HERA IPERSPETTRALE - APPLICATION NOTE

NIREOS

HYPERSPECTRAL EMISSION MAPPING OF SEMICONDUCTORS

A significant endeavor is currently in progress to **enhance the efficiency** and **reduce the costs** associated with semiconductors used in photovoltaic and light emitting applications. This entails the exploration and development of novel manufacturing and synthesis methods that yield more uniform materials with fewer defects.

Luminescence, whether induced electrically or optically, serves as a valuable tool in this pursuit. Luminescence **provides local insight into the recombination processes** occurring within the film, without complications of charge extraction through the multiple layers of a complete device.

THE **HERA** HYPERSPECTRAL CAMERA **IS THE IDEAL DEVICE** FOR MAPPING THE LIGHT EMISSION FROM SEMICONDUCTORS, AS IT ENABLES A **FAST AND QUANTITATIVE CHARACTERIZATION OF THE SEMICONDUCTOR FILM**, WITH HIGH **SPATIAL AND SPECTRAL RESOLUTIONS.**

ELECTRO–LUMINESCENCE MAPPING OF A SILICON SOLAR CELL

Defects in photovoltaic devices cause recombination of photogenerated carriers, preventing their extraction and reducing the cell efficiency. Electro-luminescence mapping can reveal the location and nature of these detrimental defects.

Driving a solar cell "backwards" (i.e., applying current) generates electro-luminescence, as carriers are injected at the electrodes and recombine in the active layer. In an ideal cell, all carriers undergo band-to-band recombination, which in silicon generates (with very low efficiency) light near 1100 nm. However, defects in the crystal structure can generate other, unfavourable recombination pathways. While often referred to as "non-radiative" recombination, occasionally these processes can generate a photon, typically with lower energy than the band-to-band emission. These very rare photons can be captured to learn about the energetics and distribution of the defects.

Figure 1: Experimental Setup

In this experiment, we used the HERA SWIR (900–1700 nm), well suited for measuring silicon luminescence. The measurement setup is shown in **Figure 1**: the HERA is mounted on a tripod, above the solar cell, which was connected to a 10 A current supply. Mounted 75 cm above the sample, the 640×512 pixels sensor gives a spatial resolution of approximately 250 μm.

Most importantly, the lack of an input slit in the HERA optical system provides a very high light throughput, making the HERA the ideal choice for measuring the very weak light emission.

Figure 2A and 2B show images of the electroluminescence (EL) at two wavelengths, 1150 nm (band-to-band emission), and 1600 nm (defect emission), which are the average of 4 scans (total acquisition time: 5 minutes). By analyzing the images, one can see that the defective regions are clearly resolved, despite being much less bright than the main emission. Also, the regions with strong defect emission feature relatively weak band-to-band emission.
One can notice several regions that are dark at both wavelengths; this is likely due to damage of the cell received during the shipping of the sample.

Spectra from the small square regions of interest (indicated in Figure 2A and 2B) are shown on a log scale in **Figure 2C**.

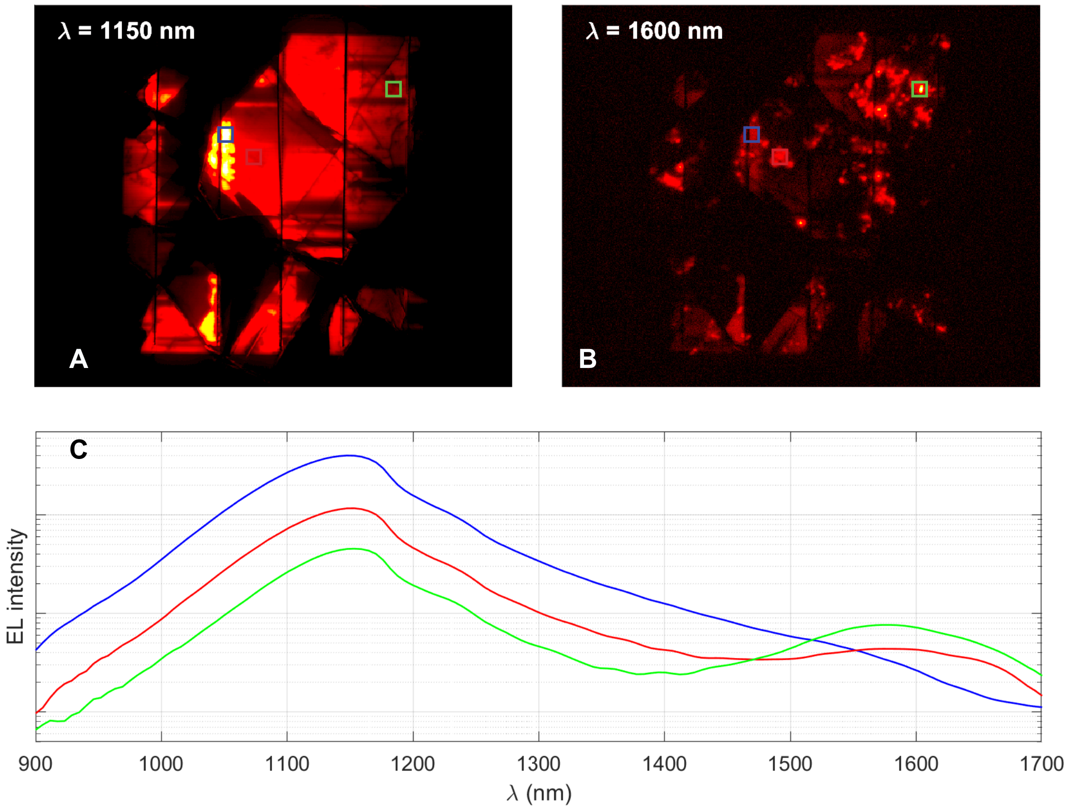

*Figure 2. **A** and **B**: Electroluminescence (EL) images at two selected wavelengths (1150 nm and 1600 nm). **C**: EL spectra corresponding to three different regions in A and B (coloured squares in the images).*

PHOTOLUMINESCENCE MICROSCOPY OF METAL–HALIDE PEROVSKITE THIN FILMS

Metal-halide perovskites enable the fabrication of very efficient solar cells and LEDs from low-tech and cost-effective methods such as spin-coating. One challenge with these methods is maintaining a uniform composition at microscopic length scales. Photoluminescence microscopy is an especially powerful tool for characterizing this inhomogeneity.

The HERA hyperspectral camera can be connected to the c-mount camera port of any microscope (upright or inverted), and begin collecting hyperspectral data straightforwardly, without the need of any calibration procedures.

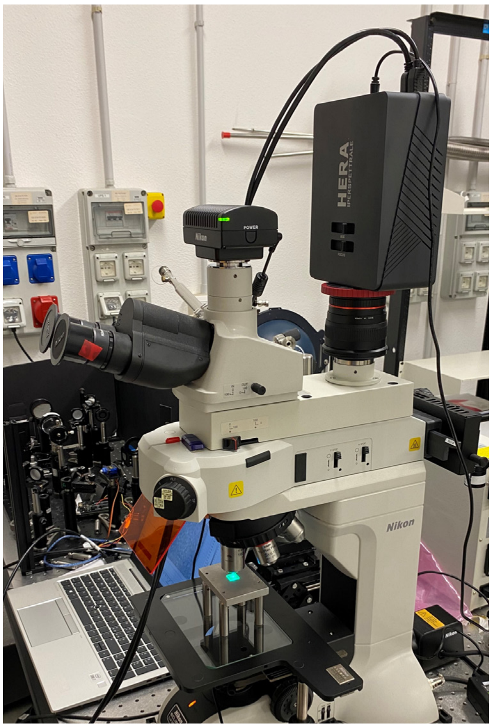

Figure 3: HERA VIS-NIR coupled to a Nikon LV100 upright microscope.

In this experiment, we used the **HERA VIS-NIR (400-1000 nm) coupled to a Nikon LV100 upright microscope** (Figure 3) to characterize the band-gap distribution of an alloy of two halide precursors. The advantage of alloying two halide precursors is the capability to tune the band-gap of the material; however, these two components often de-mix, leading loss of performance.
The goal of this experiment is then to detect this de-mixing: in fact, local changes in the mixing ratio change the local band-gap, leading to the emission of photons of different energy.

In this configuration, the excitation light was from a mercury lamp, fitered at 350 nm via a band-pass filter, and rejected from the camera using a dichroic beamsplitter in the emission path.
The high throughput of the HERA enabled collection of the full data cube (1.3 million spectra) within approximately 1 minute measurement time.

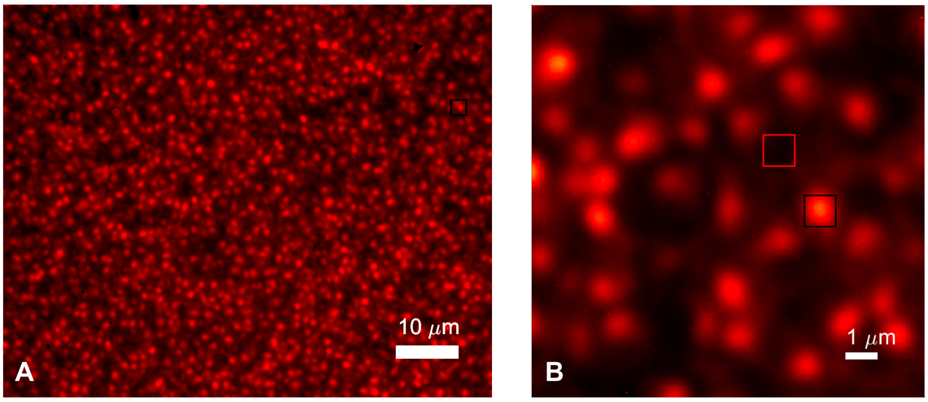

Figure 4. Spectrally integrated intensity maps of the sample (A: full scale; B: zoom-in).

Figure 4A and **4B** shows respectively the full-scale and zoomed-in images of the total integrated signal across all wavelengths (400–1000 nm), revealing bright features with length scales on the order of 1 μm.

When we compare the spectra from a bright vs a dark region (black and red curves in **Figure 5B**), we see that there is actually emission from the dark regions, and that not only is it less intense, but also centered at a shorter wavelength than the bright regions. In fact, the spectra have a bimodal shape, likely corresponding to emission from the de-mixed precursors. This variation in bandgap is clearly illustrated in the emission map of **Figure 5A**.

We can understand now why the low-bandgap regions appear brighter – carriers likely relax there from the high-bandgap regions and are unable to return before undergoing radiative recombination.

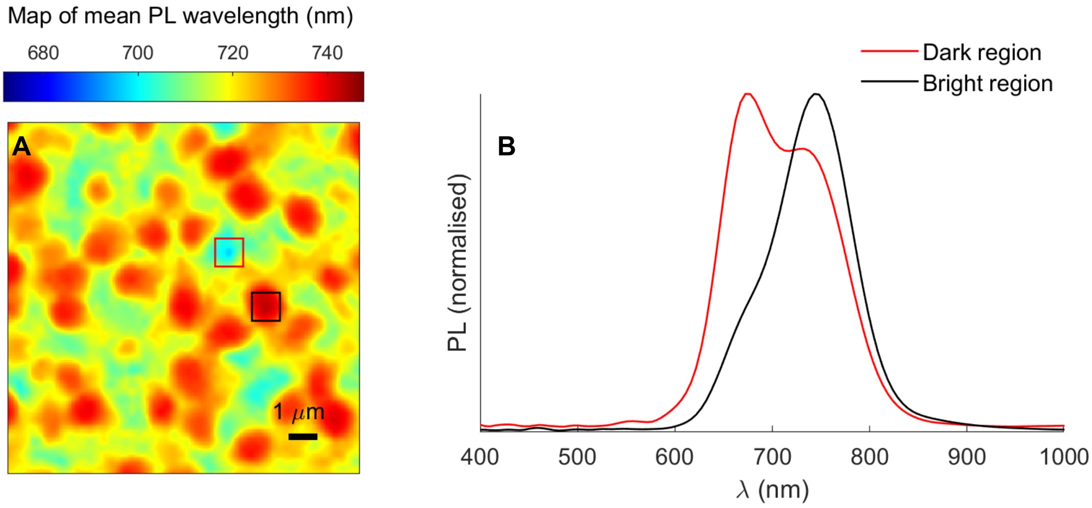

*Figure 5. **A**: Intensity map showing the mean emission wavelength. **B**: Emission spectra (normalized) from a bright and dark region.*