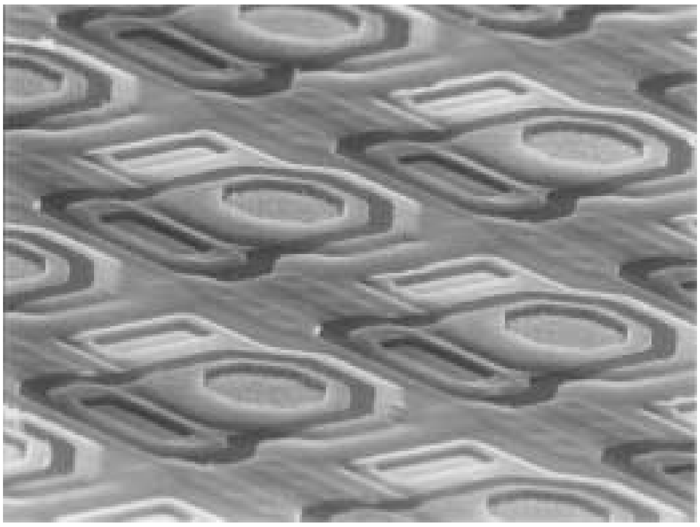
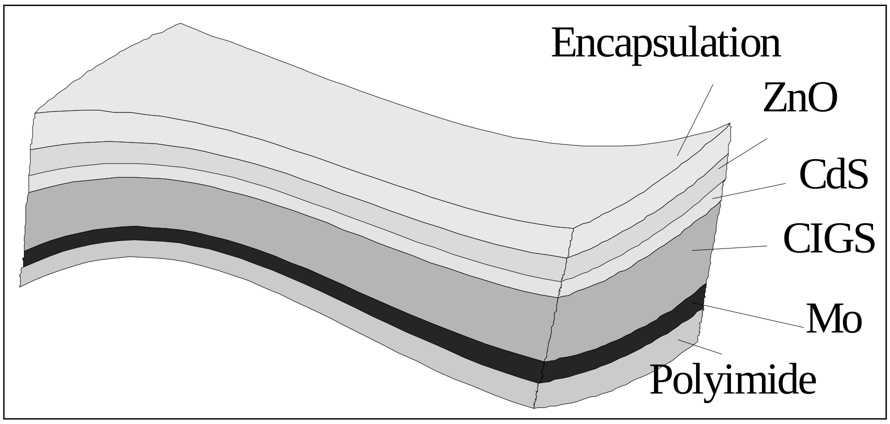
Annual Report 2000
Thin Film Physics Group





Cover page:
Top: Micrographic image of parts of a monolithic two dimensional infrared sensor array. The device is fabricated in an epitaxial PbTe layer on a silicon substrate, and the silicon substrate contains the read-out electronics.

Bottom: Flexible and lightweight thin film solar cells on polymers for terrestrial and space applications. Solar cells based on $Cu(In,Ga)Se_2$ or CdTe absorber layers are grown by vacuum deposition methods, and world record efficiencies were achieved for both type of solar cells.

CONTENT

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PERSONNEL

Head:

PD Dr. Hans Zogg

Leader Photovoltaics:

Dr. Ayodhya N. Tiwari

Academic Staff:

Karim Alchalabi	
Derk Bätzner	
Franz Haug	
Marc Kaelin	(since May 2000)
Klaus Kellermann	(since May 2000)
Alessandro Romeo	
Dominik Rudmann	
Dmitri Zimin	(since November 2000)

Technical Staff:

Thomas Kämpfer	(since December 2000)
Michael Leopold	(60%)
Gerhard Schreiber	(20%)

Administrative Staff:

Paulette Pfammatter	(20%)

Academic guest:

Matthias Terheggen	(Institute of Applied Physics, ETHZ)

Exchange student:

Dmitri Zimin	(until October 2000)

GENERAL

The thin film physics group was integrated into the Institute of Quantum Electronics, Micro- & Optoelectronics Lab. (Head: Prof. Dr. H. Melchior) in May 1997, after the organisation AFIF (Arbeitsgemeinschaft für industrielle Forschung), to which the group belonged before, was closed. Since October 2000, after the retirement of Prof. Melchior, the group is with the Laboratory for Solid State Physics (Head: Prof. Dr. H.-R. Ott).

The group is financed exclusively by projects ("Drittmittel"), including all salaries

SPONSORS

ETH
European Space Agency
GRS
Swiss National Science Foundation
Swiss Federal Office for Education and Science (BBW, for EU-projects)
Swiss Commission for Technology and Innovation (KTI)
Swiss Defence and Procurement Agency (GR)
Industries

PROJECT COOPERATION

FLIR AG, Kriens
South Bank University, UK
Ioffe Physical-Technical Institute, St.Petersburg, Russia
St. Petersburg State Technical University, Russia
Solaronix, Aubonne
Antec GmbH, Germany
BP Solar, UK
PHILIPS, The Netherlands
ISOVOLTA, Austria
ZSW, Germany
CIEMAT, Spain
INM, Germany
HMI, Germany
ENSCP, France
IAP, ETH Zürich
Uni Stuttgart, Germany
Uni Parma, Italy
Uni Ghent, Belgium
Uni Durham, UK
Uni Montpellier, France

RESEARCH ACTIVITIES

Science and technology of compound semiconductors:

- Growth of molecular beam epitaxial (MBE) and polycrystalline layers of II-VI, IV-VI, I-III-VI_2, and III-V binary and multinary compounds. Applications for optoelectronic devices. Growth kinetics of heterostructures, superlattices and nano-structures (quantum dots). Phase formation and their identification.
- Structural properties of thin films, surfaces and interfaces. Crystallographic and microstructural defects. Lattice vibrational properties of semiconductors. Measurement and modelling of strain relaxation in thin films. Kinetics of dislocation-glide and -reactions in IV-VI-on-Si epitaxial layers. Recrystallization in semiconductors.
- Optical and electrical properties of thin films and heterostructures. In- and ex-situ doping in semiconductors, electronic defects and transport properties.
- Growth, properties and applications of transparent conducting oxides (ZnO, ITO, FTO).
- Growth and properties of permeation barrier layers ("flexible glass" on plastics).
- Thin film growth processes like molecular beam epitaxy, e-beam evaporation, d.c. and r.f. sputtering, chemical bath deposition, electro-deposition, etc.

Infrared detector arrays on Silicon substrates:

- MBE growth of narrow gap IV-VI layers (lead chalcogenides) on Si-substrates.
- Fabrication of 1-d and 2-d IR sensor arrays; the Si-substrate may contain integrated read-out circuits.
- Development of microlithographic patterning techniques. Applications include thermal imaging and IR-spectrometry.

Compound semiconductor thin film solar cells:

- Solar cells based on Cu(In,Ga)Se_2 and CdTe (these materials yield stable and very high efficiency solar cells for economical production of solar electricity). Development of material technologies, fabrication processes, novel materials and processes for improved performance, and advanced tandem devices. Interface and transport properties of heterojunctions.
- Studies of basic material properties and heterostructures for large area and industrial production. Stability and reliability of devices. Terrestrial and space applications of lightweight and flexible thin film solar cells.

Bragg reflectors:

•MBE-growth of quarter-wavelengths stacks for Bragg mirrors with very high reflectivity and bandwidth by use of high/low index pairs like IV-VI or III-V semiconductors and group-IIa fluorides.

Some highlights:

- Development of 1- and 2-dimensional infrared sensor arrays for thermal imaging in epitaxial PbTe on Si-substrates which contain active circuits
- Flexible CdTe solar cells on polymers have been developed for the first time, and a world record efficiency (8.6%) is achieved
- Long term stable and low resistance quasi-ohmic contacts on CdTe that yield 11% efficiency solar cells
- Lightweight and flexible $Cu(In,Ga)Se_2$ solar cells on polymer with a world record efficiency of 12.8%
- Electronic and structural comparison of $Cu(In,Ga)Se_2$ substrate and superstrate solar cells; parameters which limit the efficiency of superstrate solar cells are identified
- A low temperature deposition process for $Cu(In,Ga)Se_2$ solar cells; cells with 14% efficiency were achieved
- Highly transparent and conducting ZnO:Al layers with high deposition rates by RF magnetron sputtering

EQUIPMENTS

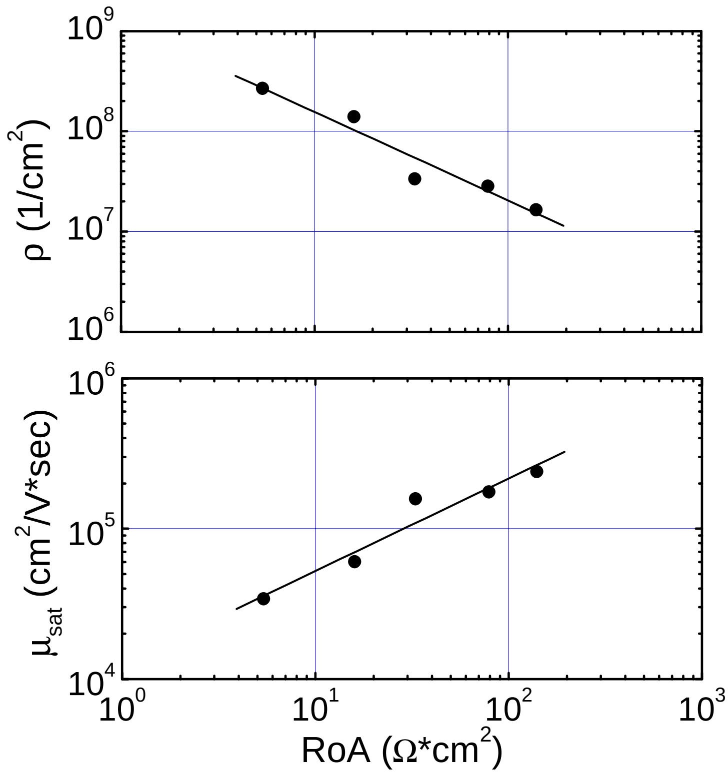
4 MBE-chambers with solid sources for CaF_2, (Pb,Sn)Se, Cu(In,Ga)Se, and CdTe
6 PVD for sample sizes up to 20 x 20 cm2, thermal and e-beam evaporation
3 sputtering chambers, DC and RF
Complete photolithographic processing equipment
Bonder
Profilometer
Light microscopy, SEM, XRD
Electrooptic characterization for infrared sensors and solar cells

Correlation of leakage currents with defect structure in epitaxial p-n^+ PbTe-on-Si(111) infrared sensors

D. Zimin, K. Alchalabi, H. Zogg

A p-n^+ stack of epitaxial PbTe is grown by molecular beam epitaxy onto Si(111). Photovoltaic infrared sensors are fabricated in this narrow gap layer (cut-off wavelength 5.5 µm at 80K).

Dislocation densities D in the layers were determined from the low temperature saturation Hall mobilities μ_{sat}; the mean distance between dislocations $L_{dis} = 1/\sqrt{\rho}$ is proportional to μ_{sat}. We observed a clear correlation between these dislocation densities and the performance of the PbTe infrared sensors: From the temperature dependence of the (differential) resistance area products RoA (inverse noise currents) of the sensors, the carrier lifetimes in the depletion region are determined. Together with the diffusion coefficient (known from the Hall mobilities), mean free paths of the minority carriers L_{mc} can be calculated. It turns out that L_{mc} correspond to L_{dis} within the measurement accuracies. This is illustrated in the Figs., where low temperature saturation Hall mobilities μ_{sat} and dislocation densities D are plotted versus RoA. As expected, RoA increases approx. prop. to $\sqrt{\mu}$ and decreases with D. This behaviour leads to the model that each dislocation crossing the active area of the n^+-p PbTe infrared sensor causes a shunt resistance of the order of G Ω.



Top:

Resistance area products (RoA) at 90K vs dislocation densities ρ (determined from low temperature saturation Hall mobilities), RoA is prop. $1/\rho$ according to the model.

Bottom:

Resistance area products (RoA) at 90K vs low temperature saturation Hall mobilities μ_{sat}, RoA is prop. $\sqrt{\mu_{sat}}$ according to the model.

Sponsor: Swiss National Science Foundation

Monolithic heteroepitaxial PbTe-on-Si infrared focal plane array with 96 x 128 pixels

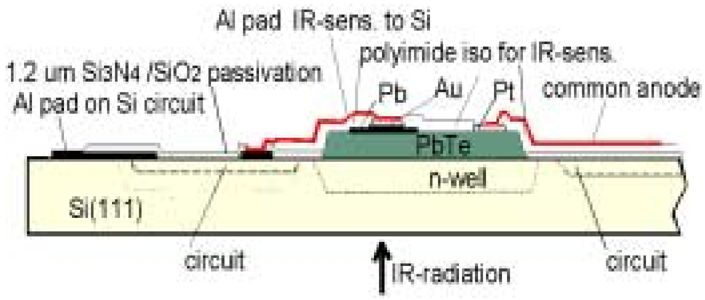
K. Alchalabi, D. Zimin, H. Zogg

A two-dimensional infrared focal plane array in a heteroepitaxial narrow gap semiconductor layer has been realized for the first time on a Si substrate containing the read-out electronics.

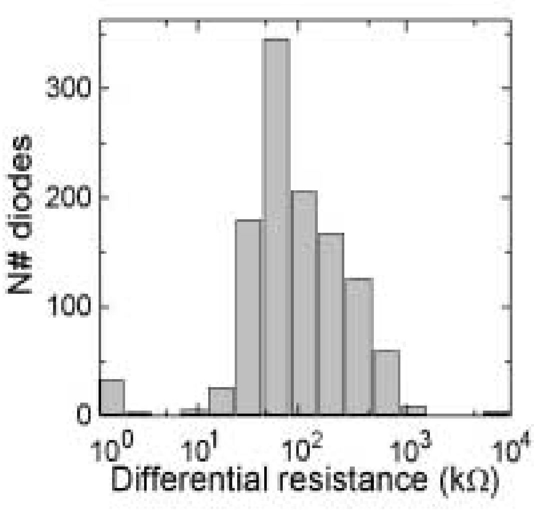
CMOS technology was used to fabricate the circuitries in the Si-substrate. Pitch of the 96 x 128 array is 75 µm, each pixel contains a bare Si-area where epitaxial growth of the narrow gap layer occurs, and an access transistor. Addressing is performed line-by-line with a shift-register integrated on the chip.

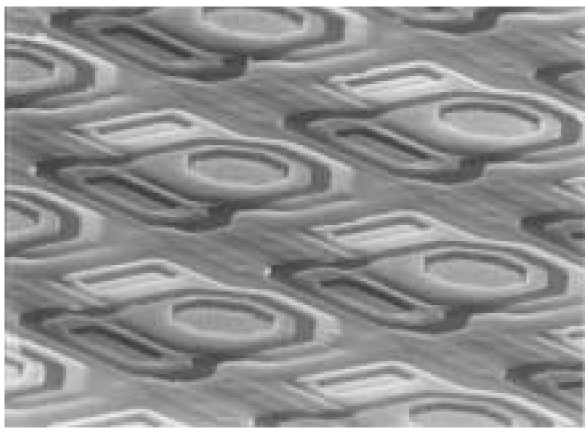
The infrared-sensitive layer (PbTe for the 3-5 µm wavelength range) is grown by molecular beam epitaxy at temperatures below 450˚C, allowing fully processed and tested Si chips to be employed. Individual pixels are obtained by mesa-etching, and photovoltaic sensors are fabricated with standard photolithographic techniques.

Within the >97% operational pixels, high quantum efficiencies and differential resistances at zero bias up to several 100 kΩ at 95K are observed.



Figures. Schematic cross section (left), part of the 2-d array (bottom), and differential resistances (sensitivities) at 95K of 12 arbitrarily chosen lines of the 96 x 128 PbTe-on-Si array with 5 µm cut-off wavelength (left bottom).





Sponsor: GR, KTI

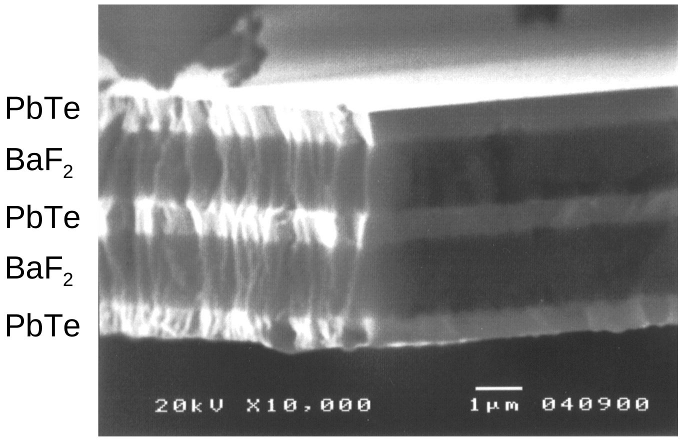
Broad-band high reflectivity Bragg mirror for the mid-infrared range

K. Kellermann, D. Zimin, K. Alchalabi, H. Zogg

We fabricated high reflectivity Bragg-mirrors using alternating layers with high and low refractive index arranged in a quarter wavelength stack. BaF_2 (n=1.4) served as low index and PbTe (n=5.5) as high index material, respectively. This large index difference leads to a high reflectance with already few layers, and the spectral response is extremely broadband.

The layers are grown by molecular beam epitaxy onto Si(111) substrates using solid sources. Fig. 1 shows an image of the stack. The measured reflectivity is shown in fig. 2, together with the calculated curve. The reflectivity is above 98% (Measurement uncertainties 2%) from about 9 µm to 16 µm wavelength.

The mid-IR range is extremely suited for trace gas analysis. The mirror will be applied for one analysis method, cavity ringdown (see report of Prof. M.W. Sigrist, Lab. for Laser Spectroscopy and Environmental Sensing). As a side result of this method, the absolute reflectance at selected wavelengths is obtained with much higher accuracy, as needed for the calibration.



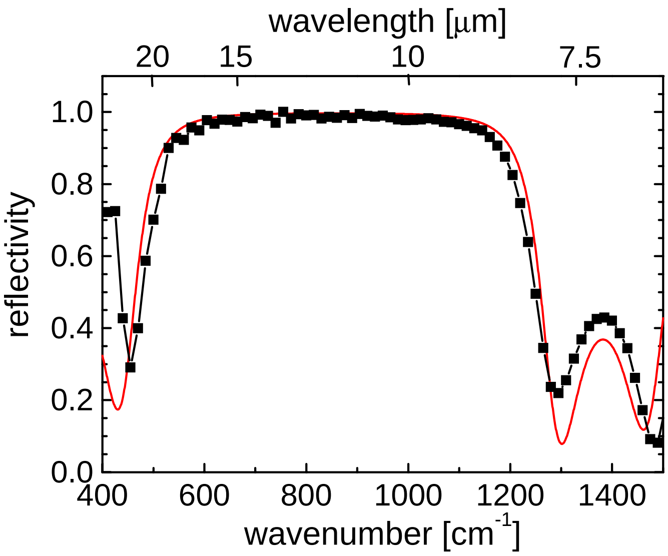


Fig. 1 (top)

BaF_2/PbTe 5 layer Bragg-mirror structure for the mid-IR range.

Fig. 2 (bottom)

Measured (squares) and calculated (full line) reflectance of the BaF_2/PbTe Bragg mirror.

Sponsor: GRS

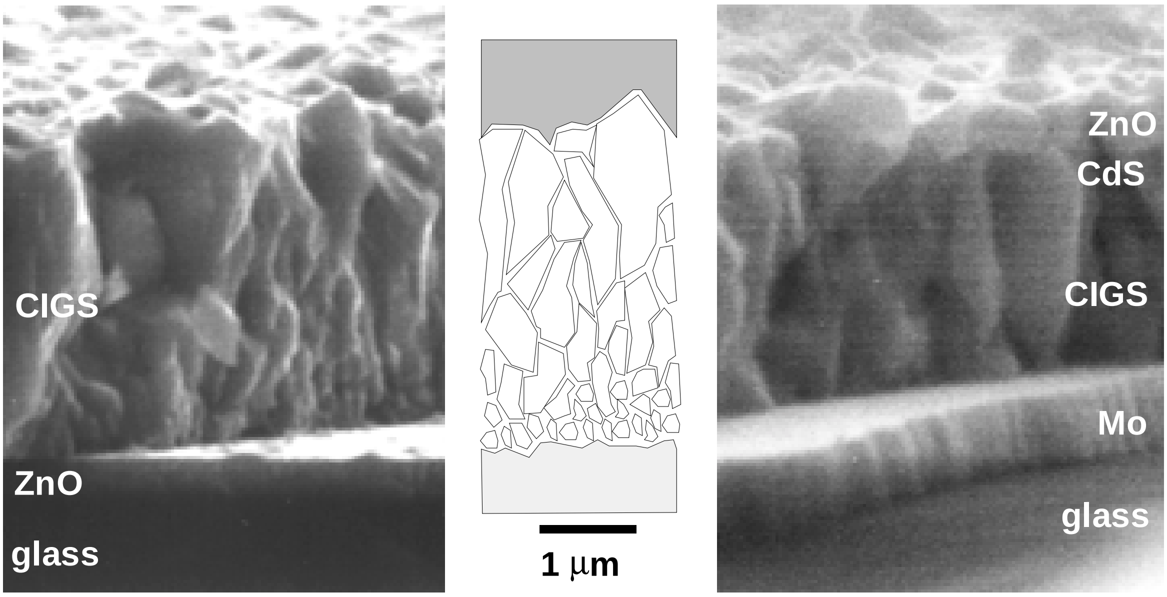
Comparison of $Cu(In,Ga)Se_2$ substrate and superstrate solar cells

F.-J. Haug, D. Rudmann, H. Zogg, A. N. Tiwari

Thin film solar cells with $Cu(In,Ga)Se_2$ absorber layers were grown by coevaporation of Cu, In, Ga and Se. The layers are deposited on glass covered either with a metal layer (substrate cell) or a transparent conducting front contact (superstrate cell). The latter offer technological advantages like easier production and encapsulation; however, their conversion efficiencies of 8.5% are low compared to substrate cells with efficiencies of more than 15%.

Differences in the electrical properties of the devices were investigated with current-voltage and capacitance-voltage measurements. Superstrate solar cells showed a high density of trap states at the interface because the p-n junction is formed between ZnO and small grained $Cu(In,Ga)Se_2$ material of the nucleation region (see figure). The density of majority carriers which influences the open circuit voltage of solar cells is typically in the order of 10^{15} cm^{-3} which is a factor of ten lower than the carrier concentration of substrate solar cells.

An evaluation of the composition depth profile with secondary ion mass spectroscopy (SIMS) showed a low concentration of Na in the absorber layer of superstrate solar cells. Na is an acceptor in $Cu(In,Ga)Se_2$ and usually it is supplied by diffusion from the glass substrate during the growth. We conclude that the ZnO layer in superstrate solar cells forms a barrier for the diffusion of Na and thus limits the carrier concentration.



Figures: Comparison of cross sections of superstrate (left) and substrate (right) solar cells. The nucleation of small grains on the substrate and the eventual formation of larger grains during the growth is drawn schematically.

Sponsor: BBW (EU-Project), SNSF, ESA, ETHZ

Lightweight and Flexible $Cu(In,Ga)Se_2$ Solar Cells on Polymer with a World Record Efficiency of 12.8%

M. Krejci, D. Rudmann, F.-J. Haug, H. Zogg, A.N. Tiwari

Development of high efficiency, stable, lightweight and flexible solar cells is important for novel terrestrial applications. The $Cu(In,Ga)Se_2$ (CIGS) solar cells are also promising for space applications because their stability against high energy irradiation are superior to crystalline Si and GaAs solar cells. The CIGS cells on polymers can yield a very high specific power of about 1.5 kW/kg, which is 3-4 times higher than that of conventional Si solar cells.

Typical CIGS absorber layers for high efficiency solar cells are grown on Mo coated soda-lime glass substrates at temperatures of about 550˚C. A certain amount of Na and high deposition temperatures are required for an optimum carrier concentration and morphology of the CIGS absorber layer. None of the known polymers can withstand such high temperatures and they do not contain Na. Thus low efficiency solar cells are expected on polymers.

A lift-off process has been developed to obtain CIGS solar cells on polymer films (see figure 1). The absorber layer is grown by a co-evaporation method on a polyimide layer, which is spin coated on a NaCl covered glass substrate. The NaCl intermediate layer can provide Na to the CIGS layer during deposition. After the complete processing of the cells, the NaCl buffer layer is dissolved to separate the glass substrate from the ZnO/CdS/CIGS/Mo/polyimide stack. The total thickness of the solar cell including polymer substrate is less than 25 microns. A record conversion efficiency of 12.8% was independently measured at FhG/ISE, Freiburg, Germany (see figure 2). This is the highest reported efficiency for any type of solar cell grown on polymers.

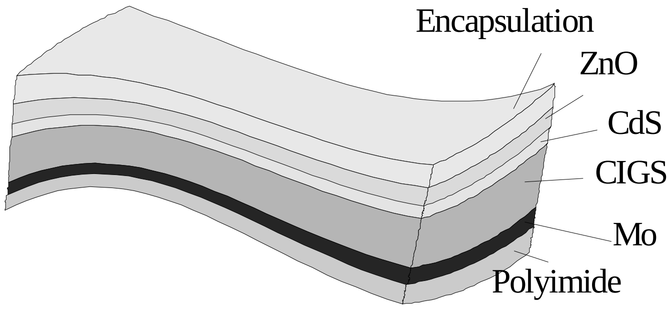


Figure 1: Schematic diagram of the ZnO/CdS/CIGS/Mo/polyimide flexible solar cell.

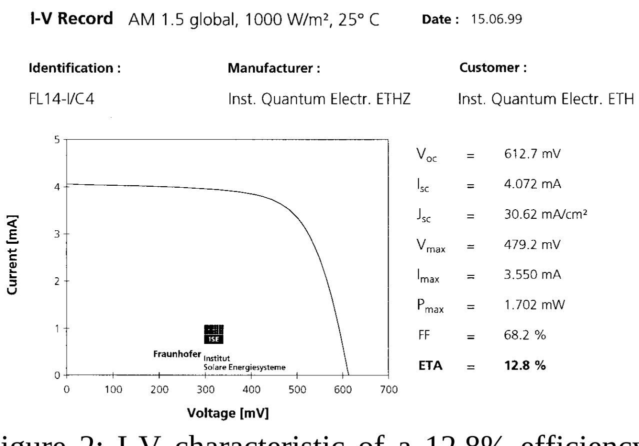


Figure 2: I-V characteristic of a 12.8% efficiency CIGS solar cell on polyimide layer measured under AM1.5 illumination.

Sponsor: BBW/EU (JOULE project), SNSF

Deposition of highly transparent and conducting ZnO layers by rf sputtering

F.-J. Haug, Zs. Geller, H. Zogg, A. N. Tiwari

Transparent conducting oxides are widely used as low resistive contact material for flat panel displays and thin film solar cells. For this purpose it is essential that the conductivity of the layers does not deteriorate during the later process steps which involve high temperatures up to 550˚C.

The conductivity of ZnO is based on intrinsic defects like oxygen vacancies and zinc interstitials. Thus treatments at high temperatures are expected to reduce the defect density of the material and consequently increase the resistivity. Extrinsic doping with group III elements like Al, Ga and In enhances the conductivity and the conduction is thermally more stable.

In order to optimize the conductivity and to study its thermal stability, ZnO layers doped with Al were grown by rf sputtering at a pressure of 0.3 Pa at deposition temperatures between room temperature and 400˚C. The power density of the plasma was varied between 1.3 and 5.1 W/cm^2 (with respect to target area). Annealing at 550˚C in vacuum was used to evaluate the thermal stability of the conductivity.

The relative changes of the resistivity show a strong dependence on the power density, and the trend is similar for each respective temperature; at low power density the conductivity is very unstable, it increases up to 800%. Also at high rf power density a regime of unstable conductivity is observed.

In an intermediate range of power densities stable layers with minor increases in resistivity between 10 and 20% are deposited. These layers have an optical transmission of more than 85% and a final resistivity of $1.3 \cdot 10^{-3}$ Ωcm.

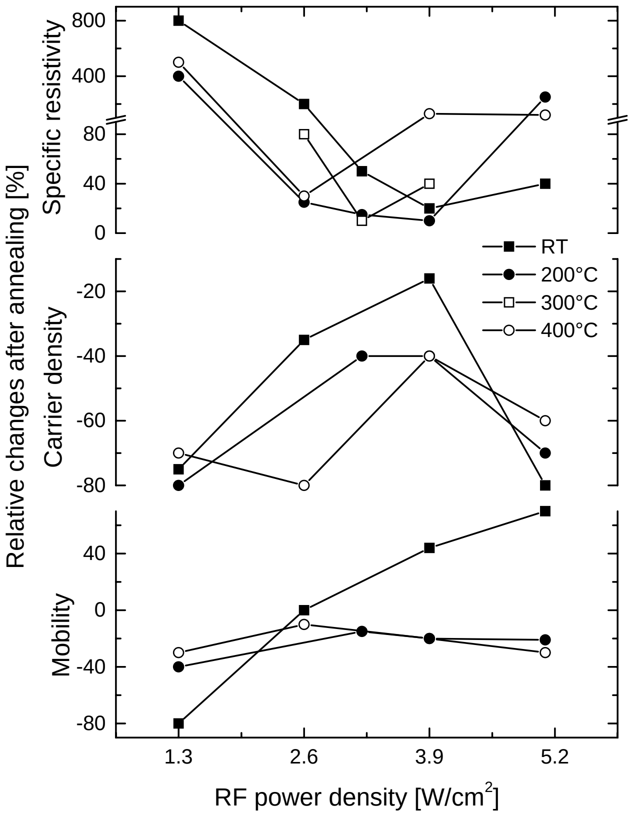


Figure: Relative changes of resistivity, carrier density and mobility after annealing at 550˚C in vacuum. The changes in resistivity are mostly due to loss in carrier density.

Sponsor: BBW (EU-Project)

High Efficiency Flexible CdTe/CdS Solar Cells

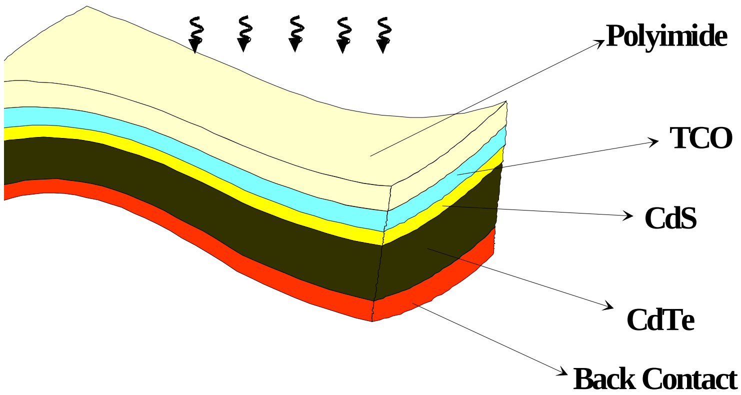
A. Romeo, D.L. Bätzner, H. Zogg, A.N. Tiwari.

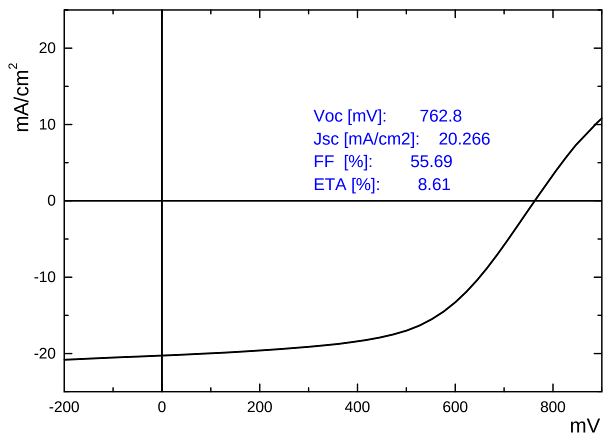
Development of flexible and lightweight solar cells is interesting for many terrestrial and space applications that require a very high specific power (defined as the ratio of output electrical power to the solar module weight). Thin film solar cells on polymer films can yield more than 2 kW/kg specific power and they are particularly suitable for PV integrated buildings (roofs and facades), solar boats and cars, portable source of electricity, consumer electronics, etc.

Lightweight and flexible CdTe/CdS solar cells in a "superstrate configuration" have been developed for the first time.

We have used a novel process in which a spin coated polyimide layer is used as a substrate and the semiconducting layers are grown at low temperatures, around 400 ˚C. The average optical transmission of a ~10 µm thin spin coated polyimide substrate layer is more than ~75% for wavelengths above 550 nm.

RF magnetron sputtering was used to grow transparent conducting ZnO:Al layers on polyimide films. CdTe/CdS layers were grown by evaporation of compounds and an annealing treatment was applied for the recrystallization and junction activation. Solar cells of 8.6% efficiency with V_{oc} = 763 mV, I_{sc} = 20.3 mA/cm^2, and FF = 55.7% were obtained. This is a record efficiency for flexible CdTe solar cell.





Schematic cross-section of the flexible CdTe solar cell on polyimide in superstrate configuration (top) and I-V characteristic of a 8.6% efficiency CdTe solar cell on polyimide measured under AM 1.5 illumination (bottom).

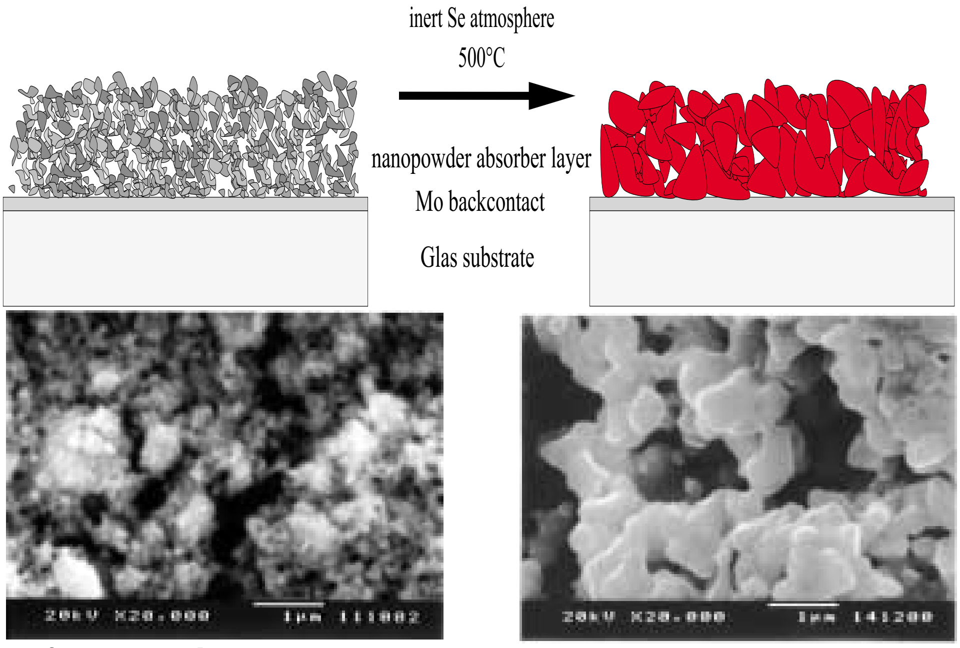
Sposor: BBW (EU-Project)

Nanoparticle Precursors for $Cu(In,Ga)Se_2$ Solar Cells

M. Kaelin, A.N.Tiwari, in collaboration with K. Wegner and S.E. Pratsinis, Institute of Process Engineering, ETH Zürich

As $Cu(In,Ga)Se_2$ based thin-film solar cells have already proven their potential for high efficiency, efforts are now concentrating on the development of low cost and large area production. Layers of good structural and electronic properties are grown with high vacuum deposition methods at the price of high processing costs. Spray deposition, screen printing and doctor blade do not generally produce high quality thin-films but are low cost large area techniques. Layers of high quality can be deposited using nanoscale precursor materials because of their higher reactivity for film formation as the number of atoms or molecules on their surface is comparable to that inside the particles.

The aim of this project is to synthesize nanoparticle precursors of optimum composition, size and morphology to obtain ~2 µm thick compact $Cu(In,Ga)Se_2$ layers of large grain size for high-efficiency cells. Jet aerosol flow condensers are employed for the production of the nanoparticles by melt evaporation due to their high flexibility in control of product particle properties. Furthermore, it is possible to synthesize metal alloys by co-evaporation and to carry out reactions like oxidation and selenization. Thus, single component particles such as In, Ga or Cu can be produced as well as metal alloys, selenides and oxides.



Sintering of nanoparticle precursor.

The product nanoparticles are deposited on a substrate, forming a precursor layer which is then subjected to a sintering/selenization step (Fig.). The resulting thin film of desired stoichiometry and microstructure can be used to process solar cells.

Sposor: KTI (TOPNANO 21)

PUBLICATIONS

Book chapter

152 Book chapter: Hans Zogg, A. Ishida,
"IV-VI (lead chalcogenide) infrared sensors and lasers", in "Electronic Materials Series", Vol. 8, "Infrared Detectors and Emitters, Materials and Devices",
P. Capper, C.T. Elliott, eds., Kluwer Academic Publ., 2000, pp. 43-75.

Journal Publications

183 Karim Alchalabi, Dmitri Zimin, and Hans Zogg, "Monolithic heteroepitaxial PbTe-on-Si infrared focal plane array with 96 x 128 pixels, Electron Device Letters 22, 4 (March 2001)

182 F.-J. Haug, Zs. Geller, H. Zogg, C. Vignali, A. N. Tiwari, "Influence of deposition conditions on the thermal stability of ZnO:Al films grown by RF magnetron sputtering", J. Vac. Sci. Tech. A 19(1), 171 (January 2001).

181 D. L. Bätzner, A. Romeo, H. Zogg, A. N. Tiwari, "Development of efficient and stable back contacts on CdTe/CdS solar cells" ,European Material Research Society 2000 Spring Meeting, 30 May-2 June 2000, Strasbourg, Thin Solid Films (in press).

180 A. Romeo, D. Baetzner, H. Zogg, A. N. Tiwari, "Influence of CdS growth process on the structural and photovoltaic properties of CdTe/CdS solar cells", Solar Energy Materials and Solar Cells 67, 311 (January 2001).

179 D. L. Bätzner, R. Wendt, A. Romeo, H. Zogg, A. N. Tiwari, "Effect of back contact metallization on the stability of CdTe/CdS solar cells", Proc. 16th European Photovoltaic Solar Energy Conference and Exhibition, 1-5 May 2000, Glasgow (in press).

178 D. Rudmann, F.-J. Haug, M. Krejci, H. Zogg, A.N. Tiwari , "Development of Flexible Cu(In,Ga)Se_2 solar cells on polymers with lift-off processes", Proc. 16th European Photovoltaic Solar Energy Conference and Exhibition, 1-5 May 2000, Glasgow (in press).

177 A. Romeo, D. Baetzner, H. Zogg, A. N. Tiwari, "A comparison of the vacuum evaporated CdTe substrate and superstrate solar cells", Proc. 16th European Photovoltaic Solar Energy Conference and Exhibition, 1-5 May 2000, Glasgow (in press).

176 F.-J. Haug, D. Rudmann, H. Zogg, A.N. Tiwari, "Stability of transparent ZnO front contacts for Cu(In,Ga)Se_2 superstrate solar cells", Proc. 16th European Photovoltaic Solar Energy Conference and Exhibition, 1-5 May 2000, Glasgow (in press).

175 A. N. Tiwari, F.-J. Haug, M. Krejci, H. Zogg, "Heteroepitaxy of $CuIn_xSe_y$: A review of the material and interface properties", Thin Solid Films 361, 34 (2000).

174 F.-J. Haug, M. Krejci, H. Zogg, A. N. Tiwari, "Characterization of $CuGa_xSe_y$/ZnO for superstrate solar cells", Thin Solid Films 361, 239 (2000).

173 D. Baetzner, A. Romeo, H. Zogg, A. N. Tiwari"A study of the back contacts on CdTe/CdS solar cells", Thin Solid Films 361, 463 (2000).

172 A. Romeo, D. Baetzner, H. Zogg, A. N. Tiwari, "Recrystallization in CdTe/CdS", Thin Solid Films 361, 420 (2000).

CONFERENCE PRESENTATIONS:

invited:

A.N. Tiwari, H. Zogg, "Entwicklungsstand hocheffizienter Dünnschichtsolarzellen", Nationale Photovoltaiktagung, Neuchâtel, 7.-8. Nov. 2000

A.N. Tiwari,"Solar cells: Present status and future prospects", Naturforschende Gesellschaft, 21 June 2000, Basel (Switzerland)

A.N. Tiwari,, "High efficiency and flexible Cu(In,Ga)Se_2 solar cells", Solar Energy 2000 Exhibition, Berlin, 9 June 2000, Berlin (Germany)

D. Rudmann, F.-J. Haug, M. Krejci, H. Zogg, A.N. Tiwari , "Lift-off processes for the development of flexible and lightweight Cu(In,Ga)Se_2 solar cells", European Material Research Society 2000 Spring Meeting, 30 May-2 June 2000, Strasbourg (France),

A.N. Tiwari, H. Zogg, "Kostengünstige Solarzellen aus dünnen Schichten", Physikalische Gesellschaft Zürich, 18. Mai 2000, Zürich

contributed:

F.-J. Haug, D. Rudmann, M. Kaelin, A.N. Tiwari, H. Zogg, "Development of Cu(In,Ga)Se_2 solar cells and charcterization of the interfaces", Nationale Photovoltaiktagung, Neuchâtel, 7.-8. Nov. 2000

D. Bätzner, A. Romeo, A.N. Tiwari, H. Zogg, "Highly stable and dfficient CdTe/CdS solar cells", Nationale Photovoltaiktagung, Neuchâtel, 7.-8. Nov. 2000,

K.Alchalabi, D. Zimin, H. Zogg, "Use of dislocation properties for MBE growth and device application in IV-VI materials", Fundamental aspects of surface science, 7. - 12. Oktober 2000, Castelvecio Pascoli, Italy

D. Zimin, K. Alchalabi, H.Zogg, "Heteroepitaxial PbTe on Si pn junctions for mid IR sensor array", MBE Workshop 2000, 25. - 26. September 2000, Bochum

K. Alchalabi, D. Zimin, H.Zogg, "Herstellung eines monolithischen Infrarotdiodenarrays im mittleren Infrarot mittels MBE", MBE Workshop 2000, 25. - 26. September 2000, Bochum

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