Lasers have long been the tool of choice in the thin-film sector and they are beginning to be used on a research basis in organic photovoltaics. Solar cell manufacturers are hoping that the future will see rapid advances in laser technology to make the production more efficient and to improve cell and module efficiency.

**Various application areas**

For processing thin-film modules, the German company Trumpf offers micro-processing lasers as part of its TruMicro series. The TruMicro 3000 series is particularly suited for solar modules made from amorphous silicon or cadmium telluride where extensive conductive and photoactive layers are applied to a substrate. After each coating, a laser subdivides the surface so that the cells are automatically connected in series. “Small compact devices such as the lasers from the TruMicro 3000 series are – with their 1,064 and 532 nm wavelengths – ideal for P1, P2 and P3 patterning. Thanks to their pulse-to-pulse stability, diode-pumped solid-state lasers not only deliver excellent process results, their cooling concept also enables them to be directly integrated into specific systems without any great effort,” explains Holger Kapp, press spokesman for Trumpf GmbH.

The company offers picosecond lasers from its TruMicro 5000 series with a wavelength of 1,030 nm for structuring molybdenum and a wavelength of 515 nm for processing photoactive materials and structuring the front contact. “Their short pulses ablate the material without significantly heating the process edge zone, which prevents cracking, melting...”
or exfoliation of the layers,” says Kapp. For edge-stripping thin-film modules, where the layer system is first removed along the edge to a width of around 1 cm before being laminated with a film and encapsulated, Trumpf recommends the TruMicro 7050 because it can process large formats reliably and securely.

**For research and production**

Jenoptik Laser, which is headquartered in Jena, Germany, also offers a range of new products for producing solar modules. Jenoptik in fact offers three different products for laser-structuring thin-film modules. According to the manufacturer, its Votan Solas 100/200 is able to conduct all structuring processes for all thin-film technologies. With beam widths of 15 to 100 μm, this solution has particularly high structuring qualities. It neither delaminates nor damages the glass, and the microcracks in the individual layers are reduced. In addition, it offers highly precise throughput rates and process stability. The Votan Compact 500 is an R&D system that provides thin-film solar module producers, development laboratories and institutes with structuring processes during the development stage at a production level. In addition, the company’s product range currently includes an R&D pilot machine, the Votan Solas Multi, which is used for optimising the structuring of thin-film solar modules in their original size. Corresponding lasers and tools for structuring as well as functionalities for laser edge-stripping are integrated here into one machine concept, whereby the processing can be automatically aligned to take place on both the glass side and the coated side. The machine resolution is designed for processing glass formats ranging in size from 300 mm x 300 mm to 1600 mm x 1200 mm and for substrate thicknesses ranging from 2 to 6 mm.

For laser edge-stripping thin-film solar modules, Jenoptik has developed the Votan Solas 400. This system was modularly designed to enable integration into production lines. The ablation rate is up to 50 cm²/s.

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The Equinox-Pilot is equipped with a load/unload wafer turntable. It is particularly suited for the production qualification of laser-based processes prior to full production line implementation.

Photo: Coherent

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Depending on the configuration, the productivity is specified with more than 60 respectively 120 modules per hour. The Votan Solas 600 is particularly suited for laser edge-stripping semi-transparent thin-film modules used for building integration. Before the module is assembled, the machine ablates selective areas of the active layer, whereby the transparency and the ablation pattern can be freely chosen.

Jenoptik has designed the Votan Solas 500 for laser separation. This machine solution, which uses a very accurate laser to separate the glass substrates of varying thicknesses required for producing thin-film solar modules, is based on thermal laser separation (TLS) technology. According to Jenoptik, the solution’s benefits include not only non-contact and safe processing of various glass thicknesses but also splinter-free laser scribing and cutting, whereby the edge quality, stability and thermal shock resistance are increased. Coatings remain undamaged right up to the edges and thus remain fully functional.

Around six months ago, the Rofin-Baasel Lasertech company launched its PowerLine L series of solid-state lasers, which, thanks to their high laser performance and pulse energy, are particularly suited for the high-speed processing of micro-materials in the photovoltaic sector. This processing includes, for example, the ablation of thin films on glass or flexible materials, the ablation of dielectric coatings and the processing of silicon, including drilling and cutting operations. With a wavelength of 1,064 nm and 300 W, the company claims that the PowerLine L 300 is particularly suited for edge-stripping thin-film cells.

In contrast to the company’s DQ series of laser sources, which offer 500 and 1,000 W, it has the advantage that it uses thinner optical fibres and, in particular, a square fibre with a 400 μm diameter. Compared with round fibres, this increases the area that can be processed with a pulse by up to 51%. “Because of the low throughput and relatively low price, the new product is particularly suitable for use in small cell production lines,” says Sales Manager Richard Hendel.

The frequency-doubled PowerLine L 100 SHG, on the other hand, is ideal for selectively opening dielectric layers and direct laser doping. “Its green light with 532 nm shows the desired near-surface absorption in silicon and enables, in contrast to shorter wavelengths, the use of a wide range of high quality and durable optical components and optical fibres,” explains Hendel.

Lasers for crystalline cells

The US company, Coherent Inc., also offers two new process systems for manufacturing solar cells – however based on crystalline silicon. Both its Aethon and Equinox systems are fully integrated process tools that, according to the company, now allow solar cell manufacturers to simplify the use of laser processes in applications that enable a high efficiency of solar cells. Such applications include edge isolation, dielectric ablation for producing photo masks (diffusion and metallisation) and laser-assisted selective-emitter formation including dopant diffusion, emitter or metal wrap-through, and etch-barrier ablation for the wet-chemical surface structuring of multi Si wafers. The Aethon platform is designed for early-stage R&D where a range of different laser-based processes are under evaluation. Integrated within the Aethon tool are high-speed beam-scanning optics as well as software-controlled wafer positioning hardware and an error diagnosis programme.

The Equinox tool was specially developed for high-throughput operation and is offered in two formats. The Equinox-Pilot is configured with a load/unload wafer turntable and is ideally suited for the production qualification of laser-based processes prior to full production line implementation. The Equinox-Fab, on the other hand, is optimised for high-throughput production line capability with up to several thousand wafers per hour. All Aethon and Equinox process tools can be equipped with any of Coherent’s nanosecond or picosecond precision manufacturing lasers. In addition, both tools can incorporate multiple lasers as demanded by the process throughput and flexibility.
Research continues

Various international research institutes are working on innovative concepts to further develop laser-assisted solar cell manufacturing. The most well known project currently underway is probably the Solasys project (Next Generation Solar Cell and Module Laser Processing System), which runs until the end of August 2011. Under the auspices of the Fraunhofer Institute for Laser Technology (ILT), European laser manufacturers, solar power companies and research institutes are looking to optimise laser processes by this date. This project is concerned with high efficiency, low-damage edge isolation, high-speed micro drilling and damage-free laser ablation of dielectric layers on crystalline cells. Ultrashort, picosecond pulse lasers are being utilised here for the ablation. In addition, new production concepts are being investigated that involve the use of laser soldering for the module manufacturing and laser doping for manufacturing selective emitters. Within the project, it is intended to develop laser prototypes that are individually matched to the various processes and are combined with high-speed laser scanning systems to achieve very high processing speeds. The ultimate aim is to demonstrate the new laser components and processes in various photovoltaic manufacturing systems with an industrial-scale production rate of 2,000 wafers per hour. A key element of the overall project is concerned with modifying and adapting laser sources and laser processes to the requirements of photovoltaic production. “What is novel about the project is that it is intended to shape the laser beam both temporally and spatially so as to achieve the highest possible processing speeds. For example, when drilling emitter-wrap-through cells, the aim is to achieve 20,000 drilling points per second,” explains Project Coordinator Arnold Gillner from the Fraunhofer ILT.

A whole series of problems have to be solved by the end of the project. For example, researchers are currently investigating whether it is possible to achieve a beam distribution and thus parallelisation of the processing with diffractive optical elements. In addition to the speed, it is above all process stability issues that are currently posing problems to the scientists.

Micro-structuring

The Fraunhofer Institute for Solar Energy Systems (ISE) has developed a process for improving the production of wafers and solar cells based on laser chemical processing (LCP).

LCP is a new micro-structuring method for various applications that combines a chemical liquid jet with a laser beam to initiate thermal and photochemical reactions. The process is suitable for the following applications: damage-free silicon micro-structuring, edge isolation, selective doping of phosphorus and combining doping with edge isolation. “Currently one of the greatest challenges is concerned with forming heavily doped selective emitters...”
under the metal fingers of the solar cells,” explains Dr. Filip Granek from the Solar Cells Development and Characterisation department at the Fraunhofer ISE. Last year, the researchers succeeded for the first time in manufacturing fully functioning, large-scale multicrystalline solar cells with LCP-selective emitters. They achieved a cell efficiency of 19% for industry-grade solar cells.

The principle behind the process is not actually new. It was developed by Daniel Kray and Gerhard Willeke and presented to the public in 2001 under the name Laser Chemical Etching (LCE). The name was based on the underlying idea of achieving damage-free silicon ablation in wafer manufacturing applications. The focus then shifted to micro-structuring and enlarged to include, for example, the local doping of selective emitters and metallisation, resulting in the new name LCP.

**Crystallisation of silicon**

New silicon thin-film solar cells are currently being developed by various research groups, including at the Institute of Photonic Technology (IPHT) in Jena, Germany. There, layers up to 1.6 μm thick are produced using solid-phase epitaxy, whereby an amorphous silicon coating with the required doping profile is applied to the seed layer. In an oven process, the layer is converted epitaxially at 600 °C, whereby the crystal structure of the seed layer is reproduced. The institute has also developed a second variation called Layered Laser Crystallisation process. Here, amorphous silicon is continually vapour deposited on the seed layer and regularly irradiated with the pulses from an excimer laser. The laser radiation melts the newly deposited amorphous silicon, which hardens epitaxially on the crystalline substrate. The laser can radiate through a window on the deposition plant without interrupting the vapour deposition and does not require any additional time. A cw diode laser with a wavelength of 810 nm is used for crystallising the seed layer. “However, even shorter wavelengths are actually required for this process, because these can be better absorbed by the silicon,” explains Fritz Falk, Head of the Photovoltaics Systems Research Department at IPHT. The process developed at the institute is unique in that the researchers are the only ones so far to have been able to create such large crystals on glass. Although the Fraunhofer ISE is also working on a similar process, they are not using glass as a substrate but graphite. A further alternative is the use of metal films.

The main advantage of the new process is that it enables efficiencies to be achieved that are comparable to those of multicrystalline wafer cells with considerably reduced manufacturing costs. A further advantage is that the optoelectronic quality of the layer is not dependent on that of the amorphous output material, which enables the more cost-effective electron beam evaporation process to be used for the vapour deposition instead of PECVD (plasma-enhanced chemical vapour deposition). “However, it will still take two
Lasers for organic PV

Laser-assisted manufacturing processes are also already beginning to be developed in the organic photovoltaics sector. A significant aspect in producing these solar cells is the monolithic serial connection of the cells in organic thin-film modules. It is very important that the structuring paths achieve an optimum edge quality without damaging the substrate or the lower-lying layers. The Laser Centre Hanover (LZH), Germany, is working on suitable laser structuring processes as part of its “Polymer Photovoltaic Processing” research project, which was launched on 1 October 2009 and continues until the end of September this year. The aim is to develop an industrial-scale mass production process for organic solar modules that enables the costs for the currently still very expensive organic material to be reduced. The researchers already have full functioning modules, although as Head of Project Dr. Aart Schoonderbeek points out, there is still a need to optimise them in terms of the efficiency. Furthermore, the organic materials are still very sensitive to moisture and oxygen. In order to protect the modules, many research institutes and companies are working on developing improved films for the encapsulation. However, by means of short pulse and ultrashort pulse lasers (nano- to femtoseconds) and different wavelengths, the scientists at LZH are already able to realise all three structuring stages required (P1-P3). The coatings do not take place at LZH but at the project partners. “By the end of the project we want to realise these steps for all three layers – in other words for both contacts and the active layer – in the demonstrator. The next stage would be a roll-to-roll process,” says Schoonderbeek.

Until that is achieved there is still a whole series of problems to solve. For example, measures must be developed that enable these processes to be realised in a protected atmosphere, whereby it is intended to ensure the process safety using suitable process monitoring with electronic and display systems. Nevertheless, compared with conventional processes such as chemical etching or printing, the laser-assisted process offers several advantages. “Whereas the area lost on the module is relatively high with chemical etching, this is not the case with laser-assisted processes. Greater speeds can also be achieved with the laser than with printing. Furthermore, lasers can scribe narrow lines considerably less than 100 μm wide that are very closely spaced,” says Schoonderbeek.

Conclusion

What are the future challenges for laser research? Arnold Gillner from Fraunhofer ILT believes that these lie in texturing surfaces to achieve best possible absorption rates, in new connection concepts, modifying amorphous and crystalline silicon layers, and in monocrystalline layers. He also sees a trend in this research field towards hybrid cells and predicts that applications in the organic photovoltaic field will also increase.

Anette Weingärtner