

**3rd EUROREGIONAL WORKSHOP ON
PHOTOVOLTAICS & NANOPHOTONICS
EUROREG-PV 2016**

21st – 23rd September 2016



<http://euroreg-pv.fe.uni-lj.si>

University of Ljubljana
Faculty of Electrical Engineering
Tržaška cesta 25, Ljubljana, Slovenia

BOOK OF ABSTRACTS

About this publication

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University of Ljubljana
Tržaška cesta 25
SI-1000 Ljubljana
Slovenia

Organisation of the workshop

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Prof. Dr. Janez Krč, UL FE

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Prof. Dr. Bernd Rech,
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About the workshop

In past decade, photovoltaics in Europe underwent a journey from rapid growth, followed by stagnation to the increasing interest in the field nowadays. Photovoltaics is facing new challenges, for example e mobility, positive energy homes and building integration in connection with reliability and architectural compliance. Therefore we believe that photovoltaics offers great opportunities for further growth in the fields of research and economics.



2nd workshop, 2014

The Euroregional workshop is intended to gather experts together with PhD students. It be organised as a forum of global R&D trends. You will get the chance to meet researchers from across the Europe, get to know their research projects and share the common issues and challenges.

The workshop consists of the following sessions:

- 1. Advanced materials, solar cells and PV modules**
- 2. Nanophotonic structures for light management**
- 3. Thin-film solar cells and PV modules**
- 4. Advanced characterisation techniques**
- 5. Challenges in optical and electrical modelling**
- 6. Performance and reliability of PV modules and systems**

Program

Wednesday, 21st September 2016

13:30 – 14:30	Registration , Location: Faculty, building B, 1 st floor	
	Lunch , Location: Faculty canteen, ground floor	
14:30 – 15:00	Coffee , Location: Faculty building B, 1 st floor	
15:00 – 15:10	Opening of the workshop Location: Faculty, building B, 1 st floor	
	Advanced materials, solar cells and PV modules - I Chairman: Janez Krč	
15:10 – 15:50 INVITED	Christophe Ballif EPFL – PV-LAB, CSEM, Neuchatel, Switzerland	Metal oxides and Transparent conductive oxides in c-Si heterojunction, perovskites and in tandem solar cells
15:50 – 16:20 INVITED	Steve Albrecht Helmholtz-Zentrum Berlin, Germany	Towards Highly Efficient Monolithic Perovskite/Silicon-Heterojunction Tandem Solar Cells
16:20 – 16:35	Manoj Jaysankar IMEC, Leuven, Belgium	Large area perovskite/silicon multi- junction modules
16:35 – 17:00	Coffee break	
	Nanophotonic structures for light management Chairman: Steve Albrecht	
17:00 – 17:30 INVITED	Klaus Jäger Helmholtz-Zentrum, Berlin, Germany	Nanophotonic light management for crystalline silicon thin-film solar cells
17:30 – 17:45	Gerhard Peharz Joanneum Research Forschungsgesellschaft GmbH, Weiz, Austria	Plasmonics for tuning the colour of c- Si solar cells – a first commercial application of nano-photonics in PV?
	Presentation of LPVO Marko Topič, University of Ljubljana, Fac. of Elec. Eng., LPVO	
17:45 – 18:10	LPVO activities – past 10 years with a look ahead	
18:15 – 19:15	Lab tour LPVO	
19:30	Pizza and beer , Location: Faculty	

Thursday, 22nd September 2016

	Thin-film solar cells and PV modules <i>Joint presentation with Slovenian PV conference SLO-PV 2016</i> <i>Location: Peterlin's pavilion (see maps)</i>	
9:30 – 10:15 PLENARY	Lars Stolt Solibro Research AB, Uppsala, Sweden	From lab research of CIGS solar cells to mass production of PV modules – historic and future challenges
10:15 – 10:20	<i>Walk to the Faculty building</i>	
10:20 – 10:45	Coffee break	
	<i>Chairman: Jakub Holovsky</i>	
10:45 – 11:15 INVITED	Olindo Isabella TU Delft, PVMD, The Netherlands	Thin-film single- and double-junction solar cells based on barium-disilicide
11:15 – 11:30	Daniel Menz Austrian Institute of Technology, Vienna, Austria	Metastable Behavior of Thin-Film Solar Cells under Colored Light
11:30 – 11:45	Vera Gradišnik Faculty of Engineering, University of Rijeka, Croatia	The a-Si:H Device Characteristics Degradation Upon the Light Induced Defects
	Advanced characterisation techniques <i>Chairman: Olindo Isabella</i>	
11:45 – 12:15 INVITED	Jakub Holovsky Institute of Physics, Prague, Czech Republic	Subbandgap absorption spectroscopy of photovoltaic materials: applicability and interpretation
12:15 – 12:45 INVITED	Beate Röder Humboldt Universität zu Berlin, Germany	Luminescence spectroscopy: Useful Tool for Evaluating EVA cross-linking in PV modules
12:45 – 13:00	Jan Schlothauer Humboldt Universität zu Berlin, Germany	Non-destructive aging investigations of EVA in PV modules: Photoluminescence reveals DLO conditions
13:00 – 14:00	Lunch	

	Advanced characterisation techniques (continued) <i>Chairman: Bart Pieters</i>	
14:00 – 14:15	Rudi Brüggemann GeePs (Group of Electrical Engineering – Paris), UMR CNRS 8507, CentraleSupélec, UPSud - UPMC France	Temperature dependence of the radiative recombination coefficient in crystalline silicon
14:15 – 14:30	Rok Kimovec University of Ljubljana, Fac. of Elec. Eng., LPVO, Slovenia	Influence of injection current and temperature on electroluminescence of GaAs laser power converters
	Challenges in optical and electrical modelling <i>Chairman: Klaus Jäger</i>	
14:30 – 15:00 INVITED	Bart E. Pieters IEK-5 Photovoltaik, Forschungszentrum Jülich, Germany	Solar Cell and Module Modelling with PVMOS
15:00 – 15:15	Benjamin Lipovšek University of Ljubljana, Fac. of Elec. Eng., LPVO, Slovenia	3D optical modelling of solar cells and PV modules with CROWM – a combined ray optics / wave optics model
15:15 – 15:30	Andrej Čampa University of Ljubljana, Fac. of Elec. Eng., LPVO, Slovenia	Opto-electronic simulation of bifacial heterojunction Si solar cells
15:30 – 15:45	Žiga Lokar University of Ljubljana, Fac. of Elec. Eng., LPVO, Slovenia	RCWA performance in 3D simulations of silicon solar cells
15:45 – 16:00	Milan Kovačič University of Ljubljana, Fac. of Elec. Eng., LPVO, Slovenia	From light in-coupling in solar cells to light out-coupling in OLEDs
16:00 – 16:30	Coffee break	

	Performance and reliability of PV modules and systems - I <i>Chairman: Michael Köhl</i>	
16:30 – 16:45	Bettina Ottersböck Polymer Competence Center Leoben GmbH, Austria	Comparison of different microclimates on the ageing behaviour of encapsulation materials used in photovoltaic modules
16:45 – 17:00	Gernot Oreski Polymer Competence Center Leoben, Leoben, Austria	Influence of Backsheet film on PV Module Reliability
17:00 – 17:15	Antonia Mihaljević Polymer Competence Center Leoben, Leoben, Austria	Influence of backsheet type on formation of acetic acid in PV modules
	Balance-of-system electronic <i>Chairman: Saša Sladić</i>	
17:15 – 17:30	Filip Žic RITEH, Rijeka, Croatia	Multiple Photovoltaic Powered DC Power Supply Design
17:30 – 17:45	Sara Belanić RITEH, Rijeka, Croatia	Stability Issues in PV Converter with Current Feedback
17:45 – 18:00	Mateo Šafarić RITEH, Rijeka, Croatia	DC/AC Power Converter Emulation by Microprocessor System
20:00	<i>Dinner at Union pub</i>	

Friday, 23rd September 2016

	Advanced materials, solar cells and PV modules - II <i>Chairman: Benjamin Lipovšek</i>	
9:00 – 9:30 INVITED	Miha Filipič IMEC, Lueven, Belgium	Silicon solar cells on epitaxial foils
9:30 – 10:00 INVITED	Karen Forberich i-MEET, FAU Erlangen- Nürnberg, Germany	Dielectric mirrors for printed solar cells
10:00 – 10:30	Coffee break	
	Performance and reliability of PV modules and systems - II <i>Chairman: Beate Röder</i>	
10:30 – 11:00 INVITED	Steve Ransome Steve Ransome Consulting Ltd, Northampton, UK	Performance rating and degradation analysis of PV modules
11:00 – 11:30 INVITED	Michael Köhl Fraunhofer ISE, Freiburg, Germany	Impact of Rain and Soiling on Potential Induced Degradation
11:30 – 11:45	Eleonora Annigoni EPFL, PV-LAB, Switzerland	Predictive models for the power degradation of c-Si PV modules: Potential-Induced Degradation and moisture ingres
11:45 – 12:00	Blaž Kirn University of Ljubljana, Fac. of Elec. Eng., LPVO, Slovenia	PV system performance analysis using PV performance models
12:00 – 12:10	Closing of the workshop	
12:15	Lunch	

ABSTRACTS

Wednesday, 21st September 2016

Sessions:

Advanced materials, solar cells and PV modules – I
Nanophotonic structures for light management

Metal oxides and Transparent conductive oxides in c-Si heterojunction, perovskites and in tandem solar cells

Christophe Ballif

EPFL, Institute of Microengineering, Photovoltaics and thin film electronics laboratory,
Maladière 71, 2000 Neuchâtel,
CSEM, PV-center, Jacquet-Droz 1, 2000 Neuchâtel
christophe.ballif@epfl.ch

Abstract

In this presentation, we'll review first some of the properties of MoOx and WOx metal oxides, in view of their integration into PV devices. In particular issues with color changes and transport will be discussed, as well as the impact of subsequent coating by TCO. We'll continue discussing some aspects of TCO coating and compare the properties of different TC's, with and without indium, in view of optimising both transmittance to the device and minimizing series resistance. We'll show then the application of these layers in a variety of devices including single junction perovskite cells and mini-modules, crystalline silicon heterojunction devices, and tandem perovskite/c-Si heterojunction devices both in two and four terminal configurations.

Towards Highly Efficient Monolithic Perovskite/Silicon-Heterojunction Tandem Solar Cells

Steve Albrecht¹, Michael Saliba², Juan Pablo Correa Baena³, Klaus Jäger⁴, Marko Jost⁵, Lukas Kegelmann⁶, Lars Korte⁶, Marko Topic⁵, Anders Hagfeldt³, Michael Grätzel², and Bernd Rech⁶

¹ Young Investigator Group Perovskite Tandem Solar Cells, ⁴ Young Investigator Group Nano-SIPPE, ⁶ Institute for Silicon Photovoltaics, Helmholtz-Zentrum Berlin für Materialien und Energie GmbH, Kekuléstraße 5, D-12489 Berlin, Germany

² Laboratory of Photonics, ³ Laboratory of Photomolecular Science, Station 6, Science Swiss Federal Institute of Technology (EPFL), Lausanne, CH1015, Switzerland

⁵ University of Ljubljana, Faculty of Electrical Engineering, Tržaška 25, 1000 Ljubljana
steve.albrecht@helmholtz-berlin.de

Abstract

Combining inorganic–organic perovskites and crystalline silicon into a tandem solar cell has recently attracted increased attention due to the high efficiency potential of this cell architecture. In this contribution, we present the development of a monolithic silicon heterojunction/perovskite tandem solar cell that requires processing at low temperatures. By implementing an electron selective contact of the perovskite sub-cell formed by atomic layer deposition of SnO₂, a monolithic tandem cell efficiency of close to 20% is achieved in reverse JV scan that showed a stabilized power output of 18%. To further increase the device performance that is currently limited by optical losses, optical simulations enabling device- and material-related guidelines are present. By tuning the thickness of all functional and the perovskite absorber layers, together with the optimization of the perovskite band-gap in the simulation, we present a simulated tandem stack that can yield reduced optical losses and thus can achieve efficiencies above 28% for planar tandem designs. We further analyse the application of different light trapping schemes such as textured surfaces that can overcome 30% power conversion efficiency for this tandem design in the simulation.

Large area perovskite/silicon multijunction modules

Manoj Jaysankar*^{1,2}, Maarten van Eerden^{1,3}, Weiming Qiu¹, Robert Gehlhaar¹,
Maarten Debucquoy¹, Ulrich Paetzold^{1,4}, Tom Aernouts¹, and Jef Poortmans^{1,2}

¹ imec, Kapeldreef 75, 3001 Leuven, Belgium

² KU Leuven, ESAT, 3001 Leuven, Belgium

³ Radboud University, 6525 Nijmegen, Netherlands

⁴ Karlsruhe Institute of Technology, IMT, 76021 Karlsruhe, Germany

* manoj.jaysankar@imec.be

Abstract

The rise of perovskite photovoltaics has opened up an exciting route to surpass the power conversion efficiency (PCE) limits of market-leading silicon solar cells. Multijunction solar cells based on perovskite and c-Si absorbers can potentially yield PCE beyond 30% but a key challenge is scaling up this technology to large areas while maintaining high PCE. In this work, we demonstrate a fully scalable four-terminal $\text{CH}_3\text{NH}_3\text{PbI}_3/\text{c-Si}$ multijunction solar module exhibiting more than 20% PCE over an aperture area of 4 cm^2 . We employ a module-on-cell architecture where a semi-transparent $\text{CH}_3\text{NH}_3\text{PbI}_3$ module of 4 cm^2 aperture area is stacked on top of an interdigitated back contacted c-Si solar cell of identical aperture area. We analyse the impact of quality of transparent electrodes and module design on overall performance of the four-terminal multijunction module. With a combination of optimised transparent electrodes and solar module design, our semi-transparent $\text{CH}_3\text{NH}_3\text{PbI}_3$ top solar module exhibits an aperture PCE of 12% and an average transmittance of 70% in the near-infrared spectral region. Finally, by a detailed opto-electronic analysis, we quantify the various losses in our four-terminal solar module and present strategies to mitigate them.

Keywords

Perovskite, Multijunction, Four-terminal, Module, Scalability

Nanophotonic light management for crystalline silicon thin-film solar cells

Klaus Jäger,^{1,2,*} David Eisenhauer,¹ Grit Köppel,¹
Duote Chen,^{1,2} Sven Burger,² and Christiane Becker¹

¹Young Investigator Group Nano-SIPPE, Helmholtz-Zentrum Berlin für Materialien und Energie
GmbH, Kekuléstr. 5, 12489 Berlin, Germany

²Zuse Institute Berlin, Takustr. 7, 14195 Berlin, Germany

* klaus.jaeger@helmholtz-berlin.de

Abstract

Liquid-phase crystallized (LPC) silicon (Si) is a material that allows to combine the advantages of thin-film technology with the high material quality of crystalline silicon. Light management is mandatory to achieve high current densities, because (1) the absorber is only about 10 μm thin, (2) Si is an indirect-bandgap material and has (3) a high refractive index, leading to high reflection losses at the front glass-silicon interface if planar structures are used. Light management structures created prior to the LPC process must be smooth as otherwise the crystallization process only yields material with inferior electronic quality.

In this contribution we investigate two different hexagonal periodic nanostructures, which are placed between the glass substrate and the absorber: (1) arrays of silicon oxide nanopillars embedded in a matrix of titanium oxide and (2) sinusoidal textures. For both types we conducted numerical studies using a time-harmonic finite element solver (JCMsuite) in order to identify the geometry, which couples light best into the Si absorber. For the sinusoidal structures we observe that not only pitch and structure height are important, but also the morphology. For both types of structures we also present experimental results and compare those to numerical results.

Plasmonics for tuning the colour of c-Si solar cells – a first commercial application of nano-photonics in PV?

Gerhard Peharz^{1,*}, Wolfgang Waldhauser¹, Bettina Großschädl¹, Christine Prietl¹,
Christine Auer¹, Wolfgang Nemitz¹, Karl Berger², Bernhard Kubicec², Michael
Grobbaauer³, Julia Gratzner³, Martin Aichinger⁴ and Gabriele Eder⁵

1 JOANNEUM RESEARCH

2 AIT

3 SFL Technologies

4 Ertex-Solar

5 OFI

*Franz-Pichler-Strasse 30

8160 Weiz

Austria

Gerhard.pehartz@joanneum.at

Abstract

The colour of crystalline silicon (c-Si) solar cells is mainly determined by their anti-reflective coating. The anti-reflective coatings is optimized for maximal photocurrent generation, resulting in the typical blue or black colours of c-Si solar cells. However, for building-integrated photovoltaic (BiPV) application the colour of the solar cells is demanded to be tuneable – ideally by a cheap and flexible coating process on standard (low cost) c-Si solar cells.

We present results on tuning the colour of standard c-Si solar cells exploiting plasmonic (nano-photonic) colouring effects. The applied approach relies on coating standard industrial c-Si solar cells with Ag nano-particles in order to tune their colour. In particular thin films (1-20 nm) of Ag were sputtered onto c-Si solar cells and thermally annealed subsequently. The size and the shape of the nano-particles (characterized by SEM) were found to depend on the thickness of the film deposited. Spectrally selective scattering corresponding to green and yellow colours was found for different types of Ag nano-particles and the performance of the coated c-Si cells was found to decrease by about 10%_{relative}. Moreover a first test module was fabricated and the feasibility of the plasmonic coating for BiPV was evaluated.

Keywords: Plasmonics, Colouring, c-Si solar cells, Module

Thursday, 22nd September 2016

Sessions:

Thin-film solar cells and PV modules

Advanced characterisation techniques

Challenges in optical and electrical modelling

Performance and reliability of PV modules and systems – I

Balance-of-system electronics

From lab research of CIGS solar cells to mass production of PV modules – historic and future challenges

Lars Stolt

Solibro Research AB

Vallvaegen 5, 75651 Uppsala, Sweden, L.Stolt@solibro-research.com

Abstract

In research, CIGS thin film solar cells had several breakthroughs. The first one can be said to be the 10 % efficiency achievement by the Boeing Aerospace group in the early 1980'ies. They achieved this using a growth recipe going from Cu-rich composition to a Cu-poor composition. Another breakthrough is the introduction of Na, which increase carrier density and leads to increased efficiency. The bandgap grading concept has also been a key contributor to efficiency, and now more recently the alkaline post deposition treatment. The paper will present this laboratory progress and the impact on industrial up-scaling from the perspective of the Solibro company's development of a commercial CIGS technology. This concerns equipment as well as cost-related items such as bill-of-materials and yield. Furthermore current challenges to improve further in order to maintain and enhance competitive strength will be outlined.

Abstract should be sent to euroreg-pv@lpvo.fe.uni-lj.si in Microsoft Word (.doc) format. First author will be used for correspondence if not marked otherwise. Consult EUROREG-PV web page at <http://euroreg-pv.fe.uni-lj.si> for additional information about the workshop.

Thin-film single- and double-junction solar cells based on barium-disilicide

Olindo Isabella, Robin Vismara, Miro Zeman

Delft University of Technology, Photovoltaic Materials and Devices group
Mekelweg 4, 2628 CD, Delft, the Netherlands o.isabella@tudelft.nl

Abstract

Thin-film silicon (TFSi) solar cells have not yet been able to compete in performance and cost with wafer-based crystalline silicon (c-Si) architectures. As the latter have now come close to their practical limit (efficiency $\eta \sim 26\%$), double-junction solar cells with c-Si as bottom sub-cell have become attractive to overcome the Shockley-Queisser limit of single-junction devices. Barium di-silicide (BaSi_2) has recently emerged as a promising material for solar cells applications, owing to its abundance, inexpensiveness and appealing opto-electrical properties (band-gap of 1.25 eV, long minority charge-carrier diffusion length up to tens of micrometers, and high absorptivity).

In this contribution, we show the optical properties of BaSi_2 and we compare its absorption coefficient α with that of other absorber materials used in photovoltaic devices. Afterwards, we present a study of the optical performance of BaSi_2 in thin-film single junction devices. Established PV technologies - such as wafer-based c-Si, Cu(In,Ga)Se_2 , etc. - will be used as benchmarks to evaluate the potential BaSi_2 -based solar cells. Finally, to demonstrate the material potential as absorber in high efficiency PV devices, we analyse the performance of a proposed thin-film double-junction architecture based on organometallic halide perovskite ($\text{CH}_3\text{NH}_3\text{PbI}_3$) and BaSi_2 absorber materials.

Metastable Behavior of Thin-Film Solar Cells under Colored Light

Menz Daniel^{1,2}, Rennhofer Marcus¹, Mittal Ankit¹, Ujvari Gusztav¹, Summhammer Johann²

1 Austrian Institute of Technology, Photovoltaic Systems, Giefinggasse 2, 1210 Vienna, Austria

2 Technical University of Vienna, Institute of Atomic and Subatomic Physics, Stadionallee 2,
1020 Vienna, Austria

Rienöblgasse 2/3 1130 Vienna, Austria
daniel.menz.fl@ait.ac.at

Key words: CIGS, characterization, light soaking, metastabilities

Abstract

This work focuses on metastable effects of CIGS solar cells where the cell's macroscopic parameters – especially V_{OC} , FF and P_{MPP} – change due to illumination. It is known that the amount as well as the direction (decrease/increase) of the illumination effect depends not only on the materials used, their quality and the working point of the solar cell, but as well on the wavelength of the incident light.

In this work we were able to confirm the already known “blue” and “red light effect”. Further insights were reached by performing illumination measurements under yellow and green light. These measurements have been performed for CIGS solar cells of different performance quality and two different buffer layers (CdS and ZnO), in order to gain information on the interaction between intrinsic characteristics of the samples and the irradiance spectra.

One of the main findings of this work was that the metastable effects on macroscopic level show smooth transitions from low to high quality of the cells as well as from low to high wavelength of the incident light. Furthermore the effects of the low quality solar cells are similar for both buffer layer materials but are different for high quality cells indicating that the effects are buffer layer determined in high quality cells.

The a-Si:H Device Characteristics Degradation Upon the Light Induced Defects

Vera Gradišnik, Željko Jeričević

Faculty of Engineering, University of Rijeka

Vukovarska 58, HR-51000 Rijeka

e-mail Vera.Gradisnik@riteh.hr

Abstract

The transient photocurrent of reverse and forward biased a-Si:H pin devices to blue light impulses and simultaneous illumination with a blue bias beam of the same intensity have been investigated. The modified optical bias dependence of modulated photocurrent method - OBMPC at low frequency is used to measure the devices responses.

The device responses were analysed as a sum of decaying exponential functions using the linear least squares method. The linearization was achieved by successive numerical integration first proposed by Foss. The sum of decaying exponentials is typical response for independent relaxation processes happening in parallel.

The interpretation of results leads to estimation of localized states energies in amorphous silicon i-layer, as well as their influence on photocurrent and capacitance degradation. It is observed that the defect states of i-layer are distributed around deeper energy levels at reverse bias than at forward bias voltages. Also, the small increase in energies of localized states is observed in region where the capacitance achieves the upper limit close to the built-in potential.

The proposed method can be used to characterize the localized states of the native and light-induced defect states in a-Si:H devices and their influence on device performances.

Keywords: a-Si:H devices, transient response, OBMPC, low frequency

Subbandgap absorption spectroscopy of photovoltaic materials: applicability and interpretation

Jakub Holovský

Institute of Physics of the Czech Academy of Sciences v. v. i. , Cukrovarnická 10, 162 00 Praha,
Czech Republic, holovsky@fzu.cz
Czech Technical University in Prague, Faculty of Electrical Engineering, Technická 2, 166 27
Praha, Czech Republic

Abstract

The subbandgap absorption spectroscopy is relatively simple defect evaluation method which is already well established in material science of the hydrogenated amorphous silicon. Whereas other methods like conductivity, photo luminescence or microstructural analysis may give results which are difficult to interpret for new materials, the subbandgap absorption spectroscopy can provide an indication of semiconductor quality already by looking at depth and steepness of the absorption edge. The differences in traditional measurement techniques: Photothermal Deflection Spectroscopy, Constant Photocurrent Method and recently introduced Fourier-Transform Photocurrent Spectroscopy will be discussed, including the frequency dependence issue and sensitivity to surface defects. The mathematical methods of absolute evaluation of absorption coefficient and defect density will be presented. Photocurrent has the advantage of high sensitivity and possibility to work with layers on absorbing substrates, however the interpretation is more complex. The question of differences in measurement of a single absorber layer on glass and of a finished cell will be addressed including the effect of optical scattering and the effect of surface states. Apart from amorphous silicon, recent results obtained on transparent conductive oxides, methyl-ammonium lead triiodide perovskites and cadmium telluride will be discussed.

Luminescence spectroscopy: Useful Tool for Evaluating EVA cross-linking in PV modules

Beate Röder*, Jan Schlothauer, Clea Peter

Humboldt-Universität zu Berlin, MNF, Department of Physics

Newtonstrasse 15, 12489 Berlin, Germany

E-Mail*: roeder@physik.hu-berlin.de

Abstract

Ethylene-Vinyl-Acetate (EVA) is the most common encapsulation polymer in photovoltaic modules. The quality of the cross-linking of the EVA is of great interest for the industry, as this greatly affects the service life of PV modules. At present no suitable methods exist, which allow an *in situ* inspection. Here we present a promising method that allows non-destructive examination of the degree of crosslinking and its homogeneity in the PV module by luminescence measurements. The luminescence of EVA after UV excitation is presented here as a non-destructive method to determine the degree of crosslinking. The luminescence intensity increases with the degree of crosslinking. Moreover, evaluating the time-dependent luminescence signal for defined spectral region it becomes possible to determine the degree of cross linkage and differentiate spatial efficiency of crosslinking.

This optical method it is suitable and comparatively easy to apply for an industrial in-line measurement.

Non-destructive aging investigations of EVA in PV modules: Photoluminescence reveals DLO conditions

Jan C Schlothauer, Beate Röder*

Humboldt-Universität zu Berlin, MNF, Department of Physics

Newtonstrasse 15, 12489 Berlin, Germany

E-Mail*: roeder@physik.hu-berlin.de

Abstract

The ability to characterize the degradation processes of materials in the product is a fundamental prerequisite for degradation investigations and lifetime prediction. Especially for PV modules suitable, non-destructive characterization methods are needed.

Photoluminescence of the most common embedding material, ethylene vinyl acetate (EVA) in differently aged PV modules and its correlation to destructive characterization methods is investigated. EVA samples, extracted systematically at different locations, were characterized by dynamic mechanical analysis (DMA). A good correlation of the photoluminescence intensity and parameters obtained from DMA is found. The results point to the fact that location-dependent differences in the crosslinking develop upon aging.

Furthermore, the spatial profiles are in accordance to kinetics of diffusion limited oxidation processes. This work provides the first comprehensive experimental evidence of diffusion limited oxidation (DLO) in the embedding material in PV modules. Apparently DLO kinetics of 1st order match the aging behavior of only-thermally aged PV modules, while in UV aged and outdoor weathered modules more complex degradation kinetics are observed.

The result imply that photoluminescence can be used to assess DLO-related inhomogeneous material aging. The method can therefore become an important tool to assess differences of accelerated aging and natural weathering.

Temperature dependence of the radiative recombination coefficient in crystalline silicon

Xu Ming, Rudolf Brüggemann*, José Alvarez, Mohamed Boutchich, Jean-Paul Kleider

GeePs (Group of Electrical Engineering – Paris), UMR CNRS 8507, CentraleSupélec, Univ. Paris-Sud, Université Paris-Saclay, Sorbonne Universités, UPMC Univ. Paris 06
11 rue Joliot-Curie, F-91192 Gif-surYvette Cedex FRANCE
rudi.brueggemann@geeps.centralesupelec.fr

Abstract

The radiative recombination coefficient in crystalline silicon is determined from a combination of temperature-dependent modulated photoluminescence and stationary spectral photoluminescence. The latter probes the radiative recombination rate while the phase shift of the modulated photoluminescence is evaluated for excess carrier densities. There is no requirement to model the temperature-dependent intrinsic carrier density in this approach. Absolute values of the radiative recombination coefficient are determined by calibrating the obtained relative coefficient data with literature values.

Published data on the radiative recombination coefficient in crystalline silicon are available between 70 K and 393 K. We extend the temperature range in this work from 70 K down to 20 K, in which the radiative recombination coefficient increases with decreasing temperature by about 2 orders of magnitude. The results for two crystalline-silicon samples with different thicknesses and doping show good agreement.

* Corresponding author

Influence of injection current and temperature on electroluminescence of GaAs laser power converters

Rok Kimovec¹, Henning Helmers², Andreas W. Bett², and Marko Topič¹

¹University of Ljubljana, Faculty of Electrical Engineering,
Tržaška cesta 25, 1000 Ljubljana, Slovenia
rok.kimovec@fe.uni-lj.si

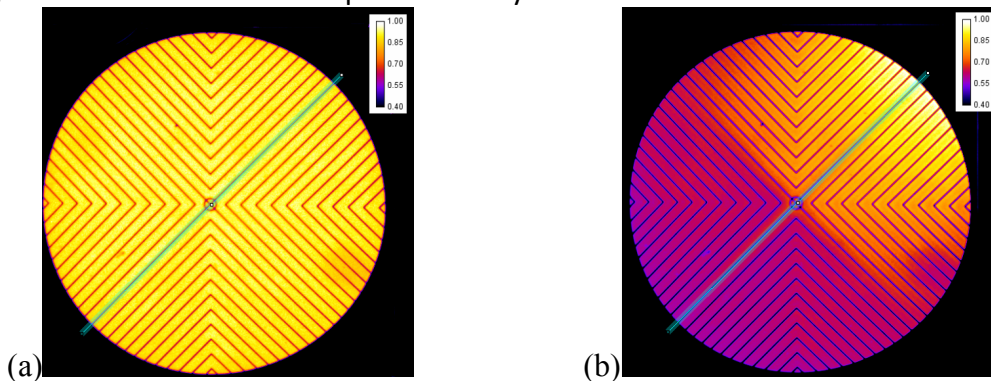
²Fraunhofer Institute for Solar Energy Systems ISE
Heidenhofstr. 2, 79110 Freiburg, Germany

Abstract

Qualitative analysis of photovoltaic (PV) device can be evaluated with spatially and spectrally resolved electroluminescence (EL) measurements taken under forward bias of device under test. Spatially resolved EL provides us with information about local performance parameters of PV devices and gives us insight into material and manufacturing quality, while spectrally resolved EL measurements enable us to observe band gap variations of the device under changing working conditions.

In this work we will present and analyse investigation on influence of injection current and temperature on EL of various GaAs laser power converters. Decrease of emitted photon energy with increasing temperature is observed in spectrally resolved EL measurements due to decrease of absorber band gap with increasing temperature. Evaluation of spatially resolved EL images at various injection currents will be presented and evaluated graphically and temperature coefficient dEL/dT will be extracted from obtained EL images.

Fig. 1: Spatially resolved EL of single-junction single-segment LPC (a), (b) at two injection current levels ((a) 1 mA, (b) 400 mA, designated cell area $A = 7,094 \text{ mm}^2$) and single-junction two-segments LPC (c), (d) at two injection current levels ((c) 1mA, (d) 100 mA, segment area $A_{\text{seg}} = 1,681 \text{ mm}^2$). A brighter colour on all images represents higher current densities. It should be noted that the current distribution under illumination is different from the current distribution under forward bias condition used for EL; thus, current densities for those different operating conditions cannot be compared directly.



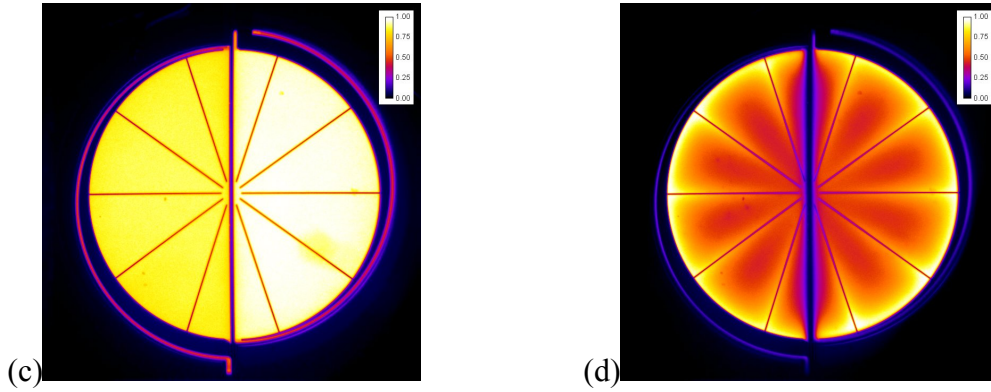
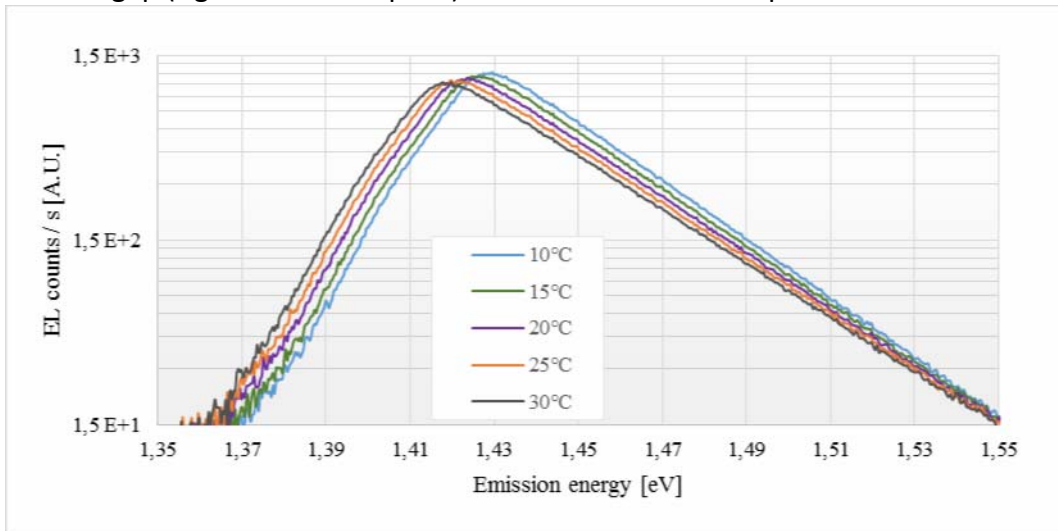


Fig. 2: Spectral EL emission of single-junction single-segment GaAs LPC under constant injection current 400 mA at various temperatures. As seen in the Fig 2 rise of temperature results in two different effects: Firstly, EL emission peak is shifted to lower energies due to dilation of crystal lattice which results in decreased bandgap. Secondly, EL emission is decreased with rising temperature in two different manners. While the slope at energies below the bandgap (left side of the peak) remains constant with increasing temperature, slope at energies above the bandgap (right side of the peak) is decreased when temperature increases.



Solar Cell and Module Modelling with PVMOS

Bart E. Pieters

IEK-5 Photovoltaik, Forschungszentrum Jülich

b.pieters@fz-juelich.de

Forschungszentrum Jülich GmbH, IEK-5, 52425 Jülich, Germany

Abstract

The performance of solar cells and modules is strongly influenced by inhomogeneities and the series resistance of lateral current transport. To better understand and analyze these effects 2D or 3D models of a solar module are required. Many such models have been developed in the past few decades. Two years ago we first presented our tool, the Photo-Voltaic Module Simulator (PVMOS). The PVMOS program is equipped with an efficient solver, variable and adaptive meshing, and flexible tools to specify a device. Furthermore, the program is freely available under an open source license. In this paper we will demonstrate the capabilities of PVMOS along several examples of both crystalline wafer based and thin-film technologies.

3D optical modelling of solar cells and PV modules using CROWM – a combined ray optics / wave optics model

Benjamin Lipovšek, Janez Krč, Marko Topič

University of Ljubljana, Faculty of Electrical Engineering
Tržaška 25, 1000 Ljubljana, Slovenia

Abstract

Optical modelling and simulation has been recognized as an indispensable tool for efficient design and optimization of novel solar cell structures and their optical performances. However, as the solar cell structures become ever more complex, so must the optical models that are used for their analysis. In this work, we focus on optical simulation using the developed optical model CROWM (Combined Ray Optics / Wave optics Model). The model is based on the combination of geometric and wave optics and enables detailed optical simulation of a wide range of modern solar cell concepts. We demonstrate its capabilities on a number of specific cases, from simple micro-textured substrates to complete solar cells and PV modules. Further on, in relation to all the presented cases, we also stress the importance of taking realistic input parameters into the account in the simulations. Only through realistic input data in conjunction with valid optical modelling we can achieve relevant results that accurately predict the optical behavior of the investigated device.

Keywords

Optical modelling, ray tracing, light management

Opto-electronic simulation of bifacial heterojunction Si solar cells

Andrej Čampa

University of Ljubljana, Faculty of Electrical engineering

Tržaška 25, SI-1000 Ljubljana, Slovenia

(E-mail: Andrej.campa@fe.uni-lj.si)

Abstract

With the development of computational power the complex multi-dimensional simulations of various opto-electronic devices are crucial for fast and accurate view of physical properties and behaviour of such devices under different test conditions.

To study electrical performance of bifacial heterojunction silicon solar cells we have utilized 3-D optical simulator and 2-D electrical simulator. The output of 3-D optical simulation was transformed and used as one of the input parameters in 2-D electrical simulations. With the simulations the performance parameters of solar cell were calculated such as: efficiency, fill factor, short circuit current, open circuit voltage and values at maximal power point. We have optimized the spacing of rear side fingers to improve the efficiency of the solar cell due to front and back illumination. The outlook for further performance improvements (lifetimes of electrons and holes in bulk silicon, and effect of the front and back transparent conductive oxide resistivity) and their effect on finger spacing will be shown.

RCWA performance in 3D simulations of silicon solar cells

Žiga Lokar, Janez Krč, Benjamin Lipovšek and Marko Topič

University of Ljubljana, Faculty of Electrical Engineering,

Tržaška 25, 1000 Ljubljana, Slovenia

Ziga.Lokar@fe.uni-lj.si

Abstract

Modelling and numerical simulations play an important role in optimization of solar cells, as they enable quick iterations and testing of many different structures and variations of parameters. In our contribution we focus on optical modelling and simulations using Rigorous Coupled Wave Analysis (RCWA). We performed a detailed study of the method, where we include different textures as light management structures in crystalline-based or thin-film silicon solar cells. Different shapes (triangular, sine, rectangular) and their lateral and vertical dimensions in nano- and micrometer range are included in the analysis and the applicability of the RCWA method tested. Following single interface tests, we continue with real solar cell structures: thin wafer-based silicon solar cells. We compared and validated RCWA simulations with the finite element method (FEM) and raytracing (CROWM model) to discover RCWA strengths, weaknesses and limitations for optical simulations of solar cells and PV modules.

From light in-coupling in solar cells to light out-coupling in OLEDs

Milan Kovačič¹, Janez Krč¹, Benjamin Lipovšek¹, Paul-Anton Will², Simone Lenk²,
Sebastian Reineke² and Marko Topič¹

¹University of Ljubljana, Faculty of Electrical Engineering,
Tržaška 25, 1000 Ljubljana

²Technische Universität Dresden, Institut für Angewandte Photophysik,
George-Bahr-Str. 1, 01067 Dresden, Germany
(contact e-mail: milan.kovacic@fe.uni-lj.si)

Abstract

Organic light-emitting diodes (OLED) have in the last years successfully entered the display market via smartphones and TVs. Research is now also on using the OLEDs for general lighting as they are promising to combine uniform large area light distribution, high efficiency, high color quality, glare free illumination and attractive designs. The research has in the last years made lots of progress in improving the material stability and device lifetimes. On the other hand, the key issue - poor light outcoupling still shows huge potential, as for normal devices with flat interfaces, only 20% of generated light is extracted to air as useful light, so there is still a lot of room for advance concepts to improve light outcoupling.

In this contribution, we present an advanced model for optical simulations of OLEDs including photonic structures in micrometer range for outcoupling of light [1]. The simulation model was first tested with a flat OLED stack and with one-dimensional (1D) sine textures. Simulation results are in good agreement with experimental ones. In this contribution, we further tested and optimized 1D and 2D sine textures to achieve best outcoupling performance. Improvements in outcoupling efficiency from optimized flat OLED stack ($\eta_{\text{out}} = 23\%$) to that of the optimized stack with 2D sine textures ($\eta_{\text{out}} = 37\%$) is more than 14% according to our simulations.

REFERENCES

[1] M. Kovačič, J. Krč, B. Lipovšek and M. Topič, "OPTICAL MODEL FOR ORGANIC LIGHT EMITTING DIODES," MIDEM conference 2015, 23-25 September 2015, Bled, Slovenia

Comparison of different microclimates on the ageing behaviour of encapsulation materials used in photovoltaic modules

Bettina Ottersböck¹, Gernot Oreski¹, Gerald Pinter²

¹Polymer Competence Center GmbH

Roseggerstraße 12, 8700 Leoben, Austria, bettina.ottersboeck@pccl.at

²University of Leoben, Departement of Material Science and Testing of Polymers,
Otto-Glöckl-Straße 2, 8700 Leoben, Austria

Abstract

To guarantee photovoltaic (PV) module lifetimes of about 25 years a high quality product standard of the components is required. The critical parts concerning lifetime are polymeric materials. The mainly used encapsulation material is ethylene vinyl acetate (EVA). Nowadays thermoplastic polyolefins (TPO) are in the focus of the PV industry. The degradation behaviour of EVAs and TPOs is well described in the literature. However, the micro-climate (single film or laminated glass/backsheet samples) can highly influence the ageing behaviour and has not been sufficiently investigated. Therefore the main focus in this work was to evaluate the influence of the micro-climate on the ageing behaviour of encapsulations.

Significant differences in the ageing behaviour of encapsulation materials were found depending on the micro-climate, induced by different sample designs. Artificial ageing with irradiation resulted in more yellowing for the laminated samples than without radiation. Single films exhibited no significant changes. However, infrared spectroscopy results indicated chemical degradation for the film samples even though no yellowing occurred. An explanation for this behaviour can be the photo-bleaching effect, where the chromophoric degradation products are decomposed by the presence of oxygen and UV radiation. Different ageing behaviour could be confirmed due to varied micro-climates induced by sample-design.

Keywords

Encapsulant, micro-climate, ageing behaviour

Influence of Backsheet film on PV Module Reliability

Gernot Oreski

Polymer Competence Center Leoben (PCCL)

Roseggerstraße 12, 8700 Leoben,

E: gernot.oreski@pccl.at, T: +43 3842 42962-51

Abstract

Many common PV module degradation modes like yellowing, corrosion, snail trails or PID can be related to the polymeric materials within a PV module. Also, several studies showed that design matching of backsheets and encapsulant can avoid or reduce these PV module degradation modes.

All of these PV module degradation processes are strongly influenced or driven by the permeation properties (water vapour, oxygen, acetic acid) of the encapsulant and the backsheet. So for backsheets selective barrier properties (low water vapor (WVTR) and high acetic acid permeation rates) and for the encapsulants low WVTR values and reduced volume resistivity are aspired. Hence, reliable and comparable data on the permeation properties of backsheets and encapsulants is necessary for optimum design matching.

Next to delamination formation of cracks is the major failure mode of backsheet itself, which is also strongly influencing the barrier properties. Hence the main mechanisms of crack formation for different backsheets will be presented and discussed. To summarize, the author wants to illustrate that long term stability of backsheets is one main factor for reliability and durability of PV modules. And that design matching with other PV module components under consideration of expected stress factors increase performance and reliability.

Influence of backsheet type on formation of acetic acid in PV modules

A. Mihaljevic¹, G. Oreski^{1*}, G. Pinter²

¹ Polymer Competence Center Leoben GmbH, Roseggerstraße 12, 8700 Leoben

² University of Leoben, Institute of Material Science and Testing of Plastics, Otto Glöckl Straße 2, 8700 Leoben

Corresponding author: gernot.oreski@pccl.at, T: +43 3842 42962-51

Abstract

Acetic acid formed during aging of ethylene vinyl acetate (EVA) influences aging mechanisms like yellowing of EVA, PID effect, corrosion of metallization and is known to accelerate the oxidation processes in EVA. Permeates like oxygen, water vapor or acetic acid are governing these degradation processes and therefore permeation properties of the backsheets are of great importance. In several studies backsheets with presumably high acetic acid permeation rates were correlated with better PV module performance. Permeation behavior of backsheet laminates depends on their composition. The lowest permeation rates were found for laminates containing a polyester (PET) core layer. Co-extruded backsheets based on polyamides and polyolefines exhibited values which were up to 100 times higher than for laminates containing PET. In this work, test laminates consisting of EVA and backsheets with different AATR values were prepared, placed in stainless steel capsules and exposed to UV/T and T conditions. The formation of acetic acid was measured via GC/MS method while degradation of EVA via Raman spectroscopy. The highest concentration of acetic acid followed by the higher degradation of EVA was found in samples containing PET based backsheet.

Keywords: PV modules, acetic acid, degradation, backsheet, Raman spectroscopy

Multiple Photovoltaic Powered DC Power Supply Design

Filip Žic, Saša Sladić

Faculty of Engineering Rijeka
Vukovarska 58, 51000 Rijeka, Croatia
flitch321@net.hr, sladics@riteh.hr

Abstract

In this paper a case study of PV powered multiple DC supply (Fig. 1) design is presented. In frame of this work a SMD populated printed circuit board with regulated and controlled supply was built. In its control circuit a PicAxe 20X2 microcontroller with Basic interpreter was used.

Keywords: power converter case study, SMD, PicAxe 20X2

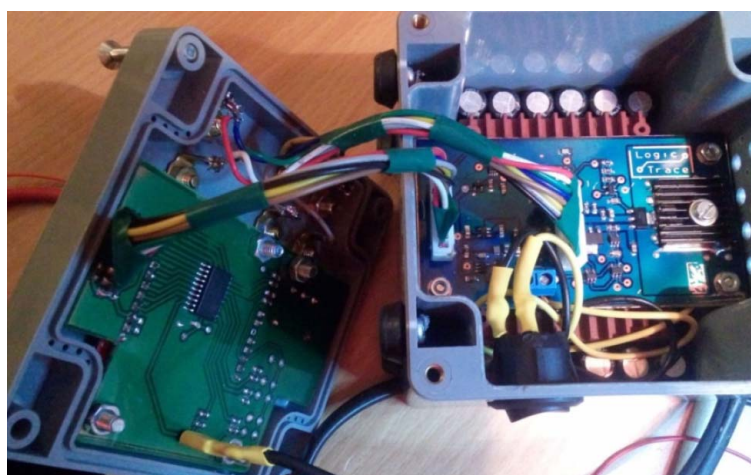


Figure 1. Multiple output, PV powered DC supply; inside look

Stability Issues in PV Converter with Current Feedback

Sara Belanić, Saša Sladić

Faculty of Engineering Rijeka
Vukovarska 58, 51000 Rijeka, Croatia
sbelanic@riteh.hr, sladics@riteh.hr

Abstract

Photovoltaic sources could be used for variety of applications including constant voltage or constant current supply. PV charging of batteries is application which generally involves constant voltage and constant current. LED lighting sources demands constant current sources, also. In this paper an approach to obtain a constant current source was investigated, as well as PV system modeling leading to nonlinear phenomena in power converter and stability analysis. In order to obtain practical results ARM Cortex-M4 processor was used.

Keywords: power converter current loop, cortex M4 processor

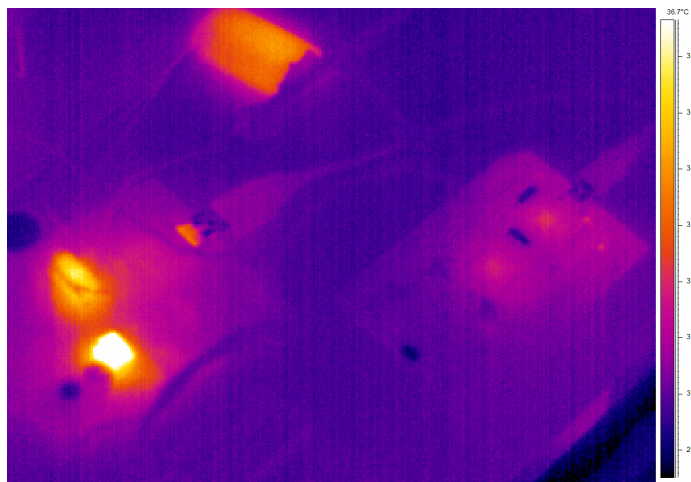


Figure 1. Thermal image of STM32F4 microprocessor sistem with ARM Cortex M4 processor

DC/AC Power Converter Emulation by Microprocessor System

Mateo Šafarić, Saša Sladić

Faculty of Engineering Rijeka
Vukovarska 58, 51000 Rijeka, Croatia
mateo.safaric@gmail.com, sladics@riteh.hr

Abstract

Power converter implementation could be time consuming and less cost effective. In this paper single phase inverter emulation (Fig. 1) with Arduino microcontroller was introduced, obtaining the emulation of load AC converter voltage and its filtering. This approach gives results comparable with simulation and practical results of emulated converter, as well involving the programming experience in power inverter modeling.

Keywords: power converter emulation, Arduino

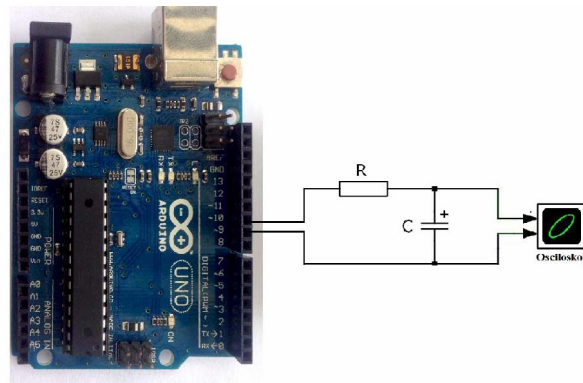


Figure 1. DC/AC power supply emulation for PV system algorithm investigation

Friday, 23rd September 2016

Sessions:

Advanced materials, solar cells and PV modules – II
Performance and reliability of PV modules and systems – II

Silicon solar cells on epitaxial foils

Miha Filipič¹, Twan Bearda¹, Valerie Depauw¹, Hariharsudan Sivaramakrishnan Radhakrishnan¹, Kris Van Nieuwenhuysen¹, Yaser Abdulraheem⁴, Acar Beran⁸, Jinyoun Cho^{1,3}, Alireza Hajjifarassat^{1,3,7}, **Mahmudul Hasan¹**, Shashi Kiran Jonnak^{1,3,5}, Yuandong Li^{1,3}, Xingyu Liu^{1,3,6}, Shuja Malik^{1,9}, Joseph Ramirez^{1,10}, Arsalan Razzaq^{1,3}, **Abdullah Umer¹**, Menglei Xu^{1,3}, Bartosz Zielinski^{1,3}, Maarten Debucquoy¹, Ivan Gordon¹, Jozef Szlufcik¹, Jef Poortmans^{1,2,3}

¹ IMEC, Kapeldreef 75, 3001 Heverlee, Belgium

² IMO, Hasselt University, Wetenschapspark 1, 3590 Diepenbeek, Belgium

³ ESAT, KU Leuven, Kasteelpark Arenberg 10, 3001 Heverlee, Belgium

⁴ Electrical Engineering Department, College of Engineering & Petroleum, Kuwait University, P.O. Box 5969, 13060 Safat, Kuwait

⁵ University of Freiburg, Fahrenbergplatz, 79085 Freiburg im Breisgau, Germany

⁶ Technical University of Dresden, Helmholtzstraße 10, 01069 Dresden, Germany

⁷ Politecnico di Milano, Dip. Chimica, Materiali e Ing. Chimica Giulio Natta, 20133 Milan, Italy

⁸ Gunam, Metu, Department of Physics, 06800 Ankara, Turkey

⁹ Amity University, Noida, India-201301

¹⁰ GPE, Technische Universität Berlin, Department of Assembly Technology and Factory Management, Pascalstr. 8-9, D - 10587 Berlin, Germany

miha.filipic@imec.be

Abstract

Thinner crystalline silicon (c-Si) solar cells with thicknesses in the range of 50 μm not only reduce material consumption but can theoretically perform better than thicker cells. Making such thin wafers with conventional methods like wire sawing is not economical due to high kerf losses. One alternative way to make thin c-Si wafers is epitaxial growth on porous substrate followed by a liftoff of the epitaxial layer – epifoil cells. Such epifoils can be processed freestanding or bonded to a glass superstrate for better mechanical stability.

To reach the full potential of the thin epifoil cells good surface passivation and light management are vital. At imec we adopt the silicon heterojunction technology based on hydrogenated amorphous silicon which results in excellent epifoil surface passivation. We compare different light management approaches based on random pyramid textures as well as on nano-sized textures. Both surface passivation and light management are not isolated problems. Optical performance depends on the surface passivation layers and contact formation. In order to find the optimal solutions, modelling and simulations are essential.

Here we give an overview of our epifoil technology and report on recent progress for both freestanding double side contacted and bonded interdigitated back contacted cells.

Dielectric mirrors for printed solar cells

Karen Forberich¹, Carina Bronnbauer¹, Christoph J. Brabec^{1,2}

¹Institute of Materials for Electronics and Energy Technology (i-MEET), Friedrich-Alexander-Universität Erlangen-Nürnberg, Martensstrasse 7, 91058 Erlangen, Germany

²Bavarian Center for Applied Energy Research (ZAE Bayern), Haberstrasse 2a, 91058 Erlangen, Germany

Abstract

Wavelength-selective dielectric mirrors are an approach to increase the efficiency of semi-transparent solar cells while keeping the transparency constant. We have fabricated solution-processed mirrors with easily adjustable reflection maxima that are ideally suited for the combination with solution-processed solar cells. The measured transmittance and reflectance curves as well as the external quantum efficiency (EQE) are in good agreement with simulations performed with the transfer matrix formalism, which shows the good optical quality of the layers. A systematic study of different absorber materials shows that the combination of an organic solar cell with a printed mirror is advantageous in terms of short-circuit current (J_{sc}) vs transparency above a certain absorber layer thickness/below a certain transparency.

In addition to enhancing the efficiency, dielectric mirrors can also be used to change the color appearance of the solar cell. This is demonstrated with semitransparent perovskite solar cells which intrinsically exhibit a brownish color. Through the combination with the dielectric mirror, we can also achieve reddish, blueish and greenish colors, which opens new possibilities for perovskite solar cells in e.g. building-integrated photovoltaics where color is an important aspect.

Performance rating and degradation analysis of PV modules

Steve Ransome

Steve Ransome Consulting Limited

99 Richmond Park Road, Kingston upon Thames, KT2 6AF, UK; steve@steveransome.com

Abstract

This talk gives an introduction to PV module power modelling (W vs. weather parameters) and Energy Rating measurements (kWh/y) for different PV technologies including crystalline Silicon, Cadmium Telluride and other thin films.

A typical efficiency curve vs. irradiance, thermal, physical and resistance values is used to determine the sensitivity of Energy Yield at world-wide climates (from Northern Europe to desert) including due to site irradiance, temperature, spectrum, angle of incidence and direct:diffuse fraction. It quantifies the yield sensitivity due to effects such as low light and high temperature performance drops.

Most reported degradation rates are just for STC corrected P_{MAX} values. PV can degrade for a variety of reasons including shunting (R_{SHUNT} drop) and contact corrosion (R_{SERIES} rise) leading to instantaneous performance changes that worsen at low light or high light levels respectively. The overall energy yield drops will be site dependent – a low Insolation site will suffer more due to shunting effects and a high insolation site drops faster with series resistance increases. We introduce advanced IV curve fit methods (such as the Loss Factors Model LFM) to determine PV module degradation rates in percent/year and their cause (such as shunt resistance, I_{SC} or V_{OC} falls or series resistance rises) for a range of examples of c-Si and thin film technologies.

Impact of Rain and Soiling on Potential Induced Degradation

Michael Koehl, Stephan Hoffmann

Fraunhofer ISE

Heidenhofstr. 2, 79110 Freiburg, Germany, Michael.koehl@ise.fraunhofer.de

Abstract

The electrical potential between the cells and ground can cause leakage currents that are a necessary but not sufficient indicator for potential induced degradation (PID) which is due to the migration of sodium ions into the silicon cells. Outdoor exposure of modules with high voltage bias in two different climate regions with monitoring of the climatic data, the module temperatures as well as the leakage currents were used to investigate the effect of rain-induced and soiling induced increase of the surface conductivity, the leakage current and the decrease of the module performance.

Keywords: high voltage stress, PID, silicon PV-modules, soiling

Predictive models for the power degradation of c-Si modules: Potential-Induced Degradation and moisture ingress

Eleonora Annigoni¹, Alessandro Virtuani¹, Christophe Ballif^{1,2}, Marko Jankovec³,
Marko Topič³

¹École Polytechnique Fédérale de Lausanne (EPFL), Institute of Microengineering (IMT),
Photovoltaics and Thin Film Electronics Laboratory, Rue de la Maladière 71b, 2000 Neuchâtel,
Switzerland

² CSEM, PV-center, Jaquet-Droz 1, 2000 Neuchâtel, Switzerland

³ University of Ljubljana, Faculty of Electrical Engineering, Laboratory of photovoltaics and
optoelectronics, Trzaska cesta 25, SI-1000 Ljubljana, Slovenia

eleonora.annigoni@epfl.ch

Abstract

During outdoor operation, photovoltaic (PV) modules are exposed to a variety of stresses that can result in power loss. Here we present some activities we are performing in order to predict the long-term performance of crystalline silicon (c-Si) modules in different climates.

The potential-induced degradation (PID) is one of the main failure modes for c-Si modules since it can lead to rapid and severe power degradation. Here, accelerated tests are performed on 2-cells mini-modules at different stress levels, and a mathematical model that describes PID-related power output is developed. Such model is then applied with weather data as inputs to simulate module performance in different climatic conditions.

Another critical issue for long-term reliability is moisture penetration into PV modules, which could promote PID, corrosion of interconnections, and other aging mechanisms. Finite-elements method simulations are employed here to predict the water diffusion into modules. A measurement technique for *in-situ* monitoring of moisture ingress is also presented, based on miniaturized humidity/temperature sensors embedded in the encapsulant material. On the one hand, we will employ these sensors to validate our simulations. On the other hand, the possibility to measure water content inside the encapsulant during accelerated tests will allow understanding the impact of water concentration on the observed degradation modes, for instance providing a link between the change of encapsulant resistivity and the PID.

PV system performance analysis using PV performance models

Blaž Kirn and Marko Topič

Faculty of Electrical Engineering, University of Ljubljana
Tržaška 25, SI-1000 Ljubljana, Slovenia
blaz.kirn@fe.uni-lj.si

Abstract

PV performance models can be used to analyze PV system potential or performance as long as solar irradiance data are provided. We have recently developed direct-diffuse-power-rating (DDPR) model that separately addresses the diffuse and direct irradiance components including angular loss compensation. In this study, the DDPR PV module performance model is extended to PV systems. In the case of 17 kW PV system in Ljubljana, the model rendered 3.6% yearly root mean square error (RMSE) compared to 4.3% RMSE of basic model used as a reference. Greater improvement is achieved in morning and evening conditions, when the diffuse component dominates. The averaging interval of PV system measurements also plays important role in accuracy, since the analysis showed, that up to 0.28% additional positive bias is induced for 1 hour averaging intervals compared to 5 minute one.

Further, the DDPR model was used to estimate the loss or gain of PV system performance at different orientations. The results for Ljubljana, Slovenia show that yearly temperature compensated performance ratio (PR_T) can be 1.8% lower for certain orientations (e.g. vertical orientation facing south) compared to optimal orientation (south, 30° inclination) due to higher share of direct irradiance with higher solar incident angles.

