Application Note: SWIR imaging in solar cell inspection

Key performance indicators:

- *Ability to see through silicon*
    - *Reveal defects in silicon ingots before cutting into wafers*
    - *Wafer inspection to detect cracks, defects and saw marks inside the wafer*
- *Electroluminescence imaging of solar cells at room temperature*
    - *Silicon, CdTe and CIGS photovoltaic solar cells*
    - *Typical exposure time: 1-10 ms (>1 s for cooled CCD cameras)*

Solar cells are large-area semiconductor devices with typical dimensions of 15 cm. Loss mechanisms such as locally reduced diffusion lengths or parallel resistances often reduce the energy conversion efficiency of solar cells. Characterization techniques that can provide spatially resolved information about the performance of a solar cell therefore are important to manufacturers not only in research and development but also in solar cell production.

Silicon material inspection

Due to silicon's transparency beyond 1200 nm, SWIR InGaAs cameras can be used to reveal defects in silicon ingots, before cutting them into wafers (see also Fig. 1). Furthermore, wafers can be inspected to detect cracks, defects and saw marks, not only on the surface but also inside in the wafer.

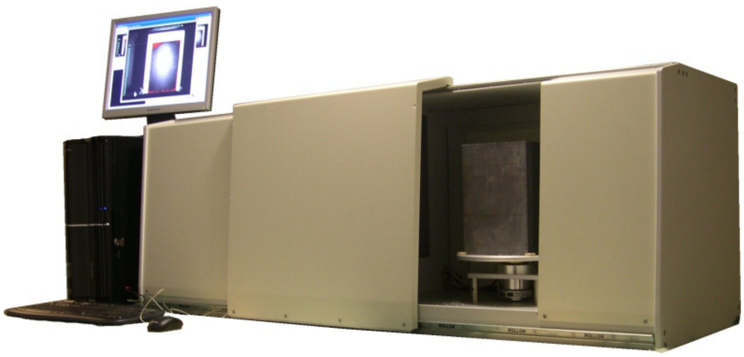

Fig. 1: System for Si ingot inspection, before cutting into wafers, based on an XS InGaAs camera.

Solar cell electroluminescence

Solar cell electroluminescence is the emission of light resulting from a forward bias voltage applied to the solar cell. The electrons injected into the solar cell recombine with the existing holes while the energy released by this process is given off to a small extent in the form of a photon. These emitted photons have wavelengths in the near and short wave infrared (see Fig. 2).
Electroluminescence imaging of solar cells is an important characterization tool. Typical solar cells often have defects which limit the efficiency or lifetime of the cell.
When using a SWIR InGaAs camera, all types of photovoltaic solar cells, mono- and polycrystalline silicon, thin-film silicon, CdTe (Cadmium Telluride) and CIGS (Cadmium Indium Gallium Selenide) can be tested for uniformity by electroluminescence. The emission directly correlates with the solar collection efficiency.

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Electroluminescence: SWIR InGaAs camera vs cooled Si CCD camera

Electroluminescence imaging takes advantage of the of the radiative band-to band recombination of excited charge carriers. The emitted photons can be captured with a sensitive camera to obtain an image of the distribution of radiative recombination in the cell. Electroluminescence imaging can be used for:

1. detection of cracks, grain boundaries, broken contacts and shunts
2. mapping of series resistances
3. distribution of diffusion length of minority carriers indicating the quality of the solar cell material

In solar cell characterization, scientific grade Si CCD cameras are typically used for luminescence imaging applications. These cameras however have to be cooled significantly to reduce noise and dark current. Moreover, Si CCD based cameras, with a cut-off wavelength at 1100 nm, will only detect the short wavelength tail of the band-to-band luminescence from silicon solar cells at room temperature. By using a SWIR InGaAs camera, about an order of magnitude enhancement of the measured photon flux can be achieved. An InGaAs camera is sensitive throughout the entire spectral range in which band-to-band emission from crystalline silicon occurs. Another benefit of using an InGaAs camera is that it is sensitive to an emission band in the spectral range 1400 to 1700 nm. This defect luminescence is linked to the presence of dislocations and is detectable as a broad spectral emission band around 1550 nm at room temperature.

Fig. 2: Electroluminescence image of a Si solar under forward bias; image taken with a XEVA 1.7 320 TE1 camera.