PRESS RELEASE

High Efficiency Meets Sustainability: Fraunhofer Lighthouse Project Shows Way for Next-Generation Tandem Solar Cells

Perovskite-silicon tandem solar cells made of stable materials and manufactured using scalable production processes are the prerequisite for the next technological leap in the photovoltaic industry. Over the past five years, six Fraunhofer Institutes combined their expertise in the Fraunhofer lighthouse project "MaNiTU" to identify the most sustainable paths for the market launch of such tandem solar cells. They were able to show for one that high cell efficiencies can be achieved using industry-oriented processes, however, that such high efficiencies were only currently achievable with lead perovskite materials. Based on these findings, the researchers developed suitable recycling concepts to ensure sustainability.

In the "MaNiTU" project the Fraunhofer researchers produced new materials with perovskite crystal structures and compared them with existing materials at the cell level. The comparisons showed that high efficiencies can only be achieved with lead perovskites. They then successfully fabricated highly efficient demonstrators, for example, a perovskite silicon tandem solar cell of more than100 square centimeters with screen-printed metallization and produced mini modules for single and interconnected tandem solar cells. Subsequent life cycle analyses showed, that by using suitable production and recycling processes and degradation rates comparable to today's silicon technology, it is feasible to make a sustainable product. "In this collaborative Fraunhofer flagship project, the Fraunhofer-Gesellschaft has worked its way back to the forefront of global photovoltaics and should remain there," declared the Fraunhofer project advisory board council at the closing event at the end of November 2024.

Scalable perovskite silicon solar cell with 31.6 percent efficiency

Manufacturing processes for perovskite materials that can be implemented industrially on large surfaces was also a research focus of the project. Thanks to the so-called 'hybrid route', a combination of vapor deposition and wet-chemical deposition, the Fraunhofer researchers were able to produce high-quality perovskite thin films on industrially textured silicon solar cells, and thus achieved a fully textured perovskite silicon tandem solar cell with 31.6 percent efficiency on 1 square centimeter cell area. "Close industrial cooperation is the next step in establishing this future technology in Europe," summarized Prof. Andreas Bett, Institute Director at the Fraunhofer Institute for Solar Energy Systems ISE and coordinator of the Fraunhofer flagship project.

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No suitable lead-free perovskites for solar cells currently in sight

Besides looking at conventional lead perovskite compounds, scientists in field of material development also focused on finding non-toxic, lead-free alternatives. They gained detailed insights into the stability and properties of the target materials by combining theoretical simulation, experimental material synthesis and cell production in the R&D process. Investigations on various perovskite compounds as well as on different synthesis routes were performed. “In particular, the scalable, semi-continuous perovskite synthesis in powder form using spray drying was shown to be a suitable screening method for a variety of compounds and their potential synthesis. This method can also be applied to industry-relevant quantities,” explained Dr. Benedikt Schug, head of Particle Technology at the Fraunhofer Institute for Silicate Research ISC. The research team was unable to produce tandem solar cells of sufficient efficiency from any of the lead-free materials that they theoretically and experimentally analyzed, however, as the intrinsic material qualities were simply not high enough.

Reduction of the ecological footprint

To account for the entire product life cycle of the tandem solar cells, the researchers considered the topics of recycling and a closed circular economy in their analyses, carrying out detailed assessments on the environmental impacts of the production, use phase and end-of-life of the tandem solar cells. They developed recycling concepts for perovskite tandem modules. Prof. Dr. Peter Dold, Director of the Fraunhofer Research Institution for Materials Recycling and Resource Strategies IWKS, summarizes the results: "By using advanced recycling processes, it is possible to create a circular economy for photovoltaic systems with lead perovskites as well, thus ensuring long-term energy efficiency."

System components for contacting the perovskite sub-cell

The researchers worked on the development of industry-oriented system components and coating technologies in order to establish high-performance contact materials for electron and hole contacts in the industrial wafer format G12. One of the challenges was the perovskite cell's temperature sensitivity, which requires temperatures to remain below 100 °C during the production of the front contact system. Yet, the deposition of a transparent conductive oxide on the cell is required. To this end, a new process chain was realized in a SALD hybrid system, consisting of a combination of an ALD and evaporation processes, and supplemented by a final sputter process. "Our objective is now the development transfer," explained Dr. Volker Sittinger, Head of the Diamond-Based Systems and CleanTech department at Fraunhofer IST. "Together with plant manufacturers and end users, we are working to transfer the new technology from the research lab to the application phase."

Evaluating the efficiency and stability of tandem solar cells

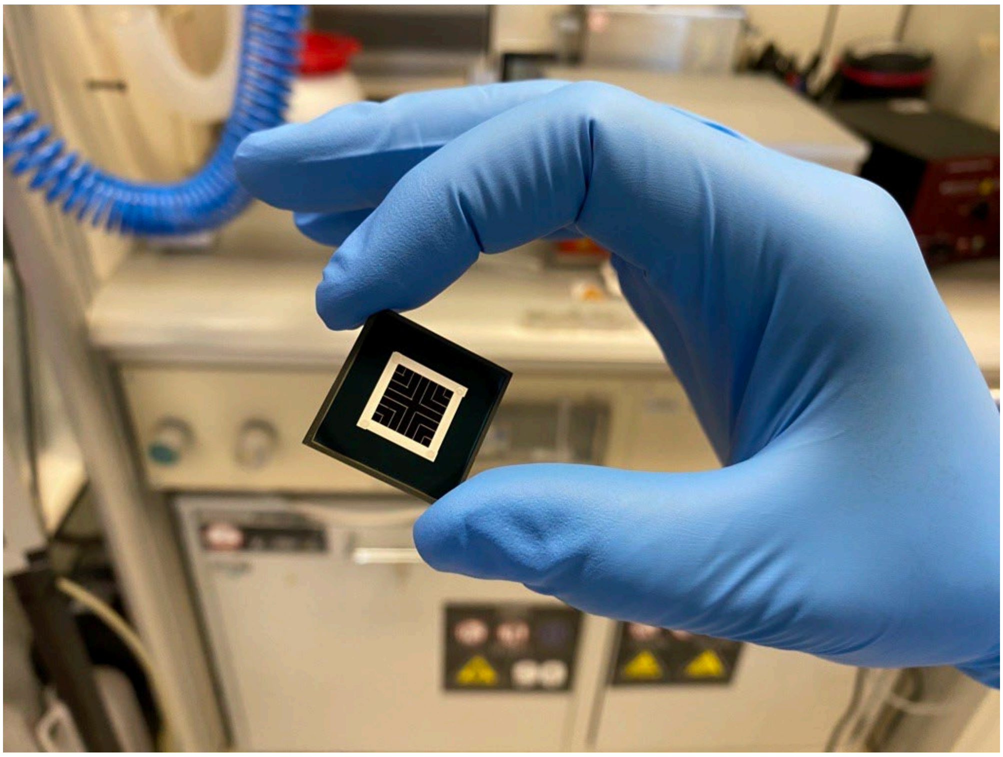
Another research focus in the project was the characterization of tandem solar cells. The researchers successfully developed methods for the non-destructive selective analysis of the silicon and perovskite sub-cells. With the characterization data obtained and an opto-electrical simulation model, they carried out a comprehensive loss analysis on the tandem solar cell, and a practical upper limit of 39.5 percent efficiency of the cell could be determined. Further developments in the microstructural analysis of the cell were carried out.

The Fraunhofer Institute for Microstructure of Materials and Systems IMWS evaluated low-energy focused ion beam techniques (FIB) for the preparation of industrial tandem solar cells, which were then analyzed in high resolution using a transmission electron microscope (TEM). In addition, a special sample holder was constructed that allows the direct deposition of absorber and contact layers on TEM substrates, to be carried out by the project partners on site. Methods were also developed to investigate the thickness, degree of coverage and chemical bonding of self-organized molecular monolayers.

Modeling of absorber materials and material interfaces

Also in the project, a research team developed calculation models that accurately and efficiently describe the structural and photovoltaic properties of relevant absorber materials and their interfaces with optically transparent and electrically conductive contact materials. The scientists at the Fraunhofer Institute for Mechanics of Materials IWM developed a computational simulation workflow that can be used not only for photovoltaics, but also for material issues on the industrial level in other technologies - such as hydrogen - that are relevant for the generation, conversion, storage, distribution, and use of sustainable electrical energy resources.

Further information on the project: https://manitu.fraunhofer.de/



The scientists in the Fraunhofer flagship project "MaNiTU" successfully produced a perovskite silicon tandem solar cell with 31.6 percent efficiency on an area of 1 cm². © Fraunhofer ISE

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