

## LASER TECHNOLOGY IN PHOTOVOLTAICS



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### Fraunhofer Institute for Laser Technology ILT

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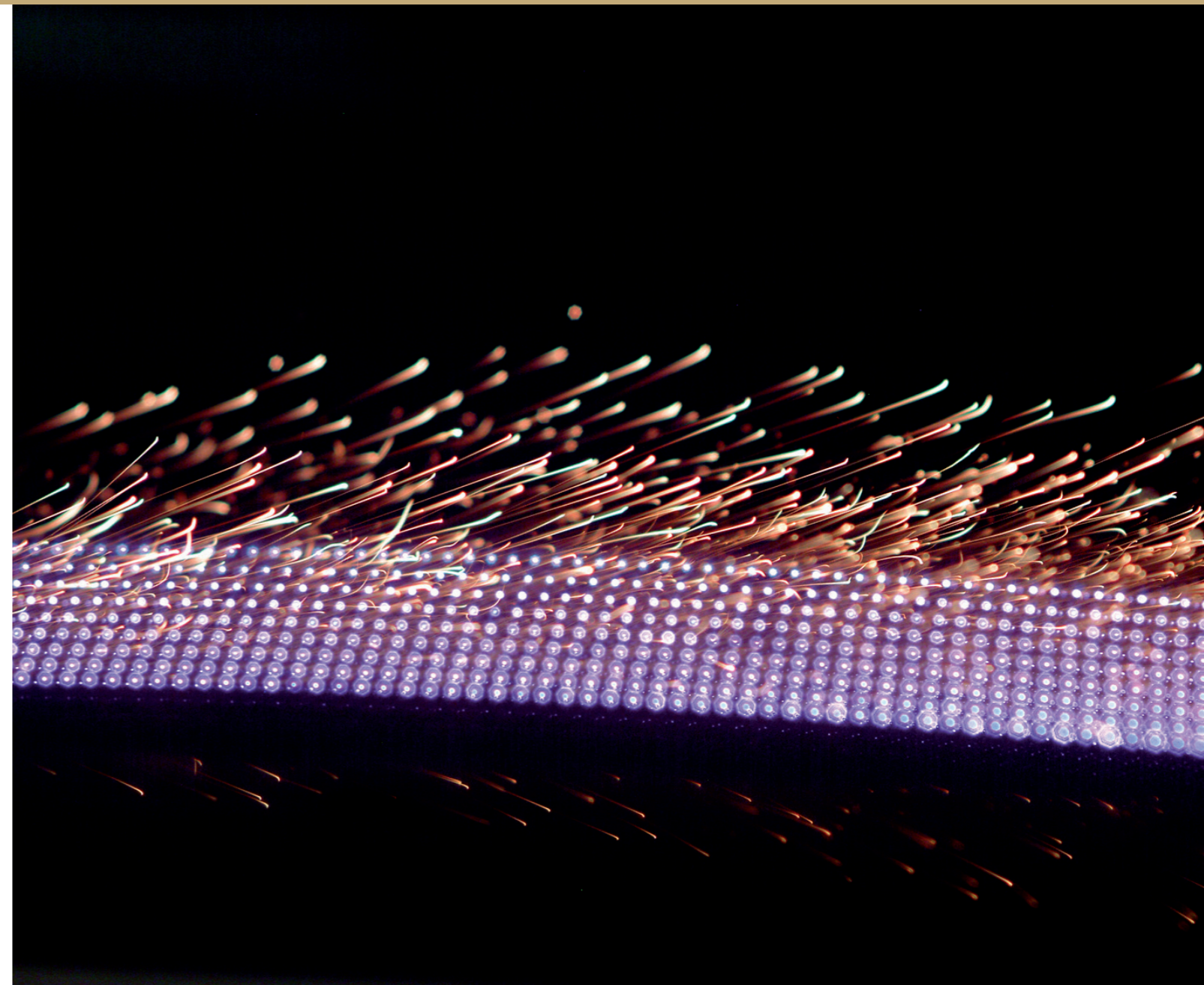
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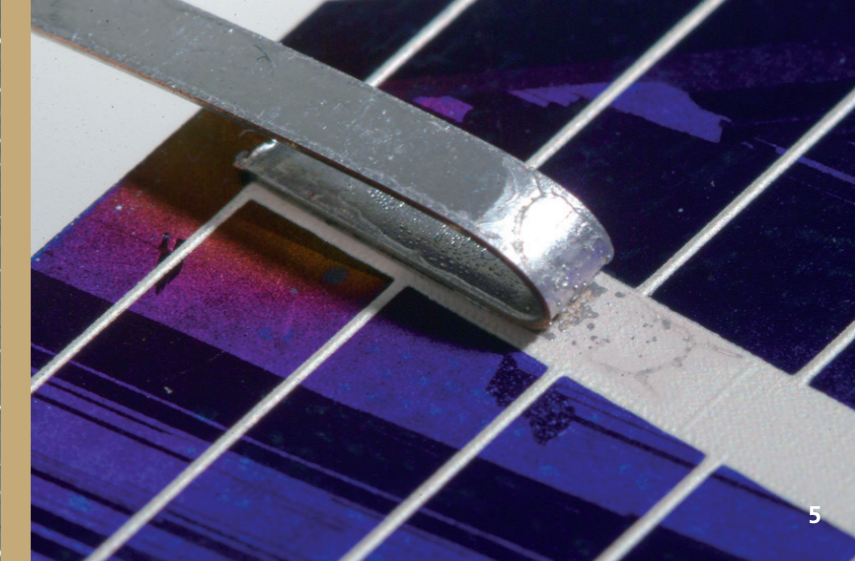
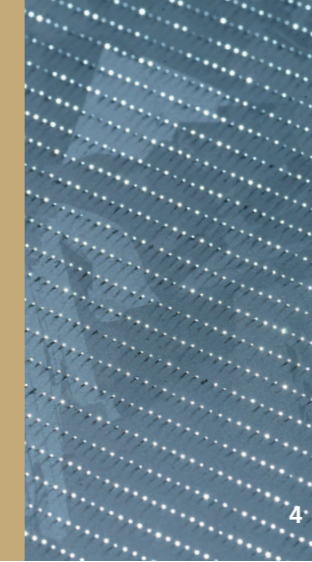
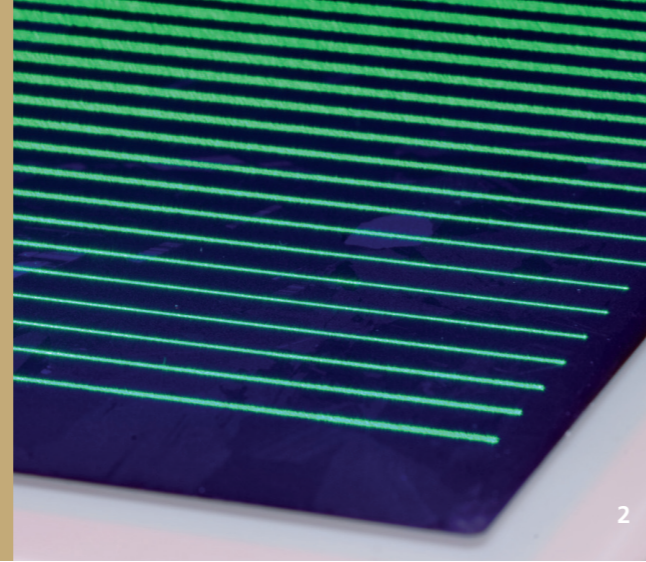
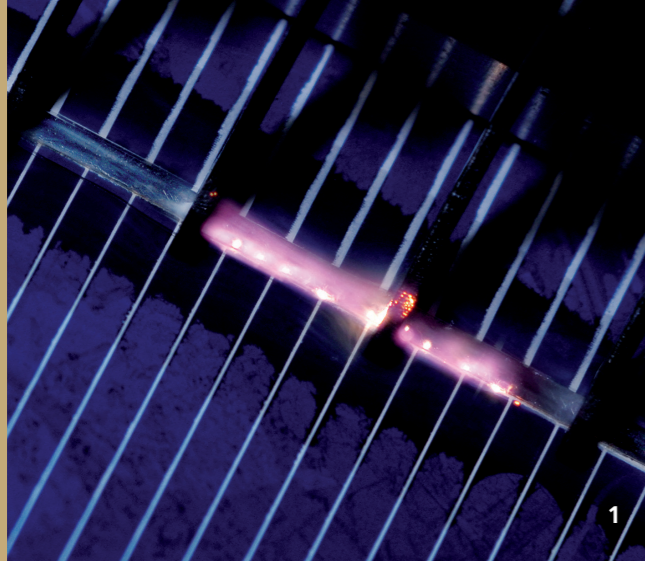
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### Fraunhofer Institute for Laser Technology ILT

The Fraunhofer Institute for Laser Technology ILT is one of the most important development and contract research institutes in laser development and application worldwide. Its activities encompass a wide range of areas such as developing new laser beam sources and components, laser-based metrology, testing technology and industrial laser processes. This includes laser cutting, ablation, drilling, welding and soldering as well as surface treatment, micro processing and additive manufacturing. Furthermore, Fraunhofer ILT develops photonic components and beam sources for quantum technology.

Overall, Fraunhofer ILT is active in the fields of laser plant technology, digitalization, process monitoring and control, simulation and modeling, AI in laser technology and in the entire system technology. We offer feasibility studies, process qualification and laser integration in customized manufacturing lines. The institute focuses on research and development for industrial and societal challenges in the areas of health, safety, communication, production, mobility, energy and environment. Fraunhofer ILT is integrated into the Fraunhofer-Gesellschaft.





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Solar energy is indispensable to tomorrow's energy mix. To ensure photovoltaic systems are able to compete with conventional fossil fuels, production costs of PV modules must be reduced and the efficiency of solar cells increased. Laser technology plays a key role in the economical industrial-scale production of high-quality solar cells. Fraunhofer ILT develops industrial laser processes and the requisite mechanical components for a cost-effective solar cell manufacturing process with high process efficiencies.

### Structuring of Thin Films with Ultrashort Pulse Lasers

Solar cells produce electrical current through a photoelectric effect in semiconducting materials. In the case of conventional silicon solar cells, a thin conductive layer of metal is applied for contacting the doped silicon. In modern organic thin-film solar cells, not only contacting, but also semiconducting layers are applied to a transparent film. In addition, thin anti-reflection and passivation layers are used for both thin-film and silicon solar cells, which lead to an improvement in the optical and electrical properties of the solar cells and thus to higher efficiencies. For both types of solar cells, these thin layers must be selectively removed at defined points with high precision. This can be achieved with high throughput at speeds of up to 10 m/s and high precision with ultrashort pulsed laser radiation. With an adapted temporal and local shaping of the laser radiation, ultrashort pulse lasers permit a complete removal of the layers with a line width of a few micrometers without damaging the substrate or the underlying layer.

### Structuring Transparent Conductive Layers for Organic Electronics

Layers with thicknesses fewer than one hundred nanometers are extremely sensitive and can easily degrade or lose their functionality. The reasons for this can be particle debris or delamination of irradiated layers, thermal damage of neighboring areas and other layers, as well as the generation of bulges in the outer areas of the ablations. In order to achieve a sufficiently high quality, parameters – such as gas atmosphere, spatial and temporal pulse shape, and subsequent cleaning – have to be taken into account while the process is developed. Alternatively, one can fall back on hybrid processes such as thermochemical ablation. In particular, during structuring of the transparent conductive Indium tin oxide (ITO) – commonly used in organic electronics – bulges can form, which are problematic for subsequent layering. The Fraunhofer ILT is developing processes which can significantly reduce these sources of defects according to the requirements of the application, for example by using adapted wavelengths, pulse durations and ablation strategies.

1 Laser beam soldering for the interconnection of solar cells.

2 Laser beam ablation of silicon nitride layers.

### Structuring Silicon Solar Cells for Increased Efficiency through Absorption Optimization

Anti-reflection layers on silicon solar cells lead to reduced reflections on the cell surface, thus increasing their efficiency. To exploit the energy potential of solar radiation, reflections must be further minimized and absorption maximized. In order to achieve this in silicon solar cells, their surfaces are processed by means of laser radiation and plasma etching. Processing with laser radiation enables a defined periodic microscale structuring of the surface, which facilitates the absorption of the most energy-intensive part of the solar spectrum. In the subsequent plasma etching process, a nano-structure is applied to this microstructure, which reduces the reflection even more. It is a combination of surface structures that will increase the efficiency of silicon solar cells.

### Laser Beam Doping for Selective Emitter Formation

In the manufacturing process of wafer-based Silicon solar cells the raw wafer is doped with Phosphor to create the emitter and thus the essential pn-junction. In today's production a trade-off is necessary between conductivity of the Silicon and the life-time of the free carriers, the former requiring a high, the latter a low doping concentration. Using selectively controllable doping profiles of the emitter the cell efficiency can be improved. Starting with a weakly doped emitter the doping concentration is increased locally at the positions of the metal contacts. For this selective doping process the laser is an ideal tool, with which the Silicon is locally heated respectively molten. The use of different dopant sources (gaseous, liquid or solid in the form of thin phosphor glass layers) allows the variation of the profiles, different laser wavelengths with suitable penetration depths and process adapted temporal irradiation profiles are used. With proper selection of process strategies, the doping process can be combined with the structuring process, which simplifies subsequent metallization.

### Soldering and Welding of Solar Modules

For the production of solar modules from individual solar cells, several cells are electrically connected with long-term stability. Currently the contacting is done with infrared or selective thermode soldering. Thermal and mechanical stress created during these processes leads to the formation of cracks, which is especially dangerous for thin wafers. The laser soldering process allows strongly localized energy deposition without heating the whole wafer. In addition the process is controlled with a pyrometer, so that the laser power can be adapted in real-time during soldering to achieve a constant temperature even at varying material conditions. This allows an ideal temperature profile on the cell and a minimum of heat input. Using a setup with two beam paths simultaneous soldering of the front and back contacts is possible, which enables process times below three seconds per cell. For future cell concepts laser beam welding allows a decrease of the processing times by a factor of ten compared to soldering.

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3 Ablated lines in the silicon nitride layer.

4 Laser beam high speed drilling for EWT cells.

5 Laser beam soldered cell connector with tensile strength of > 4 N.