Non-destructive photoluminescence investigation of PV devices with high spatial resolution microscope techniques

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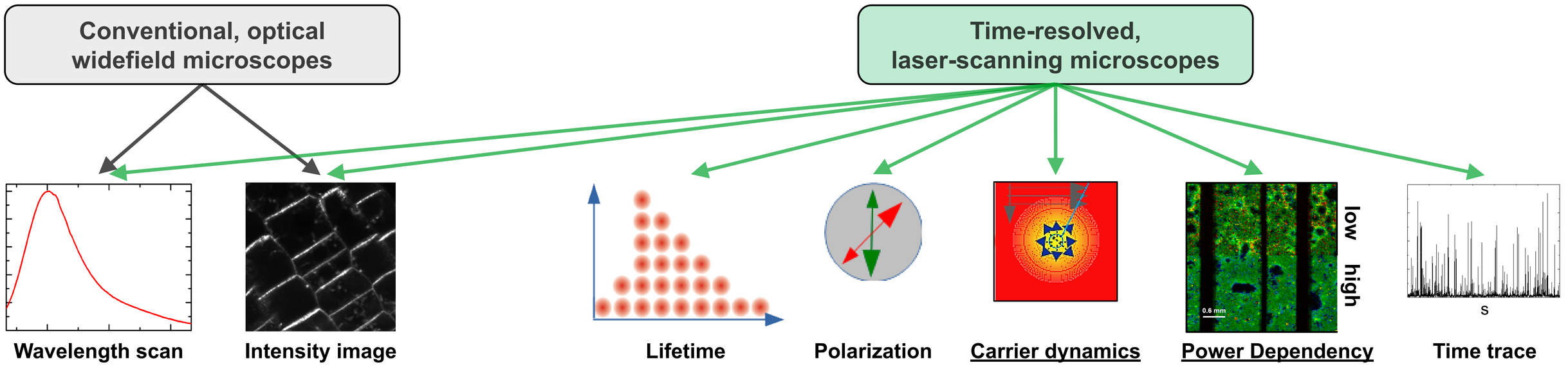
Introduction

Investigations of photovoltaic devices and semiconductors are essential to enhance the efficiency of preparation methods as well as their electronic and optical properties. We present a powerful combination of time-resolved photoluminescence microscopy with a spectrometer, which results in a powerful toolbox for researcher. This combination of microscopic (e.g., FLIM, PLIM or carrier diffusion imaging) and spectroscopic methods like wavelength dependent emission scanning enables investigations of photophysical properties of semiconductors, nanoparticles and nanostructures on a whole new level.



Carrier diffusion imaging

Why performing carrier diffusion measurements within PV and layered structures?
Carrier generation in semiconductors and PV can be induced by light e.g., cw or pulsed laser. Here the diffusion length of this formed mobile carriers is the average length between carrier generation and all recombination processes. This diffusion length can be measured and calculated by the **carrier (PL) lifetime** according to **equitation (1):**

$$(1) \quad L = \sqrt{D\tau} \quad [1]$$

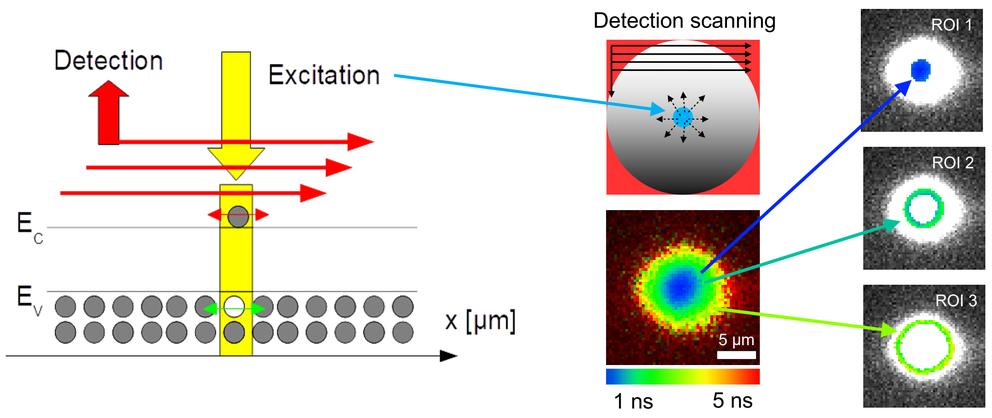
L = diffusion length [cm]

D = diffusivity [cm²/s] e.g., for Perovskites it's typically 0.005 - 2 cm²/s

τ = (PL) lifetime [s]

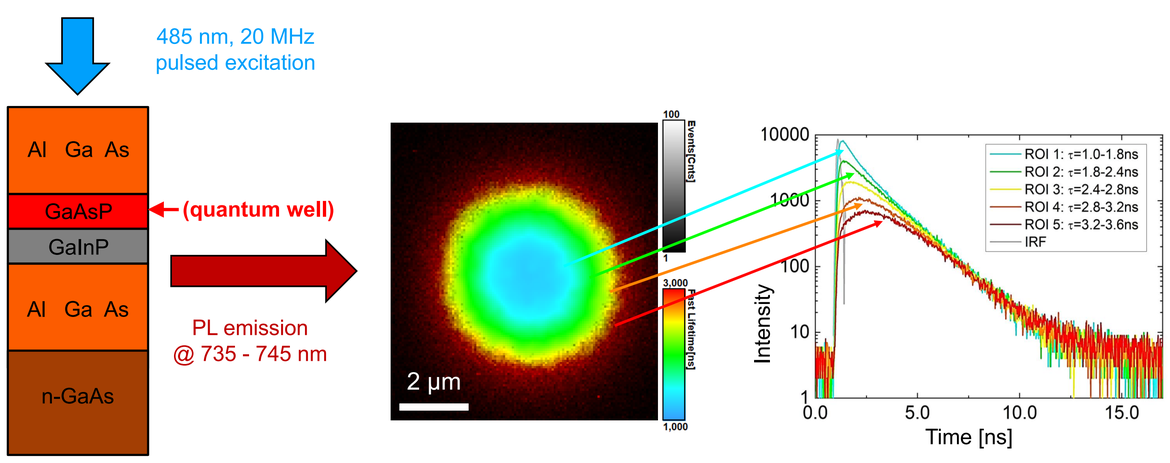
The recombination rate depends on the number of defects in the material. Likewise, doping increases the defects in the solar cell and high doping lead to high recombination rates, shorter lifetimes and short diffusion lengths also. For Perovskite with lifetime between 10 - 100 ns, the diffusion length is typical between 1 - 3 µm.

Principle of carrier diffusion imaging



The time-resolved PL detection in combination with XY raster scanning of the **confocal detection** volume over the fixed excitation spot allows a direct observation of the carrier diffusion away from the fixed excitation spot in semiconductors.

Example of carrier diffusion imaging in a quantum well

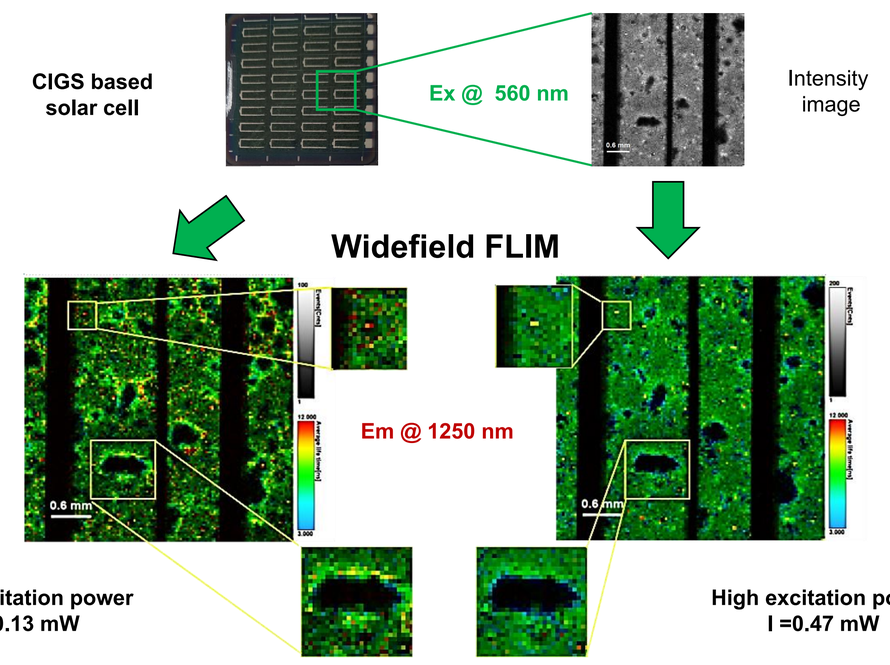


[1] J. Phys. Chem. Lett. 2015, 6, 20, 4090–4092, https://doi.org/10.1021/acs.jpclett.5b02052

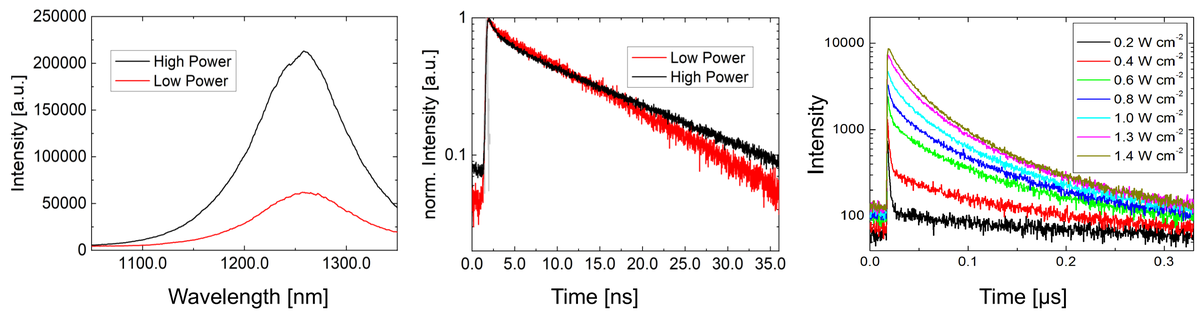
Power dependent time-resolved imaging and spectral analysis

Time-resolved photoluminescence (TRPL) imaging is a powerful technique for the characterization and inferring of structural-to-photophysical relationships in PV materials. Additionally, the kind of imaging method and the power applied to the sample are further parameters which are important for understanding TRPL imaging results. Gathering such information and knowing the chosen parameter are important steps toward the optimization of structure as well as preparation process of such materials in order to increase the performance of PV devices.

Example of power dependent time-resolved imaging of a CIGS solar cell



A picosecond pulsed 560 nm laser was used as excitation source and the PL emission at 1250 nm was detected by a coupling a scanning widefield microscope with a PL spectrometer. Both images shown above were measured under the same conditions, while the excitation power changed based on the use of two different microscope objectives: 20x (left image) and 40x (right image). The 20x objective provides an excitation spot size of ca. 60 µm and a detection area of about 10 µm, while these values change to ca. 30 µm (excitation) and 5 µm (detection) for the 40x objective.



It is obvious that both PL spectra and decays are different depending on the excitation power. At higher excitation power the TRPL image of the sample is getting more homogeneous due to saturation of trap states inside the sample. The PL lifetime is significantly affected by the applied power density (see right graph). For carrier diffusion studies, a confocal setup is required. To avoid carrier dynamics, a widefield microscope with higher excitation densities is recommended.

Conclusion

Additional information can be acquired by new time-resolved PL based microscopic techniques e.g., **FLIM / PLIM**, **TRPL imaging** and **carrier diffusion imaging as well as power-dependent imaging.** Those new time-resolved techniques are not limited to high experienced user only, because commercial and simple to use solutions are already available.

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