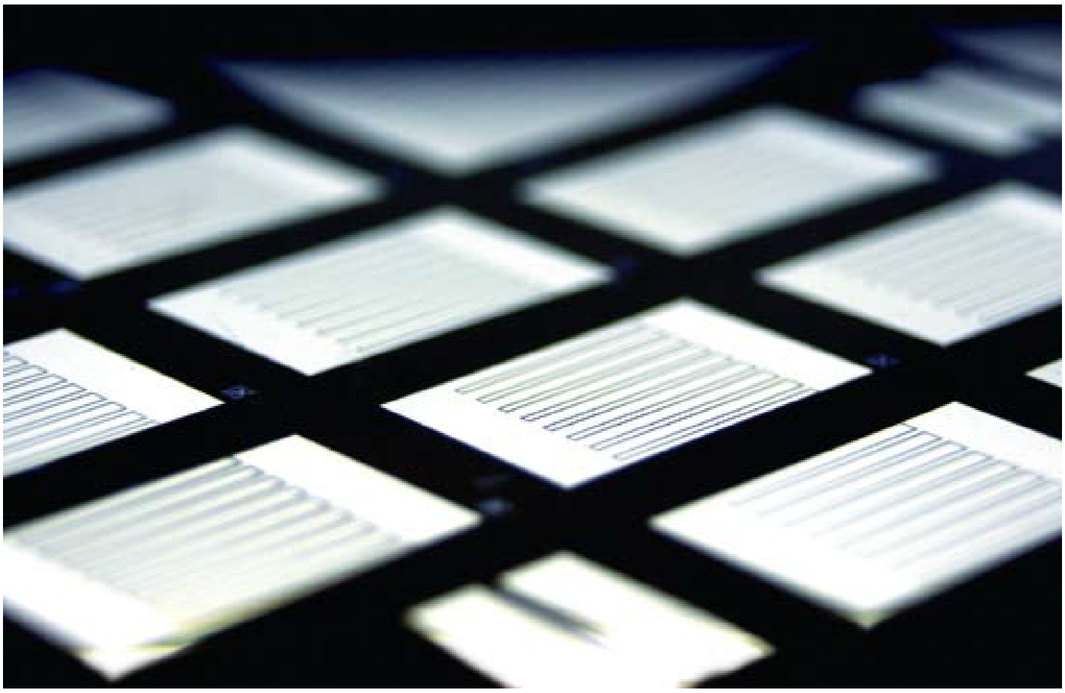
The commercialisation of standard solar cells is a highly competitive business. Photo: dpa

# Technological niche versus high-volume business

European manufacturers have to search for business opportunities rather in the area of premium technology than in high-volume business. These include new cell concepts, material improvements or new processing methods – a feat of concentrated effort based on new technology.

The photovoltaics sector is presently experiencing the first hard test of its marketability. Important markets in Europe have heavily reduced their subsidies, overproduction has increased the pressure on prices, projects are being cancelled due to financing problems and the gloves have been taken off in the battle for market shares. Up to now, the PV industry has countered the increasingly demanding commercial conditions with a strategy based on two fronts. Both optimisation of the production processes and the development of new cell concepts were the proven methods of reducing the costs per watt. Most large companies have followed both paths in parallel in order to secure their competitiveness. Many of these expensive efforts have moved into the area of process technology. Many companies are now concentrating on their own equipment and are sending their research engineers into the production halls. This makes it all the more interesting to look over the shoulders of the scientific institutes and equipping companies. Work on improving the production processes and development of new cell concepts is continuing here.



Back hetero: comb-shaped interlocking metal contacts on the back of rear-side solar cells with silicon heterocontacts. Several test cells on a silicon wafer can be seen.
Photo: HZB

## Heterojunction technology sets a new record

Equipment suppliers are attempting to score points with high-efficiency technology in order to jump on the train again after the crisis and the unavoidable market reconsolidation. At the end of last year, Roth & Rau AG were able to raise the efficiency of their heterojunction technology to 21 %. The Saxony-based company previously introduced a 6 inch cell offering 20 % efficiency at the PVSEC in Hamburg. This cell alone reduces the power generation costs by around 15 %. The current record cell, also with a 156 mm edge length, is another step towards parity with the mains grid, explained Egbert Vetter, Vice President R&D.

The technology pursued by Roth & Rau is the result of a collaboration with Neuchâtel University. As suggested by the name, the heterojunction cell consists of several different layers. Thin layers of doped, intrinsically amorphous silicon, and transparent conductive oxide layers for receiving the generated electricity, are applied to both sides of an n-doped silicon wafer. In this manner the cell combines the light absorption properties of both materials. This expands the spectrum of usable light and leads to a higher utilisation of the light. The concept also uses the good passivation characteristics of amorphous silicon.

The yield increase is also a result of the low temperature coefficients, which is also a contribution by the amorphous silicon. Roth & Rau has developed the Helias coating plant for this cell concept. The amorphous silicon is applied in a PECVD reactor and the TCO layer is applied using a sputtering process. Both coating steps can be performed using a small amount of energy in only a few steps, which provides additional cost savings. However, the entire process only functions with monocrystalline wafers. The production plants are currently designed for processing 2,400 wafers, according to Roth & Rau.

## Back contacts are in demand

Among the new cell concepts, back contact cells are enjoying special attention in the sector. The Fraunhofer Institute for Solar Energy Systems (ISE) has combined two approaches in their MWT-PERC cells. MWT stands for Metal Wrap Through, in principle an older concept from the late 1990s. Among the back contact cells, the MWT is the cell that is most similar to the standard Si cells. In this case the front side contact has been simply relocated to the back side via holes in the cell. A total of three extra process steps are necessary for this: drilling of the holes with a laser, establishment of the through-hole connection and insulation of the back side contacts.

PERC stands for Passivated Emitter and Rear Cell. The term describes optimised metal backing and passivation of the surface. Both processes increase the efficiency. Local laser-alloying establishes a contact between the screen-printed aluminium back contact and the p-doped silicon material. As early as last year the ISE scientists managed to achieve an efficiency of 19.3 % with a PERC cell. However, the cell with this efficiency requires the use of monocrystalline material.

Even higher efficiencies can be achieved when the PERC concept is combined with the MTW concept. Relocating the contacts from the front side of the cell

### Efficiency record

According to an HZB press release, the first articles relating to silicon-based hetero rear contact cells were published in 2007. The previously published efficiencies were between 15 % and 16 %. According to the HZB, the Korean cell manufacturer LG Electronics reported an efficiency of 22 % in 2011. However, the HZB also notes that this value has not been confirmed by independent sources. This means that the current confirmed record for efficiency remains at 20.2 % for the HZB/ISFH cell.

**Research rocket: start of the TEXUS research rocket at the end of November, 2011. A range of different experiments at a height of 270 km should help to improve the quality of the silicon melt.**

Photo: DLR/Otfried Joop

to the rear side greatly reduces the shadowing effects in comparison to a standard Si cell. This alone is enough to increase the efficiency of the MWT-PERC cell by an absolute value of 0.1 % to a total value of 19.4 %. This was not enough for the ISE researchers, who then resorted to using especially high quality floatzone silicon. This resulted in an efficiency of 20.2 %. This is the highest measured efficiency that has been achieved for industrial format solar cells using the standard production methods of screen printing, diffusion and oxidation. According to the ISE, this process has already been described and passed on to several German manufacturers.

A new innovation that is still in the laboratory phase is the Black-Contact-Back-Junction solar cell. With this cell, not only both metal poles are located on the rear side of the cell but also the collecting emitter. This reduces shadowing losses still further. The ISE researchers performed the necessary process steps of metallization and structuring using screen printing. The 37 x 45 $mm^2$ cell has an efficiency of 20.0 %.

## Two into one

A project of the Helmholtz Centre Berlin for Materials and Energy (HZB), in collaboration with the Hameln Institute for Solar Energy Research (ISFH), proves that "hybridising" of the back contact concept leads to an impressive improvement in efficiency. At the end of February, both renowned institutes were able to report a veritable jump in efficiency: this was not the usual small improvement expected in the solar industry but rather an impressive increase from 16 % to 20.2 %. The scientists achieved this result with a "back-contacted hetero-transfer solar cell", also known as a "heterojunction" cell.

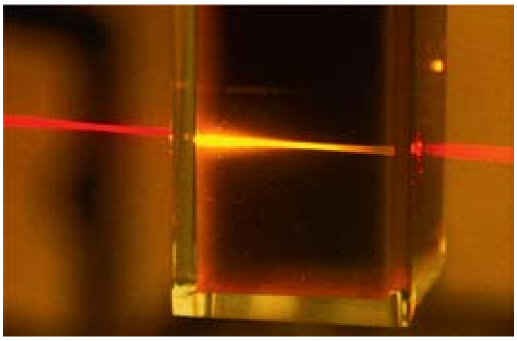
The industry has shown great interest in this development. The companies Bosch, Schott Solar, Sunways and Stiebel Eltron are participating in this development. The independent evaluation and measurement of the cell was performed by the Fraunhofer ISE in Freiburg. With this cell, the researchers in Berlin and Hameln have combined two concepts to utilise the advantages of both: the rear side contacts avoid the effects of shadowing on the front of the cell. In addition, the contacts on the back side can be thicker, thus providing less resistance, because no attention needs to be paid to reducing the effects of shadowing by the contacts.

Second: with the heterojunction technology, two different semiconductors are used for the improved cell concept. As with the approach followed by Roth & Rau, this uses the normal crystalline Si material and also a thin film of amorphous silicon. HZB President Bernd Rech justifies this choice as follows: "Both processes have the advantage that they are already used on an industrial scale." Combining both concepts allows the cell to utilise a significantly wider spectrum of light. According to Rech, the combination of both materials has the potential to achieve an efficiency of 25 %. The scientists at both institutes now want to increase the efficiency even higher than 20 % while also simplifying the manufacturing process.

Up to now they have only been able to achieve the high efficiency with a small laboratory cell. The next task is to scale up the process. "The ISFH will develop the cell concept to be suitable for industrial production," says Jan Haschke, an HZB scientist working in the project group. Haschke explains that another aim of the research is to reduce the costs. Up to now, complicated procedures such as photolithography make the manufacturing process long and expensive. Haschke explains the roots of the process: "The manufacturing process is very similar to that used in the microchip industry."

## Space experiment improves Poly-Si

The solar industry is also attempting to raise the levels of efficiency further towards the start of the value added chain. Growing of the Si crystal is the origin of all success factors here. If the process does not run according to the plan and specification then the only option is to abort the production. The melt, ingot and silicon block cannot be repaired. Simply explained, the process is as follows: the polysilicon is first melted. Various methods are then used to initiate crystal formation directly from the melt and the solid silicon body begins to grow.



**Turbocharged cell: the red light from a laser pointer is converted to higher-energy yellow light on passing through the photochemical upconverter liquid.**

Photo: University of Sydney

However, the crystallisation process results in damaging silicon carbide particles. They occur during crystallisation through the entry of carbon into the silicon melt via the gas atmosphere when the solubility limit is exceeded. The particles float through the body of the 1,400 degree melt and can become included in the crystal when it hardens.

Similar SiC particles are useful as an abrasive in the slurry when cutting wafers but they create problems when embedded in the crystal. They remain as islands of hardness in the crystal and present a massive obstacle to the mechanical processing. For example, all the cutting parameters are designed for a silicon content of 100 % in the melted block when wire sawing the wafers. When the saw "hits" the isolated SiC particles in the crystal, the ultra-thin saw is diverted and this can sometimes render the wafer unusable. For example, this can cause the thickness of the wafer to deviate outside the specifications. In addition to this, such out-of-tolerance cuts are frequently a location for short-circuit currents, which significantly reduces the efficiency. It is therefore obvious that the inclusion of these particles in the crystal must be avoided.

According to a press release from the Fraunhofer Institute for Integrated Systems and Device Technology (IISB), various theoretical work predicts that the inclusion of the particles depends on the speed at which the crystal hardens. If this speed lies below the critical growth limit, the particles are pushed ahead of the solid-liquid border and are not included in the crystal. At least this is what the theory says, however, it can be observed that SiC particles still trickle into the crystal despite a very low growth speed.

This is where gravity comes into play. This affects the flow of the melt which in turn affects the distribution of the particles within the melt. The researchers now want to exclude this gravity-induced effect by testing in space. Under weightless conditions they want to check if the existing theories on deposition of the particles are correct or perhaps do not apply to silicon in this form.

They are therefore preparing an experiment to examine the behaviour of the Si melt at a height of 270 km. By varying the parameters of the experiment they want to determine the typical limit speed at which the melt begins to absorb the SiC particles. The long-term results of this research should provide insight into the crystallisation process and the inclusion of foreign bodies. When this allows avoidance strategies to be developed then it will be possible to manufacture excellent, almost fault-free wafers, which will greatly increase the cell efficiency. The German research rocket will start from Northern Sweden next year.

## Si cell with turbocharger

One possible way of improving efficiency is via the usable light spectrum of the absorber layer. The wider the usable spectrum, the higher the performance of the solar cell. However, this approach has physical limits. The quasi-natural limit for the efficiency of a solar cell is around 30 %. Solar cells cannot absorb light at wavelengths above or below limits that are specific to the materials used. The energy of this light is lost. Even when one uses first-class raw materials, a perfect production process and a cleverly designed cell concept, it will be difficult for silicon cells to achieve the long-term target of 25 % efficiency in large-scale production.

Researchers at the Helmholtz Centre in Berlin have now developed a type of "turbocharger" for silicon solar cells. This is known as "photochemical upconversion". For non-chemists: two low-energy photons are bundled to a single high-energy photon. The photochemical solar cell turbocharger uses organic molecules to combine low-energy red photons into higher-energy yellow photons. The know-how lies in the selection of the molecules, which are provided as two different solutions. The energy transfer occurs when the two types of molecules encounter each other. This releases so much energy that it can be absorbed by the solar cell.

Project Manager Klaus Lips from HZB emphasises that for the first time it has been possible to demonstrate an improvement in solar cell efficiency resulting from photochemical upconversion. Although the efficiency improvement of 0.1 % is rather small, the path to further improvement is clearly evident. "We have not yet used a 25 % high-performance cell for the currently published concept study, as would be necessary in practice."

## Flexible forms for BIPV

Far away from the actual production process, there are applications in crystalline cell and module technology providing other opportunities for gaining an advantage in global competition. These are of course specialty products. Ever more small and medium sized companies are finding it difficult to compete with high-volume manufacturers in the standard technology markets. With prices being cut across the market, the companies with the least amount of financial room to move will not be able to compete. All that remains for these companies are niche markets.

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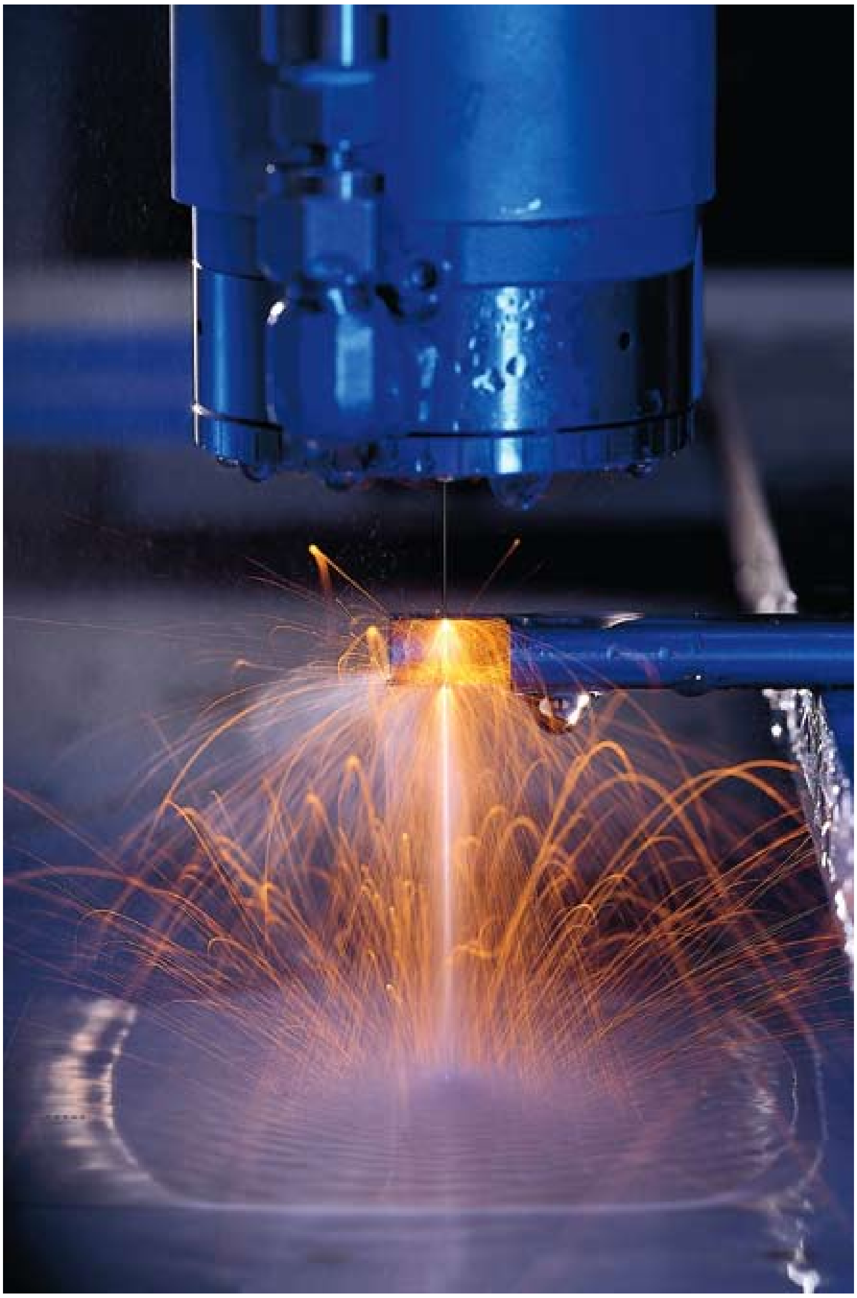

**Laser Microjet in operation: the waveguide principle of the water jet guides the pulsed laser beam to the workpiece. The cut edges are perfectly parallel to the water jet. The water jet has a cooling effect on the workpiece while cutting.**

Photo: Synova S.A.

Preferably a market requiring special know-how and which is therefore difficult to attack.

Building integrated PV is a niche of this type. BIPV requires detailed and exact knowledge of the corresponding construction standards and very special processes in order to meet the wishes of architects and building owners. “Tailor-made solutions are in demand in the BIPV sector and one cannot get very far with one-size-fits-all modules,” says Florent Bruckert, an R&D Engineer in the Swiss company Synova.

The company has developed a micro jet laser that can be used to cut solar cells. “This ability to cut cells to exact dimensions opens a whole new field in BIPV applications,” he reported in a well-received presentation at Photonics West in San Francisco at the end of January this year. “This allows us to bridge the gap between the standard cells and the tailored solar cells required for BIPV.”

Many attempts have been made in the past to produce solar cells in any desired form. Up to now, the usual industrial approaches were based on mechanically breaking the cells, with techniques such as cutting with a diamond wire saw or removing material by grinding etc. However, all these procedures damage the cell at the cut edges. Another objection to these methods is the limited range of possible shapes: breaking, sawing, etching or grinding only allow straight cuts. Lastly, the speed of these procedures is greatly limited.

## The dream team: water and lasers

Only “dry” laser cutting is able to provide free-form flexible cuts. However, dry laser cutting often causes damaging leakage current. The thermal loading also leads to undesirable changes in the crystalline structure at the cutting edges. Bruckert describes the target as follows: “We were looking for a solution providing a higher processing speed and better cutting edges that is also able to deal with thin wafers.”

As so often in the photovoltaic industry, the solution to the problem came from the semiconductor industry. Cutting of wafers is an essential process in the semiconductor industry. With the Laser MicroJet, Synova has now combined two slightly modified processes: water jet cutting and lasers. Each method has its disadvantages. Laser light is able to heat materials to over 1,000 degrees, causing it to melt and finally evaporate. However, this results in the previously described damage to the wafer.

The same applies to the abrasive water jet. It has the advantage of being cold and does not induce any heat in the wafer. At a powerful pressure of 3,000 bar it is easily able to cut metal and silicon. Unfortunately, a thin solar wafer would not be able to deal with the application of such massive force.

Scientists at the École Polytechnique Fédérale de Lausanne (EPFL) have been able to combine both processes. This makes use of the specific advantages of each process: the cold water jet and the low-force laser. Synova has now implemented this concept in their production technology. The principle: a laser beam is channelled through a water chamber and then focused in a jet. The secret lies in the special geometry of the jet and the laser. This ensures that a water jet becomes coupled into the laser. When the laser beam hits the material, the surface heats up forming plasma. This separates the water and allows only the laser to pass through. Because the laser is pulsed, the water jet cools the cut edge during the pulse pauses so that only a small amount of heat is induced in the cell or the wafer. The process can achieve impressive cutting speeds, a 200 micrometer thick wafer from the semiconductor industry can be cut at speeds of up to 80 mm/s, but the most important aspect for the use in BIPV is the ability to cut a flexible range of shapes. Bruckert summarises the results of the experiment: “In all cases we could cut any desired form, regardless of whether the contacts needed to be cut through or not.”

*Jörn Iken*

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