

2nd EUROREGIONAL WORKSHOP ON PHOTOVOLTAICS

EUROREG-PV 2014

1st – 3rd September 2014



<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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Organisation

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About the workshop

Yesterday photovoltaics represented one of the fastest growing technologies. Today, even in this area we are faced with stagnation, but we don't want to see as a problem but as a challenge and an opportunity. We believe that even in times of economic and financial crisis photovoltaics represents a promising, sustainable economic sphere.



1st workshop, 2012

Workshop is intended for a forum of global trends in photovoltaics in the fields of research, industry and market. Especially PhD students are encouraged to participate. 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 will consist of but not limited to the following themes:

1. Advanced concepts of solar cells and PV modules,
2. Photonics in photovoltaic devices,
3. Advanced optical modelling,
4. Material and device characterisation,
5. Performance, reliability and monitoring of PV modules and systems,
6. Storage and smart grid,...

Organisation



University of Ljubljana,
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Program

Monday, 1st September 2014

9:00 – 10:00	Registration	
	Coffee break	
	Opening of the workshop <i>Marko Topič</i>	
10:00 – 13:00	Session I: Manipulation of photons and electrons <i>Chairman: M. Topič</i>	
INVITED	Franz-Josef Haug	Understanding the mechanism of light-trapping
	Coffee break	
	Barbara Ressel	The CITIUS light source
	Robin Vismara	Radial heterojunction c-Si nanowire solar cells with 11.8% conversion efficiency
	Vaidvile Ulbikaite	Uniform Si/Ni junction formation using two stages electroless Ni deposition
	Vera Gradišnik	The Solar Cells and Photodiodes Capacitance
	Gizem Nogay	Silicon Based Light Emission Devices
13:00 – 14:00	Lunch break	
14:00 – 16:00	Session II: Optical and electrical modelling <i>Chairman: J. Krč</i>	
INVITED	Rudi Santbergen	A versatile optical model for optimization of advanced solar cell concepts
	Žiga Lokar	Rigorous Coupled Wave Analysis for optical simulations of solar cells
	Jakub Holovský	Thin-film limit formalism applied to surface defect absorption spectroscopy
	Milan Kovačič	Optical Filtering for Fluorescence Detection - Diffraction Grating Approach
	Moulin Etienne	Influence on light trapping of the different interfaces in micromorph thin-film silicon tandem solar cells
16:00	Coffee break	
17:00	Optical characterization demo tour at LPVO	
20:00	Beer & pizza	

Tuesday, 2nd September 2014

9:00 – 11:00	Plenary session	
	<i>Opening of Slovenian photovoltaic conference</i>	
PLENARY	Prof. Dr. Bernd Rech, Hemholtz Zentrum Berlin	Photovoltaics: a key pillar for a future sustainable energy supply
11:00 – 11:20	<i>Coffee break</i>	
11:20 – 13:00	Session IV: Advanced concepts <i>Chairman: F. J. Haug</i>	
INVITED	Martina Schmid	Concepts for absorption enhancement in Chalcopyrite solar cells
	Rudolf Brüggemann	Radiative recombination coefficients in Cu(In,Ga)Se ₂ with different Ga content
	Phillip Manley	Core Shell Plasmonic Nanoparticles for Absorption Enhancement in Ultra-Thin Chalcopyrite Solar Cells
13:00 – 14:00	<i>Lunch break</i>	
14:00 – 16:00	Session V: 3rd GEN PV <i>Chairman: B. Lipovšek</i>	
INVITED	Karen Forberich	Solution-processed semitransparent organic solar cells: Efficiency limits, materials and large-area processing
	Marko Berginc	Renewal of dye-sensitized solar cells performance with heat treatment
	Anastasiia Solodovnyk	Light Propagation in Phosphor-Filled Matrices for Photovoltaic PL Down-Shifting
	Christos Trompoukis	2D periodic photonic nanostructures integrated into 40 µm thin crystalline-silicon solar cells
	Marko Jošt	Replication of nanotextures using UV nanoimprint lithography
16:00	<i>Coffee break</i>	
17:00	PV module monitoring demo tour at LPVO	
20:00	<i>Get together in downtown</i>	

Wednesday, 3rd September 2014

9:00 – 11:00	Session VI: Power devices I <i>Chairman: K. Brecl</i>	
INVITED	Gorazd Štumberger	Micro-inverter for photovoltaic modules
	Primož Sukic	Reactive power generation in micro inverters for photovoltaic systems
	Ernest Belič	The impact of PV system reactive power generation on active power generation and distribution network losses - the case study
	Ivan Legović	LED flashlight: case study
11:00 – 11:20	Coffee break	
11:20 – 13:00	Session VII: Power devices II <i>Chairman: M. Pirc</i>	
INVITED	Saša Sladić	Single-Phase, Grid-Connected Inverter for Photovoltaic Applications
	Alen Konović	Battery lifetime improvement using supercapacitors
	Vedran Jurdana	Hybrid yacht propulsion systems
13:00 – 14:00	Lunch break	

14:00 – 16:00	Session VIII: PV modules <i>Chairman: J. Krč</i>	
	Ankit Mittal	The Power Change In Amorphous Silicon Technology By Low Temperature Annealing and Irradiance
	Andrea Canino	Study of optical characteristics and durability of nano-structured glass surfaces used in thin film photovoltaic
	Matevž Bokalič	Stabilization Process of Thin-Film Photovoltaic Modules Monitored Under Outdoor Conditions
	Bert Herteleer	Insights from continuous outdoor temperature measurements of photovoltaic modules
	Blaž Kirn	Highly Customizable PV Monitoring Systems Irradiance Measurement Solution
	Dainius Horbačauskas	Demonstration at industrial scale of the FleXible manufacturing of SMART multifunctional photovoltaic building elements
16:00	Coffee break	
17:00	PV technology demo tour at LPVO	
20:00	Farewell party	

Monday, 1st September 2014

Session I:

Manipulation of photons and electrons

Session II:

Optical and electrical modeling

Understanding the mechanism of light-trapping

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Abstract

Absorption enhancement is desirable in a variety of applications ranging from sensors to optoelectronic elements and solar cells. In the past, many ideas have been put forth for silicon-based devices because their indirect bandgaps make all types of silicon weak absorbers. Expressed in optical terminology, absorption enhancement in these applications is simply the in-coupling of radiation into an active film.

Thus, the underlying concepts are also interesting for other technologies as they can reduce the amount of costly semiconductor materials. Likewise, reversing of the light path makes them applicable to out-coupling from the active layer in light-emitting diodes.

In optoelectronic devices, the most successful concepts are based on interface textures that fulfil two functionalities; they scatter light which gives rise to an enhanced light-path, and they represent a grading between different refractive indices which provides an effective anti-reflection effect.

The CITIUS light source

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Abstract

CITIUS (Interregional Centre of Ultrafast Photonic Technology for Spectroscopies) is an innovative light source for time resolved spectroscopies in the femtosecond time domain, founded by the “Italian-Slovenian Cross-border Cooperation Program 2007-2013”.

The light source generates photons in the spectral range from 15 to 70 eV, starting from a high power ultrafast Ti:Sapphire laser system, at 5 kHz repetition rate, via an HHG (High order Harmonic Generation) process in a cell filled with noble gas.

Such harmonics are monochromatized by a novel kind of monochromator, which can work in two different configurations: “time preserving” and “energy preserving”. The first exploits a set of 3 conical gratings to cover the operating spectral range optimizing flux and preserving pulse duration. The second configuration is based on a set of 3 classical gratings. The flexibility of the monochromator makes the CITIUS light source suitable for a huge class of pump-probe experiments.

The light source offers also the possibility of spanning the spectral region from 200 nm to 2600 nm with an OPA (Optical Parametric Amplifier).

The experimental chamber for time resolved photoemission experiments is equipped a state of the art angle resolved time of flight electron spectrometer from VG-Scienta.

Radial heterojunction c-Si nanowire solar cells with 11.8% conversion efficiency

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Key Words Nanowires, heterojunction, silicon, light trapping.

Abstract

Nanowires (NWs) are promising for advanced light trapping in solar cells. In this work we analysed the impact of these nanowires on the optical performance of a solar cell with thin c-Si absorber layer. A study of the effect of the nanowire geometrical parameters (i.e. height, diameter) was carried out by means of 3-D optical modelling based on the finite element method. Results show that the nanowire height does not influence greatly the performance of the absorber layer, because the greater anti-reflective effect achieved with taller nanowires is countered by an increase of the optical losses in supporting layers, keeping the total losses almost constant. Conversely, the diameter showed a greater influence on the implied photo-current density of the device, thus an optimum could be found. Finally, to prove the feasibility of our approach, a heterojunction (HTJ) c-Si NW solar cell showing a conversion efficiency of 11.8% was fabricated and its opto-electrical performance was measured and compared to an equivalent flat device. The comparison showed that nanowire-based solar cell exhibits higher long wavelength absorption, proving the optical potential of such architecture. However, due to large surface area, the electrical performance is hindered as witnessed by relatively low open-circuit voltage.

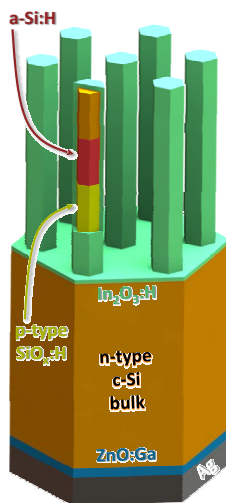


Figure 1 Sketch of the model used in the simulations

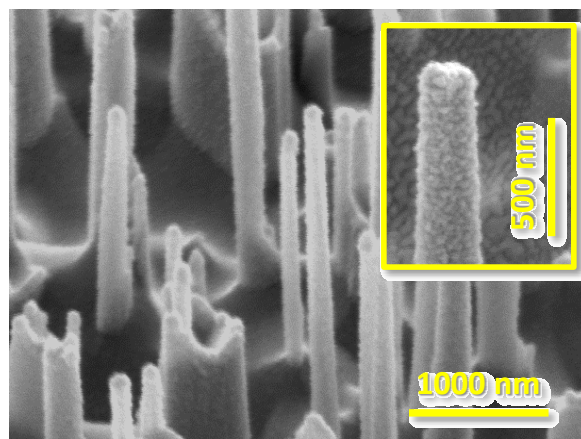


Figure 2 SEM image of the HTJ c-Si NW solar cell

Uniform Si/Ni junction formation using two stages electroless Ni deposition

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Abstract

Commercial Si solar cells are required to be low cost and have low shading loss and contact resistance. As a low price alternative to usually used Ag paste, electroless Ni and Cu can be used to form contacts. To achieve an acceptable ohmic contact a uniform Ni layer must be deposited before its anneal and Cu deposition.

Deposition quality of electroless nickel was investigated using second electron microscopy (SEM) with focused ion beam (FIB) setup. Alkaline solution composition in two step metallization process was varied: solutions with and without reducing agents, SDS and Ammonium fluoride (NH₄F) were used, with varied Ni ion source concentrations. It has been found that nickel deposition and Ni-Si junction was uniform while using solutions both containing SDS and NH₄F.

The Solar Cells and Photodiodes Capacitance

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Abstract

Integrating photodiodes and solar cells in one system can enable the usage of solar cells as a source for powering the photodiodes in an APS active pixel image sensor. The solar cell and photodiode capacitances are one of the most important parameters for designing this system.

The time domain technique at low frequency is used to measure the solar cells and photodiodes capacitance. The measurements have been carried out on a-Si:H p-i-n cells under forward and reverse bias voltages, in dark and under blue LED light illumination. It is observed, that the deep defect states of i-layer contribute to the capacitance at various bias voltages. Also, the capacitance achieves the upper limit around the built-in potential.

The proposed method can be used for further development of solar cell and photodiode integrated systems and various sensors.

Keywords: solar cells, photodiode, capacitance, CV time domain technique

Silicon Based Light Emission Devices

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Abstract

LEDs have become a commodity in every imaginable device we use in daily-life, as back lights in ever increasing display sizes, in illuminating wall panels, etc. They are actively pursued for lighting applications since they have high luminous efficiency [1] and longer lifetimes than fluorescent or halogen lighting devices. At present, III–V compound semiconductors are used as a basis material for well-established LEDs technologies due to their direct energy-gap nature [2]. However, recent work illustrates that based on its photoluminescence properties, nano-crystalline silicon is discussed as potential material for LEDs. Si-based LEDs may provide substantial advantage for large area applications because of low-cost production. The experimentally demonstrated quantum efficiencies of these Si-based LEDs do not achieve the performance of direct energy-gap semiconductors but the field is rapidly developing. As an advantage, they can be manufactured at lower cost since no expensive single-crystal substrates are needed. The technology could be applied to large-scale lighting, and also flexible lighting sheets on plastic substrates. In this contribution we demonstrate the luminescence of nanocrystals in SiO_x layers which is the first step through the realization of LEDs on the basis of Si-based materials.

Keywords: Luminescence; LEDs; nanocrystals; SiO_x

References

- [1] Beaupré, S., Boudreault, P.-L. T. and Leclerc, M. (2010). Adv. Mater., 22: E6–E27. doi: 10.1002/adma.200903484
- [2] Kortshagen, U. (2009) J. Phys. D: Appl. Phys. 42 113001 doi:10.1088/0022-3727/42/11/113001

A versatile optical model for optimization of advanced solar cell concepts

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Abstract

Optical models are an important tool for developing and optimizing novel solar cell concepts. Many of these novel concepts contain both thin films, with a thickness less than the wavelength of light, and much larger features. This makes it challenging to model them accurately, as wave optics and ray optics need to be combined. To solve this problem we developed an optical model that combines ray-tracing and thin-film optics in a unique way.

To demonstrate the versatility of our model we use it to optimize the 'Sunrise' concept. This revolutionary solar cell concept, developed by the Scheuten company, is based on 200 μm spherical glass beads coated with Mo, CIGS, CdS and ZnO:Al to form CIGS solar cells. Large quantities of these tiny spherical solar cells can be produced in a fluidized bed reactor and then placed in a hexagonal array to create modules of any size. We use our optical model to show the effect of sphere-to-sphere distance and back reflector diffusivity on module efficiency.

We will also show how our optical model can be used to optimize other solar cell concepts, such as textured c-Si cells with multi-layer anti-reflection coating or thin-film solar cells deposited on textured glass.

Rigorous Coupled Wave Analysis for Optical Simulations of Solar Cells

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Abstract

Optical modelling and simulations of solar cells present an essential tool for optimisation of device performances. They enable to identify optical losses in the structures and show directions for improvements towards increased short-circuit current and a better solar spectrum utilization, both leading to higher conversion efficiencies. Nowadays rigorous optical modelling and simulations are widely used in the field of PV.

In this contribution we will focus on Rigorous Coupled Wave Analysis (RCWA) method. Its advantages and drawbacks will be shown with respect to other approaches used in simulations of solar cells, such as finite element method.(FEM). Finally the method will be applied to optimize light guidance features (periodic textures) in thin-film and wafer-based silicon solar cells.

Thin-film limit formalism applied to surface defect absorption spectroscopy

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Abstract

We derive the so-called thin-film limit by a novel approach and present formulae for transmittance (T), reflectance (R) and absorptance (A) in highly versatile and accurate form. We draw attention to two remarkable consequences of the thin-film limit: (i) The optical properties A, R and T do not depend on the absorption coefficient (α), thickness (d) and refraction index (n) individually, but only on their product αdn . (ii) The absorptance strongly depends on the index of refraction of the surrounding media. Next, we perform experimental verification on graphene [1]. We also discuss consequences for the optimization and optical simulations of thin-film solar cells. Finally, a new method is presented that allows direct evaluation of ultrathin surface defective layer absorptance. This presents a direct and elegant way avoiding complex evaluation of surface defective layer [2].

[1] J. Holovsky, et al., "Effect of thin film limit on measurable properties of graphene" submitted
[2] J. Holovsky, et al., "Time evolution of surface defect states in hydrogenated amorphous silicon studied by photothermal and photocurrent spectroscopy and optical simulation", J. Non-Cryst. Solids. 358 (2012) 2035.

Optical Filtering for Fluorescence Detection - Diffraction Grating Approach

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Abstract

The detection of biomolecules using microarrays and lab-on-a-chip systems is a powerful diagnostic tool for acquisition of genetic, proteomic, and cellular information. To measure the concentration of targeting biomolecules, fluorescence can be employed. Fluorophores, such as non-toxic green fluorescent protein (GFP), are used to tag specific biomolecules. As a photodetector a-Si:H p-i-n diode can be employed. Since the photodiode is sensitive in a broad spectral range of light, optical filters have to be used to suppress strong excitation and to transmit weak emission light to the photodiode. In case of GFP the excitation peak ($\lambda_{\text{exc}} = 480$ nm) and the emission peak ($\lambda_{\text{em}} = 510$ nm) are close together, thus optical filters with sharp wavelength-selective characteristics are needed.

In our contribution we introduce and optimize filtering concepts based on diffraction gratings, to improve characteristics of common a-SiC:H absorption filters. Using 3-D rigorous optical simulations we analyse two types of 2-D dielectric gratings (made of non-absorbing and absorbing material) embedded in low refractive index material above the photodiode. Under ideal conditions (nanometer accuracy of gratings, perpendicular incident angle of excitation light) the proposed filter exhibits extremely sharp band stop (notch) filtering characteristics with rejection ratios up to 10^5 . To approach realistic conditions the dependence on manufacturing inaccuracies and oblique incident angles of light will be presented and related effects evaluated.

Influence on light trapping of the different interfaces in micromorph thin-film silicon tandem solar cells

Etienne Moulin, Elmar Feuser, Björn Niesen, Franz-Josef Haug, Christophe Ballif

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Abstract

An optimized light-trapping scheme is a prerequisite to reach stable efficiencies above 14% for thin-film silicon (TF-Si) solar cells in micromorph configuration. To reach such a goal, it would be helpful to understand the impact on light trapping of each relevant interface and layer constituting tandem cells in p-i-n configuration. Here, we propose to highlight the influence of the following interfaces and functioning layers on the opto-electronic cell properties: (i) the back reflector, (ii) the intermediate reflector and (iii) the antireflective/retroreflective geometric texture implemented at the air/glass interface. It is clear that the contributions of these various device constituents are interlinked, such that a straight determination of each effect cannot be made independently. However, by varying the back reflector configuration, modifying the thickness of the intermediate reflector, adding a nano-imprinted geometric texture at the front of the cell, and changing the superstrate surface texture, we are able to obtain valuable information about the role of each of these device constituents. At this workshop, the major results of this study will be presented. In addition, we will discuss which one is, in our opinion, the most promising micromorph tandem cell configuration to reach a stabilized efficiency of 14%.

Tuesday, 2nd September 2014

Plenary Session:

Opening of Slovenian photovoltaic conference

Session IV:

Advanced concepts

Session V:

3rd GEN PV

Photovoltaics: a key pillar for a future sustainable energy supply

Bernd Rech

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Abstract

The transformation towards a sustainable energy supply system based on unlimited renewable energy sources is a key challenge for the global society. Solar resources in Europe and across the world are abundant and cannot be monopolised like oil or gas resources. Photovoltaics is currently developing from a niche technology to a central pillar of the energy supply system. The plenary talk will provide an overview of current trends in research, development and application of PV. Over the last decade, the PV industry has experienced a dramatic growth phase and became a global business. Future trends in PV research will be discussed and as an example recent progress in thin film crystalline silicon thin film technology achieved at the Helmholtz Centre Berlin will be highlighted.

Concepts for absorption enhancement in Chalcopyrite solar cells

M. Schmid, P. Andrae, P. Manley, G. Yin

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Abstract

Plasmonic absorption enhancement by metal nanoparticles is often stated to improve photovoltaic devices, see e.g. [1], and also the particular application to Chalcopyrite, i.e. $\text{Cu}(\text{In,Ga})(\text{S,Se})_2$, solar cells was identified to be promising [2]. Thus, with a first focus on plasmonic nanoparticles, their fabrication and related challenge of stable integration in Chalcopyrite solar cells will be addressed, as well as investigations of far and near-field optical properties shown. Optical simulations can provide guidelines for nanoparticle design and resonance tuning – and they also lead to considerations of alternative nanoparticles made from dielectric material. Benefits and disadvantages of dielectric versus metallic nanoparticles have been evaluated [3] and various configurations of dielectric nanoparticles in Chalcopyrite solar cells are investigated in experiment and theory: spaced and closely packed nanoparticles at front and back interfaces. Finally, an outlook on micro-scaled concepts for enhanced absorption of photons will be presented; with increasing size of dielectric nanoparticles we obtain microlenses suitable for concentration of light onto micrometer-sized solar cells.

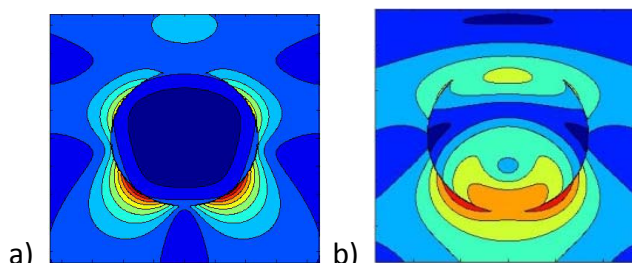


Fig.: Near-field around a) a metallic (Ag fitted with Drude model) nanoparticle with radius 120 nm and b) a dielectric nanoparticle with refractive index $n = 2$ and radius 170 nm at wavelengths of 426 and 502 nm, respectively [3].

[1] H.A. Atwater, A. Polman Nature Materials 9 205 (2010).

[2] M. Schmid, R. Klenk, M.Ch. Lux-Steiner, M. Topic, J. Krc Nanotechnology 22 025204 (2011).

[3] M. Schmid, P. Andrae, P. Manley Nanoscale Research Letters 9 50 (2014).

Radiative recombination coefficients in Cu(In,Ga)Se₂ with different Ga content

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Abstract

After a brief review on our determination of the radiative recombination coefficient B_{rad} in crystalline silicon in the temperature range up to 400 K [R. Brüggemann *et al.*, J. Optoelectr. Adv. Mater. 9 (2007) 77], we focus on the variation of B_{rad} in thin-film Cu(In,Ga)Se₂ with different Ga content. For a series of non-graded Cu(In,Ga)Se₂ absorber layers we determined B_{rad} from the evaluation of optical transmission and photoluminescence experiments. The provided values for B_{rad} allow to adequately represent radiative recombination in modelling studies on Cu(In,Ga)Se₂, especially for photoluminescence and electroluminescence characterisation.

Core Shell Plasmonic Nanoparticles for Absorption Enhancement in Ultra-Thin Chalcopyrite Solar Cells

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Abstract

Plasmonic metallic nanoparticles are an attractive option for increasing the absorption in ultra-thin chalcopyrite (CIGSe) solar cells. To fully exploit the plasmonic field enhancement, it is beneficial to place the metallic particles as close to the absorbing layer as possible. However this presents the challenge of integrating the particles in a chemically stable and electrically passivated way, whilst maintaining the benefits of the optical enhancement.

To this end we propose the use of core-shell dielectric-metallic nanoparticles. The dielectric layer blocks diffusion of the metal during the high temperature CIGSe deposition process. At the same time it will also prevent the recombination of charge carriers at the metallic surface. The key challenge is optimising the complex system by choosing material which will be capable of providing the aforementioned properties whilst maintaining the extraordinary field enhancement inside the absorbing layer. Although literature can provide examples for materials which satisfy the chemical stability and electrical isolation, consideration must also be paid to the material's optical effects. To this end, we use rigorous electromagnetic simulations to provide guidelines for the successful integration of core-shell dielectric-metallic nanoparticles into chalcopyrite solar cells.

Solution-processed semitransparent organic solar cells: Efficiency limits, materials and large-area processing

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Abstract

Due to their inherent semitransparency, organic photovoltaics cells (OPV) are an ideal candidate for integration into glass windows or other applications in buildings. We will discuss the interdependence between transparency and efficiency for semi-transparent OPV, with respect to the choice of electrode materials, the absorption spectrum of the active layer and the light management architecture.

In order to compete with other solar cell technologies, OPV needs to be produced by cost-efficient printing technologies that can be up-scaled for large area production. Using silver nanowires as both the electron- and the hole-collecting electrode, we have demonstrated fully solution-processed OPV cells where all the layers were deposited by doctor-blading. These devices show an excellent transparency of 50% at a power conversion efficiency which is 72% of the opaque reference device. In a further step towards up-scaling, we have successfully fabricated semitransparent modules with an area of 8cm x 8cm employing ultra-fast laser patterning. Due to the high accuracy of the laser patterning steps, these modules have a very high geometrical fill factor of 95% and no performance losses when compared to the single cell references.

One-dimensional photonic crystals have been shown to be an effective way to increase the efficiency of a semitransparent OPV cell at the same transparency. We will show how such a light management structure can be fabricated by a printing process which is easily compatible with large-area fabrication and integrated with the organic solar cell.

Renewal of dye-sensitized solar cells performance with heat treatment

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Abstract

Dye-sensitized solar cells (DSSCs) were developed in 1991 as a low-cost alternative to silicon based solar cells. Although the DSSCs' efficiencies nowadays exceed 12% they still did not fully enter the market since their stability remains an issue. One of the reasons of their instability is the presence of small iodine crystals in the electrolyte. In our previous study we observed that the crystals dissolved in the initial 2 months of the 7 months outdoor ageing of the DSSCs and they reappeared in the last 2 months of the ageing.

In order to better understand the reversal behaviour of the crystal growth/dissolution in the cells we examine how (i) storing the iodide based ionic liquid DSSCs in the dark at room temperature for a period of 12 months (ii) applied forward current treatment in the dark and (iii) a heat treatment influence the growth or dissolution of the crystals and consequently also cells performance. A forward current proportional to the short-circuit current is applied to non-illuminated DSSCs in order to simulate shaded DSSC connected in a PV module. The 60 °C and 80 °C are chosen for the heat treatment of the cells to mimic the outdoor cell temperature of the DSSC which can easily exceed 60 °C.

The current voltage characterization confirmed that the crystal development significantly influences the performance of the DSSCs. The crystals grew in the cells that have been stored in the dark for a longer time period (7 months), which is associated with a loss of the I_3^- in the electrolyte and causes a decrease in short-circuit current and an increase in open-circuit voltage. The growth of the crystals is significantly accelerated when a forward current is applied which further decreases the performance of the cell for up to 88% relatively. However, a heat treatment of the cells at 80 °C for 8 hours dissolves the crystals and completely renews the performance of the cell.

Light Propagation in Phosphor-Filled Matrices for Photovoltaic PL Down-Shifting

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Abstract

Efficient transparent light converters have received lately a growing interest from optical device industries (LEDs, PV, etc.). Use of phosphors in transparent matrix materials would mean a major breakthrough for this technology, as phosphors exhibit long-term stability and are widely available. For the fabrication of phosphor-filled layers tailored specifically for the desired application, it is of great importance to gain deep understanding of light propagation through the layers, including the detailed optical interplay between the phosphor particles and the matrix material. Our measurements show that absorption and luminescent behavior of the phosphors and especially the scattering of light by the phosphor particles play an important role.

In this contribution several experimental parameters are investigated: refractive index difference between transparent binder and phosphors, particle size distribution, and particle surface properties. Commercially available highly luminescent UV and near-UV absorbing μm -sized powder was chosen for this study. Solution-processed thick layers on glass substrates are optically analyzed and compared with simulation results acquired from CROWM, combined wave optics/ray optics home-built software. The results demonstrate the inter-dependence of the layer parameters, prove the importance of careful optimization steps required for fabrication of efficient light converting layers, and, thus, show a path into the future of this promising approach.

2D periodic photonic nanostructures integrated into 40 μm thin crystalline-silicon solar cells

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Abstract

Two-dimensional (2D) periodic photonic nanostructures are fabricated by nanoimprint lithography (NIL) followed by either wet chemical (Wet-NIL) or dry plasma (Dry-NIL) etching on 40 μm thick epitaxially-grown crystalline silicon (c-Si) foils. Dry-NIL results in nanostructures with a parabolic profile while Wet-NIL results in inverted nanopyramids. The fabricated nanostructures result in a higher c-Si absorption compared to the state-of-the-art random micron-scale pyramid texturing. Good effective minority-carrier lifetimes ($\tau_{\text{eff}} = 250 \mu\text{s}$) are obtained for aSi:H passivated foils when using wet etching to fabricate the inverted nanopyramids. Moreover, a maximum effective surface recombination velocity of $\sim 8 \text{ cm/s}$ at the patterned surface is calculated, which is comparable to state-of-the-art values for textured c-Si solar cells. The integration of these nanostructures into a 40 μm thick double-side contacted c-Si/aSi:H heterojunction solar cell architecture will be presented.

Keywords

Advanced light trapping, Photonic nanostructures, nanoimprint lithography, thin silicon solar cells

Replication of nanotextures using UV nanoimprint lithography

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Abstract

Light scattering at textured surfaces is an important solution in photovoltaics to prolong optical path in the active layer of solar cells, consequently the conversion efficiency increases. Textured surfaces in thin-film photovoltaics can be random or periodic and are usually in nano-scale. If not formed naturally (e.g. by the growth of poly-crystalline layers) they have to be fabricated by etching the existing layers (such as magnetron sputtered ZnO etched in HCl) or adding additional layer (e.g. lacquer) with embossed texture.

A novel effective approach in this field of embossing textures from small to large areas is a ultra-violet nanoimprint lithography (UV NIL) process. UV sensitive lacquers deposited on substrates or superstrates are used to replicate the textured surfaces from an intermediate stamp and an initial master. Compared to other replication techniques, such as thermoplastic embossing, UV NIL is accurate (nanometer scale), fast and suitable technique for roll-to-roll manufacturing. During the imprint soft lacquer of the stamp adopts the surface roughness of a master and is then hardened/cured by UV light. The texture of the stamp is negative replica. To acquire the positive replica the procedure is then repeated, carrying out similar replication process step between the stamp and final substrate for solar cell. The substrate with embossed lacquer is then ready for further processing of solar cell.

In the paper the UV NIL procedure will be described and challenges will be discussed. Results of AFM surface measurements and 3D ADF light scattering measurements of selected random nano-textured master, stamp and replica will also be presented and compared to establish the suitability and successfulness of the process.

Wednesday, 3rd September 2014

**Session VI:
Power devices I**

**Session VII:
Power devices II**

**Session VIII:
PV modules**

Micro-inverter for photovoltaic modules

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Abstract

This presentation describes the research project supported by Slovenian Research Agency under the title "Micro-inverter for solar panels". The project contains three main parts. The first part focuses on development of a new highly efficient micro-inverter without electrolytic capacitors that supports the needs of electricity networks and is able to accept references for active and reactive power generation. The second part focuses on the system that controls the group of micro inverters. It sends data regarding status and available resources to the local system for low voltage network control and receives references for active and reactive power generation from this system. Based on received references and statuses of individual photovoltaic modules with micro-inverter it generates references for active and reactive power generation of each individual micro-inverter, considering efficiency of the entire group of micro-inverters. The last part focuses on local system for low voltage network control. This system, according to the conditions in the network, generates references for active and reactive power generation of individual groups of micro inverters.

Reactive power generation in micro inverters for photovoltaic systems

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Abstract

The paper discusses the possibilities for reactive power generation in micro inverters used in photovoltaic systems. To determine the impact of reactive power generation on inverter's efficiency characteristic, measurements on existing micro inverter were performed for different values of generated active and reactive power. The obtained characteristic was further approximated and represented in the form of a surface. Increase of inverter losses due to reactive power generation can be calculated based on the obtained surface. The results of measurements performed on the tested micro inverter show that the reactive power generation deteriorates the efficiency of the micro inverter. However, according to the measured results, the additional losses caused by reactive power generation are even in the worst case lower than 2% of generated active power. The other topic discussed in this presentation is the evaluation of micro inverter's capability to generate reactive power considering its rated power and time distribution of available solar irradiation. If combined with the determined inverter's efficiency characteristic, the potential of PV systems for reactive power generation can be predicted.

The impact of PV system reactive power generation on active power generation and distribution network losses – the case study

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Abstract

Current PV systems usually operate in the way that they generate reactive power in accordance to constant power factor or they generate reactive power defined by the static voltage dependent characteristic. Problem of such operation is that reactive power is not generated according to the network needs, what can result in additional transmission losses in network. In low voltage network the impact of reactive power generation on voltage profile is barely noticeable. Therefore, the reactive power generation can be primarily used for minimization of energy transmission losses. In the case study, this paper evaluates technical and economic impacts of reactive power generation in PV systems inside low voltage network on energy production in PV systems as well as on energy losses in the discussed low voltage networks.

LED flashlight: case study

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Abstract

In order to design and test ergonomic and reliable flash light, a Buck converter has been designed. In order to achieve robust solution an industrial integrated circuit LM2595 has been used. Circuit for calibration of batteries has been designed also. Batteries was selected in order to achieve power of 30W in frame of light, ergonomic and portable flashlight. Simulation and practical results are given.

Single-Phase, Grid-Connected Inverter for Photovoltaic Applications

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Abstract

Single-phase active power filter represents a tool for improving power quality in AC distribution network. However, it can be used, also for connecting solar panels to AC electric distribution network, as a grid-connected inverter. In that case an additional bidirectional DC/DC converter could be added in order to adapt switching conditions both on AC and DC side of PV system. By optimal converter design, involving the soft switching effects, efficiency of entire system could be increased, at least for 1%. Besides, such approach is useful for smart-grid applications in frame of distributed PV power generation. Simulations and practical results were presented.

Battery lifetime improvement using supercapacitors

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Abstract

It was investigated possibility of prolongation of useful battery lifetime by adding additional parallel supercapacitors. However, an implementation of additional power converter has been analyzed in order to regulate battery and capacitor current. For this purpose a bidirectional DC/DC converter has been used. A simulation and practical results has been supplied.

Hybrid yacht propulsion systems

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Abstract

An application of different types of hybrid systems in modern low power ship (yacht) propulsion systems has been investigated. Different systems have been compared on commercial level and simulated. An influence of adding additional solar modules for range increase for yachts has been explored also.

The Power Change In Amorphous Silicon Technology By Low Temperature Annealing and Irradiance

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Abstract

Power rating instability still remains a critical issue in thin film photovoltaic (PV) technology like amorphous silicon (a-Si). Due to a-Si high susceptibility to degrade under light also called as Staebler- Wronski effect (SWE), leads to an increase in the defect density of a-Si, which further leads to an decrease in power of the PV module. Also, there are different kinds of defects states in a-Si having different activation energies. Our study is focused on investigating the behavior of annealing and degradation from different a-Si modules under low temperature conditions between 60 °C and 70°C, which allows only low activation energy for repair of the defect states. Experiments to show the influence of the charge carriers on power of the module, they were light soaked under low irradiance at open circuit, load and short circuit conditions. It leads in deeper understanding of the power change at outdoor conditions and on metastable behavior of a-Si thin film modules.

Study of optical characteristics and durability of nano-structured glass surfaces used in thin film photovoltaic

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Keywords

optics, integration, antireflection treatment, reliability

Abstract

We studied the optical and structural characteristics as well as the durability of glasses treated to improve their anti-reflective properties. A way to reduce the reflectivity of the front glass is the application of a random pattern of 3-D prominences on the surface. The anti-reflective effect leads to an increase of transmittance of the front glass and, hence, of the short circuit current of the solar cell. In this work we focus on the impact of accelerated reliability tests on front glasses with such rough surface that exhibits very good anti-reflective properties. In order to study the durability of the solar glass, extended damp-heat stress, humidity-freeze and outdoor exposure has been performed on both PV modules and glasses. Optical characterization, SEM and AFM analysis have been performed on glasses before and after the damp-heat treatment.

The aging mechanism of the glasses have been verified on AR treated surfaces and compared with references. This glass leaching phenomenon is based on Na or Ca silicates and hydroxide (OH) formation on the glass surface when exposed for long time to water. The study is important to establish the anti-reflective treatments durability for long time PV module exposition to the environment.

Stabilization Process of Thin-Film Photovoltaic Modules Monitored Under Outdoor Conditions

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Abstract

Thin-film photovoltaic modules must go through the process of preconditioning before they reach the stable and rated operating point. During the process certain changes occur in the absorber layer, which influence the electroluminescence (EL) emission.

We expose several commercially available thin-film modules to outdoor conditions to receive 120 kWh/m^2 of total solar irradiation in maximum power point and perform before, in-between and after EL inspection. Additionally, we also obtain STC performance data.

EL images are processed to remove all corruptive factors of EL image acquisition and extract relevant quantitative and spatially resolved EL data. Quantitative EL performance will be linked to the photovoltaic performance and observation will be discussed on a per-technology basis.

Inspection of spatial EL data reveals inherent inhomogeneities as well as other localised inhomogeneities, which are a consequence of structural defects in the devices. Some inhomogeneities spring up during exposure to outdoor conditions that may reduce the performance of the modules and present a threat to device reliability. Observed inhomogeneities will be discussed.

Insights from continuous outdoor temperature measurements of photovoltaic modules

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Abstract

Commercial-scale and industrial-scale photovoltaic systems represent up to 50% of installed capacity in the EU[1] and they have free and closed back mounting methods placed on flat roofs. In this work, results from continuous outdoor temperature measurements on PV modules mounted on a flat-roof mounting with free back are discussed. The measurement set-up is on the roof of KU Leuven in Ghent, with 24 Pt100 temperature sensors logged[2]. The large number of Pt100 sensors placed per PV module have shown that temperature variations within modules (e.g. top of module versus bottom, measured on cell or backsheet) can be significant ($>10^{\circ}\text{C}$), while operating at MPP or Voc/Isc. Additionally, cell-backsheet temperature differences are not constant, and can be greater than previously reported[3]. The occurrence of intra-module temperature variations can be linked to variations of irradiance and wind velocity and the relatively large thermal capacitance[4] of the modules. A consequence is that intra-module (i.e. cell-to-cell) differences in temperature of non-faulty panels under normal outdoor mounting conditions can be routinely missed when using infrared thermography or few temperature sensors per module. Temperature homogeneity of PV modules can be estimated by logging 3-5 temperature sensors at the centre and corners of a representative module.

- [1] EPIA, "Global Market Outlook for Photovoltaics 2014-2018." .
- [2] B. Herteleer, B. Morel, B. Huyck, J. Cappelle, R. Appels, B. Lefevre, F. Catthoor, and J. Driesen, "High Frequency Outdoor Measurements of Photovoltaic Modules Using an Innovative Measurement Set-Up," in *Submitted: 28th European Photovoltaic Solar Energy Conference*.
- [3] D. L. King, "Photovoltaic module and array performance characterization methods for all system operating conditions," *AIP Conference Proceedings*, vol. 394, no. 1, pp. 347–368, 1997.
- [4] S. Armstrong and W. G. Hurley, "A thermal model for photovoltaic panels under varying atmospheric conditions," *Applied Thermal Engineering*, vol. 30, no. 11–12, pp. 1488–1495, 2010.

Highly Customizable PV Monitoring Systems Irradiance Measurement Solution

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Abstract

Since rapid increase in number of installed PV systems worldwide, a demand for detecting defects and degradation of PV systems is growing in order to achieve higher economical sustainability. All such monitoring systems rely on some kind of solar irradiance measurement in plane of array to monitor the performance of PV system. In many cases a generic solar irradiance sensor is provided by a power inverter's manufacturer as a part of integrated weather station and data logging solution. Such sensors are limited in accuracy and often don't meet request for solar irradiance measurement according to standard IEC 60904-1 Ed. 2 [1], which allows usage of thermopile pyranometers or PV based radiation sensors that are spectrally matched to the specimen.

To achieve higher accuracy and reliability of solar irradiance measurements in plane of array for solar PV systems, a new sensor interface device LPVO Sensor Interface (Figure 1) was developed. It is a highly customizable system with 4 irradiance measurement channels and one digital temperature sensor input for up to eight temperature sensors. Each irradiance channel has automatic gain and input range selection which enables using pyranometer (0 – 30 mV) or solar cell based sensor (0 – 300 mV). Additionally, each channel has a circuit for measuring solar irradiance sensor temperature via PT100 or 10k Ω negative temperature resistor. If solar irradiance sensor's temperature response is known, irradiance measurements are corrected internally by user defined third-degree polynomial function. Air or PV modules temperature can also be monitored using up to eight digital temperature sensor. LPVO Sensor Interface can be easily integrated into PV power plants using data logging solutions from power inverter's manufacturer SMA Solar Technology AG, which are using communication protocols SMA Net and SMA Data. To achieve that, both protocols were studied and implemented into software of LPVO Sensor Interface.



Figure 1: LPVO Sensor Interface

Newly developed sensor interface is a step forward in commercial PV power plants monitoring systems. It enables easy integration in existing and systems under development with SMA data logging solutions and achieving better accuracy of solar irradiance measurement using higher grade solar irradiance sensors.

References

[1] IEC 60904-1, Measurement of photovoltaic current-voltage characteristics, 2nd ed. 2006.

Demonstration at industrial scale of the *FLeXible* manufacturing of SMART multifunctional photovoltaic building elements

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Abstract

SMART-*FLeX* is a large - scale collaborative project within the European Union's Seventh Framework Programme. The project focusses on the manufacture of individually designed photovoltaic building elements on an industrial scale. The SMART-*FLeX* project aims to demonstrate the multi-functional glass/glass PV building element as plug & play AC device for safe and easy installation into building electricity system.

The main technological objectives of the project are:

- **Novel approach to manufacturing:** to establish the frame for automated manufacturing of PV building elements according to architect's technical requirements by means of new software module for design of BIPV solutions communicating with CAD software platform as well as with PV manufacturing equipment;
- **Simplified installation:** to develop plug & play solution for PV building element by extending performance of state of the art junction box with the extra functions of DC/AC conversion, monitoring and maximizing the power production (MPPT) from each string of cells under different weather and shadowing conditions;
- **Product flexibility:** to increase flexibility of essential production steps to meet architectural requirements for different types of PV building elements demonstrating them on the existing module production line.

Several photovoltaic facade elements and mounting systems will be tested on-road on SMART-*FLeX* partner Glassbel's office building in Klaipeda, Lithuania.

Keywords

building integrated photovoltaics (BIPV), power optimizer, microinverter

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