EL & PL imaging

Electroluminescence (EL) & Photoluminescence (PL) imaging for fast detection of solar cell and module quality with scientific grade cameras.

1 cameras for El & PL imaging

The range of camera systems offered by PCO AG for the imaging of EL or PL offers the following application parameters, which are useful for solar cell as well as solar panel investigation and inspection

- 1.3 ... 11 Mpixel resolution
- 200 ms ... 10 s exposure time per image
- optimized NIR sensitivity
- 12, 14, 16 bit dynamic range
- CCD and scientific CMOS sensors
- free of etalon effects

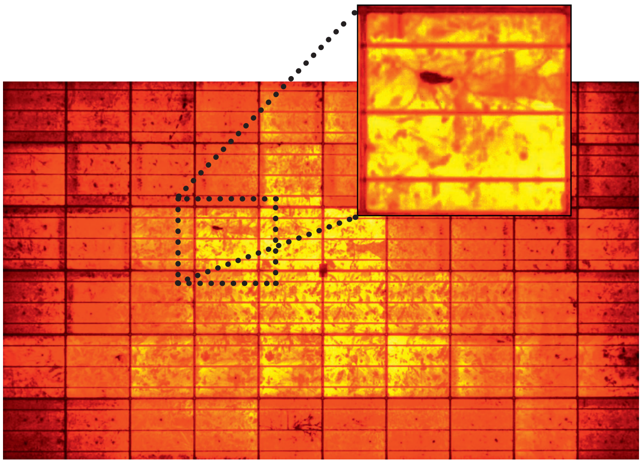

Figure 1
EL image of a solar panel obtained with a pco.4000. The electroluminescence is shown false color coded and one of the solar cells with a defect is zoomed and presented above.

1.1 pco.edge

- 5.5 Mpixel resolution (2560 x 2160 pixel)
- maximum frame rate 100 fps
- extremely low noise of 1.4 e⁻ rms
- 16 bit (22 000 : 1) dynamic range
- camera link interface

Figure 2
pco.edge - scientific CMOS (sCMOS) camera with 2560 x 2160 pixel resolution

1.2 pco.1400

- compact design
- low noise of 6 e^- rms
- 1.3 Mpixel resolution (1392 x 1040 pixel)
- 14 bit (2667 : 1 / 4000 : 1 dynamic range)
- hot pixel correction integrated
- IEEE1394a “firewire” interface

Figure 3
pco.1400 - scientific CCD camera with 1392 x 1040 pixel resolution

1.3 pco.1300 solar

- 1.3 Mpixel resolution (1392 x 1040 pixel)
- 12 bit (2667 : 1 dynamic range)
- optimal offset stability and control (< 1 count)
- adjustable Peltier cooling
- IEEE1394a “firewire” interface

Figure 4
pco.1300 solar - scientific CCD camera with 1392 x 1040 pixel resolution

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1.4 pco.4000

- 11 Mpixel resolution (4008 x 2672 pixel)
- provides full module image with one shot
- 14 bit (5455 : 1 dynamic range)
- IEEE 1394a, camera link, GigE Vision, USB2.0

Figure 5
pco.4000 - scientific CCD camera with 4008 x 2672 pixel resolution

2 cooling, noise & quantum efficiency

More detailed QE (quantum efficiency) measurements reveal, that moderate camera cooling is advantageous for EL applications. The graph clearly shows that the QE increases for higher wavelengths at higher temperatures. To exploit this phenomenon a low noise CCD image sensor is ideal, since the noise and dark current are also increasing with temperature. Similarly, the use of a binned high resolution CCD sensor is not always beneficial because binning does not change the noise figures.

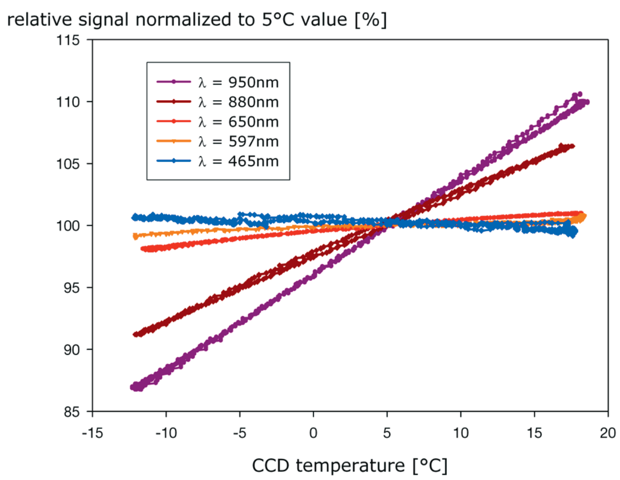

Figure 6
Relative signal vs. image sensor temperature normalized to the signal at 5 °C for different spectral wavelengths. The measurements were made with a pco.1300 solar.

Data presented in figure 6 is taken with a camera operated at different CCD image sensor temperatures, viewing a homogeneous light signal. ***For typical EL imaging it is advantageous to moderately cool the image sensor.***

2 CCD vs. emCCD

Usually the higher QE of emCCD vs. CCD is mentioned at a wavelength of 900nm. ***This is true, but not relevant for the EL measurement.***

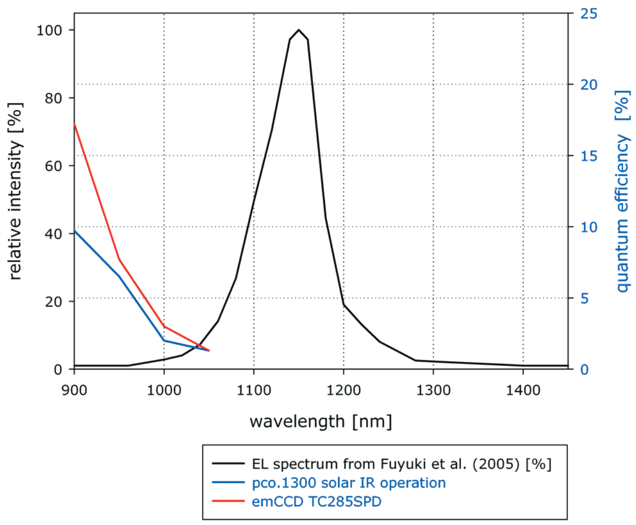

Figure 7
Quantum efficiency curves for a scientifc CCD and an emCCD (right y-axis) compared to the relative intensity of electroluminescence from literature (left y-axis).

3 optical characterization of solar cells

Optical characterization techniques which are capable of providing spatially resolved information about the performance of a solar cell are of great importance, not only for research and development, but also as a process control tool in the solar cell production lines. The distance between the camera and the solar cell is freely adjustable, solar cells of any size and even complete modules can be analyzed.

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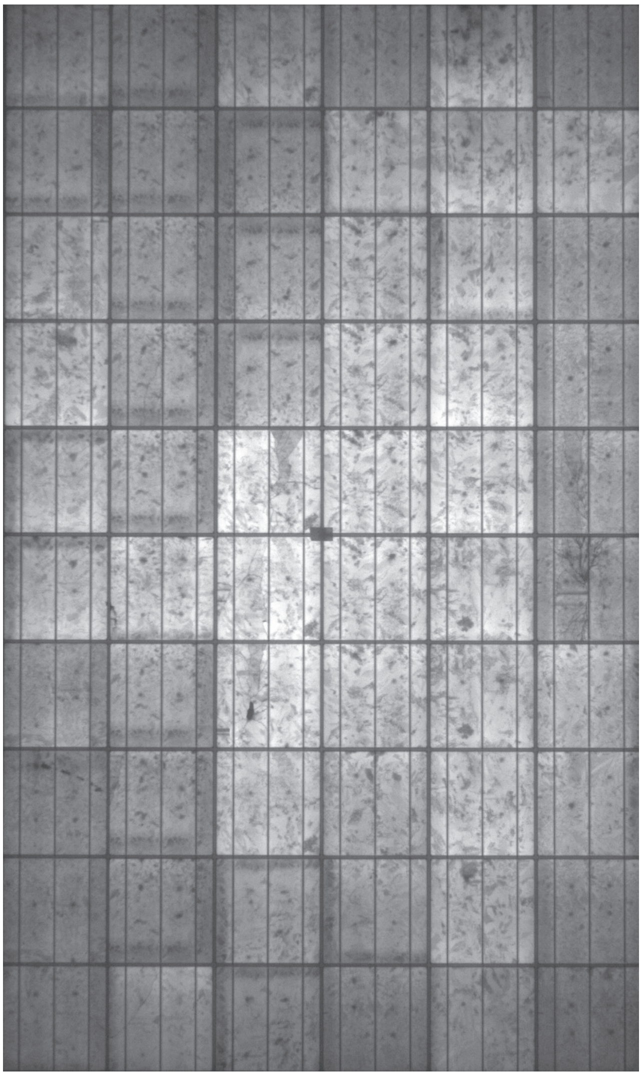

Figure 8
Raw EL data image of solar panel/module, recorded using pco.4000 and Zeiss IR lens.

4 Parameters to be tested with EL & PL imaging

The following parameters can be investigated and tested by EL or PL imaging:

- **microcracks**
- **edge isolation quality**
- **material quality**
- **process parameters:**
  - **emitter diffusion**
  - **texture**
  - **antireflective coating**
  - **firing**
  - **etc.**
- **lifetime / diffusion length**
- **series resistance**
- **shunts**
- **junction breakdown**

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