

# PVCON 2022

PHOTOVOLTAIC CONFERENCE

## 3<sup>rd</sup> International Conference on Photovoltaic Science and Technologies

05 - 07  
JULY 22

Middle East Technical University  
Culture and Convention Center, Ankara, Turkey

[pvcon.org](http://pvcon.org)

ABSTRACT BOOK



**PVCON** 2022  
PHOTOVOLTAIC CONFERENCE  
3<sup>rd</sup> International Conference on Photovoltaic  
Science and Technologies

**Organized by**



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CENTER FOR SOLAR ENERGY RESEARCH AND APPLICATIONS

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# **PVCON** 2022 PHOTOVOLTAIC CONFERENCE



In today's World, renewables are at the hub of almost all energy policy transitions to meet the increased energy needs within the global developing economy and technology. Solar energy takes its part with a significant growth rate of solar photovoltaic power plants. As the need for R/D on the subject is increasing and the steps are taken to improve the infrastructure, we organized the first PVCon (on-site) in July 2018 and the second (online) in December 2020. You can reach the organization and publication details (conference topics, abstract book, session videos, full-length proceedings in IEEE-Xplore Digital Library, special issue articles in the journal Renewable Energy, etc.) of the PVCon series through the conference website (please see the "PREVIOUS CONFERENCES" tab).

With the hope and willingness of the continuity of this conference, we are pleased to announce the third organization of the series: PVCon2022. The main aim is to present a well-established scientific and technical forum on solar photovoltaics (PV). We again plan to host international and national invited speakers, researchers, representatives of governmental bodies, and private sector representatives. The participants will share the recent research 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 establishing a fruitful platform of national and international collaborations.

## Scientific Committee

Surname, Name	Affiliation	Country	Research Field
Agresti, Antonio	University of Rome Tor Vergata	Italy	Organic and Hybrid Photovoltaics
Akinoglu, Bulent Gultekin	Middle East Technical University	Turkey	Modules and Outdoor Testing
Alptekin, Demet Asil	Middle East Technical University	Turkey	Quantum Dots and Solar Cell Applications
Aygun Ozyuzer, Gulnur	Izmir Institute of Technology	Turkey	CZTS Thin Film Solar Cells
Badescu, Viorel	Politehnica University of Bucharest	Romania	Solar Thermodynamics
Balog, Robert	Texas A&M University	Qatar	Modules, Inverter Technologies
Baran, Derya	King Abdullah University of Science & Technology	Turkey	Organic Solar Cells, Hybrid Solar Cells, Transparent Solar Cells
Becker, Christiane	Helmholtz-Zentrum Berlin	Germany	Silicon Nanostructures for PV and Photonic Applications
Bektas, Gence	ODTÜ-GÜNAM	Turkey	Ion Implanted Silicon Solar Cells
Ciftpinar, Emine Hande	ODTÜ-GÜNAM	Turkey	c-Si Solar Cells
Cirpan, Ali	Middle East Technical University / ODTÜ-GÜNAM	Turkey	Organic Photovoltaics
Colak, Uner	Istanbul Technical University	Turkey	Solar Energy Systems
Cubukcu, Mete	Ege University	Turkey	PV Modules and Power Systems
De Wolf, Stefaan	King Abdullah University of Science & Technology	Saudi Arabia	Si Heterojunction Solar Cells
Demirci Sankir, Nurdan	TOBB University of Economics and Technology	Turkey	Thin Film Solar Cells
Demirezen, Emre	ODTÜ-GÜNAM	Turkey	Environmental Impact Modelling of PV Systems, Agricultural and Rural PV Applications
Derin Gure, Pinar	Middle East Technical University	Turkey	Socioeconomic Impacts of Solar Energy Technologies
Donercark, Ergi	ODTÜ-GÜNAM	Turkey	SHJ Solar Cells
Ela Erten, Sule	Ege University	Turkey	Organic Photovoltaics
Ennaoui, Ahmed	Institut de Recherche en Energie Solaire et Energies Nouvelles	Morocco	Solar Energy Materials & Solar Cells
Eray, Aynur	Hacettepe University	Turkey	PV System Applications
Ercelebi, Çigdem	Middle East Technical University	Turkey	Thin Film Materials and Solar Cell Applications
Glunz, Stefan	Fraunhofer Institute for Solar Energy Systems	Germany	Si Solar Cells
Gordon, Ivan	Imec R&D, Nano Electronics and Digital Technologies	Belgium	Silicon Photovoltaics
Gunbas, Gorkem E.	Middle East Technical University / ODTÜ-GÜNAM	Turkey	Organic Photovoltaics, Perovskite Solar Cells
Gunes, Mehmet	Mugla University	Turkey	Amorphous-Si Solar Cells, Optical Characterization
Gunes, Serap	Yildiz Teknik University	Turkey	Organic Photovoltaics
Hagendorf, Christian	Fraunhofer – Center for Silicon Photovoltaics (CSP)	Germany	Diagnostics of Solar Cells, Indoor and Outdoor Testing, Nanotechnology, Surface Chemistry
Hizalan Ozsoy, Gonul	Middle East Technical University / ODTÜ-GÜNAM	Turkey	Organic Photovoltaics
Kalogirou, Soteris	Cyprus University of Technology	Cyprus	Hybrid Photovoltaic / Thermal Systems, Computational Simulation and Optimization of Solar Systems
Kaya, Hava Zekiye	Middle East Technical University	Turkey	Perovskite Solar Cells, Perovskite/Silicon Tandem Solar Cells
Kesler, Selami	Pamukkale University	Turkey	PV Power Systems
Kodolbas, Alp Osman	TUBİTAK Marmara Research Center	Turkey	Amorphous-Si Solar Cells
Kuhnlein, Holger	RENA Technologies GmbH	Germany	Si Solar Cells
Kurtz, Sarah	National Renewable Energy Laboratory (NREL) & University of California	USA	Quantification of the Degradation of PV Systems

Muhtaroglu, Ali	Middle East Technical University (Northern Cyprus Campus)	Cyprus	PV Performance & PV-Thermal
Nasser, Hisham	Middle East Technical University / ODTÜ-GÜNAM	Turkey	Passivating Contacts for Si Solar Cells
Nazeeruddin, Mohammad Khaja	École Polytechnique Fédérale de Lausanne	Switzerland	Perovskite Solar Cells & Recent Advancements
Oktik, Sener	Kadir Has University	Turkey	PV Material Technologies
Ozdemir, Engin	Kocaeli University	Turkey	Inverter Technologies
Ozdemir Hacioglu, Serife	Middle East Technical University	Turkey	Perovskite Solar Cells, Conjugated Polymers
Ozden, Talat	Gumushane University / ODTÜ-GÜNAM	Turkey	PV Electronics, Outdoor Testing
Ozenbas, Macit	Middle East Technical University	Turkey	Dye-sensitized Solar Cells
Ozmen, Ozge Tuzun	Bakircay University	Turkey	Amorphous-Si Solar Cells
Parlak, Mehmet	Middle East Technical University	Turkey	Copper Indium Gallium Selenide (CIGS) Solar Cells, New Thin Film Material
Paulescu, Marius	West University of Timișoara	Romania	Physics of Solar Cells, Quantum Electronics
Sedani, Sâlar H.	ODTÜ-GÜNAM	Turkey	Test & Characterization, TOPCon, Defect Analysis, ToF-SIMS
Selimoglu, Özgür	TUBITAK Space Technologies Research Institute	Turkey	Concentrator Photovoltaics (CPV)
Shariah, Adnan	Jordan University of Science and Technology	Jordan	Thin Film Silicon Solar Cells
Sinke, Wim	Energy Research Centre of the Netherlands & University of Amsterdam	Netherlands	Photovoltaic Energy Conversion
Sonmezoglu, Savas	Karamanoglu Mehmetbey University	Turkey	Dye-sensitized Solar Cells, Perovskite Solar Cells
Taghavi, Masoud	Technical and Vocational University	Iran	Renewable Energy, Solar Thermal, PV, Energy Saving
Toppare, Levent	Middle East Technical University	Turkey	Organic Photovoltaics
Unalan, H. Emrah	Middle East Technical University / ODTÜ-GÜNAM	Turkey	Nanomaterials and Solar Cells
Unsur, Veysel	Necmettin Erbakan University	Turkey	Si Solar Cells
Usman, Muhammad	National Centre for Physics	Pakistan	Ion Beam Applications
Varlikli, Canan	Izmir Institute of Technology	Turkey	Organic Photovoltaics
Yerci, Selcuk	Middle East Technical University / ODTÜ-GÜNAM	Turkey	Si Solar Cells, Perovskite Solar Cells, Light Trapping
Yilmaz, Ercan	Abant Izzet Baysal University	Turkey	Si Device Processing
Yuce, Emre	Middle East Technical University / ODTÜ-GÜNAM	Turkey	Optically Functional Surfaces for Solar Applications
Yucel, Ismail	Middle East Technical University	Turkey	Meteorology, Climate Change, Environmental Impact Assessment
Zafer, Ceylan	Ege University	Turkey	Organic Photovoltaics

### National Organizing Committee

Surname, Name	Affiliation	Country	Research Field
Akinoglu, Bulent Gultekin (Chair)	Middle East Technical University - Physics Department / ODTÜ-GÜNAM	Turkey	PV Modules and Outdoor Testing
Es, Firat	Kalyon PV	Turkey	Si Solar Cells and Modules
Gunbas, Gorkem E.	Middle East Technical University - Chemistry Department / ODTÜ-GÜNAM	Turkey	Organic PV, Perovskite Solar Cells
Karabulut, Orhan	Pamukkale University - Physics Department	Turkey	Thin Films, Electrical Properties, Optical Properties, Crystal Growth, Polymers
Nasser, Hisham	Middle East Technical University / ODTÜ-GÜNAM	Turkey	Passivating Contacts for Si Solar Cells
Ozden, Talat	Gumushane University - Electrical and Electronics Engineering / ODTÜ-GÜNAM	Turkey	PV Electronics, Outdoor Testing
Turan, Rasit (Co-chair)	Middle East Technical University - Physics Department / ODTÜ-GÜNAM	Turkey	Si Solar Cells

Unalan, H. Emrah	Middle East Technical University - Metallurgical and Materials Engineering / ODTÜ-GÜNAM	Turkey	Nanomaterials and Solar Cells
Yerci, Selcuk	Middle East Technical University - Electrical and Electronics Engineering / ODTÜ-GÜNAM	Turkey	Si Solar Cells, Perovskite Solar Cells, Light Trapping
Besen, Cigdem	GTC Inc. (Photovoltaic Solar Systems)	Turkey	Member of GTC Management Board
Aşkın, Asmin	Middle East Technical University / ODTÜ-GÜNAM	Turkey	Local Organizing Committee Member
Aydın, Elşen	Middle East Technical University / ODTÜ-GÜNAM	Turkey	Local Organizing Committee Member
Demirezen, Emre	ODTÜ-GÜNAM	Turkey	Local Organizing Committee Member
Durusoy, Beyza	Middle East Technical University / ODTÜ-GÜNAM	Turkey	Local Organizing Committee Member
Salimi, Arghavan	Middle East Technical University / ODTÜ-GÜNAM	Turkey	Local Organizing Committee Member
Zolfaghari, Mona Borra	ODTÜ-GÜNAM	Turkey	Local Organizing Committee Member

### International Organizing Committee

Surname, Name	Affiliation	Country	Research Field
Balog, Robert	Texas A&M University	Qatar	PV Modules, Inverter Technologies
Buchroithner, Armin	Graz University of Technology	Austria	Renewable Energy Technology Development
Kurtz, Sarah	National Renewable Energy Laboratory (NREL)	USA	Multijunction PV, Concentrator PV, PV reliability
Mittag, Max	Fraunhofer ISE	Germany	PV Module Assessment
Paulescu, Marius	West University of Timișoara	Romania	Physics of Solar Cells, Quantum Electronics



1935 yılında Türkiye Cumhuriyeti'nin kurucusu Mustafa Kemal Atatürk'ün vizyonu doğrultusunda Türk cam sektörünü kurmak amacıyla temelleri atılan Şişecam, cam ve kimyasallar alanında güçlü bir küresel oyuncudur. Düzcam, cam ev eşyası, cam ambalaj ve cam elyafı gibi camın tüm temel alanlarında faaliyet gösteren tek küresel şirket olan Şişecam, cam ev eşyası alanında en büyük iki, cam ambalaj ve düzcam alanlarında ise en büyük beş global üretici arasında yer almaktadır. Şişecam, dünyanın en büyük üç soda üreticisi arasında olmasının yanı sıra krom kimyasallarında dünya lideridir.

Düzcam, cam ev eşyası, cam ambalaj, kimyasallar, otomotiv, cam elyaf, maden, enerji ve geri dönüşüm iş kollarında öncü bir rol üstlenen Şişecam, üretim faaliyetlerini Türkiye'nin yanı sıra Almanya, İtalya, Bulgaristan, Romanya, Slovakya, Macaristan, Bosna Hersek, Rusya Federasyonu, Gürcistan, Ukrayna, Mısır, Hindistan ve ABD'de yürütmektedir.

Yetkin insan kaynağı ve akıllı teknolojilerle ana faaliyet alanlarında dünyanın en büyük 3 üreticisinden biri olma hedefine güçlü adımlarla ilerleyen Şişecam, yarının ihtiyaçlarını da göz önünde bulundurarak dijital altyapısını ve kültürünü dönüştürmeye kesintisiz devam etmektedir. 86 yıllık deneyim, 22 bin çalışan, dört kıtada 14 ülkeye yayılan üretim faaliyetleri ve 150 ülkeyi aşan satış ağına sahip Şişecam, "Küresel Mükemmellik" stratejisi doğrultusunda ve tüm ekosisteminin gelişimini destekleyen kapsayıcı bir yaklaşım ile büyüme yolculuğunu sürdürmektedir. Şişecam, Birleşmiş Milletler Sürdürülebilir Kalkınma Amaçları ile uyumlu ve entegre olarak hayata geçirdiği Care For Next stratejisi ile gezegeni korumak, toplumu güçlendirmek ve yaşamı dönüştürmek için sorumluluk almakta, tüm deneyim ve yetkinliklerini her alanda sürdürülebilir gelişim için kullanmaktadır.

[www.sisecam.com.tr](http://www.sisecam.com.tr)



Şişecam Düzcam Mersin Fabrikası Çatı Üzeri Güneş Enerjisi Santrali  
6,209 MWp Kurulu Güç

Şişecam'ın güneş panellerinde ve güneş kolektörlerinde kullanılması amacıyla ürettiği güneş paneli ve güneş kolektör camları, güneş enerjisinden elektrik üreten güneş panellerinin iç aksamını çevre koşullarından korurken yüksek ışık geçirgenlik performansı ile güneş panellerinin verimliliğini doğrudan etkiler. Sandy ve Prizma desenlerinde üretilen Şişecam Güneş Paneli ve Şişecam Güneş Kolektör Camları, desenli yapısıyla cam yüzeyinde oluşan yansımaları azaltarak yüksek ışık geçirgenliği ve düşük yansıtma değerleriyle güneş panellerinin ve kolektörlerinin performansında maksimum verimlilik sağlar. Cam yüzeylerinde özel Anti Reflektif (AR) kaplama uygulaması ile ışık yansımaları minimize edilirken camların ışık geçirgenliği yaklaşık %2,5 artırılarak güneş panellerinde performans artışı ve yüksek verim sağlanır.

# AR KAPLAMA İLE GÜNEŞ IŞIĞI GEÇİRGENLİĞİNDE %2,5 ARTIŞ

Yüksek geçirgenlik değerleri ile ürün performansınızı artırır.



**ŞİŞECAM**  
GÜNEŞ ENERJİSİ CAMLARI  
DÜŞÜK DEMİRLİ TEMPERLİ BUZLU CAM

## GÜNEŞ ENERJİSİ CAMLARI GEÇİRGENLİK DEĞERLERİ



	Sandy 3,2 mm	Sandy 4 mm
Işık Geçirgenliği (D65) $T_{D65}$	%91,8	%91,9
PV Geçirgenliği $F_{p, PV}$	%95,1	%95
Güneş Işığı Geçirgenliği (AM 1,5) $T_{SOL}$	%91,2	%91
SPF Sınıfı	P1	P1



	Prizma 3,2 mm	Prizma 4 mm
Işık Geçirgenliği (D65) $T_{D65}$	%91,8	%91,8
PV Geçirgenliği $F_{p, PV}$	%95,2	%95
Güneş Işığı Geçirgenliği (AM 1,5) $T_{SOL}$	%91,2	%91,1
SPF Sınıfı	P1	P1



**ŞİŞECAM**



MAJOR SPONSOR OF UNITED NATIONS  
INTERNATIONAL YEAR OF GLASS 2022



## ABOUT SMART SOLAR TECHNOLOGIES

As Smart Solar Technologies, one of Europe’s leading integrated solar energy companies in the fields of turnkey installation services, solar power plant investments and PV module production, we offer a wide range of solar energy solutions to commercial and retail users.

Founded in 2009 and based in Istanbul, Smart Solar Technologies has been operating with its branches in Turkey, Romania, Greece, Bulgaria, Germany, Switzerland and Ukraine.

Our production facility is located on an area of 23.500 m<sup>2</sup> in Gebze Kocaeli, Turkey. We produce high efficiency photovoltaic solar panels based on crystal silicon cells for use in field and rooftop solar plants. High efficiency is achieved in solar panel production by using Multi Busbar, PERC, Half-Cut Cell and Bi-Facial technologies on our production lines with cutting-edge automated machinery, which have an annual production capacity of 1.200 MW. These technologies and our state of the art production facility ensure that we provide our clients with highest quality standards available in the field of standard and glass-glass solar panel production.

Smart Solar Technologies, undertakes the operation of power plants in Turkey, Romania, Greece and Bulgaria. Generating capacity of the solar power plants operated in these countries are equivalent of 100+ MW.

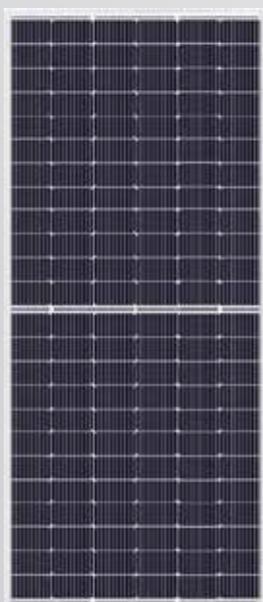
Our company is a solution partner with years of experience in the construction of solar power plants, most of which are large-scale installations over 500 MW on both land and rooftop.



## PV MODULE PRODUCTION

Starting production in 2017 with an initial capacity of 420 MW/year, Smart Solar Technologies PV module production factory has increased its production capacity to 1.200 MW/year in 2022 by making new investments and adding production lines equipped with state-of-the-art automatic stations.

Aluminum framed standard Mono/Poly, PERC, Black Silicon, Dual Glass, Bifacial, MBB and Half-Cut Cell modules are produced in Smart Solar Technologies’s fully automatized production facility in Gebze.



### WHY US?

**Frame**  
 35 mm (20 µ Eloxal Surface Coating)  
 30 mm (10 µ Eloxal Surface Coating)

**Backsheet**  
 320 / 350 Micron 3 Layers  
 180 / 270 Micron 2 Layers

**Junction Box**  
 IP68 (Silicon Potting)  
 IP65

**Connector**  
 Original Multi-Contact  
 MC4 Compatible

**Maximum Voltage**  
 1500 VDC  
 1000 VDC

**Tempered Glass**  
 Anti-Reflective Coating / Anti-Soiling  
 Anti-Reflective Coating

## PV MODULE REFERENCES

\*Some of our pv module references.

**ÇALIK ENERJİ**  
Çalık Denim Rooftop SPP  
957,00 kWp



**DOĞAN ENERJİ**  
Türkiye - Land SPP  
24.690,00 kWp



**UCK**  
Türkiye - Land SPP  
71.300,00 kWp



**SENA KABLO**  
Sena Kablo Rooftop SPP  
853,00 kWp



**DAIKIN**  
Daikin Rooftop SPP  
5.784,00 kWp



**AKFEN**  
Türkiye - Land SPP  
21.201,00 kWp



**RODOS**  
Greece - Land SPP  
99,36 kWp



**KERPE**  
Greece - Land SPP  
69,12 kWp



**CEF MALU**  
Romania - Land SPP  
1.800,00 kWp



**CHERNİ VRAH**  
Bulgaria - Land SPP  
3.100,00 kWp



## INVESTMENT REFERENCES

\*Some of our investment references.

## ENGINEERING REFERENCES

\*Some of our engineering references.

**ARISU**  
Türkiye - Van - Land SPP  
55.568,23 kWp



**RA SPP**  
Türkiye - Mardin - Land SPP  
10.889,76 kWp



**BİNGÖL**  
Türkiye - Bingöl - Land SPP  
22.641,80 kWp



**KFC GIDA**  
Türkiye - İzmir - Rooftop SPP  
316,80 kWp



**TOSYALI**  
Türkiye - Osmaniye - Rooftop SPP  
9.924,17 kWp



**SİVEREK**  
Türkiye - Şanlıurfa - Land SPP  
18.119,25 kWp



**ALPCANSIN**  
Türkiye - İstanbul - Rooftop SPP  
66,88 kWp



**AKSARAY**  
Türkiye - Aksaray - Land SPP  
11.617,76 kWp



# REFERENCES

### SMART SOLAR TECHNOLOGIES HEADQUARTERS

Energy Plaza, Rüzgarlıbahçe, Feragat Street, No: 2, 6th Floor,  
34805 Beykoz/İstanbul - Türkiye

P: + 90 216 225 72 00  
F: + 90 850 305 06 10

#### BULGARIA

35 Nikola Vapstarov  
Blvd., 3rd Floor  
Sofia - Bulgaria

#### GERMANY

Luxemburgerstr 96, 50354  
Cologne - Germany

#### GREECE

Riga Fereou 3, 55134,  
Thessaloniki - Greece

### GEBZE SOLAR MODULE FACTORY

Gebze Industrial Area, Tembelova District, 3200 Street,  
No: 3207 Gebze/Kocaeli - Türkiye

P: + 90 262 673 71 00  
F: + 90 262 673 71 03

#### ROMANIA

30 Alexandru Puskin  
Street, Sector 1  
Bucharest - Romania

#### SWITZERLAND

Maggi Strasse 16, 8046  
Zurich - Switzerland

#### UKRAINE

Novovokzalna Street 3,  
03038 Kyiv - Ukraine



# TÜRKİYE'NİN TEMİZ ENERJİ GELECEĞİNE İMZAMIZI ATIYORUZ!

Türkiye'nin Tek Merkezde Kurulu Gücü En Yüksek Çöp Gazı Santrali  
*İstanbul Enerji Silivri Seymen EÜT "37 MW"*



60  
yılıık  
deneyim

## PVCon2022 Conference Program

<b>July 5<sup>th</sup>, 2022 (Tuesday)</b>	
<b>08:30</b>	<b>REGISTRATION</b>
<b>OPENING SESSION (09:00 - 10:40)</b> 	<b>CURRENT PANORAMA AND TRENDS IN PV SCIENCE AND TECHNOLOGY</b> (Session Chair: Prof. Bulent G. Akinoglu)   <b>METU-CCC / Hall A</b>
09:00 – 09:10	<b>Welcome Speech:</b> Prof. Bulent G. Akinoglu (Chair)
09:10 – 09:40	<b>Keynote Speaker:</b> Dr. Alparslan Bayraktar (Ministry of Energy and Natural Resources, Turkiye)
09:40 – 10:10	<b>Keynote Speaker:</b> Mehmet Izzet Ozaydin (GÜNDER, Turkiye)
10:10 – 10:40	<b>Keynote Speaker:</b> Prof. Peter Dold (Fraunhofer-CSP, Germany) "Cz-Ingot Growth at Fraunhofer CSP"
<b>10:40 – 11:00</b>	<b>Coffee Break</b>
<b>SESSION 2 (11:00 - 12:30)</b> 	<b>ADVANCED c-Si TECHNOLOGIES - I</b> (Session Chair: Prof. Peter Dold)   <b>METU-CCC / Hall A</b>
11:00 – 11:30	<b>Keynote Speaker:</b> Prof. Luciano Mule'Stagno (Univ. of Malta, Malta) "Silicon Defects and Possible Impact on Solar Cell Efficiency"
11:30 – 11:45	<b>Nurhayat Yıldırım</b> (Kalyon PV, Turkiye) "A Study on Degradation Mechanisms in the Czochralski Grown Si Crystal for Solar Cell Applications"
11:45 – 12:00	<b>E. H. Ciftpınar</b> (ODTÜ-GÜNAM, Turkiye) "A New Approach for Totally Screen-Printed IBC Solar Cells"
12:00 – 12:15	<b>G. Bektas</b> (ODTÜ-GÜNAM, Turkiye) "Bifacial n-PERT Solar Cells Fabricated by Alternative Industrial Manufacturing Methods"
12:15 – 12:30	<b>S. H. Sedani</b> (ODTÜ-GÜNAM, Turkiye) "Spectroscopic Investigations of Polysilicon Defects for TOPCon Applications"
<b>12:30 – 14:00</b>	<b>Lunch</b>

## Endüstri Forumu / Industry Forum (in Turkish)

<b>OTURUM / SESSION - I</b> (14:00 - 15:15) 	<b>TÜRKİYE'DE FOTOVOLTAİK HÜCRE ÜRETİMİ / PV CELL PRODUCTION IN TURKEY</b> ( <i>Oturum Başkanı / Session Chair: Prof. Dr. Raşit Turan</i> )   <b>ODTÜ-KKM / B Salonu (Hall)</b>
	Ercan Muti (Kalyon PV – Teknik Hizmetler Direktörü) Halil Demirdağ (Smart Solar – CEO) Yusuf Bahadır Turhan (3GW – Yönetim Kurulu Başkanı) Çiğdem Besen (GTC Solar – Kurucu & CEO) Doç. Dr. Selçuk Yerci (ODTÜ-GÜNAM Müdür Yardımcısı / Gelişen Fotovoltaik Teknolojileri Birimi Koordinatörü) <i>Tartışma</i>
<b>15:15 – 15:30</b>	<b>Ara / Break</b>
<b>OTURUM / SESSION - II</b> (15:30 - 16:45) 	<b>TÜRKİYE'DE FOTOVOLTAİK MODÜL VE GÜÇ BİLEŞENLERİNİN ÜRETİMİ / PV MODULE AND POWER COMPONENT PRODUCTION IN TURKEY</b> ( <i>Oturum Başkanı / Session Chair: Mehmet Özyayın</i> )   <b>ODTÜ-KKM / B Salonu (Hall)</b>
	Haluk Erdem (Şişecam – Atmosferik Kaplama Teknolojileri Müdürü) Günay Şimşek (Aselsan – Program Müdürü (Enerji & Ulaşım)) Prof. Dr. Emrah Ünalın (Nanovatif – Kurucu Ortak) Murat Diktaş (Ekinler Endüstri A.Ş. – Ar&Ge Müdürü) Hazal Doğaroğlu (iTek Solar – AR&GE Mühendisi) <i>Tartışma</i>
<b>16:45 – 17:00</b>	<b>Ara / Break</b>
<b>OTURUM / SESSION - III</b> (17:00 - 18:15) 	<b>TÜRKİYE'DE FOTOVOLTAİK SİSTEM ENTEGRASYONU / PV SYSTEM INTEGRATION IN TURKEY</b> ( <i>Oturum Başkanı / Session Chair: Yusuf Bahadır Turhan</i> )   <b>ODTÜ-KKM / B Salonu (Hall)</b>
	Dr. Öğretim Üyesi Talat Özden (ODTÜ-GÜNAM Modül Teknolojileri Birimi Koordinatörü) Savaş Alkan (İstanbul Enerji - Enerji Yönetim Şefi) Agageldi Muhammetgulyyev (CW Enerji – AR&GE Mühendisi) Özcan Akbaba (TESCOM UPS – Genel Müdür Yardımcısı) <i>Tartışma</i>

<b>17:00</b>	<b>Poster Session</b>   <b>METU-CCC / Foyer</b>
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<b>18:30</b>	<b>Welcome Reception</b>   <b>METU-CCC / Foyer</b>
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<b>July 6<sup>th</sup>, 2022 (Wednesday)</b>	
<b>08:30</b>	<b>REGISTRATION</b>
<b>SESSION 3 (08:45 - 10:45)</b> 	<b>EMERGING PV TECHNOLOGIES - I</b> (Session Chair: Dr. Hariharsudan S. Radhakrishnan)   <b>METU-CCC / Hall B</b>
08:45 – 09:15	<b>Keynote Speaker:</b> Michele Sessolo (Univ. of Valencia, Spain) <b>"Multi-Source Vacuum Deposition of Perovskite Films and Solar Cells"</b>
09:15 – 09:45	<b>Keynote Speaker:</b> Dr. Ilker Dogan (TNO, Holland) <b>"Slot-Die Processing of Large Area Perovskite Modules for Hybrid Tandem Applications"</b>
09:45 – 10:15	<b>Keynote Speaker:</b> Yinghuan Kuang (IMEC, Belgium) <b>"Perovskite Module Upscaling Towards Industrialization Based on Efficient Cell Architectures and Scalable Processes"</b>
10:15 – 10:45	<b>Keynote Speaker:</b> Dr. Senol Öz (Solaveni, Germany) <b>"From Fundamentals to First Real World Applications of Hybrid Perovskite Photovoltaics"</b>
<b>10:45 – 11:00</b>	<b>Coffee Break</b>

<b>SESSION 4-1 &amp; 4-2 (11:00 - 12:45)</b> 	<b>ADVANCED c-Si TECHNOLOGIES - II</b> (Session Chair: Dr. Yinghuan Kuang)   <b>METU-CCC / Hall A</b>	<b>EMERGING PV TECHNOLOGIES – II</b> (Session Chair: Dr. Ilker Doğan)   <b>METU-CCC / Hall B</b>
11:00 – 11:30	<b>Keynote Speaker:</b> Dr. Erkan Aydin (KAUST, S. Arabia) <b>"Highly Efficient Monolithic Perovskite/Silicon TANDEM Solar Cells: Device Concepts and Stability Aspects"</b>	
11:30 – 12:00	<b>Keynote Speaker:</b> Dr. Hariharsudan S. Radhakrishnan (IMEC, Belgium) <b>"State-of-the-Art of Si Heterojunction Technology"</b>	
12:00 – 12:15	<b>E. Donercark</b> (ODTÜ-GÜNAM, Türkiye) <b>"Current Status of Silicon Heterojunction and Wide Band Gap Carrier Selective Solar Cells"</b>	<b>C. Kahveci</b> (Yildiz Technical University, Türkiye) <b>"Towards Flexible Perovskite Solar Cells without ITO"</b>
12:15 – 12:30	<b>M. Ghasemi</b> (ODTÜ-GÜNAM, Türkiye) <b>"Passivation of Crystalline Silicon by Organic Acids"</b>	<b>S. Erkan</b> (Niğde Ömer Halisdemir University – Dept. of Physics, Türkiye) <b>"Doped Graphene-CZTS Thin Film Solar Cells"</b>
12:30 – 12:45	<b>A. Siddiqui</b> (Quaid-i-Azam University - National Centre for Physics, Pakistan) <b>"Potential of TiO<sub>2</sub> as a Capping Layer for Industrial c-Si PERC Solar Cells"</b>	<b>Z. Elfakir</b> (IBN TOFAIL, Morocco) <b>"Influence of the <math>\pi</math>-Bridge in Carbazole-Based HTMs for Perovskite Solar Cells"</b>
<b>12:45 – 14:00</b>	<b>Lunch</b>	

<b>SESSION 5-1 &amp; 5-2</b> <b>(14:00 - 15:30)</b> 	<b>OPTICS AND PHOTONICS FOR PV APPLICATIONS</b> <i>(Session Chair: Michele Sessolo)</i>  <b>METU-CCC / Hall A</b>	<b>THIN FILM PV CELLS</b> <i>(Session Chair: Prof. Luciano Mule'Stagno)</i>  <b>METU-CCC / Hall B</b>
14:00 – 14:30	<b>Keynote Speaker: Dr. Wolfgang Tress (ZHAW School of Eng., Switzerland)</b> <b>"Device Physics of Perovskite Solar Cells"</b>	
14:30 – 14:45	<b>A. Asgari</b> (University of Tabriz – Research Institute of Applied Physics and Astronomy, Iran) <i>"Semitransparent Organic Solar Cell; The Effects of Cell Thickness"</i>	<b>A. Altuntepe</b> (Niğde Ömer Halisdemir University – Nanotechnology Application and Research Center, Turkiye) <i>"Two Dimensional Materials Based Atomically Thin Solar Cells"</i>
14:45 – 15:00	<b>A. Goodarzi</b> (ODTÜ-GÜNAM, Turkiye) <i>"Novel Silicon Texturing Method by Non-Linear Laser Lithography for Solar Cell Applications"</i>	<b>C. Ildes</b> (Yozgat Bozok University – BILTEM, Turkiye) <i>"Incorporation of Alkali Metal into CdS Thin Films during Chemical Bath Deposition as an Alternative Strategy for Cu<sub>2</sub>ZnSnS<sub>4</sub> Absorber Layer Doping"</i>
15:00 – 15:15	<b>O. Moudam</b> (Mohammed VI Polytechnic University/Applied Chemistry & Engineering Research Centre of Excellence, Morocco) <i>"Transparent Luminescent Solar Windows"</i>	<b>K. Nouneh</b> (University Ibn Tofail– Faculty of Science, Morocco) <i>"Low-Cost Solution Processing and Environmental Friendly Nanostructures for Solar Application"</i>
15:15 – 15:30	<b>P. Naghinazhadahmadi</b> (METU-Programmable Photonics Group, Turkiye) <i>"Angle Independent Diffractive Optical Elements to Improve the Efficiency of Solar Cells"</i>	
15:30 – 15:45	<b>Coffee Break</b>	

<p><b>SESSION 6-1 &amp; 6-2</b> (15:45 - 17:15)</p> 	<p><b>PV CELL TEST &amp; CHARACTERIZATION</b> (Session Chair: Dr. Erkan Aydin)</p>  <p style="text-align: right;">METU-CCC / Hall A</p>	<p><b>SPECIAL SESSION: THIN FILM PV CELLS AND RESEARCH STUDIES FROM NORTHUMBRIA UNIVERSITY</b> (Session Chair: Assoc. Prof. Selçuk Yerci)</p>  <p style="text-align: right;">METU-CCC / Hall B</p>
<p>15:45 – 16:00</p>	<p><b>Keynote Speaker: Assoc. Prof. Muhammad Usman</b> (National Centre for Physics, Pakistan) <i>"Ion Beams: A Versatile Tool in Semiconductor Industry (from Research to Applications)"</i></p>	<p><b>Y. Qu</b> (Northumbria University, United Kingdom) <i>"Kesterite Thin Film Solar Cells from Nanoparticle Inks"</i></p>
<p>16:00 – 16:15</p>		<p><b>V. Barrioz</b> (Northumbria University, United Kingdom) <i>"Exploring the Effects of Inorganic Hole Transport Layers on the Performance of Antimony Selenide Solar Cells"</i></p>
<p>16:15 – 16:30</p>	<p><b>A. S. Gudovskikh</b> (Alferov University, Russia) <i>"Defect Characterization of Heterojunction Based on Black Silicon"</i></p>	<p><b>S. Campbell</b> (Northumbria University, United Kingdom) <i>"Flexible Thin Film Solar Cells Using Photonic Lift-Off Process"</i></p>
<p>16:30 – 16:45</p>	<p><b>K. Tsoi</b> (ODTÜ-GÜNAM, Türkiye) <i>"Determination of Contact Resistivity Using Cox-Strack and Four-Point Probe Methods"</i></p>	<p><b>A. Javed</b> (ODTÜ-GÜNAM, Türkiye) <i>"Characterization of Thin Film CZTSSe Absorber Back Side Synthesized by Hot Injection Method"</i></p>
<p>16:45 – 17:00</p>	<p><b>E. Ugur</b> (KAUST – Solar Center, Saudi Arabia) <i>"Visualizing the Voltage Losses in Perovskite-Based Solar Cells"</i></p>	<p><b>R. Voyce</b> (Northumbria University, United Kingdom) <i>"Exploring the Role of Temperature on The Ribbon Orientation of Sb<sub>2</sub>Se<sub>3</sub> Solar Cells Deposited via Thermal Evaporation"</i></p>
<p>17:00 – 17:15</p>	<p><b>M. Aktaş</b> (GTC - R&amp;D Center, Türkiye) <i>"Classification of Solar Cells EI Images with Different Busbars via Deep Learning Models"</i></p>	

<p><b>19:30</b></p>	<p><b>Gala Dinner</b></p>
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<b>July 7<sup>th</sup>, 2022 (Thursday)</b>		
<b>08:30</b>	<b>REGISTRATION</b>	
<b>SESSION 7-1 &amp; 7-2 (09:00 - 10:45)</b> 	<b>SOCIOECONOMIC IMPACTS OF PV APPLICATIONS - I</b> (Session Chair: Assoc. Prof. Pınar Derin Güre)  <b>METU-CCC / Hall A</b>	<b>ADVANCED DEVICE CONCEPTS IN PHOTOVOLTAICS</b> (Session Chair: Assoc. Prof. Onur Taylan)  <b>METU-CCC / Hall B</b>
09:00 – 09:30		<b>Keynote Speaker: Dr. Armin Buchroithner (TU Graz, Austria)</b> <b>"Highly Efficient Solar Co-Generation in Parabolic Trough Collectors Using Hybrid Absorber Technologies: Potentials and Challenges"</b>
09:30 – 09:45	<b>C. Pense</b> (METU – Earth System Science, Türkiye) <i>"Cost-Benefit Analysis of Using PV Systems Onboard Electric Ferries"</i>	<b>D. Kizildag</b> (Centre Tecnològic de Transferència de Calor (CTTC) - UPC, Spain) <i>"Thermal and Fluid Dynamic Optimization of a Solar Co-Generation Absorber Module Within a CPV-T System: Numerical Modeling and Experimental Validation"</i>
09:45 – 10:00	<b>I. Tokgoz</b> (Institute of Science, Technology Faculty, Dept. of Mechanical Engineering, Türkiye) <i>"Management of Solar Si-Based PV Waste in Türkiye: A Future Projection and Proposed Methods"</i>	<b>E. Ayin</b> (ODTÜ-GÜNAM, Türkiye) <i>"Development of Low-Cost c-Si-Based CPV Cells for Solar Co-Generation Absorber in Parabolic Trough Collectors"</i>
10:00 – 10:15	<b>M. Cubukcu</b> (Ege University – Solar Energy Institute, Türkiye) <i>"The Impact of Climate Change on Solar Photovoltaic Energy Generation in Türkiye"</i>	<b>G. Kahraman</b> (Şişecam Science and Technology Center, Türkiye) <i>"Design, Production and Performance Evaluation of Solar Mirrors with and without Cu"</i>
10:15 – 10:30	<b>N. C. Duvaryapar</b> (Centre International de Formation Européenne, Global Energy Transition and Governance, France) <i>"Solar PV Uptake in Türkiye: Economic and Political Implications"</i>	<b>H. Mehmood</b> (Information Technology University of the Punjab, Dept. of Electrical Engineering, Pakistan) <i>"TCAD Simulation of Germanium-Based Heterostructure Solar Cell Employing Molybdenum Oxide as a Hole-Selective Layer"</i>
10:30 – 10:45	<b>S. Cekinir</b> (Yaşar University, Türkiye) <i>"Development and Future of Turkey's Photovoltaic Installed Power"</i>	<b>M. Codur</b> (ODTÜ-GÜNAM, Türkiye) <i>"Effect of Contact Resistance on Series Resistance of Silver Nanowire Transparent Electrodes"</i>
<b>10:45 – 11:00</b>	<b>Coffee Break</b>	

<p><b>SESSION 8-1 &amp; 8-2</b> <b>(11:00 - 12:30)</b></p> 	<p><b>SOCIOECONOMIC IMPACTS OF PV APPLICATIONS - II</b> <i>(Session Chair: Dr. Yelda Erden Topal)</i></p>  <p>METU-CCC / Hall A</p>	<p><b>PV MODULE TECHNOLOGIES, PERFORMANCE AND RELIABILITY</b> <i>(Session Chair: Dr. Armin Buchroithner)</i></p>  <p>METU-CCC / Hall B</p>
<p>11:00 – 11:30</p>		<p><b>Keynote Speaker: Max Mittag</b> (Fraunhofer ISE, Germany)  <b>"Impact of Cell Configuration, Module Design and Materials on Module Power and Yield – Holistic Loss Analysis from Cell to System"</b></p>
<p>11:30 – 11:45</p>	<p><b>C. K. Bolat</b> (METU – Earth System Science, Turkiye)  <i>"Is There a Macroeconomic Carbon Rebound Effect in EU ETS?"</i></p>	<p><b>D. Dahlioui</b> (R&amp;D Department, Moroccan Agency for Sustainable Energy (MASEN), Morocco)  <i>"Study of Floating Bifacial PV Effect on Water Savings and Energy in Arid Zones"</i></p>
<p>11:45 – 12:00</p>	<p><b>E. Ipek</b> (METU – FEAS, Turkiye)  <i>"A Computable General Equilibrium Model for Turkiye: Analyzing the Effects of Photovoltaic Systems on the Economy"</i></p>	<p><b>M. Caliskan</b> (Kalyon PV Güneş Teknolojileri Fabrikası, Turkiye)  <i>"Analysis of Mechanical and Electrical Effects of Different Cutting Methods on M10 Perc Solar Cells"</i></p>
<p>12:00 – 12:15</p>	<p><b>E. Yazici</b> (METU – TEKPOL, Turkiye)  <i>"A Bibliometric Literature Review on Socio-Economic Impact Assessment of Solar Energy and Photovoltaic Technologies"</i></p>	<p><b>H. Chamali</b> (Ecole Normale Supérieure Mohammed V University – PSES, Energy Research Center, Morocco)  <i>"New Approach for Evaluating the Distribution of Soiling Particles Size on the Surface of PV Modules"</i></p>
<p>12:15 – 12:30</p>	<p><b>A. Askin</b> (ODTÜ-GÜNAM, Turkiye)  <i>"Snapshot of Recycling Photovoltaic Modules Within a Circular Economy Approach in Turkiye (2022)"</i></p>	<p><b>M. Cubukcu</b> (Ege University – Solar Energy Institute, Turkiye)  <i>"Techno-Economic Comparative Analysis of Solar Photovoltaic Power Systems with Different Energy Storage Systems in Turkiye"</i></p>
<p><b>12:30 – 14:00</b></p>	<p><b>Lunch</b></p>	

<p><b>SESSION 9-1 &amp; 9-2</b> <b>(14:00 - 15:15)</b></p> 	<p><b>SOLAR PV ENERGY RESOURCE AND INPUT ASSESSMENT</b> <i>(Session Chair: Dr. Emre Demirezen)</i></p>  <p style="text-align: right;"><b>METU-CCC / Hall A</b></p>	<p><b>BUILDING-INTEGRATED AND AGRICULTURAL PV APPLICATIONS &amp; POWER ELECTRONICS AND ENERGY STORAGE</b> <i>(Session Chair: Dr. Emre Demirezen)</i></p>  <p style="text-align: right;"><b>METU-CCC / Hall B</b></p>
<p>14:00 – 14:15</p>	<p><b>A. Yildiz</b> (Ege University Bornova, Natural and Applied Sciences, Solar Energy Institute, Turkiye) <i>"Evaluation of the Possibilities for High Voltage Use in Solar Inverters"</i></p>	<p><b>A. Azami</b> (Eastern Mediterranean University -Dept. Of Architecture, North Cyprus) <i>"PV Incorporation into the Building Thermal Envelope and the New Certification Classes for Passive House Standard"</i></p>
<p>14:15 – 14:30</p>	<p><b>H. Wu</b> (Northumbria University, Newcastle upon Tyne, UK) <i>"An Advanced Global Maximum Power Point Tracking Technique for PV Systems"</i></p>	<p><b>B. Senturk</b> (METU-Dept. of Economics, Turkiye) <i>"Agricultural Sector Risks in Turkiye and AgroPV Potential from Farmers' Perspective"</i></p>
<p>14:30 – 14:45</p>	<p><b>M. I. Kulat</b> (Ministry of Agriculture and Forestry/General Directorate of State Hydraulic Works, METU, Turkiye) <i>"A Sound Potential Against Energy Dependency and Climate Change Challenges: Floating Photovoltaics on Water Reservoirs of Turkiye"</i></p>	<p><b>K. Ezzaeri</b> (Université Ibn Zohr, Morocco) <i>"Food and Electricity Production in Agricultural Greenhouses in Morocco: Is It Feasible?"</i></p>
<p>14:45 – 15:00</p>	<p><b>N. I. Koker</b> (METU - Earth System Science, Turkiye) <i>"Modeling and Simulating Rooftop Solar Photovoltaics for the Buildings of a University Campus"</i></p>	<p><b>N. S. Esmailzad</b> (ODTÜ-GÜNAM, Turkiye) <i>"Agrivoltaics Applications in Turkiye"</i></p>
<p>15:00 – 15:15</p>	<p><b>S. Zaim</b> (Thermodynamic-Energy Team, Energy Research Center (CRE), Faculty of Sciences, Mohammed V University, Morocco) <i>"Using Artificial Intelligence for Global Solar Radiation - Modeling from Meteorological Variables"</i></p>	<p><b>O. Taylan</b> (METU – Dept. of Mechanical Engineering, Turkiye) <i>"Sizing of a Photovoltaic Power Plant with Battery and Hydrogen Storage Using Techno-Economic Parameters for a METU Campus"</i></p>

<p><b>15:30</b></p>	<p><b>Closing Remarks &amp; End of PVCOn2022</b></p>  <p style="text-align: right;"><b>METU-CCC / Hall B</b></p>
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## PVCon2022 Poster Presentations

### CRYSTALLINE SILICON SOLAR CELLS AND MODULES



METU-CCC (Foyer)

- A. Aliefendioğlu (ODTÜ-GÜNAM, Türkiye)**  
*FABRICATION OF INTERDIGITATED BACK-CONTACT (IBC) SOLAR CELLS WITH SCREEN-PRINTED BORON DOPING PASTE*  
(Poster No: P1 / Abstract ID: 112)
- A. Aliefendioğlu (ODTÜ-GÜNAM, Türkiye)**  
*FABRICATION, PASSIVATION AND CHARACTERISATION OF BLACK-SI WAFERS FOR SOLAR CELL APPLICATIONS*  
(Poster No: P2 / Abstract ID: 111)
- A. Boucheham (Research Center in Semiconductors Technology for Energetics/DDCS, Algeria)**  
*INVESTIGATION OF BORON DIFFUSION FROM BSG LAYERS FOR P+ EMITTER ELABORATION*  
(Poster No: P3 / Abstract ID: 110)
- A. B. Koç (Kalyon PV, Türkiye)**  
*INVESTIGATION OF SOLAR MODULE RIBBON SIZE CHANGING EFFECT*  
(Poster No: P4 / Abstract ID: 53)
- A. E. Keçeci (ODTÜ-GÜNAM, Türkiye)**  
*BBR3 DIFFUSION WITHOUT BRL FORMATION FOR N-TYPE SILICON SOLAR CELLS*  
(Poster No: P5 / Abstract ID: 82)
- B. Altınsoy (ODTÜ-GÜNAM, Türkiye)**  
*THE EFFECT OF INITIAL SURFACE MORPHOLOGY ON THE FORMATION OF INVERTED PYRAMIDS BY COPPER ASSISTED CHEMICAL ETCHING OF SILICON*  
(Poster No: P6 / Abstract ID: 142)
- B. Aydoğan (Kalyon PV Research and Development Center, Türkiye)**  
*COMPARISON OF MECHANICAL BEHAVIORS OF SI CELLS WITH THREE POINT AND FOUR POINT BENDING TEST*  
(Poster No: P7 / Abstract ID: 25)
- B. G. Çiftçi (Gazi University, Türkiye)**  
*IMPROVING THE OPTICAL PROPERTIES OF SOLAR CELL WITH METAL ASSISTED CHEMICAL ETCHING METHOD*  
(Poster No: P8 / Abstract ID: 115)
- B. Uygun (ODTÜ-GÜNAM, Türkiye)**  
*PASSIVATION STUDY OF SYMMETRICAL N- TYPE TUNNEL OXIDE PASSIVATED CONTACTS (N-TOPCON) REALIZED BY LOW PRESSURE CHEMICAL VAPOR DEPOSITION*  
(Poster No: P9 / Abstract ID: 118)
- B. Şekertekin (Kalyon PV, Türkiye)**  
*INVESTIGATION OF PID EFFECTS ON CELL LEVEL*  
(Poster No: P10 / Abstract ID: 189)
- E. S. Duman (METU Micro and Nanotechnology Department, Türkiye)**  
*INFLUENCE OF PHOSPHORUS EMITTER FORMATION ON THE PERFORMANCE OF BLACK SILICON SOLAR CELLS*  
(Poster No: P11 / Abstract ID: 88)
- E. Dönerçark (ODTÜ-GÜNAM, Türkiye)**  
*ENHANCED PASSIVATION QUALITY OF HYDROGENATED AMORPHOUS SILICON LAYER FOR SI HETEROJUNCTION SOLAR CELLS*  
(Poster No: P12 / Abstract ID: 149)
- E. Aydın (ODTÜ-GÜNAM, Germany)**  
*PERFORMANCE COMPARISON OF CPV SOLAR CELLS PRINTED WITH STANDARD MASK AND FLOATING MASK*  
(Poster No: P13 / Abstract ID: 158)

**E. Han (Kalyon PV, Turkiye)**

*IMPROVEMENT OF METALLIZATION PERFORMANCE ON FRONT SILVER PASTE FOR CZ-PERC*  
(Poster No: P14 / Abstract ID: 50)

**H. Nasser (ODTÜ-GÜNAM, Turkiye)**

*DOPANT-FREE CARRIER SELECTIVE CONTACTS ON SIOX PASSIVATED N-TYPE CRYSTALLINE SILICON SOLAR CELLS*  
(Poster No: P15 / Abstract ID: 102)

**H. Nasser (ODTÜ-GÜNAM, Turkiye)**

*EXTREMELY LOW EXTINCTION COEFFICIENT ZROX ENABLES A NOVEL DOUBLE-LAYER ANTI-REFLECTION COATING FOR CRYSTALLINE SILICON SOLAR CELLS*  
(Poster No: P16 / Abstract ID: 100)

**H. Nasser (ODTÜ-GÜNAM, Turkiye)**

*SUBSTOICHIOMETRIC TANTALUM PENTOXIDE BASED SINGLE-AND DOUBLE-LAYER ANTI-REFLECTION COATING FOR BIFACIAL TOPCON SOLAR CELLS*  
(Poster No: P17 / Abstract ID: 174)

**H. Osman (ODTÜ-GÜNAM, Turkiye)**

*PLASMA ENHANCED CHEMICAL VAPOR DEPOSITED AMORPHOUS SILICON LAYERS FOR TUNNEL OXIDE PASSIVATED CONTACT (N-TOPCON) C-SI SOLAR CELLS*  
(Poster No: P18 / Abstract ID: 131)

**H. U. Kayacı (ODTÜ-GÜNAM, Turkiye)**

*LEAD-FREE CONDUCTIVE SILVER PASTES FOR CRYSTALLINE SILICON SOLAR CELLS*  
(Poster No: P19 / Abstract ID: 24)

**L. A. Madbouly (ODTÜ-GÜNAM, Turkiye)**

*MXENE CONTACTS FOR HOLE-SELECTIVE MOO<sub>x</sub> ENABLING REDUCED SILVER USE FOR DOPANT-FREE CRYSTALLINE SILICON SOLAR CELLS*  
(Poster No: P20 / Abstract ID: 75)

**L. A. Madbouly (ODTÜ-GÜNAM, Turkiye)**

*ZIRCONIUM OXIDE AS ELECTRON-SELECTIVE CONTACTS FOR N-TYPE CRYSTALLINE SILICON SOLAR CELLS*  
(Poster No: P21 / Abstract ID: 74)

**K. Tsoi (ODTÜ-GÜNAM, Turkiye)**

*NUMERICAL OPTIMIZATION OF THE FRONT METAL GRID IN SILICON HETEROJUNCTION SOLAR CELLS*  
(Poster No: P22 / Abstract ID: 52)

**M. K. Aslan METU Micro and Nanotechnology Program, Turkiye)**

*OPTIMIZATION OF LASER PARAMETERS FOR DAMAGE-FREE DIELECTRIC LAYER ABLATION PROCESS FOR PLATING METALLIZATION ON PERC SOLAR CELLS*  
(Poster No: P23 / Abstract ID: 99)

**M. Koç (ODTÜ-GÜNAM, Turkiye)**

*OPTOELECTRONIC OPTIMIZATION OF ITO LAYER IN SILICON HETEROJUNCTION SOLAR CELLS*  
(Poster No: P24 / Abstract ID: 172)

**M. Çorak (Gazi University, Turkiye)**

*OPTIMIZATION OF TEXTURING PROCESSING FOR PERC TYPE C-SI SOLAR CELLS*  
(Poster No: P25 / Abstract ID: 181)

**M. E. Karahallı (ODTÜ-GÜNAM, Turkiye)**

*DETERMINATION OF LASER CUTTING PARAMETERS FOR SOLAR CELLS*  
(Poster No: P26 / Abstract ID: 170)

**M. E. Karahallı (ODTÜ-GÜNAM, Turkiye)**

*LAYOUT OPTIMIZATION FOR SHINGLED SOLAR CELLS*  
(Poster No: P27 / Abstract ID: 169)

**M. Usman (Quaid-i-Azam University-National Centre for Physics, Pakistan)**  
*ION BEAM ANALYSIS OF PASSIVATION LAYERS FOR PERC SOLAR CELLS*  
(Poster No: P28 / Abstract ID: 67)

**S. Altinoluk (Muğla Sıtkı Koçman University – Dept. of Electrical and Electronics Engineering, Türkiye)**  
*OPTICAL IMPROVEMENT OF NANO-HOLE TEXTURED C-SI SURFACES FOR SOLAR CELL APPLICATION*  
(Poster No: P29 / Abstract ID: 157)

**S. Seyrek (ODTÜ-GÜNAM, Türkiye)**  
*INVESTIGATION OF BULK LIFETIME OF CZOCHRALSKI AND FLOAT-ZONE SILICON WAFERS UNDER TEMPERATURE VARIATION*  
(Poster No: P30 / Abstract ID: 113)

**S. Aslan (ODTÜ-GÜNAM, Türkiye)**  
*PASSIVATION PARAMETERS EXTRACTION FOR N-TOPCON ONTEXTURED N-TYPE C-SI WAFERS*  
(Poster No: P31 / Abstract ID: 97)

**S. Aslan (ODTÜ-GÜNAM, Türkiye)**  
*EFFECT OF BASE RESISTIVITY, GETTERING AND DOPANT TYPE ON LIGHT INDUCED DEGRADATION OF P-TYPE MONO SILICON WAFER*  
(Poster No: P32 / Abstract ID: 96)

**S. H. Sedani (ODTÜ-GÜNAM, Türkiye)**  
*NON-HAZARDOUS AND LOW-COST E-BEAM EVAPORATED P-POLY-SI LAYERS FOR BIFACIAL DOUBLE-SIDED TOPCON*  
(Poster No: P33 / Abstract ID: 178)

**S. K. Bütüner (ODTÜ-GÜNAM, Türkiye)**  
*EFFECT OF SURFACE MORPHOLOGY ON PASSIVATION QUALITY AND CELL PERFORMANCE OF SILICON HETEROJUNCTION SOLAR CELLS*  
(Poster No: P34 / Abstract ID: 62)

**S. Kılıçkaya (ODTÜ-GÜNAM, Türkiye)**  
*SCREEN-PRINTING OPTIMIZATION OF LOW-TEMPERATURE SILVER PASTES FOR SILICON HETEROJUNCTION SOLAR CELLS*  
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IS1

## CZ-INGOT GROWTH AT FRAUNHOFER CSP

**Peter Dold<sup>1</sup>**

<sup>1</sup>Fraunhofer CSP, Germany

The progress in Czochralski growth of silicon ingots is tremendous. For many years, the standard size for solar cells was 156x156 mm<sup>2</sup>, but it increased within a short time to 210x210 mm<sup>2</sup>. For ingot growth, this means that the diameter increased from approx. 218 mm to 300 mm. At the same time, the crucible charge increased to several hundred kilograms (800 kg and more are reported from China) and the operation time of crucibles in production might be as long as 300 hours. Together with the strong cost reduction required for successful operation, it results in an enormous challenge for the ingot and wafer industry. At Fraunhofer CSP, we have three Czochralski pullers in operation, together with four multi-wire saws. We are able to grow successfully 300 mm ingots and cut 210x210 wafers using diamond wire. Our work in progress includes the increase of the hot zone dimension and the implementation of internal feeders for increased crucible filling. An important task we are working on is the reuse of the cut-off pieces and the question of dopant uniformity for gallium and for phosphorous doping. In the second part, we will discuss the topic of recycling end-of-life PV modules or modules out of production, which did not pass the qualification test. Today, the globally installed amount of c-Si PV-systems accumulates to more than 100 million tons and just the weight of the consumed silicon exceeds more than 1.5 million tons. An industrial reliable and scalable and eco-nomically profitable recycling process for recovering silicon from end-of-life PV modules does not exist, at least not to the knowledge of the authors. We had been able to extract the cell debris from end-of-life modules, purify the silicon to a high degree, use it for Cz-ingot growth and make new PERC-cell from the wafers made out of 100% recycling silicon. We will discuss the actual trends and developments for ingot growth and for wafering, the solved and unsolved problems as well as the questions still to be answered.

IS2

## **DEVICE PHYSICS OF PEROVSKITE SOLAR CELLS**

**Wolfgang Tress<sup>1</sup>**

<sup>1</sup>*ZHAW School of Engineering*

In the last decade, metal-halide perovskite semiconductors have received tremendous attention in research due to their excellent optoelectronic properties, making them highly interesting materials for solar cells and light emitting diodes (LEDs). It is fascinating that these perovskites are highly tolerant against electronic defects, which allowed for solar-cell efficiencies >25%, and at the same time show ionic conductivity mediated through mobile lattice defects. In this talk the device physics of perovskite solar cells is discussed. Focus is on the peculiar properties of the material, which enable low recombination losses and thus high photovoltages. Furthermore, the various effects of ion migration on device performance are described. They range from hysteresis in the current-voltage curve of solar cells to phase segregation and reversible degradation during long-term operation. Key in understanding these phenomena is the interplay between ionic and electronic conductivity, where the ionic response belatedly modifies the electronic response, which is the one commonly observed in devices. This interplay has consequences on how to interpret the results of common characterization techniques. In addition, the real-world long-term operation of perovskite optoelectronic devices under varied ambient conditions is affected. These points lead towards the open challenges, which conclude the talk.

IS3

## FROM FUNDAMENTALS TO FIRST REAL WORLD APPLICATIONS OF HYBRID PEROVSKITE PHOTOVOLTAICS

Şenol Öz<sup>1</sup>

<sup>1</sup>*Solaveni GmbH*

Since the emergence of hybrid perovskite photovoltaics in 2009 the scientific community has witnessed disruptive progress of the technology in terms of solar to electric power conversion efficiency (25.7%)<sup>1</sup> accompanied by advancement in addressing stability issues and developing a deeper understanding of fundamental structure-processing-property relationships. Merely a decade after discovery, the commercialization of organic-inorganic metal halide perovskites photovoltaic devices is just around the corner! Many issues had to be tackled to meet industrialization, among them large area deposition techniques, safety standards and material wastage without compromising efficiency and stability. Saule technologies has been developing a fully scalable inkjet printing process of perovskite solar cell modules on lightweight flexible substrates. This talk will focus on recent advancements in the technology and the product development process required to bring inkjet printed perovskite modules closer to market entry. Moreover, it will underline the unique properties of the inkjet printing technique, which allow scalable solution-based fabrication of high-quality perovskite films and devices, processed in ambient atmosphere. [1] <https://www.nrel.gov/pv/cell-efficiency.html>

IS4

## **HIGHLY EFFICIENT MONOLITHIC PEROVSKITE/SILICON TANDEM SOLAR CELLS: DEVICE CONCEPTS AND STABILITY ASPECTS**

**Erkan Aydın<sup>1</sup>**<sup>1</sup>KAUST

Due to their unique semiconductor properties, metal halide perovskites have attracted considerable attention for their application in tandem solar cells. Perovskite/silicon tandem solar cells are particularly appealing as they pair proven high power conversion efficiencies (PCEs, values close to 30% have already been reported) with the industrial maturity of crystalline silicon (c-Si) photovoltaics (PVs). Specifically, their solution-processing on industry-relevant textured crystalline silicon solar cells is critical to unlocking this technology's full potential. This talk delivers the rationale behind working textured bottom cells, explaining how we develop our efficient perovskite/silicon tandem solar cells, different device architectures and concepts, and lessons we learned from their indoor and outdoor stability tests.

IS5

## HIGHLY EFFICIENT SOLAR CO-GENERATION IN PARABOLIC TROUGH COLLECTORS USING HYBRID ABSORBER TECHNOLOGIES: POTENTIALS AND CHALLENGES

Armin Buchroithner<sup>1</sup>

<sup>1</sup>Graz University of Technology

Parabolic trough collectors (PTCs) play an important role in concentrated solar power (CSP) as they provide economic heat up to 400°C and above, which can be used for industrial processes or electricity generation. In recent years, several PTCs incorporating absorber tubes equipped with concentrator photovoltaics (CPV) have emerged, resulting in highly efficient hybrid (CPV-T) absorbers providing both, process heat and electricity. This talk discusses not only the general market potential of this technology, but also concrete technological approaches, which have led to overall average system efficiencies of 75.5% (26.8% electrical + 48.8% thermal) While even higher efficiencies seem possible in the near future by deploying more advanced optical components and cells as well as highly accurate tracking systems, low-cost designs based on large-batch manufacturing methods inspired by the automotive industry might revolutionize the market. By comparing challenges and potentials, it can clearly be seen that the proposed technology can contribute significantly to a more rapid transition to renewable energy supply, which is of absolute importance given the global political, economic and climate-related events in recent years. The conclusions and approaches presented in this presentation are also backed by findings research projects conducted by the authors.

IS6

## **IMPACT OF CELL CONFIGURATION, MODULE DESIGN AND MATERIALS ON MODULE POWER AND YIELD - HOLISTIC LOSS ANALYSIS FROM CELL TO SYSTEM**

**Max Mittag<sup>1</sup>**

*<sup>1</sup>Fraunhofer ISE, Germany*

- Introduction of loss analysis for PV modules and financial motivation - Explanation of major gain and loss channels in PV modules - Application of this knowledge on specific module designs - Analysis of the impact of larger solar cells on modules - Analysis of the impact of the number of busbars for different cell sizes on the cell and the module output

IS7

## **ION BEAMS: A VERSATILE TOOL IN SEMICONDUCTOR INDUSTRY (FROM RESEARCH TO APPLICATIONS)**

**Muhammad Usman<sup>1</sup>**

<sup>1</sup>*National Centre for Physics*

Energetic ions produced in an ion beam accelerator cause many physical and chemical changes in the target material upon their interaction. They are usually employed for synthesis, modification, and analysis of materials to exploit various engineering and scientific applications. Semiconductor industry is the biggest user of ion beams for their controllable energy, dose (fluence) and species; to dope the semiconductors, tune the lifetime, analyze the material, and test the radiation hardness of electronic devices. The ions carrying keV to MeV energy impacting the target either penetrate (Ion Implantation, Ion Beam Modification of Materials) or scatter from it (Ion Beam Analysis) carrying useful information about the material, depending on the incident energy and geometry. The basic mechanism of interaction is the loss of energy via electronic or nuclear stoppings of ions in the target. The complex specific effects of interactions produce the destructive modification in the materials as well as nondestructively analyze the elemental composition of the target making ion beams an essential tool for the semiconductor industry. In this talk, the basic mechanisms of ion-solid interactions, a broader review of the usual applications of ion beams in scientific research and a detailed usage in the semiconductor industry will be discussed.

IS8

## MULTI-SOURCE VACUUM DEPOSITION OF PEROVSKITE FILMS AND SOLAR CELLS

**Michele Sessolo<sup>1</sup>**

*<sup>1</sup>University of Valencia*

The most stable and efficient perovskite solar cells reported so far, have mostly been prepared by solution-processing. This is due to the technical difficulties associated with the vacuum deposition from multiple thermal sources. Here we present multi-component materials obtained by using multiple sources (up to 4) thermal vacuum deposition. Different stoichiometries are studied, varying the A-site cations, as well as mixed halide systems. Both narrow bandgap and wide bandgap materials will be presented, with bandgap spanning from 1.5 to 1.8 eV. We highlight the importance of the control over the film morphology and composition, which differs substantially when these compounds are vacuum processed. We identify thermally stable compositions and apply them to opaque and bifacial perovskite solar cells. Avenues to improve the stability and to maximize the open circuit voltage using additives and/or novel charge transport layers will also be discussed.

IS9

## **PEROVSKITE MODULE UPSCALING TOWARDS INDUSTRIALIZATION BASED ON EFFICIENT CELL ARCHITECTURES AND SCALABLE PROCESSES**

**Yinghuan Kuang<sup>1</sup>**

<sup>1</sup>IMEC

In recent years, organometal halide perovskite based photovoltaics (PV) have attracted great interest for their high energy conversion efficiency potentially at low manufacturing cost. Despite the massive progress made by the community at laboratory small scale (typically at ~0.1 cm<sup>2</sup> cell area), manufacturability at large scale (~m<sup>2</sup>) with stability and reproducibility remains very challenging. In this talk, the typically used perovskite coating methods and solar cell architectures will be introduced, followed by a brief overview of the current status of perovskite upscaling in the industry. The talk will focus on the highly efficient and stable perovskite materials and solar cell structure designs at imec. Upscaling of perovskite solar modules to 30x30 cm<sup>2</sup> using industrial compatible deposition techniques developed at imec will be highlighted in the end.

IS10

## **SILICON DEFECTS AND POSSIBLE IMPACT ON SOLAR CELL EFFICIENCY**

**Luciano Mule'stagno<sup>1</sup>**

<sup>1</sup>*University of Malta*

It is well known that single-crystal silicon grown by the Czochralski method contains a certain level of interstitial oxygen and a low level of other impurities. Crystals also contain a small excess of interstitial Silicon atoms or vacancies (missing atoms) which as the crystal cools agglomerate to form extended defects. There is also an interaction between the vacancies and interstitial oxygen which results in another class of growth in defects. The density of these defects was found to impact electronic devices' yield decades ago but until recently there was little understanding of how or if they impact solar cell yield. As efficiencies are pushed higher, evidence is starting to emerge that these defects can in fact have an impact on cell efficiency under certain circumstances. This presentation will explain these defects and examine how they could impact solar cell efficiency.

IS11

## **SLOT-DIE PROCESSING OF LARGE AREA PEROVSKITE MODULES FOR HYBRID TANDEM APPLICATIONS**

**Ilker Doğan<sup>1</sup>**

<sup>1</sup>TNO

Mixed metal-halide perovskite solar cells (PSC) are advancing in power conversion efficiency (PCE) faster than any other photovoltaic technologies, reaching up to 25.5% [1]. However, the reported record efficiencies are obtained with lab-scale devices. Promoting this technology to the market level with efficient and stable devices manufactured with cost-effective, industrially scalable processes is the persisting challenge. In this talk, we will demonstrate the activities within TNO-Solliance towards large scale, stable rigid and flexible perovskite modules. A specific attention will be given to the semitransparent perovskite modules, and their application in bifacial tandem technologies. [1] <https://www.nrel.gov/pv/assets/pdfs/pv-efficiency-chart.20200203>

IS12

## **STATE-OF-THE-ART OF SI HETEROJUNCTION TECHNOLOGY**

**Hariharsudan S. Radhakrishnan<sup>1</sup>**

<sup>1</sup>IMEC

The next PV cell technology node after PERC will be based on passivating contacts, namely, the low-temperature Si heterojunction technology (HJT) and the high-temperature tunnel-oxide passivating contacts technology (TOPCon). The PV industry appears to be betting on both of these high efficiency technologies. While the latter is considered to be an evolution from PERC technology, the HJT process flow is simpler and has the potential for higher efficiencies compared to TOPCon. In fact, the current world record efficiency is held by a HJT cell with a back-contacted design, fabricated by Kaneka, reaching 26.7%. Nevertheless, costs reductions (both OPEX and CAPEX) need to continue for HJT to be competitive. In this talk, an overview of the state-of-the-art of Si HJT technology in research and industry will be given, touching on both the front/back contacted (FBC) and interdigitated back-contacted (IBC) designs. The aspects of this technology being addressed in the international collaboration project between METU-GÜNAM and imec/imomec under the 1004 program will also be highlighted.

O1

## A BIBLIOMETRIC LITERATURE REVIEW ON SOCIO-ECONOMIC IMPACT ASSESSMENT OF SOLAR ENERGY AND PHOTOVOLTAIC TECHNOLOGIES

**Esin Yazici<sup>1</sup>, Pinar Derin Güre<sup>2</sup>, Besim Can Zırh<sup>3</sup>, Yelda Erden Topal<sup>4</sup>, Ezgi Ipek<sup>2</sup>,  
Abdulkadir Deveci<sup>5</sup>, Erkan Erdil<sup>4</sup>, Ramazan Sari<sup>6</sup>**

<sup>1</sup>METU, TEKPOL

<sup>2</sup>METU, Economics

<sup>3</sup>METU, Sociology

<sup>4</sup>METU, Economics & TEKPOL

<sup>5</sup>METU, GSSS

<sup>6</sup>Technical University of Denmark, Department of Technology, Management and Economics

This paper aims to give a quantitative and qualitative literature survey on the Socio-economic Impact Assessment (SIA) of Solar Energy and PV Technologies. Although there has been an increasing number of research articles on PV and Solar Technologies, how their social impact has been assessed in the literature has not been studied widely. This paper offers a bibliometric and narrative literature review on the socio-economic impact analysis of Solar and PV Technologies. Using a bibliometric approach with the latest analysis tools like Vosviewer and HistCite, illustrations and tabulations of journals, authors, articles, keywords, citations, languages, institutions, and countries are generated from comprehensive Web of Science (WOS) data. The paper highlights the most influential works and authors in the field, emphasize their essential findings on the social impact of solar PV literature and includes recommendations on future action areas. Using qualitative techniques, this paper also discusses the main components of Socio-Economic Impact assessment using Economic Assessment, Environmental Assessment, Health Assessment, Policy Assessment, and other Social Assessment methods used in energy literature and solar energy literature specifically.

### Keywords

Socio-Economic Impact Assessment, Renewable Energy Policy, Acceptance, Solar, Photovoltaic

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02

## **A COMPUTABLE GENERAL EQUILIBRIUM MODEL FOR TURKEY: ANALYZING THE EFFECTS OF PHOTOVOLTAIC SYSTEMS ON THE ECONOMY**

**Ezgi Ipek<sup>1</sup>, Pınar Derin-Güre<sup>1</sup>**

*<sup>1</sup>Middle East Technical University, FEAS, Ankara, Turkey*

Computable general equilibrium (CGE) models are highly used for economic impact analysis. They offer a benchmark for analyzing changes in the overall economy due to new policies, shocks, or technological improvements by using the data from various resources such as social accounting matrices and input-output tables. Therefore, CGE models are appropriate for analyzing the energy market, especially renewable energy resources. The use of solar photovoltaic energy has improved in Turkey, aiming to reach a cleaner and more sustainable energy supply. A CGE for Turkey will be presented to analyze how the increase of photovoltaic systems, especially the domestic production of solar cells and panels, affects the economy. The 2012 Input-Output table will be used to obtain a social accounting matrix for Turkey, and with the CGE model, changes in the economic indicators will be calculated.

### **Keywords**

Computable General Equilibrium, Photovoltaic Systems, Solar Energy, Input Output Table, SAM

03

## A NEW APPROACH FOR TOTALLY SCREEN-PRINTED IBC SOLAR CELLS

**Emine Hande Ciftpinar<sup>1,2</sup>, Ateşcan Aliefendioğlu<sup>1,2</sup>, Mona Zolfaghari Borra<sup>1</sup>, Ahmet Emin Keçeci<sup>1,2</sup>, Hasan Hüseyin Canar<sup>1,2</sup>, Sümeyye Koçak Bütüner<sup>1</sup>, Raşit Turan<sup>1,2,3</sup>**

<sup>1</sup>ODTÜ-GÜNAM, Ankara, TURKEY

<sup>2</sup>Middle East Technical University/Graduate School of Micro and Nanotechnology, Ankara, TURKEY

<sup>3</sup>Middle East Technical University/Department of Physics, Ankara, TURKEY

Reducing the optical losses plays a crucial role to improve the cell performance. Amongst the other cell structures, IBC solar cells have the highest efficiency potential with their zero optical shading losses [1]. Due to the complex process flows relying on multiple photolithography steps, IBC cells are hindered from increasing their market share. In this study, we offer a novel, lithography-free, and industry-compatible process flow for IBC solar cells to aid that problem. The process flow developed in GUNAM Laboratories, does not require any special equipment or complicated process steps. Instead, patterning of the diffusion barriers is done by using a screen-printable ink with enhanced chemical resistance in dilute acid solutions.

Following the patterning steps, high-temperature  $\text{BCl}_3$  and  $\text{POCl}_3$  diffusions are carried out to have the emitter and the BSF regions at the rear side. Various diffusion recipes and passivation layers were applied to optimize the diffused regions. Applying the optimized diffusion and passivation recipes resulted in promising implied  $V_{oc}$  values above 650 mV prior to the metallization of the cells. The  $iV_{oc}$  values and corresponding cross-section of the cells with FFE and FSF are given in Figure 1 (a),(c). The corresponding screen design is shown in Figure 1(b). Metallization of those cell precursors using industrial fire-through paste resulted in cell efficiency of around 19.3%.

### Keywords

Interdigitated back contact solar cells, industry-compatible, lithography-free.

Figure1. Implied Voc of the cells with FFE (a) and FSF (c), and corresponding screen design (b)

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04

## **A SOUND POTENTIAL AGAINST ENERGY DEPENDENCY AND CLIMATE CHANGE CHALLENGES: FLOATING PHOTOVOLTAICS ON WATER RESERVOIRS OF TURKEY**

**Muhammed Imran Kulat<sup>1,2</sup>, Kursad Tosun<sup>2</sup>, Abdullah Bugrahan Karaveli<sup>3,4</sup>, Ismail Yucel<sup>2,5</sup>, Bulent Gultekin Akinoglu<sup>2,4,6</sup>**

<sup>1</sup>Ministry of Agriculture and Forestry/General Directorate of State Hydraulic Works, Ankara, Turkey

<sup>2</sup>Middle East Technical University/ Graduate School of Natural and Applied Sciences - Earth System Science Program, Ankara, Turkey

<sup>3</sup>Ministry of Energy and Natural Resources/Department of Energy Efficiency and Environment , Ankara, Turkey

<sup>4</sup>Middle East Technical University/Centre for Solar Energy Research, Ankara, Turkey

<sup>5</sup>Middle East Technical University/ Department of Civil Engineering, Ankara, Turkey

<sup>6</sup>Middle East Technical University/ Department of Physics, Ankara, Turkey

Energy security and climate change are among the top priority challenges for Turkey. High dependency on imported energy resources jeopardizes the fragile economy. In addition, Turkey has already been experiencing the climate change impacts such as increasing temperature along with drought. To this end, solar energy is an important energy resource potential for the country. Floating photovoltaics have proven themselves to be quite efficient in energy production, with evaporation reduction as positive externality. The purpose of this article is to reveal the possible capacity of floating photovoltaics on constructed water reservoirs of Turkey and draw policy perspectives against existing or anticipated challenges. A total of 4,003 reservoirs were analyzed based on water surface coverage scenarios. The results proposed that if 10% area of suitable reservoirs is used around 125 TWh electricity generation is possible which is slightly above 40% of the nation-wide electricity demand. This generation would be highly instrumental in reducing energy dependency and substituting renewables for conventional resource uses. Through the installations the avoided CO<sub>2</sub>, is calculated to be 77.1 Mton equivalent. This would obviously be favorable considering the carbon emission reduction policy of the country and Paris Agreement requirements. Moreover, 1,242.1 hm<sup>3</sup> freshwater was assessed to save resources from evaporation loss, which in turn would help to mitigate the climate change pressure on water resources.

### **Keywords**

Floating Solar, Photovoltaics, Climate Change Mitigation, Energy Dependency, Potential Assessment

Electricity Production Potentials by Floating Photovoltaics on Reservoirs

05

## AN ADVANCED GLOBAL MAXIMUM POWER POINT TRACKING TECHNIQUE FOR PV SYSTEMS

**Haimeng Wu<sup>1</sup>, Mohammed Alkanderi<sup>1</sup>, Zubair Akbar<sup>1</sup>, Div Duggal<sup>1</sup>**

<sup>1</sup>Northumbria University, Newcastle upon Tyne, UK

The optimal efficient maximum power point tracking (MPPT) algorithms are critical in PV power conversion systems that can maximise the PV panels' energy output [1]. However, because of the partial shade situation in a PV system, many local maximum power points (MPP) can be generated as well as a global maximum power point (GMPP). Thereby, the PV systems simply using the conventional MPPT techniques cannot reach the overall peak point effectively [2-3]. This study reviews the recent GPPT and MPPT techniques comprehensively and develops a hybrid GPPT technique to compensate for the incompetency of the most modern algorithms. The principle of the control algorithm has been discussed to compare with the widely used approaches such as the modified perturb and observe (P&O) method [4] and the improved Cuckoo Search (CS) algorithm [5]. In addition, a thorough numerical study and comparison were carried out to validate the dynamic performance of the proposed GPPT approaches. The findings show that this proposed algorithm can effectively allocate the global peak power position under partially shadowed PV situations in terms of improving the tracking speed and steady-state oscillations.

### Keywords

Photovoltaic (PV) System, Global Maximum Power Point (GMPP), Partial Shade, Power Conversion

Fig (a) Flowchart of the proposed Algorithm (b) Schematic of Simulation (c) Key results

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06

## **AGRICULTURAL SECTOR RISKS IN TURKEY AND AGROPV POTENTIAL FROM FARMERS' PERSPECTIVE**

**Seven Agir<sup>1</sup>, Pinar Derin Gure<sup>1</sup>, Bilge Senturk<sup>1</sup>**

*<sup>1</sup>Middle East Technical University, Faculty of Economics and Administrative Sciences, Department of Economics, Ankara, Turkey*

AgroPV applications, in which renewable energy production and agricultural production are combined through photovoltaic panels on agricultural land, have come to the fore as an innovative application that alleviates or eliminates competition on land use, especially with the widespread use of renewable energy production in developed countries. In Turkey, although there is not yet a fully-fledged legislation in this area, both the increasing risks in terms of agricultural yields and income due climate change and the rising financial difficulties due to increased input (especially energy) costs indicate that AgroPV may have a strong potential not only in terms of the widespread use of renewable energy but also in terms of sustainability of agricultural production. In this study, in-depth interviews will be conducted with "pioneer/expert" farmers and "agricultural experts" as a first step in evaluating the potential of AgroPV systems. These interviews on producers' perspectives will help us determine the challenges and incentives (such as productivity estimations, installation costs, and energy pricing) that may play a role in producers' adoption and spread of AgroPV. The sample will include farmers with experience in field crops (greenhouse and open) and orchard practices. The preliminary findings are expected to shed light on how the characteristics of producers (such as product selection, land size, education, etc.) shape their perceptions of the barriers and opportunities in AgroPV applications. It will also be a preliminary step in the follow-up study with all stakeholders to examine socioeconomic and institutional complementarities in technology adoption.

### **Keywords**

Agriphotovoltaics, Renewable Energy (Solar), Agriculture, Sustainable Farming

Figure 1: Using Photovoltaic Solar System in Agricultural Fields (Fraunhofer ISE, 2020)

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07

## AGRIVOLTAICS APPLICATIONS IN TURKEY

**Nasim S Esmailzad<sup>1</sup>, Talat Özden<sup>1,2</sup>**

<sup>1</sup>ODTU-GUNAM, Cankaya, Ankara, Turkey

<sup>2</sup>Gumushane University, Department of Electrical and Electronics Engineering, Gumushane, Turkey

New approaches and perspectives have emerged in response to the growing demand for photovoltaics as a key component in many countries' energy transition strategies—which includes land use issues as well as concerns about landscape transformation, biodiversity, ecosystems, and human well-being. Agrivoltaics is developing as one of the most promising technologies for offering benefits in the food-energy (and water) nexus (Weselek et al. 2019).

Different Agrophotovoltaic (APV) projects are being developed worldwide. However, their applicability and influence on agricultural productivity have received little attention (Toledo and Scognamiglio 2021). Our main purpose is to establish APV projects in Turkey and survey the potential effects of these projects on crops. These projects not only assist farmers in reducing their energy consumption costs in their farming areas but also improve crop yields in many cases. Given the effects of climate change and circumstances in arid climate areas, including the Mediterranean region, crop output may benefit from shading and increased water productivity provided by APV structures.

In this study, we provide a brief overview of the present state of the art and potential applications for APV systems. We plan to use a thorough, detailed analysis in the field and propose a comprehensive methodology based on design and performance parameters that allow us to define suitable structures in Turkey.

### **Keywords**

Agrophotovoltaic, Agrivoltaic, Photovoltaics, Crop production

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08

## ANALYSIS OF MECHANICAL AND ELECTRICAL EFFECTS OF DIFFERENT CUTTING METHODS ON M10 PERC SOLAR CELLS

**Bedrettin Aydoğan<sup>1</sup>, Betül Şekertekin<sup>1</sup>, Meriç Çalışkan<sup>1</sup>, Fırat Es<sup>1</sup>, Şule Özdemir<sup>2</sup>**

<sup>1</sup>Kalyon PV Güneş Teknolojileri Fabrikası

<sup>2</sup>Kocaeli Üniversitesi, Kocaeli

Half cut solar cell technology is an advanced version over the traditional solar cell due to the efficiency increase in many aspects. To observe the effects of cutting technologies, two different cutting methods on module performance were investigated. The laser drawing and splitting method is based on a laser ablation process that creates a full-length scratch along the half-cell edge. In some cases, this scratch doesn't separate the cell, but results in a groove with a depth of about half the cell thickness. Next, the mechanical rupture of the cell, guided by the laser, takes place. The Thermal Laser Separation (TLS) method occurs with a nonablative process in which a small crack is first induced, then propagated by applying a highly localized thermal gradient to the material along the half-cell edge. This thermal gradient causes some local mechanical stress within the cell, causing the crack to propagate. In this paper the mechanical strength of the cells that were cut by two different cutting methods, was compared by applying the four-point bending test. It was determined that the mechanical strength of the cells cut with the "TLS" method was 38% higher. The Voc and pFF values of corresponding halved M10 cells were compared with Sun Voc characterization technique. No significant difference was detected for the Voc values of the half cut M10 cells (Figure 1). Similarly, when the pseudo fill factor values were compared, it was observed that it was close to 84% in both methods (Figure 2).

### Keywords

Half Cell Technology, Laser Drawing and Splitting, Thermomechanical Cell Separation

Figure

09

## ANGLE INDEPENDENT DIFFRACTIVE OPTICAL ELEMENTS TO IMPROVE THE EFFICIENCY OF SOLAR CELLS

**Parisa Naghinazhadahmadi<sup>1,2</sup>, Berk Nezir Gun<sup>1,3</sup>, Sena Atila<sup>1,2,3</sup>, Alim Yolalmaz<sup>1,2,3</sup>,  
Emre Yuce<sup>1,2,3</sup>**

<sup>1</sup>Programmable Photonics Group, Department of Physics, Middle East Technical University, 06800 Ankara, Turkey

<sup>2</sup>Micro and Nanotechnology Program, Middle East Technical University, 06800 Ankara, Turkey

<sup>3</sup>Center for Solar Energy Research and Applications (GUNAM), Middle East Technical University, 06800, Ankara, Turkey

The broadband spectrum of the sunlight, which contains wavelengths of 350 nm-2000 nm, and the daily and seasonal variations of the incident angle are the most important factors that largely affect the solar panels<sup>1,2</sup>. Combining diffractive optical elements (DOEs) and multi-junction solar cells are considered promising solutions<sup>3</sup>. However, DOEs are mainly designed and optimized to operate under normal incident angles, hindering their use in solar cell applications. Therefore, the response of DOEs under angled illuminations is of paramount importance in these applications. This study uses an experimental approach to split and concentrate broadband radiation using a DOE operating under angled illumination. In our setup, a phase-only spatial light modulator (SLM) is used to emulate the DOE, where the thickness variations in the DOE are emulated by controlling and modifying the refractive index in the SLM<sup>4,5</sup>. By programming a SLM, the desired pattern of the DOE has been examined. The broadband spectrum splitting and concentration regions are chosen for red (560 nm-875 nm), green (425 nm-620 nm), and blue (420 nm-535 nm) wavelengths. We obtain 60%, 51%, and 60% spectral splitting ratios with an enhancement factor of 206%, 196%, and 210% for red, green, and blue channels, respectively.

### Keywords

Solar energy, spectral splitting, spatial light modulator, diffractive optical element

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O10

**BIFACIAL N-PERT SOLAR CELLS FABRICATED BY ALTERNATIVE INDUSTRIAL MANUFACTURING METHODS****Gence Bektaş<sup>1,2</sup>, Ahmet Emin Keçeci<sup>1,2</sup>, Hasan Hüseyin Canar<sup>1,3</sup>, Hasan Asav<sup>1,2</sup>, Selin Seyrek<sup>1,3</sup>, Sümeyye Koçak Bütüner<sup>1</sup>, Raşit Turan<sup>1,2,3</sup>**<sup>1</sup>Center for Solar Energy Research and Applications (ODTU-GUNAM), Ankara, Turkey<sup>2</sup>Micro and Nanotechnology, Middle East Technical University, Ankara, Turkey<sup>3</sup>Department of Physics, Middle East Technical University, Ankara, Turkey

Bifacial solar cells have the potential to produce more power than monofacial ones due to higher photogenerated current since they take advantage of the albedo light. N-PERT with higher bifaciality compared to PERC solar cells attract attention but the requirement for doping two different species at the front and rear surfaces makes the fabrication of n-PERT solar cells relatively complex. In this work, we present five alternative process flows and compare the cell performance fabricated by each method. For the emitter and back surface field (BSF) formation, we utilize either diffusion or ion implantation methods. Our results show that boron (B) diffused emitter compared to implanted one yields a significantly higher open-circuit voltage ( $V_{oc}$ ) on the fabricated devices. The cells with diffused emitter and either diffused or implanted BSF have similar  $V_{oc}$  values for rear textured surfaces; however, the cells with single side etched rear surfaces and implanted BSF have approximately 5 mV higher  $V_{oc}$  compared to others. We obtain a higher performance on fabricated n-PERT solar cells with relatively lower process complexities, thus for the ones with B-diffused emitter and phosphorus(P)-implanted BSF. Our champion solar cells with B-diffused emitter and P-implanted BSF on single side etched surface have a power conversion efficiency of 20.54% from the front side with bifaciality of 0.89%.

**Keywords**

n-PERT solar cell, bifaciality, process complexity, diffusion, ion implantation

Figure 1. The alternative process flows applied in fabrication of bifacial n-PERT solar cells in thi

O11

## CHARACTERIZATION OF THIN FILM CZTSSE ABSORBER BACK SIDE SYNTHESIZED BY HOT INJECTION METHOD

**Ahmed Javed<sup>1</sup>, Selcuk Yerci<sup>1</sup>, Michael Jones<sup>2</sup>, Yongtao Qu<sup>2</sup>, Vincent Barrioz<sup>2</sup>,  
Stephen Campbell<sup>2</sup>, Oliver Hutter<sup>2</sup>, Linzi Dodd<sup>2</sup>**

<sup>1</sup>Middle East Technical University, Ankara, Turkey

<sup>2</sup>University of Northumbria, Newcastle, England

Among thin film photovoltaic devices, Copper-Zinc-Tin-Sulfide-Selenide (CZTSSe) offers a promising alternative to CIGSSe and CdTe due to its less toxic and Earth-abundant composition. However, its highest reached efficiency of 12.6% is still far below from the champion CIGSSe cell efficiency of 23.35% showing potential for improvement among CZTSSe solar cells. Major culprit in hindering the efficiency is high Voc deficit (around 350-500mV). Voc deficits in CZTSSe are caused by high number of both bulk and interface defects that encourages recombination events. Various solution-based methods have been widely used for CZTSSe synthesis.

We have utilized CZTSSe absorber synthesized by a hot injection-based method for characterization. In the synthesis process, toluene is used as a solvent (for the precursors mixture) which leaves carbon residues at the back side of synthesized CZTSSe absorber. This back side is in contact with glass substrate therefore carbon gets locked there and becomes detrimental for smooth carrier transport. A careful peel off procedure can expose this back side with carbon rich content. Our XPS study on back side revealed that concentration of carbon and oxygen are highest whereas Cu, Zn, and Sn are lowest at the surface. The argon ion sputtering technique in XPS enabled us to investigate the material deeper. This further revealed that carbon and oxygen decreased gradually while other elements increased at larger depth. We have attempted wet etching to eliminate this carbon rich layer from the bottom side. Upon complete removal of impure layer, it is expected that it would enhance PV performance of this device.

### Keywords

CZTSSe, Carbon, XPS, Characterization, Wet Etching

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012

## CLASSIFICATION OF SOLAR CELLS EL IMAGES WITH DIFFERENT BUSBARS VIA DEEP LEARNING MODELS

**Miktat Aktaş<sup>1</sup>, Ferdi Doğan<sup>2</sup>, Ibrahim Türkoğlu<sup>3</sup>**

<sup>1</sup>GTC GUNES SAN. ve TIC. A.S./R&D Center, Adiyaman, Turkey

<sup>2</sup>ADIYAMAN UNIVERSITY/Department Of Computer Engineering, Adiyaman, Turkey

<sup>3</sup>FIRAT UNIVERSITY/Software Engineering, Elazig, Turkey

Renewable energy sources, especially solar energy sources, play an increasingly important role for alternative energy production methods. The solar energy cell is an indispensable part of the solar energy ecosystem, and defective cells cause financial losses in energy production. Experts in the field are needed to detect these errors in solar cells. Making processes with autonomous systems is an important way to accelerate the process by eliminating requirement of experts. AI techniques and deep learning models can be an important solution for this. In this study, AI techniques and deep learning models were used to classify solar cells. Mobilenet-v2, Darknet-19, Darknet-53, Alexnet, Googlenet, Vgg-16, Vgg-19, Resnet-50, Resnet-101, Densenet201 deep learning models and SVM and KNN machine learning algorithms were used. Electroluminescence images of defective and normal solar cells with 4 and 5 busbars were used in the study. The dataset provided by GTC, includes 9360 images of solar cells, 4680 of which are defective and 4680 are normal. Performance evaluation of the models made according to the confusion matrix and F1 score obtained from this matrix. According to the results, Mobilenet-v2 and VGG-19 achieved the highest validation accuracy rate of 99.68%. According to F1 scores, Mobilenet-v2 achieved the highest performance of 99.73%. It has been shown that the Mobilenet-v2 is more successful than other models in terms Accuracy and F1-score. The results show trained DL models can be used as an inspection method in the production line of solar panels and cells. Thus, financial losses can be prevented by using classification of solar cells via DL models.

### Keywords

solar cells, deep learning, Image processing, EL Image, defects

013

## **COST-BENEFIT ANALYSIS OF USING PV SYSTEMS ONBOARD ELECTRIC FERRIES**

**Caner Pense<sup>1</sup>, Bulent G. Akinoglu<sup>1</sup>**

<sup>1</sup>*Earth System Sciences, Graduate School of Natural and Applied Sciences, Middle East Technical University,  
06800, Ankara, Turkey*

Expected effects of Global Warming and Climate Change in the following decades are major drivers to change how industries operate since the 1970s. From the 1972 Stockholm Declaration to the 2016 Paris Agreement; the way we live and our knowledge of our effect on the environment has changed tremendously. Our needs, our industries, and with them, the maritime transportation sector have changed in an unforeseen manner. The maritime transportation sector is responsible for Greenhouse Gas and Particulate Matter emissions comparable to advanced industrious nations. There are various advances to reduce this emission, such as the electrification of ships. Today, more than 200 ships use battery systems to increase energy efficiency and lower or even reach zero emission levels. However, electric ships still need to be recharged. It is possible to reduce the total costs of electric energy used for charging ferries by utilizing freely available solar energy. In our study, we will conduct a cost-benefit analysis of using PV systems onboard hypothetical full-electric catamaran passenger ferries and car ferries that can be operated in Turkey.

### **Keywords**

Renewable energy, solar power, electric ships, electric ferries, intelligent transportation systems

O14

## CURRENT STATUS OF SILICON HETEROJUNCTION AND WIDE BAND GAP CARRIER SELECTIVE SOLAR CELLS

**Ergi Dönerçark<sup>1</sup>, Arghavan Salimi<sup>1,2</sup>, Seda Kılıçkaya<sup>1</sup>, Emine Hande Çiftpınar<sup>1</sup>,  
Milad Ghasemi<sup>1,2</sup>, Konstantin Tsoi<sup>1</sup>, Sümeyye Koçak Bütüner<sup>1</sup>, Büşra Altınsoy<sup>1,2</sup>,  
Hisham Nasser<sup>1</sup>, Mehmet Koç<sup>1</sup>, Raşit Turan<sup>1,2,3</sup>**

<sup>1</sup>ODTÜ-GÜNAM, Ankara, Turkey

<sup>2</sup>Middle East Technical University, Micro and Nanotechnology Department, Ankara, Turkey

<sup>3</sup>Middle East Technical University, Physics Department, Ankara, Turkey

The photovoltaic (PV) industry is dominated by silicon-based solar cells owing to the abundance of silicon and its full-fledged technology. The main road map for the PV industry points out to enhance the conversion efficiency of solar cells while decreasing production costs, which is crucial for improving the capacity of renewable energy. The silicon heterojunction solar cells (SHJ) are receiving attention on this road map due to their higher conversion efficiencies, simple process flow, and low-temperature fabrication sequence. In order to further enhance the SHJ device performance, both electrical and optical properties should be improved simultaneously.

In this work, we have addressed various aspects of SHJ solar cells, such as surface texturing, surface passivation, and wide band gap material choices for the emitter. The surface passivation of silicon was studied using different process conditions and material systems. The SHJ solar cell performance was significantly improved by understanding the chemical passivation kinetics and improving the surface passivation quality. Moreover, wide band gap materials were integrated into the SHJ solar cell structure to decrease parasitic absorption losses. Furthermore, the free-carrier absorption losses were reduced significantly by tuning TCO's electrical and optical properties. Lastly, the metal contact properties of the SHJ solar cells were enhanced by the optimization of the screen-printing conditions. With these new material systems and process improvements, we have achieved high-efficiency values of up to 21.2% in the SHJ solar cells fabricated at ODTÜ-GÜNAM.

### Keywords

Silicon heterojunction solar cell, wide band gap, surface passivation, metallization.

O15

## DEFECT CHARACTERIZATION OF HETEROJUNCTION BASED ON BLACK SILICON

**Alexander S. Gudovskikh<sup>1</sup>, Artem I. Baranov<sup>1</sup>, Alexander V. Uvarov<sup>1</sup>, Ekaterina A. Vyacheslavova<sup>1</sup>, Alina A. Maksimova<sup>1</sup>, Ergi Dönerçark<sup>2</sup>, Rasit Turan<sup>2</sup>**

<sup>1</sup>*Alferov University, Renewable energy laboratory, Saint-Petersburg, Russia*

<sup>2</sup>*ODTÜ-GÜNAM, Ankara, Turkey*

A combination of black silicon and heterojunction solar cell technology with a bifacial design could potentially increase solar cell efficiency, especially in the case when angle dependency does matter. However, to reach such advantages, it is necessary to find a way to produce black silicon surface with low defect density located at the interface, which could provide excellent optical properties and passivation. Black silicon is mainly fabricated by a dry plasma process, which could produce radiation defects that leads to the degradation of the minority charge carrier lifetime [1]. Thus, special attention should be paid to the study of heterojunction interfaces and their electrical properties. The main experimental studies of the heterojunctions were performed by using admittance spectroscopy, deep level transient spectroscopy, and temperature dependence of I-V curve. In this study, we performed and analyzed how different etching processes (RIE, ICP, and cryogenic ICP) and conditions might affect defect formation in Si. ICP process, which could keep a charge carrier lifetime value up to 5 ms, was demonstrated to be preferable in terms of plasma-induced damages in Si. However, to reach such values a special attention should be paid to avoid contamination of etching chamber. Moreover, we investigated the surface passivation quality of different morphologies and treatments based on black Si for silicon heterojunction solar cell application. A significant interface defect density determined for the fabricated heterojunctions indicates the importance of this issue. Different approaches, including wet chemical and thermal treatments, are explored to decrease defect densities at the interface.

### Keywords

Heterojunction, solar cells, black silicon, dry etching, defects

Figure 1. DLTS signal curves for RIE and ICP (contaminated and cleaned chamber) process. No defect r

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O16

## DESIGN, PRODUCTION AND PERFORMANCE EVALUATION OF SOLAR MIRRORS WITH AND WITHOUT CU

**Gülşah Kahraman<sup>1</sup>, Zeynep Aydın<sup>1</sup>, Haluk Erdem<sup>1</sup>**

*<sup>1</sup>Türkiye Şişe ve Cam Fabrikaları A.Ş., Şişecam Science and Technology Center, Atmospheric Coating Technologies Management, Kocaeli, Turkey*

Şişecam contributes to sustainability on a global scale with innovative products developed to support the renewable energy sector. Şişecam's most recent achievement in the field is the Şişecam solar mirror, which is an ultra-clear high reflectivity glass mirror appropriate for use in solar tower collectors. This highly qualified and environmentally safe product has a composition (silver, copper, two paint layers) that provides a very high chemical and mechanical endurance. The new generation of Şişecam solar mirror products offers good reflection values, a high degree of safety and excellent chemical resistance. Copper (Cu) has long been a key component in the manufacture of silvered-glass reflectors used in concentrated solar power (CSP) systems [1]. However, because of the increased material prices and environmental burdens, we have focused on strategies to develop copper-free reflecting mirrors for solar thermal applications. Here, we developed two different versions of glass based solar mirrors with and without copper. Additionally, we compare their performances in terms of accelerated aging tests to obtain the aging characteristics of reflective surfaces. Our findings not only compare optical capabilities, but also provide design goals for the future generation of copper-free reflecting surfaces. In this study, the most significant durability experiments done on the two types of glass-based solar mirrors and prospective techniques for enhancing future attempts are discussed.

### **Keywords**

Solar reflector, Copper free mirror, Accelerated aging testing, Durability, Concentrated solar power

017

## DETERMINATION OF CONTACT RESISTIVITY USING COX-STRACK AND FOUR-POINT PROBE METHODS

Deniz Türkay<sup>1,3</sup>, Konstantin Tsoi<sup>1,2</sup>, Ergi Dönerçark<sup>1,4</sup>, Raşit Turan<sup>1,4</sup>, Selçuk Yerci<sup>1,2,3</sup>

<sup>1</sup>ODTÜ-GÜNAM, Ankara, Turkey

<sup>2</sup>Department of Electrical and Electronics Engineering, Middle East Technical University, Ankara, Turkey

<sup>3</sup>Department of Micro and Nanotechnology, Middle East Technical University, Ankara, Turkey

<sup>4</sup>Department of Physics, Middle East Technical University, Ankara, Turkey

With the introduction of alternative silicon-based solar technologies incorporating low-temperature processed materials, passivating heterocontacts, accurate characterization (determination of passivation and contact resistivity) of new interfaces is of particular interest. For an accurate analysis of a particular interface, one could benefit from understanding the working principles of utilized characterization methods. In this work, we present an overview of two methods for determining the contact resistivity ( $p_c$ ), namely, Cox and Strack (CS) and four-point probe (4PP) methods. We discuss their advantages and disadvantages and propose a guideline for when to use them or when it is best to turn to other methods like Transfer Length Method (TLM). Furthermore, based on our recent work [1], [2], we present extensions to these methods [extended CS (ECS) and 4PP methods (E4PP)], which help overcome some of their intrinsic shortcomings, such as time-consuming fabrication of test samples, expensive process flows in terms of material consumption, and complicated numerical analysis. We outline a detailed procedure for developing the extended versions. We show that the proposed formulations agree well with simulations (performed in COMSOL software) and demonstrate their applicability experimentally by comparing  $p_c$  determined using proposed methods with those obtained by the standard ones (e.g., TLM). Moreover, we offer a guided user interface for both the 4PP and E4PP methods that allows to perform quick analysis of the experimental data and calculate  $p_c$  based on the measured sheet resistance values. Finally, we will also discuss possibilities of extending these methods to measure  $p_c$  of thin film solar cells.

### Keywords

Contact resistivity, Cox and Strack, Transfer Length Method, Four-point probe

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018

## DEVELOPMENT AND FUTURE OF TURKEY'S PHOTOVOLTAIC INSTALLED POWER

**Selen Çekinir<sup>1</sup>, Önder Özgener<sup>2</sup>, Leyla Özgener<sup>3</sup>**

<sup>1</sup>Yasar University / Computer Technologies, Izmir, Turkey; Ege University / Solar Energy Institute, Izmir, Turkey

<sup>2</sup>Ege University / Solar Energy Institute, Izmir, Turkey

<sup>3</sup>Celal Bayar University / Mechanical Engineering, Manisa, Turkey

Turkey, which is very rich in renewable energy resources, plans to increase the use of these resources in electricity production. In this direction, it wants to increase investments in this field with various incentive mechanisms. The use of solar energy in electricity production has increased significantly in recent years and will continue to increase in line with Turkey's future targets. In this study, the share of solar energy in electricity production and its future prediction are stated. In addition, it was emphasized why Turkey should increase the use of renewable energy.

### Keywords

European Green Deal, Paris Agreement, PV System, electricity generation, installed power

Renewable-based installed power by years

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019

## DEVELOPMENT OF LOW-COST C-SI-BASED CPV CELLS FOR SOLAR CO-GENERATION ABSORBER IN PARABOLIC TROUGH COLLECTORS

**Elsen Aydin<sup>1,2</sup>, Armin Buchroithner<sup>3</sup>, Richard Felsberger<sup>3</sup>, Rupert Preßmair<sup>3</sup>, Raşit Turan<sup>1,4,5</sup>, Bulent G. Akinoglu<sup>1,4,6</sup>**

<sup>1</sup>Center for Solar Energy Research and Applications (GÜNAM), METU, Ankara, Turkey

<sup>2</sup>Archaeometry, Middle East Technical University, Ankara, Turkey

<sup>3</sup>Institute of Electrical Measurement and Sensor Systems (EMS) Graz University of Technology (TUG), Austria

<sup>4</sup>Department of Physics, Middle East Technical University, Ankara, Turkey

<sup>5</sup>Department of Micro and Nanotechnology Middle East Technical University, Ankara, Turkey

<sup>6</sup>Earth System Science Program, Graduate School of Natural and Applied Sciences, Middle East Technical University, Ankara, Turkey

In recent years, several Parabolic trough collectors (PTCs) incorporating absorber tubes equipped with concentrator photovoltaics (CPV) have emerged, resulting in efficient hybrid (CPV-T) absorbers providing both, process heat and electricity. Higher efficiencies are possible in the near future and this technology is still considered somewhat of a niche product, mainly due to increased system complexity and cost.

Within the framework of an international research project called ECOSun, efforts are undertaken to drastically reduce the cost of CPV-cell that is designed to work under concentrated sunlight. This replaces much more expensive GaAs multi-junction cells, which are usually used in CPV applications. In this context, the simulations of CPV cell's metal design (busbar width, finger number, finger length and width and finger space etc.) was obtained with Griddler Pro 2.5 and some basic cell parameters were carried out such as high phosphor doping, cell type, junction depth etc. and these cells will be working at 90 °C.

Additionally, to take measurements under different concentration, produced cell were laminated and their performance was measured. These measurements were taken at Graz University of Technology (TUG) solar simulator and ODTÜ-GÜNAM simulator and results were compared. Preliminary results that we obtained that some of the cells  $V_{oc}$  reach to 683 mV and their efficiency nearly to 13,5% for mono-junction mono-crystalline Si solar cells.

### Keywords

CPV-T, PV, CPV, c-Si Solar Cell

O20

**DOPED GRAPHENE-CZTS THIN FILM SOLAR CELLS****Serkan Erkan<sup>1</sup>, Ali Altuntepe<sup>2</sup>, Recep Zan<sup>1</sup>, Mehmet Ali Olğar<sup>1</sup>**<sup>1</sup>Niğde Ömer Halisdemir University, Department of Physics, Niğde, Turkey<sup>2</sup>Niğde Ömer Halisdemir University, Nanotechnology Application and Research Center, Niğde, Turkey

Cu<sub>2</sub>ZnSnS<sub>4</sub> (CZTS) thin films have attractive absorber properties such as high absorption coefficient ( $>10^4 \text{ cm}^{-1}$ ), 1.4-1.5 eV optical band gap, p-type conductivity [1]. However, the current record efficiency (12.6%) is still far behind the theoretical limit (~30%) [2]. The efficiency of CZTS solar cells depends on many factors such as the crystalline quality of CZTS and selection of n-type buffer layer. CdS is the most widely used material as a buffer layer. However, the toxicity of the Cd and the band alignment problems have led to search for alternative materials [3]. 2D materials have gained great attention due to their outstanding properties [4]. The graphene has superior conductivity that provided better collection of charge carriers thus contributing significant improvement in the cell efficiency. However, high sheet resistance of graphene has been shown as a big problem. To overcome this issue, doping strategy (nitrogen/boron) have been carried out in the literature [5]. Thus, nitrogen doped graphene films was used as a buffer layer instead of CdS in this study. The CZTS thin films were deposited by magnetron sputtering and the graphene sheets was synthesized by CVD method. XRD and Raman spectroscopy measurements confirmed formation of kesterite CZTS phase. Raman spectroscopy and AFM measurements revealed that single and homogenous graphene film structure was obtained. The solar cell structure (Mo/CZTS/doped-graphene/i-ZnO/ITO/Ag) was fabricated and characterized by I-V measurement that revealed 2.5% conversion efficiency.

This research was supported by The Scientific and Technological Research Council of Turkey (TUBITAK) with the project number of 120F275.

**Keywords**

CZTS, Doped-graphene, Sputtering, CVD, Solar cell

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021

## EFFECT OF CONTACT RESISTANCE ON SERIES RESISTANCE OF SILVER NANOWIRE TRANSPARENT ELECTRODES

**M. Mustafa Çodur<sup>1,2</sup>, Konstantin Tsoi<sup>3</sup>, Mehmet Koc<sup>3</sup>, H. Emrah Unalan<sup>4</sup>, Selcuk Yerci<sup>1,3,5</sup>**

<sup>1</sup>Department of Micro and Nanotechnology, Middle East Technical University, 06800 Ankara, Turkey

<sup>2</sup>Department of Electrical and Electronics Engineering, Erzurum Technical University, Erzurum, Turkey

<sup>3</sup>ODTU-GUNAM, Middle East Technical University, 06800 Ankara, Turkey

<sup>4</sup>Department of Metallurgical and Materials Engineering, Middle East Technical University, 06800 Ankara, Turkey

<sup>5</sup>Department of Electrical and Electronics Engineering, Middle East Technical University, 06800 Ankara, Turkey

The brittle nature of the transparent conductive oxides, common TCEs, restricts their use as flexible electrodes, which leads to the development of metal nanowires (e.g., silver nanowires, Ag-NW) as an alternative solution. To implement them into the photonic devices, the optoelectronic properties (i.e., optical transparency and electrical resistance) of Ag-NW electrodes need to be optimized. Transparency and resistance are typically inversely proportional, meaning the more transparent Ag-NW networks have larger resistive losses. While the transparency depends on the coverage of nanowires on the surface, the resistance consists of two major resistance sources (1) junction resistance between coinciding nanowires and (2) contact resistance between the nanowires and the underlying layer.

Typically, in the devices with Ag-NWs, it is assumed that the major resistive losses arise from the NW-NW junctions. Therefore, there is an emphasis on decreasing the junction resistance of NWs, and numerous methods have been developed, such as light-assisted welding, joule heating, and thermal annealing. However, contact resistance (between the NW and underlying layer) is another resistive source that is usually overlooked. In this work, we show that the contact resistance can have a more significant effect on the electrical performance of Ag-NW networks than the junction resistance in certain scenarios. We arrive at this conclusion by building a custom simulation tool that estimates resistive losses in terms of series resistance. Moreover, the tool paves the way for simulating a solar cell with an Ag-NW electrode because it provides a series resistance of a random network.

### Keywords

silver nanowires, transparent conductive electrodes, junction resistance, contact resistance,

022

## EVALUATION OF THE POSSIBILITIES FOR HIGH VOLTAGE USE IN SOLAR INVERTERS

**Ahmet Yıldız<sup>1</sup>, Önder Özgener<sup>2</sup>, Leyla Özgener<sup>3</sup>**

<sup>1</sup>Natural and Applied Sciences, Solar Energy Institute, Ege University Bornova, Izmir TR 35100, Turkey

<sup>2</sup>Solar Energy Institute, Ege University, Bornova, TR 35100 Izmir, Turkey,

<sup>3</sup>Department of Mechanical Engineering, Faculty of Engineering, Manisa Celal Bayar University, Muradiye, TR 45140 Manisa, Turkey

This study aims to evaluate the use of different AC voltage levels for solar inverters. It is generally a less discussed area for solar systems. Customary solar fields use low voltage solar inverters and step up transformers to transfer the photovoltaic electricity to the interconnected grid. While systems such as 0.33 kV, 0.4 kV and 0.7 kV at low voltage level are used, high voltage systems above 1 kV are not preferred commercially. Although there are some studies in literature criticizing the effects of raising the voltage, there are deficiencies in the application at the experimental level. The scope of work includes realizing a solar inverter at high voltage level, as well as comparing its advantages and disadvantages. Hence, the suitability can be checked for different power values and the optimization can be possible with considering voltage level and power value together. This study is unique in that it comprehensively covers different inverter output voltages. In addition, it is rare that need for new connection structure is emphasized, especially for GW sized photovoltaic sites. It is clear that solar energy gaining more and more importance due to decreasing installation cost. Despite the inverters have secondary importance for photovoltaic sites, they become important with large scale installations.

### Keywords

Solar inverters, voltage comparison, high voltage use, inverter size optimization, inverter voltage optimization

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023

## EXPLORING THE EFFECTS OF INORGANIC HOLE TRANSPORT LAYERS ON THE PERFORMANCE OF ANTIMONY SELENIDE SOLAR CELLS

Stephen Campbell<sup>1</sup>, Laurie Phillips<sup>2</sup>, Jon Major<sup>3</sup>, Oliver Hutter<sup>1</sup>, Ryan Voyce<sup>1</sup>,  
Yongtao Qu<sup>1</sup>, Neil Beattie<sup>1</sup>, Guillaume Zoppi<sup>1</sup>, Vincent Barrioz<sup>1</sup>

<sup>1</sup>Northumbria University, Department of Mathematics, Physics and Electrical Engineering, Newcastle Upon Tyne, UK

<sup>2</sup>University of Liverpool, Department of Physics, Liverpool, UK

<sup>3</sup>University of Liverpool, Stephenson Institute for Renewable Energy, Liverpool, UK

To explore long-term alternative to silicon wafer photovoltaics (PV), for applications such as BIPV, the PV research field is investigating emerging absorber materials with Earth abundance, low toxicity, high stability and low fabrication costs. Candidate absorber materials include antimony-based chalcogenides such as binary selenides ( $\text{Sb}_2\text{Se}_3$ ), sulphides ( $\text{Sb}_2\text{S}_3$ ) and sulfoselenides, having near-ideal optical bandgap energy range 1.1 - 1.7 eV [1] and large absorption coefficient ( $> 10^5 \text{ cm}^{-1}$ ) [2]. They also have an interesting nanoribbon grain structure, unlike conventional thin film absorbers, with no limiting grain boundary effects [3]. At present, these devices are limited by a low open-circuit voltage ( $V_{oc}$ )  $< 440 \text{ mV}$  [4] but have rapidly developed to  $> 9 \%$  efficiency [5]. One of the challenges is to investigate routes to overcome such voltage limitation caused by carriers recombination at the metallic back contact interface. In this study, two p-type inorganic oxides layers, namely  $\text{MoO}_x$  and  $\text{NiO}$ , have been investigated as hole transport layers (HTL) for  $\text{Sb}_2\text{Se}_3$  devices fabricated in both substrate and superstrate configurations. Solar cell capacitance simulator (SCAPS) was conducted to interpret the effect of HTLs on  $\text{Sb}_2\text{Se}_3$  device characteristics. This revealed the critical role of  $\text{NiO}$  and  $\text{MoO}_x$  in altering the energy band alignment and increasing device performance due to the high energy barrier to electrons introduced at the rear absorber/metal interface. Closed-space sublimation and thermal evaporation techniques were used to deposit the  $\text{Sb}_2\text{Se}_3$  absorbers, while the HTLs were E-beam evaporated in both device configurations. Their effect on  $\text{Sb}_2\text{Se}_3$  crystallinity and SC performance will be comprehensively reported.

Acknowledgements: EPSRC-Collaborative-Flex-fund-NECEM-(EP/R021503/1); EPSRC-CDT-in-ReNU-(EP/S023836/1); British-Council-Newton-Fund-(UK-Turkey)-(623804307).

### Keywords

$\text{Sb}_2\text{Se}_3$ , photovoltaic, inorganic hole transport layers, SCAPS, thin films

Figure 1. Standard planar (A) superstrate and (B) substrate configuration  $\text{Sb}_2\text{Se}_3$  solar cells.

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O24

## EXPLORING THE ROLE OF TEMPERATURE ON THE RIBBON ORIENTATION OF SB<sub>2</sub>SE<sub>3</sub> SOLAR CELLS DEPOSITED VIA THERMAL EVAPORATION

**Ryan Voyce<sup>1</sup>, Stephen Campbell<sup>1</sup>, Oliver S. Hutter<sup>1</sup>, Guillaume Zoppi<sup>1</sup>, Neil S. Beattie<sup>1</sup>, Vincent Barrioz<sup>1</sup>**

<sup>1</sup>*Department of Mathematics, Physics and Electrical Engineering, Northumbria University, Newcastle Upon Tyne, United Kingdom*

Antimony selenide (Sb<sub>2</sub>Se<sub>3</sub>) has emerged as a promising candidate for next generation solar cell devices due to its non-toxicity, low cost, and earth abundance. Coupling these factors with its promising optoelectrical properties of its high absorption coefficient and almost ideal band gap for single-junction cells yields an incredibly attractive absorber material. Issues in the material come from poor carrier management, particularly in the mobility of photogenerated carriers within the absorber layer and through the immediate interfaces [1-2].

The orientation of the (Sb<sub>4</sub>Se<sub>6</sub>)<sub>n</sub> ribbons grown via thermal evaporation was investigated by varying the deposition temperature and the post-annealing treatment. Texture coefficient analysis was performed on x-ray diffraction (XRD) results across these temperature ranges which displayed a strong dependence on both the initial deposition temperature and the annealing temperature. Crystal structures formed in all films deposited above 250 °C but all could be recrystallized with various preferred orientations at annealed temperature of 200 °C. While fairly large differences in ribbon orientation were displayed in annealing variations, a greater emphasis should be placed on the initial deposition temperature since more significant transformations were present compared to effects caused by the annealing process. It was found that the deposition temperature of 300 °C was the most conducive to promoting ribbon orientations being perpendicular to the substrate and can be further enhanced by annealing treatments, especially at 100 °C.

### Keywords

Sb<sub>2</sub>Se<sub>3</sub>, thermal evaporation, thin-film solar cells

Texture coefficient analysis of (002) ribbon orientation across deposition & annealing temperatures.

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O25

## FLEXIBLE THIN FILM SOLAR CELLS USING PHOTONIC LIFT-OFF PROCESS

**Stephen Campbell<sup>1</sup>, Michael Jones<sup>1</sup>, Giulia Longo<sup>1</sup>, Neil Scott Beattie<sup>1</sup>, Guillaume Zoppi<sup>1</sup>, Vincent Barrioz<sup>1</sup>, Selcuk Yerci<sup>2</sup>, Yongtao Qu<sup>1</sup>**

<sup>1</sup>*Department of Mathematics, Physics and Electrical Engineering, Northumbria University, Newcastle upon Tyne NE1 8ST, United Kingdom*

<sup>2</sup>*Middle East Technical University, ODTU-GUNAM, Turkey*

The rapid development of wearable consumer electronics has increased the demand for environmentally-friendly, low-cost, robust and portable electricity generating sources to power them. To this end, thin film photovoltaic (PV) materials, such as  $\text{Cu}_2\text{ZnSn}(\text{S},\text{Se})_4$  (CZTSSe) and  $\text{Sb}_2\text{Se}_3$ , which can be deposited on a range of flexible substrates would facilitate the fabrication and integration of power supplying solar cells into wearable electronics. Fabricating PV devices on flexible materials such as plastic or fabric is often limited by the poor thermal stability of the chosen substrates, where it is necessary for the substrate to withstand elevated temperatures associated with the processing steps of PV materials. To mitigate, glass carriers are used during fabrication, but removing the thin film solar cell (TFSC) from the glass to transfer to a flexible substrate without damaging the device remains challenging.

To achieve this, we use a large-area, high-throughput photonic lift-off (PLO) process to rapidly detach the TFSC from the rigid glass substrate and be transferred to the flexible carrier (Figure 1). A very short pulse of broadband light separates the device at the Mo/absorber interface and exposes the rear surface of the absorber material. This enables treatment of the absorber surface prior to deposition of a hole transport layer and metallic back electrode to optimise energy band alignment at the metal/semiconductor interface and increase device performance. As such, ultralight TFSCs on flexible substrates can be fabricated and integrated into novel applications, such building-integrated photovoltaics and wearable electronics.

Acknowledgement: The authors appreciate the support from British Council Newton Fund Institutional Links Grant in Ultralight Absorber for Remote Energy Source (No.623804307).

### Keywords

CZTSSe,  $\text{Sb}_2\text{Se}_3$ , thin film solar cells, photonic lift-off, ultralight

Figure 1. Photonic lift-off process for flexible thin film solar cells

026

## FOOD AND ELECTRICITY PRODUCTION IN AGRICULTURAL GREENHOUSES IN MOROCCO. IS IT FEASIBLE?

Kabira Ezzaeri<sup>1</sup>

<sup>1</sup>Agadir

Using of solar photovoltaic panels in agricultural greenhouses could result in co-production of electricity and food products. The photovoltaic greenhouses based on integrating of photovoltaic modules above the roof of greenhouses in order to enhance the resilience of climate and allow energy production and sustainable food on the same time and same place. Whilst in the past it was a question of either solar energy or food production, photovoltaic greenhouse technology can married both successfully. This paper aims at identifying the use of PV modules in the roof of greenhouses that could be used to produce electricity with innovative and new solutions based on flexible opaque PV modules.

Measurements were carried out in an experimental Canary type greenhouse covered with flexible photovoltaic panels on 20% of its total roof area. Results illustrate that this occupancy rate of the photovoltaic panels arranged in checkerboard pattern does not have a significant effect on the agronomic parameters e.g. height, stem diameter and tomato yield...Additionally, the presence of photovoltaic panels has a negative effect on the development of the population of *Tuta absoluta*.

### Keywords

Tomato, photovoltaic panels, greenhouse, solar energy

027

## INCORPORATION OF ALKALI METAL INTO CDS THIN FILMS DURING CHEMICAL BATH DEPOSITION AS AN ALTERNATIVE STRATEGY FOR CU<sub>2</sub>ZNSNS<sub>4</sub> ABSORBER LAYER DOPING

**Caner Ildes<sup>1</sup>, Mehmet Ali Olgar<sup>2</sup>, Hatice Kanbur Cavus<sup>3</sup>, Bünyamin Ümsür<sup>4</sup>**

<sup>1</sup>Application and Research Center of Science and Technology (BILTEM), Yozgat Bozok University, , Yozgat, 66100, Turkey

<sup>2</sup>Department of Physics, Niğde Ömer Halisdemir University, Niğde, 51240, Turkey

<sup>3</sup>Department of Physics, Yozgat Bozok University, Yozgat, 66100, Turkey

<sup>4</sup>Department of Energy Science and Technology, Turkish-German University, 34820 Istanbul, Turkey

In this study, alkali doped CdS thin films grown by chemical bath deposition method that is used as a buffer layer in Cu<sub>2</sub>ZnSnS<sub>4</sub> (CZTS) thin film solar cells. Alkali metal doped CdS thin films were produced by adding of NaCl, KCl, CsCl and RbCl salts into the chemical bath solution as illustrated in Figure 1a. With this strategy, we aimed to dope the CZTS structure by alkali metals through the CdS buffer layer (see Fig 1b). The similar strategy was conducted by Sanchez et al. for doping CZTSe thin films [1]. In this way, the photovoltaic performance of CZTS thin film solar cell can be enhanced through preventing current leakage across the p-n heterojunction and establishing proper electronic band alignment [2, 3].

The CZTS thin films were prepared by two stage process that is deposition of precursor films by sputtering method followed by sulfurization process. The structural, optical and electrical properties of the CZTS and alkali metal doped CdS thin films were investigated by using FE-SEM, GI-XRD, Raman spectroscopy, Uv-Vis and HEMS measurements. We observed that alkali metal doping into the CdS thin film improved the structural, morphological and optical properties of this film as a first function at certain doping levels. The improved CdS thin films were employed in CZTS thin films and impact of alkali doping on photovoltaic performance of CZTS thin film solar cells was investigated.

### Keywords

Thin film solar cells, CdS buffer, alkali metal, Cu<sub>2</sub>ZnSnS<sub>4</sub>

Figure 1.a) Illustration of Alkali metal doping into the CBD, b) Sample illustration

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## INFLUENCE OF THE $\pi$ -BRIDGE IN CARBAZOLE-BASED HTMS FOR PEROVSKITE SOLAR CELLS

**Zouhair Elfakir<sup>1</sup>, Abdennacer Idrissi<sup>1</sup>, Redouan Atir<sup>1</sup>, Said Bouzakraoui<sup>1</sup>**

<sup>1</sup>IBN TOFAIL, chemistry, kenitra, Morocco

### Abstract:

Perovskite solar cells (PSCs) have attracted worldwide attention due to their improved power conversion efficiency (PCE) and ease of fabrication processes<sup>1-2</sup>. Hole transport materials (HTMs), an important active material in PSCs, are responsible for efficiently extracting holes at the perovskite/HTM interface and preventing unwanted charge transfer processes, thereby enhancing device performance. In this study, we focus on different carbazole-based HTMs and investigate the effect of  $\pi$  bridge on their structural and optoelectronic properties. The calculations are based on density functional theory, time-dependent density functional theory and Marcus theory. Important parameters such as electronegativity, solubility and stability, absorption and emission spectra, stock shift, exciton binding energies, and frontier molecular orbitals are identified and discussed.

### Keywords

perovskite solar cells, DFT TD-DFT, computational study

Figure: Molecular structures of the investigated HTMs.

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029

## INFLUENCE OF THICKNESS ON THE STRUCTURAL AND OPTICAL PROPERTIES OF ZNS THIN FILMS PREPARED BY SOL-GEL DIP COATING TECHNIQUES

**Ertugrul Sena Cagiltay<sup>1</sup>, Busra Kocakoc<sup>1</sup>, Baran Burhan Gunder<sup>1</sup>, Burcin Dag<sup>2</sup>, Yanki Gunduz Ozvaris<sup>1</sup>, Ali Kose<sup>1</sup>, Haslet Eksi Kocak<sup>3</sup>, Izzet Parug Duru<sup>4</sup>, Dogan Akcan<sup>5</sup>, Utku Canci Matur<sup>6</sup>**

<sup>1</sup>Department of Mechanical Engineering, Istanbul Gedik University, Istanbul, Turkey

<sup>2</sup>Department of Electrical and Electronics Engineering, Istanbul Gedik University, Istanbul, Turkey

<sup>3</sup>Department of Metallurgy and Materials Engineering, Istanbul Gedik University, Istanbul, Turkey

<sup>4</sup>Medical Imaging Programme, Istanbul Gedik University, Istanbul, Turkey

<sup>5</sup>Department of Mathematics, Faculty of Engineering and Natural Sciences, Bahcesehir University, Istanbul

<sup>6</sup>Energy Technologies Application and Research Center, Istanbul Gedik University, Istanbul, Turkey

II-VI group ZnS semiconductor with zinc blende and hexagonal wurtzite crystal structures are good candidates for solar cells, optoelectronics and ultraviolet light emitting diodes technologies with their wide band gap energy of 3.7 eV and 3.5 eV respectively. In this study ZnS thin films are deposited by sol-gel dip coating method layer by layer on glass substrates. The structural and optical properties of ZnS thin films are analysed at different thickness (10-20-30-40-50 layer). Structural and optical properties were investigated by means of XRD analysis, ultraviolet-visible (UV-VIS) and photoluminescence (PL) spectroscopy.

### Keywords

ZnS 1, solar cell 2, sol-gel 3

O30

## INSIGHT INTO IRON GETTERING IN SILICON BY PHOSPHORUS-IMPLANTED EMITTER

**Nabil Khelifati<sup>1</sup>, Hannu S. Laine<sup>2</sup>, Ville Vähänissi<sup>2</sup>, Ghania Fortas<sup>1</sup>, Hele Savin<sup>2</sup>,  
Faouzi Kezzoula<sup>1</sup>, Djoudi Bouhafs<sup>1</sup>**

<sup>1</sup>Research Center in Semiconductor Technology for the Energetic, Development of Semiconductor Conversion  
Devices Bd. 2 Frantz Fanon, les sept merveilles B.P.140, 16038, Algiers, Algeria

<sup>2</sup>Department of Micro- and Nanosciences, Aalto University, 02150, Espoo, Finland

In this work we have studied the efficacy of iron gettering in silicon by phosphorus-implanted emitter. The samples used are B-doped silicon wafers with Fe-contamination level around  $1.8 \times 10^{13} \text{ cm}^{-3}$ . The experimental details of samples preparation can be found in our previous work [1]. The investigation was essentially made according to the temperature and the annealing time, where the possible underlying mechanisms of gettering were discussed. The first findings showed that the bulk minority carrier lifetime increases monotonically with annealing time, and the order of magnitude of this increase directly depends on the gettering temperature which is varied between 550°C and 850°C. Furthermore, the carrier lifetime increment was found to be less important at higher annealing temperatures. The correlation between the carrier lifetime and interstitial iron concentration showed a linear relationship indicating an effective gettering (see Figure 1). On the other hand, the analysis of iron concentration variation according to the annealing temperature for different durations, demonstrated the presence of an optimum temperature, around which the gettering becomes more efficient. By using two-level-defects model [2, 3], the quantitative exploitation of the residual lifetime extracted from effective lifetime showed that the reduction of interstitial iron content is accompanied by a decrease in the recombination activity of defect centers with characteristics very similar to those of oxygen precipitates decorated by iron atoms. The results were interpreted by an effective segregation gettering of iron through their trapping in the implanted emitter, where SIMS analysis of this latter confirmed a significant iron accumulation of  $\sim 10^{18} \text{ cm}^{-3}$ .

### Keywords

Silicon, Iron gettering, P-implanted emitter, Carrier lifetime, SIMS

Figure 1

### References

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## IS THERE A MACROECONOMIC CARBON REBOUND EFFECT IN EU ETS?

**Cankut Kaan Bolat<sup>1</sup>, Uğur Soytaş<sup>2</sup>, Bülent G. Akınoğlu<sup>1</sup>, Şaban Nazlıoğlu<sup>3</sup>**

<sup>1</sup>Middle East Technical University, Graduate School of Natural Sciences, Earth System Science Department,  
Ankara, Turkey

<sup>2</sup>Denmark Technical University, Department of Technology, Management and Economics, Climate Economics  
and Risk Management, Lyngby, Denmark

<sup>3</sup>Pamukkale University, Faculty of Economics and Administrative Sciences, Department of International Trade  
& Finance, Denizli, Turkey

We collect annual data covering the 2005-2019 period for 26 European countries in order to measure the macroeconomic carbon rebound effect for the European Union Emissions Trading System. Conducting an econometric analysis on a panel data framework, we use growth equations to construct a panel regression model to see how emissions are affected by GDP, fixed capital formation, emissions allowances, energy intensity and labor. We also conduct a Granger causality analysis on the variables to see how the relationship is between them. Results show that a 1% increase in emissions allowances results in an increase of 7 - 8% on the emissions, in addition to a bidirectional Granger causality, indicating a self enforcing macroeconomic rebound that should be considered when evaluating the efficacy of EU ETS. Results also show a unidirectional causality from economic growth to emissions and energy intensity to allowances, showing that energy intensity significantly impacts emissions directly and indirectly, via the macroeconomic rebound effect. In line with our results, we make policy suggestions on how the macroeconomic carbon rebound can be dealt with.

### Keywords

ETS, Carbon Rebound Effect, EU, Panel Data

032

## KESTERITE THIN FILM SOLAR CELLS FROM NANOPARTICLE INKS

**Yongtao Qu<sup>1</sup>, Vincent Barrioz<sup>1</sup>, Stephen Campbell<sup>1</sup>, Michael Jones<sup>1</sup>, Selcuk Yerci<sup>2</sup>, Martial Duchamp<sup>3</sup>, Neil Beattie<sup>1</sup>, Guillaume Zoppi<sup>1</sup>**

<sup>1</sup>*Department of Mathematics, Physics and Electrical Engineering, Northumbria University, Newcastle upon Tyne NE1 8ST, United Kingdom*

<sup>2</sup>*Middle East Technical University, ODTU-GUNAM, Turkey*

<sup>3</sup>*Laboratory for In Situ and Operando Electron Nanoscopy, School of Materials Science and Engineering, Nanyang Technological University, 637371, Singapore*

Building upon the earth-abundant, low cost and excellent optoelectronic properties, kesterite has the added benefit of solution-based fabrication via nanoparticle inks decoupling purification steps for better compatibility with high volume and boasting much lower energy payback times. As summarized in Figure 1,  $\text{Cu}_2\text{ZnSnS}_4$  (CZTS) nanoparticles were synthesized by hot injection method. The resulting nanoparticle ink were deposited on Mo substrates and soft-baked to dry the precursor thin film and evaporate solvent molecules. CZTS thin films are then annealed in selenium atmosphere to introduce grain growth and fabricate  $\text{Cu}_2\text{ZnSn(S,Se)}_4$  (CZTSSe) light absorbers. The crystal structure and morphology change in the selenisation process is real-time observed inside a transmission electron microscope. S-Se exchange in nanoparticles starts at a low temperature of 200 °C, while CZTSSe grains with improved crystallinity grows at an elevated temperature of around 500 °C.

Flexible CZTSSe solar cells are further fabricated on a range of substrates, including Mo foil and ultrathin glass. 100 cycle loading test shows no degradation in flexible solar cell performance. Low temperature heat treatment is applied to overcome the poor charge extraction that developed in the natural aging process. It is suggested that defect states at aged CZTSSe/CdS heterojunctions were reduced while apparent doping density in the CZTSSe absorber increased due to Cd/Zn inter-diffusion at the heterojunction during the annealing process. Ultralight kesterite solar cells integrated on flexible substrates are promising to provide disruptively high specific power solar modules that are ideal for “self-powered” distributed IoT applications.

### Keywords

Kesterite, thin films, photovoltaic, nanoparticle inks, ultralight

Figure 1. CZTS nanoparticle inks and solar cells

033

## LOW COST SOLUTION PROCESSING AND ENVIRONMENTAL FRIENDLY NANOSTRUCTURES FOR SOLAR APPLICATION

Khalid Nouneh<sup>1</sup>

<sup>1</sup>Faculty of Science, University Ibn Tofail, Kenitra, Morocco

Thin films and metallic nanoparticles are the subject of growing interest in various fields of science and technology. Indeed, obtaining materials of controlled size and shape at the nanometric scale is a necessary prerequisite to develop many applications. The principle is to introduce nanostructures, for example nanoparticles, into a matrix or thin layer (metal, organic or inorganic material, etc.), to obtain specific properties of hardness, mechanical resistance, conductivity or electrical insulation, It is therefore now possible to build custom materials. The economic stakes are immense.

We are therefore interested in optimizing the physical methods combined with drift approaches soft chemistry synthesis techniques like spray ultrasonic mist CVD, SILAR and electrodeposition to grow high quality thin films layers for energy and environment applications [1-4]. In this presentation we will focus on the preparation of thin films layer based ZnO, ZnS, CuS, CZTS and CFTS. Very innovative ways to develop nanostructured alloys or metallic nanoparticles are also studied [5]. Indeed, the controlled synthesis of this type of system remains a major challenge: the arrangement of atoms necessary for the emergence of the desired property does not always correspond to the thermodynamically most stable state. There are several sought-after applications of these nano-objects and we are focusing, with our collaborators to develop optimal solutions.

### Keywords

Thin films, Ultrasonic Spray Assisted CVD, ZnO, ZnS, CZTS

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## **MANAGEMENT OF SOLAR SI-BASED PV WASTE IN TURKEY: A FUTURE PROJECTION AND PROPOSED METHODS**

**Ibrahim Tokgoz<sup>1</sup>, Canan Kandilli<sup>2</sup>, Abdullah Demir<sup>3</sup>**

<sup>1</sup>*Institute of Science, Technology Faculty, Department of Mechanical Engineering, Istanbul, Turkey*

<sup>2</sup>*Engineering Faculty, Department of Mechanical Engineering, Usak, Turkey*

<sup>3</sup>*Technology Faculty, Department of Mechanical Engineering, Istanbul, Turkey*

Solar capacities are increasing rapidly in Turkey in recent years, as in the world [1]. The facilities, built with 95% Si-based solar panels, reached a total capacity of 7950 MW by the end of 2021 [2,3]. On the other hand, local PV manufacturers, which also started to produce Si-based solar cells, increased their annual cumulative production capacity to approximately 6 GW with their new investments, thus providing a domestic market sufficient for increasing demands [4]. From solar power plants established in 2014, considering the annual production capacity of 6 GW and its 2053 carbon neutral targets, approximately 3 GW every year as of 2035, and approximately 5 GW every year as of 2040, As of 2045 it is estimated that approximately 8 GW Si-based solar panel waste will be revealed each year [5,6]. The aim of this study is to address the recycling of Si-based PV panels in the frame of many different aspects for Turkey, to draw a future projection that can help identify its current situation and select the best method; to discuss existing recycling methods and to provide an infrastructure for the creation of the model that is most suitable for Turkey [7,8]. Because when our focus on solar energy is supported by the sustainable waste management model, its contribution to reducing carbon emission rates will increase and will gain a great deal in achieving the zero-waste target [9,10].

### **Keywords**

Solar Waste, Recycle, Reuse, Sustainability, LCA

LCA and Techno Economic Assessment Model [11,12,13,14]

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035

## MODELING AND SIMULATING ROOFTOP SOLAR PHOTOVOLTAICS FOR THE BUILDINGS OF A UNIVERSITY CAMPUS

**Nesrin Irmak Köker<sup>1</sup>, **Bülent G. Akinoğlu**<sup>1,2,3</sup>**

<sup>1</sup>*Earth System Science Program, Graduate School of Natural and Applied Sciences, Middle East Technical University, Ankara, Turkey*

<sup>2</sup>*Department of Physics, Middle East Technical University, Ankara, Turkey*

<sup>3</sup>*Centre for Solar Energy Research and Application, Middle East Technical University, Ankara, Turkey*

As a country with high solar energy potential, Turkey has been growing its solar power capacity as part of the Sustainable Development Goals. In just 2021, solar power capacity increased by 17%. However, most of these implementations were photovoltaic solar power plants varying from 1 GW large-scale to 1 MW small-scale power plants. Over the past 5 years, the implications of these ongoing installments on the grid have been observed quite well. Despite being widely popular on global scale, photovoltaic panels on residential and non-residential rooftops are still not that common in Turkey but are expected to be in upcoming years. As a result, there is a need for research on the effects of multiple grid-connected rooftop photovoltaic applications on the total electricity demand of an area.

University campuses consist of buildings with varying levels of electricity consumption. Therefore they are an excellent sample for designing and analyzing rooftop photovoltaic panel installments. In this study, suitable rooftops on the Middle Eastern Technical University Campus, Ankara, Turkey is chosen for modeling and simulation since it contains lots of different types of buildings and roof types. Simulations are run over a year to observe the decrease in consumption and the effect of bulk rooftop photovoltaic installments. Results shed a light on the future of solar photovoltaics and the demand of energy, together with the handling of future smart grid organizations.

### **Keywords**

rooftop PV, green campus, solar energy

036

## NEW APPROACH FOR EVALUATING THE DISTRIBUTION OF SOILING PARTICLES SIZE ON THE SURFACE OF PV MODULES

**Hajar Chamali<sup>1</sup>, Abdelouahed Dahrouch<sup>2</sup>, Bouchra Laarabi<sup>1</sup>, El Houssaine Fathi<sup>2</sup>, Abdelfettah Barhdadi<sup>1</sup>**

<sup>1</sup>*Semiconductors Physics and Solar Energy Research Team (PSES), Energy Research Centre, Ecole Normale Supérieure, Mohammed V University in Rabat, Morocco*

<sup>2</sup>*Royal Gendarmerie Forensic Science Institute Rabat, Morocco*

In this research, an image analysis technique combining a new generation optical microscope (Leica DM6 M) and Cleanliness Expert image acquisition and processing software is proposed for the study of dirt particles on PV modules. This method offers the possibility of providing an appropriate assessment of the particles size distribution. The analyzed glass samples (20x25 mm<sup>2</sup>) were installed in three different regions (Souss-Massa, Drâa-Tafilalet, Rabat-Salé-Kénitra), on wooden holders tilted 15°, 30° and 45°, and for a period ranging from 64 to 75 days. On each sample, images were captured and analyzed on 3 spots, 5 spots and 9 spots and compared to the total scan of the whole sample. Furthermore, the glass samples have been used to investigate soiling impact in these three regions. The results obtained of the microscope show that the percentages of the number of particles are the same for all areas. This means that the analysis of 3 spots is representative of the total area of the sample. These results are confirmed by a comparative study using the T-test. In addition, the dominant particle diameters are in the range (1-5 µm). Furthermore, the result of the deposition density and transmittance losses varies by region and inclination in the range of [1.73 - 14.71] g / m<sup>2</sup> / period for the deposition density and [6% - 40%] for the transmittance loss. The results obtained in this study clearly show the number of images that will be enough to represent the whole area of the sample.

### Keywords

Solar energy, Soiling, Density of deposits, Transmittance, Correlation.

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## NOVEL SILICON TEXTURING METHOD BY NON LINEAR LASER LITHOGRAPHY FOR SOLAR CELL APPLICATIONS

**Arian Goodarzi<sup>1</sup>, Besna Bülbül Tatbul<sup>2</sup>, Bülent Arikan<sup>2</sup>, Emine Hande Çiftpınar<sup>1</sup>, Hisham Nasser<sup>1</sup>, Mona Zolfaghari Borra<sup>1</sup>, Alban Bek<sup>3</sup>, Raşit Turan<sup>3</sup>, Ihor Pavlov<sup>3</sup>**

<sup>1</sup>ODTÜ-GÜNAM, The Center for Solar Energy Research and Applications, Ankara 06800, Turkey

<sup>2</sup>ODTÜ-GÜNAM, The Center for Solar Energy Research and Applications, Ankara 06800, Turkey;

<sup>3</sup>ODTÜ-GÜNAM, The Center for Solar Energy Research and Applications, Ankara 06800, Turkey, Physics Department, Middle East Technical University, Ankara 06800, Turkey, Micro and Nanotechnology Program, Middle East Technical University, Ankara 06800, Turkey

Surface texturing is essential step in the fabrication procedure of single-crystalline (sc) and multi-crystalline (mc) silicon solar cells (SC) with record-high efficiencies, targeting the reduction of the reflectance of the SC surface. In this perspective, we used nonlinear laser lithography to texture the silicon surface for solar cells applications. The structure on the surface arises from the interference of surface plasmonic waves with the incident wave, near the laser ablation threshold, producing a quasi-periodic structure with period around 900 nm. By focusing the beam on the surface and scanning it along the surface line by line, the structure coherently extends over large area. Without the need for additional processing, we achieved the necessary conditions for solar cell fabrication with proper efficiency. By investigating the pulses energy and the pulse density effects on the final cell efficiency, we achieved less than 7% reflectivity in the range from 300 nm to 1200 nm. For the final full size laser structured solar cells (based on as-cut saw damage etched wafers 15.6x15.6 cm<sup>2</sup>) we reached 17.3% efficiency for sc-Si and 15% efficiency for mc-Si. We have shown that this method can be used for large dimensions, and the structuring speed even in laboratory scale was higher than 1500 cm<sup>2</sup>/hour. The structuring procedure is the same for sc-Si and mc-Si, without changing any processing steps, and without any chemical compounds involved. The method is cost effective, fast, environmental-friendly, and can be easily implemented in industrial scale.

### Keywords

Nonlinear laser lithography, Photovoltaic, Silicon solar cells, Femtosecond laser structuring,

figure 1. from the left, SEM image from created structure on As-cut silicon wafer, Comparison of the

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038

## OF BUFFER LAYER PROPERTIES ON THE PHOTOVOLTAIC RESPONSE OF MAGNETRON SPUTTERED GROWN SB<sub>2</sub>SE<sub>3</sub> THIN FILM SOLAR CELLS

Seher Hazal Gündoğan<sup>1</sup>, Ayten Cantas<sup>2</sup>, Lütfi Özyüzer<sup>1</sup>, Gülnur Aygün<sup>1</sup>

<sup>1</sup>Izmir Institute of Technology, Physics, Izmir, TURKEY

<sup>2</sup>Pamukkale University, Electric and Energy, Denizli, TURKEY

The thin-film solar cell technologies have gained increasing interest from the photovoltaic industry because of their potential to produce 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, and Te and include toxic elements like Cd [1]. Antimony selenide (Sb<sub>2</sub>Se<sub>3</sub>) is a newly explored p-type semiconductor material. As an absorber layer, the Sb<sub>2</sub>Se<sub>3</sub> compound is composed of Sb and Se elements which are pretty low cost, non-toxic, and have high surface reserves. Sb<sub>2</sub>Se<sub>3</sub> also has favorable photovoltaic properties, such as proper bandgap (1-1.2 eV), high absorption coefficient ( $\sim 10^5$  cm<sup>-1</sup>), intrinsically benign grain boundaries, and high theoretical conversion efficiency up to 31% [2,3]. Instead of a toxic CdS buffer layer commonly used in Sb<sub>2</sub>Se<sub>3</sub> solar cells, an environmental buffer layer was used in the superstrate configuration. In this study, Sb<sub>2</sub>Se<sub>3</sub> thin-film solar cells have been fabricated using a buffer layer with different material properties. Structural characterizations of Sb<sub>2</sub>Se<sub>3</sub> thin films have been done by Raman Spectroscopy and X-Ray Diffraction (XRD). The surface morphology and elemental composition of films have been examined by Scanning Electron Microscopy (SEM) and electron diffraction spectroscopy (EDS), respectively. Photovoltaic analysis of the solar cells has been occurred by the solar simulator under AM1.5 illumination. The photovoltaic response of solar cells was evaluated concerning the properties of the buffer layer.

### Keywords

thin film, solar cell, antimony selenide, magnetron sputtering

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039

## PASSIVATION OF CRYSTALLINE SILICON BY ORGANIC ACIDS

**Milad Ghasemi<sup>1,2</sup>, Mohammadreza Fathollahi<sup>1</sup>, Konstantin Tsoi<sup>1</sup>, Selcuk Yerci<sup>1,2</sup>**

<sup>1</sup>ODTU-GUNAM, Ankara, Turkey

<sup>2</sup>Micro and Nanotechnology department, Ankara, Turkey

To reduce the carrier recombination in crystalline silicon (c-Si), various inorganic dielectric materials have been employed to obtain a high carrier effective lifetime by suppressing the surface recombination. As known from the literature, depositing inorganic materials requires high-vacuum equipment and high-temperature annealing and processing steps which costs considerably. Here, we present spin-coating passivation of silicon surface in atmospheric ambient conditions with organic superacid layers achieving a high effective carrier lifetime above  $\sim 5$ ms on textured n-type low resistivity (1.2 - 2.3  $\Omega\cdot\text{cm}$ ) c-Si samples corresponding to an implied Voc of  $\sim 770$ mV. The upper limit surface recombination velocity (SRV) of less than  $\sim 6$  cm/s has been attained at the level of hydrogenated amorphous silicon passivation commonly exploited in the heterojunction solar cell technology. It seems these super acids without modifying the dangling bonds at the silicon surface provide field-effect passivation by the existence of fixed charge induction in the organic layer [1]. The simplicity of the technique, the sample preparation, and the coating method make these materials attractive for the next generation in the silicon solar cell industry as an alternative to well-known inorganic dielectrics (SiNx, AlOx, SiOx).

### Keywords

Silicon solar cells, surface passivation, super acids, and high effective carrier lifetime

Figure 1

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O40

## PATTERNING OF PHOTORESIST BY MICROHOLES SUCCESSFULLY VIA MASKLESS PHOTOLITHOGRAPHY

**Furkan Güçlüer<sup>1,2</sup>, Filiz Keleş<sup>3,2</sup>, Ayşe Seyhan<sup>3,2</sup>**

<sup>1</sup>Energy Science and Technologies, Niğde Ömer Halisdemir University, Niğde, TURKEY

<sup>2</sup>Nanotechnology Application and Research Center, Niğde Ömer Halisdemir University, Niğde, TURKEY

<sup>3</sup>Department of Physics/Niğde Ömer Halisdemir University, Niğde, TURKEY

Surface patterning of the substrate to enhance the performance of optoelectronic devices is one of the most widely studied areas in literature. Photolithography [1], which can be counted in today's largest industries, has arose as an irreplicable method to produce the patterns especially with microstructures in many fields such as photovoltaics, micromachining, and integrated circuits. Photolithography process is mainly described as the delineation of defined microstructures on photoresist material coated on substrate by exposing the laser light. The photoresist decorated by microstructures via photolithography behaves as a mask on the substrate prior to the actual etching process. Therefore, a successful photoresist patterning should be conducted by accordingly tuning the photolithography process parameters. In this study, we performed the formation of microholes on positive photoresist on both glass and silicon substrates via maskless photolithography with UV-laser. Specifically, we examined the effect of velocity (writing speed, mm/s) and modulation (energy percentage, %) of the laser on the properties of the microstructures delineated on photoresist [2]. As a result, we observed that the speed of laser is more effective than the modulation in successfully forming the well-defined microholes. In addition, we investigated the substrate effect on the photoresist patterning, as well [3]. We revealed that microholes with almost perfectly circular and desired diameters could be obtained on both substrates. However, extra rings around the holes are observed on silicon which can be attributed to the shiny surface of silicon.

### Keywords

Maskless photolithography, positive photoresist, microholes, FZ silicon, glass

Figure 1. General Steps of the Photolithography Process / Coating substrate, exposing and developing

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O41

## POTENTIAL OF TiO<sub>2</sub> AS A CAPPING LAYER FOR INDUSTRIAL C-SI PERC SOLAR CELLS

**Amna Siddiqui<sup>1</sup>, Muhammad Usman<sup>1,3</sup>, Anders Hallén<sup>2</sup>**

<sup>1</sup>Experimental Physics Department, National Centre for Physics, Quaid-i-Azam University, Islamabad, Pakistan

<sup>2</sup>Royal Institute of Technology KTH, School of EECS, Stockholm, Sweden

<sup>3</sup>Pakistan Academy of Sciences, Islamabad, Pakistan

TiO<sub>2</sub> has gained popularity specially in photovoltaic applications [1], owing to its transparency in the visible region, and scratch resistance [2]. Though the quality of TiO<sub>2</sub> as a standalone passivation layer is not well understood for c-Si solar cells, it is widely used in double layer ARCs with other films such as SiO<sub>2</sub> and Al<sub>2</sub>O<sub>3</sub> [3]. In this work, the potential of TiO<sub>2</sub> as a capping layer for c-Si p-type SiN<sub>x</sub> passivated PERC solar cells is studied. For this, the photogeneration data for the investigated ARC stacks is acquired from the OPAL2 tool and imported into the TCAD-based Silvaco ATLAS device/process simulator. The PERC solar cell model used in this study is calibrated with an experimental device having an efficiency of 22.19% [4].

Device simulation results show that TiO<sub>2</sub> deposited by the mesoporous technique outperforms atmospheric pressure-CVD-based TiO<sub>2</sub> layers when capped over SiN<sub>x</sub> (n=2.1) passivated solar cells. Furthermore, it is shown that the efficiency of SiN<sub>x</sub>(n=2.1)/TiO<sub>2</sub> based solar cells is maintained at 22.33%, even when the TiO<sub>2</sub> layer thickness varies from 75 to 95 nm. To enhance the efficiency further, the type of SiN<sub>x</sub> layer (characterized by the n value), and the thicknesses of SiN<sub>x</sub> and TiO<sub>2</sub> layers are optimized simultaneously to find the best combination of these parameters. The best solar cell efficiency, η=22.44%, is obtained when a stack of SiN<sub>x</sub>(n=1.99)/TiO<sub>2</sub> (t=58/76 nm) is used. This is 0.25% higher when compared to the original SiN<sub>x</sub> passivated PERC solar cell, demonstrating the prospective of using TiO<sub>2</sub> in commercial photovoltaic applications.

### Keywords

Efficiency, PERC, ARC, SiN<sub>x</sub>, capping layer, mesoporous, TiO<sub>2</sub>

Effect of adding TiO<sub>2</sub> on J(sub). The efficiency improves from 22.19 to 22.44% for mesoporous TiO<sub>2</sub>.

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O42

## PV INCORPORATION INTO THE BUILDING THERMAL ENVELOPE AND THE NEW CERTIFICATION CLASSES FOR PASSIVE HOUSE STANDARD

Somaye Eftekhari Ranjbar<sup>1</sup>, Ahadollah Azami<sup>2</sup>

<sup>1</sup>Department of Architecture, Chalous Azad University, Chalous, Iran

<sup>2</sup>Department of Architecture, Eastern Mediterranean University, Famagusta, North Cyprus

Passive House Standard (PHS) is the world's leading standard in energy efficient construction that primarily focuses on reducing the energy demand of a building's key services: HVAC, lighting, appliances, and auxiliary energy demands. However, in designing a Passivhaus, there are often opportunities to incorporate PV panels as BAPV or BIPV for solar electricity generation. Although, onsite PV generation not considered for reducing energy demand of building. But, based on their renewable Primary Energy (PER) demand and their primary electricity generation-mainly by onsite PV generation- Passive Houses are classified into three categories including Passive House Classic, Passive House Plus and Passive House Premium. The PER generation-especially by PV panels- per the projected area of the building footprint regarding the Plus and Premium classes are greater than 60 and 120 [kWh/m<sup>2</sup>] respectively while, a total demand of primary energy renewable per the treated floor area for Classic, Plus, and Premium classes are less than 60, 45, and 30 [kWh/m<sup>2</sup>] respectively. So, PER demand and supply must be taken into account for the new passive house classes. Also, within certain limits, a lower demand can compensate for lower energy generation and vice versa. This research investigates the PER for demand and supply due to the PV utilization into the building thermal envelope of single-family and multi-family houses-with the same projected building footprint- to meet Net Zero energy and the PHS Certification Classes.

### Keywords

Passive House Standard (PHS), PV Performance, Building Form, Certification Classes, Primary Energy Renewable (PER)

The New Passive House Classes

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## **RUBRENE SINGLE CRYSTAL SOLAR CELLS AND THE EFFECT OF CRYSTALLINITY ON INTERFACE CHARGE RECOMBINATION**

**Duygu Akin Kara<sup>1</sup>, Edmund K. Burnett<sup>2</sup>, Koray Kara<sup>3</sup>, Burak Gultekin<sup>1</sup>, Alejandro L. Briseno<sup>2</sup>**

<sup>1</sup>*solar energy Institute, ege university, izmir, turkey*

<sup>2</sup>*Department of Polymer Science and Engineering, University of Massachusetts Amherst, Amherst, MA, 01003, USA*

<sup>3</sup>*Izmir Graphene Application and Research Center, Izmir Katip Celebi University, 35000, Izmir, Turkey*

Single crystal studies provide a better understanding of the basic properties of organic photovoltaic devices. In this work, rubrene single crystals with a thickness of 250 nm to 1000 nm were used to produce an inverted bilayer organic solar cell. Then polycrystalline rubrene (triclinic) and amorphous bilayer solar cells of the same thickness as single crystals were studied to make comparisons across platforms. Light intensity measurements were carried out to understand how single crystal, polycrystalline (triclinic orthorhombic) and amorphous forms alter the charge carrier recombination mechanism at the rubrene /PCBM interface. The light intensity dependency of the short circuit current,  $J_{SC}$  open circuit voltage,  $V_{OC}$  and fill factor, FF parameters in organic solar cells with different forms of rubrene was investigated. Monomolecular (Shockley Read Hall SRH) recombination is observed in devices employing amorphous and polycrystalline rubrene in addition to bimolecular recombination, whereas the single crystal device is weakly affected by trap assisted SRH recombination due to reduced trap states at the donor acceptor interface. The proposed work is a systematic study examining charge transport and interface charge recombination mechanisms in organic solar cells produced by different structure forms of rubrene.

### **Keywords**

Rubrene, Single crystal, solar cell, interface recombination

O44

## SEMITRANSSPARENT ORGANIC SOLAR CELL; THE EFFECTS OF CELL THICKNESS

Elmira Annabi Milani<sup>1</sup>, Asghar Asgari<sup>1</sup>, Mina Piralaee<sup>1</sup>

<sup>1</sup>Photonics Devices Research Group, Research Institute of Applied Physics and Astronomy, University of Tabriz

Semitransparent organic solar cells (ST-OSC) are attracted recently because they harvest photons in the near-infrared and ultraviolet range and pass in the visible light region. Semitransparent organic solar cells with ITO/ ZnO/ PBDB-T: ITIC/ MoO<sub>3</sub>/Ag/MoO<sub>3</sub> structure have been studied in this work. The effects of cell thickness (active layer, PBDB-T: ITIC, and transparent top electrode, MoO<sub>3</sub>/Ag/MoO<sub>3</sub>), on the power conversion efficiency, the average visible transmittance, and the color coordinates in the CIE color space are investigated. To find out the drift-diffusion model, including the density of excitons, and their displacement is used. The obtained results show that for OSC with AVT of more than 25%, the devices with an active layer thickness of 100nm and metal layer thickness of 8 nm in the transparent top electrode have optimum PCE, also, the color coordinates of these devices are close to the achromatic point.

### Keywords

Semi-transparent, organic solar cells, non-fullerene acceptor, ITIC, MoO<sub>3</sub>/Ag/MoO<sub>3</sub>

Fig. 1

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## **SIZING OF A PHOTOVOLTAIC POWER PLANT WITH BATTERY AND HYDROGEN STORAGE USING TECHNO-ECONOMIC PARAMETERS FOR A METU CAMPUS**

**Zahra Medghalchi<sup>1</sup>, Fahrettin Aydemir<sup>1</sup>, Onur Taylan<sup>1</sup>**

<sup>1</sup>Middle East Technical University, Department of Mechanical Engineering, Ankara, Turkey

Today's world suffers from an increasing dependence on fossil fuels, which are finite and whose unbalanced distribution in different regions causes political conflicts. Furthermore, burning these fuels adversely affects the environment and results in global warming. Thus, renewable energy systems (RES), such as PV systems, could support the future need and lead to a sustainable environment. The main problem of PV is that the resource is intermittent. This problem could be relieved by coupling the PV system with an energy storage system. This study assesses two different storage systems, electrolyzer-fuel cell (EFC) and battery (BESS), for a PV power plant at a METU campus. The PV plant is sized as 4.5 MW which would generate electricity to meet the annual demand, whereas the storage systems are initially sized as 467 kW based on the average deficit energy of the campus. The preliminary, main results are presented in the table below. As the table indicates, the annual fraction of the demand supplied by the system (RES Fraction) without storage is 49.6%; this fraction is increased by 6.2% and 2% by installing EFC and BESS, respectively. Besides, the autonomy fraction also increased by 1.5% and 2.1% utilizing EFC and BESS, respectively, compared to the system without storage. Although the RES fraction of EFC is higher than BESS, the autonomy of BESS is a bit greater than EFC. The full version of the paper will include LCOE and another sizing method based on LCOE and the grid tariff.

### **Keywords**

battery, electrolyzer-fuel cell, energy storage, PV, renewable energy system modelling

Table 1. Technical Performance Parameters of the PV Plant with Electrolyzer-Fuel Cell and Battery.

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O46

## SNAPSHOT OF RECYCLING PHOTOVOLTAIC MODULES WITHIN A CIRCULAR ECONOMY APPROACH IN TURKEY (2022)

**Asmin Aşkın<sup>1</sup>, Bülent G. Akınoğlu<sup>2</sup>, Şiir Kılış<sup>3</sup>**

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

<sup>2</sup>Middle East Technical University, Physics, Ankara, Turkey

<sup>3</sup>TÜBİTAK, Ankara, Turkey

The Sustainable Development Goals (SDGs) adopted by the United Nations in 2015 (1) aimed to create a more equality-dependent, peaceful, and inhabitable environment for the world and the living creatures. Although it may seem the greatest and most sustainable energy type utilized today, It is crucial to discuss what can be achieved with solar technologies, especially solar photovoltaics, in the production, use, and consumption stages. In this analysis, we will focus on the existing circumstances in Turkey regarding solar photovoltaic recycling.

With the survey conducted, we aimed to answer the questions about what current order of technologies needed solar energy to be 100% green in Turkey. Questions that depend on the public opinions, needs, and interests in dealing with solar photovoltaic technologies in the scope of the circular economy approach (2) in Turkey. We investigate, what one needs to implement, develop, and integrate in terms of existing and future systems of solar photovoltaic technologies to target 2030 and 2050 Sustainable Development Goals (SDGs) (3). While we will provide a brief overview of the research and applications conducted in the rest of the world, we will examine the topic of Turkey's position within the scope of the results from the survey.

### Keywords

SDGs, Circular Economy, Silicon PV, 100% green, Recycling

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047

## **SOLAR PV UPTAKE IN TURKEY: ECONOMIC AND POLITICAL IMPLICATIONS**

**Nazım Çınar Duvaryapar<sup>1</sup>, Pınar Derin Güre<sup>2</sup>, Işık Kuşçu Bonnenfant<sup>3</sup>**

<sup>1</sup>Centre International de Formation Européenne, Global Energy Transition and Governance, Nice France

<sup>2</sup>Middle East Technical University, Faculty of Economic and Administrative Sciences, Economics, Ankara, Turkey

<sup>3</sup>Middle East Technical University, Faculty of Economic and Administrative Sciences, International Relations, Ankara, Turkey

Energy security, defined as uninterrupted, secure access to energy resources at stable prices, is vital for all states. Fossil fuel reserves are concentrated in the hands of a few countries that may use them as a tool to achieve foreign policy objectives, posing a direct threat to the energy security of others. The latest Ukraine-Russia war demonstrated that Russia is not refraining from weaponizing its energy reserves. Turkey, a country having rapid economic growth, needs energy imports from other countries in order to ensure economic, political, and social stability. The EU is also reliant on external energy supplies, which has major economic and political repercussions that have become increasingly evident with the war in Ukraine. The EU has been developing green energy policies for some time, but the recent crisis has accelerated the development of renewable energy sources, many of which are also consistent with the EU's green policy framework. This framework aims to create changes within the Union; however, it will indirectly affect trading partners and countries in the EU accession process through policy tools such as the carbon border adjustment mechanism (CBAM).

Our paper's goals are twofold:

- 1) To measure the economic and political implications of Turkey's solar PV uptake
- 2) To analyze the influence of Turkey's solar PV uptake on its political relations with the EU and international trading capacity, considering the ongoing green transition of international trade (particularly with the EU, Turkey's largest trading partner) through policies such as CBAM.

### **Keywords**

Energy Security, Political Economy of the Energy, Renewable Energy, Turkey-EU Relations

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## SPECTROSCOPIC INVESTIGATIONS OF POLYSILICON DEFECTS FOR TOPCON APPLICATIONS

**Salar Habibpur Sedani<sup>1,2</sup>, Emre Erdem<sup>3</sup>, Raşit Turan<sup>1,4</sup>**

<sup>1</sup>ODTÜ-GÜNAM, Middle East Technical University, 06800 Ankara, Turkey

<sup>2</sup>Department of Micro and Nanotechnology, Middle East Technical University, 06800 Ankara, Turkey

<sup>3</sup>Sabancı University, Faculty of Engineering and Sciences, Orhanlı, 34756 Istanbul, Turkey

<sup>4</sup>Department of Physics, Middle East Technical University, 06800 Ankara, Turkey

The tunnel oxide passivated contact (TOPCon) structure is getting more consideration for developing high-performance solar cells. TOPCon Solar Cells improve the efficiency by introducing a tunnel oxide layer between the bulk substrate and polysilicon (poly-Si). The quality of TOPCon solar cell passivation properties is widely investigated in the objective of interface passivation quality, namely the tunnel oxide layer[1]. The missing points to be considered for improving the performance are the poly-Si layer's defects and physical properties. The TOPCon cell has poly-Si on the front as an emitter and/or at the back as a back-surface field layer.

The poly-Si is formed on the structure by annealing of deposited amorphous silicon. The annealing process crystallized the layer while making dopants activate and diffuse part of it inside the bulk. The crystallization annealing temperature and duration should be optimized as higher temperatures and duration lead to a better crystallization while it causes undesired diffusion of dopants into the bulk silicon. Therefore, the optimal layer should be investigated. In this study, we controlled crystallinity fraction by annealing duration and quantified it by Raman Spectroscopy. These different layers were analyzed by electron paramagnetic resonance spectroscopy to understand the defects in the poly-Si. All the layers on the quartz substrate and on the cell structure are fulfilled simultaneously. The comparison of these two sets reveals the flaws of stand-alone poly-Si as well as the poly-Si's role in the cell. Consequently, we propose the optimal crystallization process with defect-controlled poly-Si for TOPCon solar cells (with optimal lifetime).

### Keywords

TOPCon, EPR, Raman Spectroscopy, Defect Analysis, p-poly-Si

### References

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## STUDY OF FLOATING BIFACIAL PV EFFECT ON WATER SAVINGS AND ENERGY IN ARID ZONES

**Dounia Dahlioui<sup>1</sup>, Fatimazahra Aoujil<sup>2</sup>, Hicham Bouzekri<sup>1</sup>, Barry De Rijke<sup>3</sup>**

<sup>1</sup>R&D Department, Moroccan Agency for Sustainable Energy (MASEN), Rabat, Morocco

<sup>2</sup>Polydisciplinary Faculty of Ouarzazate, Morocco

<sup>3</sup>HydroPV technologies

Bifacial photovoltaic (PV) modules have known a great development in recent years compared to monofacial technology [1], [2]. The annual electrical energy gain of a bifacial module compared to monofacial could reach 25% [3]. This value can be increased by combining the advantage of bifaciality with a cooling effect on a floating structure. To this end, we will be interested in this work to evaluate in an East-West oriented floating bifacial structure both energy and water savings. The experimental measurements have been conducted over a four-month period of exposure at the R&D platform in Ouarzazate, city in the southeast of Morocco, which is characterized by a hyper-arid climate. The demonstrator consists of two ponds of water, the first one is covered by a string of bifacial PV and the adjacent one is kept exposed to sunlight and evaporation. A third string is installed on land for comparison matters.

The effect of water on panel efficiency manifesting a cooling effect, was investigated by based on the temperature and voltage output measured by an I-V tracer.

Furthermore, we evaluated the soiling of the bifacial modules of the floating structure compared to the structure on the land. The results showed that soiling rate (SR) of a system installed in an East-West orientation is lower than the one oriented North-South. Regarding water savings, this study has showed that floating PV has contributed in reducing the evaporation by 50%.

### Keywords

Bifacial PV, Floating, Water Savings, Soiling, Energy

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O50

## TCAD SIMULATION OF GERMANIUM-BASED HETEROSTRUCTURE SOLAR CELL EMPLOYING MOLYBDENUM OXIDE AS A HOLE-SELECTIVE LAYER

**Haris Mehmood<sup>1</sup>, Hisham Nasser<sup>2</sup>, Raşit Turan<sup>2</sup>**

<sup>1</sup>Electrical Engineering Department, Information Technology University of the Punjab (ITU), Lahore, Pakistan

<sup>2</sup>Center for Solar Energy Research and Applications (ODTÜ-GÜNAM), Middle East Technical University, Ankara, Turkey

The implementation of Molybdenum Oxide ( $\text{MoO}_x$ ) as a dopant-free carrier-selective film for Germanium (Ge)-based solar cell has been scarcely reported in the literature that impedes the successful understanding of the working principle of such novel design. For the first time in literature, this research work aims to physically model the solar cell heterostructure design involving the Ge wafer with carrier-selective contacts. Various structures have been investigated for ascertaining the photovoltaic (PV) conversion capability of the proposed device, as shown in Fig. 1a. Several design parameters influencing the charge transportation characteristics, such as work function of  $\text{MoO}_x$ , Ge doping concentration, thickness of the passivation film, and interface recombination velocities, have been analyzed in order to attain in-depth physical insights into electric field, band offsets, and photogeneration rate capability of the simulated device. With a corresponding increase in  $\text{MoO}_x$  work function, energy barrier height against electrons increased at the front interface that minimized recombination as well as increased the hole-selectivity of  $\text{MoO}_x$ <sup>1</sup>. A manifold reduction in recombination rate has been observed by insertion of a thin passivation film of amorphous silicon (*i*-a-Si:H) with Ge wafer that also assisted in maintaining the field strength. However, thickness optimization of a front passivation film is a challenging task due to interface inversion (Fig.1b) and parasitic light absorption (Fig.1c)<sup>2</sup>. The reference device ( $\text{MoO}_x/\text{Ge}$ ) exhibited a simulated  $\eta$  of 4.23%. The proposed device with an optimum front passivated thickness of 2 nm for *i*-a-Si:H numerically attained a higher  $J_{sc}$  of 46.4  $\text{mA}/\text{cm}^2$ ,  $V_{oc}$  384 mV, FF 73.0%, and  $\eta$  of 13.10%.

### Keywords

germanium, heterostructure, molybdenum oxide, passivation, solar cell

Figure 1. (a) Proposed structure, (b) energy band diagram, and (c) parasitic light absorption

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## TECHNO-ECONOMIC COMPARATIVE ANALYSIS OF SOLAR PHOTOVOLTAIC POWER SYSTEMS WITH DIFFERENT ENERGY STORAGE SYSTEMS IN TURKEY

**Mete Cubukcu<sup>1</sup>, Harun Gumus<sup>1</sup>**

<sup>1</sup>Ege University, Solar Energy Institute, Izmir, Turkey

Solar energy can be converted into electricity by photovoltaic technology. However, renewable resources like solar energy are intermittent. It is directly dependent on the weather. Moreover, photovoltaic panels cannot be generated electricity at night. Hence, the main challenge of electricity generation by photovoltaic technology is that its fluctuating nature can cause a mismatch between demand and supply. In addition, photovoltaic system performance and grid power quality can be affected. The intermittent nature of solar energy can cause a decrease in photovoltaic panels' performance and the power quality of the grid. Energy storage systems integrating with photovoltaic power systems are used as a prevailing remedy to mitigate these problems.

One of the ways to further improve PV installations is through battery storage, which can enhance the PV self-consumption rate and avoid instability problems caused by errors of estimation. In the past, high costs and limited usage case of batteries were the most important obstacles for energy storage systems. Nevertheless, as energy storage system costs have been considerably decreased in recent years and with the development of electric vehicles, energy storage systems have become one of the most popular solutions to benefit from renewable energy sources more efficiently. In this study, the techno-economic analysis of a PV system with different energy storage technologies (Li-ion, lead-acid and vanadium redox battery) is carried out. The results show that Li-ion battery integrated with a photovoltaic is the most feasible system.

### Keywords

Photovoltaics, Techno-economic analysis, Storage technologies.

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## THE IMPACT OF CLIMATE CHANGE ON SOLAR PHOTOVOLTAIC ENERGY GENERATION IN TURKEY

**Metecubukcu<sup>1</sup>, Harun Gumus<sup>2</sup>**

<sup>1</sup>Ege University, Solar Energy Institute, zmir, Turkey

<sup>2</sup>Ege University, Solar Energy Institute, Izmir, Turkey

With the development of the industry and the increase of the world population the energy requirement is also increasing. However, most of the energy demand is met by fossil fuels that emit greenhouse gasses. In this situation, renewable sources should be used to mitigate greenhouse gas emissions and their negative impacts. Photovoltaic technology is one of the great remedies for obtaining clean energy. Nevertheless, all renewable energy sources and therefore photovoltaic systems can also be affected by climate change.

Intergovernmental Panel on Climate Change (IPCC) defined four pathways to be used for climate modelling and research for the IPCC fifth Assessment Report (AR5) in 2014. These pathways are called Representative Concentration Pathway (RCP) -originally RCP2.6, RCP4.5, RCP6, and RCP8.5 - labelled after a possible range of radiative forcing values in the year 2100 (2.6, 4.5, 6, and 8.5 W/m<sup>2</sup>, respectively). In this study, climate change effects on photovoltaic energy generation in Turkey are analysed. The study considers RCP4.5 and RCP8.5 emission scenario temperature change for seven different regions of Turkey. The result indicates that the major factor that determines the photovoltaic performance with rising temperature is the sunshine duration and radiation to the region.

Although photovoltaic panels' performance will decrease due to climate change it is anticipated that photovoltaic energy potential rises with environmental awareness, the downtrend in the photovoltaic cost of energy and government policies.

### Keywords

Photovoltaics, Greenhouse gas emissions, Climate change, Climate modelling.

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## **THERMAL AND FLUID DYNAMIC OPTIMIZATION OF A SOLAR CO-GENERATION ABSORBER MODULE WITHIN A CPV-T SYSTEM. NUMERICAL MODELING AND EXPERIMENTAL VALIDATION.**

**Daniel Santos<sup>1</sup>, Jesús Castro<sup>1</sup>, Deniz Kizildag<sup>1</sup>, Joaquim Rigola<sup>1</sup>, Ahmet Azgın<sup>2</sup>, Bilge Tunçel<sup>3</sup>, Raşit Turan<sup>4</sup>, Richard Felsberger<sup>5</sup>, Rupert Preßmair<sup>5</sup>, Armin Buchroithner<sup>5</sup>**

<sup>1</sup>Centre Tecnologic de Transferencia de Calor (CTTC) Universitat Politècnica de Catalunya BARCELONA TECH (UPC), Terrassa, Barcelona, Spain

<sup>2</sup>Ileri Arge Teknolojileri Muhendislik Yazilim Egitim Danismanlik ve Ticaret LTD STI - iTechSolar, Ankara, Turkey

<sup>3</sup>Department of Physics, Middle East Technical University, Ankara, Turkey

<sup>4</sup>Center for Solar Energy Research and Applications (GUNAM), METU, Ankara, Turkey

<sup>5</sup>Institute of Electrical Measurement and Sensor Systems (EMS) Graz University of Technology (TUG), Austria

In this work, a validated finite volume model for thermal and fluid dynamic simulation of a solar Co-Generator Absorber Module (CAM) integrated into a Parabolic Trough Concentrated Photovoltaic-Thermal CPV-T system is compared against a specific lab-scale prototype, experimentally tested under real-world operating conditions. The silicon-based PV cell, which was specially designed to work under concentrated irradiance, is cooled by means of an attached pipe containing a heat transfer fluid (HTF) (see Figure 1), which can serve as process heat.

The numerical simulation tool solves:

1. fluid flow inside the tube via Computational Fluid Dynamics CFD resolution, linked with
2. conduction and radiation through the tube, the connections and the solar cells in a coupled manner.

Different conduct geometries (circular, rectangular, etc.) were used within this work to find an optimal pipe design including heat sink fins in order to maximize the heat transfer between the solar cells and the heat transfer fluid. The model was previously validated by means of experimental data obtained using a cylindrical pipe, in the laboratory and under real conditions ([1], [2], [3]).

After this optimization process, different experimental new configuration prototypes have been constructed and tested under laboratory conditions. A preliminary thermal test has been done to test the reliability of the prototypes (e. g. for the paste used in the cold welding). The numerical and experimental comparison not only demonstrates the Co-Generator Absorber Module (CAM) possibilities but also the robustness of the numerical model for working conditions analysis.

### **Keywords**

CPVT, Solar Energy, FVM, parabolic collector, solar cell

Figure 1 CPV-T system; heat sink manufacturing details; CAM configuration for numerical analysis.

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## TRANSPARENT LUMINESCENT SOLAR WINDOWS

**Omar Moudam<sup>1</sup>, Othmane Essahili<sup>1</sup>, Mouad Ouafi<sup>1</sup>**

<sup>1</sup>Mohammed VI Polytechnic University/Applied Chemistry & Engineering Research Centre of Excellence,  
Benguerir, Morocco

The high demand for building integrated photovoltaic solar panels presents tremendous challenges in terms of cost, efficiency, and transparency. As a type of emerging photovoltaic solar panel, Luminescent solar concentrators possess the necessary requirement for installation in large areas, thus replacing the more complex (in terms of fabrication and installation) thin-film solar cells. Furthermore, production costs of LSCs are considerably cheap necessitating only two materials: a luminescent fluorophore doped in a host plastic as shown in Figure 1. The fluorophore is generally an organic, quantum dot or lanthanide-based luminescent<sup>1</sup> that can absorb poisonous ultra-violet light and convert it to visible light by the luminescent down-shifting (LDS). The absorbed light is trapped through the device into the edge by the attenuated total reflection (ATR), and then the concentrated light is collected by a solar cell placed at the front of the solar panel. In addition, LSCs are highly transparent as shown in Figure 1 and could replace glass windows in buildings and skyscrapers, for instance. In this work, we will present the preparation of these types of solar cells and their use as an alternative for thin-film solar cells in windows and BIPV.<sup>2</sup>

### Keywords

Luminescent Solar Concentrators, Windows, Optical Properties, Energy Conversion

Fig.1: A concept of LSC (left); A piece of transparent solar window (middle); Eu-LDS (right)

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## TWO DIMENSIONAL MATERIALS BASED ATOMICALLY THIN SOLAR CELLS

**Ali Altuntepe<sup>1</sup>, Serkan Erkan<sup>1</sup>, Mehmet Ali Olgar<sup>1,2</sup>, Recep Zan<sup>1,2</sup>**

<sup>1</sup>Niğde Ömer Halisdemir University, Nanotechnology Application and Research Center, Niğde, Turkey

<sup>2</sup>Niğde Ömer Halisdemir University, Department of Physics, Niğde, Turkey

Two-dimensional (2D) materials, such as graphene, carbon nanotube, molybdenum disulfide (MoS<sub>2</sub>) have gained remarkable attention of many scientists due to their superior structural and physical properties [1]. Graphene is one of the most popular 2D material because of that has high transmittance, high thermal conductivity and high mechanical strength [1, 2]. Transition metal dichalcogenides (TMDs) exhibits similar properties to/as graphene to some extent, however, they have a direct band gap when they thinned down to single layer [3]. Graphene and MoS<sub>2</sub> have been employed to enhance the performance of solar cells in the literature [4, 5] thanks to high optical transmittance of graphene and high optical absorption of MoS<sub>2</sub>.

In this study, both graphene and MoS<sub>2</sub> layers were employed to fabricate atomically thin film solar cell, which is different than the current literature. The MoS<sub>2</sub> was used as n-type layer and graphene was used p-type layer in the cell structure. Large scale and homogeneous boron doped graphene and MoS<sub>2</sub> layers were synthesized by CVD and PVD respectively. p-type single layer graphene obtained using diborane during the growth in the CVD. The cell structure consists of Ag back contact, 20nm MoS<sub>2</sub> (n-type), single layer graphene (p-type), 50nm ITO and Ag front contact, from bottom to top respectively. The constructed cell parameters were measured under 1.5AM using sun simulator. The cell conversion efficiency was determined to be around 1.8%.

The authors gratefully acknowledge funding from Nigde Omer Halisdemir University Scientific Projects Unit under a project number of FMT 2021/4-ÖNAP.

### Keywords

graphene, chalcogen, MoS<sub>2</sub>, thin film, PVD

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## USING ARTIFICIAL INTELLIGENCE FOR GLOBAL SOLAR RADIATION MODELING FROM METEOROLOGICAL VARIABLES

**Salma Zaim<sup>1,2</sup>, Mohamed El Ibrahim<sup>1</sup>, Asmae Arbaoui<sup>1</sup>, Abderrahim Samaouali<sup>1</sup>, Abdelfettah Barhdadi<sup>2</sup>**

<sup>1</sup>*Thermodynamic-Energy Team, Energy Research Center (CRE), Faculty of Sciences, Mohammed V University in Rabat, Morocco*

<sup>2</sup>*Physics of Semiconductors and Solar Energy Research Team (PSES), Energy Research Center (CRE), Ecole Normale Supérieure, Mohammed V University in Rabat, Morocco*

Long-term quantification of solar energy variables at the ground level is not easily achievable in many locations. In order to overcome this limitation, the use of artificial intelligence such as the application of artificial neural network methods is commonly used for solar irradiance prediction. In this context, this study proposes a modelling of daily global solar radiation using a back-propagation artificial neural network trained with the Levenberg Marquardt algorithm. For this purpose, several daily meteorological data from the city of Rabat in Morocco were selected in order of importance using the random forests method, for training and testing the models, namely date and time, sun duration, temperature, relative humidity, wind speed/direction and pressure. Subsequently, models were selected after the validation phase for testing, whose performance was evaluated using various statistical indicators reporting the fidelity and accuracy of each model. As a result, the two best models were identified by a correlation coefficient greater than 97.9% as well as a Nash-Sutcliffe criterion (the normalized MSE) beyond 0.979, which are indeed very satisfactory values, confirming the accuracy and suitability of the model for the hourly prediction of global solar radiation.

### Keywords

Global solar radiation, Modelling, Artificial neural network, Levenberg Marquardt algorithm, Random forests method

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## VISUALIZING THE VOLTAGE LOSSES IN PEROVSKITE-BASED SOLAR CELLS

**Esma Ugur<sup>1</sup>, Mingcong Wang<sup>1</sup>, Jiang Liu<sup>1</sup>, Erkan Aydin<sup>1</sup>, Randi Azmi<sup>1</sup>, Michele De Bastiani<sup>1</sup>, Frédéric Laquai<sup>1</sup>, Stefaan De Wolf<sup>1</sup>**

*<sup>1</sup>KAUST, KAUST Solar Center, Thuwal, KSA*

To achieve higher electricity generation at low cost, the most substantial impact on the energy generation from solar cells is to make existing technologies more efficient per area. This forms the focus of tandem solar cells, which utilize different photoactive materials with different bandgaps, allowing to benefit from a broader range of the solar spectrum. To increase the efficiency in perovskite-based multi-junction (e.g. perovskite/silicon tandem) solar cells - also single-junction ones -, it is important to understand the voltage losses. To do so, we use absolute (photo- and electro-) luminescence imaging which is used to extract the quasi-Fermi level splitting (QFLS) of the samples and devices using modified generalized Plank law.

On the device level, recombination losses could occur either in the bulk of the perovskite or at the adjacent transport layers due to higher trap density which mainly reduces the photovoltage of the device. Therefore, we focus on how the different passivation routes affect the QFLS of the samples, also the device stability. Furthermore, photoluminescence imaging of the perovskite layer in perovskite/silicon tandem devices has been used to investigate the origin of degradation after field test experiment.

### **Keywords**

perovskite/silicon tandem, perovskite solar cells, voltage loss, QFLS

P1

## A NEW DESIGNED SHINGLED SOLAR CELL STRINGER

**Ahmet Hamdi Aksoy<sup>1,2</sup>, Meryem Ezgi Karahalli<sup>1,3</sup>, Bulent Arikan<sup>1</sup>, Talat Ozden<sup>1,4</sup>**

<sup>1</sup>ODTU-GUNAM, 06800, Cankaya, Ankara, Turkiye

<sup>2</sup>Department of Automotive Engineering, Kocaeli University, 41380, Kocaeli, Turkiye

<sup>3</sup>Micro and Nanotechnology Programme, METU, 06800, Cankaya, Ankara, Turkiye

<sup>4</sup>Department of Electrical and Electronics Engineering, Gumushane University, 29100, Gumushane, Turkiye

Electrically conductive adhesives (ECA) have replaced the traditional ribbon connections for photovoltaic module manufacturing in recent years. This method makes it possible to create reliable and robust strings for the shingled solar cells using ECA from one shingled cell slice to another one. Thus, a busbar-free solar module using classic PERC cell can be obtained, and the active area for power generation can be increased. However, this process includes several challenges while using the ECA, such as creating a thin ECA layer on the shingled cell before curing and aligning them while stringing, etc. This study presents a novel designed stringer which can align and apply the adhesive to the shingled solar cells. The machine enables the operator to be easily set to use the different shingled cell dimensions and shapes. It can automatically combine with approximately 15 shingled cells side by side.

### Keywords

Shingled cell, ECA, String

P2

## A LOW-COST SCALABLE SOLUTION PROCESS FOR CZTS NANOPARTICLE SYNTHESIS

**Michael D. K. Jones<sup>1</sup>, Stephen Campbell<sup>1</sup>, Vincent Barrioz<sup>1</sup>, Selcuk Yerci<sup>2</sup>, Yongtao Qu<sup>1</sup>**

<sup>1</sup>*Department of Mathematics, Physics and Electrical Engineering, Northumbria University, Newcastle upon Tyne NE1 8ST, United Kingdom*

<sup>2</sup>*Middle East Technical University, ODTU-GUNAM, Turkey*

Thin film solar cells (TFSC) are an important area of interest in the pursuit of net zero to provide the world with scalable manufacturing of solar cells. Whilst many of the most dominant technologies boast power conversion efficiencies (PCE) greater than 20%, the scarcity and toxicity of constituent elements could be limiting for their large-scale adoption. Kesterite Cu<sub>2</sub>ZnSnS<sub>4</sub> (CZTS) has long been known for its low-cost synthesis of earth-abundant, non-toxic elements. CZTS absorber layers can be synthesised from a multitude of methods namely hot injection solution processing [1], replacement reaction solution processing [2], PVD sputtering [3] and evaporation [4], [5]. Nanoparticle solution processing via the hot injection method is a well-established and low energy input approach to synthesise kesterite CZTS thin films. The process can be scaled with relative ease given simplicity of the required apparatus and the involved metallic precursor salts and a solvents. However, at larger scale synthesis processes the thermodynamics of the 1M Sulphur OLA solution incorporation differs from that of the small scale. EDX analysis shows the atomic percentage (at%) of Sulphur in a drop-casted nanoparticle layer falls short of the desired 50 at% for a kesterite CZTS lattice. A detailed study in the nanoparticle morphology, crystal structure and the influence on solar cell performance will be systematically reported in the full paper. This scalable process would address the barriers to large scale deposition methods, including ultrasonic spray-coating of low-cost and non-toxic Earth abundant energy material.

The authors are grateful for the funding provided by both the EPSRC CD in ReNU (EP/S023836/1) and the British Council-Newton Fund (UK-Turkey) (623804307).

### Keywords

CZTS<sub>Se</sub>, thin film solar cells, nanoparticles, Solution processing

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P3

## **A TRIO-HYBRID SYSTEM: OFFSHORE SOLAR, WIND AND ARTIFICIAL CORAL REEF**

**Muhammed Imran Kulat<sup>1,2</sup>, Bulent Gultekin Akinoglu<sup>2,3</sup>**

<sup>1</sup>*Ministry of Agriculture and Forestry/General Directorate of State Hydraulic Works, Ankara, Turkey*

<sup>2</sup>*Middle East Technical University/ Graduate School of Natural and Applied Sciences - Earth System Science Program, Ankara, Turkey*

<sup>3</sup>*Middle East Technical University/ Department of Physics, Ankara, Turkey*

Hybrid systems are techno-economically more feasible than conventional. Solar and wind power plants will be the main energy sources of the future for the mankind. Offshore solar and wind systems are continuously installed almost all over the world. Hybrid off-shore solar and wind system are relatively new concept. However, there is no consensus application regarding how the stability of the system is provided. Also, one of the drawbacks is the marine and underwater eco-system. Artificial reefs are proved to be good in invoking the local eco-system underwater. In this thesis, a hybrid offshore solar, wind power plant with artificial reef underwater will be designed for a coastal region. The energy conversion systems (wind turbines and solar panels) will be designed to be stable on a floating platform and the platform will be moored to an artificial reef located at sea bottom. In addition, a techno-economic analysis and ecological evaluation will be carried out so to propose a complete feasibility of investment to the investors and stakeholders. In doing so, an interdisciplinary study will be being conducted in order to achieve the design.

P4

## AGRIVOLTAIC SYSTEM DESIGN AND ITS ANALYSIS WITH PVSYST FOR WHEAT PRODUCTION IN TURKEY

**Omer Yalcin<sup>1</sup>, Duygu Kuzyaka<sup>1</sup>, Fırat Es<sup>1</sup>**

<sup>1</sup>KALYON GÜNEŞ TEKNOLOJİLERİ ÜRETİM A.Ş., ANKARA, TÜRKİYE

The main purpose of this study is to provide efficiency and acquisition from both the agricultural and the electrical energy production area without hindering agricultural activities on arable lands. It is known that agrivoltaic systems create a bidirectional positive effect both in terms of the plant growth and energy production. While negative conditions such as temperature increase causing the loss of module efficiency are prevented thanks to the microclimate occurring under the agrivoltaic systems, increase in the crop yield may be observed especially for the crops that are negatively affected from direct sunlight by using agrivoltaic systems [1]. In this study, investigating the performances of agrivoltaic systems and evaluation of the results were performed for wheat fields in cities located in different climate zones of Turkey, and their analysis were performed through PVSyst simulation program. The locations of the systems were identified as Konya, Antalya, Manisa, Tekirdag, Samsun, Sivas, and Diyarbakir due to their high global radiation and high wheat production. In this study, the values of global horizontal radiation, effective global radiation, effective energy at the output of the array, and energy produced in one month were compared. Besides, the values of temperature, reference efficiency, array efficiency, final efficiency, performance ratio, and losses were also compared and discussed. In summary, it was aimed to emphasize the usability of agricultural areas in Turkey for electricity generation with this study. It was shown that agrivoltaic systems, are economically viable and sustainable for both our country and our world.

### Keywords

Agrivoltaics, Solar Power Plants, Renewable Energy, Sustainability, Crop Yield.

Figure 1. Schematical view of an agrivoltaic system design.

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P5

## BASIC MEASUREMENTS OF SOLAR BAGS AND A CONCENTRATING PHOTOVOLTAIC CELL AT 3200 METER ALTITUDE

**Yaren Sarıboğa<sup>1</sup>, Onur Satır<sup>2,3</sup>, Elsen Aydın<sup>4,5</sup>, Cahit Yeşilyaprak<sup>2,3</sup>, Bulent G.  
Akinoglu<sup>1,4,6</sup>**

<sup>1</sup>Middle East Technical University, Department of Physics, Ankara, Turkey

<sup>2</sup>Atatürk University, Erzurum, Turkey

<sup>3</sup>Atatürk University, Astrophysics Applications and Research Center, Erzurum, Turkey

<sup>4</sup>Middle East Technical University, Center for Solar Energy Research and Application, Ankara, Turkey

<sup>5</sup>Middle East Technical University, Archaeometry, Ankara, Turkey

<sup>6</sup>Middle East Technical University, Graduate School of Natural and Applied Sciences, Earth System Science Program, Ankara, Turkey

Photovoltaic solar energy systems are heavily installed all over the World but interestingly research and development of solar cells are also heavily carried out. Different type of applications is possible and some of these applications are still on their research paths. Although also produced, solar bags are very usable in harsh fields for many different purposes. Another recent research of interest is concentrating solar PV(CPV) cells and they are also under development for future market shares. In this study, we measured the fundamental properties of two solar bags and a CPV at an altitude of 3200 m during the winter season. Open circuit voltage and short circuit current values are quite high, and they are compared with their normal outdoor performances and standard laboratory performances. The low outdoor temperature of the winter environment gives important clues to the use of PV at high latitudes and altitudes on the surface of Earth.

P6

## BASIC MEASUREMENTS OF TWO SOLAR BAGS AND A CONCENTRATING PHOTOVOLTAIC CELL AT HORSESHOE ISLAND - ANTARCTICA

**Onur Satir<sup>1</sup>, Elsen Aydin<sup>2,3</sup>, Cahit Yesilyaprak<sup>1,4</sup>, Bulent G. Akinoglu<sup>2,5,6</sup>**

<sup>1</sup>Atatürk University Astrophysics Research and Application Centre (ATASAM), Erzurum, Turkey

<sup>2</sup>Centre for Solar Energy Research and Application, Middle East Technical University, Ankara, Turkey

<sup>3</sup>Archaeometry, Middle East Technical University, Ankara, Turkey

<sup>4</sup>Astronomy and Space Sciences Department, Atatürk University, Erzurum, Turkey

<sup>5</sup>Department of Physics, Middle East Technical University, Ankara, Turkey

<sup>6</sup>Earth System Science Program, Graduate School of Natural and Applied Sciences, Middle East Technical University, Ankara, Turkey

Photovoltaic solar energy power plants are increasingly being installed all over the World. In parallel, research and development studies on solar cells do continue heavily in many laboratories. There are many different approaches possible, and most of them are still at early stages on their research paths.

While different types of solar bags are commercially available, and are being very useful in harsh fields for many different purposes, concentrating solar PV(CPV) cells attract the interests of researchers recently and under development for future market shares. The CPV cells are mainly small in size to be placed at the focal area or linear foci of focusing solar systems.

In this study, we measured the fundamental properties of two commercial solar bags and a CPV cell we are developing at Horseshoe island of Antarctica, where Turkey's scientific research station is based. Open circuit voltage and short circuit current values are measured for two different days at two different regions. Before mentioned PV systems' performances at Antarctica are compared with their normal outdoor and standard laboratory performances. Low outdoor temperature of the site environment gives important clues of the use of PV at poles of Earth.

### Keywords

Photovoltaic, Solar Cell, CPV, Solar Bag

P7

## BBR3 DIFFUSION WITHOUT BRL FORMATION FOR N-TYPE SILICON SOLAR CELLS

**Ahmet Emin Keçeci<sup>1,2</sup>, Yiğit Mert Kaplan<sup>3</sup>, Hasan Hüseyin Canar<sup>3,1</sup>, Sercan Aslan<sup>1,3</sup>, Vahdet Özyahni<sup>1,2</sup>, Hasan Asav<sup>1,2</sup>, Sümeyye Koçak Bütüner<sup>1</sup>, Gence Bektaş<sup>1,2</sup>, Raşit Turan<sup>1,2</sup>**

<sup>1</sup>Center for Solar Energy Research and Applications (ODTÜ-GÜNAM), Ankara, Turkey

<sup>2</sup>Micro and Nanotechnology Department, Middle East Technical University (METU), Ankara, Turkey

<sup>3</sup>Department of Physics, Middle East Technical University (METU), Ankara, Turkey

N-type Cz-Si wafers are free of light-induced degradation (LID) and less sensitive to metallic impurities than p-type ones [1]. For emitter formation in n-type silicon solar cells, BBr<sub>3</sub> diffusion is a commonly used method that typically results in formation of a layer so-called boron-rich layer (BRL) on emitter. The removal of BRL is necessary since it reduces effective minority carrier lifetime, thus lowering the open-circuit voltage of the solar cells. Unlike the PSG growing during the POCl<sub>3</sub> diffusion process, BRL requires an additional process other than HF dipping, which is either low-temperature oxidation or chemical etching treatment [2]. As an alternative way to remove BRL after the diffusion process, the formation of the BRL layer can be avoided during the diffusion process. In this study, we analyze the diffusion parameters and perform a set of BBr<sub>3</sub> diffusion processes to form a p<sup>+</sup> emitter without creating BRL. Figure 1. shows the bulk lifetime ( $\tau_{\text{bulk}}$ ), implied open-circuit voltage ( $iV_{\text{oc}}$ ), and emitter saturation current density ( $J_{0,e}$ ) values which were measured on the symmetrical emitter samples by quasi-steady-state photo-conductance method (QSSPC) using the Sinton WCT-120TS instrument [3]. The graph on the left side represents the emitter that underwent a BRL removal after the diffusion process; while no additional BRL removal process was applied since no BRL was formed during the diffusion process. In addition, sheet resistances of the emitters are measured by the 4-point-probe (4PP) method using TLM-Scan by PV tools, and active dopant profiles of the emitters are measured using electrochemical capacitance-voltage (ECV).

### Keywords

BBR3 Diffusion, BRL, In-Situ Oxidation, p+ Emitter, n-type Cz-Si

Figure 1. Lifetime measurement results of symmetrically diffused and passivated emitters

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P8

## BIPV OPPORTUNITIES AND PERFORMANCE IN THE VERNACULAR BUILDINGS' ENVELOPES OF HOT-DRY AND COLD-DRY CLIMATES OF IRAN

**Ahadollah Azami<sup>1</sup>, Somaye Eftekhari Ranjbar<sup>2</sup>**

<sup>1</sup>Department of Architecture, Eastern Mediterranean University, Famagusta, North Cyprus

<sup>2</sup>Department of Architecture, Azad University of Chalous, Chalous, Iran

Building Integrated Photovoltaics (BIPV) is determined as PV module application for integration in the building envelope-conventionally into roof and facades-by substituting typical building materials and acting as an inseparable segment of the building element to make the dual function of adjusting the interior environment and energy generation as well. Nowadays, BIPV is discussed by architects, engineers, contractors, and building owners as an ingenious technique for eco-friendly energy generation and reducing environmental pollution. The importance of this issue becomes more when the feasibility for PV integration into the valuable traditional vernacular buildings is discussed. These vernacular buildings are based on climatic responsive architecture within high added value and low energy consumption. However, it is hard to measure some advantages of BIPV systems because they are subjective. A building owner might think a BIPV system is of great value if it has a positive image, public's perception, or its effect on the environment once the technology is mounted.

Although, BIPV utilization in the traditional vernacular buildings is harnessed yet because of lots of barriers including aesthetical, technical, social aspects and rough renovation limitations as well. This paper investigates main challenges for PV integration in highly well-known vernacular buildings and BIPV performance both in cold-dry and hot-dry climates in Iran. The results indicates that despite the barriers for BIPV concept utilization in these types of buildings, significant energy efficiency and highly added values are achieved.

### Keywords

BIPV Design, Vernacular Building, Advantages and Barriers, Energy Performance

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P9

## CARBAZOLE DERIVATIVE ACCEPTOR MOLECULES FOR NON-FULLERENE ORGANIC SOLAR CELLS

Gulay Zeynep Gunel<sup>1</sup>, Hatice Arıcı<sup>1</sup>, Burak Gultekin<sup>1</sup>, Ceylan Zafer<sup>1</sup>

<sup>1</sup>Solar Energy Institute, Ege University, Izmir, Turkey

Fullerene derivatives (phenyl-C61-butyric acid methyl ester (PC60BM) and its C71 analog PC70BM) are mostly used as electron acceptors in organic solar cells. Due to the disadvantages of fullerenes such as limited spectral absorption, cost, and morphological stability problems, studies with new non-fullerene acceptors stands out.[1] Non-fullerene acceptor molecules are an important alternative for organic solar cell applications, through their facile synthesis, low cost, absorption in the UV-Vis region, and easily adjustable electronic energy levels (HOMO/LUMO). In this study, three main molecules were designed as acceptor-donor-acceptor (A-D-A) types. The molecules (CRB-RD, CRB-BTD-RD, and CRB-IM) which are a type of non-fullerene acceptors were synthesized. Carbazole was used as a donor molecule and benzothiadiazole, 3-ethylrhodanine, and malononitrile were used as an acceptor. The structural characterizations of the synthesized molecules were performed, followed by electrochemical and photophysical characterizations such as UV-Vis absorption, photoluminescence (PL), and cyclic voltammetry. According to the absorption spectrum, CRB-BTD-RD has the widest absorption (350-600 nm), and also lowest unoccupied molecular orbital (LUMO) level is -5.68 eV. It is thought that the synthesized molecules will create new potential in device studies by using them instead of PCBM in organic solar cells.

### Keywords

non-fullerene acceptors, organic solar cells, carbazole, donor:acceptor molecules

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P10

## CHARACTERIZATION OF THERMALLY EVAPORATED GESE ABSORBER LAYERS FOR SOLAR CELLS

**Elif Peksu<sup>1</sup>, Hakan Karaağaç<sup>1</sup>**

<sup>1</sup>Istanbul Technical University, Department of Physics Engineering, Istanbul, Turkey

GeSe has recently been recognized as a promising photovoltaic absorber material due to its excellent optical and electrical properties such as its abundance in the Earth's crust, ideal band gap of 1.14 eV, strong light absorption ( $>10^5 \text{ cm}^{-1}$ ). In this study, thermal evaporation method was preferred for the deposition of GeSe thin films. Then, the deposited films were annealed at different annealing temperatures in  $\text{N}_2$  atmosphere, and the effects of annealing temperatures on the structural, optical and morphological properties of the deposited films were systematically investigated. Energy dispersive X-ray *analysis* (EDX) analysis revealed that GeSe thin films have a nearly stoichiometric composition before and after annealing treatment. It was determined by X-Ray Diffraction (XRD) analysis that the as-grown GeSe thin films have an amorphous matrix and then transform into a polycrystalline form with an orthorhombic phase having (400) oriented plane direction following the post-annealing process at 450 °C. Morphologies of the films were studied by scanning electron microscopy (SEM) and atomic force microscopy (AFM) measurements. A gradual increase in grain size, on the surface of the films, was observed with increasing annealing temperature. Optical properties were investigated in the wavelength range of 300-1100 nm. The optical band gap of both unheated and annealed films was determined through the recorded transmittance and reflectance values.

### Keywords

GeSe, absorber layer, solar cell

P11

## COMPARISON OF DIFFERENT STABILIZERS IN SOL-GEL DIP COATING METHODS FOR ZNS

**Busra Kocakoc<sup>1</sup>, Ertugrul Sena Cagiltay<sup>1</sup>, Baran Burhan Gunder<sup>1</sup>, Burcin Dag<sup>2</sup>, Yanki Gunduz-Ozvaris<sup>1</sup>, Ali Köse<sup>1</sup>, Haslet Eksi-Kocak<sup>3</sup>, Izzet Parug Duru<sup>4</sup>, Dogan Akcan<sup>5</sup>, Utku Canci Matur<sup>6</sup>**

<sup>1</sup>Department of Mechanical Engineering, Istanbul Gedik University, Istanbul, Turkey

<sup>2</sup>Department of Electrical and Electronics Engineering, Istanbul Gedik University, Istanbul, Turkey

<sup>3</sup>Department of Metallurgy and Materials Engineering, Istanbul Gedik University, Istanbul, Turkey

<sup>4</sup>Medical Imaging Programme, Istanbul Gedik University, Istanbul, Turkey

<sup>5</sup>Department of Mathematics, Faculty of Engineering and Natural Sciences, Bahcesehir University, Istanbul

<sup>6</sup>Energy Technologies Application and Research Center, Istanbul Gedik University, Istanbul, Turkey

ZnS is a very popular material due to their great potential in optoelectronics applications. There are lots of advantages of ZnS such as; large direct band gap of almost 3.6 eV, along with the large exciton binding energy, new generation of ultraviolet light emitting diodes, solar cell, gas sensor, and lasing devices operating at high temperatures and in harsh environments.

In this study, ZnS thin films are deposited by sol-gel dip coating method layer by layer on glass slide substrates. 4 different basic chelating agents monoethanolamine(MEA), diethanolamine(DEA), triethanolamine(TEA) and acetyl acetone are used as a stabilizer in sol-gel system. In previous studies, linear temperature increase and short-term pre-annealing were performed at constant temperature during the sol-gel dip coating process. In addition, sol-gel dip coating was done with MEA, DEA and TEA to obtain ZnS. However, ZnS was not obtained by using acetyl acetone, which is a stabilizer before. In this study, constant speed sol-gel dip coating makes and after the process, pre-annealing makes at constant temperature (300°C) for 2 minutes. Then, 3 minutes cooling process happens. After the slide has cooled down, it subjects to sol-gel dip coating again. Thus, it is envisaged that 1 layer of coating will be made. By repeating this process 5 and 10 times, sol-gel dip coating process performs with 4 different solutions. Influence of the stabilizers on structural and optical properties of the ZnS thin films are compared. This comparison is investigated by means of XRD analysis, ultraviolet-visible (UV-VIS) and photoluminescence (PL) spectroscopy.

### Keywords

ZnS 1, sol-gel 2, dip coating 3

P12

## COMPARISON OF MECHANICAL BEHAVIORS OF SI CELLS WITH THREE POINT AND FOUR POINT BENDING TEST

**Meriç Çalışkan<sup>1</sup>, Betül Şekertekin<sup>1</sup>, Bedrettin Aydoğan<sup>1</sup>, Fırat Es<sup>1</sup>**

<sup>1</sup>KalyonPV Research and Development Center, Kalyon Güneş Teknolojileri Üretim A.Ş., 06909 Ankara, TURKEY

The brittle nature of silicon material limits its applications in photovoltaic (PV) industry. It is crucial to investigate the material strength properties of Si solar cells, to guide the fabrication process of Si solar cells, to avoid breaking the cells and to enhance strength of PV modules<sup>1</sup>. It is known that the different cell technologies can yield a similar electrical performance of the cells but can lead to totally different mechanical behavior of the cells. In this work, mechanical strength features of different types of PV cells were analyzed both by four-point bending test and three-point bending test. Two types of solar cells namely passivated emitter rear contact (PERC) and interdigitated back contact (IBC) solar cells were subjected to mechanical stress characterization. The strengths of solar cells were analyzed on front and backside and in two different directions, parallel and perpendicular to the busbars. According to test results it is shown that the breakage and strength depend strongly on the side and direction of loading. The highest strength was detected for the front side being loaded with tensile stress perpendicular to the busbars within the IBC cell by applying four-point bending test. On the other hand, same cell possesses the lowest strength with three-point bending test with stress applications to the front side of cell parallel to busbars. In accordance with the test results the mechanical strength on module laminate level will be evaluated for best performing solar cells.

### Keywords

bending test, strength, photovoltaic mechanical

Figure 1. Fracture strength as a function of bending for the cells perpendicular to the busbars

P13

## DETERMINATION OF LASER CUTTING PARAMETERS FOR SOLAR CELLS

**Meryem Ezgi Karahalli<sup>1,2</sup>, Emircan Ozdemir<sup>3</sup>, Aysegul Afal Genis<sup>3</sup>, Hasan Ozkara<sup>3,4</sup>,  
Hazal Dogaroglu<sup>5</sup>, Gulfidan Tursun<sup>5</sup>, Talat Ozden<sup>1,6</sup>**

<sup>1</sup>ODTU-GUNAM, 06800, Cankaya, Ankara, Turkiye

<sup>2</sup>Micro and Nanotechnology Programme, METU, 06800, Cankaya, Ankara, Turkiye

<sup>3</sup>ASELSAN A.S., 06200, Yenimahalle, Ankara, Turkiye

<sup>4</sup>Department of Electrical and Electronics Engineering, Gazi University, 06570, Cankaya, Ankara, Turkiye

<sup>5</sup>İleri ArGe Teknolojileri, 06930, Sincan, Ankara, Turkiye

<sup>6</sup>Department of Electrical and Electronics Engineering, Gümüşhane University, 29100, Gümüşhane, Türkiye

Many photovoltaic (PV) applications apply with standard modules that produce using regular-sized PV cells. However, special size PV modules for calculators or IoT devices are generally produced with sliced solar cells by using a fiber laser machine. To avoid efficiency loss, the determination of cutting parameters for the laser is essential. Nowadays, besides particular size PV modules, most PV modules need to be cut solar cells; for example, half-cell and shingled modules. In this study, damage caused by laser cut of the cell, and decreases in the output power and efficiency of the cell by changing the cutting parameters of the laser are observed. By changing the power, speed, and the number of the pulse of the fiber laser device, ideal cutting parameters are presented.

### Keywords

Solar cell, PERC, Shingled cell

P14

## DETERMINATION OF THE PROPERTIES OF THERMAL INTERFACE MATERIALS USED FOR THE HEAT MANAGEMENT OF PHOTOVOLTAIC SOLAR CELLS USED IN CONCENTRATED SOLAR ENERGY SYSTEMS

**Ahmet Azgın<sup>1,2</sup>, Bilge Tunçel<sup>3,4</sup>, Elsen Aydın<sup>5,6</sup>, Raşit Turan<sup>5,4,2</sup>**

<sup>1</sup>İleri Arge Teknolojileri Muhendislik Yazılım Eğitim Danışmanlık ve Ticaret LTD STI - iTechSolar, Ankara, Turkey

<sup>2</sup>Department of Micro and Nanotechnology Middle East Technical University, Ankara, Turkey

<sup>3</sup>Energy Engineering, Ankara University, Ankara, Turkey

<sup>4</sup>Department of Physics, Middle East Technical University, Ankara, Turkey

<sup>5</sup>Center for Solar Energy Research and Applications (GUNAM), METU, Ankara, Turkey

<sup>6</sup>Archaeometry, Middle East Technical University, Ankara, Turkey

One of the main issues for the improvement of the Concentrated Photovoltaic systems, such as parabolic trough systems, is the heat management of the cells. The thermal energy resulting from the focusing of the sun through various optical media causes a significant temperature increase in the cell. Therefore, rapid removal of heat and maintaining the temperature of the cell are the primary objectives. A Si cell operating with an ordinary heatsink can lower the cell temperature by up to 15 °C and thus increase its power by 6%. Here, this study looks for various materials to be used in a CPV-T system. A simple thermal experiment was conducted to calculate the thermal conductivity of these materials. There is no cell directly involved from this side of the measurement and materials that may be suitable for CPV have been evaluated, which is somewhere between the heat-dissipating parts. The materials tested are very thin and the heat capacity is important in transient effects. Therefore, its temporary effects have been ignored. The resulting thermal conductivity of materials; a sheet of paper 0.030 W/mK, FR4 as 0.188 W/mK, FR4 below 100 µm with black paint coating 0.099 W/mK, M3 8708 Series Thermal Tape 0.027 W/mK, inexpensive thermal paste 0.370 W/mK, a two copper tapes with adhesive side, different thickness (0.03 mm and 0.09 mm) as 0.005 and 0.013 W/mK.

### Keywords

CSP, PV-T Systems, PV, Heat Management, Thermal Interface Material

Used Material Properties and Results of Test Set-up

P15

## DOPANT-FREE CARRIER SELECTIVE CONTACTS ON SiO<sub>x</sub> PASSIVATED N-TYPE CRYSTALLINE SILICON SOLAR CELLS

**Hisham Nasser<sup>1</sup>, Basil Eldeeb<sup>1,2</sup>, E. Hande Ciftpinar<sup>1</sup>, Ergi Donercark<sup>1</sup>, Mona Zolfaghari Borra<sup>1</sup>, Rasit Turan<sup>1,2</sup>**

<sup>1</sup>The Center for Solar Energy Research and Applications (ODTÜ-GÜNAM), 06800 Ankara, Turkey

<sup>2</sup>Department of Physics, Middle East Technical University, 06800 Ankara, Turkey

In this work, we demonstrate front and back contacted dopant-free crystalline silicon (c-Si) heterojunction solar cells utilizing lithium fluoride (LiF<sub>x</sub>) and molybdenum oxide (MoO<sub>x</sub>) and as electron- and hole-selective contacts, respectively [1]. First, solar cells with one carrier-selective polarity are developed while keeping conventional Si heterojunction on the other polarity. In these designs, the MoO<sub>x</sub> thickness is fixed at 5 nm, while the LiF<sub>x</sub> thickness on textured Si surface is investigated to obtain the highest fill factor (FF). Heterojunction solar cells with MoO<sub>x</sub> directly deposited on c-Si at the front and i/n a-Si:H at the rear resulted in an efficiency of 17.5% with modest open-circuit voltage (V<sub>oc</sub>) of 590 mV. On the other hand, solar cells with direct LiF<sub>x</sub>/Si contact at the rear and p/i a-Si:H at the front are limited by poor V<sub>oc</sub> of only 520 mV with the best FF of 76.5%. The optimized LiF<sub>x</sub> film thickness is then integrated into the dopant-free c-Si solar cell structure. The solar cell performance is found to be enhanced by the application of wet-chemically grown SiO<sub>x</sub> (W-SiO<sub>x</sub>) in nitric acid as a passivation layer on both sides. With optimized LiF<sub>x</sub> thickness and MoO<sub>x</sub>/SiO<sub>x</sub> recipe, our dopant-free solar cell has reached an efficiency of 17.83% with V<sub>oc</sub> of 605.3 mV, J<sub>sc</sub> of 38.2 mA/cm<sup>2</sup>, and FF of 77.15%. To our knowledge, this is the highest efficiency obtained from solar cells with dopant-free carrier selective contacts on both polarities without the use of intrinsic a-Si:H as a passivation layer.

### Keywords

carrier selective contacts, MoO<sub>x</sub>, LiF<sub>x</sub>, W-SiO<sub>x</sub>, c-Si solar cell

Fig 1

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## EFFECT OF BASE RESISTIVITY, GETTERING AND DOPANT TYPE ON LIGHT INDUCED DEGRADATION OF P-TYPE MONO SILICON WAFER

**Sercan Aslan<sup>1,2</sup>, Vahdet Özyahni<sup>1,3</sup>, Ahmet Emin Keçeci<sup>1,3</sup>, Hasan Hüseyin Canar<sup>1,2</sup>, Sümeyye Koçak Bütüner<sup>1</sup>, Hasan Asav<sup>1,3</sup>, Gence Bektaş<sup>1,3</sup>, Bülent Arikan<sup>1</sup>, Raşit Turan<sup>1,2,3</sup>**

<sup>1</sup>Middle East Technical University - Center for Solar Energy Research and Applications (ODTÜ-GÜNAM), Ankara, Turkey

<sup>2</sup>Department of Physics, Middle East Technical University (METU), Ankara, Turkey

<sup>3</sup>Micro and Nanotechnology Program (MNT), Middle East Technical University (METU), Ankara, Turkey

Czochralski (Cz) grown P-type Silicon (Si) wafer is the commonly used wafer type for solar cell production in industry. They can be formed by either Boron (B) or Gallium (Ga) doping. Generally, they have many background defects because of production process. Widely used B doped wafers suffer from both metallic impurities and B-related (B-O, Metal-B, etc.) complexes, while Ga doped wafers suffer from metallic impurities and Ga-related (Metal-Ga) complexes which can cause lifetime drop. Metallic impurities in the bulk can be reduced under some level by so called gettering processes. On the other hand, B/Ga-related complexes can be activated and deactivated under annealed illumination which is known as Light Induced Degradation (LID)[1]. However, base resistivity may also have an effect on gettering and LID. In this study, Phosphorus (P) gettering was applied to wafers with different base resistivities to reduce metallic impurities. Then, surfaces were etched, and  $\text{SiO}_x\text{N}_y + \text{SiN}_x$  passivation layer was deposited by PECVD. After fast firing, wafers were left for degradation in ambient condition, and then regeneration process was applied by annealing during light soaking. Effective lifetime ( $\tau_{\text{eff}}$ ) and implied open circuit voltage ( $iV_{\text{oc}}$ ) were measured at each step by Photoconductive-Decay method(PCD) using Sinton Instruments WCT-120TS[2-4]. Surface recombination current density ( $J_{\text{os}}$ ) and bulk lifetime ( $\tau_{\text{bulk}}$ ) were determined to observe whether the loss and the gain of  $iV_{\text{oc}}$  were from bulk, surface or both. Photoluminescence-Imaging(PLI) was used for recombination mapping. The effect of base resistivity, gettering and dopant type on LID will be shown after complete analysis done at conference.

### Keywords

P-Type Cz-Si, Base Resistivity, Gettering, LID, surface recombination current density

Effect of gettering process on effective lifetime values of p-type Si wafers

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P17

## EFFECT OF SURFACE MORPHOLOGY ON PASSIVATION QUALITY AND CELL PERFORMANCE OF SILICON HETEROJUNCTION SOLAR CELLS

**Sümeyye Koçak Bütüner<sup>1</sup>, Arghavan Salimi<sup>1</sup>, Milad Ghasemikashtiban<sup>1</sup>, Seda Kılıçkaya<sup>1</sup>, Mehmet Koç<sup>1</sup>, Ergi Dönerçark<sup>1</sup>, Raşit Turan<sup>2</sup>**

<sup>1</sup>ODTÜ-GÜNAM, Ankara, Turkey

<sup>2</sup>METU Physics, Ankara, Turkey

Silicon heterojunction (SHJ) solar cells have gained importance in the photovoltaic market thanks to its high photoconversion efficiency and lean production chain. The performance of SHJ solar cells is affected by the surface passivation of crystalline silicon. In addition, surface passivation is strongly correlated with surface morphology. Although surface texturing is crucial for increasing optical path length, a surface recombination appears due to an increase in surface area. Besides, defect density develops in tips and valleys of the pyramidal structure, which could create epitaxial growth of a-Si:H layers and hence lower passivation quality[1]. To overcome poor passivation quality resulting from surface morphology, rounding of pyramidal structure with wet etching chemicals is suggested. Three different approaches are available for the pyramid rounding. The first approach involves dipping the textured samples in polish-etch solution ( $\text{HNO}_3+\text{HF}+\text{CH}_3\text{COOH}$ ), and the second method includes sequentially oxidizing in  $\text{HNO}_3$ ,  $\text{H}_2\text{SO}_4+\text{H}_2\text{O}_2$ , or hot DI and etching in HF or  $\text{NH}_4\text{F}$  the textured silicon wafers. The final relatively new approach is based on HF and ozone-containing chemical solutions [2]. In this study, the impact of surface smoothing by an industrial RENA tool containing etching chemicals of  $\text{HNO}_3$ , HF, and  $\text{H}_2\text{SO}_4$  is investigated. Various surface morphologies are obtained based on the etching time of the samples. The surface structures will be characterized by scanning electron microscopy, atomic force microscopy, and reflectance measurements. The effect of surface morphology on passivation quality and cell performance will be investigated using lifetime and I-V measurements. The experimental results will be compared to the simulation results.

### Keywords

silicon heterojunction, pyramid rounding, wet chemical etching

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## ENHANCED PASSIVATION QUALITY OF HYDROGENATED AMORPHOUS SILICON LAYER FOR SI HETEROJUNCTION SOLAR CELLS

**Ergi Dönerçark<sup>1</sup>, Hariharsudan Sivaramakrishnan Radhakrishnan<sup>2,3,4</sup>, Devika Rajagopal<sup>2,3,4,5</sup>, Arghavan Salimi<sup>1,6</sup>, Milad Ghasemi<sup>1,6</sup>, Raşit Turan<sup>1,6,7</sup>**

<sup>1</sup>ODTU-GUNAM, Ankara, Turkey

<sup>2</sup>Imec, imoimomec, Genk, Belgium

<sup>3</sup>EnergyVille, imo-imomec, Genk, Belgium

<sup>4</sup>Hasselt University, imo-imomec, Hasselt, Belgium

<sup>5</sup>KU Leuven, ESAT, Heverlee, Belgium

<sup>6</sup>Middle East Technical University, Micro and Nanotechnology, Ankara, Turkey

<sup>7</sup>Middle East Technical University, Physics, Ankara, Turkey

The passivation of the recombination centers on the crystalline silicon (c-Si) surface is a crucial step for performance enhancements of silicon heterojunction (SHJ) solar cells. This is because the surface of the c-Si wafer contains dangling bonds and contaminations, which create defects on the surface that act as a recombination centers for the charge carriers. Surface recombination is the main limitation in achieving high efficiencies in SHJ cells. The initial surface condition of Si wafers has a significant impact on the surface passivation quality. For this reason, chemical surface cleaning steps are necessary after texturing to obtain low interface defect density between c-Si and a-Si:H interface. Moreover, the thickness and deposition conditions of a-Si:H layer influences the passivation quality. In this study, the impact of different surface cleaning processes on the passivation quality of textured and saw-damaged removed n-type c-Si wafers is investigated. The relationship between hydrogen dilution ratio during deposition of a-Si:H layers and passivation quality is clarified under various thicknesses of a-Si:H layers. We have achieved more than 740mV implied  $V_{oc}$  values for samples cleaned with both i2PV ( $O_3:HF$ ; typically used in the PV industry) and SPM ( $H_2SO_4:H_2O_2$ ) cleaning recipes.

### Keywords

Silicon heterojunction solar cell, a-Si:H, passivation, surface cleaning.

Figure 1. Effective lifetime and implied Voc results of samples coated with 5 and 7 nm thick a-Si:H

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## ENHANCING PERFORMANCE AND IMPROVING ANTI-SOILING EFFECT OF SILICON SOLAR CELLS

**Omar Lakbita<sup>1</sup>, Othmane Essahili<sup>2</sup>, Mouad Ouafi<sup>2</sup>, Omar Moudam<sup>2</sup>**

<sup>1</sup>Technology Development Cell (TechCell), Mohammed VI Polytechnic University (UM6P), Lot 660 - Hay Moulay Rachid, 43150 Benguerir, Morocco

<sup>2</sup>Applied Chemistry & Engineering Research Centre of Excellence (ACER CoE), Advanced Organic Optoelectronics Laboratory (AOL), Mohammed VI Polytechnic University (UM6P), Lot 660 - Hay Moulay Rachid, 43150 Benguerir, Morocco.

In this study, a clear improvement in power conversion efficiency (PCE) of the silicon solar cell is observed by protecting the cell from harmful UV rays. This improvement is achieved by adding a protective layer of poly (methyl methacrylate) PMMA doped with europium (Eu) complex and coated on the surface of the silicon solar cell. The Eu complex  $\text{Eu}(\text{TTA})_3(\text{MePhen})$  has been synthesized for use as a luminescent down-shifter (LDS) displaying excellent absorption properties up to 400 nm and a strong, sharp red emission around 612 nm.<sup>1,2</sup>

Furthermore, a high hydrophobic character of resulting layer is showing, and it could potentially be used, simultaneously, as a waterproof layer to resolve water leaks and soiling poisonous effects.

The structure of LDS complex without and with PMMA are characterized by FTIR analysis, XRD, <sup>1</sup>H NMR spectroscopy and SEM. The optical properties are measured by using UV-Visible and emission spectroscopy. Finally, the hydrophobic character of resulting layer is measured by contact angles.

The *I-V* testing of the silicon solar cells without and with LDS layer under one sun shows an increase in power conversion efficiency of +2.61% for a surface of 118.56 cm<sup>2</sup>, similar to Guerrero-Lemus et al., work's which is about +2.87%.<sup>3</sup> Furthermore, the resulting layer exhibits a high hydrophobic character when the PMMA is doped by Eu complex. Thus, the measurement of the contact angle gives a value of 101° which demonstrates that the film has a hydrophobic character and can be used to protect against soiling problematics.

### Keywords

Silicon solar cell, Luminescent down-shifting, Anti-UV-light, Anti-soiling, Waterproof

Waterproof luminescent-down shifter layer-based Eu-complex with PMMA film added at the top of the si

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## ENHANCING PERFORMANCE OF GAAS SOLAR CELL VIA WAVEFRONT SHAPING

**Sena Atila<sup>1,2,3</sup>, Alim Yolalmaz<sup>1</sup>, Berk Nezir Gün<sup>1,3</sup>, Parisa Naghinazhadahmadi<sup>1,2</sup>,  
Emre Yüce<sup>1,2,3</sup>**

<sup>1</sup>Programmable Photonics Group, Department of Physics, Middle East Technical University, 06800 Ankara, Turkey

<sup>2</sup>Micro and Nanotechnology Program, Middle East Technical University, 06800 Ankara, Turkey

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

Conversion efficiency of broadband spectrum of the light for single-junction solar cells is limited to  $\sim 30\%$ <sup>1</sup>. Higher energy photons are wasted due to thermalization and excess energy is lost as heat, while lower energy photons are not absorbed. Overcoming this obstacle is possible via utilizing laterally placed solar cells, and illuminating each solar cell with relevant spectrum to make use of full spectrum of the Sun. Previously presented, a DOE is designed for simultaneous splitting and concentration of broadband light to two sub-bands<sup>2</sup>, and the broadband light is experimentally split and concentrated to chosen positions on the CCD camera as three sub-bands<sup>3</sup>.

We demonstrate a system with optical elements, a gallium arsenide (GaAs) solar cell and a silicon photodetector for spectral splitting and concentration of broadband light (360 - 2600 nm) to increase the measured current from solar cell and photodetector. The broadband light is spatially and spectrally controlled on laterally arranged GaAs solar cell and silicon photodetector via a spatial light modulator (SLM). SLM alters phase of incident light in a pixel-wise of way, and has pixels in the number of  $\sim 10^6$ . For convenience, we group pixels squarely which are called superpixels. By sequentially scanning each superpixel of the SLM, we increased the electrical current generated by GaAs solar cell. As a result, we obtained excess  $\sim 6\%$  to  $\sim 11\%$  short-circuit current read from GaAs. At the maximum power point, excess current varies from  $\sim 10\%$  to  $\sim 20\%$ , while the power output increased from  $\sim 6\%$  to  $\sim 14\%$  for different number of superpixels.

### Keywords

Wavefront shaping, spatial light modulator, solar concentration

For GaAs solar cell (a) current density and (b) power density of various numbers of superpixels.

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## EQE MEASUREMENTS OF BIFACIAL SOLAR CELLS ON A MONOFACIAL SETUP

**Dilek Demiroglu<sup>1</sup>, Salar H. Sedani<sup>1</sup>**

<sup>1</sup>ODTU-GUNAM,06800,Ankara, Turkey

Bifacial solar cells are becoming increasingly popular in the photovoltaic industry because of their high-efficiency and cost-effective manufacturing techniques, and potential for stable electrical performance [1]. In most cases, researchers use front-side illumination to investigate the electrical properties of bifacial cells where the rear side of the cell is assumed as a full contact area [1-3]. Busbar and finger areas, which are too small compared to the cell area, and back contact reflection are the main troubles for this concept. Defining an error margin of different back contact areas for front-side illumination will strengthen this method.

In our research, we study point-probing from different contact areas on the rear side to evaluate the external quantum efficiency and Jsc properties. We determined that there is a significant increase in Jsc and a difference for EQE result in the 800-1050 nm range, resulting from the back side of the cell (Fig. 1). Furthermore, the albedo ratio is directly affected the rear side illumination and cell properties must be evaluated, too. Therefore, albedo ratio effects on external quantum efficiency and Jsc would investigate by utilizing black silicon and BaSO<sub>4</sub> surfaces at back. We provide a better understanding of EQE measurement error margins for bifacial cells.

### Keywords

Bifacial solar cell, EQE measurements

Figure 1

### References

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## EXPERIMENTAL STUDY OF AN ELECTRONIC CONTROL OF A SOLAR WATER PUMP

Drici Manel Azizi Amina Houabes Mourad Bahri Mebarek<sup>1</sup>

<sup>1</sup>University of Annaba

All countries of the world ,to promot sustainable developement by securing and increasing primary production,especially in the agricultural and pastoral sectors that depend on water supplies available in the depths .Nowadays ,water demand is becomig increasingly important ,especially in rural and isolated locationwhere access to conventionalenergy is difficult if not practically impossible.Since solar energy is the most common availablerenewable energy sources ,today it represents a profitable solution for the future to be widely used in various terrestrialapplication such as electrification of isolated areas deprived of electricity grid and irrigation for agricultural applications [1].Good performance and excelent reliable water supply and operational independence arethe desire that any resident of this region can expect [2].

the problem raised in this part,is to use the energy produced by our device to automatically manage water reqyurements in irrigation.so a suitable control methodology was also focused on an experimental realization of electronic control for system.with the main objective to operate th pump automatically with the time delay using a push button for automatic stop and start.This helps to maintaining system proved to determine the performance and reliability for control and for prime efficiency solar gathering applications with a greater degree of precision which make renewables smarter .However ,we used a photovoltaique panel (12)V,an MPPT regulator to control the charge and a battery to supply the regulator and Arduino UNO controller as the picture (1) show.

### Keywords

solar water pumping system 1, Controller 2, renewables energies 3, sustainable development 4

Figure 1. a) Installed energy flow control system b) solar pump system

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## EXTREMELY LOW EXTINCTION COEFFICIENT ZROX ENABLES A NOVEL DOUBLE-LAYER ANTI-REFLECTION COATING FOR CRYSTALLINE SILICON SOLAR CELLS

**Hisham Nasser<sup>1</sup>, Gokhan Altiner<sup>1,2</sup>, Loay Akmal Madbouly<sup>1,3</sup>, Husnu Emrah Unalan<sup>1,3</sup>, Rasit Turan<sup>1,2</sup>**

<sup>1</sup>The Center for Solar Energy Research and Applications (ODTU-GUNAM), Ankara, Turkey

<sup>2</sup>Department of Physics, Middle East Technical University, Ankara, Turkey

<sup>3</sup>Department of Metallurgical and Materials Engineering, Middle East Technical University, Ankara, Turkey

Simulated single- and double-layer anti-reflective coatings (ARC) based on SiN<sub>x</sub> and ZrO<sub>x</sub> are presented. The current generation ( $J_{ph}$ ) in c-Si, current absorbed in the ARC ( $J_A$ ), and the front-surface reflected light ( $J_R$ ) were simulated using OPAL2 [1]. The simulated solar cell structure is shown in Figure 1. Different SiN<sub>x</sub> refractive indices ( $n$ ) in the 1.8-2.13 range were considered. The  $n$  and extinction coefficient ( $k$ ) of ZrO<sub>x</sub> were extracted by fitting the ellipsometry parameters of electron-beam deposited ZrO<sub>x</sub>. The results show that ZrO<sub>x</sub> has  $n \sim 2$ ,  $k =$  with a sharp absorption edge in the c-Si useful wavelength range, and  $E_g \sim 5.2$  eV. For a single SiN<sub>x</sub> or ZrO<sub>x</sub> layer, the corresponding optimum thickness weighted on the layer  $n$  was calculated and used in the simulation. The results reveal that a single layer comprising SiN<sub>x</sub> can result in the highest  $J_{ph} \sim 43.2 \text{ mA/cm}^2$  at  $n = 1.92$ . The -extinction coefficient of ZrO<sub>x</sub> enables  $J_{ph} \sim 43.27 \text{ mA/cm}^2$ . For a double-layer ARC, to maintain c-Si front surface passivation quality of the, the SiN<sub>x</sub> thickness was fixed at 20 nm, while the thickness of ZrO<sub>x</sub> was varied to achieve the highest  $J_{ph}$ . A remarkable  $J_{ph} \sim 43.3 \text{ mA/cm}^2$  was obtained from the combination of SiN<sub>x</sub> with  $n \sim 1.92$  or  $n \sim 1.96$  covered by 57 nm ZrO<sub>x</sub>. More importantly, for all SiN<sub>x</sub> refractive indices,  $J_{ph}$  is in the 43.26-43.3 mA/cm<sup>2</sup> range which is remarkably higher than that of a single SiN<sub>x</sub> layer. This gives flexibility during SiN<sub>x</sub> deposition; mainly to achieve an excellent surface passivation to c-Si surface, where  $J_{ph}$  becomes independent of  $n$  of SiN<sub>x</sub> when ZrO<sub>x</sub> is used as the second layer in double-layer ARC design.

### Keywords

crystalline silicon, solar cells, anti-reflection coating, zirconium oxide, optical simulation

Figure 1.

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## FABRICATION, PASSIVATION AND CHARACTERISATION OF BLACK-SI WAFERS FOR SOLAR CELL APPLICATIONS

**Ateşcan Aliefendioğlu<sup>1,2</sup>, Ahmet Emin Keçeci<sup>1,2</sup>, Hasan Hüseyin Canar<sup>1,3</sup>, Hisham Nasser<sup>1</sup>, Sümeyye Koçak Bütüner<sup>1</sup>, Raşit Turan<sup>1,2,3</sup>**

<sup>1</sup>ODTU-GUNAM, Ankara, TURKEY

<sup>2</sup>Middle East Technical University/Graduate School of Micro and Nanotechnology, Ankara, TURKEY

<sup>3</sup>Middle East Technical University/Department of Physics, Ankara, TURKEY

In this study, black-Si samples were produced with the reactive ion etching (RIE) method. With this method, virtually zero reflectance can be achieved for the feasible solar spectra due to the high aspect ratio features formed on the surface. The features trap the photons until they are absorbed and thus, increasing the efficiency. A set of process parameters was scanned to find the lowest reflectivity value which was around 4% (Figure 1(a)). Then, the uniformity over full-size wafers was investigated and the surface was analysed using EDS for simple elemental composition and residue analysis. To investigate the passivation properties of the b-Si samples, symmetric samples were fabricated and passivated with varying thicknesses of ALD deposited Al<sub>2</sub>O<sub>3</sub> layer and capped with PECVD SiN<sub>x</sub> layer and an  $iV_{oc}$  of around 700 mV was achieved (Figure 1(c)). Lastly, the nitride layer was substituted with the hole selective transition metal oxides (TMO) to have dopant-free asymmetric heterocontact (DASH) concept<sup>[1]</sup>. For hole selective TMO layers, WO<sub>x</sub>, MoO<sub>x</sub> and V<sub>2</sub>O<sub>x</sub> was thermally deposited, and the resulting thin films were characterised using Sinton tool. It was realised that V<sub>2</sub>O<sub>x</sub> resulted in the highest  $iV_{oc}$  (Figure 1(d)).

### Keywords

Black-Si, ESL TMO, DASH Solar Cells, RIE, Characterisation

(a) Reflectance of b-Si, (b) b-Si surface SEM image, (c) Al<sub>2</sub>O<sub>3</sub>/SiN<sub>x</sub> and (d) Al<sub>2</sub>O<sub>3</sub>/HSL passivation

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## FABRICATION OF INTERDIGITATED BACK-CONTACT (IBC) SOLAR CELLS WITH SCREEN-PRINTED BORON DOPING PASTE

**Ateşcan Aliefendioğlu<sup>1,2</sup>, E. Hande Çiftpınar<sup>1,2</sup>, Raşit Turan<sup>1,2,3</sup>**

<sup>1</sup>ODTÜ-GÜNAM, Ankara, TURKEY

<sup>2</sup>Middle East Technical University/Graduate School of Micro and Nanotechnology, Ankara, TURKEY

<sup>3</sup>Middle East Technical University/Department of Physics, Ankara, TURKEY

Interdigitated back-contact (IBC) solar cells, due to their complex process flow, require multiple photolithography steps to form the emitter and the BSF regions on the rear side. This complexity can be reduced tremendously with the well-established and industrially accepted method of screen-printing by introducing printable boron doping paste. In this work, with regards to the boron doping paste, we present the wide range of doping profiles achievable by controlling the printing and diffusion parameters and the associated sheet resistance values ranging from 18 to 365  $\Omega/\text{sq}$  as well as the passivation properties<sup>[1]</sup>. For solar cell fabrication, we present our simplified process flow for the IBC cells and the cell results with different pitches and the best performing cell achieved an efficiency of 8.70% with FF over 75% (Figure 1).

### Keywords

Boron Doping Paste, Screen-Printing, IBC Solar Cell, BC-BJ, Doping Optimisation and Characterisation

The ECV profiles (left) and the J-V curve of the best cell (right).

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## FIRST 4-INCH MONO-SI INGOT PRODUCTION TRIAL ON THE INDUSTRIAL SCALE IN TURKEY

**Nurhayat Yıldırım<sup>1</sup>, Kübra Çelen<sup>1</sup>, Ahmet Yiğit Kurtuluş<sup>1</sup>, Ece Çamkara<sup>1</sup>, Hacer Koç<sup>1</sup>, Ali Giray Gülhan<sup>1</sup>, Sezai Akay Çiftçi<sup>1</sup>, Kaan Görgişen<sup>1</sup>, Burak Kaan Cihan<sup>1</sup>, Güven Korkmaz<sup>1</sup>, Fırat Es<sup>1</sup>**

<sup>1</sup>Kalyon PV Research and Development Center, Kalyon Gunes Teknolojileri Uretim A.S., 06909, Ankara, Turkey

Due to Covid-19, online education and working life have been started in many regions all world. However, there has been a significant increase in the time spent at home due to the lockdown time. Therefore, there has been more demand for electronic devices than ever before, and this demand is increasing every day. The increase in the use of electronic devices also means the need for semiconductor integrated circuits which used in these devices. Through the increasing supply of semiconductor materials and the problems experienced in their distribution, it was also insufficient to meet the demands and problems were experienced. There has been crisis in the production of semiconductor wafers around the world, and many users have been affected by this crisis [1,2].

As KalyonPV, we aimed for this study is to be affected by this semiconductor wafer crisis at the lowest level and to produce wafers used in integrated circuits as domestic production. According to this aim, 4-inch (101.6 mm) ingot trials were done, and results analysed. With the production, not merely on the scale of solar energy, but also on the scale of integrated circuit systems, capacity to produce ingots and wafers have been studied and the results have been examined. Oxygen content, carbon content and lifetime measurements were done, CZ furnace working parameters as temperature, growth rate, power and CZ-growth recipe were determined for this special production. Differences between solar scale and integrated systems production have been observed, and the change of production parameters has been examined.

### Keywords

4-inch ingot, integrated circuits, CZ method, electronic devices, semiconductor wafer crisis

Figure 1

### References

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## GRAPHENE/SILICON SCHOTTKY SOLAR CELLS WITH SILICON SURFACE TEXTURED BY PHOTOCHEMICAL ETCHING METHOD

**Nardin Avishan<sup>1</sup>, Alp Akbiyik<sup>2,3</sup>, Khurram Shehzad<sup>2</sup>, Alpan Bek<sup>1,2,3</sup>, Emre Yuce<sup>1,2</sup>**

<sup>1</sup>*Micro and Nanotechnology Program, Graduate School of Natural and Applied Sciences, Middle East Technical University, Ankara, Turkey*

<sup>2</sup>*Physics Department, Faculty of Art and Science, Middle East Technical University, Ankara, Turkey*

<sup>3</sup>*ODTU-GUNAM, Ankara, Turkey*

The two-dimensional nature of graphene combined with its extraordinary physical and optical properties leads to a new photovoltaic area: Graphene/Silicon (Gr/Si) solar cell. Over the years, different methods such as surface texturing, molecular doping of graphene, and anti-reflection coating are suggested to improve the performance of the graphene/silicon solar cell [1]. For surface texturing purpose, patterns of nanoholes are known as the most auspicious structures for effective light trapping [2]. In this study, random nanoholes are formed on the silicon surface by laser-assisted wet chemical etching method which is called photochemical etching. In this method, the irradiation of n-type Si(111) submerged in HF(aq) with a high-power CW Diode-pumped solid-state laser at 532 nm leads to the formation of porous or textured silicon. By utilizing a Digital Micromirror Device (DMD) it is possible to modify the output light of the laser and texture the surface in specific patterns. The aim is to catch a trade-off between the higher majority carrier lifetime of the smooth area and reduced reflectance of the etched area. On the other hand, in terms of graphene/silicon junction, the junction is formed on the smooth area while the silicon on the nanoholes acts as suspended graphene which has 10 times higher electron mobility compared to graphene that is bonded directly to silicon [3]. In this study, the improved reflectance, the Raman measurements for the transferred graphene, and the I-V characteristics of the Gr/Si Schottky photovoltaics for both fully and partially etched Si surfaces are reported in detail.

### Keywords

Graphene/silicon Schottky solar cells, Graphene, Photochemical etching, Silicon etching, Nanoholes

a) Schematic of the Gr/Si Schottky solar cell and b) the related I-V measurement.

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## HIGH STABILITY PEROVSKITE SOLAR CELLS UNDER AMBIENT CONDITIONS

**Elif Altürk<sup>1</sup>, Emre Aslan<sup>2</sup>, Tülin Ateş Türkmen<sup>3</sup>, Emine Tekin<sup>1</sup>, Tülay Aslı Tumay<sup>1</sup>**

<sup>1</sup>Photonic Technologies Laboratory, TÜBİTAK MAM Material Institute, 41470 Gebze, Kocaeli, Turkey

<sup>2</sup>Metallurgical and Materials Engineering, Sakarya University, 54050 Sakarya, Turkey

<sup>3</sup>Department of Physics, Yıldız Technical University, Davutpaşa, 34220 İstanbul, Turkey

Though perovskite solar cells have outstanding commercialisation potential, perovskite materials are very vulnerable to moisture and oxygen. So the main issue for perovskite solar cell is very fast degradation. In order to elaborate on this concern, the stability of perovskite solar cells were investigated in this study. The effect of oxygen and moisture on perovskite solar cells decreased with encapsulation of the cells. Encapsulation has been carried out with ultraviolet cured epoxy resin. Stability tests were taken place in laboratory conditions under solar simulator and also shelf-life tests

Solar cells showed the highest power conversion efficiency (PCE) of 9.77% with a short circuit current density of 22.5 mA/cm<sup>2</sup>, the open-circuit voltage of 0.94 V and fill factor of 0.46. After 2800 h, perovskite solar cells were still 85% stable in atmospheric conditions. (Figure1) Perovskite solar cells exhibited distinctive durability for shelf-life test in laboratory conditions. The PCE of perovskite solar cells were decreased only 15% of its initial value after 2800 h. In order to elaborate the degradation of perovskite solar cells, the cells are exposed to solar irradiation AM1.5G. Perovskite solar cells degraded gradually with time under solar irradiation; however, this stability test indicated that the solar cells were durable 20% after 500 h exposure to solar irradiation.

### Keywords

perovskite solar cells

Figure1

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## HIGHLY TRANSPARENT LUMINESCENT SOLAR CONCENTRATORS FOR AGRIVOLTAICS

**Othmane Essahili<sup>1</sup>, Mouad Ouafi<sup>1</sup>, Omar Moudam<sup>1</sup>**

<sup>1</sup>Mohammed VI Polytechnic University (UM6P), Applied Chemistry & Engineering Research Centre of Excellence (ACER CoE), Benguerir, Morocco

Agrivoltaic systems are a strategic and innovative approach to combining solar photovoltaic (PV)-based renewable energy generation with agricultural production. [1] Luminescent Solar Concentrators (LSCs) have the potential to be used in agriculture to produce electricity while increasing agricultural productivity (Figure 1). [2] An LSC is composed of luminescent species (fluorophores) doped in plastic material with a unique characteristic: they can capture sunlight and concentrate it along their edges, intercepted by small photovoltaic cells and converted into electricity. [3] Several studies are focused on agri-LSC based on organic dyes and quantum dots due to their high photophysical performances. However, they still suffer from some issues such as reabsorption losses, photostability, and short stock shift. [4] for this reason, agri-LSC based on rare-earth complexes can be used as an alternative to organic material and quantum dots due to their excellent photo-physique properties, high photoluminescence quantum yields, and a wide stock shift. [5] In addition to their excellent optical properties and increased stability, LSC based on rare-earth complex can be effectively integrated into greenhouses since photosynthetically active radiation (PAR) (400-700 nm range) can pass across the greenhouses, promoting an effective crop growth during the photosynthetic process. [6] On the other hand, non-photosynthetically active radiation, typically a light outside of the 400-700 nm range, can be directly captured by the LSC and converted into electricity without affecting the photosynthesis process. [6] The work is ongoing to improve all the photophysical properties and test the LCS devices in an actual application for crop production.

### Keywords

luminescent solar concentrators, rare-earth, Agri-PV, Agri-LSC, Greenhouse.

Figure 1. Simple schematic of LSC for Agrivoltaics

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## IMPACT OF DOPED AMORPHOUS SILICON DEPOSITION CONDITIONS ON THE ACTIVATION ENERGY AND CONTACT RESISTIVITY FOR SILICON HETEROJUNCTION SOLAR CELLS

Arghavan Salimi<sup>1,2</sup>, Konstantin Tsoi<sup>1</sup>, Seda Kılıckaya<sup>1</sup>, Devika Rajagopal<sup>3,4,5,6</sup>, Milad Ghasemi<sup>1,2</sup>, Ergi Donercark<sup>1</sup>, Hariharsudan Sivaramakrishnan Radhakrishnan<sup>4</sup>, Rasit Turan<sup>7,2,8</sup>

<sup>1</sup>ODTU- GUNAM, 06800, Ankara Turkey

<sup>2</sup>Micro and Nanotechnology Graduate Program, Middle East Technical University, Ankara Turkey

<sup>3</sup>Hasselt University, imo-imomec, Hasselt, Belgium

<sup>4</sup>Imec, imoimomec, Genk, Belgium

<sup>5</sup>EnergyVille, imo-imomec, Genk, Belgium

<sup>6</sup>KU Leuven, ESAT, Heverlee, Belgium

<sup>7</sup>ODTÜ- GÜNAM, 06800, Ankara Turkey

<sup>8</sup>Department of Physics, Middle East Technical University, Ankara Turkey

Silicon heterojunction (SHJ) solar cells have gained attention in the last decades due to their features, such as high-efficiency cell results and good temperature coefficient (Holman et al., 2012). Material properties of amorphous silicon (a-Si:H) contacts directly influence the device performance of SHJ solar cells. On the front side of an SHJ solar cell with an n-type Si substrate, the doping density of (p) a-Si:H emitter layer has a deterministic role in building a sufficient electric field at the junction (Bivour, Reichel, Hermle, & Glunz, 2012). Moreover, the contact properties between (p) a-Si:H and the indium tin oxide (ITO) layer are one of the sources of series resistance losses due to the relatively high contact resistivity (Schulze, Leendertz, Mingirulli, Korte, & Rech, 2011). In this work, we analyzed the impact of doping and hydrogen dilution ratio on the activation energy of n- and p-type a-Si:H layers deposited by the PECVD technique. The relation between activation energy and doping ratio was clarified. The contact resistivity between ITO and a-Si:H layers was analyzed using the 4PP technique under thermal treatment in air ambient at 85°C over 30 days. The lowest contact resistivity for (p) a-Si:H/ITO and (n) a-Si:H/ITO was found as 230 and 100 mΩ.cm<sup>2</sup>, respectively. It is found that contact resistivity values increase for both contact types under heat exposure at 85°C for a longer duration and stabilize around 21 days with heat treatment.

### Keywords

SHJ, activation energy, contact resistivity.

Figure 1.  $\rho_{co}$  of p-type and n type samples Figure 2. Activation energy

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## IMPROVEMENT OF METALLIZATION PERFORMANCE ON FRONT SILVER PASTE FOR CZ-PERC

Fatma Cambay Kuban<sup>1</sup>

<sup>1</sup>KalyonPV Research and Development Center, Ankara, Turkey

*Metallization pastes containing silver (Ag) are the most process-critical and expensive materials used in the fabrication of Passivated Emitter Rear Contact (PERC) solar cells. According to the ITRPV report, the amount of Ag per cell is predicted to be reduced by roughly 30% by 2031 [1]. However, one of the most significant obstacles in Si-solar cell metallization is the reduction in finger width and Ag paste consumption. A new model of the screen-printing process is developed in this work to better understanding of the screen-printing process, with an emphasis on the interplay of Ag-paste, conventional-screen, and knotless-screen. Figure 1 depicts the front finger width and height for the conventional screen used in KalyonPV routine production. The paste laydown was reduced from 65.8 mg to 54.5 mg by modifying the mesh design and finger opening of the front finger screens for the conventional screen. Furthermore, as compared to conventional mesh screens, the knotless screen improves efficiency by 0.02 percent while cell classification quality is unaffected. This study proves the potential of the new screen technologies and a guide for future studies.*

### Keywords

Metallization, Printing, Si-solar cell, Production Technology

Figure 1. SEM-image of contact finger cross section on a Cz-PERC solar cell

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## IMPROVING THE OPTICAL PROPERTIES OF SOLAR CELL WITH METAL ASSISTED CHEMICAL ETCHING METHOD

**Burcu Gumus Ciftci<sup>1,2</sup>, Fatma Çiğdem Güldür<sup>1</sup>**

<sup>1</sup>Gazi University, Chemical Engineering, Ankara, Turkey

<sup>2</sup>Kalyon-Pv, Research&Development Center, Ankara, Turkey

Surface texturing is used to enhance the absorption rate of the incident sunlight in mono crystalline Silicon (Si) solar cell. The anisotropic alkali chemical etching is one of the methods to form the upright pyramid structure. It is based on low-concentration strong-alkaline solutions such as sodium hydroxide (NaOH) or potassium hydroxide (KOH) texturing the surface at about 80°C [1]. Metal-assisted chemical etching (MACE) is another effective chemical etching method to generate an inverted pyramid structure in mono Si [2]. In MACE, noble metals with higher electronegativity than Si, are used to chemically assist in etching the silicon surface to obtain hole-like light trapping structures [3]. Among them, Ag is the most widely used catalyst for formation of Si nanopores due to its rapid and uniform preferential etching on the [100] crystal orientation of silicon [4]. To speed up the catalytic reaction and reduce nanostructure production cost, the Cu/Ag diatomic system is used. In this work, inverted pyramids are produced with different Cu concentration and process time to analyze inverted pyramid effect. The influences of surface textures on passivation and performance of solar cells were investigated. The results show that inverted pyramid structure generated by Cu/Ag facilitates better passivation effect and efficiency, compared with upright structure obtained by alkaline texturing. While reflectivity of inverted pyramids with Cu/Ag process were below 10%, wafer with upright pyramid were above 13%. The highest conversion efficiency of 22.12 % that is higher than alkaline textured solar cell by 0.1%.

### Keywords

MACE, Inverted pyramids, crystalline silicon solar cell

2D microscope 500x of Cu/Ag treatment a) 15 min b) 3 min c) 5 min e) 1 min d) alkaline texture

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## INFLUENCE OF ANNEALING OF PEDOT:PSS LAYERS ON THE PERFORMANCE OF INVERTED TYPE PEROVSKITE AND ORGANIC SOLAR CELLS

**Tugba Demirbay<sup>1</sup>, Cihangir Kahveci<sup>1</sup>**

*<sup>1</sup>Yildiz Technical University, Faculty of Arts and Science, Department of Physics, 34210  
Esenler/ISTANBUL/TURKEY*

Influence of Annealing of Pedot:PSS Layers on the Performance of Inverted Type Perovskite and Organic Solar Cells

Tuğba Demirbay<sup>1</sup>, Cihangir Kahveci<sup>1</sup>

<sup>1</sup>Yildiz Technical University, Faculty of Arts and Science, Department of Physics, Davutpasa Campus, 34210, Esenler/Istanbul/Turkey

tugba.demirbay@gmail.com

Solar energy is one of the most promising and viable renewable energy technologies since solar energy is abundant and clean. Solar energy can be converted into electrical energy using solar cells. Organic and perovskite solar cells, belonging to emerging PV technologies attracted a great attention due to the rapid increase in their efficiencies.

In this study, organic solar cells are fabricated in the normal geometry as ITO/Hole Transport Layer (HTL)/Active Layer/Al. and also in the inverted device geometry as ITO/Electron Transport Layer (ETL)/Active Layer/Au or Ag. For the perovskite solar cells, active layer was replaced with perovskite, methylammonium lead iodide ( $\text{CH}_3\text{NH}_3\text{PbI}_3$ ).

We have investigated the effect of annealing of Pedot:PSS layers on the device performance and also compared the device performances.

Keywords: Perovskite Solar Cells, Pedot:PSS

### Keywords

Keywords: Perovskite Solar Cells, Pedot:PSS

Figure. AFM images of (a) Reference solar cells annealed Pedot:PSS (b) annealed Pedot:PSS Layer

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## INFLUENCE OF PHOSPHORUS EMITTER FORMATION ON THE PERFORMANCE OF BLACK SILICON SOLAR CELLS

**Elif Sarıgül Duman<sup>1,2</sup>, Gence Bektaş<sup>1,2</sup>, Hasan Hüseyin Canar<sup>2,3</sup>, Ahmet Emin Keçeci<sup>1,2</sup>, Hasan Asav<sup>1,2</sup>, Sümeyye Koçak Bütüner<sup>2</sup>, Alpan Bek<sup>1,2,3</sup>, Raşit Turan<sup>1,2,3</sup>**

<sup>1</sup>Micro and Nanotechnology Department, Middle East Technical University, Ankara, Turkey

<sup>2</sup>Center for Solar Energy Research and Applications (ODTU-GUNAM), Cankaya, Ankara, Turkey

<sup>3</sup>Department of Physics, Middle East Technical University, Ankara, Turkey

Black silicon (b-Si) has been drawing attention due to its promising surface and optical properties for various applications including solar cell applications. Optical reflection can be minimized, and light harvesting can be achieved without the necessity of anti-reflection coating film by utilizing b-Si formation on the surface of c-Si. In this study, we present the effect of various phosphorus-doped n<sup>+</sup> emitters on the performance of p-type monocrystalline black silicon (b-Si) solar cells. B-Si is fabricated via inductively coupled plasma reactive ion etching (ICP-RIE) by using SF<sub>6</sub> and O<sub>2</sub> gasses. Reflection is suppressed in a broad spectral range with an omnidirectional incidence of light by b-Si fabrication with high aspect ratio nano-needles on the surface of c-Si. Two alternative phosphorus emitter formation routes which are ion implantation and diffusion are applied on b-Si and their performances are examined in cell level. To be able to tune the phosphorus emitter profile, a study on phosphine (PH<sub>3</sub>) implantation dose and phosphorus oxychloride (POCl<sub>3</sub>) flow is carried on for implantation and diffusion processes, respectively. Moreover, surface passivation of b-Si is also taken into consideration with varied passivation materials and techniques (i.e., silicon oxynitride by plasma-enhanced chemical vapor deposition and aluminum oxide by atomic layer deposition) which will be presented at the conference.

### Keywords

black silicon, ICP-RIE, phosphorus implantation, phosphorus diffusion

Figure 1. a) SEM image of b-Si b) Photograph of b-Si cell c) Photograph of pyramidal textured cell

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## INVESTIGATION OF BORON DIFFUSION FROM BSG LAYERS FOR P+ EMITTER ELABORATION

**Abdelghani Boucheham<sup>1</sup>, Ahmed Bahaeddine Bensedira<sup>2</sup>, Abbes Marref<sup>1</sup>, Chahinez Nasraoui<sup>1</sup>, Lyes Benharrat<sup>1</sup>, Boutaleb Labdelli<sup>1</sup>, Abdelkader Djelloul<sup>1</sup>, Mohamed Kezrane<sup>2</sup>**

<sup>1</sup>Research Center in Semiconductors Technology for Energetics/DDCS, Algiers, Algeria

<sup>2</sup>Yahia Fares University/Department of mechanical engineering/LMP2M, Medea, Algeria

N-type silicon has several advantages over p-type silicon. First, it has a relatively higher resistance to the most common metallic impurities. This allows for higher minority carrier diffusion lengths for Si wafers with similar impurity levels. Second, light-induced degradation (LID) is not present in n-type silicon wafers. This LID is the result of boron-oxygen complex formation and is observed for p-type Si wafers. Several concepts of solar cells have been made on n-type silicon, in particular, the PERT structure (Passivated emitter and rear totally diffused).

In this work, BSG (Borosilicate) layers are used for the diffusion of boron in n-type silicon in order to create a p+ junction on the surface and consequently an emitter, our study is focused mainly on the influence of temperature and the duration of the diffusion on the properties of the p+n junction, in particular on its depth and the concentration of boron on the surface. The characterization techniques used are: the four points for the measurements of the sheet resistance, the ECV and the SIMS for the calculation of the concentration of active and total boron, respectively, and for the calculation also of the depth of the junction.

### Keywords

Solar cells, boron diffusion, Boron Silicate Glass, n-type silicon, p-type emitter

SEM image showing a BSG layer

### References

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## INVESTIGATION OF BULK LIFETIME OF CZOCHRALSKI AND FLOAT-ZONE SILICON WAFERS UNDER TEMPERATURE VARIATION

**Selin Seyrek<sup>1,2</sup>, Gence Bektaş<sup>1,2</sup>, Sercan Aslan<sup>1,3</sup>, Ahmet Emin Keçeci<sup>1,2</sup>, Raşit  
Turan<sup>1,2,3</sup>**

<sup>1</sup>ODTU-GUNAM, Ankara, Turkey

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

<sup>3</sup>Department of Physics, Middle East Technical University, Ankara, Turkey

Degradation of the silicon (Si) wafers after the required fabrication processes is one of the most significant parameters that restrains reaching high conversion efficiency values in solar cells. Czochralski (Cz) and float-zone (FZ) methods are two of the growing techniques to produce Si wafers. FZ-grown wafers are known to have higher purity and lower concentrations of oxygen and carbon [1], whereas a significant amount of oxygen precipitates enter the Si ingot and react with the intrinsic point defects of Si during Cz growth. These precipitates become larger in size and create significant bulk lifetime degradation after high-temperature processes, typically above 950°C [2]. Additionally, several studies have shown the bulk lifetime values of FZ wafers tend to decrease drastically between the annealing temperatures of 450-700°C [3]. Hence, the wafers which are grown with these two particular techniques have different degradation mechanisms under varying temperatures. For the preliminary work of this study, a set of n-type Cz wafers with a resistivity of 2.2-2.3 Ω.cm are annealed at 875°C and 1050°C, whereas some of them are set aside in order to be the references. Following, the samples are passivated with ALD:Al<sub>2</sub>O<sub>3</sub> layer and activated at 450°C. Figure 1 shows that at 1050°C, bulk lifetime decreases drastically, highly likely due to impurities that are created at high temperature. In this study, the bulk lifetime degradation of Cz and FZ silicon wafers under different annealing temperatures are analyzed and compared. In addition, supporting impurity concentration measurements using Fourier-Transform Infrared Spectroscopy (FTIR) will be provided.

### Keywords

Czochralski, float-zone, silicon bulk lifetime, oxygen precipitation, degradation

Bulk lifetime vs. Annealing Temperature plot of n-si Cz wafers

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**INVESTIGATION OF PID EFFECTS ON CELL LEVEL****Betül Şekertekin<sup>1</sup>, Meriç Çalışkan<sup>1</sup>, Bedrettin Aydoğan<sup>1</sup>, Fırat Es<sup>1</sup>**<sup>1</sup>Ankara

Potential Induced Degradation (PID) is an extremely serious photovoltaic (PV) endurance problem in crystalline silicon PV modules by virtue of rapid power drop owing to temperature, humidity, and voltage. The PID effect highly depends on cell properties, such as base resistivity, emitter sheet resistance and Anti-Reflecting Coating (ARC) [1]. The leakage current occurs by environmental factors and high potential passes through front glass and encapsulant material. Hereby, this situation leads accumulation of positive charges for p-type solar cells and these charges result on a breakdown of surface passivation of a corresponding cells with a power degradation. In this study, PID effect on cell level was investigated by utilizing different types of glasses that are chemically strengthened and thermally tempered glasses with various thicknesses. Furthermore, PID test was performed for both annealed and nonannealed PERC solar cell. For all analysis, PIDcon test setup contains module-like layer stack of PERC solar cell polymeric encapsulant material (EVA) and glass between two metal electrodes. According to analysis results, with annealed cells, power losses were detected as 19.92 % for 4 mm glass, 17.88 % 3.2 mm thermally tempered glass, 17.42 % for 2 mm chemically strengthened glass and 8.21 % for 1.1 mm chemically strengthened glass respectively.

**Keywords**

Potential Induced Degradation (PID), thermally tempered glass, chemically strengthened glass.

PIDcon Test Results and Lowest power loss result for PID test

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## INVESTIGATION OF SOLAR MODULE RIBBON SIZE CHANGING EFFECT

**Ahmet Berkay Koc<sup>1</sup>, Merve Corak<sup>1</sup>, Yasemen Deniz<sup>1</sup>, Firat Es<sup>1</sup>**

<sup>1</sup>Kalyon PV, R&D, Ankara, Turkey

For reducing material costs in PV modules, the ribbon size is one of relevant parameter during production. According to ITRPV 2022 report, PV industry is still trying to improve PERC technology and diminishing production costs and by optimizing process parameters, changing raw material consuming rates or applying new innovative materials [1]. This study deals with the investigation of the ribbon size effects based on both cost and quality of the PV modules. With this purpose, two types of PV modules with various ribbon size were produced and examined. The 144 pieces half-cut G1 size PERC cells with 5 busbars were utilized to fabricate 5 pieces of G1 full size trial modules. The ribbon size of the trial group is as following; 0.9 mm x 0.20 mm for interconnector, 0.30 mm x 8 mm and 0.30 mm x 5 mm for string busbars. On the other hand, the ribbon size of the reference group is 0.9 mm x 0.25 mm for interconnector, 0.35 mm x 8 mm and 0.35 mm x 5 mm for string busbars. For characterization of the trial modules peeling test, EL test and I-V test were performed. According to I-V measurements, CTM values of the trial group were detected as %1 higher than reference group. The maximum power values that were obtained from the trial sets 3 W higher than reference group. The analysis results showed that changing the size of the string connectors saves the %14.3-20 ribbon compared to the reference group.

### Keywords

Photovoltaic, Ribbon, Interconnector, String Busbar

### References

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## ION BEAM ANALYSIS OF PASSIVATION LAYERS FOR PERC SOLAR CELLS

**Muhammad Usman<sup>1,2</sup>, Gence Bektaş<sup>3,4</sup>, Hisham Nasser<sup>3</sup>, Amna Siddiqui<sup>1</sup>, Anders Hallén<sup>5</sup>, Hasan Hüseyin Canar<sup>3,4</sup>, Ahmet Emin Keçeci<sup>3,6</sup>, Turab Ali Abbas<sup>1</sup>, Raşit Turan<sup>3,4</sup>**

<sup>1</sup>Experimental Physics Department, National Centre for Physics, Quaid-i-Azam University, Islamabad, Pakistan

<sup>2</sup>Pakistan Academy of Sciences, Pakistan

<sup>3</sup>The Center for Solar Energy Research and Applications (ODTÜ-GÜNAM), Middle East Technical University, 06800 Ankara, Turkey

<sup>4</sup>Department of Physics, Middle East Technical University, 06800 Ankara, Turkey

<sup>5</sup>Royal Institute of Technology KTH, School of EECS, Stockholm, Sweden

<sup>6</sup>Micro and Nanotechnology Department, Middle East Technical University, Çankaya, 06800, Ankara

Rear side passivation layers are the main feature in mono-crystalline silicon passivated emitter and rear cell (PERC) that set it apart from the conventional solar cell design. These layers prevent carrier recombination within the silicon substrate, allowing the photogenerated carriers to contribute to power generation and significantly improve the open circuit voltage. Compared with the traditional back surface field (BSF) solar cell, a passivation layer on the back side commonly consists of aluminum oxide ( $\text{Al}_2\text{O}_3$ )/silicon nitride ( $\text{SiN}_x$ ) stack [1,2]. However, the quality and thickness, and quantity of hydrogen in these layers play a significant role in the overall efficiency of the solar cells.

In the present contribution, we have prepared various passivation schemes to assess their quality and to monitor the impact of post deposition processes, such as annealing and high-temperature firing. These include PECVD deposited  $\text{SiN}_x$  (120 nm), ALD grown  $\text{Al}_2\text{O}_3$  (varying thickness 5/10/30 nm) with/without annealing and a coating of  $\text{SiN}_x$ . Few layers were treated with a firing process also to investigate the changes in the hydrogen concentration in the films. The analysis of these films is mainly conducted through ion beam techniques such as Rutherford backscattering (RBS), and elastic recoil detection analysis (ERDA) to determine the stoichiometry, thickness, and especially the location of the hydrogen atoms in the films [3]. The results show that the inter layer of  $\text{Al}_2\text{O}_3$  plays an imperative role in the migration of hydrogen from  $\text{SiN}_x$  to the silicon interface. Additionally, the thickness of  $\text{Al}_2\text{O}_3$  is also observed to be an important parameter.

### Keywords

Ion beam analysis, passivation layers, ERDA, RBS

(left) RBS analysis and (right) ERDA measurements of the layers showing hydrogen concentration

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## KALYON ESS

**Ali Eren Kok<sup>1</sup>, Akif Kaplan<sup>1</sup>, Duygu Kuzyaka<sup>1</sup>, Fırat Es<sup>1</sup>**

<sup>1</sup>KalyonPV Research and Development Center, Kalyon Gunes Teknolojileri Uretim A. S., 06909 Ankara, Turkey.

Research and development on alternative energy sources has become one of the hot topics aiming at meeting the increasing demand on World's energy due to the fact that nonrenewable energy sources are rapidly running out. However, intermittent nature of renewable energy sources directs research also on energy storage systems to benefit from the energy obtained from renewable sources in a continuous way. In this regard, we, as Kalyon PV R&D center, started to work on energy storage systems, Kalyon ESS, integrated with solar modules for residential applications. In order to produce the prototype, first, outer shell covering battery, inverter, and battery management system was designed for a practical and aesthetic use. In order to increase the user-friendly features of the system, a 4.2 inch touch screen and led animation visuals were used. Power consumption and battery pack information can be obtained via the touchscreen. The cooling system of the battery pack was designed to provide passive cooling through vent holes. Increasing of the battery pack capacity, effective cooling, weight reduction, aesthetic and durable outer shell design studies are still being investigated. Besides, system designs targeting the user's requirements were also accomplished such as on-grid and off-grid applications containing solar modules and storage system. In conclusion, we aimed at increasing the efficiency of energy storage systems, continuous flow of energy especially for smart buildings, minimize the cost of energy, and meet the energy demands for various applications such as electrical vehicle charging stations.

### **Keywords**

Energy Storage System, Photovoltaics, Lithium Battery, Inverter, Continuous Energy.

Figure 1. Photos of Kalyon ESS.

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## KALYON EV-ON CHARGE

**Merve Tuncez<sup>1</sup>, Ali Eren Kok<sup>1</sup>, Duygu Kuzyaka<sup>1</sup>, Firat Es<sup>1</sup>**

<sup>1</sup>KalyonPV Research and Development Center, Kalyon Gunes Teknolojileri Uretim A. S., 06909 Ankara, Turkey

The fact that fossil-fuel-based fuels are rapidly running out, directs the academic and industrial research into alternative resources for vehicles. As Kalyon PV, we aim to meet this demand and started a project on electrical vehicle charging stations supported with solar energy. p-type PERC mono c-Si solar modules as renewable energy source, communication and software, and storage unit were identified as the keystones of this project. Solar modules were placed on a special construction designed by our researchers. Power capacities of the charging units were identified for fast charging and slow charging. It is aimed to enable electric vehicle users to charge their vehicles even in hardship areas where the grid never reaches. In accordance with this purpose, AC and DC charging units were designed for slow charging and fast charging, respectively. Communication and software solution was identified, and a roadmap was determined for a system enabling mobile payment and energy flow monitoring via mobile and website. For the storage group solution, a system was designed operating in open air conditions, and it has been decided that the most appropriate solution is to place the storage group consisting of battery, battery management system, inverter, and cooling system in a container. This system design has the feature of the first hybrid model constructed in Turkey. Besides, power systems include an isolation transformer, which prevents irregularities in the grid and isolates the input and output, providing a safe charging experience for both the user and the vehicle.

### **Keywords**

Electrical vehicle, photovoltaics, sustainability, charging stations, energy storage

Figure 1. Schematical view of the construction designed for charging stations.

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## LAYOUT OPTIMIZATION FOR SHINGLED SOLAR CELLS

**Meryem Ezgi Karahalli<sup>1,2</sup>, Hasan Asav<sup>1,2</sup>, Bulent Arikan<sup>1</sup>, Talat Ozden<sup>1,3</sup>**

<sup>1</sup>ODTU-GUNAM, 06800, Cankaya, Ankara, Turkiye

<sup>2</sup>Micro and Nanotechnology Programme, METU, 06800, Çankaya, Ankara, Türkiye

<sup>3</sup>Department of Electrical and Electronics Engineering, Gümüşhane University, 29100, Gümüşhane, Türkiye

Recently, shingled modules sliced solar cells have gained popularity in the solar market. Compared to standard modules, the shingling approach has several advantages: lower ohmic losses, better area utilization, lower processing temperature, and lower operating temperature. These advantages result in increased energy yield and a better aesthetic appearance. However, the design of the solar cell layout is important to reach the best efficiency from the solar wafer. In this study, simulation results obtained from presented using Griddler simulation software. According to the results, five slices and 110 fingers provide the best efficiency for the M2 (156,75mm) solar cell dimension.

### Keywords

Griddler 2.5, Solar Cell, PERC, Shingled cell

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## LEAD-FREE CONDUCTIVE SILVER PASTES FOR CRYSTALLINE SILICON SOLAR CELLS

**Huseyin Utkucan Kayaci<sup>1,2</sup>, Gurcan Utku Ozdemir<sup>3,4</sup>, Enes Saygi<sup>2</sup>, Hasan Asav<sup>4,5</sup>, Doga Doganay<sup>2,3</sup>, Sahin Coskun<sup>2</sup>, Rasit Turan<sup>4,5</sup>, Husnu Emrah Unalan<sup>2,3</sup>**

<sup>1</sup>Middle East Technical University, Graduate School of Natural and Applied Sciences, Micro and Nanotechnology, Ankara, Turkey

<sup>2</sup>Nanovatif Materials Technologies, ODTU Teknokent, Ankara, Turkey

<sup>3</sup>Middle East Technical University, Faculty of Engineering, Metallurgical and Materials Engineering, Ankara, Turkey

<sup>4</sup>ODTU-GUNAM, Ankara, TURKEY

<sup>5</sup>Middle East Technical University, Faculty of Arts and Science, Department of Physics, Ankara, Turkey

Conductive silver pastes are one of the most critical components of solar cells (Ebong and Chen 2012). They are used to collect the current produced in the cells. Pastes are typically produced by mixing silver particles with suitable solvents, binders, glass frits, dispersants and other additives in appropriate proportions (Che et al. 2013). It is highly desired to reduce the amount of silver paste used in the cells, thus reducing the shading effect and paste production costs (Ebong and Chen 2012). In addition, the tightening of restrictions on the use of the lead pushes manufacturers towards environmentally friendly solutions (Maruyama et al. 2008). In this work, we formulate our pastes (Figure 1) considering the effects of particle-particle interactions, paste rheology, particle packing and sintering characteristics on solar cell performance (Park et al. 2008; Vinod 2011). Lead-free glass frit composition and particle size as well as silver particle morphology (nanowires, flakes and spherical particles) are also investigated in detail.

*This work is supported by TUBITAK, Center of Excellence Support Program (1004 Program) under grant numbers 20AG002 and 20AG018.*

### Keywords

Silver Pastes, Particle Morphology, Glass Frit, Rheology, Cell Performance

Pastes produced using silver particles with different morphologies and glass frits for solar cells.

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## MODELLING AND PERFORMANCE ANALYSIS OF A LARGE-SCALE GRID-CONNECTED PHOTOVOLTAIC SYSTEM IN THE UK

Divyabhan Singh Duggal<sup>1</sup>, Haimeng Wu<sup>1</sup>

<sup>1</sup>Faculty of Engineering and Environment, Northumbria University, Newcastle-upon-Tyne, United Kingdom

The United Kingdom has committed to a 'Net-Zero Strategy', aiming towards decarbonising all the sectors of the economy by 2050 [1]. One of the main objectives, as part of the strategy, is to power the energy needs of the country using low-carbon sources of energy [1]. Hence, the injection of renewable energy in the UK's power grid is highly important for the country to achieve its Net-Zero targets. However, there have been few feasibility studies on large-scale photovoltaic (PV) systems in the UK. This study aimed at designing a 9 MW<sub>p</sub> PV farm in the UK for modelling and analysing the performance of the system by considering comprehensive aspects from both renewable energy generation and energy storage, and hence, can provide a case study of using large-scale PV systems for the UK government and private industries. The feasibility study of the PV system was conducted by analysing its performance using the indicators of total annual production, specific production, and performance ratio, as well as a detailed analysis of the critical losses in the system [2-4]. In addition, the option of integrating an Energy Storage System (ESS) and its influence was explored. The designed PV system can produce a total 8 GWh of energy annually and had a specific production of 886 kWh/kW<sub>p</sub>/year. The highest performance ratio achieved for the system was 74.63%. Finally, the results showed that the system can save an estimated CO<sub>2</sub> emissions of 81,457.1 tCO<sub>2</sub> over a period of 30 years.

### Keywords

Photovoltaics, Large-Scale PV, Energy Storage, Feasibility Study; PVSyst

Key Results

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## MONITORING SOILING PROPERTIES OF SURFACE TREATED PANEL-GLASSES IN ANKARA

**Zeynep Cantürk<sup>1,2</sup>, Ahmet Hamdi Aksoy<sup>1,3</sup>, Nasim S. Esmailzad<sup>1</sup>, Arian Goodarzi<sup>1</sup>,  
Gizem Aydın Sobacı<sup>4</sup>, Nahide Özben Kaya<sup>4</sup>, Osman Burak Okan<sup>4</sup>, Deniz Avcı<sup>4</sup>, Ihor  
Pavlov<sup>1,2</sup>, Refika Budakoğlu<sup>4</sup>, Alpan Bek<sup>1,2</sup>, Talat Özden<sup>1,5</sup>**

<sup>1</sup>ODTÜ-GÜNAM, 06800 Ankara, Turkey

<sup>2</sup>Physics Department, ODTÜ, 06800 Ankara, Turkey

<sup>3</sup>Automotive Eng. Dept., Kocaeli University, 41380, İzmit/Kocaeli, Turkey

<sup>4</sup>Şişecam Science, Technology and Design Center, 41420 Kocaeli, Turkey

<sup>5</sup>Electrical and Electronics Eng. Dept., Gümüşhane University, 29100 Gümüşhane, Turkey

Soiling of the solar panels is the major cause behind under-performance of the solar plants in warm climates where the land is especially poor in vegetation. Automated or manual routine forced cleaning procedures including manned and robotic cleaning agents consume valuable time, energy and materials. Moreover, vast majority of the utility-scale PV plantation zones reside in water poor regions where aqueous cleaning should be avoided for preserving arguably the most valuable natural resource, water, after solar energy. In this study, we aim to quantify the soiling properties of panel-glasses treated in 5 different kinds of procedures. The soda-lime panel-glasses are prepared and treated by Şişecam Science, Technology and Design Center. 4 cm x 10 cm glass samples are fitted in specially designed holders and mounted on a test platform on the roof of METU Physics Department in Ankara. Each treatment is represented by 12 samples. Out of 12 samples one is removed from each set every month for characterization. This way it is possible to monitor accumulated monthly soiling amount. Particle accumulation is characterized using dark-field optical and scanning electron microscopies. Optical properties are characterized using spectrally resolved optical transmission and haze measurements. It is found that weather conditions such as rain and wind has significant impact on the total particle accumulation. The effect of different surface treatments is found also to have an impact, albeit to a lesser extent. This work is supported by TÜBİTAK under grant nr 20AG002.

### Keywords

anti-soiling, panel-glass, dust, accumulation, outdoor test

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## MXENE CONTACTS FOR HOLE-SELECTIVE MOOX ENABLING REDUCED SILVER USE FOR DOPANT-FREE CRYSTALLINE SILICON SOLAR CELLS

**Loay Akmal Madbouly<sup>1,2</sup>, Hisham Nasser<sup>2</sup>, Oyku Cetin<sup>1</sup>, Mona Zolfaghari Borra<sup>2</sup>,  
Yaqoob Khan<sup>1</sup>, Hasan Asav<sup>2</sup>, Rasit Turan<sup>2,3</sup>, Husnu Emrah Unalan<sup>1,2</sup>**

<sup>1</sup>Department of Metallurgical and Materials Engineering, Middle East Technical University (METU), 06800  
Ankara, Turkey

<sup>2</sup>Center for Solar Cell Energy and Applications (ODTÜ-GÜNAM), 06800 Ankara, Turkey

<sup>3</sup>Department of Physics, Middle East Technical University (METU), 06800 Ankara, Turkey

MXenes are novel 2D materials that have attracted significant interest from researchers due to their outstanding electrical and optical properties [1]. Only a few studies have been conducted on their use as contacts in solar cells [2]. In this work, we have investigated how the use of  $Ti_3C_2T_x$  MXene reduces the use of back contact silver in semi-DASH (dopant-free asymmetric heterocontact) solar cells (Figure 1). Materials characterisation of in-house produced MXene is followed by detailed performance investigation of the fabricated solar cells. Then MXene is applied as a contact to semi-DASH solar cell on p-type c-Si absorber (Figure 1). The solar cell features front side conventional phosphorus diffused emitter passivated by  $SiN_x$  and contacted by screen-printed contacts [3]. The back surface field consists of hole-selective molybdenum oxide ( $MoO_x$ ). To protect the  $MoO_x$  layer during MXene deposition, 15 nm Ag or 15 nm Al was deposited on top of  $MoO_x$  right after  $MoO_x$  deposition, without breaking the vacuum. The highest efficiency of over 14% was achieved from the Al/MXene with a remarkable Fill Factor of over 61%.

### Keywords

MXenes, 2D materials, crystalline silicon, solar cells, molybdenum oxide

a) 3D schematic of the MXene coated solar cell b) J-V curve of the champion solar cell.

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## NON-HAZARDOUS AND LOW-COST E-BEAM EVAPORATED P-POLY-SI LAYERS FOR BIFACIAL DOUBLE-SIDED TOPCON

**Salar Habibpur Sedani<sup>1,2</sup>, Ergi Donerçark<sup>1</sup>, E. Hande Çiftpınar<sup>1</sup>, Raşit Turan<sup>1,3</sup>**

<sup>1</sup>ODTÜ-GÜNAM, Middle East Technical University, 06800 Ankara, Turkey

<sup>2</sup>Department of Micro and Nanotechnology, Middle East Technical University, 06800 Ankara, Turkey

<sup>3</sup>Department of Physics, Middle East Technical University, 06800 Ankara, Turkey

Carrier selective passivating connections have permitted higher conversion efficiencies by decreasing minority carrier recombination velocities at c-Si/metal contact surfaces [1]. Pioneers of photovoltaics are investigating the remarkable passivation properties of doped polysilicon (poly-Si) layers over silicon oxide (SiO<sub>x</sub>) [2, 3, 4]. Photovoltaic industry experts are predicting a bright future for poly-Si/SiO<sub>x</sub> structures (TOPCon), as the future of the PV industry [5]. It is possible to minimize the cost of poly-Si layer deposition by using e-beam evaporation equipped with effusion cells, even if CVD methods such as PECVD and LPCVD are available. The e-beam technology also eliminates the use of hazardous process gases, such as PH<sub>3</sub> and B<sub>2</sub>H<sub>6</sub>, from the manufacturing process.

Passivating contact applications were investigated using e-beam-deposited p-type a-Si layers, while low-temperature PECVD was used to deposit the n-type a-Si layer on the opposite side. We investigate the impact of boron and phosphorous dopant crystallization temperatures on doping activation. This layer of p-a-Si, which is non-hydrogenated, is ideal for low-temperature activation of boron doping in the absence of boron-hydrogen complexes. Ultimately, blister-free p-poly and n-poly layers develop concurrently on both sides of the cell. Additional hydrogenation steps and ITO deposition heal the defects of the non-hydrogenated passivating contacts. As a result of this study, we fabricate bifacial double-sided TOPCon cells which reach an efficiency of 18.7% on the p-poly side and 20.2% on the n-poly side.

### Keywords

Doble-sided TOPCon, e-Beam Evaporation, Non-hazardous, p-poly-Si

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## NUMERICAL OPTIMIZATION OF THE FRONT METAL GRID IN SILICON HETEROJUNCTION SOLAR CELLS

**Konstantin Tsoi<sup>1</sup>, Mehmet Koç<sup>1</sup>, Ergi Dönerçark<sup>1</sup>**

<sup>1</sup>ODTÜ-GÜNAM, Ankara, Turkey

Silicon heterojunction (SHJ) solar cells have hit a record efficiency of more than 26%. At this performance, attention must be paid to every detail of the design and fabrication of solar cells. Material thicknesses, deposition parameters, handling of samples during the transfer, all of these, and many more contribute to the final performance of a device. One facet that needs particular attention is the design of the metal grid on the front side of SHJ solar cells. While the metal grid is used for collecting generated carriers, it inhibits their generation by shadowing the active area. Typically, there is a trade-off between the electrical gains (losses) and optical losses (gains) of any grid design. With an inappropriate choice of the grid design, the performance of a solar cell can be limited. Therefore, optimization of the metal grid to be used in the SHJ devices is needed. Generally, optimization can be done analytically or numerically (using simulation tools). In this work, we utilize GRIDDLER software to numerically optimize grid design for various SHJ solar cell configurations. We determine the optimum number of busbars, fingers, and their dimensions for the range of sheet resistance of the front transparent conductive oxide (TCO), and wafer dimensions. In our simulations, we also consider the optical properties of the utilized TCO by performing optical analysis. Lastly, following the current trend of increasing wafer sizes in the industry, we consider wafers with areas ranging from 156×156 to 210×210 mm<sup>2</sup>.

### **Keywords**

SHJ solar cells, Front Grid Design, Numerical Simulations

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## OBSERVATION OF LID EFFECT ON PERC SOLAR CELLS WITH DIFFERENT SINX STOICHIOMETRY

**Vahdet Ozyahni<sup>1,2</sup>, Hasan Hüseyin Canar<sup>1,3</sup>, Sercan Aslan<sup>1,3</sup>, Hasan Asav<sup>1,2</sup>, Ahmet Emin Keçeci<sup>1,2</sup>, Sümeyye Koçak Bütüner<sup>1</sup>, Gence Bektaş<sup>1,2</sup>, Bülent Arıkan<sup>1</sup>, Raşit Turan<sup>1,2,3</sup>**

<sup>1</sup>Center for Solar Energy Research and Applications (ODTU-GUNAM), Ankara, Turkey

<sup>2</sup>Micro and Nanotechnology Department (MNT), Middle East Technical University (METU), Ankara, Turkey

<sup>3</sup>Department of Physics, Middle East Technical University (METU), Ankara, Turkey

Light-Induced Degradation (LID) has been reported to be an important effect on solar cell performances of Boron-doped Cz-Si solar cells that occurs during first hours of light exposure. LID is mainly attributed to Boron-Oxygen defects. Oxygen is a common contamination in Cz-Si cells at the order of  $[O] \approx 3-5 \cdot 10^{17} \text{cm}^{-3}$  [1] caused by dissolution of quartz crucible ( $\text{SiO}_2$ ) during ingot growth [2]. The main source of hydrogen in solar cells is  $\text{SiN}_x\text{:H}$  passivation layer. During the subsequent firing step for metallization, hydrogen diffuses into the bulk from the passivation layer. Then, recovery by hydrogen passivation occurs via annealing during light soaking. Hydrogen concentration within the bulk is a key factor for the passivation rate of B-O defects. Stoichiometry of nitride film is an important parameter of hydrogen diffusion into the bulk [3]. The diffusion is determined by the stoichiometry of the passivation layer. Therefore, by changing the stoichiometry, diffusion of hydrogen can be manipulated. Within this work, we investigate the degradation of Si bulk related to LID effect on fabricated PERC solar cells by varying  $\text{SiN}_x\text{:H}$  stoichiometries. Hydrogen concentration of  $\text{SiN}_x\text{:H}$  layer varies from low to high for the samples B to D.  $V_{oc}$  is used to follow LID process. It is obtained from the Figure 1 that sample B which has the lowest hydrogen concentration showed the highest  $\Delta V_{oc}$ , while sample D with the highest hydrogen concentration showed the least  $\Delta V_{oc}$ . According to these results, there is an inverse dependency on hydrogen concentration of  $\text{SiN}_x\text{:H}$  layer diffused into the Si bulk.

### Keywords

LID, silicon nitride, stoichiometry, hydrogen passivation

Figure 1. Light Induced Degradation effect on different stoichiometric samples B, C and D

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## OPEN-PLATFORM SENSOR NODE FOR PV POWERED SMART AGRICULTURE

**Robert S. Balog<sup>1</sup>, Sajida Yazjeen<sup>2</sup>, Nabila Elbeheiry<sup>3</sup>**

<sup>1</sup>Texas A&M University

<sup>2</sup>Texas A&M University at Qatar

<sup>3</sup>Texas A&M University

To meet increasing world demand for food, modern agricultural is adopting smart manufacturing concepts. Real-time remote monitoring systems automatically measure and manage the production environment, combined with machine learning/ artificial intelligence algorithms to understand the complex intricacies of the many factors to maximize production yield. Smart farming depends on data collected from the field, transmitted to a controller, curated, and analyzed. Actuators then are controlled, such as adjusting irrigation or nutrient dosing. The need to power the newly integrated devices in the field has motivated the support of Smart Agrivoltaics, illustrated in Figure 1, where photovoltaic energy production is co-located with crop cultivation.

The problem is that existing agrivoltaics commercial solutions are proprietary, closed ecosystems; the user cannot modify or alter the system from sensor to actuator, limiting the usefulness for research. On the other hand, open-sourced designs, such as those available freely through an internet search, tend to be more oriented toward the hobbyist; various functions may not work together and there has been little system-oriented design. Thus, these open-sources designs are also unsuitable for research.

This paper presents an open-platform sensor platform that is flexible, customizable, and reliable. Off-the shelf commercial sensor modules are used to increase accessibility for prototyping while system and firmware design was structured in a way to allow robust operation yet also allow easy customization. Figure 2 illustrates the key functional blocks of the sensor node. The full paper will provide detailed explanation of the design and operation, including parts.

### Keywords

Smart Farming, Advanced Agriculture, Agrivoltaics, Internet of Things (IoT), Remote Monitoring

Figure 1

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## OPPORTUNITY OF RARE-EARTH-BASED LUMINESCENT SOLAR CONCENTRATORS FOR AGRI-PHOTOVOLTAICS

**Mouad Ouafi<sup>1</sup>, Othmane Essahili<sup>2</sup>, Omar Moudam<sup>3</sup>**

<sup>1</sup>Applied Chemistry & Engineering Research Centre of Excellence (ACER CoE), Advanced Organic Optoelectronics Laboratory (AOL), Mohammed VI Polytechnic University (UM6P) Lot 660 - Hay Moulay Rachid, 43150 Benguerir, Morocco

<sup>2</sup>Applied Chemistry & Engineering Research Centre of Excellence (ACER CoE), Advanced Organic Optoelectronics Laboratory (AOL), Mohammed VI Polytechnic University (UM6P), Lot 660 - Hay Moulay Rachid, 43150 Benguerir, Morocco

<sup>3</sup>Applied Chemistry & Engineering Research Centre of Excellence (ACER CoE), Advanced Organic Optoelectronics Laboratory (AOL), Mohammed VI Polytechnic University

Integrating luminescent solar concentrators (LSCs) technology, as a type of solar photovoltaics, into the agriculture sector is paving the way for achieving highly efficient plant and crop growth as well as high electrical power conversion.<sup>1</sup> In this context, several studies have been focused on LDS devices based on organic dyes and quantum dots which demonstrate high photo-physical properties employed for Agri-PV technology application.<sup>2</sup> However, they still possess some issues regarding reabsorption, photostability, and short stock shift. To tackling these issues, rare-earth complexes can be utilized in LSCs as an alternative to organic and quantum dot materials due to their high photoluminescence quantum yields with wide high stock shift. In this study, a simple synthesis method of the Eu(TTA)<sub>3</sub>Pyra complex is presented, the photoluminescence study shows that the complex is highly luminescent at 613 nm. Furthermore, combining a Eu-complex with a hybrid host polymer PMMA:PVB leads to a highly luminescent and very transparent layer. Under excitation at 345 nm, the Eu complex exhibits a very strong red emission at 613 nm due to the hypersensitive 4D<sub>0</sub>- 7F<sub>2</sub> transition, which is the most dominating transition.<sup>3,4</sup> The luminescent solar concentrator serves as a luminescent down shifter layer that simultaneously absorbs harmful ultraviolet light, which is poisonous for crops growth, and reemits the red light essential for the photosynthesis process.

### Keywords

LSC, rare-earth, Agri-LSC, Greenhous

Transparent Agri-PV based Eu-LSC doped PVB :PMMA

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## OPTICAL IMPROVEMENT OF NANO-HOLE TEXTURED C-SI SURFACES FOR SOLAR CELL APPLICATIONS

**Serra Altinoluk<sup>1</sup>, E. Hande Çiftçinar<sup>2,3</sup>, Ateşcan Aliefendioğlu<sup>2,3</sup>, Samet Özdemir<sup>2</sup>, Ahmet Abusnoubar<sup>1</sup>, Ergi Dönerçark<sup>2</sup>, Özge Demirdoğan<sup>4</sup>, Meryem Tunçkanat<sup>4</sup>, Bilge Imer<sup>4</sup>, Raşit Turan<sup>2,3,5</sup>**

<sup>1</sup>Muğla Sıtkı Koçman University/Department of Electrical and Electronics Engineering, Muğla, TURKEY

<sup>2</sup>ODTÜ-GÜNAM, Ankara, TURKEY

<sup>3</sup>Middle East Technical University/Graduate School of Micro and Nanotechnology, Ankara, TURKEY

<sup>4</sup>Middle East Technical University/Department of Metallurgical and Materials Engineering, Ankara, TURKEY

<sup>5</sup>Middle East Technical University/Department of Physics, Ankara, TURKEY

In this study, we have focused on the nano-hole decorated c-Si surfaces. The patterns were achieved with the reactive ion etching (RIE) method. The diameter of the nano-holes varied from 400 to 800 nm. Before the experimental passivation studies, SILVACO simulations were carried out to narrow down the possible passivation layers. For passivation purposes, Al<sub>2</sub>O<sub>3</sub> and ZnO layers were deposited using thermal ALD, and SiO<sub>2</sub> layers grown by dry oxidation which were then capped with SiN<sub>x</sub>. Following the passivation; lifetime,  $iV_{oc}$ , and reflection measurements were carried out on single side decorated samples. From these measurements, the best passivation stack layer was found to be SiO<sub>2</sub>/SiN<sub>x</sub> with an  $iV_{oc}$  of  $634 \pm 6.13$  mV and a reflection of around 8%. For the textures having 600 nm diameter, the weighted average reflection (WAR) was observed to decrease with the decreasing pitch size (Figure 1). The best simulated cell efficiency was achieved with 4 nm SiO<sub>2</sub> and 80 nm SiN<sub>x</sub> layers with SILVACO, while the efficiency value was 16.71 and 16.75% with 4 nm ZnO and Al<sub>2</sub>O<sub>3</sub> layers, respectively.

### Keywords

Hole texturing, Solar Cell, SILVACO, Passivation, Optical Characterisation

Figure 1. Optical characterisation of surfaces decorated with 600 nm diameter features and SEM image

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## OPTIMIZATION OF EMITTER LAYER IN N-TYPE BIFACIAL CRYSTALLINE SOLAR CELL

**Yasaman Salimi<sup>1,2</sup>, Emine Hande Çiftçınar<sup>1,2</sup>, Ahmet Emin Kececi<sup>1,2</sup>, Hasan Hüseyin Canar<sup>3,1</sup>, Raşit Turan<sup>1,2,3</sup>**

<sup>1</sup>The Center for Solar Energy Research and Applications (GÜNAM), Middle East Technical University, Dumlupınar Bulvarı no:1, 06800, Ankara Turkey

<sup>2</sup>Micro and Nanotechnology Graduate Program, Middle East Technical University, Ankara Turkey

<sup>3</sup>Department of Physics, Middle East Technical University, Ankara Turkey

There is an ever-increasing interest in n-type wafers due to their advantages. Compared to p-type cells, n-type cells yield higher efficiency and lifetime values and are immune to boron-oxygen defect, metal impurities, and light-induced degradation (LID). According to the ITRPV's estimation, the n-type cell structures will be taking 70% of the industry's share by 2032[1]. Boron diffused p+ emitter layer requires to be efficiently oxidized post diffusion to obtain a uniform and BRL free emitter. The passivation layer also plays a crucial role in gaining high  $V_{oc}$  values by reducing the recombination rate.

Various thermal and chemical oxidation recipes were tested in this work to find an optimum recipe that would successfully eliminate the BRL while simultaneously avoiding boron depletion region formation. As a result, we were able to improve both dry oxidation and wet chemical oxidation recipes, achieving a peak carrier concentration of  $1.35 \times 10^{20} \text{ cm}^{-3}$  and a junction depth of 0.4  $\mu\text{m}$ . Different passivation stack layers were also tested to reduce the recombination. Consequently, samples passivated with  $\text{Al}_2\text{O}_3/\text{SiN}_x$  stack layer yielded an imp  $V_{oc}$  of 660 mV after passivation. Screen printed TLM samples were also tested to optimize the peak firing temperature, where we were able to achieve contact resistivity of  $4.66 \pm 0.89 \text{ m}\Omega\text{cm}^2$ . Finally, we produced large area ( $156.75 \times 156.75 \text{ mm}^2$ ) bifacial cells as a proof of concept, with the Best performing cell yielding an efficiency of 18.2% and a  $V_{oc}$  of 631 mV.

### Keywords

Boron Emitter Doping, BRL Removal, n-type Solar Cell, Bifacial Solar Cell

figure.1

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## OPTIMIZATION OF LASER PARAMETERS FOR DAMAGE-FREE DIELECTRIC LAYER ABLATION PROCESS FOR PLATING METALLIZATION ON PERC SOLAR CELLS

**Melisa Korkmaz Arslan<sup>1,2</sup>, Hasan Asav<sup>1,2</sup>, Bülent Arıkan<sup>2</sup>, Raşit Turan<sup>2,3</sup>**

<sup>1</sup>Micro and Nanotechnology Program (MNT), Middle East Technical University (METU), Ankara, Turkey

<sup>2</sup>Middle East Technical University - Center for Solar Energy Research and Applications (ODTU-GUNAM), Ankara, Turkey

<sup>3</sup>Department of Physics, Middle East Technical University (METU), Ankara, Turkey

Screen printed Ag is the most widely used metallization scheme for the front contact of commercial silicon solar cells in the PV industry. Owing to relatively high contact resistance and the high cost of this process it is necessary to develop a cost-effective metallization process with improved cell performance. Solar cell metallization based on Ni/Cu/Ag metal stack is a strong candidate for this technology. This metallization scheme has proven to be successful for the commercial production of silicon solar cells [1-3]. However, there are additional steps that the plating metallization process brings to the standard process flow. Prior to plating metallization, dielectric layer ablation in accordance with the front-side contact pattern is the primary process. In this study, it is aimed to perform this process with an industrial picosecond laser at a wavelength of 532nm and obtain a deeper understanding of the laser interaction with the SiN<sub>x</sub> layer. Values such as the power, frequency, and scanning speed of the laser light were systematically changed to determine the parameter set that caused the least damage to the surface. Afterward, the Ni seed layer was plated on the SiN<sub>x</sub> ablated surfaces by the light-induced plating (LIP) technique, and the microscopic and electrical properties of metal layers were investigated. Finally, the best uniformly plated Ni seed layer with a width of ~32.1µm is achieved so far at the laser frequency of 1MHz, power of 2.8W, and scan speed of 2m/s. Detailed characterization results and further improvements will be presented at the conference.

### Keywords

Picosecond, Laser, SiN<sub>x</sub> Ablation, Plating, Metallization

Figure 1. Optical microscope (left) and SEM images (right) of uniformly deposited Ni finger.

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## OPTIMIZATION OF TEXTURING PROCESSING FOR PERC TYPE C-SI SOLAR CELLS

**Merve Corak<sup>1</sup>, Fatih Akkurt<sup>2</sup>, Firat Es<sup>3</sup>, Mete Gunoven<sup>3</sup>, Burcu Gümüş Çiftçi<sup>3</sup>**

<sup>1</sup>Gazi University, Kalyon PV-R&D department, Science and Engineering Institution, Engineering Faculty, Ankara, Turkey

<sup>2</sup>Gazi University, Science and Engineering Institution, Engineering Faculty, Ankara, Turkey

<sup>3</sup>Kalyon PV, R&D department, Ankara, Turkey

Passivated Emitter Rear Contact (PERC) type solar cells, is expected to be the dominant type of the photovoltaic (PV) market in near future (ITRPV, 2022) due to its high performance/cost ratio. Hence, it is critical to optimize PERC process steps to achieve higher efficiencies. In this study, it is aimed to improve the saw damage and texturing process, which are the basic production stages of PERC cells. For this purpose, firstly, two-dimensional simulation of pyramid patterned cells of different sizes was performed with PV lighthouse-Quokka 2 software and optimal pyramid dimensions were determined. In order to obtain these pyramid dimensions, the surface configuration process parameters were optimized. The different pyramid pattern sizes obtained were examined by SEM imaging and pyramid size statistics were determined. To investigate the effects of parameter changes on the following production processes; XRF for measuring the amount of potassium pollution after etching, life time analysis after anti-reflective layer to determine the surface passivation effects, and TLM measurements for determining the effects on metallization contact resistance were performed. I-V efficiency measurements were made to show the effects of process improvement on the optimized cell; Experimental loss analysis was carried out with characterization of surface reflectivity and internal quantum efficiency. As a result; The effects of process optimization and loss analysis on cell reflectivity and efficiency were analyzed and it was seen that there was a 0.4 % (22.5% average efficiency) increase in cell efficiency as a result of the improvement.

### Keywords

PERC, texturing process, Quokka

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## OPTIMIZATION OF THERMAL SILICON OXIDE FOR CHEMICAL PASSIVATION BORON AND PHOSPHORUS DOPED EMITTERS

**Yiğit Mert Kaplan<sup>1</sup>, Ahmet Emin Keçeci<sup>2,3</sup>, Hasan Hüseyin Canar<sup>1,2</sup>, Gence Bektaş<sup>2,3</sup>, Raşit Turan<sup>1,2,3</sup>**

<sup>1</sup>Department of Physics, Middle East Technical University (METU), Ankara, Turkey

<sup>2</sup>Center for Solar Energy Research and Applications (ODTÜ-GÜNAM), Ankara, Turkey

<sup>3</sup>Micro and Nanotechnology Department, Middle East Technical University, Ankara, Turkey

Thermally grown silicon dioxide ( $\text{SiO}_2$ ) is a dielectric layer applied for the chemical passivation silicon (Si) surfaces.  $\text{SiO}_2$  has a lower interface defect density than other industrially feasible dielectric layers [1]. This study investigates the thermally grown  $\text{SiO}_2$  on boron and phosphorus diffused emitters. To optimize the  $\text{SiO}_2$  layer on the emitter, symmetrically diffused and passivated samples are fabricated. For boron emitter samples, n-type Cz-Si wafers with bulk resistivity of 1-3  $\Omega\cdot\text{cm}$  underwent the  $\text{BBr}_3$  diffusion process, while for phosphorus emitter samples, p-type Cz-Si wafers having bulk resistivity of 0.5-1  $\Omega\cdot\text{cm}$  underwent to  $\text{POCl}_3$  diffusion process. For characterization of the samples, a Sinton WCT-120TS instrument is used to measure implied open-circuit voltage ( $iV_{oc}$ ), emitter saturation current density ( $J_{0,e}$ ), and bulk lifetime ( $\tau_{bulk}$ ) by quasi-steady-state photoconductance (QSSPC) method. Oxidation time was kept at 40 minutes to find the optimum oxidation temperature during the experiments. Five different groups are designed such that four of these group is oxidized at the temperatures of 550°C, 600°C, 650°C, and 800°C, while the last group has not undergone any oxidation process.  $\text{Al}_2\text{O}_3$  is deposited on the thermal oxide layer to passivate boron emitters to provide field-effect passivation. Then both the boron and phosphorus emitter samples are symmetrically deposited with an anti-reflection coating (ARC). In conclusion, it is demonstrated that thermal oxidation at 650°C is the optimum condition for n+ emitter samples, while p+ samples have similar results of 550°C, 600°C, and 650°C.

### Keywords

$\text{POCl}_3$  diffusion,  $\text{BBr}_3$  diffusion, oxidation, thermally grown  $\text{SiO}_2$ ,  $iV_{oc}$

$iV_{oc}$  results for both n+ and p+ emitters at different oxidation temperatures

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## OPTOELECTRONIC OPTIMIZATION OF ITO LAYER IN SILICON HETEROJUNCTION SOLAR CELLS

Mehmet Koc<sup>1</sup>

<sup>1</sup>ODTU-GUNAM

SHJ solar cells are widely integrated both in the industrial and researchers' society in both their monofacial and bifacial configurations. One of the bottlenecks of the SHJ solar cells is the TCO layer. This layer both opto-electronically and from the cost perspective possesses significant challenges waiting to be addressed. In this study, we show it is possible to reduce the cost of solar cells by reducing the TCO thickness and improving its optoelectronic performance at the same time. Carrier densities are investigated within a range from  $1 \times 10^{20}$  to  $1 \times 10^{21} \text{ cm}^{-3}$ . Optically, it can be said intuitively that, the thickness of the front ITO layer should be  $\sim 75 \text{ nm}$ , and it should have the lowest possible charge carrier density to provide the best optical anti-reflective performance. Rear ITO has negligible effects on the optical properties of SHJ solar cells. Optimum ITO thickness around 75 nm value is supported with simulation studies. However, the front ITO layer should also have low resistivity values to provide sufficient fill factors. In monofacial configuration, the rear ITO layer can be designed to have best optical properties while neglecting its electrical performance. On the other hand, for bifacial solar cells, rear ITO layer should also be carefully tuned to have efficient electrical and optical properties. In this study, we show that it is possible to improve the monofacial SHJ solar cells around  $1 \text{ mA.cm}^{-2}$  with fine tuning the front and rear ITO layers concurrently. Similarly, it is possible to obtain  $\sim 24\%$  energy conversion efficiencies with various albedo values by carefully optimizing the ITO layers.

### Keywords

SHJ, bifacial, optics, PV

Figure 1

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## PASSIVATION PARAMETERS EXTRACTION FOR N-TOPCON ON TEXTURED N-TYPE C-SI WAFERS

**Sercan Aslan<sup>1,2</sup>, Hisham Nasser<sup>1</sup>, Berkay Uygun<sup>1,3</sup>, Emine Hande Çiftpınar<sup>1,3</sup>, Raşit Turan<sup>1,2,3</sup>**

<sup>1</sup>Middle East Technical University – Center for Solar Energy Research and Applications (ODTÜ-GÜNAM), Ankara, Turkey

<sup>2</sup>Department of Physics, Middle East Technical University (METU), Ankara, Turkey

<sup>3</sup>Micro and Nanotechnology Program (MNT), Middle East Technical University (METU), Ankara, Turkey

Tunnel oxide passivated contacts (TOPCon) solar cells are viewed as the forthcoming technology to the current passivated emitter and rear cell (PERC). The TOPCon (thin SiO<sub>x</sub>/doped poly-Si) is based on passivating and carrier selective contacts [1]. The SiO<sub>x</sub> chemically passivates the c-Si surface while it is thin to allow feasible carrier transport. The doped poly-Si induces strong electric field which improves the field-effect passivation and is conductive to the carrier. In this study, symmetrical n-TOPCon layers were prepared on pyramid textured n-type (100) c-Si wafers with base resistivities in the range of 1.64-1.84 Ωcm, and thickness was 170 μm. After capping with 1.2 nm of SiO<sub>x</sub> and 50, 70 and 100 nm of poly-Si, they are capped with 8 nm Al<sub>2</sub>O<sub>x</sub>/70 nm SiN<sub>x</sub>/10 nm Al<sub>2</sub>O<sub>x</sub>. Some wafers are fired in temperatures between 750-850 °C. In order to enhance dropped values of  $iV_{oc}$ , they are hot plated at 400°C for 25 min. Their surface recombination current density values were determined by using Photoconductive Decay method (PCD) in Sinton Instruments WCT-120TS [2-4]. Richter model provided by WCT was utilized, and band gap narrowing effect was included in the analysis because of reaching high injection levels. Effective lifetime ( $\tau_{eff}$ ), inverse Auger corrected lifetime ( $\tau_{corr}^{-1}$ ), and surface recombination current density ( $J_{0s}$ ) were plotted versus injected minority carrier density (MCD). Moreover, the model provided by K. Dapprich et al. [5] will be also utilized to extract the passivation parameters of the samples, and its result will be compared with the obtained  $J_{0s}$  values. Results of the detailed analysis will be shown at conference.

### Keywords

n-TOPCon, PCD, effective lifetime, inverse corrected lifetime, surface recombination current density

a) The structure of n-TOPCon sample, b) Measured  $J_{0s}$  value, c) Obtained inverse corrected lifetime

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## PASSIVATION STUDY OF SYMMETRICAL N- TYPE TUNNEL OXIDE PASSIVATED CONTACTS (N-TOPCON) REALIZED BY LOW PRESSURE CHEMICAL VAPOR DEPOSITION

Berkay Uygun<sup>1,2</sup>, Hisham Nasser<sup>2</sup>, Emine H. Çiftçinar<sup>3,2</sup>, Sercan Aslan<sup>2,3</sup>, Hasan H. Canar<sup>2,3</sup>, Ahmet E. Kececi<sup>1,2</sup>, Raşit Turan<sup>1,2,3</sup>

<sup>1</sup>Middle East Technical University, Department of Micro and Nano Technology, Ankara, Turkey

<sup>2</sup>Middle East Technical University, The Center for Solar Energy Research and Applications (ODTU-GUNAM), Ankara, Turkey

<sup>3</sup>Middle East Technical University, Department of Physics, Ankara, Turkey

Tunnel oxide passivated contact (TOPCon) solar cells are widely seen as the next dominant crystalline silicon solar cell in the photovoltaic industry [1]. In ODTÜ-GÜNAM, symmetrical life-time samples for n type-tunnel oxide passivated contacts (n- TOPCon) solar cells as shown in figure 1.a were produced on crystalline silicon (c-Si), Czochralski n-type wafers with area of 156.75 mm x 156.75 mm. Both ultra-thin oxide interfacial layer with thickness of 1.2 nm and poly-Si layer with thicknesses of 50, 70, 100 and 150 nm were deposited using low pressure chemical vapor deposition (LPCVD) furnaces. This is followed by phosphorous doping in reduced pressure diffusion furnace. In order to enhance the passivation, hydrogenation was utilized by SiN<sub>x</sub>, Al<sub>2</sub>O<sub>x</sub>, or stacks of SiN<sub>x</sub>/Al<sub>2</sub>O<sub>x</sub>/SiN<sub>x</sub> produced by ALD and PECVD to reduce the dangling bonds in the interfacial layer between c-Si and ultra-thin oxide and the other defects in the poly-Si layer [2]. Hydrogenation greatly improved the implied open-circuit voltage ( $iV_{oc} > 740$  mV) with remarkable recombination current density ( $J_{0, \text{per side}} \sim 2.5$  fA/cm<sup>2</sup>) for some samples, which is revealed by measuring lifetime in Sinton Instruments [3]. The samples were fast fired in temperatures between 750-850 °C, and forming gas annealing (FGA) was done in temperatures between 425-500 °C. The degradation of some wafers occurred during firing process while all samples showed no detectable change in the passivation quality during FGA process. Hydrogen atoms are activated by applying a hot-plate annealing step at 425 °C for 25 minutes as shown in the figure 1.b- c [4].

### Keywords

Passivating contacts, poly-Si, hydrogenation, LPCVD, n-TOPCon

(a) 2D representation of n-TOPCon lifetime samples. (b)  $iV_{oc}$  (c)  $J_0$  values of the process samples.

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## PERFORMANCE COMPARISON OF CPV SOLAR CELLS PRINTED WITH STANDARD MASK AND FLOATING MASK

**Elsen Aydin<sup>1,2</sup>, Gence Bektaş<sup>1,3</sup>, Ahmet Emin Keçeci<sup>1,3</sup>, Hasan Hüseyin Canar<sup>1,4</sup>,  
Raşit Turan<sup>1,3,4</sup>, Bulent G. Akinoglu<sup>1,5</sup>, Bulent G. Akinoglu<sup>4</sup>**

<sup>1</sup>Centre for Solar Energy Research and Application, Middle East Technical University, Ankara, Turkey

<sup>2</sup>Department of Archaeometry, Middle East Technical University, Ankara, Turkey

<sup>3</sup>Micro and Nanotechnology Program, Graduate School of Natural and Applied Sciences, Middle East Technical University, Ankara, Turkey

<sup>4</sup>Department of Physics, Middle East Technical University, Ankara, Turkey

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

Concentrated photovoltaic cells (CPV) are rapidly gaining importance in developing solar cells and the photovoltaic (PV) industry. The most crucial factor for CPV cells to take part in the renewable energy market is to get more electricity production with less silicon used in CPV solar cells. So the techno-economic feasibility of such systems should be achieved.

In this study, the developments and reasons for the measurements taken under 1 sun after the front surface metallization of a low-cost crystalline silicon-based solar cell, which is designed to work under medium concentration and can perform well at high temperatures, are shared with normal mask and floating mask. The screen-printing technique was used for the front surface metallization using the same silver paste and it was observed that the difference between the Voc values for the two mask types has a difference of about 20 mV. The possible technical and physical reasons are analyzed and discussed.

### Keywords

CPV, PV, Metallization, Screen Print

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## PLAMSA ENHANCED CHEMICAL VAPOR DEPOSITED AMORPHOUS SILICON LAYERS FOR TUNNEL OXIDE PASSIVATED CONTACT (N-TOPCON) C-SI SOLAR CELLS

**Hassan Osman<sup>1,2</sup>, Hisham Nasser<sup>1</sup>, Berkay Uygun<sup>1,2</sup>, Milad Ghasemi<sup>1</sup>, Ergi Donercak<sup>1</sup>, Salar Sedani<sup>1,2</sup>, Emine H. Ciftpinar<sup>1</sup>, Rasit Turan<sup>1,2,3</sup>**

<sup>1</sup>ODTÜ-GÜNAM, 06800 Ankara, Turkey

<sup>2</sup>Micro and Nano Technology Graduate Program of Natural and Applied Sciences, Middle East Technical University (METU), 06800 Ankara, Turkey

<sup>3</sup>Department of Physics, Middle East Technical University (METU), 06800 Ankara, Turkey

In this work, n-TOPCon layers prepared using low-temperature phosphorus-doped hydrogenated amorphous silicon (a-Si:H) on top of ultra-thin oxide are presented. Lifetime samples are fabricated (Fig. 1(a)) using textured n-type silicon (Si) wafers (Cz; 156.75mm × 156.75mm, Base resistivity ~ 1.6 ohm/sq). Following the standard cleaning procedure, a Low Pressure Chemical Vapor Deposited - LPCVD silicon oxide of about 1.2nm or 1.6nm is deposited. Subsequently, using a Plasma Enhanced Chemical Vapor Deposition tool, 50nm, 75nm, and 100nm a-Si:H layers are deposited on the Si wafers, as well as on polished c-Si and quartz pieces to check the thickness and the crystallinity of the deposited layers, respectively. The samples then experienced different crystallization temperatures and durations to create the polycrystalline silicon and are then characterized by lifetime analysis, ECV, FTIR, RAMAN, SIMS as well as microscope imaging before and after annealing to monitor blistering phenomenon. The effect of a-Si:H deposition parameters on the crystallinity is also investigated.

By tuning the a-Si:H deposition parameters, LPCVD oxide thickness, as well as the crystallization temperature/duration, we have achieved precise control of the dopant concentration levels and uniformity in the poly-Si layer, and we have successfully reduced the undesired dopant diffusion into the c-Si substrate (Fig.1 (c), (d)). The passivation values have reached a remarkable  $iV_{oc}$  of ~700mV even without applying any post-deposition hydrogenation (Fig.1 (b)). Furthermore, we have mitigated blistering by varying the precursor gas flow ratios. In the upcoming studies, various hydrogenation mechanisms will be conducted for implementation on industrial TOPCon solar cells.

### Keywords

Passivating contacts, TOPCon, PECVD, c-Si solar cells.

Figure 1. Lifetime structure (a), results (b), (c&d) dopant distribution profiles [PH3 - 10sccm]

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## PV INVERTERS DEVELOPED BY TUBITAK MAM

**Aydın Başkaya<sup>1</sup>, Mustafa Deniz<sup>1</sup>, Ayberk Kaan Filik<sup>1</sup>, Ahmet Yüksel<sup>1</sup>**

<sup>1</sup>TÜBİTAK MAM Başkan Yardımcılığı (Enerji Teknolojileri-BYET)

Photovoltaic inverters are special forms of power electronics technology that converts the electricity produced by solar panels into a form that can be used in the network. According to the power levels and usage areas on the market; it is divided into 3 main categories as micro inverter, string inverter and central inverter.

Micro-inverters: These are the inverters, each of which is mounted behind a panel. In addition to being preferred in roof systems, it is also used in field applications today. A microinverter was designed by us in cooperation with King Abdulaziz City for Science and Technology (KACST) of Saudi Arabia between 2011-2014. The 300 W micro-inverter has been designed for harsh environments such as desert climates and has been operating smoothly since 2014 as 24 units.

String inverters: It is the type of inverter where the number of panels suitable for DC input voltages is connected in series and the PV strings are directly connected to the inverter. They can be preferred in both field and roof applications. Within the scope of the project titled "Türkiye Fotovoltaik Teknolojileri Platformu-1004", we are continuing to design a 1500V, 125 kW string inverter.

Central Inverters: Central inverters are used in large(MW-levels) power plants. The Solar Power Plant with a capacity of 6 MW, established in Şanlıurfa TİGEM, has been operating since February 2021, using 1 MW central inverters produced by us within the scope of the "Fotovoltaik Temelli Güneş Enerjisi Santral Teknolojilerinin Geliştirilmesi" Project (MİLGES) 1007, carried out between 2015-2020.

### Keywords

power electronics, inverters, solar PV, converters, power quality

MİLGES Project

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## SCREEN-PRINTING OPTIMIZATION OF LOW-TEMPERATURE SILVER PASTES FOR SILICON HETEROJUNCTION SOLAR CELLS

**Seda Kılıçkaya<sup>1</sup>, Arghavan Salimi<sup>1,2</sup>, Milad Ghasemi<sup>1,2</sup>, Emine Hande Çiftpınar<sup>1</sup>, Ergi Dönerçark<sup>1</sup>, Raşit Turan<sup>1,2,3</sup>**

<sup>1</sup>ODTÜ-GÜNAM, Ankara, Turkey

<sup>2</sup>Middle East Technical University, Graduate School of Micro and Nanotechnology, Ankara, Turkey

<sup>3</sup>Middle East Technical University, Department of Physics, Ankara, Turkey

Solar cell metallization is one of the deterministic process steps affecting the device performance. The electrical and optical losses of the fabricated solar cell could be decreased by optimizing the metallization under different curing and annealing temperatures and durations. This study clarifies the impact of various post annealing/curing conditions of two different commercially available low-temperature pastes on the contact properties and shadowing losses. Pastes from different suppliers were printed on n-type, textured silicon wafers with 75 nm thick indium tin oxide (ITO) at the surface deposited by the sputtering technique. Different curing and annealing temperatures as well as durations were applied to the samples and the electrical properties were characterized by using the Transfer Length Method (TLM) technique. The pastes were evaluated in terms of contact resistivity (Fig.1a), line resistance, sheet resistance (Fig.1b) and aspect ratio. Furthermore, the solvent spreading and shadowing properties were traced by scanning electron and optical microscopes. As a result of this study, relatively low contact resistivity values were achieved, resulting in below 1 mOhm.cm<sup>2</sup>.

### Keywords

Silicon heterojunction solar cell, screen printing, low-temperature Ag paste

Figure 1. Ag paste dried at 120°C for 10/20/30 minutes a) Contact resistivity b) Sheet resistance

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## SELECTIVELY GROWN ZNO NANORODS ON GRAPHANE-COATED SUBSTRATES FOR THE FABRICATION OF SEMI-TRANSPARENT NEW GENERATION SOLAR CELLS

**Elif Peksu<sup>1</sup>, Cigdem Yener<sup>2</sup>, C. Gokhan Unlu<sup>2</sup>, Hakan Karaagac<sup>1</sup>**

<sup>1</sup>Istanbul Technical University, Department of Physics Engineering, Istanbul, Turkey

<sup>2</sup>Pamukkale University, Department of Biomedical Engineering, Denizli, Turkey

Today, although electricity generation from solar energy is being studied intensively, power generation is still far from the desired level. In order to achieve the desired level of electricity generation from the sun, it is not enough to reduce costs and improve the performance of these solar cells. But, there will be also a need to expand the areas where these systems can be installed. Therefore, multidimensional studies have been carried out recently in order to spread the electricity generation from the sunlight. One of these efforts is the fabrication of semi-transparent solar cells that can be integrated into buildings.

In this study, our goal was to construct a high-efficiency semi-transparent core-shell solar cell based on selectively grown well-aligned ZnO nanorods on graphene-coated glass substrates that can exhibit a high power conversion efficiency and sufficient transparency in the *visible portion* of the solar spectrum. Hydrothermal technique along with nanosphere lithography was employed for the first time for the synthesis of well-ordered ZnO nanorod (NR) arrays on graphene-coated glass substrates. For the fabrication of single-layer graphene, the chemical-vapor -deposition (CVD) technique was preferred. The structural, optical and morphological properties of the selectively grown ZnO nanorods on single layer graphene will be discussed in detail. The synthesized ZnO nanowires on graphene-coated glass substrates in a certain order will be employed for the fabrication of core-shell CZTS based semi-transparent solar cells in our future studies. *The conducted research offers the realization of new generation of semi-transparent photovoltaic cells in near future.*

### Keywords

Graphene, ZnO NRs, solar cells

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## **SENSOR NODES IN SMART AGRICULTURE: METHODOLOGICAL REVIEW**

**Robert S. Balog<sup>1</sup>, Nabila Elbeheiry<sup>2</sup>**

<sup>1</sup>Texas A&M Univeristy at Qatar

<sup>2</sup>Texas A&M Univeristy

The need to meet the food demand of the ever-increasing population along with the declining agricultural workforce have motivated the modernization of agriculture (Smart Farming). Internet of Things (IoT) is a significant contributor to smart farming practices as it improves the productivity and quality of crops through controlling and monitoring the field from anywhere over the Internet. Sensor nodes are the common building block among all smart farming IoT systems. To this extent, extensive work has been performed to develop sensor nodes for agricultural applications. The methodologies and platforms for developing the sensor nodes have diversified, leaving the best practices vague.

This paper reviews the methods/approaches followed by literature to design, build and integrate sensor nodes in smart farming. The contribution of this paper is categorizing and comparing the features of various hardware and software sensor node development platforms and identifying the best practices. The benefits of this paper are twofold. First, it enables an application developer to determine which practice is appropriate for their particular field. Second, as the paper identifies major obstacles for the deployment of sensor nodes in the agricultural field, researchers can use this paper to develop agriculture tailored sensor nodes.

Table 1 compares various commercial of the shelf sensors reported in the literature. The full paper will provide an analysis of the sensor system designs found in the literature. It will present commonalities and differences and discuss pros and cons of the various platforms which will assist a researcher with selecting sensors for his/her application.

### **Keywords**

Smart Farming, Energy Harvesting, Firmware, Embedded Electronics, Internet of Things (IoT)

Table 1

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## SOLAR'S ROLE IN ENERGY SECURITY AND CLIMATE CHANGE MITIGATION

**Hasan Hüseyin Miraç Gül<sup>1</sup>, Hakan Ercan<sup>2</sup>, Şenay Açıkgöz<sup>3</sup>, Bülent Gültekin  
Akinoğlu<sup>4</sup>**

<sup>1</sup>*Earth System Science, Middle East Technical University, Ankara, Turkey*

<sup>2</sup>*Department of Economics, Middle East Technical University, Ankara, Turkey*

<sup>3</sup>*Department of Econometrics, Ankara Hacı Bayram Veli University, Ankara, Turkey*

<sup>4</sup>*Department of Physics, Middle East Technical University, Ankara, Turkey*

The experiences of the last two years brought energy security again as a hot issue for decision makers. Energy security is the sole aim of energy policy of a country. When the concept first emerged, it was only referring to oil security. Through decades, energy security has evolved and today it has a far wider scope that is concerned with sustainability along with affordability and continuity. Climate change is basically driven by energy sector and share of electricity generation is as important as the share of transportation sector. Therefore, long-term planning of energy policies is vital for the mitigation of climate change. This study aims to analyze role of solar power in securing energy and reducing carbon emissions and attains this aim by econometrics. Energy-related data for 47 countries have been compiled from IEA webpage, WDI and BP databases, covering the period between 1990 and 2017. The results indicate that electricity generation by solar helps both securing energy and climate change mitigation as anticipated. 1% increase in solar-based electricity generation releases 0.003% less carbon dioxide and results in 0.026% less energy imports.

### **Keywords**

solar, energy security, climate change mitigation, panel econometrics

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## STABILITY AND DEVICE PERFORMANCE FOR PEROVSKITE SOLAR CELLS

Eni Muka, Bülent G. Akinoglu<sup>1</sup>

<sup>1</sup>Department of Physics, Middle East Technical University, Ankara, Turkey

Increased levels of energy consumption have created the need for alternative energy sources. Additionally, environmental issues have taken on special awareness in the recent decades, encouraging research in the field of photovoltaics. One branch of this industry receiving great attention is perovskite solar cells (PSCs). This type of solar cell is one of the most researched topics in photovoltaic scenery due to the advantages of low manufacturing costs, flexibility, and simplicity in fabrication. The ongoing and frequent research resulted in an emerging potential of PSCs that have shown an efficiency from 3.5% in 2009 up to 25.2% in 2019. Despite all the promising developments, PSCs are not commercialized yet. The main reason for this limitation is the fast degradation of the device.

The focus of this work is on the long-term stability problem. The aim is to analyze the PSC's performance when improvement steps are applied. Simulations were achieved by SCAPS-1D. The device proposed consisted in a lead-free tin-based perovskite absorber layer, PEDOT: PSS+WO<sub>3</sub> hole transport layer, PC61BM material for electron transport layer and FTO for active window layer. The model was simulated and optimized to improve power conversion efficiency using SCAPS-1D. After the optimization of basic parameters, the final performance parameters of the solar cell device obtained improved with a short-circuit current density (J<sub>SC</sub>) of 19.28 mA/cm<sup>2</sup>, an open-circuit voltage (V<sub>OC</sub>) of 0.82 V, a fill factor (FF) of 42%, and power conversion efficiency (PCE) of 6.7%.

### Keywords

Perovskite Solar Cell

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## SUBSTOICHIOMETRIC TANTALUM PENTOXIDE BASED SINGLE- AND DOUBLE-LAYER ANTI-REFLECTION COATING FOR BIFACIAL TOPCON SOLAR CELLS

Hisham Nasser<sup>1</sup>, Mehmet Koc<sup>1</sup>, Rasit Turan<sup>1</sup>

<sup>1</sup>The Center for Solar Energy Research and Applications (ODTU-GUNAM)

Recently, the Tunnel Oxide Passivated Contact (TOPCon) c-Si solar cells, elevated the efficiency values of c-Si solar cells to ~26% [1]. This is mainly due to the excellent electrical carrier transport and surface passivation of the TOPCon structure (poly-Si/SiO<sub>x</sub>). In this contribution, we investigated the potential of using high band gap substoichiometric tantalum pentoxide (T<sub>2</sub>O<sub>x</sub>) to act as the second layer in a double-layer anti-reflection coating (DLARC) design for both sides of bifacial TOPCon solar cells with 50 nm poly-Si (Figure-1) using an in-house developed ray-wave coupled optics algorithm. The DLARC consists of SiN<sub>x</sub> as the first layer passivating the Si surface followed by T<sub>2</sub>O<sub>x</sub>.

The optical parameters of Ta<sub>2</sub>O<sub>x</sub> were extracted by ellipsometry (SE) measurement and fitting of e-beam evaporated T<sub>2</sub>O<sub>x</sub> thin film. The SE results show that Ta<sub>2</sub>O<sub>x</sub> has refractive of 1.84, extinction coefficient of , and Eg of 4.15 eV, which make Ta<sub>2</sub>O<sub>x</sub> the best candidate for DLARC designs. The simulation results show that several combinations of SiN<sub>x</sub>/Ta<sub>2</sub>O<sub>x</sub> thicknesses can result in weighted reflection much less than 1.5% (Figure-1). Single SiN<sub>x</sub> or T<sub>2</sub>O<sub>x</sub> resulted in weighted reflection as low as our proposed DLARC revealing the capability of Ta<sub>2</sub>O<sub>x</sub> to act as ARC. This will be more important when applying Ta<sub>2</sub>O<sub>x</sub> to silicon heterojunction (SHJ) solar cells to reduce the thickness of the rather expensive ITO which be presented in the conference. Applying these results to bifacial TOPCon or SHJ solar cells will enhance the light absorption by the cell and thus the short-circuit current density and the overall cell performance.

### Keywords

Tantalum pentoxide, anti-reflection coating, c-Si, TOPCon, SHJ

left: Simulation structure of TOPCon solar cell. right: Simulation results

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## SURFACE TEXTURING OF PANEL-GLASSES FOR ANTI-REFLECTIVE AND ANTI-SOILING PROPERTIES

**Mersiye Karakaş<sup>1,2</sup>, Zeynep Cantürk<sup>1,3</sup>, Serena Erkızan<sup>1,3</sup>, Nasim S. Esmailzad<sup>1</sup>,  
Arian Goodarzi<sup>1</sup>, Gizem Aydın Sobacı<sup>4</sup>, Nahide Özben Kaya<sup>4</sup>, Osman Burak Okan<sup>4</sup>,  
Deniz Avci<sup>4</sup>, Ihor Pavlov<sup>1,2,3</sup>, Refika Budakoğlu<sup>4</sup>, Talat Özden<sup>1,5</sup>, Alpan Bek<sup>1,2,3</sup>**

<sup>1</sup>ODTU-GUNAM, 06800 Ankara, Turkey

<sup>2</sup>Micro and Nanotechnology Program, ODTU, 06800 Ankara, Turkey

<sup>3</sup>Physics Department, ODTU, 06800 Ankara, Turkey

<sup>4</sup>Şişecam Science, Technology and Design Center, 41420 Kocaeli, Turkey

<sup>5</sup>Electrical and Electronics Eng. Dept., Gümüşhane University, 29100 Gümüşhane, Turkey

An alternative approach to anti-reflection coating of solar panel-glass for minimizing reflective losses is texturing of the panel-glass surface at micro- and nano-scales. Texturing does not only reduce back-reflection but it also redirects the normally incident rays to more oblique inclinations which are beneficial for extending the optical path length of the rays in the underlying solar cells. In addition to improved light management properties, nano-texturing of glass surface also has the potential to lend anti-soiling properties by minimizing contact area between dust and glass surface and exhibiting super-hydrophobic property. As the soiling of the solar panels is the major cause behind under-performance of the solar plants in warm climates where water is a scarce resource, forced-cleaning procedures should be avoided as much as possible. We propose micro- and nano-texturing of the panel-glass top surface as an agent to facilitate self-cleaning of panel-glasses from soiling. In this work we use 4 and 2 mm thick flat soda-lime panel glasses fabricated by Şişecam. The glass samples are textured using 2 methods. The first method is metal assisted chemical etching (MACE) using an aqueous solution of HF as etchant and Ag and Al as catalysts. The second method is reactive ion etching (RIE) using SF<sub>6</sub> as etch gas. The resulting glass surface textures are characterized using dark-field optical and scanning electron microscopies. Optical properties are characterized using optical transmission and haze measurements and the results are presented and compared. This work is supported by TÜBİTAK under grant nr 20AG002.

### Keywords

panel-glass, nano-texturing, RIE, MACE

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## SYNTHESIS AND CHARACTERIZATION OF CSSNXPB1-XBR3 QUANTUM DOTS AS ACTIVE LAYER

**Müge Öztürk<sup>1</sup>, Dilek Çırak<sup>1</sup>, Burak Gültekin<sup>1</sup>, Ceylan Zafer<sup>1</sup>**

<sup>1</sup>Solar Energy Institute, EGE UNIVERSITY, Izmir, Turkey

Lead halide perovskite quantum dots (PQDs), also called perovskite nanocrystals, are considered one of the most promising photovoltaic materials for solar cells due to their superior optoelectronic properties and effortless preparation techniques. The ecotoxicity of lead-based perovskite materials creates environmental pollution problems in optoelectronic applications. Therefore, new studies are carried out to discover non-toxic or less environmentally harmful materials such as Sn, Ge and Mn cations that can replace Pb cations.<sup>[1]</sup> In this study, Quantum dots to be used as active layers in solar cells were synthesized and it was aimed to reduce the toxicity of these quantum dots by using tin. Hot injection has been chosen to synthesize homogeneous quantum dots. The quantum dots were synthesized using cesium oleate which is important part for quantum dots. Synthesized quantum dot is  $CsPb_xSn_{x-1}Br_3$  which has  $ABX_3$  crystal structure. To determine the size of the QDs, SAXS results have been investigated in the solution phase. Moreover, thin film phase analyzes were carried out to understand the crystal quality and crystalline properties of QDs. In addition, UV-Vis absorption spectroscopy were done for solution and thin film phases to examine the light absorption properties of QDs to be used as active layers in solar cells. Finally, photoluminescence characterizations were performed to elucidate charge transfers in the thin-film phase.

### Keywords

Perovskite Quantum Dots, Perovskite Solar Cells, Hot Injection, Thin Film

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## THE EFFECT OF INITIAL SURFACE MORPHOLOGY ON THE FORMATION OF INVERTED PYRAMIDS BY COPPER ASSISTED CHEMICAL ETCHING OF SILICON

**Busra Altinsoy<sup>1,2</sup>, Ergi Donercark<sup>1</sup>, Rasit Turan<sup>1,2,3</sup>**

<sup>1</sup>ODTU GUNAM, Ankara, 06800, Turkey

<sup>2</sup>Middle East Technical University (METU), Micro and Nanotechnology Department, Ankara, 06800, Turkey

<sup>3</sup>Middle East Technical University (METU), Department of Physics, 06800 Ankara, Turkey

Inverted pyramids with promising light management capability were typically fabricated by complex techniques involving laser [1] and photolithography processes [2]. Random inverted pyramids on crystalline silicon (c-Si) produced by a single-step anisotropic copper-assisted chemical etching have also reduced surface reflectance down to around 5 % in the wavelength range of 400-1000 nm. In this work, micro-scale random inverted pyramids are formed by copper-assisted chemical etching (CACE) on n-type c-Si wafers with different surface topographies and morphologies. Surfaces of as-cut, polished, saw damage removed Si wafers are structured by  $\text{Cu}(\text{NO}_3)_2/\text{HF}/\text{H}_2\text{O}_2$  wet chemical solutions. Different distributions of inverted pyramids with special optical characteristics are observed on the Si surface depending on the initial Si surface features. Etching rates with the novel solution, final surface morphologies of Si wafers after the etching process, and corresponding reflectivity values, distributions of each surface structure, and optical simulations of these morphologies are investigated.

Oriented grooves, scratching following wire-cutting direction, and craters that are produced due to higher penetrations on the surfaces of as-cut wafers have determined the size and distribution of inverted pyramids that are formed as a result of etching in  $\text{Cu}(\text{NO}_3)_2/\text{HF}/\text{H}_2\text{O}_2$  solution. Because the formation of the copper nanoparticles is more random on polished surfaces, the size distribution of inverted pyramids was more diverged when polished wafers are subjected to CACE. Uniform distributions of inverted pyramids are observed on the surfaces of saw damage removed Si wafers following the CACE. The lowest reflectance has been measured to be 4.3 % when Diamond Wire Saw silicon wafers are etched.

### Keywords

Chemical Etching, reflectance, silicon texturing

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## THE EFFECTS OF DIFFERENT SCREEN DESIGNS ON AG PASTE CONSUMPTION AND CELL EFFICIENCY

**Yasemen Deniz<sup>1</sup>, Merve Çorak<sup>1</sup>, Ahmet Berkay Koç<sup>1</sup>, Fırat Es<sup>1</sup>**

<sup>1</sup>Kalyon PV, R&D, Ankara, TURKEY

Silicon solar cell fabrication process involves several crucial steps that affects cell efficiency to large extent. Among the other production steps, metalization is more significant to optimize optical losses and to achieve precise contacts of the solar cells. PV solar cells are usually metalized by screen printing process by utilizing Ag and Al pastes. According to the ITRPV 2022 report, Ag paste consumption has decreased over the past years [1,2]. In this study, the effects of classical and knotless screen designs on the Ag consumption and the effect on the cell efficiencies were investigated. The main difference between classical and knotless screens is based on the mesh angles; while the of classical screens mesh angle is 22.5°, knotless screens mesh angle is 0°. Additionally, the difference between the number of mesh, wire diameter and mesh opening on the screens affects the screen quality and paste consumption. For instance, the high number of mesh on the screen reduces the paste consumption by reducing finger opening [3]. Crystalline silicon PERC cells produced by utilizing both knotless and classical screens. The amount of paste consumptions, as well as the width-height of finger and busbar were evaluated in scope of the this work. Furthermore, the performance of the corresponding cells were measured via I-V solar simulator and PL, SEM and TLM measurements were also carried out. According to analysis results, upon application of knotless screen, Ag consumption was decreased by 28.3% and the cell efficiencies were increased by 1.06%.

### Keywords

Mono PERC, Knotless Screen, Efficiency

Acquired numerical results from I-V flash tester measurements for screen groups (C1: Classical scree

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## THREE NEW DESIGNED HTMS BASED ON THIOPHENE FOR PEROVSKITE SOLAR CELLS

**Abdennacer Idrissi<sup>1</sup>, Zouhair Elfakir<sup>1</sup>, Redouane Atir<sup>1</sup>, Amar Habsaoui<sup>1</sup>, Said Bouzakraoui<sup>1</sup>**

*<sup>1</sup>Ibn Tofail University, faculty of science, kénitra, morocco*

### Abstract :

Computational methods and molecular modelling are very practical to understand the main parameters that control properties of the Hole Transporting Materials for Perovskite Solar Cells. In the present study, we suggest three new thiophene-based hole transporting materials, namely 2TOMe1,2,3, that can be integrated easily with the perovskite material, and enhances its conversion efficiency. The obtained results point out that among the three compounds, 2TOMe3 is the best candidate as an active material in organic solar cells, due to its good light absorbance in the visible region, its stability, and its enhanced solubility.

### Keywords

Thiophene derivatives, OSC, Perovskite Solar Cells, HTMs, DFT

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**TOWARDS FLEXIBLE PEROVSKITE SOLAR CELLS WITHOUT ITO****Cihangir Kahveci<sup>1</sup>, Tugba Demirbay<sup>1</sup>**

<sup>1</sup>*Yildiz Technical University, Faculty of Arts and Science, Department of Physics, 34210  
Esenler/ISTANBUL/TURKEY*

Low carbon emission energy production is the biggest challenge that human being will face soon. Therefore, producing energy through energy and cost efficient and environmentally friendly routes is both off great interest and very challenging. In recent years, the perovskite solar cells have gained much attention due to their promising power conversion efficiencies (PCEs), fabrication through simple solution fabrication processes and low-cost materials constituents etc. Over the last few years, the efficiency of perovskite solar cells has surpassed 25% due to high-quality perovskite-films accomplished through low-temperature synthesis techniques along with developing suitable interfaces. Besides, the stability of perovskite solar cells has attracted much well-deserved attention. Methylammonium lead iodide ( $\text{CH}_3\text{NH}_3\text{PbI}_3$ ) based hybrid organic–inorganic halide perovskite solar cells have revealed to be very encouraging next-generation photovoltaic technology due to their potential for cost-effective manufacturing, light weight, and mechanical flexibility [1-2].

In this study, we have fabricated perovskite solar cells over flexible substrates without a conductive ITO surface. The conducting copper electrodes replacing the ITO was achieved through low temperature and low cost fabrication techniques. The flexible devices also demonstrate excellent stability against mechanical deformation, retaining considerable its original efficiency after many times fully bending.

**Keywords**

Perovskite Solar Cells, Flexible Solar Cells

Figure 1. (a) Cu and Au coated flexible substrates (b) flexible perovskite solar cells.

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## ZIRCONIUM OXIDE AS ELECTRON-SELECTIVE CONTACTS FOR N-TYPE CRYSTALLINE SILICON SOLAR CELLS

**Loay Akmal Madbouly<sup>1,2</sup>, Hisham Nasser<sup>2</sup>, Mona Zolfaghari Borra<sup>2</sup>, Emine Hande Ciftpinar<sup>2</sup>, Atescan Aliefendioglu<sup>2,3</sup>, Hasan Huseyin Canar<sup>2,3</sup>, Rasit Turan<sup>2,4,3</sup>, Husnu Emrah Unalan<sup>2,1,3</sup>**

<sup>1</sup>Department of Metallurgical and Materials Engineering, Middle East Technical University (METU), 06800 Ankara, Turkey

<sup>2</sup>Center for Solar Cell Energy and Applications (ODTÜ-GÜNAM), 06800 Ankara, Turkey

<sup>3</sup>Graduate School of Micro and Nanotechnology, Middle East Technical University (METU), 06800 Ankara, Turkey

<sup>4</sup>Department of Physics, Middle East Technical University (METU), 06800 Ankara, Turkey

Fermi-level pinning complicates the formation of Ohmic, low-resistance and economically feasible contacts to lightly doped n-type crystalline silicon (c-Si) [1,2]. Here, we introduce, for the first time, a zirconium oxide ( $ZrO_x$ ) thin film that gives low contact resistivity to n-type c-Si.  $ZrO_x$  is deposited by e-beam evaporation at room temperature. The layer is profoundly characterized by SE, XPS, XRD, and contact resistivity ( $\rho_c$ ) measurements. The contact resistivity is found to be highly dependent on the  $ZrO_x$  thickness. The lowest  $\rho_c$  of  $22 \text{ m}\Omega\cdot\text{cm}^2$  is achieved using only 1 nm thick  $ZrO_x$ . As a proof-of-concept,  $ZrO_x$  is applied at the rear side of a lightly doped n-type c-Si solar cell with boron-diffused emitter at the front side achieving above 17% efficiency with a remarkable FF around 80%. These values successfully demonstrate the use of  $ZrO_x$  as an emerging electron-selective layer contact for lightly doped n-type c-Si wafers.

### Keywords

zirconium oxide, metal oxides, n-type crystalline silicon, solar cells, contact behaviors

3D schematic of the  $ZrO_x$  passivated n-type solar cell

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