

1 High resolution inkjet printer during optical alignment.

2 Flexographic relief plate (cliché) for high volume printing of contact grid lines.

## FUNCTIONAL PRINTING

Equipped with an excellent infrastructure and long-standing expertise, Fraunhofer ISE offers a variety of services in the field of functional printing. Silicon solar cells serve as a well-known example for printed devices which are produced on an industrial level. The future of solar cells lies in optimization and higher efficiencies, which can be achieved by developing new cell concepts. With increasingly sophisticated cell concepts, new printing processes featuring high precision and fine details are required in the production.

At PV-TEC (Photovoltaic Technology Evaluation Center) our pilot production line for silicon solar cells features state-of-the-art printing technologies such as screen, stencil, inkjet and flexographic printing and dispensing technologies. Our services include in-depth characterizations of ink and paste rheology, substrate surface conditions as well as the geometry and electrical performance of printed structures. With our expertise we assist both material suppliers as well as equipment and device manufacturers, for example, in selecting a suitable printing technology

or in developing functional materials or innovative processes. Our know-how can be applied to other areas such as displays and batteries.

### Methods of Printing on Solar Cells

One focus of our research is reducing the grid line width of solar cells. For conventional solar cell structures with a printed front side grid, we developed screen and stencil printing processes to realize grid line widths of less than 50  $\mu\text{m}$ . In-house we developed a parallel dispensing print head with which line widths below 30  $\mu\text{m}$  and aspect ratios above 0.7 can be achieved. Using this dispensing technology, we have demonstrated solar cell conversion efficiencies of 20.6 % on industrial large-area solar cells.

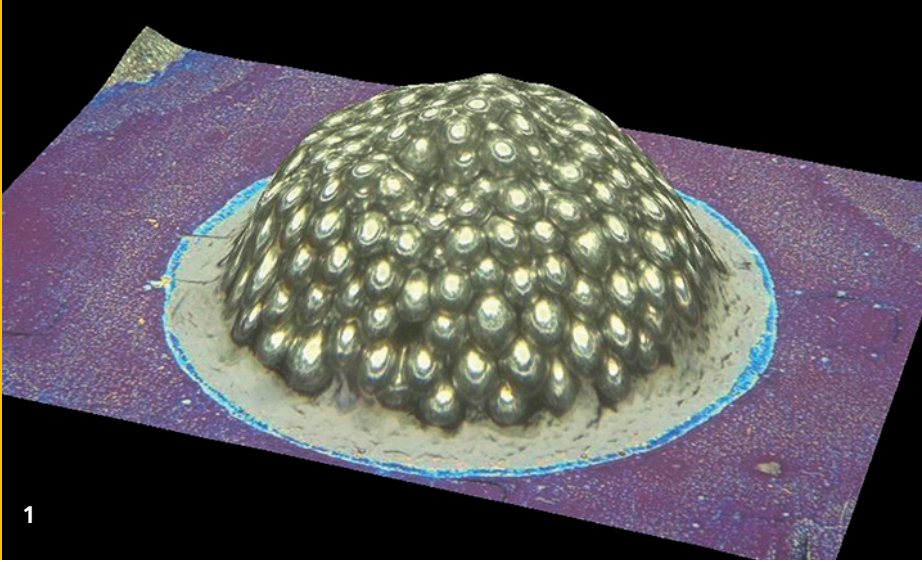
BC-BJ (back-contact back-junction) solar cells feature both polarities of the metal electrodes on the rear side, thus eliminating shading due to the grid fingers. In PV-TEC we produce BC-BJ solar cells with conversion efficiencies above 20%. All structuring steps were realized by applying hotmelt etching masks with an industrial inkjet printer. Dimensions below 20  $\mu\text{m}$  are possible.

### Fraunhofer Institute for Solar Energy Systems

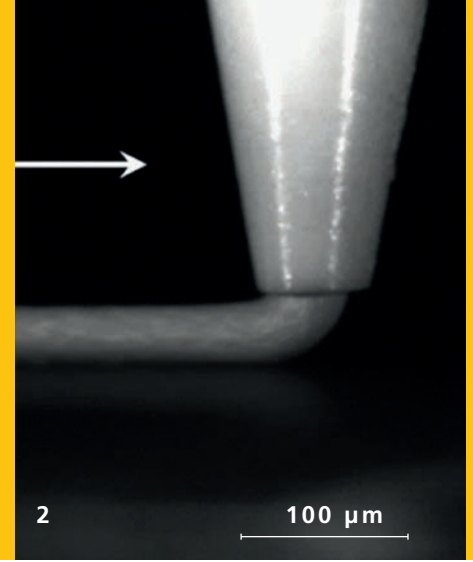
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### Silicon Photovoltaics – Production Facilities and Process Development

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1



2

100 μm

### Infrastructure and Expertise

We have a wide range of high-quality printing equipment at our disposal, which allows us to perform a variety of different processes. Most of our printers feature high precision optical alignment, meaning that customized structures, requiring multiple printing or structuring steps, can be realized. Simulation and characterization also play a large role in the services we offer.

### Screen and Stencil Printing

- fully automated screen printing line with ASYS printers and Centrotherm inline dryers
- semi-automated Ekra and Baccini printers
- UV inline dryers
- in-house screen development
- solar cell front and rear side metallization process
- etching processes for structuring of dielectric layers and silicon
- printing processes for dopant sources and diffusion barriers
- solder masks for advanced module concepts

### Dispensing

- semi-automated dispensing platform (Asymtec, Vieweg) for individual structures
- automated ASYS dispenser for high throughput production
- single-nozzle print heads for high flexibility
- multi-nozzle print head for high throughput (developed by Fraunhofer ISE)
- printing of dopants and etchants
- high aspect ratio printing process for grid lines with widths below 30 μm

### Flexographic Printing

- flexographic printing test platform for high-throughput metallization using low-cost polymer forms
- printing processes for grid lines with widths as low as 25 μm and very low silver consumption

### Inkjet Printing

- Schmid DOD 300 with temperature controllable substrate table (-5 °C to +70 °C)
- PixDro LP50 with temperature controllable substrate table (+95 °C)
- Dimatix DMP 2800
- print heads from FUJIFILMDimatix, Xerox, Trident and Océ successfully integrated
- printing of hotmelt masks that allow for the structuring of dielectric layers, silicon and metals
- printing of hotmelt masks as plating barriers
- printing of dopant sources and diffusion barriers
- etchant printing process for the selective structuring of dielectric layers and metals

### Simulation Tools

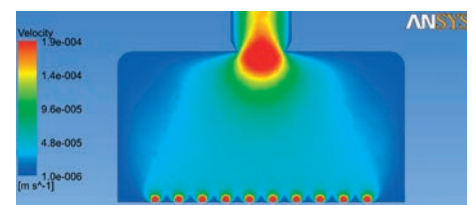
- analytic grid design tool "Gridmaster" enables optimal design of contact structures
- computational fluid dynamics with implemented paste rheology applied for multifunctional print head design

1 Laser scanning microscope image of a screen printed stack of Al, Cu and solder paste for advanced module integration of BC-BJ solar cells on printed circuit boards.

2 High-speed camera image of a dispensing nozzle during the deposition of silver paste.

### Choice of Characterization Tools

- rotational rheometer
- capillary viscosimeter
- contact angle measurement
- laser beam reflection for the measurement of particle size
- optical microscopes
- laser scanning microscope for 3D-measurements of structures
- scanning electron microscope including EDX detector
- transmission electron microscope including FIB (Focused Ion Beam)
- contact and sheet resistance measurements for printed structures
- statistical analysis of structures



3 Simulated velocity distribution of a functional fluid in a 10-nozzle dispenser print head.