ThinPV
Cost Efficient Thin Film Photovoltaics for Future Electricity Generation

Co-financed by CCEM and swisselectric research

Final report

ThinPV is an interdisciplinary project focused on the realization of breakthroughs in the field of thin film photovoltaics. It brings together Swiss research groups active in fundamental and applied research. Two main directions are promoted. Part A is targeting silicon plasma deposition processes and its influence on device performance. Part B is focusing on hybrid solar cells combining dye sensitized solar cells (DSC), Cu(In,Ga)Se_2 solar cells (CIGS) as well as polymer solar cells (OPV). Although the clear emphasis is given to these two directions, it is the aim to synergize the research and development activities in photovoltaics taking further advantage of the CCEM framework. Interdisciplinary collaborations supporting the principal goals of this project were launched. Research groups interested in photovoltaics benefited from the thin film PV platform which was established within this project (part C). This platform intends to be a scientific discussion platform, and shall attract the interest of younger scientists towards thin film photovoltaics.

Scientific challenges of the project

Part A

- 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.
- Development and implementation of in-situ diagnostic tools.
- Understanding and characterizing the changes in plasma conditions when transferring process from small to large PECVD reactors.
- Understanding the resulting changes in the structural and electronic properties of the thin film laboratory devices as a function of plasma parameters.
- Achieving devices with properties and techniques suitable for mass-production (i.e. higher efficiency devices produced at high deposition rates).

Part B

- Optimization of individual DSC, CIGS and OPV cells in such a way that highest efficiency of a mechanically stacked tandem cell is achieved.
- Monolithical integration of the hybrid DSC-CIGS tandem cell.
- Research and development of solution based device manufacturing processes
- Development of organic solar cells active in the red to near infrared domain to be used in tandem solar cells.
- Acquire intellectual property and promote industrial activities in this field.

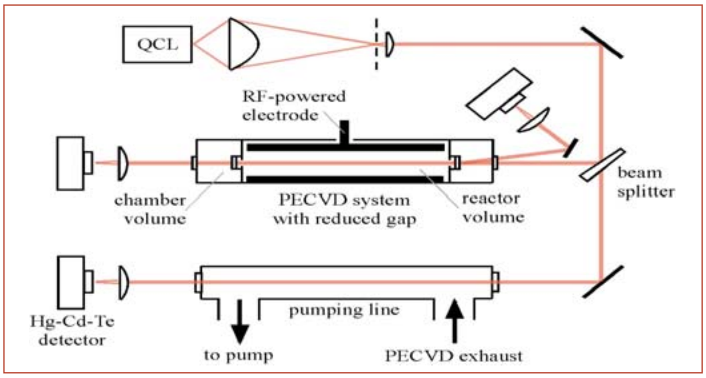
Part C

- Organize yearly workshops and conferences.
- Seed new research collaborations involving theoretical modelling.
- Generate new funding by common proposal submission.

Status of project

During the regular running time of 3 years, important knowledge was generated and published in refereed journals as well as at conferences. Technological knowhow was transferred to industry and secured in patents. New funding was generated during the project due to joint project submission between partners of ThinPV.

Figure 1: Experimental arrangement of the QCL-based absorption spectrometer and the plasma enhanced chemical vapour deposition (PECVD) system. Silane was monitored in the reactor volume, the chamber volume, and the pumping line.



List of abbreviations

CIGS	Cu(In,Ga)Se_2 Solar Cells
DSC	Dye Sensitized Solar Cells
FTO	Fluorine doped Tin Oxide
ITiO	Titanium doped Indium Oxide
OPV	Organic Photovoltaics (polymer and small melecule based solar cells)
PECVD	Plasma Enhanced Chemical Vapor Deposition
QCL	Quantum Cascade Laser
SIMS	Secondary Ion Mass Spectroscopy
XRD	X-Ray Diffraction

Main Investigator
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Project Partners
Empa (FP, TFPV)
EPFL (LPI, CRPP, IMT)
ZHAW (ICP)

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Main scientific results of workgroups

Part A: Silicon technology

The major results regarding the work on silicon deposition processes using plasma enhanced chemical vapour deposition (PECVD) as well as device fabrication include:

- The influence of non planar electrode geometries in plasma deposition chambers have been investigated experimentally and theoretically to model real plasma chambers with screws, showerheads or other geometries. It was found that the presence of sharp edges at holes or cylinders had no significant influence on radio frequency electric field breakdown. The breakdown zone, however, depends strongly on the chamber gas pressure.
- Optical emission spectroscopy for in situ silane depletion and electron temperature fluctuation measurements were installed.
- In situ and ex situ laser scattering methods for poly-silane and powder detection were installed in the research chamber.
- Infrared absorption spectroscopy was implemented in large area research reactor for in situ and ex situ silane depletion measurement. Using a quantum cascade laser, it allowed to monitor the silane concentration in the reactor volume, the chamber volume, and the pumping line. The system was subsequently developed to measure time dependent phenomena with a resolution of 40 ms.
- A reduced electrode gap was used on the large area PECVD reactor in order to improve fast deposition of microcrystalline silicon layers and drastically lower powder formation such that microcrystalline deposition regimes can be achieved at higher pressures.
- Intrinsic layers of microcrystalline silicon have been deposited at 1 nm/s in the large scale research reactor and have been characterized with secondary ion mass spectroscopy (SIMS) and x-ray diffraction (XRD) measurements to assess the material quality. 1.2 µm thick solar cells with efficiencies up to 7.3 % have been obtained.
- First implementation of time-resolved measurements of absolute silane concentration in PECVD reactors and simultaneously in the surrounding chamber.
- Under typical process conditions, it was shown that – for a given deposition rate – powder can be an indicator of favourable process conditions.
- Based on the various diagnostic tools, a reduction of the transients observed during the initial growth of the devices could be controlled by optical emission spectroscopy during deposition of microcrystalline cells. The efficiency of the reference microcrystalline cell could thus be improved from 7.1 to 7.9 %. Based on the findings of this project a micromorph cell with 11.9 % initial efficiency at a deposition rate of 1 nm/s could be realised.

Part B: Hybrid, dye sensitized or polymer solar cells

Regarding the development of hybrid tandem solar cells and cyanine solar cells the following important results have been achieved during the project:

- Mechanically stacked tandem cells with a record efficiency of 15.1 % were established in the submission period of the ThinPV workshop.
- Investigation of new organic dyes in a DSC with a view to comply in an optimal way with the absorbance characteristics of a CIGS bottom cell. Evaluation of novel near infrared dyes to be used for double DSC tandems at a later stage. Band-gap tuning of CIGS cells by varying the stoichiometric composition of the absorber in order to get a matching current from both the CIGS bottom cell and the DSC top cell.
- Replacement of commonly used fluorine doped tin oxide (FTO) electrodes in DSCs by titanium doped indium oxide (ITiO). By replacing just the back contact of the DSC cell, an increase in the transmission by more than 20 % could be achieved in the near infrared domain.
- Modelling of the absorption in thin film stacks to find the optimized combination of CIGS and DSC cells in the tandem assembly. For

The history of ThinPV

ThinPV was born during the first workshop of the freshly founded Swiss Competence Centre for Energy and Mobility (CCEM), which was organized by the managing directors of the CCEM at Paul Scherrer Institute in October 2005.

Four Swiss research groups active in thin film photovoltaics including microcrystalline and amorphous silicon, cupper-indium-gallium-selenide (CIGS), dye sensitised solar cells (DSC) as well as organic photovoltaics (OPV) came together.

The world renowned research teams included:

- Laboratory for Photonics and Interfaces at EPFL (Prof. M. Grätzel),
- Institute for Microengineering at Neuchâtel University (now EPFL, Prof. C. Ballif),
- Thin Film Physics group at ETHZ (now Empa, Prof. A. Tiwari)
- Functional Polymers Laboratory at Empa (Dr. F. Nüesch).
- the Plasma Processing Group at CRPP-EPFL (Dr. C. Hollenstein) joined the project working tightly together with the group of Prof. C. Ballif.

A further partnership was seeded with the Institute of Computational Physics at the University of Applied Science in Winterthur (Prof. B. Ruhstaller) with the aim to start numerical modelling on multilayer device architectures.

The main industrial partner Oerlikon Solar also joined the project, making clear that scientific exchange and collaboration as well as innovation were targeted.

After several proposal application and evaluation rounds, the project was granted and co-financed both by the CCEM and «swisselectric research» in 2007, though, first collaborations already started during the submission period. It has to be pointed out that ThinPV is the first project in Switzerland bringing together the main players in thin film photovoltaic research.

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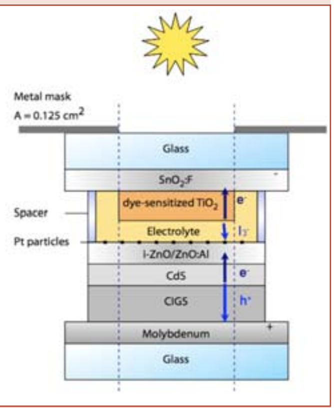

Figure 2: Monolithic DSC/CIGS tandem device reaching a power conversion efficiency of 12.2 % at full sunlight.

the thicker layers, incoherent optics were used, while for thin layers coherent optics were employed. Calculation of the conversion efficiency.

- A monolithic tandem cell consisting of a DSC top cell and a CIGS bottom cell with 12 % power conversion efficiency was fabricated
- A power conversion efficiency of 2 % was reached in cyanine based solid state organic solar cells by oxidative doping of the cyanine film and by optimizing the charge injecting layers at cathode and anode.
- High power conversion efficiencies from 3 % to 4 % could be achieved in cyanine solar cells without requiring chemical doping of the cyanine layer by using a high workfunction anode. Red to near infrared absorbing squaraine dyes have been successfully implemented in bi-layer organic solar cells.
- Modelling of organic solar cells to help optimizing layer thicknesses from the optical point of view. Extension of the optical device model by including charge transfer excitons. The influence of the coherence length of the incident light irradiation on the interference phenomena in thin layer organic solar cells has been investigated.
- A photo-CELIV (charge extraction by linearly increasing voltage) measurement has been installed in order to measure material parameters for modelling purposes such as charge carrier mobility and lifetime.

Figure 3: ThinPV Workshop «A look inside solar cells», 16.–18.11.2008, Monte Verità, Ascona.

Part C: Exchange platform and educational activities

Several workshops with different focuses have been held during the project and even in the submission phase of the project. The average attendance was about 60 persons per workshop.

- The first workshop «Photovoltaics of the future» between the partners was held shortly before the submission phase of the proposal and for the first time gathered all major players in thin film photovoltaic research in Switzerland. (http://www.empa.ch/plugin/template/empa/*/32621)
- The second workshop was dedicated to the needs of the thin film photovoltaic industry representing all major solar module manufacturers and companies offering module production equipment. (http://www.empa.ch/plugin/template/empa/*/64531/---/l=2)
- The third workshop «A look inside solar cells» had an educational purpose and allowed students to interact with world renowned experts in the different fields of thin films photovoltaics and to present posters and seminars. (http://www.empa.ch/plugin/template/empa/*/73310/---/l=2)
- The last workshop focused on an emerging and comprehensive topic of the future: «Transparent Conducting Electrodes for Photovoltaics». Several approaches including doped oxides, dispersed carbon nanotubes, thin metal grids as well as fabric electrodes were added. As for the preceding events, a panel of high ranking scientists and industrials was invited. (http://www.empa.ch/plugin/template/empa/*/88257)

Outlook

In order to continue and extend the exchange and common research activities between Swiss research laboratories in thin film photovoltaics, considerable effort has been dedicated in developing and submitting common research projects for the coming years. These projects include an NCCR (National Centre of Competence in Research NCCR, leading house EPFL), a CCEM (Competence Center Energy and Mobility, leading house Empa), as well as other more specific projects (Commission for Technology and Innovation CTI, Elektrizitätswerk der Stadt Zürich EWZ) between the ThinPV partners. A Gebert Rüf foundation project between EPFL and ZHAW on combining coherent and incoherent optical modelling was granted.