



ThinPV

Cost Efficient Thin Film Photovoltaics for Future Electricity Generation

Scope of project

ThinPV is a project with the mission to mobilize resources in thin film photovoltaics by performing world-class research and development that targets breakthroughs in photovoltaic device efficiency, and cost efficient production. The project is structured into three main parts, part A being oriented towards the short term improvement of plasma deposition processes of thin silicon films, part B addressing hybrid solar cells on the medium to long term and combining dye sensitized solar cells (DSC), Cu(In,Ga)Se₂ solar cells (CIGS) as well as polymer solar cells (OPV). Part C is defined to be an exchange platform to allow for workshops and educational activities.

Goals and activities

Part A: Silicon technology

Micromorph tandem cells rely on finely tuned microcrystalline and amorphous silicon layers, which require precision and control in the plasma deposition process.

Scientific challenges and results

Understanding the parasitic processes (arcing, powder generation) occurring in large area reactors which can limit the process reliability at high injection power and high excitation frequency.

- Understanding and characterizing the changes in plasma conditions when transferring process from small to large PECVD reactors (injection of power, generation of radicals, substrate bombardment)
- Understanding the resulting changes in the structural and electronic properties of the thin film laboratory devices as a function of plasma parameters
- Performing the first initial field testing (stability of devices)
- Achieving large scale devices with properties and techniques suitable for mass-production (i.e. higher efficiency, also with triple junction devices and with high deposition rates).

An optical analysis tool and an electrical analysis tool have been installed and used to evaluate

some basic parameters of plasma glow discharges used for the deposition of microcrystalline silicon in an industrial KAI-S reactor. The optical tool based on optical emission spectroscopy, has allowed to compare the emission intensities of two atomic hydrogen lines and, limited to two assumptions that must be verified, to compute the electron temperature. The electrical tool, peak to peak voltage on the RF driven electrode, was used to compare the relative average ion bombardment energy on the growing substrate in three different deposition regimes.

Outlook

Three new diagnostic tools will be implemented on KAI-M system during the first semester of 2008.

1. Electrical diagnostic tool to monitor voltage, current and phase difference between them. This tool will allow characterizing different deposition regimes from an electrical point of view and it is expected that the data analysis, supported by simple plasma models, will allow the estimation of basic plasma parameters.
2. Optical laser light scattering diagnostic tool for the detection of polysilane powder formation. This phenomenon is frequently associated with deposition regimes of microcrys-

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EPFL (LPI, CRPP)
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talline silicon material and must be limited in order to guarantee process stability.

- Infrared optical absorption diagnostic tool for the detection of silane molecules. This optical diagnostic tool will allow quantifying the silane depletion fraction.

Part B: Hybrid, dye sensitized or polymer solar cells

The main target of the project is to design and fabricate tandem solar cells based on hybrid technologies. The Dye Sensitized Solar Cell (DSC) developed at LPI (EPFL) is an ideal top cells for the tandem approach, since it employs two transparent electrodes and since its spectral absorbance characteristics can be easily tuned. As bottom cell, CIGS solar cells developed at the Thin Film Physics group at ETHZ are the pre-

ferred candidates. Among other benefits they are highly efficient and stable. Organic solar cells may also be used once their optical properties are suitable and photocurrent generation can match those of the other technologies.

Scientific challenges

- Optimization of individual DSC, OPV and CIGS cells in such a way that highest efficiency of the system consisting of two mechanically stacked individual cells is achieved (tandem cells).
- Monolithical integration of the cells.
- Research and development of solution based device manufacturing processes
- Novel concepts for hybrid organic-inorganic cells on glass and flexible foils
- Acquire intellectual property and promote industrial activities in this field.

Main scientific results of workgroups

Laboratory of Photonics and Interfaces (LPI) at EPFL

The proof-of-principle of a stacked multi-junction device using a DSC and a Cu(In,Ga)Se_2 (CIGS) solar cell has already been given. In the latter work the spectral overlap of the two cells is relatively large. To comply with the absorbance characteristics of the CIGS bottom cell we have investigated new organic dyes, which transmit all light with wavelengths above $\lambda = 700$ nm. The dyes exhibit very high external quantum efficiency (up to 90%) and current-voltage characteristics that are similar to the standard ruthenium dye.

To increase the overall transmittance of the DSC in the near-infrared region, several commercially available tin-doped indium oxide (ITO) glasses have been studied.

Theoretical device modeling has been discussed with the Institute of Computational Physics at the Zürcher Hochschule für Angewandte Wissenschaften (ZHAW).

The LPI will focus on the monolithical integration of a DSC/CIGS tandem, since the potential of a stacked DSC/CIGS is limited due to significant optical and electrical losses at the interfaces. By eliminating excess glass and transparent conductive oxide (TCO) interfaces increasing the performance of such a tandem should be possible.

Thin Film Physics group at ETHZ

Efforts on the CIGS side to achieve highly efficient CIGS-DSC tandem devices concentrated on the possibility of band-gap tuning of the absorber to get a matching current from both the CIGS bottom cell and the DSC top cell. Therefore, CIGS cells of different compositions were fabricated and measured.

Furthermore, ellipsometry measurements were initiated for all layers of our cells to determine their optical properties, especially the wavelength-dependent absorption coefficients and refraction indices. These results will also be used for optical/electrical simulations of the DSC/CIGS tandem devices which will be conducted by the group of Dr. Ruhstaller at the Institute for Computational Physics, ZHAW Winterthur.

Institute of Computational Physics (ICP) at ZHAW

The design of emerging thin film photovoltaic cells has several aspects in common:

- The collection of ambient light in multilayers can be enhanced with the help of structured surfaces,
- it shall be absorbed inside the thin film stack,
- generate excited states that relax at nearby dissociation sites into electrons and holes,
- which finally shall be transported to the electrodes with minimal loss.

Glossary

DSC:	Dye Sensitized Solar Cells
CIGS:	Cu(In,Ga)Se_2 Solar Cells
OPV:	Organic Photovoltaics (polymer and small molecule based solar cells)
TCO:	Transparent conductive oxide
ITO:	Tin-doped indium oxide

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The optical modelling of thin film stacks need to be carried out first in order to get guidance in the thickness optimization of the stacked layers.

We have thus demonstrated the calculation of the spectral light penetration profile as well as the layer-specific absorbance in case of coherent thin film optics. Second, the light in-coupling was calculated in order to evaluate layer-specific absorbances and fluxes at certain locations in the system. This then allows to calculate the charge carrier generation profile under AM1.5 illumination conditions and the theoretical maximum of the achievable short-circuit current. This simplified modelling approach is currently under development. As a first step we have adapted the thin film optics simulation method to deal with both optically thick and thin layers. I.e. we allow for incoherent as well as coherent layers in the same solar cell stack.

Laboratory for Functional Polymers at Empa

Research work focused on the synthesis of strongly absorbing polymethine dyes and polymers, in particular towards strategies to push the absorption maximum into the near infrared domain. Cyanine dyes were then applied in thin film organic solid state solar cells, while squaraine dyes were tested in dye sensitized solar cells at LPI (EPFL). Preceding application in devices the novel organic compounds were thoroughly purified and characterized by standard analytical methods.

Far red absorbing squaraines for DSC application:

Essential for the construction of tandem solar cells based on DSCs is the availability of two absorbers harvesting the sunlight in different spectral regions while providing current matching. Ruthenium complexes are very efficient and stable sensitizers for the visible to red spectral domain, but are insufficient absorbers in the near infrared. Therefore, development of sensitizers with extended spectral sensitivity into the infrared region is essential. Squaraines are well known for their intense absorption in the red/near IR regions and are therefore an excellent option to explore for solar cell applications. At the laboratory for Functional Polymers, squaraine dyes with asymmetric anchoring groups were synthesized and tested.

Doping of cyanine solar cells: enhancing charge transport:

Cyanine dyes show extraordinarily high extinction coefficients and tunable absorption spectra. Most interesting is the possibility to achieve strong light absorption in the near-infrared domain, which is presently thought to be one possibility to enhance power conversion efficiency of organic solar cells. So far only few works have studied thin solid cyanine films as active layers in solar cells. Simple bilayer heterojunction devices were fabricated, proving the concept of using cyanines as electron donors or acceptors. Unfortunately the power conversion efficiency has been typically around 0.1% or lower, which is too modest for most applications. When the same cyanine films were exposed to ambient atmosphere under white light irradiation, a steep rise of the conductivity of the film could be observed. It could be shown that a photoinduced electron transfer reaction with oxygen leads to superoxide anion O_2^- -species and oxidized cyanine dyes that are responsible for charge carrier doping. Photochemical doping of the cyanine film has a tremendous impact on the device performance of cyanine – fullerene C_{60} bilayer solar cells fabricated on transparent conducting glass. Most importantly the power conversion efficiency of the device increased from 0.14% to 1.2% which is among the best efficiencies for organic bilayer devices.

Publications

- Liska, Thampi, Grätzel, Brémaud, Rudmann, Upadhyaya, Tiwari, Appl. Phys. Lett., 88 (2006), 203103.
- J. H. Yum, P. Walter, S. Huber, D. Rentsch, T. Geiger, F. Nüesch, F. De Angelis, M. Grätzel, and M. K. Nazeeruddin, «Efficient far red sensitization of nanocrystalline TiO₂ films by an unsymmetrical squaraine dye», J. Am. Chem. Soc. 129 (34), 10320 (2007).
- J.-H. Yum, S.-R. Jang, P. Walter, T. Geiger, F. Nüesch, S. Kim, J. Ko, M. Grätzel, M. K. Nazeeruddin, Chem. Comm, 4680–4682 (2007).
- D. Kuang, P. Walter, F. Nüesch, S. Kim, J. Ko, P. Comte, S. M. Zakeeruddin, M. K. Nazeeruddin, M. Grätzel, «Co-sensitization of Organic Dyes for Efficient Ionic Liquid Electrolyte-Based Dye-Sensitized Solar Cells», Langmuir 23 (22): 10906–10909 (2007).
- Bin Fan, Roland Hany, Jacques-Eduard Moser, Frank Nüesch, Organic Electronics, 9(1), 85–94 (2007).

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