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Photoluminescence and Electroluminescence for Silicon Solar Cell Inspection

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Silicon solar cells emit light when excited with light or voltage. The luminescence from the silicon is emitted from 950 – 1250 nm with the peak occurring at approximately 1150 nm. The emission is caused by a band-to-band transition, and is a relative measure of the minority carrier diffusion length. Areas of silicon with a long diffusion length have brighter luminescence and higher conversion efficiency. Therefore, the luminescence image is a rapid and direct measure of the overall cell efficiency and a map of any cell defects.

Photoluminescence (PL) is the re-emission of light from an object after absorbing light of a higher energy (shorter wavelength). Visible light from a flash lamp or pulsed laser/LED excites electrons in the silicon. Most of the photo-generated electrons give up their energy as heat, but a small fraction of the electrons recombine with a hole, emitting a photon (radiative recombination). More defects in the silicon will result in more energy lost as heat, and fewer emitted photons. Fewer defects in the silicon will result in more radiative recombination, and more emitted photons.

Electroluminescence (EL) is the emission of light due to an applied voltage. When a silicon solar cell is forward biased, it will act as a (very inefficient) light emitting diode. Emission intensity is again dependent on the density of defects in the silicon, with fewer defects resulting in more emitted photons. The solar cell is usually driven by a constant current source, with the light emission directly proportional to the induced current.

PHOTOLUMINESCENCE	
ADVANTAGES <ul style="list-style-type: none">● Can be applied to in-process wafers or finished solar cells● No contact with the cell required	DISADVANTAGES <ul style="list-style-type: none">● Usually requires pulsed light source and gated detection● Timing between light source and detector is critical● Requires a uniform illumination source and appropriate non-uniformity correction● Shot-to-shot reproducibility is usually poor
ELECTROLUMINESCENCE	
ADVANTAGES <ul style="list-style-type: none">● Can use non-gated detectors● Simple current source supply● Good reproducibility	DISADVANTAGES <ul style="list-style-type: none">● Requires electrical contact to cathode and anode (finished cell)

As this chart shows, PL is better for in-process measurements because it is non-contact and can be applied to unfinished wafers. The higher reproducibility of EL is better for cell quality control.

Application of TE-EBAPS to Photoluminescence and Electroluminescence

The Transferred Electron-Electron Bombarded Active Pixel Sensor (TE-EBAPS) is ideally suited to image photoluminescence (PL) and electroluminescence (EL) from silicon solar cells. Both InGaAs and InGaAsP based photocathodes can collect >20x the luminescence signal that a silicon based imager can. It takes several seconds to minutes for a cooled CCD-based camera to collect an EL image. A TE-EBAPS imager can collect the image in just a few milliseconds. PL is not generally used as an imaging technique, since an appropriate detector is not readily available. Since the TE-EBAPS can be gated, it makes PL imaging practical.

The low dark current of the InGaAsP photocathode makes it ideal for EL measurements, where exposure times will be a few milliseconds. An uncooled camera running at video rates could easily capture the EL measurements of finished cells as quickly as they could be loaded in the fixture.

A typical EL system starts with a TE-EBAPS camera and a suitable lens to image the solar cell. The solar cell is held in a fixture to reproducibly place it in the camera's field of view, and to make contact to the anode and cathode leads of the solar cell. A constant current source is connected to the contacts. The whole system is inside an enclosure to keep out ambient light, and protect the operator from exposed current on the solar cell (via an interlock on the current source). The camera collects an image while the current is on, then sends it to a computer for analysis. The computer displays the EL image and gives information on the solar cell such as overall efficiency, uniformity, dark defects, etc. This information is used to accept/reject cells, and to bin them so that solar panels can be manufactured with a consistent efficiency rating (Figure 1).

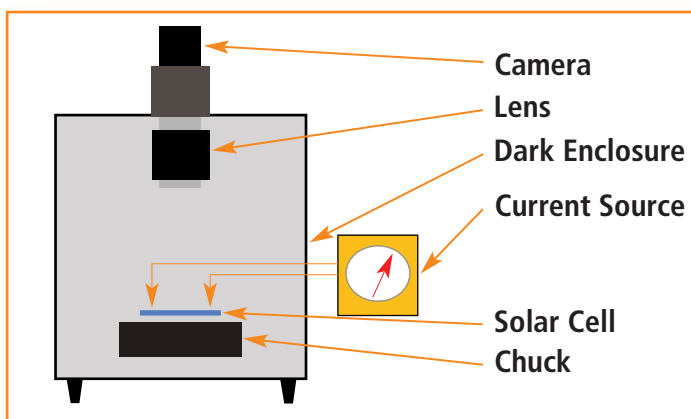


Figure 1: Electroluminescence System

A PL system could likely use either InGaAs or InGaAsP photocathode as a gated detector — the higher dark current of InGaAs is not an issue for such short exposures. Using a flash lamp or LED array and a simple timing generator, the system could collect PL images of wafers travelling on a conveyor at a rate of several wafers per second. The limiting speed for a PL system is most likely the image analysis software (Figure 2).

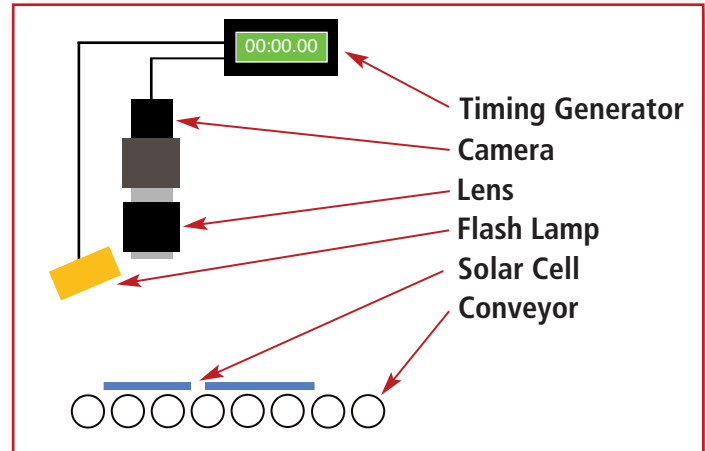


Figure 2: Photoluminescence System

A typical PL system would need the same camera and lens configuration as the EL system. As a wafer approaches the measurement area, a trigger signal is sent from the timing generator to the pulsed light source. The light source illuminates the sample for a few microseconds as it passes under the camera's field of view. After a suitable delay, the timing generator sends a second trigger pulse to the camera. The camera gates the photocathode to capture the photoluminescence from the wafer. The recorded image is then sent to a computer for image analysis (uniformity, dark defect count) that then feeds back into the process control system. Since the light pulse and camera gate are in the microsecond time scale, ambient lighting is not an issue, the only precaution is limiting human exposure to the rapid bright flashes.

For additional information about Intevac's solar inspection solutions, please call Bruce True at (408) 986-9888.



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