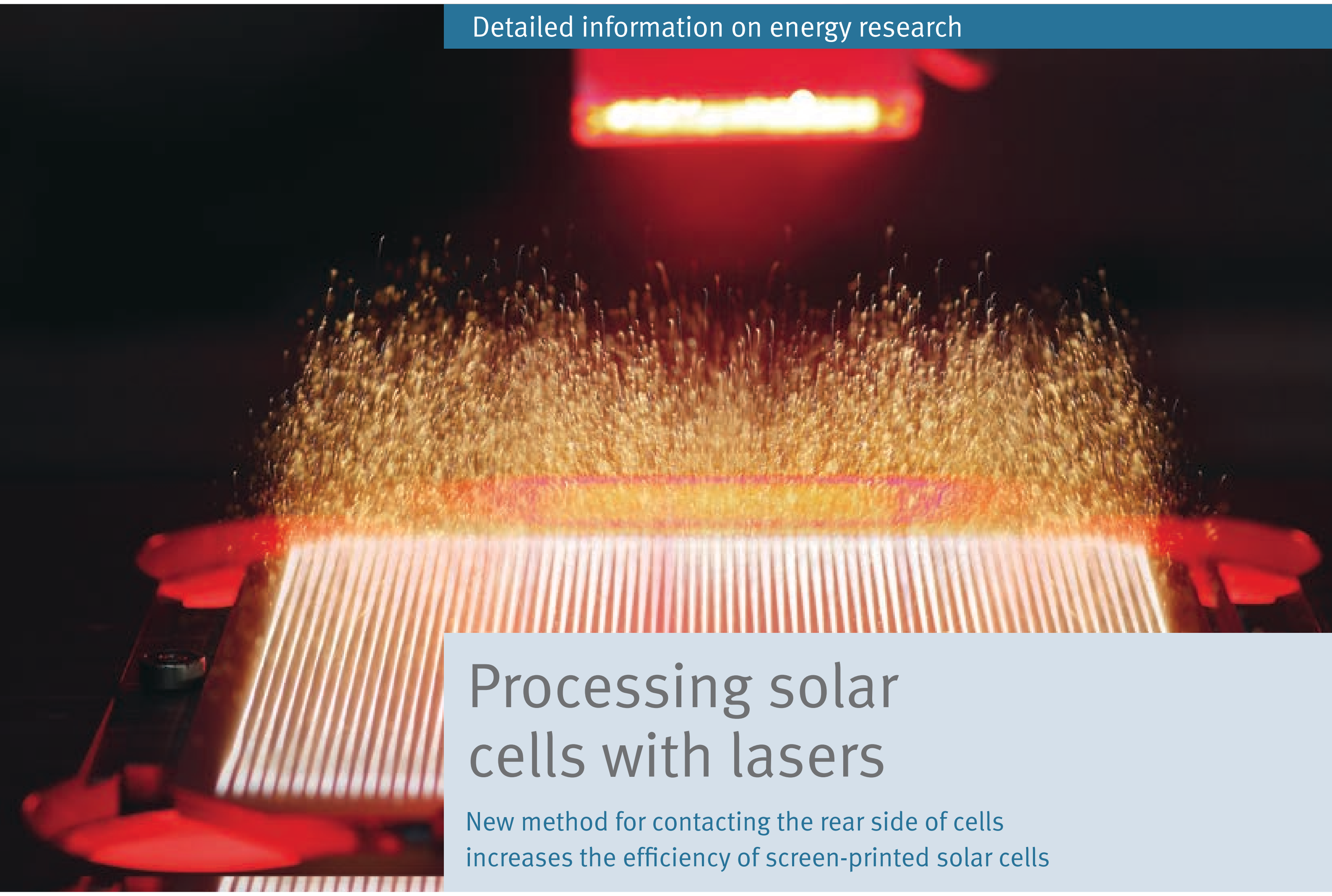

# Processing solar cells with lasers

## New method for contacting the rear side of cells increases the efficiency of screen-printed solar cells

BINE Information Service

*Laser technology enables solar cells to be produced with greater efficiency. It replaces or eliminates costly processing steps that were previously required. Researchers have developed a method for laser contacting the rear side of solar cells that can be integrated into existing production lines for screen printing solar cells. The new technique enables the cells to be produced at a lower cost, reduces the energy and materials deployed, and eliminates previously required environmentally harmful chemicals.*

An important goal for the new development was that the laser processing can be quickly transferred into practice and be easily integrated into production lines that utilise the widely used screen printing technology.

Researchers at Fraunhofer ISE have developed a new laser method for contacting the rear sides of cells. Whereas previously several successive processing steps using photolithography and wet-chemical processes and subsequent heat treatment were often required to structure the contact openings in the function layers, this can now be done with a single laser operation. A newly developed system places 100,000 point contacts on the rear side of a standard format cell within just a few seconds. This plant for the laser-fired contact (LFC) process has been tested at a manufacturer and integrated into the series production there in 2012.

The LFC process is used for producing PERC (Passivated Emitter and Rear Contact Cell) solar cells that achieve efficiencies of over 20 %. These silicon solar cells are passivated on the rear side with dielectric layers and are then contacted locally. The passivation, which these days mostly consists of a 100 nm-thick layer structure comprising aluminium oxide and silicon nitride, reduces the optical and electrical losses in these cells. This increases the relative output power by up to 5 %. A high

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## Lasers in PV production

Lasers are used as important tools in several solar cell production steps:
- Texturing and targeted opening of anti-reflective and passivation layers
- Selectively increasing the doping in the contact finger area
- Contacting, soldering and welding cell connector strips in solar modules
- Edge isolation (electrical separation of front and back after doping)
- High speed drilling for cell concepts such as metal wrap-through (MWT) and emitter wrap-through (EWT)
- Cutting wafers and cells
- Marking solar cells

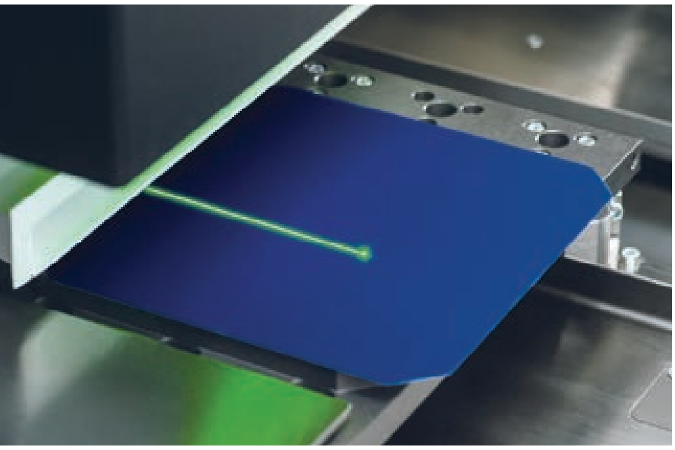

Fig. 1 *Laser processing a solar cell.*

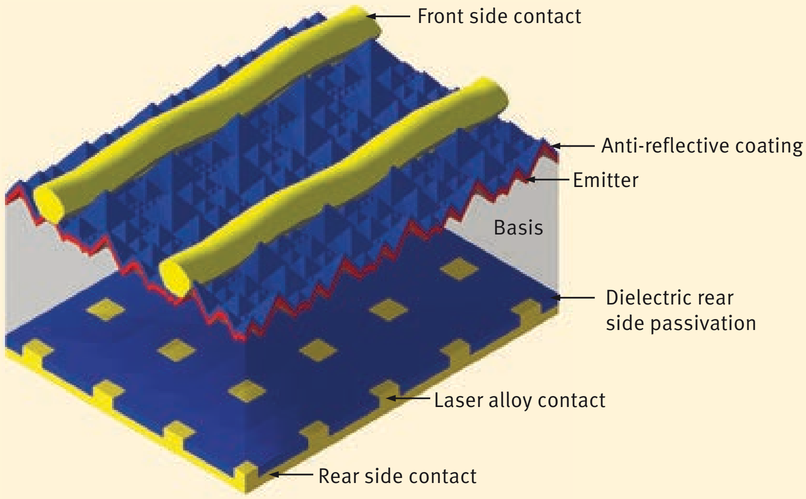


Fig. 2 *Structure of a highly efficient solar cell whose rear side contact has been created using the LFC process.*

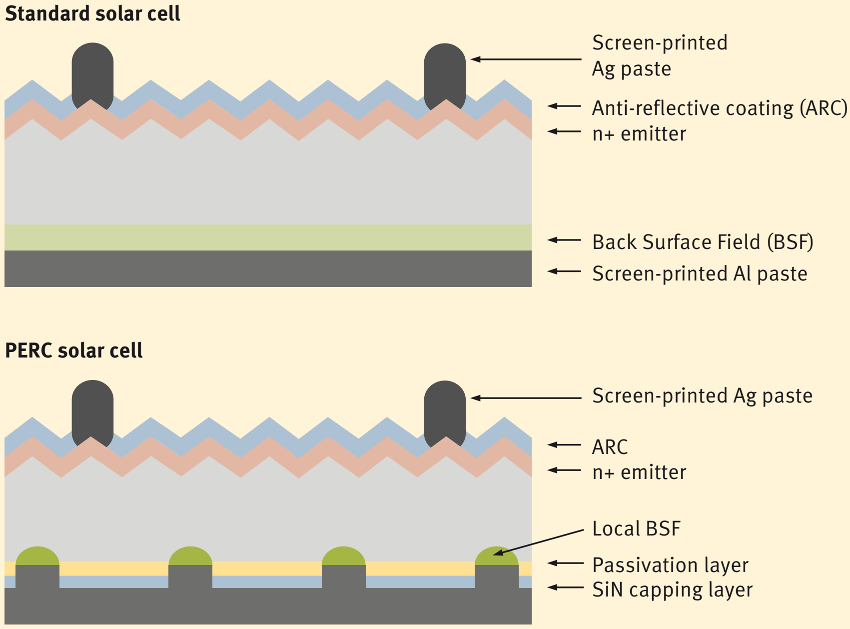


Fig. 3 *Comparison of a standard industrial solar cell that has a full-area, aluminium back surface field with a PERC solar cell that has rear side passivation and screen-printed, local aluminium contacts on the rear of the cell. The emitter on the textured front surface is covered with an anti-reflective coating.*

number of point contacts are required in order to connect the electrode with the wafer via the passivation layer. Ideal is a structure with 400 contacts per square centimetre – which corresponds to 100,000 contacts per standard wafer (156 x 156 mm$^2$). The contacts only take up 1 % of the area, which means that these hardly impair the passivation layer.

### Laser-fired contact process

The LFC process simplifies the otherwise complicated contacting of the cell's rear side. It produces efficient and sparing point contacts between the silicon and the metallisation layer on top of the passivation layer. The contacting is carried out in three process steps: Once the dielectric passivation layer has been applied this is then followed by an aluminium layer, and the laser then creates the contact points through the passivation layer. Here the aluminium from the screen printing paste is re-melted with the underlying silicon and generates a highly doped region within the laser-contacted surface. Its depth can be set by adjusting the laser process. For this purpose the researchers investigated various beam profiles which, in addition to a Gaussian profile, also included a flattened „top hat“ profile. It was discovered that the top hat profile, which was generated using a diffractive optical element, can be used to create a very flat contact structure. This therefore creates a deep, highly doped area.

### Laser process adapted for screen-printed cells

For the development of the LFC process, Ralf Preu, Jan Nekarda and Martin Graf from Fraunhofer ISE won first prize in 2014 at the international Innovation Award Laser Technology competition. Decisive for their success was the fact that they had adapted the laser process for contacting rear sides to the special requirements of industrial PERC cells and transferred the process into production.
The basic development for contacting the screen-printed cells was carried out as part of Fraunhofer ISE's LFCC project in conjunction with several German

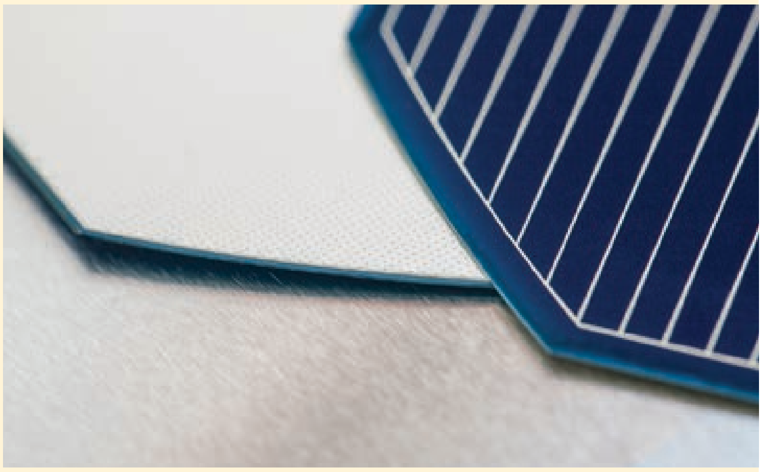

*Fig. 4 Rear and front side of a 156 x 156 mm² industrial solar cell with a rear side passivation layer and lasered electrode made of conventional aluminium foil.*

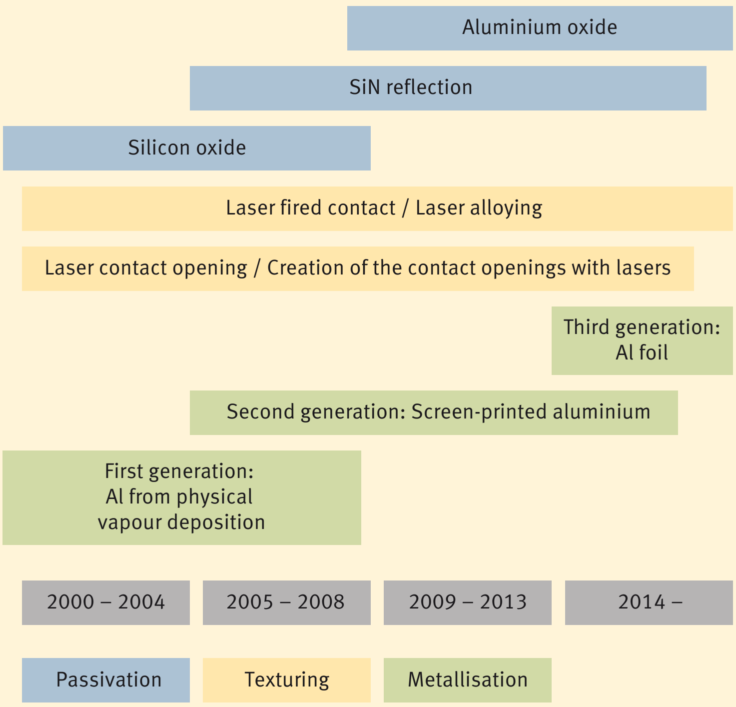


*Fig. 5 The various generations of PERC cells, ranging from PVD and screen printing to the use of aluminium foil to provide rear side metallisation.*

## Laser improves Si-solar cells

A silicon solar cell consists of a stack of function layers. In order to produce these, small numbers of foreign atoms must be introduced in the correct places by means of doping. To achieve this, Si atoms are replaced – for example by P atoms – in several places in the upper layer directly under the contact fingers and the antireflective coating. Although low doping here enables a high efficiency, this also creates high resistances at the transition to the contact fingers. In order to counteract this loss of efficiency, high doping with a laser is therefore applied in the area around the contacts. A further improvement is provided by passivating (and reflection coating) the rear side of the cell by using a protective layer, which is known as the PERC (passivated emitter and rear cell) process. This then has to be opened with a laser again so that the solar current generated can be transferred. Here, the screen-printed aluminium rear contact is connected at thousands of point contacts to the p-doped silicon material, for example by local laser alloying (LFC process).

solar cell manufacturers. Prior to this, only solar cells coated using the PVD process (physical vapour deposition) were furnished with laser-fired contacts. The screen-printed metal layers are considerably thicker, which necessitates longer pulse lengths and greater pulse energies, whereby it was discovered that longer laser pulses several micro-seconds in length are required to penetrate the thick-film electrodes, which consist of a 20 to 30 µm-thick porous aluminium layer applied during the screen printing. They achieved this combination of longer pulses with high energies by using disk lasers. Since this layer has to be largely removed, deeper structures are created. In particular, local contacting using LFC technology creates efficiency advantages relative to standard solar cells with a full-area, aluminium back surface field (Al-BSF). A new long-pulse disk laser, combined with beam steering using a piezoelectric-controlled galvanometer mirror, enabled the processing time for large-area solar cells with more than 100 cm² to be shortened from a few minutes to just a few seconds. The researchers have already achieved efficiencies of up to 20.6 % on purely screen-printed, industrial-level solar cells.

In a follow-up project (GRIPS), the LFC technology was developed to industrial maturity and tested in a pilot line from 2009 to 2010. Since 2012, it has been integrated in the series production. It has now been used to produce more than 30 million solar cells. Using the LFC process, the solar cell manufacturer succeeded in setting several world records for efficiency: 19.5 % for large-scale multicrystalline silicon solar cells and 18.5 % for modules in standard sizes. With a similar, laser-based texturing approach, SolarWorld AG set a new efficiency record in 2015 amounting to 21.7 % for industrially produced PERC solar cells.

In the projects, the investigations focussed on the screen-printed metallisation process widely used in industry, since the initially used PVD method proved to be too costly. In a follow-up project, the researchers are now working together with a laser manufacturer on using aluminium foil instead of screen printing pastes for the rear side metallisation and are adapting the method for industrial production (Fig. 4). This approach has both cost and efficiency advantages.

# Research for the solar industry of the future

In the Photovoltaics Innovation Alliance and the R&D for Photovoltaics research initiative, experts from science and industry are developing joint concepts for the photovoltaic industry. They are aiming to transfer new developments more quickly into practice to enable high-performance solar cells to be produced as cheaply as possible. For this purpose they are investigating which improvements and simplifications can be achieved. They are supplementing individual projects on specific aspects with projects that analyse and optimise the entire production chain. In addition, the intention is to integrate newly developed process steps as easily as possible into existing production lines.

As part of the Rück-Si project, the Institute for Photovoltaics (IPV) at Stuttgart University has developed a laser process for producing rear side contact cells without any masking steps. That makes almost half of the previously required process steps obsolete. The researchers managed to increase the efficiency of a 20 x 20 $mm^2$ crystalline silicon cell to 23.2 %. In the follow-up project they are working on scaling up the process to an industrially relevant area of 125 x 125 $mm^2$.

The aim of the joint UltraLas project is to create a laser processing system that can process silicon wafers with an edge length of 156 millimetres within five seconds. This requires beam deflection velocities of over 100 metres per second. The Institute for Solar Energy Research Hamelin (ISFH) therefore wants to deploy for the first time high repetition rate, ultra-short pulse lasers in the megahertz range for single-pulse applications.

In the FeinPass project, a team of researchers from Fraunhofer ISE and industrial partners has brought a fine line metallisation and double-sided passivation process for c-Si solar cells to application readiness, which involves the double-sided coating of the solar cells using a highly productive plasma enhanced chemical vapour deposition (PECVD) coating tool and an innovative method for the targeted ablation and transformation of the passivation layer using laser technology.

In the FutureFab project, a research team is working on designing a next-generation solar factory. It is investigating new technologies for producing crystalline solar cells such as laser doping, passivated rear sides, fine line metallisation and modular assembly. The aim is to achieve cell efficiencies greater than 20 % and to reduce the production costs per watt-peak by 30 %.

## Project participants

- **Basic development for industry-level passivated silicon solar cells (GRIPS):** Fraunhofer-Institut für Solare Energiesysteme ISE, Freiburg, Dr Andreas Wolf, andreas.wolf@ise.fraunhofer.de
- **Development of a laser-contacted rear side to increase the efficiency of screen-printed solar cells (LFCC):** Fraunhofer-Institut für Solare Energiesysteme ISE, Freiburg, Dr Ralf Preu, ralf.preu@ise.fraunhofer.de

## Links

- Laser Innovation Award: www.innovation-award-laser.org
- Photovoltaics Innovation Alliance: www.innovationsallianz-photovoltaik.de
- R&D for Photovoltaics: www.solarstromforschung.de
- Photonic research: www.photonikforschung.de

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