Light Microscopy of Solar Cells
Whenever sunlight falls onto a solar panel, the individual solar cells capture the rays’ energy, converting it into electricity. Roughly speaking, the material absorbs photons, which causes electrons to be dislodged and leads to a current flow. This is known as the photovoltaic effect. Solar energy plays a significant role in the struggle to lessen our dependence on limited fossil fuel resources. Economic efficiency and cost-effectiveness count among the key aspects in the manufacture of photovoltaic panels. Therefore, strict requirements for quality control and cleanliness have to be met.

**Light Microscopy of Solar Cells**

Light microscopical investigations provide valuable information in solar cell research, development and production, including details such as surface texture, microstructure and homogeneity as well as thin film properties.

**Major Types of Solar Cells**

Two main types of solar cells dominate the market today – bulk silicon and thin film solar cells.

**Crystalline Silicon Solar Cells**

Crystalline silicon solar cells are fabricated from material varying in degree of crystallinity and crystal size, most notably monocrystalline and polycrystalline silicon. Monocrystalline silicon cells are produced from wafers cut from a single crystal ingot and yield highly efficient solar cells. However, these tend to be too expensive for mass production. Polycrystalline silicon cells on the other hand are made from cast blocks, are less costly to manufacture and therefore constitute a viable economical alternative to monocrystalline silicon solar cells, in spite of their generally lower efficiency.

![Crystalline silicon solar cells](image)

**Figure 1** Crystalline silicon solar cells.
Thin Film Solar Cells

Thin film technologies were developed in order to reduce the amount of material required in the production of a solar cell. Thin film solar cells consist of a number of layers providing individual functionalities such as light trapping and photovoltaic properties, collectively mimicking the effect of surface textured crystalline silicon. While the conversion effect of these cells tends to be lower, this technology does indeed make solar cells less expensive to produce. Well-known materials for this type of solar cells include (amongst others) cadmium telluride, gallium arsenide, silicon and – slightly more exotic – light-absorbing dyes.

Crystalline Silicon Solar Cells

Surface morphology of textured silicon solar cells
The front surface of silicon cells must be textured in order to trap as much light as possible and to prevent efficiency losses due to reflectance. On monocrystalline cells, surface texturing is usually achieved by alkaline etching, which creates a surface covered with pyramidal structures. On polycrystalline substrates different techniques are employed, including acid and reactive ion etching. Here the textured surface tends to adopt an irregular appearance made up of wormlike features. In either case, the homogeneity and regularity of the resulting surface texture needs to be ensured.
Analysis of Silver Fingers

Metal contacts are applied to both back and front of the solar cell. The contacts on the back are usually formed by screen printing using aluminum paste and may cover the entire area or take the form of a grid. Similarly, metal contacts are screen printed onto the front in form of a grid-like pattern, using a silver paste. The pattern consists of both fine structures, so-called "fingers", and larger "busbars". The typical size of the fingers is around 120 μm in width and (although this does vary) approximately 20 – 30 μm in height. Following the construction of the contacts, the cells are usually connected by flat wires, and assembled into solar panels or other modules. The microscopical examination of the fingers aims to confirm whether the imprint has been completed as intended.

Figure 4
Surface structures of mono- and polycrystalline silicon solar cells. 3D topography of the surface of a polycrystalline silicon cell imaged with an Axio CSM 700 confocal microscope with an EC Epiplan-APOCHROMAT 100x/0.95 objective.

Figure 5
Silver fingers on crystalline silicon solar cells. Silver finger on a polycrystalline solar cell, imaged with an Axio Imager microscope and an EC Epiplan-APOCHROMAT 20x/0.60 objective.

Figure 6
Silver fingers on crystalline silicon solar cells. 3D topography of a silver finger on a monocrystalline solar cell imaged with an Axio Imager and an EC Epiplan-NEOFLUAR 20x/0.50 objective using the topography module in the AxioVision imaging software.
**Insulation trenches**

Edge insulation constitutes one of the final steps in crystalline solar cell production and is normally performed either mechanically – with the help of a scribing needle – or by means of a laser. In this context, the light microscope is employed to ascertain that the insulation trench is continuous, of regular shape and constant depth. The analysis can be performed with a light microscope or a confocal system.

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**Figure 7**
Insulation trenches on crystalline silicon solar cells, created with lasers. Monocrystalline silicon solar cell imaged with an Axio Imager microscope and EC Epiplan-APOCHROMAT 20x/0.60 objective.

**Figure 8**
Insulation trenches on crystalline silicon solar cells, created with lasers. 3D topography of a poly-crystalline solar cell imaged with an Axio CSM 700 confocal microscope with an EC Epiplan-NEOFLUAR 50x/0.80.
Thin Film Solar Cells

Surface / silicon microstructure
Silicon thin film solar cells are produced by depositing a silicon layer of several micron thickness onto a supporting glass carrier. Crystallization of the silicon can subsequently be induced via a heat treatment. The resulting structural and mechanical characteristics – as for example distribution and orientation of the crystals, tension and microcracks in the crystalline silicon thin film – are critical and can to some degree be analyzed by microscopical methods.

Properties of layers
Thin film solar cells usually consist of several layers which are typically deposited onto glass substrates. A transparent conducting oxide layer forms the front electrical contact while the semiconductor layer followed by a metal layer forms the rear contact. In order to generate useful voltage from the resulting thin film panel, the panel is divided into 100 or more individual cells – interconnected in series – by insulation scribes. In general, film properties can be grouped into two major categories of interest, one dealing with coverage, continuity and homogeneity, the other with the thickness of the films. Depending on the layer properties, continuity can be analyzed either with transmitted light or with reflected light brightfield. The thicknesses of layers in thin film photovoltaics range in the order of several hundred nanometres. These (usually continuous) layers are therefore difficult to measure with the help of standard light microscopical methods. However, the height of a layer can be determined at its edges, e.g. near the cell periphery, either by means of a regular light microscopy in conjunction with Total Interference Contrast (TIC) or by using a confocal microscope.
Properties of scribes

Insulation scribes on thin film cells are generated similarly to edge insulation trenches on crystalline solar cells, that is, either mechanically or with lasers. Regardless of the method used to create them, the scribes have to be continuous and deep enough to create the desired effect in the targeted layer, however not so deep as to damage the layer underneath.

The continuity of laser scribes generated by laser pulses of specific wavelengths depends on both pulse frequency and laser writing speed, and is measured as the extent of the overlap of the circular laser shots. The penetration depth on the other hand depends on the laser wavelength. As the material which is removed by the laser is not fully vaporized, dislodged fragments can fall into the trenches and create a short circuit. Hence it is crucial to make sure that this is not the case and that the channels are blockage-free.

Figure 13  Laser scribes on thin film solar cells. Scribe in transparent electrode (TCO) layer on glass, performed with an ExplorerTM laser at 532 nm wavelength, imaged with an Axio Scope Vario microscope with an EC Epiplan-NEOFLUAR 50x/0.80 objective.

Figure 14  Laser scribes on thin film solar cells. 3D topography of a thin film layer with a laser scribe imaged with an LSM 700 on an Axio Imager microscope with an EC Epiplan-APCHROMAT 50x/0.95 objective.