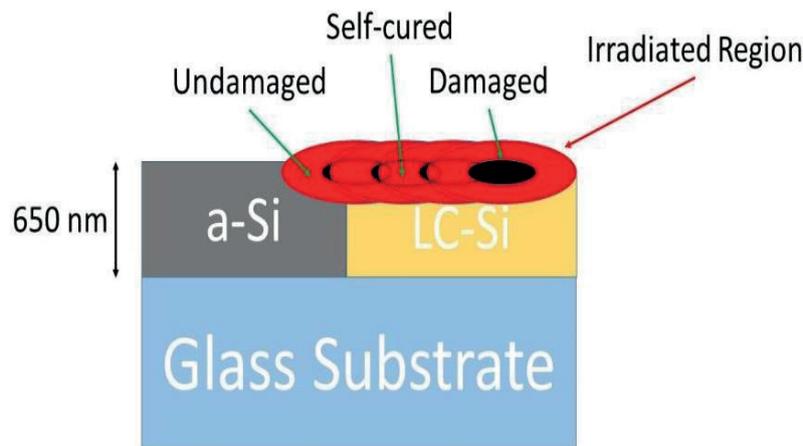


Figure 1. Laser Crystallization Surface

References

- [1] Cinar, K., Yesil, C., & Bek, A. (2019). Revealing Laser Crystallization Mechanism of Silicon Thin Films via Pulsed IR Lasers. *Journal of Physical Chemistry C*.
- [2] Cinar, K., Karaman, M., & Bek, A. (2018). Improvement of Laser-Crystallized Silicon Film Quality via Intermediate Dielectric Layers on a Glass Substrate. *ACS Omega*, 3(5), 5846–5852.

Airbrush Coated PEDOT:PSS Back Contacts for Silicon Solar Cells

Deniz Turkey^{1,2}, Batuhan Ülkütaşır^{1,2}, Kerem Artuk^{1,4}, Elif Cüce^{1,4}, Konstantin Tsoi^{1,4}, Naser Beyraghi^{1,2}, Milad Ghasemi^{1,2}, Selçuk Yerci^{1,2,4,*}

¹ Center for Solar Energy Research and Applications (GÜNAM), Middle East Technical University, Ankara, Turkey

² Department of Micro and Nanotechnology, Middle East Technical University, Ankara, Turkey

³ Department of Mechanical Engineering, Middle East Technical University, Ankara, Turkey

⁴ Department of Electrical and Electronics Engineering, Middle East Technical University, Ankara, Turkey

*syerci@metu.edu.tr

Wide range of available commercial products and adjustability in electrical properties makes poly(3,4-ethylenedioxythiophene):poly(styrenesulfonate) (PEDOT:PSS) a promising candidate as an hole transport layer (HTL) for low-cost silicon based heterojunction solar cells. However, majority of works utilizing PEDOT:PSS layers on silicon surfaces incorporate spin-coating for the deposition, which is not particularly a suitable technique for mass production. In this work, we investigate the use of airbrush coating technique to deposit PEDOT:PSS HTLs on p-type monocrystalline silicon wafers, using an in-house built, automated system. First, we present the effect of chemical additives on continuous operation of the airbrush, enabling a systematic investigation of the technique. Second, using a suitable chemical composition, we present the electrical performance of deposited layers in terms of surface passivation and contact resistivity between PEDOT:PSS and silicon. In particular, the effect of substrate temperature, and sample-to-nozzle distance is investigated. Lastly, performance is presented using 2x2 cm² solar cells utilizing phosphorus diffused n+ emitters at the front side. A power conversion efficiency of 16.26% is demonstrated. We expect the findings presented here to provide guidance in the development of industrially-feasible spraying techniques that can enable high-performance heterojunction cells based on PEDOT:PSS HTLs.

Keywords: PEDOT:PSS, silicon, solar cell, rear, spray, airbrush

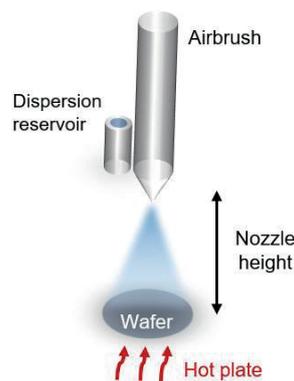


Figure 1. A schematic of the airbrush coating technique.

Utilizing wet chemically grown silicon oxides for surface passivation of silicon by PEDOT:PSS

Deniz Turkey^{1,2}, Milad Ghasemi^{1,2}, Selcuk Yerci^{1,2,3,*}

¹ Center for Solar Energy Research and Applications (GÜNAM), Middle East Technical University, Ankara, Turkey

² Department of Micro and Nanotechnology, Middle East Technical University, Ankara, Turkey

³ Department of Electrical and Electronics Engineering, Middle East Technical University, Ankara, Turkey

*syerci@metu.edu.tr

Availability of simple fabrication techniques (e.g. spin coating) and the low temperature budget makes PEDOT:PSS an attracting choice for utilization in silicon solar cells and related test structures. So far, this material has been used in silicon solar cells with the aim of achieving hole transport through the Si interface, and passivation of the same interface, simultaneously. However, configurations yielding efficient hole transport through the interface can limit the degree of surface passivation that can be achieved with this material. In this work, we investigate the potential of PEDOT:PSS solely as a surface passivation layer, with no obligation for charge transport. In particular, we focus on improvements that can be obtained with various types of wet-chemically grown silicon oxides (see Fig. 1). We demonstrate relevant wet-chemical process parameters that improve surface passivation, such as process duration and temperature.

Keywords: PEDOT:PSS, silicon, surface, passivation

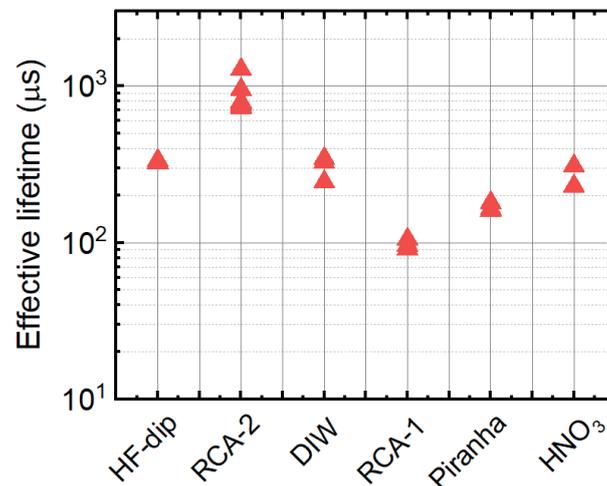


Figure 1. A comparison of effective minority carrier lifetime obtained by different wet chemical processes. The wafers are p-type, 100 Ω.cm, mirror polished and spin-coated with PEDOT:PSS on both sides. The shown effective lifetime is at an excess carrier concentration of $1 \times 10^{15} \text{ cm}^{-3}$.

A Study on Contamination Detection and Trace for Various Cell Structures Fabricated in Clean Room Environment

E. Hande Çiftpınar^{1,2}, Ergi Dönerçark^{1,2}, Salar H. Sedani^{1,2,4}, Raşit Turan^{1,2,3}

¹Micro and Nanotechnology Department, Middle East Technical University (METU), 06800 Ankara, Turkey

²Centre for Solar Energy Research and Applications (GUNAM), Middle East Technical University, 06800 Ankara, Turkey

³Department of Physics, Middle East Technical University (METU), 06800 Ankara, Turkey

⁴Central Laboratory, Middle East Technical University (METU), 06800 Ankara, Turkey

* ciftpinar.handegmail.com

Metallic impurities are the most common contaminants for the wafer-based silicon (Si) solar cells. Fe, Cu, Co, Cr, Ni are the transition metals deteriorating the device performance of photovoltaic grade crystalline Si amongst which Fe is a well-known lifetime killer([1,2]). Moreover, K⁺, Na⁺ and Ca²⁺ could also be listed as the most encountered ionic contaminants, which are naturally arising out of the cell fabrication processes and process environment itself. Within the scope of this study, impurities affecting device performances of various cell structures are investigated and analyzed using Time of Flight Secondary Ion Mass Spectroscopy (ToF-SIMS,) Inductively Coupled Plasma- Mass Spectroscopy (ICP-MS) and Photoluminescence (PL) measurements.

Depending on the process history, different contaminants were detected at various doses for Si wafers exposed to the same cleaning procedure. Both passivated and un-passivated samples were prepared to correlate the device performance with the contamination doses. While some samples were passivated with intrinsic a-Si:H layer deposited at low temperature (200°C), some samples were passivated with thin dry oxide layers grown at high temperature (850°C). It was observed that high temperature dry oxidation process makes metallic and ionic contaminants more visible for PL imaging while they were not visible after low temperature a-Si:H passivation but still that contaminants were detected by SIMS and ICP-MS at lower doses with different profiles. Representative ToF-SIMS profile of K⁺ ion in (i)a-Si:H/n-Si and SiO₂/n-Si structures and corresponding PL images are shown in Figure 1. Details for all other detected ions on different samples for different process will be discussed in the final version of the manuscript.

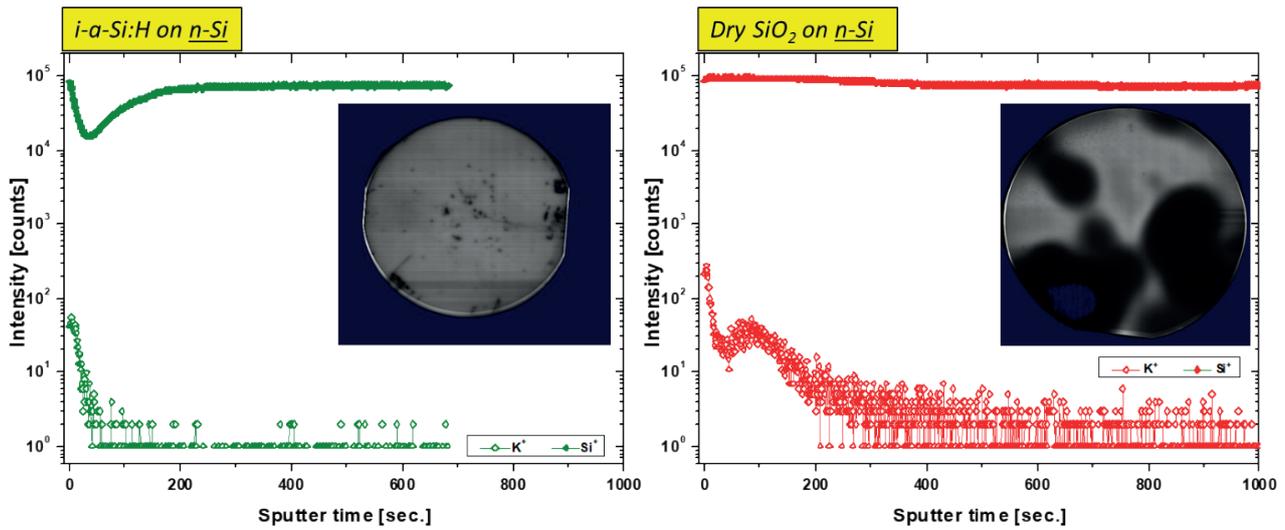


Figure 1. SIMS profile of K⁺ in (i)a-Si:H/n-Si (left) and in SiO₂/n-Si (right) structure. Samples were simultaneously clean and HF/HCl dip was carried out right before the deposition/oxidation processes.

References:

- [1] D. Macdonald and L. J. Geerligs, "Recombination activity of interstitial iron and other transition metal point defects in p- and n-type crystalline silicon," *Appl. Phys. Lett.*, vol. 85, no. 18, pp. 4061–4063, 2004.
- [2] D. Macdonald, S. P. Phang, and A. Liu, "Detection and reduction of iron impurities in silicon solar cells," pp. 23–26, 2012.

FABRICATION OF BLACK SILICON VIA REACTIVE ION ETCHING: EFFECT OF PRE-ETCHING TREATMENT ON SUPERIOR UNIFORMITY IN LARGE SCALE

Elif Sarigül Duman^{1,2}, Raşit Turan^{2,3}

¹ Micro and Nanotechnology Department, Middle East Technical University, Ankara, Turkey

² Center for Solar Energy Research and Applications (GÜNAM), Middle East Technical University, Ankara, Turkey

³ Department of Physics, Middle East Technical University, Ankara, Turkey

* sarigul.elif@metu.edu.tr

Black silicon (bSi) has been drawing attention for various applications such as solar cells, infrared (IR) devices and biomedical studies due to its promising optical properties and light harvesting with minimization of reflection loss since its discovery in 1995 [1-5]. Inductively coupled plasma (ICP) reactive ion etching (RIE) is advantageous over other bSi fabrication methods (i.e. metal-assisted chemical etching, femtosecond laser irradiation etc.) due to high throughput, independence of silicon substrate and crystal orientation, process flexibility and reduced loss of silicon during etching process [6]. In this work, we present maskless bSi fabrication method with excellent uniformity in large scale (156 x 156 mm²) by combination of wet and dry etching processes. BSi on c-Si was fabricated via ICP-RIE (Leuven Instruments) by mixture of SF₆ and O₂ gases on random pyramidal textured wafers via wet etching with alkaline (KOH) and organic additive. SEM images of bSi on c-Si with and without pre-etching treatment (pyramidal texturing) are shown in Fig.1b and Fig.1a, respectively. Pre-etching treatment is found to be beneficial to improve bSi uniformity and to reduce inelastic deformation of silicon during ICP-RIE process. Our bSi fabrication method combined with pre-etching process results in nano-textured surfaces with excellent uniformity on 156 x 156 mm² wafers. Total and diffuse reflection less than 4% in a broad spectrum (400-1000 nm) can be achieved by this method (See Fig.1c). Optical and morphological properties of bSi fabrication with various pre-etching treatments will be presented in this conference.

Keywords: Black silicon, nano-texturing, inductively coupled plasma reactive ion etching, ICP-RIE

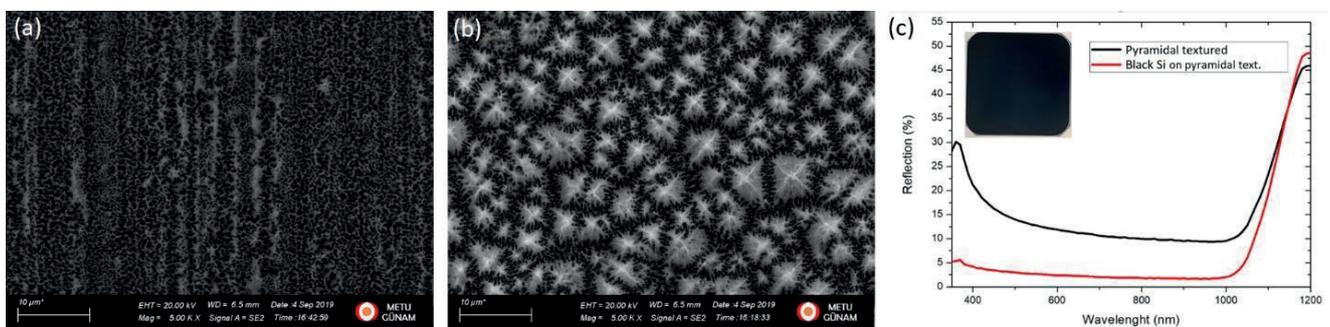


Figure 1. a) ICP-RIE black silicon fabrication without pre-etching b) ICP-RIE black silicon fabrication combined with pyramidal texturing c) Reflection measurements after pyramidal texturing and ICP-RIE bSi fabrication

References

- [1] H. Jansen, M. de Boer, R. Legtenberg, and M. Elwenspoek, "The black silicon method: A universal method for determining the parameter setting of a fluorine-based reactive ion etcher in deep silicon trench etching with profile control," *J. Micromechanics Microengineering*, 5 (2) (1999) 115–120.
- [2] H. Savin et al., "Black silicon solar cells with interdigitated back-contacts achieve 22.1% efficiency," *Nat. Nanotechnol.*, 10 (7) (2015) 624–628.
- [3] P. Repo et al., "N-type black silicon solar cells," *Energy Procedia*, 38 (2013) 866–871.
- [4] J.H. Park, L. Gu, G.V. Maltzahn, et al., "Biodegradable luminescent porous silicon nanoparticles for in vivo applications," *Nat. Mater.* 8 (4) (2009) 331–336.
- [5] A.K. Shalek, J.T. Robinson, E.S. Karp, et al., "Vertical silicon nanowires as a universal platform for delivering biomolecules into living cells," *Proc. Natl. Acad. Sci. U.S.A* 107 (5) (2010) 1870–1875.
- [6] Q. Tan, F. Lu, C. Xue, W. Zhang, L. Lin, and J. Xiong, "Nano-fabrication methods and novel applications of black silicon," *Sensors Actuators, A Phys.*, 295 (2019) 560–573.

Fabrication and Characterization of ZnO Nanorods Based CZTS Superstrate Solar Cells

Elif Peksu¹, Hakan Karağaç^{1*}

¹ Istanbul Technical University/Department of Physics Engineering, Istanbul, Turkey

*karaagacha@itu.edu.tr

Intensive studies have recently been performed to produce low-cost, environmentally friendly and high-efficiency cells. Some of these studies are associated with the incorporation of one-dimensional nanostructures into thin film based solar cell architecture. The aim of this work was therefore to build one of these structures (a superstrate solar cell) by incorporating ZnO nanorod into the conventional CZTS thin film system. To achieve this, conformally CdS-coated vertically-aligned ZnO nanorods (NRs) were first successfully synthesized on ITO-coated substrates by using the hydrothermal technique. ZnO NRs were then decorated with 600 nm thick CZTS thin layer by a one-step thermal evaporation route to produce a SLG/ITO/ZnO-NR/CdS/CZTS/Ag superstrate solar cell architecture. SEM, AFM, X-ray diffraction, Raman spectroscopy, transmittance and reflectance measurements have been conducted for the structural, optical, morphological and compositional characterization of each component-material of the constructed solar cell. The findings revealed the formation of Cu-poor mono-phase kesterite CZTS thin film with an optical band gap of 1.45 eV. The performance of the fabricated solar cell was measured both in the dark and under irradiation of AM 1.5G at room temperature. The superstrate solar cell had a short-circuit current density of 20.80 mA/cm², an open-circuit voltage of 0.46 V, a fill factor of 29.5 %, providing 2.82 % of the energy conversion efficiency. The achieved power conversion efficiency is the highest output yet recorded for nanostructured superstrate SLG/ITO/ZnO-NR/CdS /CZTS/Ag configured solar cells.

Keywords: solar cells, nanostructures, superstrate, ZnO nanorods, CZTS

WIDE BAND GAP a-SiC_x:H PASSIVATION LAYER FOR THE APPLICATION OF SILICON HETEROJUNCTION (SHJ) SOLAR CELLS

Ergi Dönerçark^{1,2}, İsmail Kabaçelik^{2,5}, Argahavan Salimi^{1,2}, Salar H. Sedani^{1,2,4}, Raşit Turan^{1,2,3}

¹Micro and Nanotechnology Department, Middle East Technical University (METU), 06800 Ankara, Turkey

²Centre for Solar Energy Research and Applications (GUNAM), Middle East Technical University, 06800 Ankara, Turkey

³Department of Physics, Middle East Technical University (METU), 06800 Ankara, Turkey

⁴Central Laboratory, Middle East Technical University (METU), 06800 Ankara, Turkey

⁵Department of Medical Services and Techniques Vocational School of Health Services, Bartın University, 74100, Bartın, Turkey

*ergidonercark@gmail.com

Thin intrinsic a-Si:H layer provides an excellent surface passivation on c-Si wafers. Although passivation by a-Si:H layer leads to very high carrier lifetime, the parasitic absorption caused by a-Si:H is one of the major drawbacks. Therefore, a-SiC_x:H layers with a wide band gap attract attention as an alternative passivation layer instead of a-Si:H layers. Band gap of a-SiC_x:H can be adjusted in the range of 1.7 eV and 2.4 eV [1]. An increase in the band gap makes this layer appropriate as the window material by reducing the parasitic absorption [2]. The a-SiC_x:H layers were deposited by plasma-enhanced chemical vapor deposition (PECVD) system using SiH₄, H₂ and CH₄ precursor gases. The influence of several deposition parameters such as SiH₄, H₂ and CH₄ flow rates, radio frequency power and chamber pressure on the a-SiC_x:H layers were investigated by spectroscopic ellipsometry (SE), fourier transform infrared spectroscopy (FTIR), current-voltage (I-V), capacitance-voltage (C-V), conductance-voltage (G/ω-V), time-of-flight secondary ion mass spectrometry (ToF-SIMS) and lifetime measurements. The band gaps of a-SiC_x:H layers determined by SE vary between 1.8 and 2.16 eV. After determining the structural and chemical composition by FTIR measurements, the H% and C% content was found under 4% and 0.5%, respectively. From the I-V measurements, it was calculated that the resistivity of the a-SiC_x:H layers varied between 1.95x10⁶ and 9.35x10⁷ Ω.cm. Interface trap density (D_{it}) were determined between 8.23x10¹¹ and 4.19x10¹² eV⁻¹cm⁻² from C-V and G/ω-V measurements by using conductance method. ToF-SIMS measurements showed that the increase in amount of C increasing possibility of bonding with Si (Figure 1). The lifetime measurements of the a-SiC_x:H layers symmetrically grown on the c-Si wafer were measured as 45 μs. Furthermore, the passivation quality of a-SiC_x:H layer was improved by stack layer deposition with a-Si:H resulting effective lifetime above 100 μs.

Keywords: Wide band gap, surface passivation, a-Si:H, a-SiC_x:H, SHJ

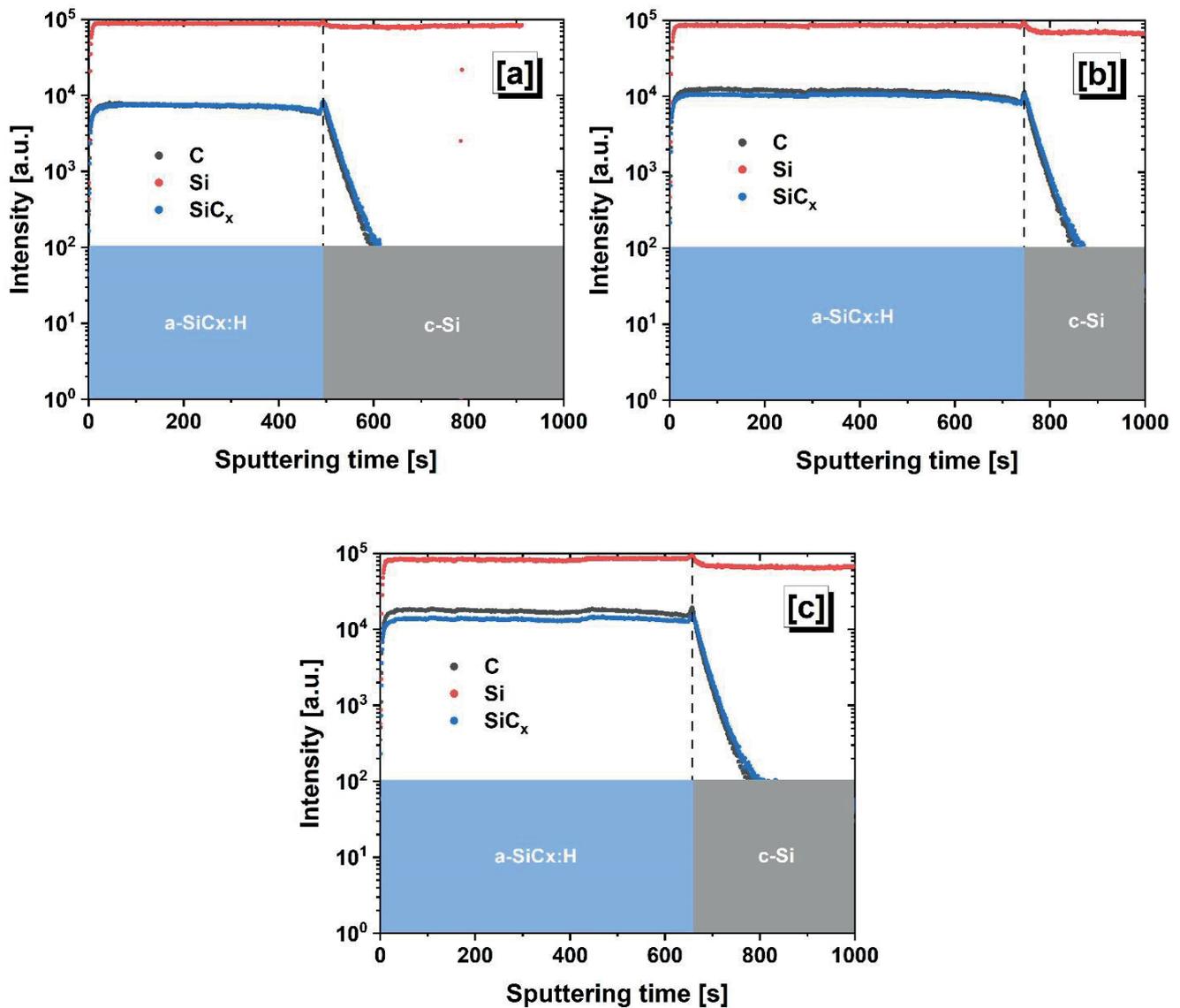


Figure 1. ToF-SIMS curves of a-SiCx:H layers deposited at different production parameters. CH₄ flow rate and RF power of PECVD system (a) 50 sccm-30W (b) 50 sccm-50W and (c) 80 sccm-50W respectively.

References

- [1] J.L. He, M.H. Hon and L.C. Chang, "Properties of amorphous silicon carbide film deposited by PECVD on glass", Mater. Chem. Phys., 45(1) (1996) 43.
- [2] F. Giorgis, F. Giuliani, C.F. Pirri, E. Tresso, J.P. Conde and V. Chu, "Wide band gap a-SiC:H films for optoelectronic applications", J. of Non-Cryst. Solids, 227-230, Part 1 (1998) 465.

AIR AND WATER BASED PHOTOVOLTAIC PANEL COOLING SYSTEMS

Ersin Karacabey^{1*}, Birol Kayışođlu², Levent Taşeri¹

¹ Viticulture Research Institute/ Tekirdađ, Turkey

² Tekirdađ Namık Kemal University/Biosystem Engineering Department, Tekirdađ, Turkey

*ersin.karacabey@tarimorman.gov.tr

Photovoltaic panels are systems which convert sun energy to electrical energy directly and they have been used widely in our country and world in recent years. The most important problem in these systems is low efficiency and due to that they need larger surface area. Researches on increasing panel efficiency are still in progress. One of the most important factors affecting solar panel efficiency is cell temperature. Panel efficiency decreases when cell temperature increases. Water jackets are generally placed under panel to decrease cell temperature (PV/T hybrid system) and in this way panel efficiency is both increased and heat energy is transferred to water. Air cooling systems are also used even if not they are common. It is also possible to evaluate heat energy transferred to fluid for purposes such as drying, climatization, domestic use based on fluid type and temperature while cell temperature is decreased. According to recent studies, it can be said that PV/T systems provide significant increases in electrical performance value. Although thermal energy outputs depend on different factors, they can provide sufficient energy values, mostly in use such as air conditioning and ambient heating. In this article it is targeted to introduce these systems which are widely used abroad and have no common use in our country with their effects on panel efficiency.

Keywords: photovoltaic, pv/thermal hybrid systems, pv performance, sun energy

Growth and Characterization of Mn doped ZnS Thin Films for Photovoltaic Applications

Esra Kus¹, Ayse Kucukarslan², Barbaros Demirselcuk³, Vildan Bilgin²

¹Uludag University/Department of Physics, Bursa, Turkey

²Canakkale Onsekiz Mart University/Department of Physics, Canakkale, Turkey

³Canakkale Onsekiz Mart University/Department of Electricity and Energy, Canakkale, Turkey

*esraakus@hotmail.com

In this work, Mn-doped (0-4-8 and 12 at.%) zinc sulfide (ZnS) films were deposited on glass substrates by using ultrasonic spray pyrolysis technique at substrate temperature of $300^{\circ}\text{C}\pm 5$. The spraying solution was prepared by mixing the appropriate volumes of zinc chloride (0.05 M), thiourea (0.075 M) and manganese chloride (0.1 M). The spraying solution (150 cc) was sprayed during 30 min, and the solution flow was kept at 5 cc/min. The effect of Mn incorporation on the morphological, electrical and magnetic properties of ZnS films was investigated. The morphological characterization of the films was determined by using atomic force microscope (AFM). AFM images showed that the surfaces of the films had almost homogeneous morphology. In addition, surface roughness values of the films were determined from these images. In order to determine the electrical conductivity mechanisms and electrical conductivity values, Current-Voltage (I-V) measurements of all films were obtained by using the two probe method. The magnetic characterization of all films was determined at room temperature using a vibrating sample magnetometer (VSM).

Keywords: ZnS:Mn thin films; Ultrasonic spray pyrolysis technique; morphologies, electrical and magnetic properties.

Acknowledgements: This work was supported by the Canakkale Onsekiz Mart University Scientific Research Projects Committee under the Project Number FBA-2019-3039.

Characterizing DC Arcs for Photovoltaic Arc Fault Detection

Fatima Al-Janahi¹, Sawsan Shukri^{1,2}, Kais Abdulmawjood¹, Robert S. Balog^{1,2}

Renewable Energy and Advanced Power Electronics Research Laboratory,
¹Texas A&M University at Qatar, Doha, QATAR, ²Texas A&M University, TX, USA

fatima.al-janahi@qatar.tamu.edu
sawsan.shukri@qatar.tamu.edu
kais.abdulmawjood@qatar.tamu.edu
robert.balog@ieee.org

Arc faults, one of the main causes of electrical fires, can be due to equipment failure or improper installation [1]. Therefore, a PV arc fault detector is essential to protect people's lives and properties and is now required by many safety codes. Since an arc is a chaotic phenomenon, it is important to study the electrical characteristics in order to develop a robust arc fault detector [2]. An automated mechatronics testbed, shown in Figure 1, was developed to allow highly repeatable testing needed to create a library of arc voltage and current waveforms. Electrode material and geometry, electrical voltage and current, and electrode gap separation profile were set as experimental parameters, as these factors were hypothesized to affect arc characteristics. In this paper, example of data from the arc generation system is presented to show how the results of the parameter values can be compared. For each combination of parameter value shown in Table 1, the paper will show the arc voltage and current waveforms, the line of gap (Time vs. Distance), and the Short-Time Fourier Transform (STFT). The output figures of Study 1 and Study 2 are shown in Figure 2 and Figure 3, respectively. The results of the analysis presented in this paper can be used in the development of a reliable and effective arc fault detector.

Keywords: Photovoltaic, DC Arcs, Arc Faults, Arc Fault Detector, Fault Detection, Signal Analysis, Short Time Fourier Transform, STFT.

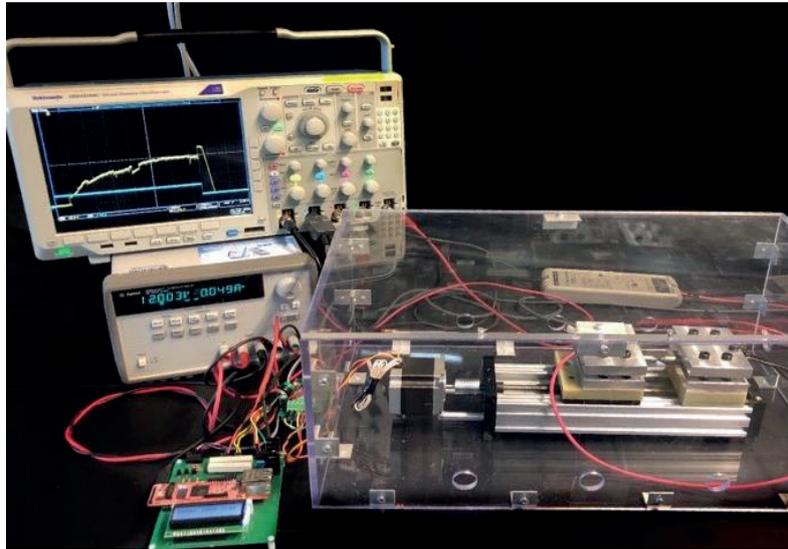
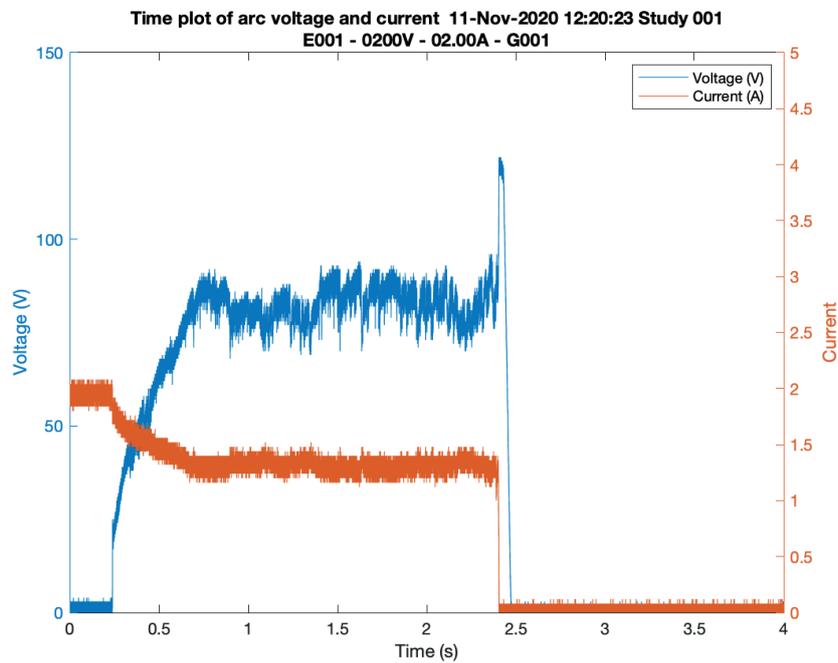


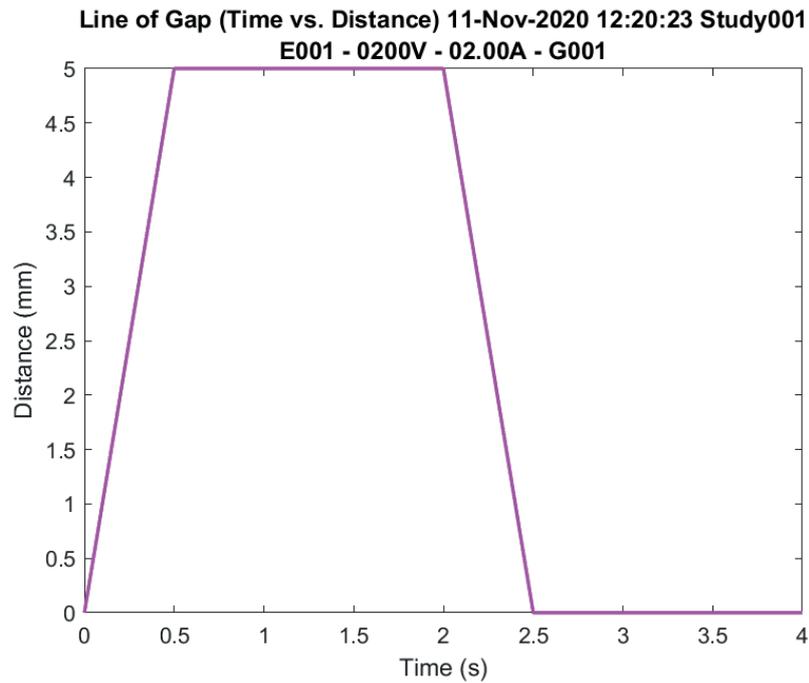
Figure 1. Arc generator system.

Table 1. Parameters combination used to perform arc generation experiments.

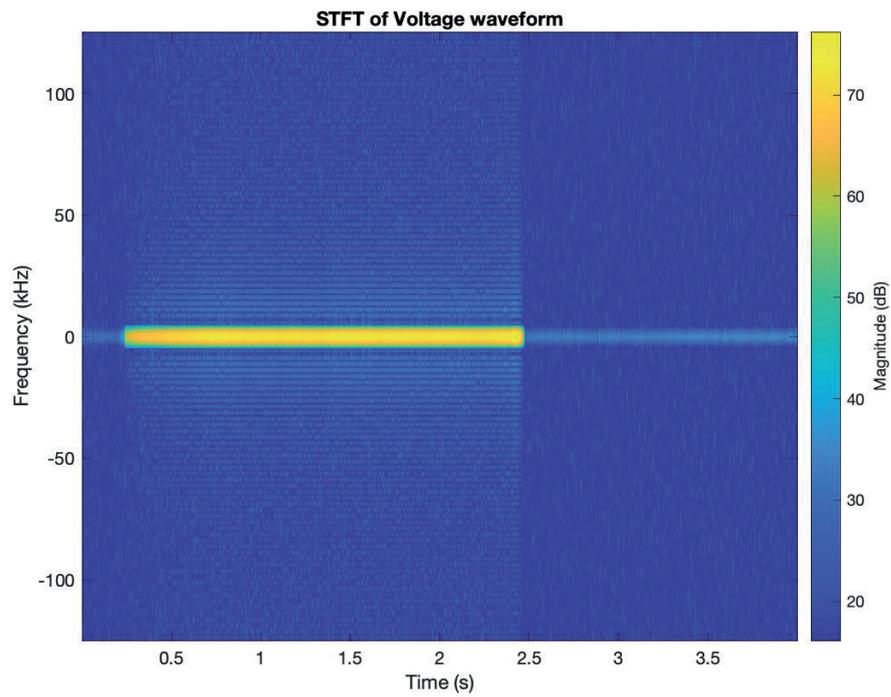
Study no.	Electrode	Voltage (V)	Current (A)	Gap Separation Distance (mm)	Gap Separation Time (s)
1	Flat Brass	200	2	5	0.5
2	Flat Brass	500	5	5	0.5



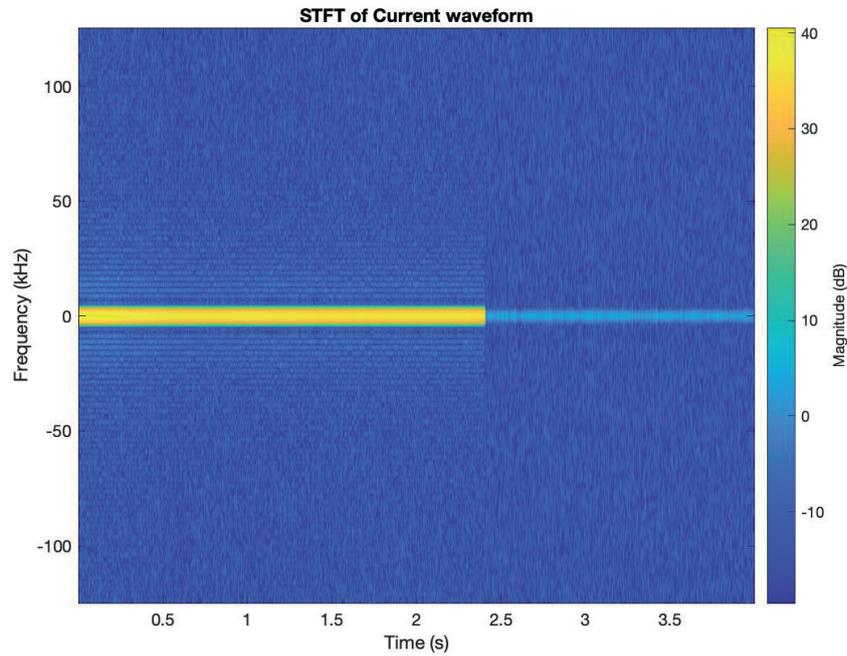
a) Arc voltage and current waveforms



b) Line of Gap

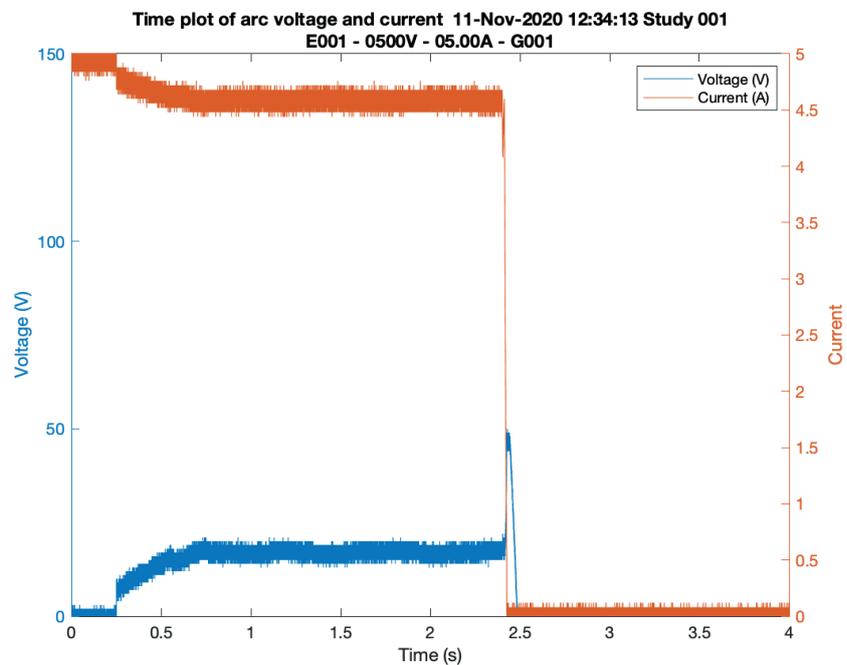


c) STFT of the voltage waveform

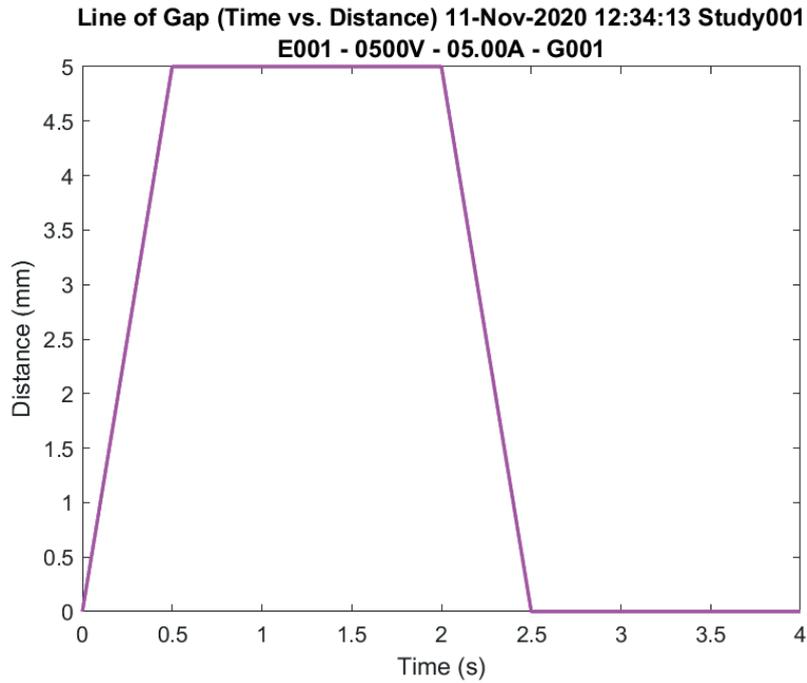


d) STFT of the current waveform

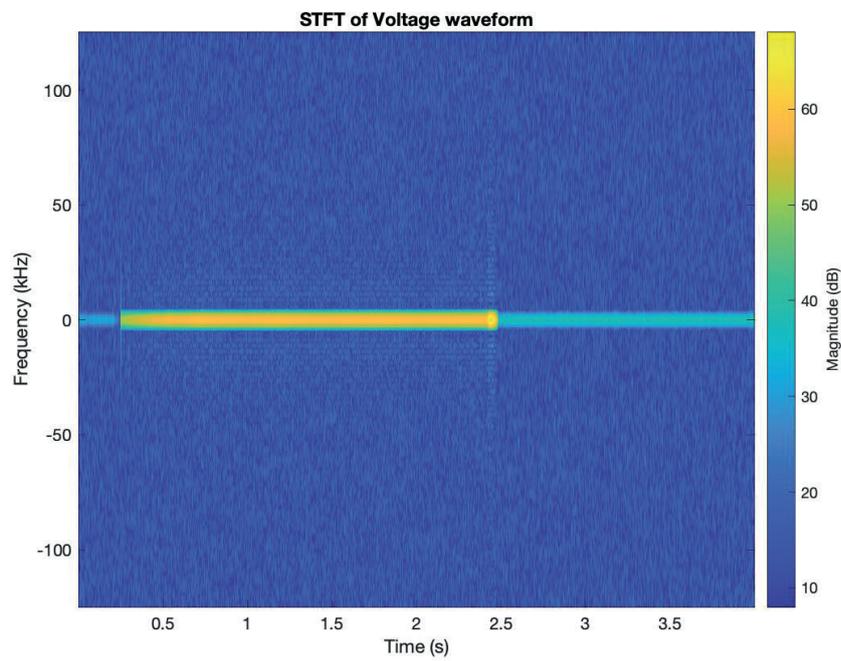
Figure 2. a) The recorded arc voltage and current waveforms of study profile 1 shown in Table 1. b) The Line of Gap (Time vs. Distance) of the gap parameters used in this study. c) The STFT of the arc voltage waveform is shown in Figure 2a. d) The STFT of the Arc Current Waveform is shown in Figure 2a.



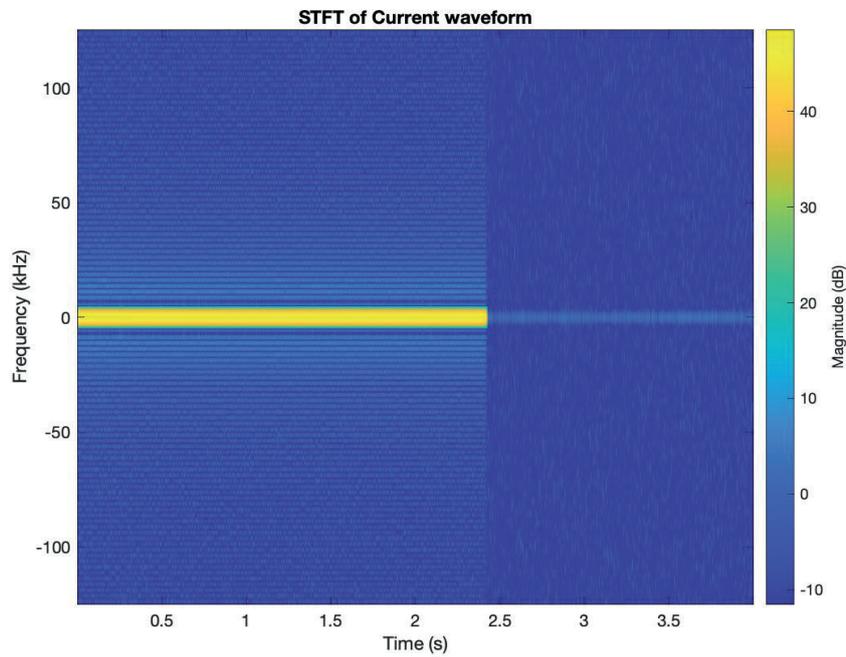
a) Arc voltage and current waveforms



b) Line of Gap



c) STFT of the voltage waveform



d) *STFT of the current waveform*

Figure 3. a) The recorded arc voltage and current waveforms of study profile 2 shown in Table 1. b) The Line of Gap (Time vs. Distance) of the gap parameters used in this study. The Line of Gap in Figure 2b is identical since both studies have the same gap separation time and distance. c) The STFT of the arc voltage waveform is shown in Figure 3a. d) The STFT of the arc current waveform is shown in Figure 3a.

References

- [1] M. K. Alam, F. Khan, J. Johnson, and J. Flicker, "A Comprehensive Review of Catastrophic Faults in PV Arrays: Types, Detection, and Mitigation Techniques," *IEEE Journal of Photovoltaics*, vol. 5, no. 3, pp. 982-997, May 2015.
- [2] P. C. Hatton, M. Bathaniah, Z. Wang and R. S. Balog, "Arc generator for photovoltaic arc fault detector testing," 2016 IEEE 43rd Photovoltaic Specialists Conference (PVSC), Portland, OR, 2016, pp. 1702-1707.

Comparative Evaluation of Rear Local Contact Patterns for P-Type Mono Crystalline Silicon PERC Solar Cell

**Hasan Asav^{1,2}, Gence Bektaş^{1,2}, Ahmet Emin Keçeci^{1,2}, Gamze Kökbudak^{1,2}, Bülent Arıkan¹
Raşit Turan^{1,2,3}**

¹The Center for Solar Energy Research and Applications (GÜNAM), Middle East Technical University, Dumlupınar Blvd. 1, 06800 Ankara – Turkey

² Micro and Nanotechnology Graduate Program, Middle East Technical University, Dumlupınar Blvd. 1, 06800 Ankara – Turkey

³ Department of Physics, Middle East Technical University, Dumlupınar Blvd. 1, 06800 Ankara –Turkey

*hasan.asav@metu.edu.tr

The passivated emitter and rear cell (PERC) is an advantageous type of solar cell in order to reduce rear surface recombination along with its improved back surface reflectivity [1]. Therefore, many researches and developments have been taking place on this type of solar cell to increase the overall solar cell performance. In this study, different type of rear local contact opening patterns (line and dash) are formed by industrial-type picosecond laser which has 532 nm wavelength with fixed laser contact opening (LCO) width on M2 p-type mono c-Si wafers. Manufactured cells are investigated in terms of photovoltaic parameters depending on the rear metallization fractions. We ablated rear SiNx layer with 4 different LCO patterns by varying rear local contact pitches from 900 μm to 1200 μm by an increment of 100 μm using (1:1) dash pattern together with the reference pattern of line which has 1500 μm line pitch is evaluated. Characteristics and quality of laser opening areas are analyzed by photoluminescence (PL) images as well as implied open circuit voltage (iV_{oc}) values. As a result, rear contact pattern with 3.19% metal fraction (1000 μm pitch) is found to be relatively more beneficial than the others investigated in this study. Average of 0.2% conversion efficiency, 2 mV V_{oc} and 0.6 % FF gain are attained with this LCO pattern with respect to the reference line patterned cells.

Keywords: Laser contact opening (LCO), rear local contact pattern, rear local contact pitch, PERC Solar Cells

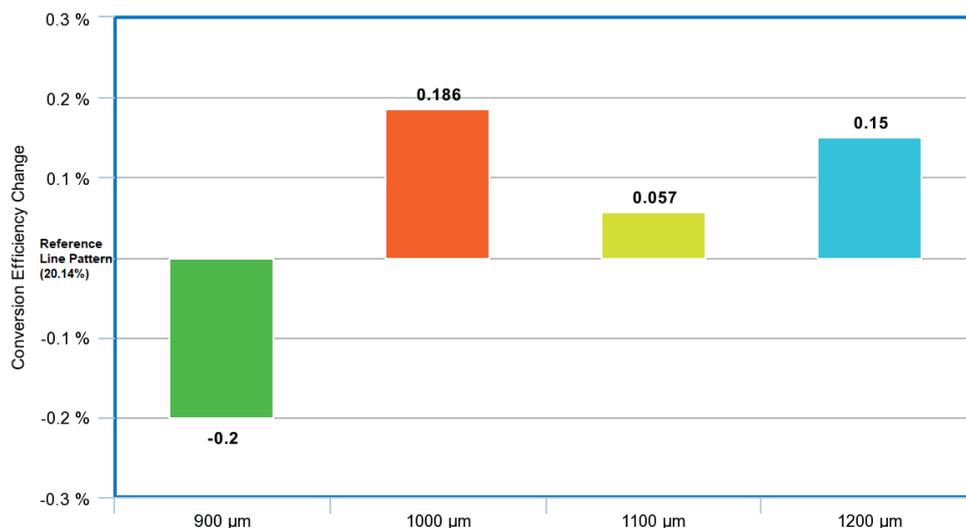


Figure 1. Relative conversion efficiency gain/loss of the solar cells with different LCO patterns with respect to the reference pattern.

Reference

[1] M.Green, The Passivated Emitter and Rear Cell (PERC): From conception to mass production, Solar Energy Materials & Solar Cells, 143 (2015) 190-197

THE EFFECT OF AGING ON c-Si SOLAR CELLS EXPOSED TO 8 MEV ELECTRONS IRRADIATION

Ismail Kabacelik^{1,2}, Mustafa Kulakci^{3,4}

¹ Center for Solar Energy Research and Applications (GÜNAM), Middle East Technical University, 06800 Ankara, Turkey

² Department of Medical Services and Techniques, Vocational School of Health Services, Bartın University, 74100, Bartın, Turkey

³ Department of Physics, Eskişehir Technical University, 26470 Eskişehir, Turkey

⁴ *Nanoboyut Research Laboratory, Department of Physics, Eskişehir Technical University, 26470, Eskişehir, Turkey*

*ikabacelik@gmail.com

The performance of mono-crystalline Silicon (c-Si) solar cells were investigated under various electron irradiation doses ranging from 225 to 900 Gy with the energy of 8 MeV. The effect of electron irradiation doses on c-Si solar cells performance were analyzed in detail by means of current-voltage (I-V) (under dark and light condition), external quantum efficiency (EQE) measurements before and after electron irradiation. The experimental results showed that the main parameters of solar cells such as short circuit current (I_{sc}), open-circuit voltage (V_{oc}), fill factor (FF), power conversion efficiency (η) decrease with the increase of the electron irradiation doses [1]. The EQE measurements show that electron-induced displacement damages occurred in the base layer of the solar cell. After 40 months later, the illuminated I-V and EQE measurements were carried out again. It is found that a slight improvement was observed in the J_{sc} parameter after 40 months later (see Figure 1). All measurement results were compared and discussed before and after electron irradiation.

Keywords: Aging, c-Si solar cell, electron irradiation, current–voltage, carrier lifetime

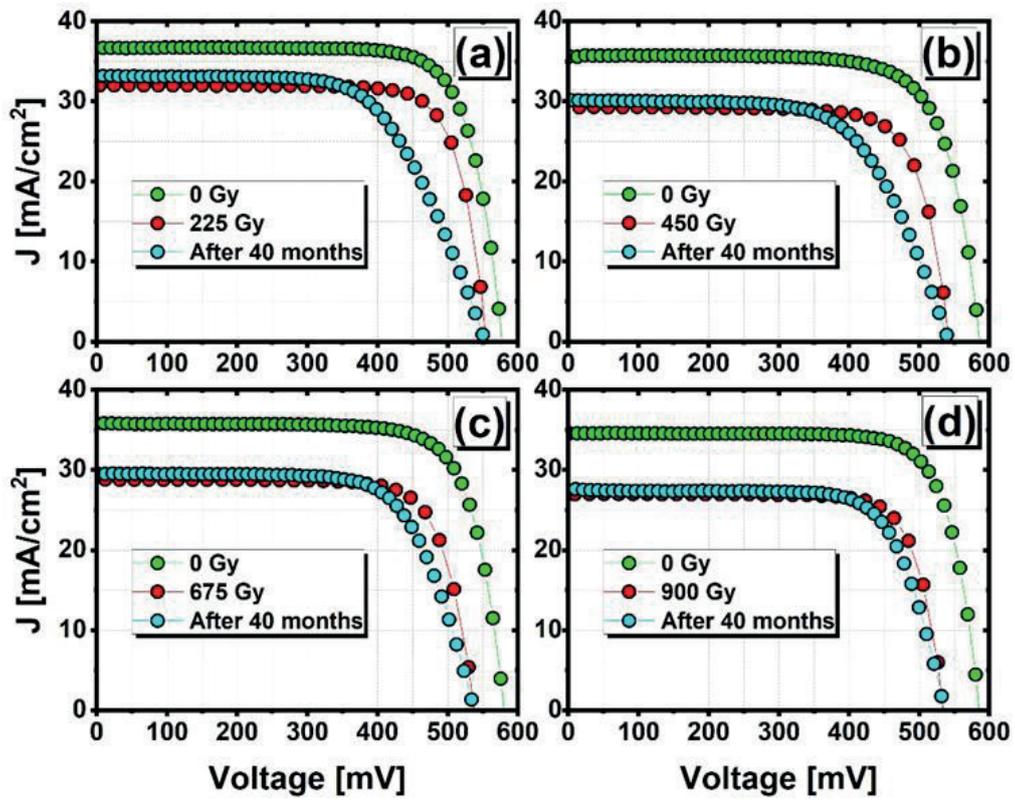


Figure 1. Illuminated J-V characteristics of c-Si solar cells before and after electron irradiation at different doses.

References

- [1] Sahin R., Kabacelik I., Effects of ionizing radiation on the properties of mono-crystalline Si solar cells, Radiation Physics and Chemistry, 150 (2018), 90-94.

Development of CVD Process for Hybrid Physical Chemical Vapor Deposited Perovskite Absorbers

Kerem Artuk^{1,2}, Thierry Moser¹, Yan Jiang¹, Thomas Feuer¹, Ayodhya N. Tiwari¹ and Fan Fu¹

¹ Laboratory for Thin Films and Photovoltaics, Empa - Swiss Federal Laboratories for Materials Science and Technology, Dübendorf, Switzerland

² Department of Information Technology and Electrical Engineering, ETH Zurich, Zurich, Switzerland

kartuk@ethz.ch, fan.fu@empa.ch

Vapor-based deposition of organic-inorganic perovskite absorbers exhibits several advantages over their solution-processed counterparts. For example, vapor-based approaches provide precise thickness control as well as uniform thin films and are compatible with industrial large area production [1]. However, in terms of power conversion efficiency, perovskite solar cells (PSCs) with vapor-processed perovskite absorbers (20.8%) have not been able to reach the performance of solution-processed PSCs (25.2%), yet [2]. The main reason causing this discrepancy lies in the sensitive growth process of perovskite during the vapor-deposition process as the growth behavior is heavily influenced by the processing parameters such as temperature, pressure and time [1]. One of the promising vapor-based deposition methods is Hybrid Physical Chemical Vapor Deposition (HPCVD). In HPCVD, an inorganic metal halide layer (template layer) is thermally evaporated in the first step. The perovskite is subsequently formed in a CVD tube by the reaction of organic vapor and the inorganic template layer at reduced pressure in mbar range. To fabricate high-quality perovskite absorbers with this two-step method, an optimized combination of processing parameters should be found for both CVD and PVD steps [3]. In this study, we focus on the second step, i.e, the CVD process. We investigated (Cs,FA)Pb(I,Br)₃ perovskite formation considering a series of factors such as substrate temperature, sublimation temperature, deposition time and pressure during the CVD process, and characterized the optical and structural properties of absorber layers.

Keywords: Perovskite, vapor-deposition, CVD

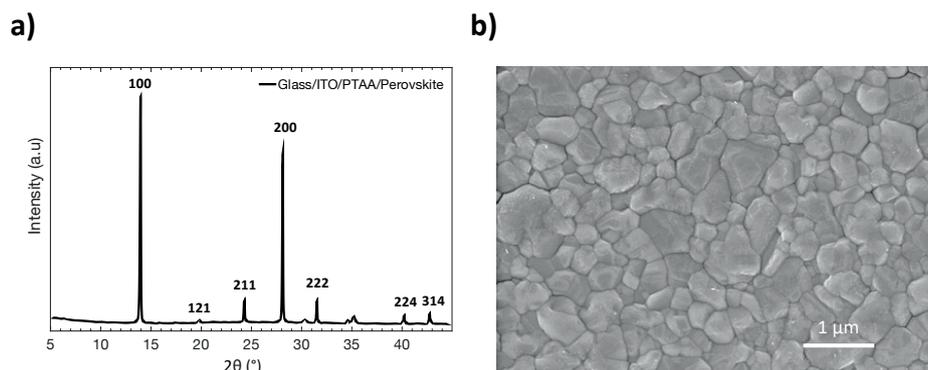


Figure 1. a) XRD pattern of perovskite film on Glass/ITO/PTAA. b) SEM image of a typical (Cs,FA)Pb(I,Br)₃ film.

THE ROADMAP OF CELL TO MODULE (CTM) CONVERSION LOSS ANALYSIS OF MONO PERC BIFACIAL GLASS-GLASS MODULES

Meriç Çalışkan¹, Melis Çetmeli¹, Betül Şekertekin¹, Baybars Sarıca¹, Mete Günöven¹, Fırat Es¹

¹Kalyon Solar Technologies Production Corporation-KalyonPV / Research and Development, Ankara, Turkey

*mcaliskan@kalyonpv.com

During photovoltaic module manufacturing, the efficiency and output power of mono silicon PV module excessively depends on components used in the module design technologies. The fabrication of module from cells causes different physical power loss and gain mechanisms [1,2]. Generally, the total power sum of individual cells is much than the assembled module power and this difference is called as cell to module (CTM) losses. While predicting the performance of module, it is necessary to demonstrate factors including optical, geometrical as well as electrical that impact the CTM ratio [1-3]. Necessary geometrical, electrical and optical information of module materials are collected and classified according to product data sheets and laboratory measurements. All related data was processed to perform CTM analyses via software namely SmartCalc.CTM developed by Fraunhofer ISE.

For a 72 half-cut bifacial mono PERC full square solar cell, simulated efficiency is found as 21.77% which is very close to real fabricated cell efficiency 21.8% at standard conditions. The estimated module power 383.42 W is obtained from the simulation and shows good agreement within the flasher measurement that is found as 385 W. Hence, a deviation in module power is only 0.4% between simulated and real values. It is observed that the power gain is obtained for the cell-encapsulant coupling which is related with the selection of POE encapsulant instead of usage of EVA. The absorption losses are the major factor affecting the performance of module and are found to be in the range of 6.9 and 9.41 W.

Keywords: CTM, mono PERC, bifacial, performance

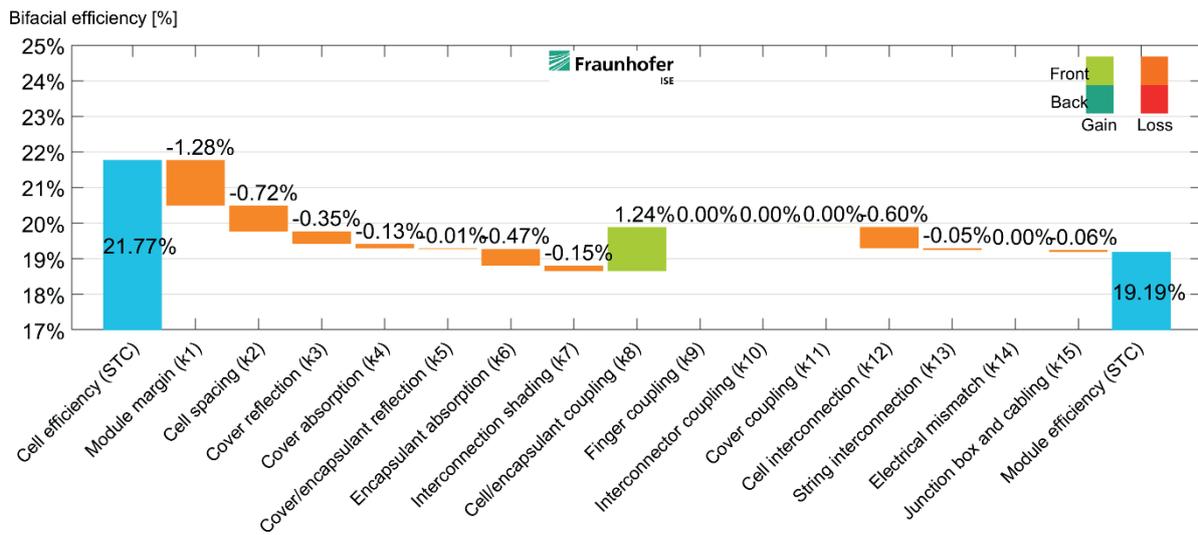


Figure 1. Waterfall efficiency diagram of the 72-half cut mono PERC bifacial glass-glass module

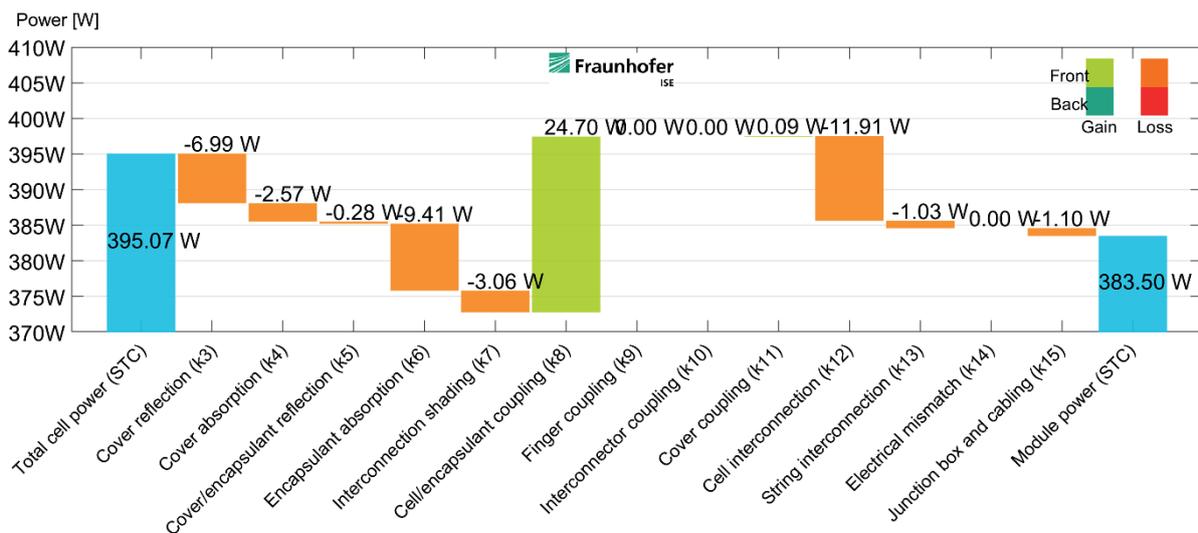


Figure 2. Waterfall power diagram of the 72-half cut mono PERC bifacial glass-glass module

References

- [1] M. Mittag and M. Ebert, "Systematic PV module optimization with the cell-to-module (CTM) analysis software," *Photovoltaics International*, no. 36, pp. 97–104, 2017.
- [2] M. Mittag et al., "Analysis of backsheet and rear cover reflection gains for bifacial solar cells," *33rd European PV Solar Energy Conference and Exhibition*, vol. 2017.
- [3] A. Pfreundt, M. Mittag, M. Heinrich, and U. Eitner, "Rapid Calculation of the Backsheet Coupling Gain Using Ray Groups," *32nd European Photovoltaic Solar Energy Conference and Exhibition (EUPVSEC)*, 2018.

CHARACTERIZATION OF GaAs THIN-FILM SOLAR CELL STRUCTURES GROWN BY MOLECULAR BEAM EPITAXY TECHNIQUE ON Si SUBSTRATES FOR FLEXIBLE THIN FILM SOLAR CELL APPLICATIONS

Muhammed AKTAŞ¹, Ali BÜYÜKPINAR², Burcu ARPAPAY¹, Mustafa KULAKCI^{1,3}

¹ Eskişehir Technical University/Department of Physics, Eskişehir, TURKEY

² Eskişehir Technical University/Department of Material Science and Engineering, Eskişehir, TURKEY

³ Eskişehir Technical University/ Institute of Earth and Space Sciences, Eskişehir, TURKEY

muhammedaktas@eskisehir.edu.tr

There have been intensive efforts dedicated to growth of group III-V semiconductor materials on to the cost-efficient, high-strength Si substrates. By this way, both manufacturing cost of III-V devices could be minimized and advantageous sides of Si and III-V semiconductors could be utilized on the same platform for more generative applications. Due to their lattice mismatch, differences in chemical and crystal properties, direct growth of III-V compounds on Si prevents the efficient device applications due to huge number of defect generation in the film structure. Therefore, it is imperative to grow intermediate buffer/dislocation filter layer between Si substrate and III-V epilayer to minimize the defect generation in the active film used for device fabrication.

In this study, for cost effective flexible GaAs thin film solar cell applications, GaAs based device structures have been grown on Si substrates by molecular beam epitaxy (MBE). To minimize defect generation in the active cell film three different dislocation filter layer scheme were designed and applied in a systematic way to reach the best quality in active cell epilayers. Effects of the filter layers on the quality of active cell structures were examined through structural and optical characterization techniques.

Keywords: GaAs on Si, MBE, Buffer layer, Thin film, solar cell

EMITTER FORMATION BY ION IMPLANTATION METHOD FOR N-TYPE BLACK SILICON

Mona Zolfaghari Borra^{1,2}, Hande Çiftçınar^{1,2}, Gence Bektaş^{1,2}, Ahmet Keçeci¹, Gamze Kökbudak^{1,2}, Ozan Aydın^{1,5}, Sümeyye Koçak Bütüner¹, Hisham Nasser¹, Emel Semiz^{1,3}, Ihor Pavlov^{1,4}, Firat Es^{1,5}, Raşit Turan^{1,2,4}

¹The Center for Solar Energy Research and Applications (GÜNAM), Middle East Technical University, Dumlupınar Blvd. 1, 06800 Ankara – Turkey

²Micro and Nanotechnology Graduate Program, Middle East Technical University, Dumlupınar Blvd. 1, 06800 Ankara – Turkey

³Science and Technology Policy Studies (METU-TEKPOL), Middle East Technical University, Dumlupınar Blvd. 1, 06800 Ankara – Turkey

⁴Department of Physics, Middle East Technical University, Dumlupınar Blvd. 1, 06800 Ankara –Turkey

⁵Kalyon Güneş Teknolojileri Üretim A.Ş., Malıköy, Şaditürk Blv., 06909 Malıköy Başkent Osb/Sincan/Ankara– Turkey

*mona.zolfagariborra@metu.edu.tr, Tel: +90 312 210 5095, Fax: +903122105099

Bifacial n-type black silicon PERT solar cell, a novel design to absorb sunlight from both sides, features two doped faces with enhanced light trapping by nano-sized surface textured c-Si. N-type wafer, which has superior bulk lifetimes enabling longer diffusion path and decreased light-induced degradation (LID) due to absence of boron–oxygen complex formation, is used in this study as it is convenient for back junction cell designs. In this study, we apply ion implantation method for formation of back side emitter and front surface field due to its uniformity and controllable single side doping [1-2]. Figure 1(a) and 1(b) represent the cell structure of back emitter with Al₂O₃/SiN_x stack passivation layer at the rear side and front surface field (FSF) formed by phosphorus implantation or with POCl₃ diffusion. Both front surface doping scenarios are passivated with PECVD SiN_x ARC layer. We will present the optimization of emitter formation, FSF and Al₂O₃/SiN_x stack passivation layer for black silicon (an area of 244.3 cm²) to be utilized in n-type PERT solar cells.

Keywords: black silicon, PERT bifacial solar cells, ion implanted, back junction

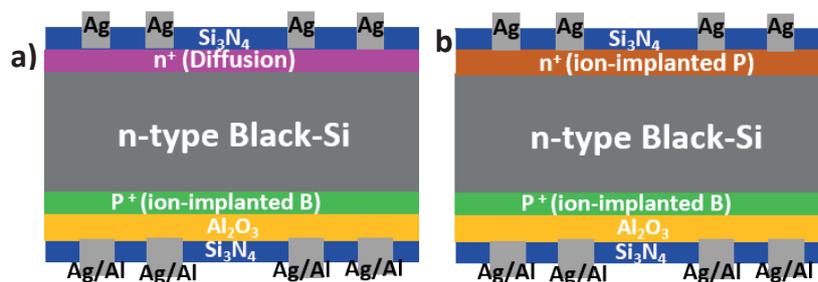


Figure 1. Schematic of the back junction of the n-type black silicon a) front side Pocl3 diffusion b) front side phosphorous ion implanted

References

- [1] A. Rohagti, D. Meier, B. Mcperson, Y. Ok, A.D. Upadhyaya, J. Lai, and F. Zimbardi, "High-throughput ion-implantation for low -cost high-efficiency silicon solar cells", Energy Procedia 15 (2012): 10-19.
- [2] M. Hermle, J. Benick, M. Rüdiger, N. Bateman, S.W. Glunz, "N-type silicon solar cells with implanted emitter", 26th European Photovoltaic Solar Energy Conference, Hamburg, Germany, September 2011.

Sizing of Differential Power Processing Converters Based on Statistical Modeling for Non-Planar Photovoltaic Applications

Morcos Metry²; **Sawsan Shukri**²; **Robert S. Balog**^{1,2}

¹ Renewable Energy & Advanced Power Electronics Research Laboratory, Texas A&M University, College Station, TX 77843, USA

² Department of Electrical and Computer Engineering, Texas A&M University at Qatar, Doha, Qatar

morcos.m.metry@ieee.org

sawsan.shukri@qatar.tamu.edu

robert.balog@ieee.org

Flexible non-planar photovoltaic modules (PV) is an emerging field with a variety of benefits to many applications [1, 2]. The challenge with non-planar PV is to mitigate partial shading as well as self-shading that is inherent to the shape of the PV surface, which diminishes the energy harvest. One practical solution is to use differential power processing (DPP), in Figure 1, as a current equalization approach [3, 4]. Since the DPP converter only processes a small portion of the total energy, it would require lower component ratings and hence lowers the system costs compared to submodule architectures [5, 6]. Sizing the DPP converter can be challenging as the current mismatch values are unpredictable. This paper aims to develop a statistical modeling technique to predict current mismatch values. The benefit of this statistical model is to size the DPP converters to be both reliable and cost-effective. Equations that estimate the power of the DPP converter are in *Table 1*. The developed Simulink model in Figure 2(a) is comprised of series-connected PVs, which use *in-situ* PV parameters collected by the non-planar PV setup in Figure 3, and a controlled resistor. The outcome of each run is a set of *i-v* and *p-v* curves, and the ratio (β) is between the processed power and the total power of the array, as shown in Figure 4. The mean value of β over multiple runs provides a statistical inference that determines the current ratings of the power electronics in the DPP converter.

Keywords: Non-planar Photovoltaic, Differential Power Processing, Statistical modeling, Partial Shading.

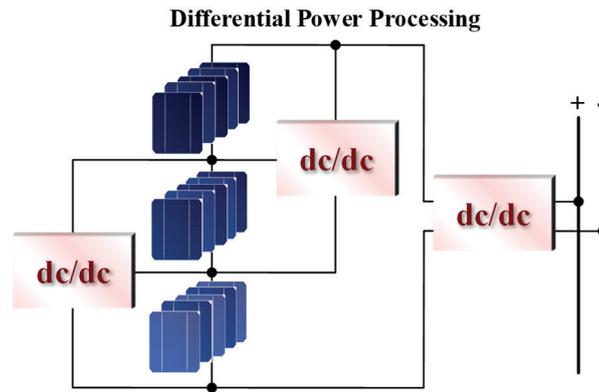


Figure 1. Existing PV power processing architecture to mitigate partial shading of differential power processors that have converters process only the difference in current to allow single-stage power processing.

Table 1. The differential power relations [5] calculated For each run from Figure 1. The current mismatch and the differential power is recorded to create a statistical inference model.

Variable	Equation
DPP converter duty ratio (D_i)	$D_i = \frac{v_{PV,i}}{v_{PV,i+1} + v_{PV,i}}$
Matrix relation of the module currents (i_{pv}), the estimated duty ratios, and the differential current (current passing through the DPP converter- i_L) for all n modules	$\begin{bmatrix} 1 & -(1-D_{n-2}) & 0 & \dots & 0 & 0 \\ -D_{n-1} & 1 & -(1-D_{n-3}) & \ddots & \vdots & \vdots \\ 0 & -D_{n-2} & \ddots & \ddots & 0 & \vdots \\ \vdots & \ddots & \ddots & 1 & -(1-D_1) & \vdots \\ 0 & \dots & 0 & -D_2 & 1 & 0 \\ 0 & \dots & \dots & 0 & D_1 & 1 \end{bmatrix} \begin{bmatrix} i_{L,n-1} \\ i_{L,n-2} \\ \vdots \\ i_{L,2} \\ i_{L,1} \\ i_{main} \end{bmatrix} = \begin{bmatrix} i_{PV,n} - i_{PV,n-1} \\ i_{PV,n-1} - i_{PV,n-2} \\ \vdots \\ i_{PV,3} - i_{PV,2} \\ i_{PV,2} - i_{PV,1} \\ i_{PV,n} \end{bmatrix}$
Differential power (P_{DPP})	$P_{DPP} = \sum_{i=1}^{n-1} v_{PV,i} i_{L,i} $
The ratio between DPP and the string power (β)	$\beta = \frac{P_{DPP}}{P_{PV}}$

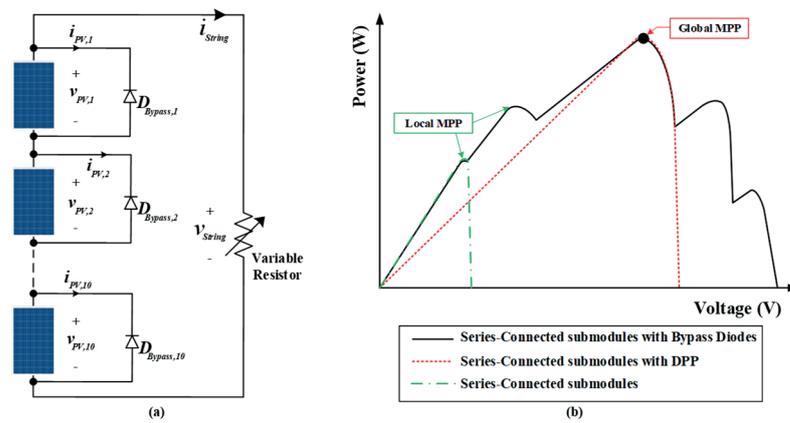


Figure 2. Understanding partial shading. (a) A study of 9 series-connected modules, each receiving a set of irradiance values based on in-situ PV characteristics, was studied to observe the effects of partial shading. (b) A sketch of the different $p-v$ curves that would be observed on the final stage converter showing that series-connected modules MPPT will be stuck at a local maximum, while a DPP allows for global MPP operation.



Figure 3. The experimental setup used to obtain results of in-situ PV parameters for non-planar structures. A Seaward Irradiance Meter (Solar Survey 200R) was used to get the values of the temperature and irradiance while experimenting.

Irradiance (W/m ²)										String Characteristics			DPP	
IR 1	IR 2	IR 3	IR 4	IR 5	IR 6	IR 7	IR 8	IR 9	IR 10	String P (W)	String V (V)	String I (A)	DPP P (W)	BETA
400	200	650	150	400	800	550	200	800	800	907.6	394.8	2.299	36.12	3.98%

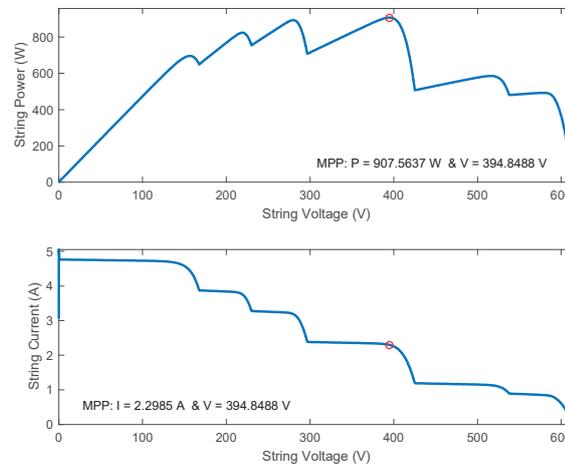


Figure 4. A sample run from a thousand-run simulation with 10 PV modules, each receiving a random irradiance value for each run. Differential power, β , and the p - v and i - v curves are presented.

References

- [1] M. B. Shadmand and R. S. Balog, "Design Considerations for Long-Term Remote Photovoltaic-Based Power Supply using Non-Planar Photovoltaic Surfaces," presented at the IEEE Int. Conf. on Technologies for Homeland Security, Waltham, MA, USA, 12-14 Nov 2013.
- [2] A. Karavadi and R. S. Balog, "Novel non-flat photovoltaic module geometries and implications to power conversion," presented at the IEEE Energy Conv. Congr. and Expo. (ECCE), Phoenix, AZ, 17-22 Sept. 2011. Available: <https://ieeexplore.ieee.org/document/6063742>
- [3] S. Qin, S. T. Cady, A. D. Dominguez-Garcia, and R. C. N. Pilawa-Podgurski, "A Distributed Approach to Maximum Power Point Tracking for Photovoltaic Submodule Differential Power Processing," *IEEE Trans. Power Electron.*, vol. 30, no. 4, pp. 2024-2040, Apr 2015.
- [4] P. T. Krein and R. S. Balog, "Life Extension Through Charge Equalization of Lead-Acid Batteries " presented at the Annual International Telecommunications Energy Conference, Montreal, Quebec, Canada, 29 Sept.-3 Oct. 2002. Available: <https://ieeexplore.ieee.org/abstract/document/1048705>
- [5] P. S. Shenoy, K. A. Kim, B. B. Johnson, and P. T. Krein, "Differential Power Processing for Increased Energy Production and Reliability of Photovoltaic Systems," *IEEE Trans. Power Electron.*, vol. 28, no. 6, pp. 2968-2979, Jun 2013.
- [6] M. Uno and A. Kukita, "PWM Converter Integrating Switched Capacitor Converter and Series-Resonant Voltage Multiplier as Equalizers for Photovoltaic Modules and Series-Connected Energy Storage Cells for Exploration Rovers," *IEEE Trans. Power Electron.*, vol. pp, pp. 1-13, Dec 2016.

Green and Sustainable Energy

Muratcan IŞILDAK

¹ Genç Düşünce Enstitüsü/Ankara-Turkey

²

*muratcanisildak@gmail.com

Due to the geographical conditions of our country, many of these clean energy resources can be utilized. As a country that spends almost half of the year sunny, solar panels will be efficient in both houses and companies. The Black Sea region is quite windy and a suitable region for wind energy production. In the field of hydrothermal energy the production in the Aegean, especially in the Inner Aegean region and in the Eastern Anatolia region, due to rich thermal water resources. The Turkish clean energy density, as an energy efficiency indicator, proves that energy consumption reduces the rate of the gross domestic product value. Improvement of the energy density is a must. Energy efficiency in the economy is a driving force for sustainable development. In every country, these energy sources can be used in some way, but if the availability is low, the efficiency of it will be low. In order to increase energy efficiency, renewable energies should be applied in the most suitable regions. For example, wind power should be in the windy regions to achieve the highest efficiency, such as the Netherlands. Similarly, tidal energy production is more efficient in countries such as Canada and the UK where tidal events in the oceans are more common than in the coastal countries. Again, for hydrothermal energy, hot water sources should be available. The energy crisis in the 1970s brought energy conservation, saving and new resources to the agenda in countries such as Europe, the USA and Japan, which are especially dependent on energy. In addition, the greenhouse effect caused by heavy fossil fuel dependence that started with the industrial revolution started to increase the world's average temperature dangerously. As a result of the use of fossil fuels such as petroleum, coal and natural gas, the amount of greenhouse gases, especially carbon dioxide, has increased rapidly in the atmosphere. Unlike natural climate changes, the 1990s were the hottest ten years in the world as a result of climate changes triggered by

human activities, and in 2003, when the hottest article of the last 500 years was experienced, more than 20,000 people died in Europe due to the heat wave. These negative developments, which are the result of the endless consumption of natural riches perceived as an endless source, threaten humanity and all living beings. Against these global threats that do not recognize the borders of the country, the concept of sustainable development years has been developed by the United Nations Commission on Environment and Development in 1987, which is defined as meeting the needs of the present generations without jeopardizing the possibilities of meeting the needs of future generations. Sustainability was also a priority of the energy sector and a rapid orientation towards renewable energy sources was initiated.

As well as the presence of energy efficiency accelerators on the basis of sectors, the presence of legislation in more than 130 countries, the ambitious targets of more than 100 countries and cities and the road map and investment movements were reported as positive developments for the public energy efficiency approach. The greenhouse effect plays an important role on climate change and has a negative impact on living life. In most European countries, the promotion and use of renewable energy sources has increased considerably, but when the world is considered, there are very few countries that have been able to revise themselves to generate energy. All of these energy types can be converted into each other. Therefore, energy use areas cover every moment of human life; use of electronic devices, enlightenment, heating, all kinds of machinery usage etc. The most important features are, as previously emphasized, they are renewable. They will not end after a certain point, such as oil or natural gas. They can be used continuously with the right techniques and can be easily integrated into life. In addition, they have no negative effects on the environment or the equipment used is minimal.

Keywords: Solar Energy, Sustainable Economy, Greenhouse effect, Solar Economy

References

[1] Kandpal T.C. and Garg H.P. Financial Evaluation of Renewable Energy Technologies, Macmillan publishers India limited, 2003.

[2] Singh Shobh Nath. Non-Conventional Energy Resources, Pearson, 2015

....

Periodic Surface Texturing of Silicon by Photoelectrochemical Etching for Photovoltaics

Nardin Avishan^{1,2}, Alp Akbıyık^{2,3}, Emre Yüce^{1,2,3}, Alban Bek^{1,2,3}

¹ Middle East Technical University Micro and Nanotechnology Program, Ankara, Turkey

² The Center for Solar Energy Research and Applications (GÜNAM), Ankara, Turkey

³ Middle East Technical University Department of Physics, Ankara, Turkey

*nardin.avishan@gmail.com

Although silicon is the most used material in the photovoltaics, its high reflection index must be reduced for solar cell application. Apart from anti-reflection coatings, an efficient and long-lasting method to reduce the reflection is texturing the silicon surface itself. Instead of the common etching methods that utilize bias voltage, plasma, or metals, in this work, laser-assisted wet chemical etching or more commonly Photoelectrochemical etching [1] is used to create nano-holes on the surface of the silicon. In this technique, laser triggers the hole generation and the etching process is driven by laser irradiation in a non-contact manner [2]. The Silicon sample under laser illumination is immersed in an HF solution. The laser radiation is directed into a digital micro-mirror device (DMD), to shape the laser beam, and texture the silicon in a specific pattern. The purpose is to keep the electrical properties as high as possible by keeping some regions smooth while the nanostructures on the etched regions will improve the optical properties by light trapping. In this study, full and partial Si surface texturing achieved by structured light PEC etching are reported. The laser power, illumination time, and the periodic pattern are optimized. The lowest average measured reflectance value for fully textured Si was 9% at a laser power of 650 mW. The lowest average measured reflectance value for the periodically textured Si was 15% at a laser power of 350 mW. Further etching optimization, surface passivation, and carrier lifetime measurements are the subjects of our next studies.

Keywords: c-Si, Silicon Solar Cell, Etching, Laser Processing, Surface Texturing

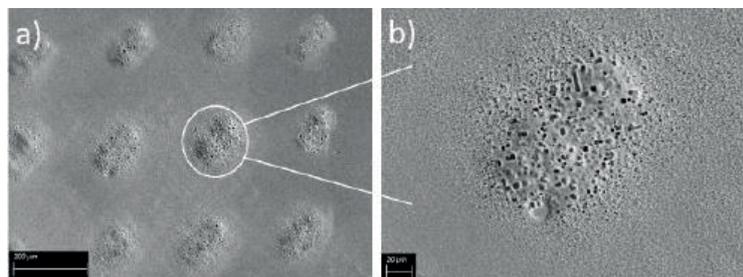


Figure 1. SEM images of a) the overall periodically etched surface and b) the focused SEM image illustrating the border between irradiated (on) and unirradiated (off) regions.

References

- [1] N. Noguchi and I. Suemune, Appl. Phys. Lett. 62 (1993) 1429.
[2] L. Koker and K.W. Kolasinski, Phys. Chem. Chem. Phys. 2 (2000) 277.

SYNTHESIS, CHARACTERIZATION, AND PHOTOVOLTAIC PROPERTIES OF DITHIENYL BENZOOXADIAZOLE BASED POLYMERS FOR HIGH PERFORMANCE ORGANIC SOLAR CELLS

KARAKURT Oğuzhan¹, YILMAZ ALEMDAR Eda¹, ÇIRPAN Ali^{1,2,3,4}

¹ Middle East Technical University, METU/Department of Chemistry, Ankara, Turkey

²Department of Polymer Science and Technology, Middle East Technical University, 06800, Ankara, Turkey

³The Center for Solar Energy Research and Application (GUNAM), Middle East Technical University, 06800 Ankara, Turkey

⁴Department of Micro and Nanotechnology, Middle East Technical University, 06800 Ankara, Turkey

*karakurt@metu.edu.tr, ealemdar@metu.edu.tr, acirpan@metu.edu.tr

Two conjugated polymers from literature PBDTBO¹ and PBDTBO² were synthesized with superior molecular weights and renamed as PBDTBOv2 and PBDTBOv2. As known, electronic and mechanical properties of conductive conjugated polymers are strongly correlated with molecular weight and can be enhanced by increasing molecular weight³. Film forming properties of these polymers are excellent and they are soluble in common solvents such as tetrahydrofuran and chlorobenzene. Their structures are verified by IR spectroscopy and the molecular weights were determined by Gel Permeation Chromatography (GPC). Thermal properties of the polymers were identified by thermal gravimetric analysis (TGA) and differential scanning calorimetry (DSC). Redox behaviors and electronic band gaps of polymers were investigated by cyclic voltammetry (CV) method and Keithley 2400 instrument was used to obtain current density vs voltage measurements. Photo-current was simulated with 100 mW cm² and measured under 1.5 G illumination. The PCE_{max} of %10.3 was reached without using any additive by device structure of ITO/ PEDOT:PSS/PBDTBOv2:PC₇₁BM/LiF/Al with a high open-circuit voltage (V_{oc}) of 0.87 V, a short circuit current density (J_{sc}) of 17.3 mA/cm² and fill factor (FF) of 69%. To the best of our knowledge, this power conversion efficiency is the highest among dithienyl benzooxadiazole (DTBO) –based organic solar cells.

Keywords: solar radiation, organic solar cell, power conversion efficiency, molecular weight, conductive conjugated polymer

References

- [1] Liu, B., Chen, X., He, Y., Li, Y., Xu, X., Xiao, L., Li, L., & Zou, Y. (2013). New alkylthienyl substituted benzo[1,2-b:4,5-b']dithiophene-based polymers for high performance solar cells. *Journal of Materials Chemistry A*, 1(3), 570–577. <https://doi.org/10.1039/c2ta00474g>
- [2] Jiang, J. M., Yang, P. A., Chen, H. C., & Wei, K. H. (2011). Synthesis, characterization, and photovoltaic properties of a low-bandgap copolymer based on 2,1,3-benzoxadiazole. *Chemical Communications*, 47(31), 8877–8879. <https://doi.org/10.1039/c1cc12040a>
- [3] Heeger, A. J. (2010). Semiconducting polymers: The Third Generation. *Chemical Society Reviews*, 39(7), 2354–2371. <https://doi.org/10.1039/b914956m>

Build a Decision tree model for maximum power point tracker based on a fuzzy logic controller

Rabah Benkercha Samir Moulahoum

Research Laboratory of Electrical Engineering & Automatic, LREA, University of Medea, Algeria

*samir.moulahoum@gmail.com

moulahoum.samir@univ-medea.dz

One of the main parts in the Grid Connected PV System is the DC/DC boost converter which several researches seek to improve, this component is commanded by a control algorithm which extracts and tracks the maximum power generated by the PV array throughout any weather conditions. Several approaches in the literature are proposed to accomplish this task; among the well-known ones is the intelligent technique such as fuzzy logic controller (FLC). On one side, even though the FLC has many advantages as convergence time, accuracy, efficiency and so forth. On the other side, there are some disadvantages points as the complexity of the controller, hard to implement in the embedded systems. For this purpose, a new approach has been proposed, using data set of the FLC got from simulation in order to build a decision tree model (DTM) with the aim to obtain both advantages of FL and DTM. Therefore, 66% of the data set will be directed to the learning process and the rest is for the model test. The learning process is performed based on the C4.5 algorithm, where splitting criteria used to form the tree is called the gain ratio, this one is applied on the data set recursively to find the best model that fittest with FLC data. A validation step was carried out to verify the performances of the model by using new data unseen in the learning process. Lastly, the results have shown that the DT model has a high correlation with the FLC thus have both advantages of the two approaches, moreover, the new model has compared with P&O and PID controllers and shown high effectiveness.

Keywords: Grid Connected PV System, Maximum Power Point Tracker, Fuzzy Logic Controller, Decision Tree, C4.5 algorithm.

Improving Measured Horizontal Solar Radiation Data: The case Study-Asia Continent

Raimon O. Bawazir , Numan S. Çetin and J. Chakchak

Solar Energy Institute/EGE University, Izmir, Turkey

*raimonengineer@gmail.com

Horizontal solar radiation is the backbone of any solar power application. Solar radiation data collecting from the ground-based meteorological station is the most reliable compared to others such as satellite database since it is not influenced by factors outside of the atmosphere. In literature, there is a number of recent studies that utilize directly old measured solar radiation data without any consideration. Time gap periods of collecting solar radiation data show a difference. For example considering the horizontal solar radiation that occurred in 2007 and between 1971 and 1980, the Root Mean Squared Error (RMSE) and Mean Percentage Error (MPE) are 2.1247 and 8.3508 respectively. As a consequence, the solar system can exposure to poor techno-economic assessment. This paper attempts to find a close agreement to enhance the old measured data within the period 1971 and 2003 to make it more applicable for further studies and applications. Therefore, NASA POWER, PVGIS, Meteonorm and old measured data are investigated and compared to the new measured data (used as reference). All measured data are collected from the World Radiation Data Centre (WRDC) and published articles. Six distributed locations in the Asian continent are used as a case study for this paper. Statistical methods including Global Performance Indicator (GPI) are used to investigate and compare solar data sources. It yielded that, the improvement of old measured data can be obtained either by proposed method for each country or by a proposed hybrid of all solar data sources for the any location in Asian continent.

Keywords: Horizontal solar radiation, NASA POWER, PVGIS, Meteonorm and Global Performance Indicator

Table 1. The most suitable data source for each country

Countries	Ranks			
	1	2	3	4
Thailand	$H_{m.old}$	$H_{Meto+m.old}$	$H_{NASA+Meto+m.old}$	$H_{NASA+m.old}$
Malaysia	H_{Meto}	$H_{NASA+Meto}$	$H_{NASA+PVGIS+Meto+m.old}$	$H_{PVGIS+Meto+m.old}$
India	$H_{NASA+Meto+m.old}$	H_{Meto}	$H_{Meto+m.old}$	$H_{NASA+PVGIS+Meto+m.old}$
Iraq	$H_{m.old}$	$H_{NASA+Meto+m.old}$	$H_{Meto+m.old}$	$H_{NASA+PVGIS+Meto+m.old}$
UAE	$H_{PVGIS+m.old}$	$H_{PVGIS+Meto+m.old}$	$H_{NASA+PVGIS+Meto+m.old}$	H_{Meto}
Indonesia	$H_{PVGIS+Meto}$	$H_{NASA+Meto}$	$H_{NASA+PVGIS+Meto}$	$H_{NASA+PVGIS+Meto+m.old}$

References

- [1] REN21, "Renewables 2019: Global Status Report," 2019.

- [2] REN21, "Renewables 2018 Global Status Report," 2018.
- [3] REN21, "Renewables 2017: global status report," 2017.
- [4] REN21, "Renewables 2016 Global Status Report," 2016.
- [5] REN21, "Renewables 2015 Global Status Report," 2015.
- [6] R. O. Bawazir and N. S. Cetin, "Comprehensive overview of optimizing PV-DG allocation in power system and solar energy resource potential assessments," *Energy Reports*, vol. 6, pp. 173–208, 2020.
- [7] R. O. Bawazir, J. Chakchak, N. S. Cetin, and K. Ülgen, "Investigating the Optimum Tilt Angle for Solar Receiver in Izmir," in 3rd International Symposium on Environment and Morality, 2016, no. November, pp. 4–6.
- [8] M. Mwanza, J. Chachak, N. S. Cetin, and K. Ülgen, "Assessment of solar energy source distribution and potential in Zambia," *Period. Eng. Nat. Sci.*, vol. 5, no. 2, pp. 103–116, 2017.
- [9] J. Chakchak and M. Mwanza, "Methodology for Assessment of the Potential of Photovoltaic Electricity Production in the Non-residential Areas of Tunisia Methodology for Assessment of the Potential of Photovoltaic Electricity Production in the Non-residential Areas of Tunisia," no. November, 2016.
- [10] C. Budig, J. Orozaliev, and K. Vajen, "Comparison of Different Sources of Meteorological Data for Central Asia and Russia," *EuroSun 2010*, p. 8, 2010.
- [11] S. M. Robaa, "On the estimation of global and diffuse solar radiation over Egypt," *Mausam*, vol. 54, no. April, pp. 17–35, 2003.
- [12] K. Skeiker, "Correlation of global solar radiation with common geographical and meteorological parameters for Damascus province, Syria," *Energy Convers. Manag.*, vol. 47, no. 4, pp. 331–345, 2006.
- [13] H. Li, Y. Lian, X. Wang, W. Ma, and L. Zhao, "Solar constant values for estimating solar radiation," *Energy*, vol. 36, no. 3, pp. 1785–1789, 2011.
- [14] M. Maroof Khan and M. Jamil Ahmad, "Estimation of global solar radiation under clear sky radiation in Yemen," *J. Eng. Sci. Technol. Rev.*, vol. 5, no. 2, pp. 12–19, 2012.
- [15] M. F. Li, X. P. Tang, W. Wu, and H. Bin Liu, "General models for estimating daily global solar radiation for different solar radiation zones in mainland China," *Energy Convers. Manag.*, vol. 70, pp. 139–148, 2013.
- [16] T. E. Boukelia, M. S. Mecibah, and I. E. Meriche, "General models for estimation of the monthly mean daily diffuse solar radiation (Case study: Algeria)," *Energy Convers. Manag.*, vol. 81, pp. 211–219, 2014.
- [17] K. Mohammadi, S. Shamshirband, C. W. Tong, M. Arif, D. Petković, and C. Sudheer, "A new hybrid support vector machine-wavelet transform approach for estimation of horizontal global solar radiation," *Energy Convers. Manag.*, vol. 92, pp. 162–171, 2015.
- [18] K. Mohammadi, S. Shamshirband, M. H. Anisi, K. Amjad Alam, and D. Petković, "Support vector regression based prediction of global solar radiation on a horizontal surface," *Energy Convers. Manag.*, vol. 91, pp. 433–441, 2015.
- [19] K. Mohammadi, S. Shamshirband, C. W. Tong, K. A. Alam, and D. Petković, "Potential of adaptive neuro-fuzzy system for prediction of daily global solar radiation by day of the year," *Energy Convers. Manag.*, vol. 93, pp. 406–413, 2015.
- [20] M. Tanweer, F. Ahmad, Z. Uddin, S. Rehman, and I. Ulfat, "Estimation of Diffuse Solar Radiation from Clearness Index for Multan, Southern Punjab, Pakistan," *Journal of Basic & Applied Sciences*, 2016. .
- [21] O. W. Mohammed and G. Yanling, "Estimation of diffuse solar radiation in the region of northern Sudan," *Int. Energy J.*, vol. 16, no. 4, pp. 163–172, 2016.
- [22] B. Jamil and A. T. Siddiqui, "Generalized models for estimation of diffuse solar radiation based on clearness index and sunshine duration in India: Applicability under different climatic zones," *J. Atmos. Solar-Terrestrial Phys.*, vol. 157–158, no. March, pp. 16–34, 2017.
- [23] M. Ali, B. Jamil, and Fakhruddin, "Estimating diffuse solar radiation in India: performance characterization of generalized single-input empirical models," *Urban Clim.*, vol. 27, no. December 2018, pp. 314–350, 2019.
- [24] R. Meyer, M. Schlecht, and K. Chhatbar, "Solar resources for concentrating solar power (CSP) systems," in *Concentrating Solar Power Technology: Principles, Developments and Applications*, 2012, pp. 68–90.
- [25] L. Wald, "Basics in solar radiation at earth source," HAL, 2018.
- [26] N. Samuel Chukwujindu, "A comprehensive review of empirical models for estimating global solar radiation in Africa," *Renew. Sustain. Energy Rev.*, vol. 78, pp. 955–995, 2017.
- [27] C. Sharma, A. K. Sharma, I. Purohit, S. C. Mullick, and T. C. Kandpal, "Comparison of solar radiation data sources for design and performance appraisal of CSP systems in India," *Int. J. Ambient Energy*, vol. 39, no. 6, pp. 594–605, 2018.
- [28] P. Ineichen, "Long term satellite hourly, daily and monthly global, beam and diffuse irradiance validation. Interannual variability analysis," no. March, 2013.
- [29] P. W. Stackhouse et al., "POWER Release 8.0.1 (with GIS Applications) Methodology," *NASA Langley Res. Cent.*, vol. 1, 2018.
- [30] P. Handbook, R. Authorities, and T. Pvgis, "PVGIS: estimating photovoltaic electricity production at local level," pp. 51–52.

- [31] R. K. Tarai and P. Kale, "Development of rasterized map using PVGIS for assessment of solar PV energy potential of Odisha," *Int. J. Renew. Energy Res.*, vol. 6, no. 1, 2016.
- [32] Joint Research Centre (JRC), "Pvgis 5 Internet tools for the assessment of solar resource and photovoltaic solar systems," 2017.
- [33] E. D. Thomas Huld, Irene Pinedo Pascua, Ana Gracia Amillo, Ruben Urraca, "PVGIS version 5: improvements to models and features," in *33rd European Photovoltaic Solar Energy Conference and Exhibition PVGIS, 2017*, pp. 2069–2074.
- [34] Meteotest, "Handbook Part I : Meteonorm Software," no. May, 2012.
- [35] A. Abdulameer, A. Al-khazzar, and A. Jamal, "Journal of Renewable A Comparative Study of the Available Measured Global Solar Radiation in Iraq," vol. 4, no. 2, pp. 47–55, 2017.
- [36] Meteonorm, "<https://meteonorm.com/en/>," 2019. .
- [37] B. Jamil and A. T. Siddiqui, "Estimation of monthly mean diffuse solar radiation over India: Performance of two variable models under different climatic zones," *Sustain. Energy Technol. Assessments*, vol. 25, no. September 2017, pp. 161–180, 2018.
- [38] K. Bakirci, "Models for the estimation of diffuse solar radiation for typical cities in Turkey," *Energy*, vol. 82, pp. 827–838, 2015.
- [39] B. Jamil and N. Akhtar, "Comparison of empirical models to estimate monthly mean diffuse solar radiation from measured data: Case study for humid-subtropical climatic region of India," *Renew. Sustain. Energy Rev.*, vol. 77, no. February, pp. 1326–1342, 2017.
- [40] S. Manju and M. Sandeep, "Prediction and performance assessment of global solar radiation in Indian cities: A comparison of satellite and surface measured data," *J. Clean. Prod.*, vol. 230, pp. 116–128, 2019.
- [41] M. Despotovic, V. Nedic, D. Despotovic, and S. Cvetanovic, "Review and statistical analysis of different global solar radiation sunshine models," *Renew. Sustain. Energy Rev.*, vol. 52, pp. 1869–1880, 2015.
- [42] K. Ulgen and A. Hepbasli, "Diffuse solar radiation estimation models for Turkey's big cities," *Energy Convers. Manag.*, vol. 50, no. 1, pp. 149–156, 2009.
- [43] M. Despotovic, V. Nedic, D. Despotovic, and S. Cvetanovic, "Review and statistical analysis of different global solar radiation sunshine models," *Renew. Sustain. Energy Rev.*, vol. 52, pp. 1869–1880, 2015.
- [44] B. Jamil and N. Akhtar, "Empirical models for estimation of diffuse solar radiation based on measured data for humid-subtropical climatic region of India," *J. Renew. Sustain. Energy*, vol. 9, no. 3, 2017.
- [45] A. M. AL-Salihi, M. M. Kadum, and A. J. Mohammed, "Estimation of global solar radiation on horizontal surface using routine meteorological measurements for different cities in Iraq," *Asian J. Sci. Res.*, vol. 3, no. 4, pp. 240–248, 2010.
- [46] W. E. Alnaser et al., "First solar radiation atlas for the Arab world," *Renew. Energy*, vol. 29, no. 7, pp. 1085–1107, 2004.
- [47] M. D. Islam, I. Kubo, M. Ohadi, and A. A. Alili, "Measurement of solar energy radiation in Abu Dhabi, UAE," *Appl. Energy*, vol. 86, no. 4, pp. 511–515, 2009.
- [48] Y. A. G. Abdalla and G. M. Feregh, "Contribution to the study of solar radiation in Abu Dhabi," *Energy Convers. Manag.*, vol. 28, no. 1, pp. 63–67, 1988.

Low-Cost, Stand-Alone, In-Situ PV Curve Tracer

Safin H. Bayes¹, Sawsan Shukri¹, Robert S. Balog^{1,2}

Renewable Energy and Advanced Power Electronics Research Laboratory,
¹Texas A&M University at Qatar, Doha, QATAR, ²Texas A&M University, TX, USA

.....

safin.bayes@qatar.tamu.edu
sawsan.shukri@qatar.tamu.edu
robert.balog@ieee.org

The *i-v* characteristic curve provides information about the parameters and operation of a photovoltaic (PV) module to validate its performance and efficiency [1]. A flexible and scalable *i-v* curve tracer was published in [2] that consists of a Source Measuring Unit (SMU), a relay board, and a dedicated computer hosting a MATLAB software. However, the system is expensive for institutions in developing countries where researchers may suffer from insufficient resources and funding [2]. Therefore, the paper describes an improvement to reduce the cost by eliminating the dedicated computer with a \$35 Raspberry Pi and the MATLAB software with a free Python program. The SMU and the relay board are connected to the Raspberry Pi through a USB cable and an ethernet cable, respectively, as shown in Figure 1. The new software provides three modes of operation. First is the one-time test mode, in which user tests one or multiple PV modules, as shown in Figure 2. In addition to generating individual plots, the software generates a combination of all the selected PV modules' plot, useful for comparative testing, as shown in Figure 3. The next mode, in Figure 4, enables testing of various interconnections by configuring relays based on the connections described in an excel file. Shown in Figure 5 is the time-sequenced mode in which individual PV modules or interconnections are tested for a certain duration at regular intervals. For example, in Figure 5(a), the user selects PVs 5,6,7 to test every 30 minutes for eight hours.

Keywords: Photovoltaic, *i-v* curve, Solar energy, low cost, stand-alone

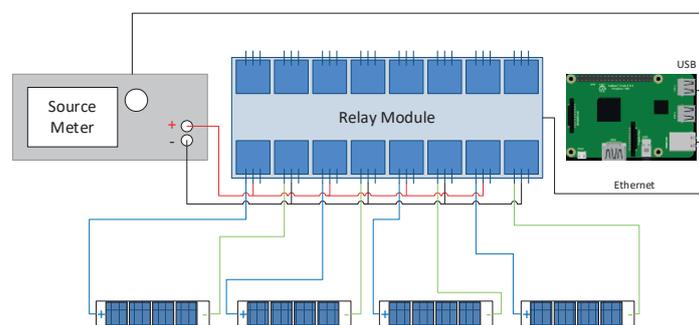


Figure 1: New Hardware Setup

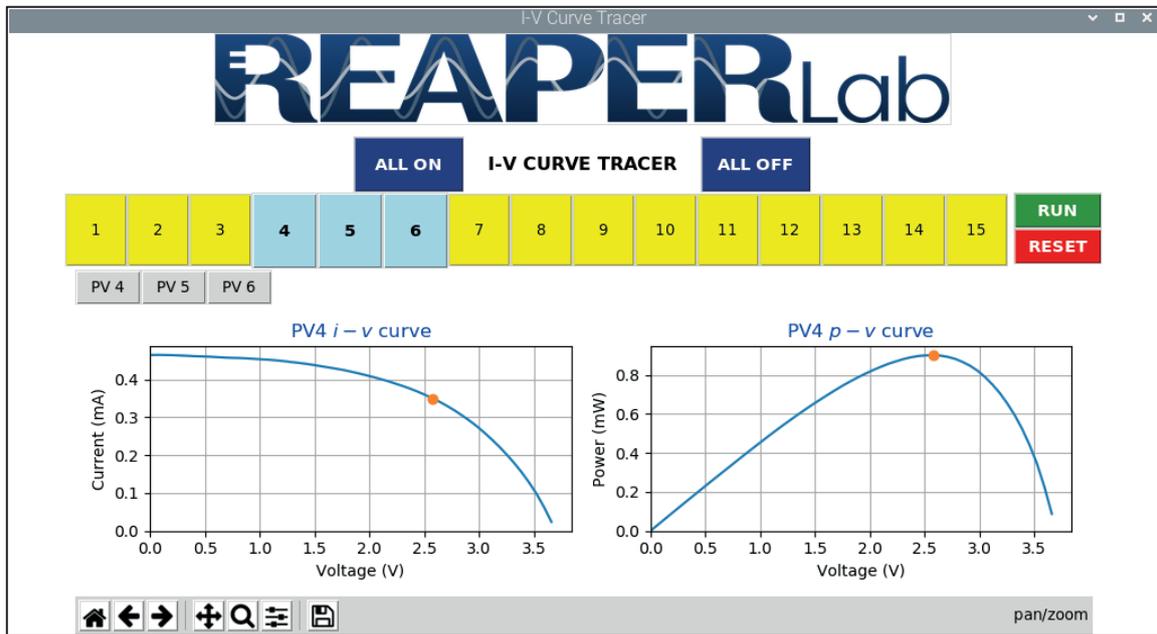
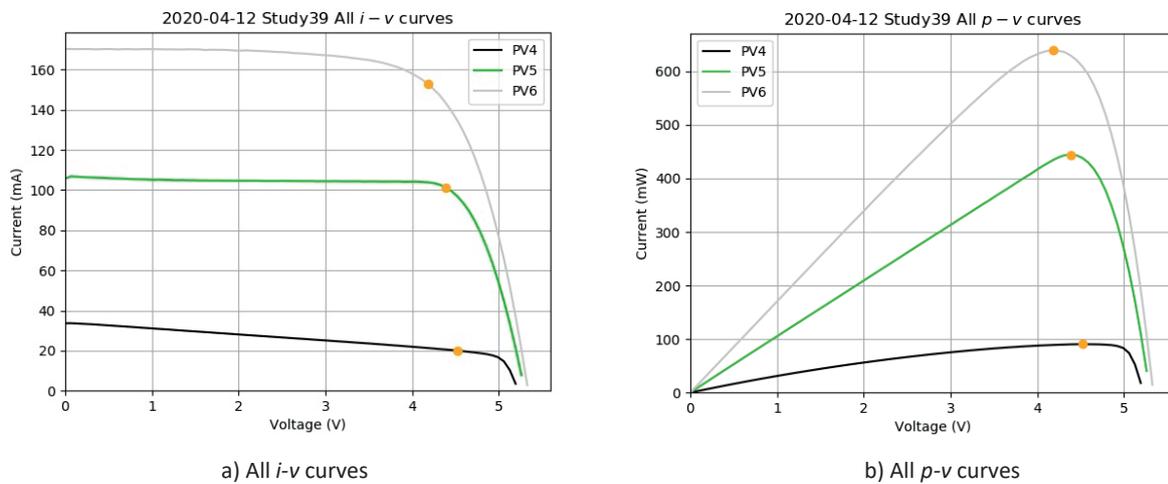


Figure 2: One-Time Test



a) All *i-v* curves

b) All *p-v* curves

Figure 3: In post-processing, multiple figures are combined as shown in a) and b)

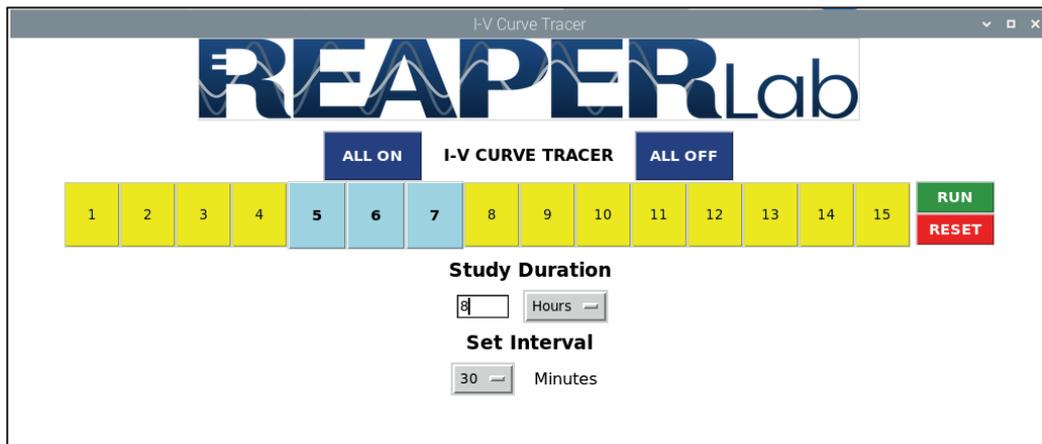
```

*****
RENEWABLE ENERGY AND ADVANCED POWER ELECTRONICS RESEARCH LABORATORY
I-V CURVE TRACER
*****

1. RelaySetup_TB4_SS0G.xlsx
2. Relay_Setup.xlsx
3. RelaySetup_TB4_SS.xlsx
4. RelaySetup_TB4.xlsx
Choose Excel File: 4
RelaySetup_TB4.xlsx

Starting Configuration 1
Turning On relays.....
    
```

Figure 4: Excel Configurations Mode



a) Individual PV testing

```

*****
RENEWABLE ENERGY AND ADVANCED POWER ELECTRONICS RESEARCH LABORATORY
I-V CURVE TRACER
*****

1. RelaySetup_TB4_SS2.xlsx
2. RelaySetup_TB4_SS0G.xlsx
3. RelaySetup_TB4_S.xlsx
4. Relay_Setup.xlsx
5. RelaySetup_TB4_SS.xlsx
6. RelaySetup_TB4.xlsx
7. RelaySetup_TB4_pv7.xlsx
Choose Excel File: 3
RelaySetup_TB4_S.xlsx
Study Duration (Hours): 8
Interval (Minutes): 30
Starting Configuration 1
Turning On relays.....
    
```

b) Testing configurations from excel files

Figure 5: Time-Sequenced Mode in a) and b)

References

- [1] "Solar Cell I-V Characteristic," Alternative Energy Tutorials, [Online]. Available: <http://www.alternative-energy-tutorials.com/energy-articles/solar-cell-i-v-characteristic.html>. [Accessed April 2020].
- [2] R. Ameen and R. S. Balog, "Flexible and Scalable Photovoltaic Curve Tracer," in *PVCON - International Conference on Photovoltaic Science and Technology*, Ankara, 2018.
- [3] S. M. Mutula, "Challenges of postgraduate research: Case of developing countries," *South African Journal of Libraries and Information Science*, pp. 184-190, 2011.

Complications and Analytical Solutions for ToF-SIMS Characterization of Silicon-Based Solar Cells

Salar H. Sedani^{1,2,3}, Ilker Yildiz³, Raşit Turan^{1,2,4}

¹Micro and Nanotechnology Department, Middle East Technical University (METU), 06800 Ankara, Turkey

²Centre for Solar Energy Research and Applications (GÜNAM), Middle East Technical University, 06800 Ankara, Turkey

³Central Laboratory, Middle East Technical University (METU), 06800 Ankara, Turkey

⁴Department of Physics, Middle East Technical University (METU), 06800 Ankara, Turkey

* salar@metu.edu.tr

Time of flight secondary ion mass spectrometry (ToF-SIMS) is one of the most potent spectroscopy techniques in the elemental characterization field. Due to the high detection limit at a spatial resolution of ppm-ppb and layer-by-layer profiling of elements and compounds, ToF-SIMS could enlighten many details of a solar cell structure. However, there are complications about the differentiation of the chemical compounds with identical masses by ToF-SIMS [1]. Impurities/dopant distribution and concentration in deposited films and bulk substrates are essential aspects for silicon-based solar cell materials analyzed by ToF-SIMS properly [2], which motivated us to study these topics.

ToF-SIMS does characterization through each component mass amount. Reasonably, it could present results as overlap peaks in identical masses for a rather heavier element compared to lighter atom-based compounds. Alkali and alkaline earth metals are abundant impurities of silicon-based cells, which could originate from the used raw materials or fabrication processes. In the investigation of Ca impurity in the structure, the peak appeared at the same mass spectrum with SiC ion. The further study of Si, C, and Ca pattern of distribution through the film and substrate (Figure1a) lead us to name the peak as SiC. A similar case could be proposed and argued for recombination affecting Fe contamination [3] and P dopant determination with the mass of 56 a.u. (Fe) and 31 a.u. (P) which weigh as Si₂ compound and ³⁰SiH (Figure1b). This study investigates the most probable complication cases (over tens of compounds and elements) in silicon-based photovoltaic devices and proposes analytical differentiation methods to overcome this problem.

Keywords: ToF-SIMS, silicon-based solar cells, identical mass complication

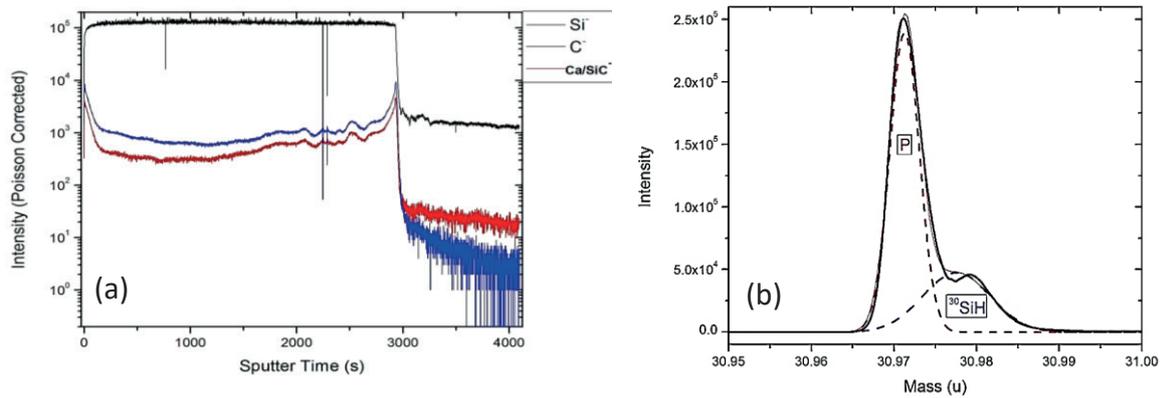


Figure 1. a) ToF-SIMS depth profile of Ca^+ in a-Si/c-Si, and b) mass spectrum deconvolution of P dopant in a c-Si bulk structure.

References:

- [1] J. C. Vickerman, D. Briggs, ToF-SIMS: surface analysis by mass spectrometry, IM Publications, 2013.
- [2] S. H. Sedani, O .F. Yasar, M. Karaman, R. Turan, Effects of boron doping on solid phase crystallization of in situ doped amorphous silicon thin films prepared by electron beam evaporation, Thin Solid Films 694, (2020) 137639, <https://doi.org/10.1016/j.tsf.2019.137639>.
- [3] D. Macdonald and L. J. Geerligs, Recombination activity of interstitial iron and other transition metal point defects in p- and n-type crystalline silicon, *Appl. Phys. Lett.*, vol. 85, no. 18, pp. 4061–4063, 2004.

Tailored Doping Profile with Commercial Nanosecond Laser for Low-cost PV Industrial Applications

Salar H. Sedani^{1,2,3}, **Ergi Dönerçark**^{1,2}, **E. Hande Çiftpınar**^{1,2}, **Raşit Turan**^{1,2,4}

¹Micro and Nanotechnology Department, Middle East Technical University (METU), 06800 Ankara, Turkey

²Centre for Solar Energy Research and Applications (GÜNAM), Middle East Technical University, 06800 Ankara, Turkey

³Central Laboratory, Middle East Technical University (METU), 06800 Ankara, Turkey

⁴Department of Physics, Middle East Technical University (METU), 06800 Ankara, Turkey

* salar@metu.edu.tr

The most common reported properties of solar cells as open-circuit voltage (V_{oc}) and short-circuit current (J_{sc}) is related to the dopant's doping profile. Additionally, in the manufacturing line, implied V_{oc} and sheet-resistance values are measured. All of these are evaluated to sense the doping while the main case is the doping depth profile. Generally, the shape and the tail in the bulk of the absorber auto-tuned within the thermal load of the processes. Even extra annealing steps could be added to the solar cell fabrication flow to shape a desirable doping profile. Emitter layer and back-surface field region properties must be optimized due to the limitations of the junction depth and recombination possibilities. As the thermal step is applied to all of the cell structure simultaneously, utilizing a laser could be beneficial. However, due to laser doping restrictions, it is a challenging case[1,2]. It needs proper tuning of process and accurate characterization techniques to trace the doping profile.

In this study, we pursue a low-cost approach for tailoring the doping profile. We process a coated boron and an aluminum layer on silicon with the help of a commercial marking nanosecond laser. Boron layer evaporated by a boron effusion cell and encapsulated with a thin sacrificial amorphous silicon coating. On the other hand, aluminum evaporated thermally on the silicon as the source layer. A pulsed laser had used to drive in these two layers inside the silicon. The laser pulses had affected the interface of the boron-silicon and aluminum-silicon layers. By localized heating of this interface with a laser pulse, it is possible to carry the layer ingredients through the silicon's surface. The aluminum diffusion process most probably ends up as active doping with atom substitution due to the eutectic temperatures' similarity. But, boron might end up with higher interstitial boron atoms acting as passive dopants and introducing extra defects. Therefore, we characterized the end-products by a time of flight secondary mass spectroscopy (ToF-SIMS), and an electrochemical capacitance-voltage (ECV). These techniques show the laser process results as passive and active dopant profile. Figure 1 shows the effect of laser pulse tunings on the penetrating of boron (a) and aluminum (b) layers as p-type emitter candidates and aluminum back-surface filed candidates.

Keywords: laser doping, Effusion cell, Tof-SIMS, ECV

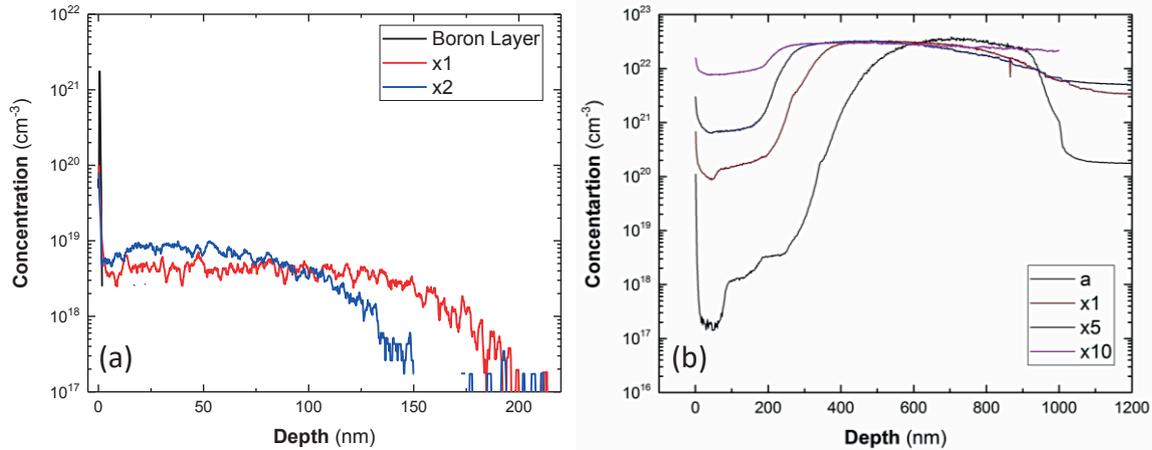


Figure 1. ToF-SIMS profiles of a) boron layer and b) aluminum layer drive-in by different laser pulse tunings as a p-type emitter and Al-BSF layer candidates.

References:

- [1] S. Gall, S. Manuel, J. F. Lerat, Boron laser doping through high quality Al₂O₃ passivation layer for localized B-BSF PERL solar cells. Energy Procedia 2013;38:270-7.
- [2] M. M. Moslehi, V. V. Rana, P. Anbalagan, Laser annealing for aluminum doping and formation of back-surface field in solar cell contacts, US20120178203A1, 2011.

Parameter Extraction to Optimize Interconnections of Non-Planar Photovoltaics

Sawsan Shukri² Safin H. Bayes², Morcos Metry²; Robert S. Balog^{1,2}

¹ Renewable Energy & Advanced Power Electronics Research Laboratory, Texas A&M University, College Station, TX 77843, USA

² Department of Electrical and Computer Engineering, Texas A&M University at Qatar, Doha, Qatar

sawsan.shukri@qatar.tamu.edu

safin.bayes@qatar.tamu.edu

morcos.m.metry@ieee.org

robert.balog@ieee.org

The performance of photovoltaic (PV) systems drops considerably due to partial shading [1]. Partial shading is inherent to non-planar PV applications where the surface normal of various segments of the PV material is not uniformly oriented, which causes non-uniform insolation. A mitigation technique is to optimize the interconnections between the PV elements to yield the highest energy harvest [2] by finding the homogeneous cells. This paper presents results from an experimental study using a new experimental testbed, shown in Figure 1, that was developed to extract PV parameters *in-situ*. The experimental testbed is flexible, scalable, and suitable for research and development of non-planar PV applications. The benefit of this testbed is to collect data considering factors like cell aging, partial shading, and temperature effects. Such factors are not accounted for in the manufacturers' datasheets [4]. The non-planar surface in Figure 2 enables the testing of a variety of PV interconnections, using a relay board. Using the setup in Figure 3, the characteristic *i-v* and *p-v* curves using an *i-v* curve tracer are measured, as shown in Figure 4. From the *i-v* and *p-v* curves, parameters in Table 1 can then be extracted and used to model, simulate, and emulate the operation of the non-planar PV systems using the parameter characterization [3] relations in Table 2. Developed simulation and emulation models are used for testing and tuning maximum power point tracking (MPPT).

Keywords: Photovoltaics, non-planar PV, Partial Shading, Parameter Extraction

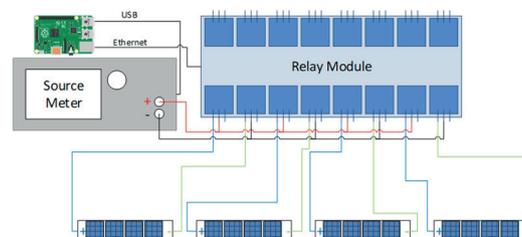


Figure 1. The *i-v* curve setup that uses a Python programming code to interface with the Keithley 4162 Source Meter Unit (SMU) and Sainsmart relay board to collect and record the *i-v* and *p-v* curves of the selected PV.

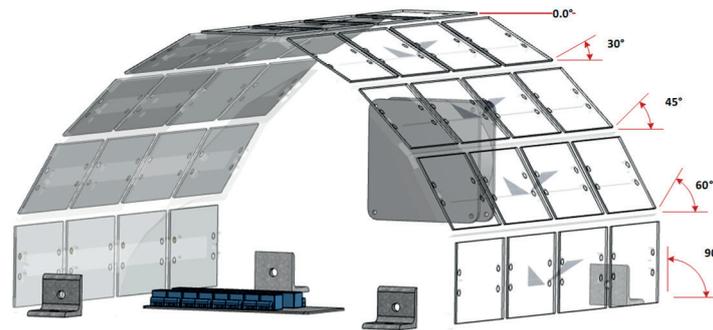


Figure 2. Acrylic structure to test the PV module at different angles: 0°, 30°, 45°, 60°, and 90°.

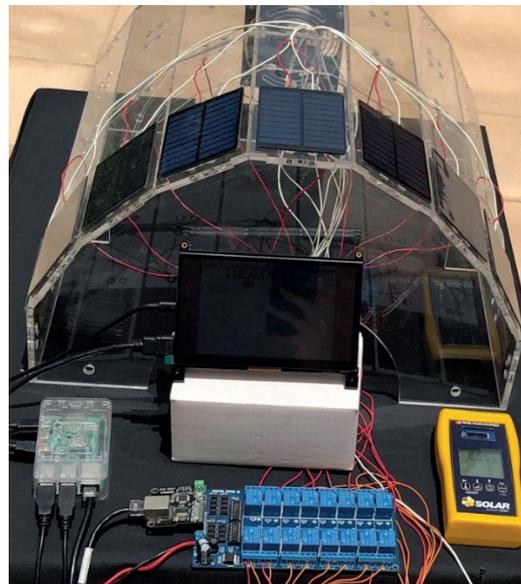


Figure 3. The experimental setup used to obtain results of different PV interconnections. A Seaward Irradiance Meter (Solar Survey 200R) was used to obtain the values of the temperature and irradiance while experimenting.

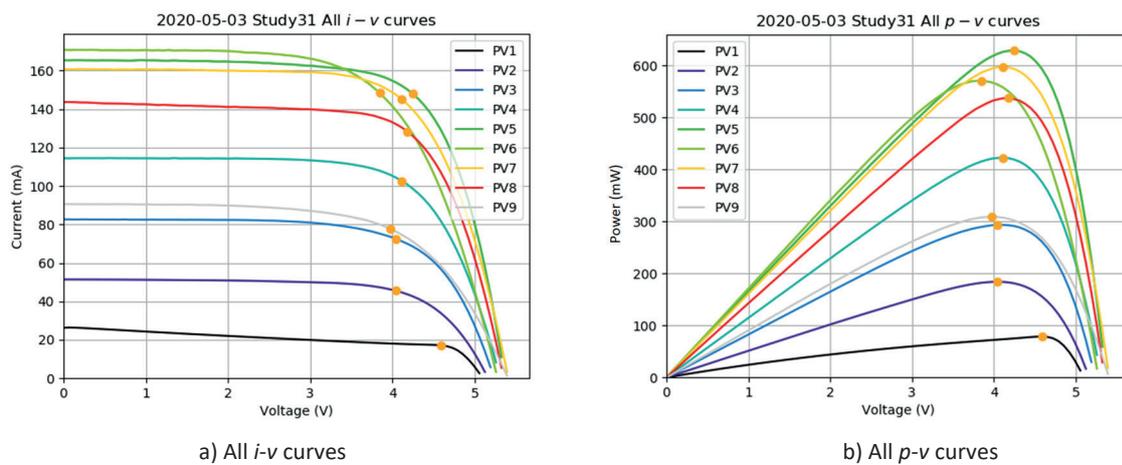


Figure 4: Post-experiment processing, a) *i*-*v* curve of 9 different PV cells, and b) *p*-*v* curve of 9 different PV cells.

Table 1. Results from the *i-v* curve tracer

Parameters	PV 1	PV 2	PV 3	PV 4	PV5	PV 6	PV 7	PV 8	PV 9
Date and Time	May 3 rd , 2020 at 13:45 Local time, Doha, Qatar								
Irradiance (W/m²)	209	240	425	586	810	833	773	674	338
R_s (Ω)	32.81	16.89	10.90	8.15	5.24	6.87	5.92	6.22	12.41
R_p (Ω)	483.92	4775.1	951.3	4161.9	975.65	865.05	794.07	707.71	2295.2
I_{sc} (mA)	26.10	51.40	83.36	115.32	166.23	171.97	161.87	144.96	91.44
V_{oc} (V)	5.09	5.15	5.23	5.30	5.36	5.27	5.41	5.35	5.40
MPP (mW)	78.60	183.94	293.27	422.36	628.34	570.67	597.20	536.89	308.84
V_{mpp} (V)	4.58	4.04	4.04	4.11	4.24	3.84	4.11	4.18	3.97
I_{mpp} (mA)	17.14	45.47	72.49	102.70	147.93	148.49	145.21	128.44	77.64

Table 2. Equations used for parameter characterization.

Parameter	Equation
Diode current (I_d)	$I_d = I_0 \left(\exp \left(\frac{qV_d}{\eta kT} \right) - 1 \right)$
Current due insolation (I_{ph})	$I_{ph} = I_{sc} \left(1 + \frac{R_s}{R_p} \right) + I_0 \left(\exp \left(\frac{I_{sc} R_s}{\eta V_T} \right) - 1 \right)$
Current flowing to the load (I_{pv})	$I_{pv} = I_{ph} - I_0 \left(\exp \left(\frac{qV_d + I_{pv} R_s}{kT} \right) - 1 \right) - \frac{V_{pv} + I_{pv} R_s}{R_p}$
Shunt resistance (R_p)	$R_p = - \left(\frac{\Delta V}{\Delta I} \Big _{I=I_{sc}} \right)$
Series resistance (R_s)	$R_s = - \left(\frac{\Delta V}{\Delta I} \Big _{V=V_{oc}} \right)$

References

- [1] A. Ramyar, H. Iman-Eini, and S. Farhangi, "Global Maximum Power Point Tracking Method for Photovoltaic Arrays Under Partial Shading Conditions," *IEEE Trans. Ind. Electron.*, vol. 64, no. 4, pp. 2855-2864, Apr 2017.
- [2] L. Alpuerto and R. S. Balog, "Comparing Connection Topologies of PV Integrated Curved Roof Tile for Improved Performance," presented at the IEEE Texas Power and Energy Conference (TPEC), College Station, TX, 6-7 Feb. 2020. Available: <https://ieeexplore.ieee.org/document/9042523>
- [3] E. Batzelis, "Non-Iterative Methods for the Extraction of the Single-Diode Model Parameters of Photovoltaic Modules: A Review and Comparative Assessment," *Energies*, vol. 12, no. 358, pp. 1-26, Jan 2019.
- [4] Kyocera. (May 2018). *Kyocera KC50T: High Efficiency Multicrystal Photovoltaic Module* [Online]. Available: <https://www.kyocerasolar.com>

2D-BENZODITHIOPHENE–BENZOTRIAZOLE COPOLYMERS FOR EFFICIENT ORGANIC SOLAR CELLS: EFFECT OF DIFFERENT SIDE GROUPS ON PHOTOVOLTAIC PERFORMANCE

Sultan Taşkaya Aslan¹, Duygu Cevher², Ümmügülsüm Şahin¹, Soner Öztürk³, Ali Çırpan^{1,2,4,5}

¹ Department of Chemistry, Middle East Technical University, Ankara, Turkey

² Department of Polymer Science and Technology, Middle East Technical University, Ankara, Turkey

³ The National Boron Research Institute (BOREN), Ankara, Turkey

⁴ The Center for Solar Energy Research and Application (GUNAM), Middle East Technical University, Ankara, Turkey

⁵ Department of Micro and Nanotechnology, Middle East Technical University, Ankara, Turkey

*tsultan@metu.edu.tr

Solar energy stands out because of its abundance and global character, and various photovoltaic (PV) technologies have been developed to harvest this energy.¹ In recent years, because of the high absorptivity of organic semiconductors and the use of non-toxic and cheap carbon-based active materials, organic photovoltaics (OPVs) have attracted considerable attention as promising candidates for renewable energy technology.² Therefore, the design and synthesis of novel conjugated polymers play important role to obtain higher photovoltaic properties and improve the power conversion efficiencies (PCEs) of the OPVs.

In this study, in order to enhance the efficiency of the bulk heterojunction OPV, two conjugated polymers were designed and synthesized via Stille coupling reaction. For this purpose, 2D-benzodithiophene and selenophene bearing benzotriazole moieties were independently synthesized, then polymerized to obtain P1 and P2 polymers. Electrochemical characterizations of the polymers were investigated with cyclic voltammetry and UV-Vis-NIR spectrophotometer was used to specify optical features of the polymers. Electronic and optical band gaps of the polymers were recorded as 1.92 eV, 1.69 eV for P1 and 1.79 eV, 1.58 eV for P2, respectively. Device fabrications of these polymers were constructed with ITO coated glass substrate, PEDOT:PSS, (P1 or P2):PC₇₀BM, LiF and Al in a given order. Preliminary studies showed that the highest PCE of these photovoltaic devices were recorded as 3.49% for P1:PC₇₀BM (1:2, w/w) in 3.5% chlorobenzene solution and 2.49% for P2:PC₇₀BM (1:2, w/w) in 2% chlorobenzene solution. The device optimization studies for P2 are in progress.

This work was funded through DEU Department of Scientific Research Projects Project No: 2019.KB.MLT.001.

Keywords: benzodithiophene, benzotriazole, conjugated polymers, power conversion efficiency, organic photovoltaics

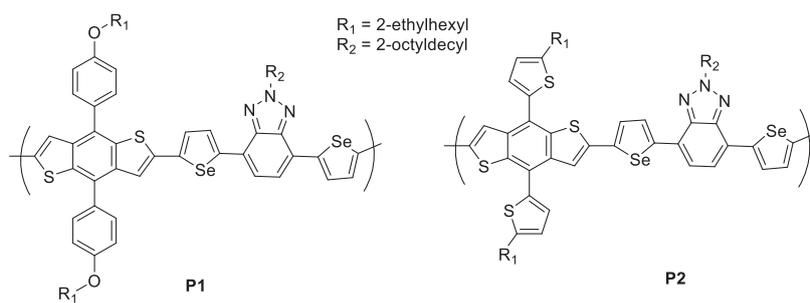


Figure 1. Structures of polymers

References

- [1] K. A Mazzio and C. K. Luscombe, *Chem. Soc. Rev.* **2015**, 44, 78.
- [2] Cui, Y.; Yao, H.; Zhang, J.; Zhang, T.; Wang, Y.; Hong, L.; Xian, K.; Xu, B.; Zhang, S.; Peng, J.; et al. *Nat. Commun.* **2019**, 10, 2515.

Long Term Assessment of Two On-Grid PV Systems for Nine Years

Talat Ozden¹², Ensar M. Ozgun³, Bedirhan Keles⁴, Bulent G. Akinoglu²³⁵

¹ Department of Energy Systems Engineering, Gumushane University, Gumushane, Turkey

² The Center for Solar Energy Research and Applications (GÜNAM), METU, Ankara, Turkey

³ Earth System Science Program, METU, Ankara, Turkey

⁴ Ozden AS, Gumushane, Turkey

⁵ Department of Physics, Middle East Technical University (METU), Ankara, Turkey

*tozden@metu.edu.tr

Nine years outdoor testing of the two on-grid PV systems at central Anatolia under the same ambient conditions are very important toward transition to renewables. The systems consist of a Mono-Si and $\mu\text{-Si/a-Si}$ thin film and, with installed capacities are 1.14 and 1.26 kWp, respectively as shown below. The evaluated data starts from 2012 to end of the 2020. The analyses are carried out on monthly based on outdoor efficiency and performance ratio. In addition, degradation rates of these systems are calculated and compared with each other and also with international literature. The degradation rates presented before of these systems were obtained as 0.40% and 1.88%, respectively. While, the yields of 7.584 m² Mono-Si and 14.4 m² $\mu\text{-Si/a-Si}$ thin film systems were 218.44 kWh/m² and 123.79 kWh/m² of the year 2012, the new yields of 2019 are 215.04 kWh/m² and 112.93 kWh/m², respectively. Performance ratios and efficiencies are analyzed and presented.

Keywords: Degradation rate, Outdoor testing of solar PV, Performance of PV Systems



Figure - Mono-Si and $\mu\text{-Si/a-Si}$ grid connected PV systems.

Voltage Profile Enhancement Using Capacitor-less D-STATCOM to Increase PV Penetration in Distribution Network Under Transient Cloud Conditions

Wesam Rohouma¹, Robert S. Balog², Aaqib Ahmad Peerzada³, Miroslav M. Begovic³

¹ College of North Atlantic Qatar/ Electrical Engineering Technology department, Doha, Qatar

² Texas A&M University at Qatar/ Electrical & Computer Engineering, Doha, Qatar

³ Texas A&M University/ Electrical & Computer Engineering, College Station, TX, USA

* wesam.rohouma@ieee.org

Over the past decade, the emergence of Distributed Energy Resources (DERs) has significantly disrupted the traditional approach of having centralized plants that distribute electricity through an extensive transmission and distribution network. Given the proliferation of DERs in recent years, more importantly the rise of grid –connected distributed photovoltaic (PV) systems, and the implementation of the smart grid concept the electric utility industry of today is in the midst of an aggressive expansion and an unprecedented evolution. While the grid-connected PV systems deliver electric energy closer to the consumer, thus aiding the paradigm shift from a centralized to distributed generation, the stochastic nature of PV output has created new challenges in the operation and maintenance of electric distribution systems. Of particular significance is the direct correlation between the PV power output and rapid voltage fluctuations. Reactive power compensation can be used to keep the voltage profile on the network within the allowable limits set by the relevant standards. A traditional approach may be to use switched capacitors, but this requires system analysis to locate the bus(es) that require compensation, siteplanning to obtain right-of-way and install the equipment, and then a control means to obtain desired operation from the system operator. Also, switched capacitors are not capable of providing a continuously-adjustable reactive power support at shorter time scales of minutes or seconds. Recently, the focus has been to require the PV inverter become “smart” and provide the ancillary service of reactive power support; the impact on the reliability, operational constraints, and cost imposed on the inverter are actively being studied. This paper proposed an alternative, a distribution static synchronous compensator (D-STATCOM) based matrix converter (MC) for use in low voltage distribution network. This technology is controlled using finite-set model predictive control, the compensator device can operate in a variety of modes and can be deployed and dispatched as needed in the distribution system. This paper presents an experimental results to show the effectiveness of the proposed technology in improving voltage profile in low voltage distribution network.

Keywords: D-STATCOM, Voltage profile, Reactive power compensation, Model predictive control, Matrix converter, Grid integration of renewable energy sources

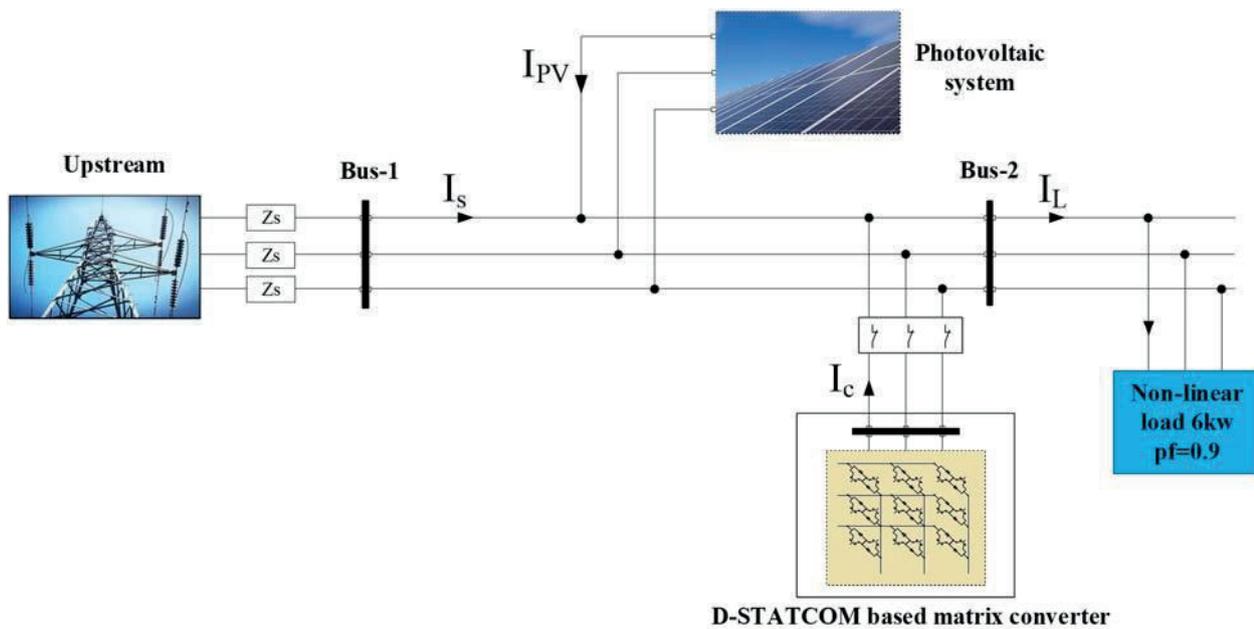


Figure 1. Three phase diagram showing the system under study. D-STATCOM is sunt connected to improve the voltage profile in distribution system with high PV penetration

References

- [1] W. Rohouma, R. S. Balog, A. A. Peerzada, and M. M. Begovic, "D-STATCOM for harmonic mitigation in low voltage distribution network with high penetration of nonlinear loads," *Renewable Energy*, vol. 145, pp. 1449-1464, 2020/01/01 2020, doi: <https://doi.org/10.1016/j.renene.2019.05.134>
- [2] A. Safayet, P. Fajri, and I. Husain, "Reactive Power Management for Overvoltage Prevention at High PV Penetration in a Low-Voltage Distribution System," *IEEE Transactions on Industry Applications*, vol. 53, no. 6, pp. 5786-5794, 2017, doi: 10.1109/TIA.2017.2741925.
- [3] M. Begovic, A. Peerzada, S. Mohan, W. Rohouma, and R. S. Balog, "Impact of Large Distributed Solar PV Generation on Distribution Voltage Control," in *Proceedings of the 52nd Hawaii International Conference on System Sciences (HICSS)*, Maui, Hawaii USA, 8-11 January 2019 2019: IEEE, pp. 3473-3482, doi: 10.24251/HICSS.2019.420. [Online]. Available: <http://hdl.handle.net/10125/59783>.
- [4] R. Tonkoski, D. Turcotte, and T. H. El-Fouly, "Impact of high PV penetration on voltage profiles in residential neighborhoods," *IEEE Transactions on Sustainable Energy*, vol. 3, no. 3, pp. 518-527, 2012.

PVCON 2020
PHOTOVOLTAIC CONFERENCE