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Detailed information on energy research

New method comes closer to the ideal solar cell

Both sides-contacted monocrystalline silicon solar cell achieves efficiency of 25.7 per cent

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The goal of developers and customers is to achieve solar cells that come as close as possible to the maximally achievable efficiency. And it should also be possible to produce these cells even more cost-effectively. Researchers at the Fraunhofer Institute for Solar Energy Systems (ISE) have been investigating which methods and processes can be used to increase cell efficiency and reduce internal losses. In accordance with these requirements, they have developed a monocrystalline silicon solar cell that is contacted on both sides. This achieves an efficiency of 25.7 %.

The efficiency of silicon solar cells can be increased by reducing the loss mechanisms. The researchers have investigated how they can reduce the losses caused by recombining charge carriers and how they can improve the absorption of the light. Their goal is to produce highly efficient cells with less complex procedures and less process steps than before.
Dr. Martin Hermle, Head of Department „Advanced Development of High-Efficiency Silicon Solar Cells“ at Fraunhofer ISE, explains the approach: “Until now, increasingly complex solar cell structures have been used to increase the efficiency of solar cells. Compared with the high-efficiency solar cell structures currently used, we have simplified the manufacturing process but nevertheless increased the efficiency of the solar cells.” High-performance laboratory solar cells made of crystalline silicon are now reaching the 27 per cent efficiency level – an ideal silicon solar cell achieves a theoretical value of 29.4 %. This means that it converts 29.4 % of the total energy in the solar spectrum – ranging from ultraviolet light to long-wave radiation – into electrical energy. In practice, the most significant efficiency losses are caused by recombining charge carriers, metallisation and optical losses.

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Optimising the surface, backside and contacts

To reduce the efficiency losses, the aim is to prevent charge carriers from recombining and to transfer free charge carriers as loss-free as possible out of the solar cell. Another goal is to optimally trap and utilise light. To achieve this, shading by (front) contacts, losses due to reflection and the re-escape of the light not absorbed in the silicon wafer need to be minimised. In order to increase efficiency, the researchers have developed new technologies and processes that can be used to optimise the surface, backside and contacts of the cells. The main areas of action are briefly summarised here and are described in more detail below:

- A highly conductive emitter layer collects free charge carriers and conducts them as loss-free as possible from the cell to the metal contacts.
- New passivating contacts transport the solar cell current as loss-free as possible. Fewer charge carriers recombine at these new contacts than with the previous selective emitters and local BSFs.
- New multi-functional surface layers have improved optical and electrical properties; new dielectric backside passivation simultaneously improves the light trapping.

Producing more efficient solar cells more easily

The aim of the ForTES project was to investigate new technologies for increasing the efficiency of next-generation silicon solar cells. The researchers achieved the highest efficiency for silicon solar cells with metal contacts on the front and back sides by means of new, full-area selective and passivating contacts. They were thus able to close in on the world record for backside-contacted silicon solar cells where the front side is not shaded by contact fingers that reduce the efficiency.

The technologies developed in the project aim to achieve greater efficiency for simple cell structures and be suitable for n- and p-type silicon. They are designed to be used both evolutionarily for improving current technology lines as well as for new cell concepts such as heterojunction technology.

With improving material and passivation quality the metal contacts limit the efficiency. Therefore the contact area on the back is minimised to thousands of point-shaped contacts in so-called Passivated Emitter and Rear Locally Contacted cells (PERC cells). PERC cells achieve higher voltages than conventional cells with full-area metallisation on the back side by using dielectric surface passivation and reducing the metallised area. However, this also simultaneously increases the series resistance because the charge carriers have to travel across longer distances within the silicon (Fig. 1).

The full-area, selective contact developed in the project aims to avoid this conflict. This tunnel oxide passivating contact suppresses, on the one hand, the recombination of charge carriers on the metal contact while simultaneously allowing loss-free transport of the majority charge carriers (Fig. 2).

Innovative tunnel oxide backside contact

With a new process, the researchers are optimising the charge carrier transport in solar cells and are eliminating previously required processing steps. The so-called Tunnel Oxide Passivated Contact technique (TOPCon technology) eliminates the structuring or point-like contacting of the back side required by cell technologies such as PERC. The new backside contacting is composed of an ultra-thin tunnel oxide and a thin silicon layer.

For this new contacting, the scientists are applying an ultra-thin, tunnel oxide backside contact across the full rear area of the Si cell. The silicon oxide passivation layer is only one to two nanometres thick. The charge carriers can overcome this barrier layer by means of quantum mechanical tunnelling processes. A thin layer of highly doped silicon is deposited across the entire surface of this tunnel oxide.

Hermle explains: “We have therefore managed to get one of the defining loss mechanisms in silicon solar cells under control, namely the recombination of the charge carriers on the metal contacts. The new full-area passivated contact transports the majority charge carriers with virtually no losses. At the same time it prevents the charge carriers from recombining on the metal contacts so that they can no longer contribute to the current.”

The researchers developed these cells with a view to making production processes more effective and simpler.

Texturing improves the light coupling

The greater the proportion of incident radiation that the solar cell can convert into electrical energy, the higher the cell efficiency. Structures on the micro- or nanometre scale help solar cells capture the light and make optimum use of it. Crystalline silicon solar cells only absorb very little light in the near-infrared spectrum between 900 and 1,200 nm. However, diffractive structures on the back side of the solar cells bend and scatter the incident light and can minimise the absorption losses. A surface texture reduces the front reflection and extends the light paths in the silicon. New concepts for trapping light often combine textures with different structural dimensions, for example a pyramidal front side and a backside diffraction grating.

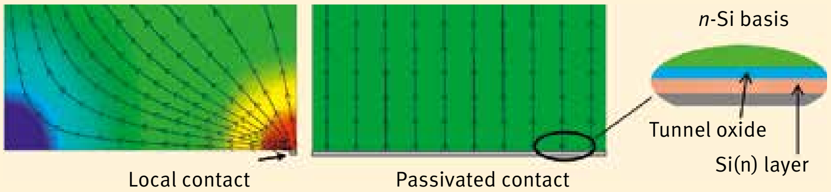

Fig. 1 *The simulation shows the difference between the electrical current transport in solar cells with local backside contacting (left) and in cells with the new, full-area passivated TOPCon backside contact (right).*

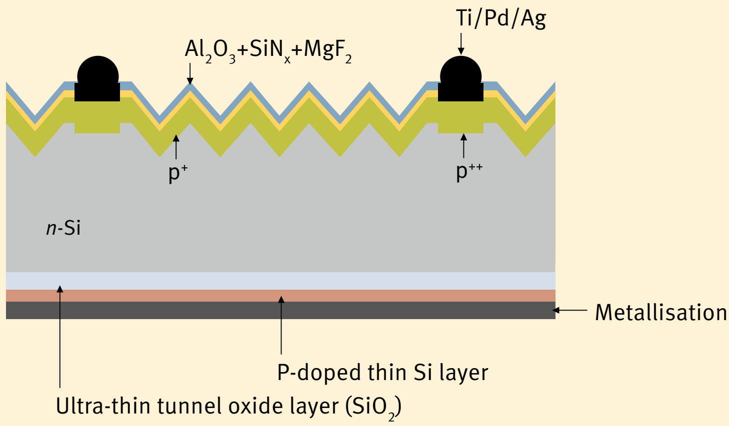

Fig. 2 *Schematic diagram of the TOPCon (Tunnel Oxide Passivated Contact) solar cell with full-area selective contacts.*

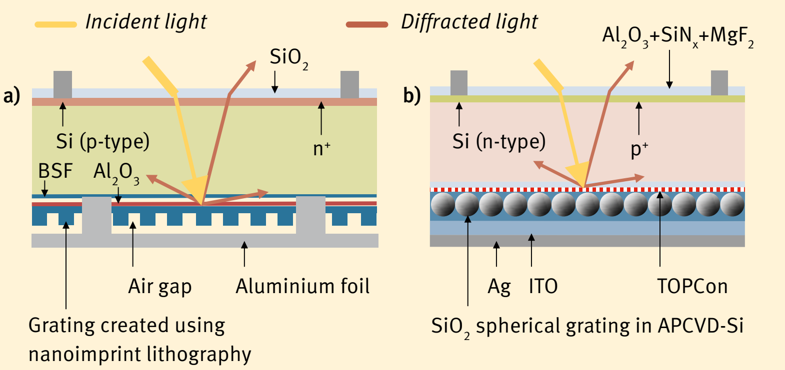

Fig. 3 *EPOS solar cells with diffractive backside gratings: (a) p-type cell with thin Al_2O_3 backside passivation and a binary crossed grating in a-Si. (b) n-type cell with a passivated backside contact (TOPCon) and a sphere grating on the rear. Full-area backside contact (ITO/silver).*

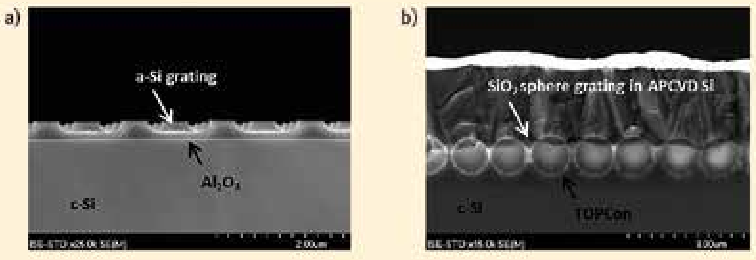

Fig. 4 *SEM micrographs of the cross-sections through EPOS cells: on the left the crossed grating produced by nanoimprint lithography, on the right the structure on TOPCon cells created using SiO_2 spheres (each without metallisation).*

Silicon solar cells

These days most silicon solar cells are made from p-type material. This means that the base of the solar cell is positively conductive. A thin, negatively conductive layer, the so-called emitter, is applied to the cell; this collects the charge carriers. Solar cells with a negatively conducting base are known as n-type solar cells.
Silicon cell technology is developing in fast cycles: During the duration of the project, the industry transitioned from Al-BSF (Aluminium Back Surface Field) technology to PERC technology (Passivated Emitter and Rear Locally Contacted Cells). The efficiency of monocrystalline PERC industrial solar cells is currently over 21 %. The even more efficient Si-Heterojunction (SHJ) technology is now considered to have reached industrial maturity. A high-performance cell using this layer system achieved a new world record efficiency for silicon solar cells of 26.7 % (IBC from Kaneka).
In SHJ cells, the charge-separating pn junction is formed on both wafer sides by doped nanometre-thin layers of amorphous silicon (a-Si) or optically more transparent nanocrystalline (nc) SiO_x. The metal contacts are applied to the transparent, conductive oxide layers.
Significantly higher efficiencies are possible with tandem or multi-junction solar cells. Fraunhofer ISE has achieved 31.3 % for a fully integrated, silicon-based multi-junction solar cell.

In order to determine ideal texture combinations on the front and back sides of solar cells, the Fraunhofer researchers developed the OPTOS method. This makes it possible to simulate and optimise the reflection and absorption of solar cells with surfaces structured in varying ways on both sides. It was found that the absorption in the near-infrared spectrum increases with two different diffractive backside gratings – hexagonal spherical gratings and binary crossed gratings.

EPOS cells: electrically planar, optically structured

The researchers produced highly efficient solar cells with such diffractive backside structures: on the one hand on n-type silicon-based TOPCon solar cells with a full-area passivated contact and a hexagonal spherical grating on the rear; on the other hand on p-type silicon-based EPOS solar cells with a binary backside grating produced by means of nanoimprint lithography and aluminium foil-based contacting (Fig. 3). These so-called EPOS cells capture the light very efficiently. The researchers describe them as electrically flat but optically rough because the cell back side is plane with very good electrical passivation and at the same time optically structured. This enables both high voltages and high currents to be achieved and thus high efficiency levels.
In the n-type cell, the back side was passivated using TOPCon. To improve the optics, a layer of 1 µm-thick SiO_2 spheres was applied on which a µ-Si matrix was deposited by means of APCVD. A TCO (Transparent Conductive Oxide) layer separates the metallisation and the rough µ-Si layer.
With the p-type cell, the back side was passivated using an approximately 5 nm-thin Al_2O_3 layer. An approximately 300 nm-thick a-Si layer was then sputtered on it. This layer is then furnished with a crossed grating produced using nanoimprint lithography. Aluminium foil is then applied to this structured a-Si layer as contacting, which is locally soldered on by laser. This creates an air gap between the Si grating and the flat metal layer. This is good for the light coupling because it allows a high refractive index jump. Figure 4 shows SEM micrographs of the respective backside structure.
The EPOS cells are suitable for both silicon-based tandem concepts where front side texturing cannot be used and for very thin c-Si solar cells. In combination with textured front sides, the current gains through the backside structures were significantly lower.

Further developing silicon solar cells

The developed TOPCon technology can provide an important building block for the evolutionary development of Si solar cell technology. The processes are currently being transferred to industrial plants with efficiencies greater than 24.5 % demonstrated on 100 cm² areas. The efficiency gains achieved show that the technology development is not yet at an end. This will lead to a further reduction in the electricity production costs for PV by reducing the process costs and increasing the efficiency. The researchers emphasise that the technological development should attach considerable importance to the industrial viability of the individual process steps.

Ways to cheap high-performance cells

Research facilities and manufacturers are improving current cell concepts and developing new technologies and methods. They are pursuing quite different approaches with the aim of increasing performance and optimising production. Two focus areas are PERC and heterojunction cells.

As a further development of the PERC technology, bifacial PERC+ solar cells have an aluminium finger grid on the back instead of full-area aluminium metallisation. This enables the cell to also absorb scattered light incident on the back and convert it into electricity. Modules with PERC+ solar cells can generate about 5 to 10 % more electrical energy than conventional monofacial modules.
New high-performance industrial cells are set to be connected with a new wire-foil electrode. This so-called smart-wire connection technology enables about two thirds of the usual amount of silver used to be saved. This reduces the charge carrier recombination on the front side of the cell and improves the light coupling.

Heterojunction cells

Heterojunction solar cells achieve high efficiencies with comparatively low production costs. They combine the advantages of c-Si solar cells with those of thin-film technologies. The ITRPV (International Technology Roadmap for Photovoltaics) expects them to achieve a slowly but steadily growing share of the market during the next few years.
To further improve the optical performance of heterojunction solar cells, researchers from the Helmholtz Zentrum Berlin and Forschungszentrum Jülich have produced a transparent contact made of SiO_2 and doped microcrystalline silicon carbide (µc-SiC:H).

In 2016, the German Federal Ministry for Economic Affairs and Energy approved more than 116 million euros for 166 new photovoltaic research projects. In total more than 154 million euros were invested during that year in the further development of photovoltaics.

Project participants

- **Project management:** Fraunhofer Institute for Solar Energy Systems, Freiburg, Dr Martin Hermle, martin.hermle@fraunhofer.ise.de

Links

- Production of solar cells with heterojunction technology, https://youtu.be/GEgaV0aFBsg

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Project Management Jülich
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Dr Sven Macko
52425 Jülich
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Hermann-von-Helmholtz-Platz 1
76344 Eggenstein-Leopoldshafen
Germany

Author
Gerhard Hirn

Contact · Info

Questions regarding this Projektinfo brochure? We will be pleased to help you:

+49 228 92379-44
kontakt@bine.info

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Kaiserstraße 185–197
53113 Bonn, Germany
www.bine.info

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