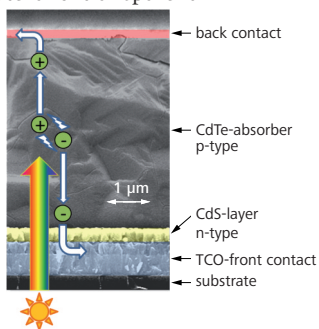


CdTe THIN FILM SOLAR CELLS ON GLASS

15.6% - Low-temperature CdTe solar cells on low-cost TCO

Lowest solar module production costs on the global PV market have been achieved with CdTe based technology.

Low-temperature processing (<450°C) is the key for utilization of low-cost substrate and transparent conducting materials for further cost reduction. Empa developed a vacuum based deposition process for highly efficient CdTe solar cells on ZnO based front contacts. This process is suitable for fully automated in-line manufacturing of large area solar modules.

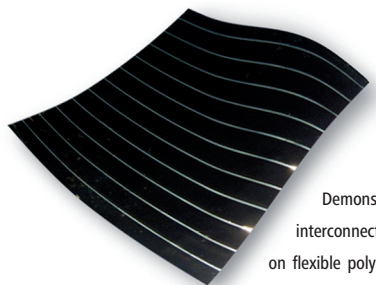


CdTe PV technology is safe and environmentally benign!

FLEXIBLE CdTe THIN FILM SOLAR CELLS

13.8% - World record for flexible CdTe solar cells

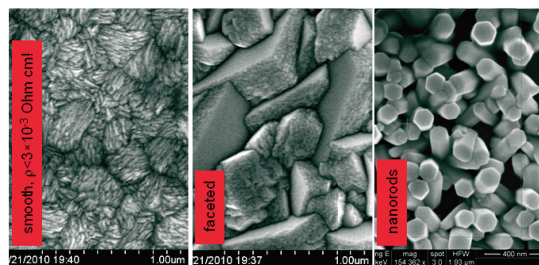
We are involved in the development of flexible CdTe solar cells on polymer films and metal foils. We have demonstrated 13.8% efficient CdTe solar cells on flexible polyimide films. Our low-temperature processes are suitable for high throughput roll-to-roll manufacturing.



Demonstration of a monolithically interconnected CdTe mini-module (32 cm²) on flexible polyimide substrate with 8.0% total area efficiency (9.4% active area).

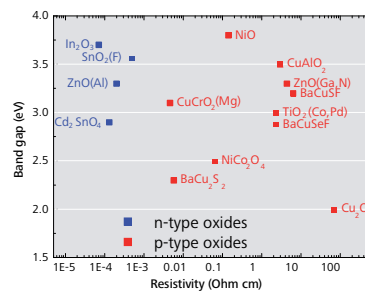
MULTIFUNCTIONAL OPTICAL AND ELECTRICAL COATINGS

The demanded properties of advanced coatings extend well beyond the characteristics of transparency and/or conductivity and aim at multi-functionality: element diffusion barriers, moisture and corrosion resistant barriers, control of electronic transport at interfaces, texturing for efficient light trapping. Investigated materials include metals, oxides (SiO₂, TiO₂, ZnO, In₂O₃ or SnO₂-based) and nitrides (SiN, Ti₃N₄) deposited by PVD and non-vacuum methods.



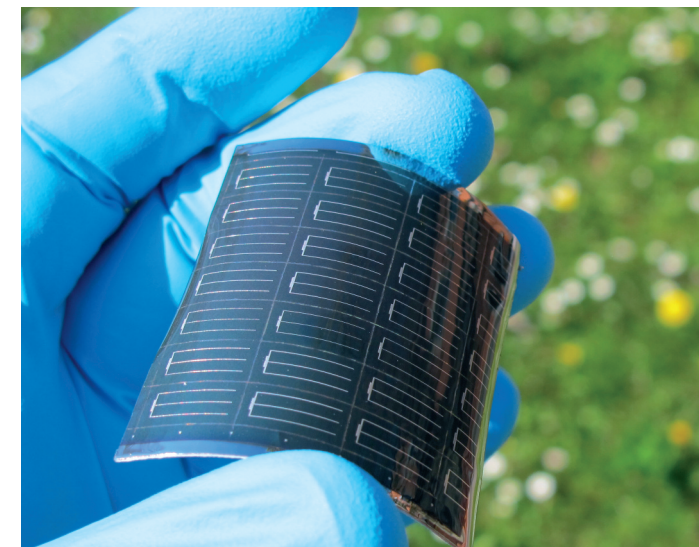
By controlling solution chemistry, the morphology of Al-doped ZnO transparent conductive layers can be tuned from flat to faceted and nanorod.

We are interested in the research of alternative processes and materials for functional and multifunctional coatings. Development of both n- and p-type transparent conductive oxides makes it possible to fabricate transparent p-n junctions and transistors, basic components of "Transparent or Invisible" electronics.



Compared to classical n-type oxides, p-type oxides require further development to obtain similar resistivities.

Laboratory for Thin Films and Photovoltaics



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RESEARCH PORTFOLIO AND EXPERTISE

- Development of deposition processes for thin films based on **vacuum** (sputtering, thermal evaporation, e-beam) and **non-vacuum** (printing, spray, doctor blade) techniques
- R&D on transparent conductive, semiconducting and insulating thin films
- Development of multifunctional optical and electrical coatings including diffusion barrier layers
- Characterization of surfaces, layers, and interfaces in multi-layer structures
- R&D on inorganic thin film solar cells based on Cu(In,Ga)Se₂, CdTe, CZTSe absorber materials
- Full diagnostics of lab scale solar cells
- World leader in R&D of flexible and lightweight inorganic solar cells on polymer and metal foils
- Novel materials (e.g. p-type TCOs, or nano-composites), processes, applications including transparent and printed electronics

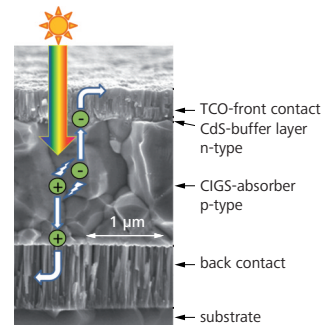
OUR OFFER

- **Collaboration in R&D projects:** If you are looking for a partner to realize scientific and development projects in the field of photovoltaics (PV) or multifunctional coatings, we are interested to team up with scientific and industrial partners.
- **Services:** We offer characterization services for thin films and small PV devices and assist in interpretation of the results and correlation to material properties.
- **Consulting:** Experts will assist and advise you in solving your specific problems on PV devices, diagnostics, and thin film coatings including up-scaling of deposition processes.
- **Technology transfer:** Some of our technologies are ready for industrialization.

CIGS THIN FILM SOLAR CELLS ON GLASS

18.8% - Highly efficient CIGS solar cells on low-cost glass

Solar cells based on Cu(In,Ga)Se₂ absorbers show the highest efficiencies and performance stabilities among all thin-film technologies. Empa developed a deposition process for CIGS thin-film solar cells which is suitable for high-speed and in-line production on low-cost glass substrates. Main research topics are focused on: band gap and interface engineering of the CIGS absorber in order to find the optimum tradeoff between highest device efficiency and cost-effective mass production; development of processes for other constituent layers; multijunction (tandem) solar cells.

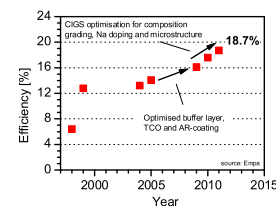


FLEXIBLE CIGS THIN FILM SOLAR CELLS

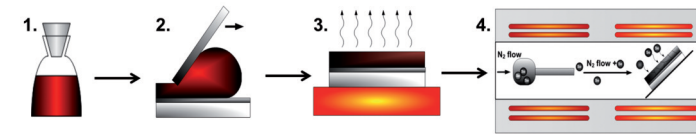
18.7% - World record for flexible CIGS solar cells on plastic film

Substituting flexible and lightweight foils for rigid glass substrates opens the possibility for cost-effective roll-to-roll production as well as novel attractive product applications. Empa developed a low-temperature deposition process which is suitable for polymer films (e.g. polyimide) as well as for metal foils (e.g. steel). By combining roll-to-roll deposition with laser scribing technology for monolithical interconnection, high-speed production of large area flexible CIGS solar modules is feasible. We have high level of experience in up-scaling of vacuum deposition techniques on moving substrates.

Solar cell performance of flexible CIGS devices on polyimide film.



NON-VACUUM CIGS THIN FILM SOLAR CELLS



Non-vacuum deposition includes: 1) paste formulation from solutions or nanoparticle dispersions; 2) paste deposition by doctor-blading, printing or spraying; 3) drying, and 4) selenization.

Non-vacuum based deposition methods from non-toxic and non-explosive solvents and without critical to handle process gases enable a very high potential for low-cost production due to the simplicity and rapidness of the deposition process. This technology is targeting a high throughput roll-to-roll processing at high materials utilization. New material systems e.g. kesterites based only on earth abundant elements Cu, Zn, Sn, Se and S – Cu₂ZnSn(Se,S)₄ – are under investigation.



Non-vac CIGS:

7.7% – highest efficiency reported from true solutions with non-toxic and non-hazardous solvents and gases

Non-vac CZTSe:

4.2% – highest efficiency reported for pure selenium based kesterite solar cells

Empa, Swiss Federal Laboratories for Materials Science and Technology

Empa is an interdisciplinary research and services institution for material sciences and technology development within the ETH Domain. Empa's research and development activities are oriented to meeting the requirements of industry and the needs of our society, and link together applications-oriented research and the practical implementation of new ideas, science and industry, and science and society.