Measuring Steady-state and Time-Resolved Photoluminescence of a Thin Film CIGS Solar Cell by a Positionable, Micrometer-Sized Observation Volume

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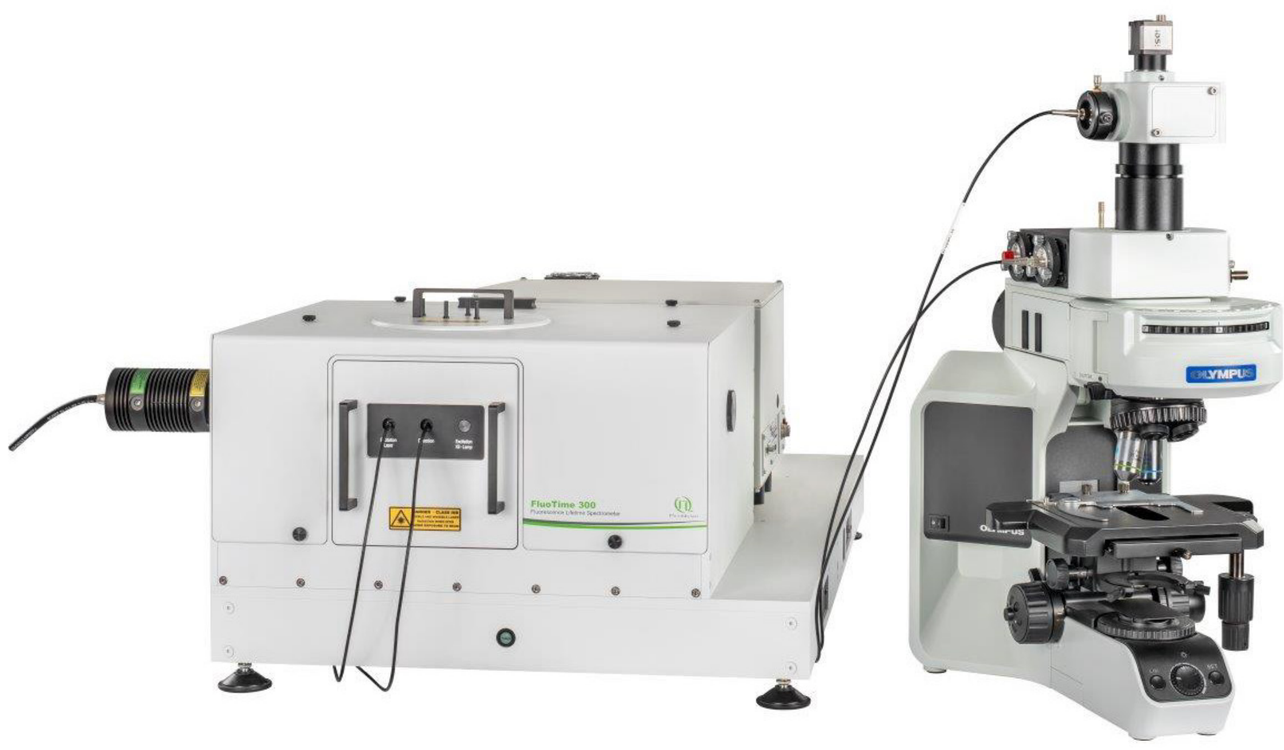
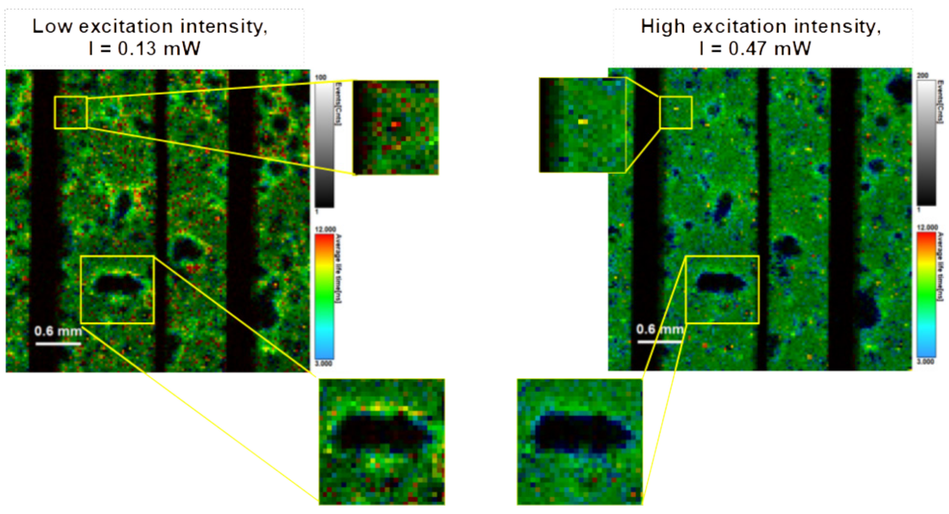
Over the years, luminescence spectroscopy has established itself as one of the fundamental methods for analyzing the photophysical properties of a variety of samples, ranging from simple organic molecules to semiconductor light-emitting materials and photovoltaic (PV) devices. The commonly used steady-state methods (i.e. excitation and emission spectroscopy) provide valuable insights into the photophysics of samples. However, such results give only a partial view of sample`s behavior after photoexcitation.
A further piece of the puzzle is often revealed by performing time-resolved luminescence spectroscopy, as it provides deeper insights into the photophysical processes occurring in the sample under investigation. It is worth to mention, that the luminescence lifetime is an intrinsic characteristic ofemitting species. It indicates how long species under consideration will remain in electronically excited states before returning to ground state. Each emitting species has a characteristic luminescence lifetime, that can be influenced by its environment.
A series of spectroscopic and microscopic methods based on luminescence lifetime have been developed and provide further information, which are not accessible by steady-state experiments. Acquiring time-resolved spectroscopic data at regions of interest (ROI) of the sample can help in inferring structural-to-photophysical relationships in different materials and can give information about important photophysical processes as well as changes in the local environment of emitting species. For example, fluorescence lifetime imaging microscopy (FLIM) is a very well established imaging method in life sciences where the lifetime information is combined with spatial localization in the sample, allowing investigating biochemical or physical processes, or probing the local environment of the fluorophore. As processes commonly investigated in materials science are mostly not classical fluorescence processes, in general the term time-resolved photoluminescence (TRPL) imaging is more adequate. In materials science, TRPL imaging can be used for the characterization of key parameters like e.g. charge carrier dynamics and mobility in semiconductors. It is worth to mention, that very often these processes occur on timescales ranging from tens of picoseconds to several hundreds of nanoseconds.
Here we will demonstrate the performance of a spectrometer-microscope assembly for characterization and analysis of different materials in terms of lifetime, spectral and spatial resolution. Using a laser driver with burst capabilities enables measurements of long luminescence decays in the range of µs to ms. The benefitsof this multi-dimensional approach will be demonstrated with a series of examples reflecting a broad range of applications in materials science research.

Experimental setup



A spectrometer-microscope assembly based on the FluoTime300 spectrometer and FluoMic add-on was used for investigating a CIGS based solar cell.
In all experiments, a picosecond pulsed laser module (VisUV-560) emitting at 560 nm was used as excitation source.
The FluoMic add-on was outfitted with either a 20x or 40x objective.
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.
This spot size variation is useful for checking whether the photoluminescence depends on the excitation power density.

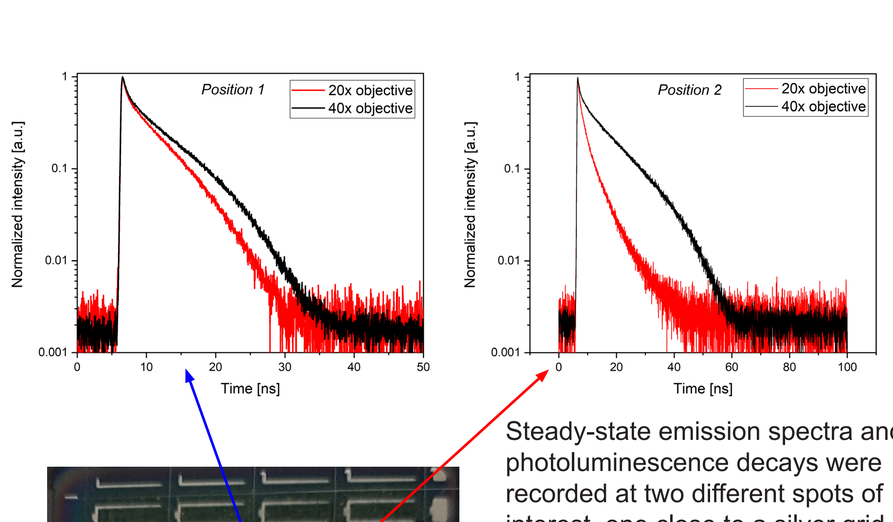
Studying the photoluminescence of a solar cell



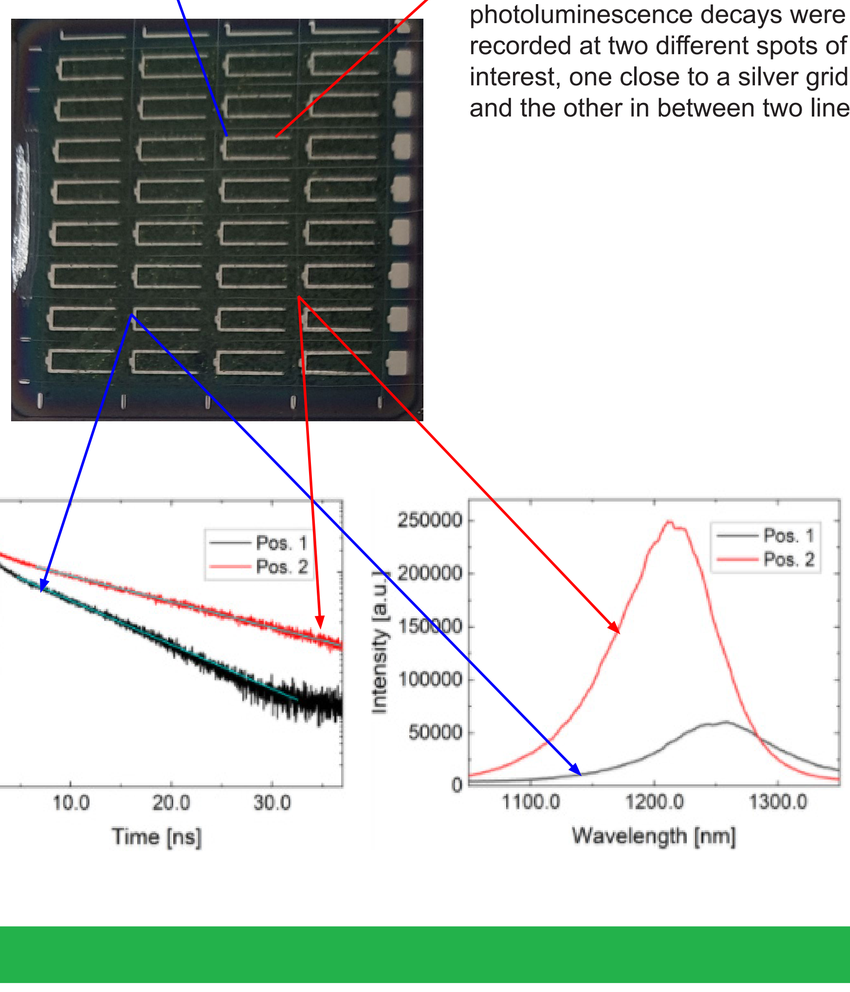
With higher excitation intensity the TRPL image of the sample becomes more uniform due to saturation of energy traps.

All examples highlights that being able to acquire data from well defined excitation/detection area can provide deeper insights into the relationships between structure and photophysical behavior.

A switching of objectives with different magnifications leads to a size difference in both excitation and detection spots.
A 20x objective provides an excitation spot size of ca. 60 µm and a detection area of about 10 µm, while a 40x objective provides a 30 µm excitation and 5 µm detection spots.
This spot size variation is useful for checking whether the photoluminescence depends on the excitation power density.
The emission spectra recorded at both spots are identical: a broad, featureless band with a maximum at 1250 nm.
However, the luminescence decays recorded at 1250 nm are significantly affected by the objective change.
The difference is even more pronounced at position in between two lines, where not only the average lifetime is quite shorter, but also the shape of the decay curve changes massively.



Steady-state emission spectra and photoluminescence decays were recorded at two different spots of interest, one close to a silver grid line and the other in between two lines.



Conclusion

The FluoMic add-on extends the power and capabilities of the FluoTime 300 with the ability to gather steady-state and time-resolved spectroscopic data from a well defined POI that can be freely chosen. The obtained information is not readily available when investigating such a sample with a conventional spectrometer as the luminescence signal is averaged over a larger area (typically 1 mm² or more).

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