Crystalline silicon thin-film (c-SiTF) solar cells present a promising concept to combine the advantages of conventional wafer-based silicon solar cells with those of thin-film solar cells: high and stable efficiencies and low production costs. In our approach, the electrically active base of the solar cell with a thickness of a few tens of micrometers is grown upon a substrate material, which gives the necessary mechanical stability. Subsequently, well-established cell process technology from wafer-based solar cells can be applied. Research and development at Fraunhofer ISE cover the entire manufacturing chain:

- development of substrates from low-cost silicon and ceramics
- adapted functional coatings (e.g. of silicon carbide)
- recrystallization of silicon
- deposition of silicon layers with customized doping profiles
- solar cell processes as well as new module concepts specifically adapted to our thin-film technology

Development of High Speed Epitaxial Silicon Deposition Tools

The development of a reliable epitaxial deposition and recrystallization process for crystalline silicon layers, which are transferable into the photovoltaic industry, is one of our top priorities and competences. For a long time, we have been focussing on atmospherical pressure chemical vapor deposition (AP-CVD) at temperatures up to 1300°C using chlorosilane as the silicon carrier gas. This process is well-known from microelectronics, but had to be radically adapted for photovoltaic applications in terms of throughput of the equipment at the expense of higher tolerable defect densities of the layers. At Fraunhofer ISE, we have developed different deposition reactors, ranging from very flexible batch-type laboratory setups to large multi-chamber deposition systems with the option of continuously depositing p- and n-type doped epitaxial layers. Our latest development, the ProConCVD, has been designed for near-industrial throughput demonstrating...
low-cost high-quality silicon epitaxy for PV. When using non-silicon substrates, a thin polycrystalline seed layer is deposited which is subsequently recrystallized. For this purpose a batch-type and a continuous zone melting recrystallization equipment have been developed and are available.

**Solar Cell and Module Concepts**

Our so-called wafer-equivalents, thin crystalline silicon layers on conductive carrier substrates, can be processed to solar cells just like “normal” silicon wafers. They profit from nearly any progress achieved in the area of standard wafer solar cells, like e.g. passivation or metallization technology. Some recrystallized wafer equivalents (RexWE) and module concepts however, based on cost-efficient substrates (such as e.g. zirconium silicate ceramics), require innovative methods for contacting and interconnection of the single cell. One approach is a wrap-through cell concept where holes are drilled into the substrate with a laser which enables rear contacting of either the base or the emitter from the non-illuminated side. On the module level, we are working on integrated designs with customized single cells which are interconnected with printing technologies.

**Innovative Solar Cell Processes**

The advantage of c-SiTF solar cells is their compatibility with wafer solar cell process technology. Beyond these, we are developing specially adapted cell process steps for c-SiTF solar cells, which also can be of great interest for wafer processing:

- epitaxially grown emitters and back surface fields which offer a large variety of dopant profile designs not limited by diffusion and with very short process times
- light trapping mechanisms such as structuring the back surface by epitaxial lateral overgrowth, or plasma texturing, creating very effective textures with extremely low surface removal
- chemical vapor etching, i.e. the chemical etching of silicon with HCl gas at elevated temperatures, able to substitute wet chemical damage etching or time-consuming external impurity gettering

1 Large chemical vapor deposition reactor for inline applications.
2 Zone Melting Recrystallization device.

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**Cell efficiencies of crystalline silicon thin-film solar cells on monocrystalline Cz substrates.**