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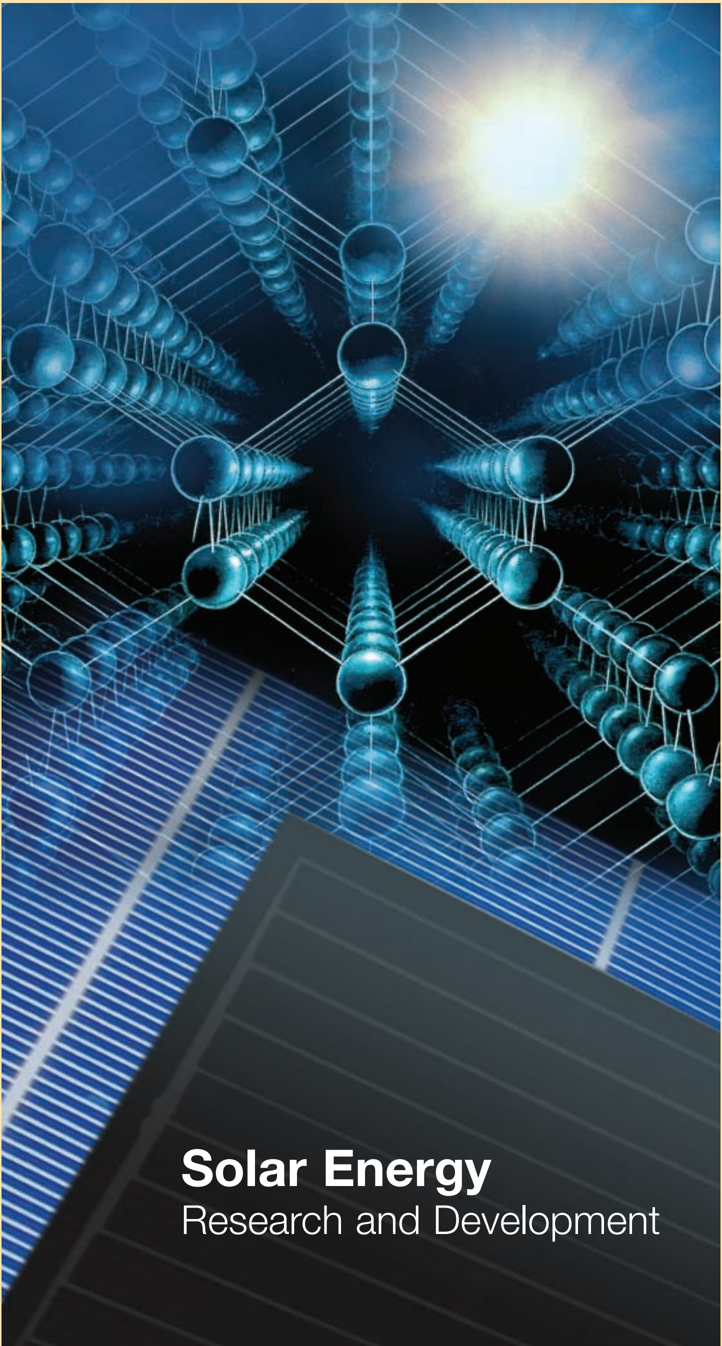

Solar Energy
Research and Development

The energy of the solar radiation

reaching the earth is many times greater than current global power consumption. There is already a variety of technologies for making solar energy usable. Photovoltaics, however, is the only way of converting sunlight directly into electrical energy.

The efficiency

of a photovoltaic system is measured as the ratio of electrical power produced to the energy of the incident solar radiation. In theory, it is possible to achieve efficiencies of about 30 % using different solar cell materials. This limitation is due to the fact that the low-energy component of solar radiation (infra-red) can not be absorbed. Another part of solar radiation (ultra-violet) has a high energy content and some of this is given off as heat. The best solar cells, of monocrystalline silicon, achieve an efficiency of about 25 % under laboratory conditions. The efficiency of complete photovoltaic systems is usually not higher than 15 %. At present, the photovoltaic market is dominated by mono- and polycrystalline silicon technologies, in which silicon wafers of about 0,3 mm thickness are processed to make solar cells.

The current cost

of photovoltaic power generation, which in Germany is approximately 0,70 € per kilowatt hour, stands in the way of its wider terrestrial use. Hence, cost reduction is a primary objective in all attempts to improve existing technologies and material systems, as it is in the assessment of new materials and methods of energy conversion.

Thin-film technologies

have lower manufacturing costs: they use less material, have simpler production technology and achieve higher productivity. Energy-saving processes lead to a reduced energy pay-back time: thin-film solar cells of the next generation, with absorber layer thicknesses of only a few microns (thousandth parts of a millimetre) will take less than one year to produce the same amount of energy that went into making them.

Research being carried out at HMI

is aimed at developing cost-effective thin-film technologies for photovoltaic energy conversion.

Solar Energy Research at HMI

The Challenge

Solar energy research is part of a long-term strategy to ensure a stable and adequate supply of electrical power in the future. The finite availability of fossil fuels and their negative impact on the environment and climate may lead to future shortages in the energy supply. This necessitates the development of solar technologies based on criteria of sustainability. In the solar energy research department at the Hahn-Meitner Institute, we focus on developing new generations of cost-effective thin-film solar cells.

Thin-film Technology

We carry out research projects to develop efficient solar cells, concentrating on thin-film technologies. This should lead to substantial reductions in the cost of solar power. In close collaboration with partners from industry, we are implementing a strategy of bringing existing and already established options to technological maturity, while also developing new materials and solar cell concepts for the future. The focus here is on highly promising materials, such as polycrystalline silicon and compound semiconductors (I-III-VI_2 and III-V compounds). Scientific and technological progress is to be achieved by a broadly based approach to research and design. Fundamental systematic research complements the empirical work.

The subjects of work range from basic scientific research on materials to industrial applications:

- Fundamentals of materials;
- Concepts for solar cell structures;
- Solar cells at laboratory scale and prototype modules;
- Analysis and numerical simulation of devices;
- Process development and process monitoring.

We examine materials, solar cells and modules using state-of-the-art methods of physical analysis. The analysis and preparation of semiconductor interfaces and defect structures is of particular importance.

Cristallin Silicon Thin-Film Solar Cells

Prof. Dr. Walther Fuhs, SE1, Berlin-Adlershof

The aim of our research work is to develop the scientific and technological basis of a new generation of polycrystalline silicon thin-film solar cells on inexpensive substrates, such as glass. This type of solar cell combines the advantages of crystalline silicon wafer and thin film technologies. Efficiencies of around 15% can be achieved, if the silicon crystallite grain is made large in comparison to the thickness of the absorber layer (d = 2 – 5 µm). The challenge lies in the deposition on glass substrates, since the use of glass limits the temperature at all steps of the process to values lower than 650 °C.

Research centres on:

- Recrystallisation processes to generate granular crystalline seed layers;
- Growth mechanisms at gas phase deposition (low-temperature epitaxial growth by ion-assisted deposition);
- Development of low-temperature emitter technologies (heterostructures);
- Identification and passivation of active defect structures;
- Mechanisms of transport and recombination, electronic structure of interfaces, modelling and numerical simulation.

Solar cell concepts based on heterostructures are a very attractive option for all kinds of cost-effective silicon absorber layers such as multicrystalline silicon, ribbon silicon and polycrystalline films. Current physical and technological work is primarily concerned with heterostructures of amorphous silicon and crystalline silicon (a-Si:H/c-Si) with different silicon absorber structures. An efficiency of 17 % has already been achieved by solar cells of this type using monocrystalline silicon.

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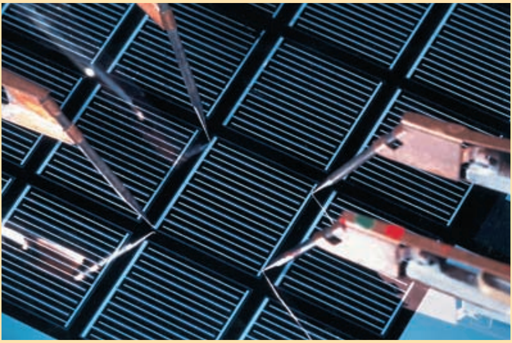

Heterostructure Solar Cell

Heterogeneous Material Systems

Prof. Dr. Martha Ch. Lux-Steiner, SE2, Berlin-Wannsee

Our long-term aim is to develop a tandem solar cell based on compound semiconductors with a high optical absorption, paying particular attention to its technological application. In comparison to single solar cells, tandem structures can potentially achieve higher efficiency over the same surface area. The subjects of our research range from the basic principles of material and interface properties to device-oriented technologies and industrial deposition processes. Using highly sensitive analysis techniques such as synchrotron radiation, ion beam diagnosis, and KPFM (Kelvin Probe Atomic Force Microscopy), we investigate chemical structural and electronic characteristics locally-resolved on real material systems.

The efficiency of solar cells depends on photogeneration and the separation of charge carriers. Absorber surfaces, functional materials and interfaces are designed and are examined to establish their potential for application. In addition, cost-effective and sustainable deposition processes are developed. New concepts in photovoltaics and optoelectronics in general, based on inorganic and organic materials, are investigated.

Our current research objectives are:

- Cadmium-free thin-film solar cells based on $Cu(In,Ga)(S,Se)_2$;
- Efficient $Cu(In,Ga)S_2$ and $CuGaSe_2$ solar cells with high open-circuit voltages;
- Development of infrared-transparent solar cells as top cell for tandem structures;
- Prototypes based on new solar cell concepts, such as highly-structured ETA cells with an extremely thin absorber layer, and organic solar cells.

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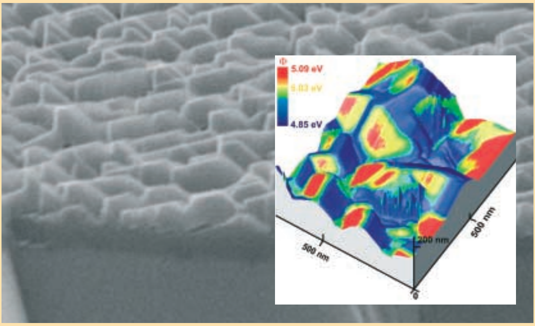

Copper-gallium-diselenide layer through scanning electron and atomic force microscopes

Technology of Solar Cells and Modules

Dr. Hans-Werner Schock, SE3, Berlin-Wannsee

The development of new solar cells requires new technologies and production processes. The work of the photovoltaic technology department is centred on aspects of the application of thin-film solar cells. Materials and processes are developed and optimised in close cooperation with partners from industry.

Our research is chiefly concerned with:

- Development of prolific deposition processes and encapsulation technologies;
- Examination of process stability and long-term stability of devices;
- Development of methods of in-situ process monitoring and quality control;
- Identification of defect mechanisms.

A bench-scale unit for the production of thin-film solar modules is available at the institute for use in studying new technologies. Fixed and flexible substrates are employed as carrier materials. Their full processing, from cleaning of the substrate to encapsulation of the module, serves to try out new process steps and to quantify process yields. Fully functional modules, connected in series, with surface areas of 10 x 10 cm^2 are produced. At present, the bench-scale unit is being used to develop modules based on chalcopyrite semiconductors, focussing on the use of a new compound, $CuInS_2$, as absorber layer. The unit also serves to develop process monitoring systems using in-situ methods.

The quality of a solar device and its constituents is assessed by means of imaging and non-contact processes. The objective is to enable efficient, low-cost monitoring at all stages of an industrial production line.

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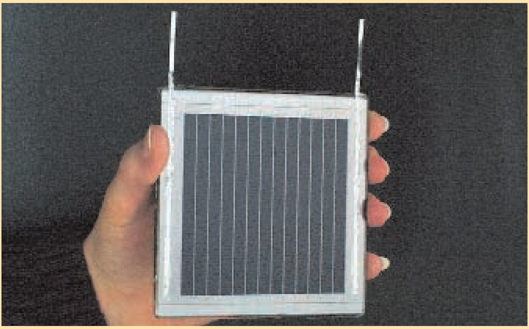

Laminated $CuInS_2$ module with 13 integrated cells connected in series

Dynamics of Interfacial Reactions

Prof. Dr. Frank Willig, SE4, Berlin-Wannsee

The department has developed highly accurate measuring techniques and new sample preparation techniques. These enable the most cost-effective preparation method and the functioning of new types of solar cell to be examined in detail and the potential for practical application to be assessed. Of particular interest are the solar cells of the so-called third generation, which are predicted to convert solar energy with efficiencies of over 30 %. Up to now, the only solar cells for which there is experimental proof of an efficiency greater than 30 % are multi-junction cells (having at least two band gaps) based on III-V semiconductors. Using the latter type of semiconductor, the department is working on a solution of two as yet unsettled questions. A significantly cheaper substrate for III-V solar cells is to be developed on a silicon basis. A epitaxial 3-junction cell on lattice constant of InP are to be produced. The procedure is illustrated below. The III-V semiconductors are grown in a MOCVD reactor (Metal Organic Chemical Vapour Deposition), the process being controlled by an optical signal (RAS). The specific growth parameters for the production of a desired interface are verified exactly. In doing so, the following steps are performed:

Firstly, the sample is transferred from the MOCVD reactor into a UHV (Ultra-High Vacuum). Then the sample is analysed in the ultra-high vacuum using practically every measurement method of surface science. In particular, these include measuring electron dynamics in real time with several techniques to a time resolution of under 10 femtoseconds (14 noughts after the decimal point on the scale of one second).

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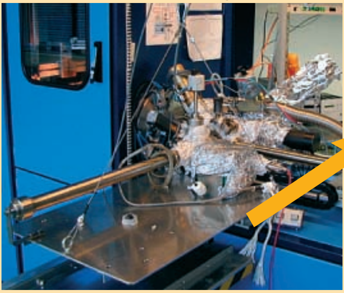
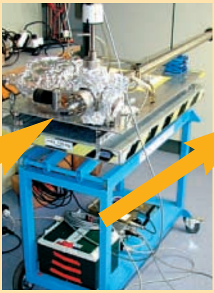
MOCVD to UHV transfer system



UHV shuttle



Surface Science

Solar Energetics

Prof. Dr. Helmut Tributsch, SE5, Berlin-Wannsee

Research activities are concentrated on the development of new materials and innovative solar cell concepts for photovoltaic power generation and fuels extraction, giving special consideration to wet energy systems. The orientation of research is guided by our knowledge of evolution and the strategies of nature, environmental compatibility, the sustainable or responsible use of raw materials, and the potential for increasing the cost-effectiveness of production processes.

The subjects of research are:

- Nano-composite solar cells with few demands on materials quality, due to kinetically-limited charge carrier separation. Preferred absorbers are MoS_2 and WS_2 particles, owing to their inherent photo-stability as d-band materials. Mechanisms of kinetic non-reversibility are developed;
- Titanium-based photovoltaic fuel membranes that use light energy directly to produce hydrogen for fuel cells, without prior charge collecting and with an integrated simplified CIS structure;
- Catalysts for fuel cells that can use iron, cobalt and similar frequent transition metals instead of noble metals;
- The development of new energy systems after biological paradigms following bionic strategies (tensile water technology, fixation of CO_2 by autotrophic bacteria provided with solar energy);
- Electrochemical and in-situ microwave optimisation of interfaces;
- Bionic research on cost-effective encapsulation techniques and cooling systems for solar cells.

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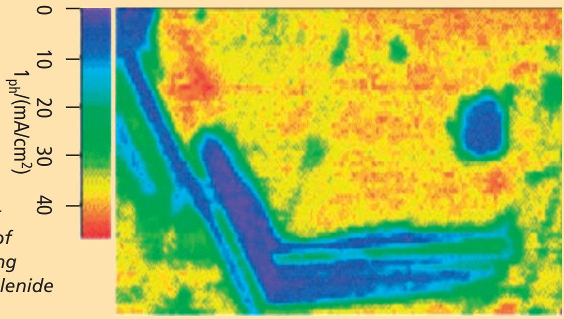

Photocurrent distribution of a p-conducting wolfram-diselenide crystal

Electronic Structure of Semiconductor Interfaces

Dr. Christian Pettenkofer, SE6, Berlin-Wannsee

Further advances in the development of photovoltaic systems can only be made if the fundamental physical processes at the potential-controlling interfaces of solar cell layers are known to us and can deliberately be influenced. Device optimisation depends on the analysis of structural, chemical, and electronic interfacial characteristics at atomic level. The formation of interfaces and the development of their characteristics are investigated with highly controlled preparation of the interfaces concerned and using synchrotron radiation at BESSY. To examine morphology and electronic interfacial structure, photoelectron spectroscopic methods are used. The research aims to clarify the differences between theoretical models, exemplary model systems, and characteristics of real solar cell structures.

Medium-term objectives are as follows:

- In-situ analysis of the sequential deposition of solar cell layers;
- Analysis of lateral inhomogeneities (XPEEM) using micro-spectroscopic methods;
- Investigation and analysis of technological relevant deposition processes;
- Investigation of chemical interfacial reactions between the absorber and buffer layers, as well as between the buffer and window layers.

Longer-term objectives concern the development of stable, electronically-matched buffer layers for multi-spectral solar cells by means of model systems.

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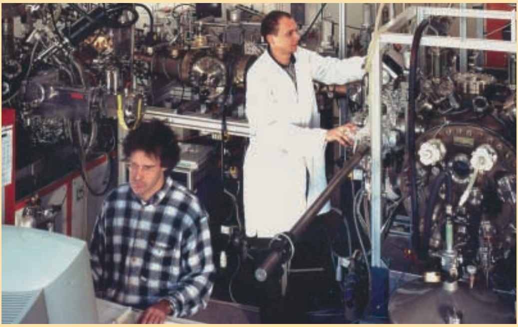


The "integrated system" for characterisation of interfaces during layer growth

Methods

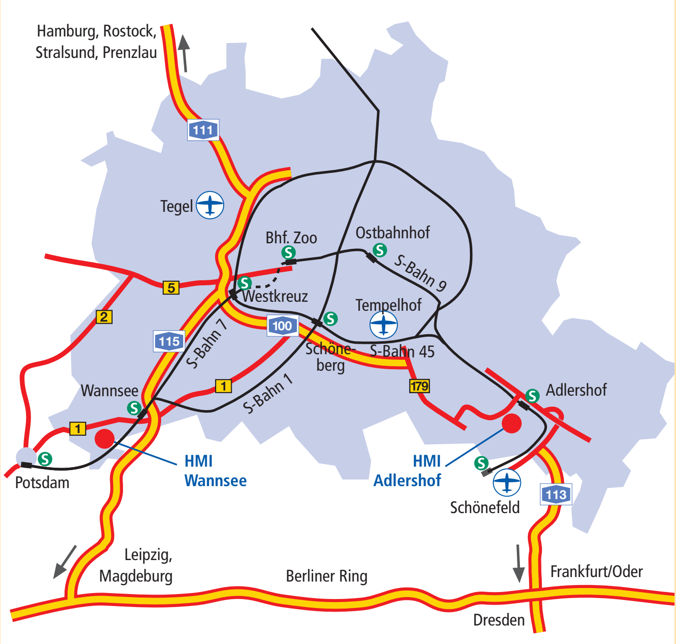
Preparation:

- Electron beam and thermal evaporation
- Chemical gas phase deposition (MOCVD, MEB, CVD, CSVT)
- Crystal-growing and recrystallisation (CVT, high-pressure growing, RTP)
- Wet chemical methods (electrodeposition, CBD, ILGAR)
- Plasma deposition techniques (magnetron sputtering)

Material characterisation:

- Structural analysis (XRD, EXAFS, neutron scattering, DTA, in-situ laser light scattering)
- Surface analysis (UPS, XPS, EELS, SEM, STM, AFM, LEED, AES)
- Electrical parameters (Hall measurement, conductivity measurement, TRMC, FRMC, moving grating, Kelvin probe, infra-red thermography, current-voltage characteristics (temperature-sensitive), EBIC, SR, time-resolved (100 ps) photocurrent, locally-resolved surface photovoltage)
- Optical characterisation (optical spectroscopy, photoluminescence, femtosecond time-resolved spectroscopy)
- Chemical composition (EDX, RBS, ERDA, NRA, SNMS, LEISS, QMS)
- Electron spin resonance (ESR, ODMR, EDMR)

How to reach us



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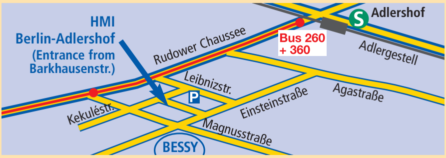

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