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CIGS Electroluminescence Offers Insights Into Cell Structure, Quality

Performing electroluminescence analysis, such as with InGaAs SWIR cameras, can help accelerate thin-film solar cell development.

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Copper indium gallium diselenide (CIGS) thin-film cells for solar energy generation offer decisive economical advantages over other types of cells by enabling the manufacture of lightweight and flexible modules. They consume less energy and materials in their fabrication than crystalline solar cells do, and they yield high energy levels across a broad spectrum - even under unfavorable weather conditions.

Furthermore, analyzing CIGS cells' inherent near-infrared electroluminescent radiation with sensitive indium gallium arsenide shortwave infrared (InGaAs SWIR) cameras allows for detailed structural examination that can shorten the development cycle of new module types and support module manufacturing through components and facilities that meet high reliability, high efficiency and long-term operability.

CIGS and other thin-film solar cells are made of semiconductor layers measuring just a few micrometers thick. This structure enables their integration in functional and aesthetic building elements, such as roof shingles and roofing tiles, as well as entire façades of buildings, glass domes and air wells.

One drawback of thin-film solar cells, however, is that not much information is known yet about their behavior under various light and weather conditions, compared to the information we have on cells and modules made of crystalline silicon, which have reached impressive levels of maturity over the last 25 years.

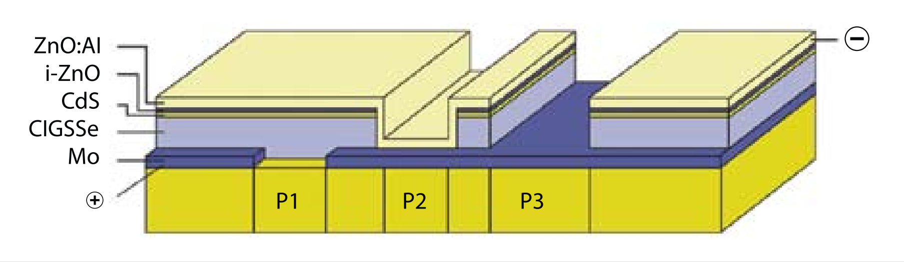
Certain test methods have recently become available for a detailed structural investigation of thin-film modules, which can substantially accelerate their market-introduction process and improve manufacturing quality.

One of the most important occurrences in all functional photovoltaic cells is their weak electroluminescence due to their external bias voltage. A solar cell can be regarded as a parallel interconnection of numerous p-n junctions. The external bias voltage injects electrons into these p-n junctions that, in part, re-combine with the available holes.

The surplus energy exits as photons, whose wavelengths depend on the bandgap of the cell's absorber material.

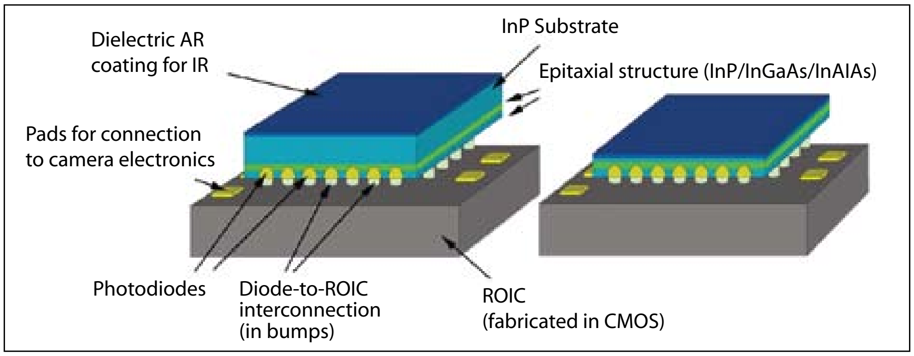
The table on the next page summarizes the correlation of bandgap energy and wavelength of the resulting electroluminescent emission in four commercially available solar cell types.

Figure 1: Cross-Section Of A CIGS Cell



Source: Xenics

Figure 2: SWIR InGaAs Imager



Source: Xenics

For comparison, the spectral coverage of a VISWIR camera (a camera that also captures the visible spectrum) using InGaAs technology is also shown.

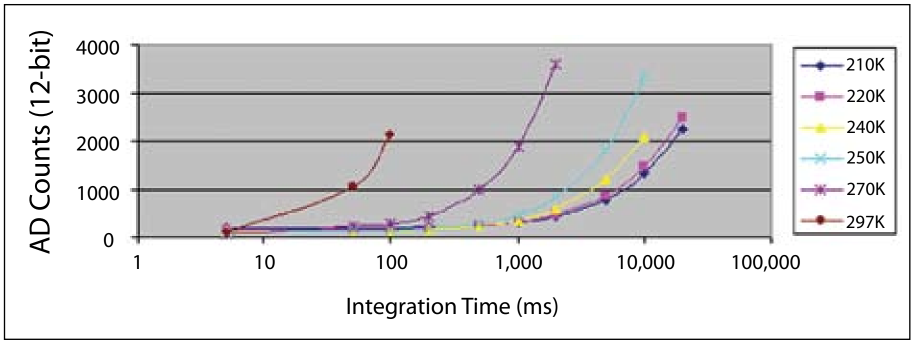
Generally, CIGS thin-film modules have bandgap energies from 0.9 eV to about 1.7 eV, depending on the ratio of indium to gallium. A higher share of indium will lower the bandgap energy, and more gallium will increase it.

Properties Of Commercial Materials For Solar Cells

Type	Material	Bandgap (eV)	Wavelength (microns)
CdTe	Cadmium telluride	1.4	0.8
CIGS	Copper indium gallium diselenide	0.9 to 1.7*	0.7 to 1.3*
CIS	Copper indium diselenide	0.9	1.3
c-Si	Crystalline silicon	1.2	1.2
For comparison: VISNIR camera with InGaAs technology			0.4 to 1.7
* depending on the ratio of indium/gallium used			

Source: Xenics

Dark Current



Source: Xenics

Power losses

The wavelengths of the corresponding electroluminescence in CIGS cells ranges from 800 nm to about 1,200 nm. This range matches the spectral area in which SWIR image sensors show their largest sensitivity.

To cover even larger bandgaps well into the visible realm, and to enable parallel imaging in the visible and the infrared areas, image sensors can work with larger bandwidths. With appropriate constructive measures, this arrangement yields VISWIR sensor arrays with a high spectral sensitivity at wavelengths between 0.4 μm and 1.7 μm.

The intensity of a solar cell's electroluminescent emission is determined by the concentration of electrons and holes, which increases exponentially with bias voltage, as expected from the regular I-V curve of a diode.

Thus, measuring the electroluminescence emission intensity of a solar cell will yield valuable spatially distributed details of mechanisms that could substantially diminish the power yield of a solar module. Among the causes of power losses are locally reduced diffusions lengths, micro fissures within the cell, parallel-resistance effects and contamination of the semiconductor layers.

A look at the cross-section of a CIGS thin-film solar cell monolithically connected in series to the neighboring cell (See Figure 1) reveals three critical areas that might be affected by humidity penetrating under the transparent and conductive oxide (TCO) layers and thereby diminish the cell's properties.

First, in the area marked P1, there may be lowered parallel resistance (shunt Rsh). Second, at P2, there may be a corroding ZnO/Mo contact. Third, at P3, there may be a rising series Rs due to corrosion of the molybdenum layer. All these effects may, at some point, cause a significant loss of power.

Examination of the electroluminescence image of a CIGS module can enable a quick and accurate diagnostic process for the module as a whole. This strategy can be of utmost value in research and development, as well as in the production of thin-film modules.

SWIR imaging

Figure 2 shows the structure of an SWIR InGaAs imager for a wavelength area measuring 0.9 μm to 1.7 μm. The IR photodiodes are built on an InP epi-wafer substrate that is usually more than 125 μm thick.

Because this technology is not particularly well suited for realizing readout circuits, the photodiode array, together with its readout integrated circuit, is flip-chip mounted via indium bumping on a CMOS chip. The solar cell's exposure is then fashioned from the back, through the substrate. This setup, however, absorbs all light from the visible realm to 0.9 μm.

To prevent this loss of light, the substrate is thinned after the flip-chip mounting step, as is routinely done in standard InGaAs sensors to improve response. To enable the safe removal of the substrate without damaging the InGaAs detector, additional layers of InGaAsP are inserted just below the photodiodes. These layers function as etch stops within the InP area.

An HCL etch then selectively removes the InP epi-substrate exactly up to the InGaAsP etch-stop layer. This step effectively thins the sensor chip down from 125 μm to just 5 μm, making it transparent to light in the visible realm and opening up the sensor to a broad wavelength coverage from 0.4 μm to 1.7 μm.

The observed electroluminescent emission is of very weak intensity, which imposes stringent requirements on the measuring technique used. Accurate measurements will necessitate long integration times.

In this regard, the dark current of the image sensor imposes limits that can be detrimental, especially when the user is seeking to carry out accurate examinations in the design of novel photovoltaic cells and modules. Dark current can be reduced by employing low-noise sensors and one- or multi-stage thermoelectric cooling of the sensor array, as shown in the chart on the right. Doing so will enable an exponentially longer integration time and prevent weak local imperfections from going unnoticed in the noise floor.

An analysis of the weak electroluminescent emission given off by photovoltaic cells and modules using cameras substantially supports the development of thin-film solar cells, as well as their integration in functional carrier structures and quality assurance during manufacturing.

Ultimately, these efforts will serve the overall goal of reducing the historical lead of traditional crystalline solar cells in favor of thin-film cells and developing effective power supply solutions.

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