

Progress Report for the Boris Mints Institute – July 2020

Project topic: Development of a method for extracting spatial photon recycling efficiency of solar energy conversion devices.

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Summary: Our experiment focus on measuring the photon recycling efficiency for characterizing materials and devices for solar energy conversion. we constructed a Photoluminescence quantum yield measuring system and preformed preliminary experiments on an InP sample wafer, producing photoluminescence quantum yield measurement from a sample excited by a range of incident light wavelengths. Over the next year, we plan to calibrate the system and to measure and extract spatial photon recycling efficiency of different materials and various solar devices, while improving the experimental technique.

Description of experimental work:

An increasing effort is being put towards developing new materials for high efficiency solar energy conversion systems.^{1,2} The performance of a solar energy conversion device is greatly affected by various loss mechanisms and different charge transport properties. Further and in-depth understanding of loss and charge transport mechanisms could be key in establishing potential new materials for the use in future solar energy conversion devices. The research aim is to develop a nondestructive technique, for quantifying efficiency loss mechanisms, and to provide insights on devices performance under relevant operating conditions.

Photogenerated charge carriers recombination processes define the possible collection of current from a device. These recombination interactions release energy in the form of heat or through light emission in a process termed photoluminescence (PL). The probability for a charge carrier, generated at a specific point in the device to contribute to the photoluminescence is defined as the spatial photon recycling efficiency (SPRE). Obtaining spatial photon recycling efficiency in different materials and solar cells, could shed light on different loss mechanisms throughout the cell, and lead to development of higher performance solar cells.³ The photon recycling efficiency is related to photoluminescence quantum yield (PLQY) which is defined as the fraction of emitted photons from the absorbed photons. In the experiment we will measure the PL signal and obtain the photoluminescence quantum yield over a wide range of incident wavelengths. From the analysis of the wavelength dependent PLQY, we will compute the SPRE profiles, as previously shown in a similar analysis.^{4,5}

In order to investigate the properties of the photoluminescence of the sample over a range of excitation wavelengths our experiment, we position our sample in an integrating sphere - an internally diffusive and reflective sphere, that allows light emitted inside the sphere, to be collected by an output port using an optical fiber. By using an integrating sphere, we are able to read the faint photoluminescent signal emitted by the sample. For photoluminescence excitation, we use a

bright light source coupled to a monochromator. This allows us to produce a tunable monochromatic incident light. This light beam is focused on the device testing sample, positioned inside the integrating sphere. Figure 1 shows the set-up layout. The reflected light and the photoluminescent emitted light are reflected inside the sphere and collected from the bottom port via an optical fiber to the measuring spectrometer.

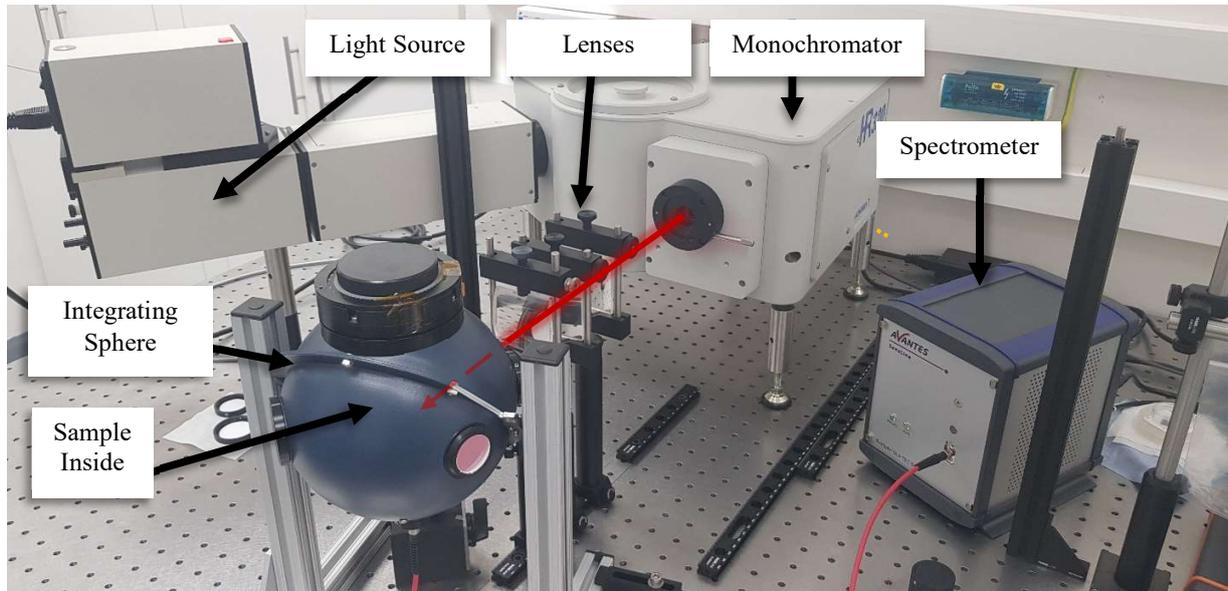


Figure 1 – PLQY Experiment layout. The image depicts the (red) light from the monochromator output to the sample inside the integrating sphere. The light is focused on the sample via a set of lenses. The PL signal is collected with a fiber at the bottom of the integrating sphere to a spectrometer.

We performed preliminary measurements of photoluminescence signal when the sample is excited by various wavelengths. For these experiments, we used a strong LED light source coupled to the monochromator. Figure 2 shows measured photoluminescence quantum yield results from the measurements using an undoped InP wafer, with different excitation wavelengths.

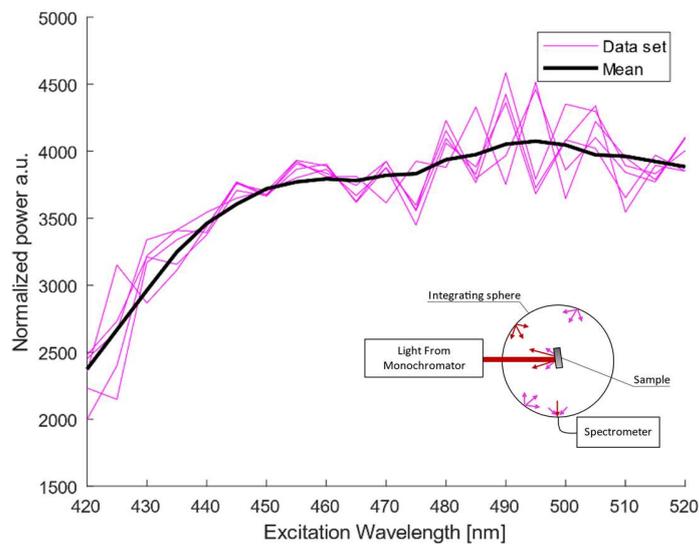


Figure 2 – Photoluminescence quantum yield measurements results using various excitation wavelengths on an undoped InP sample, positioned inside an integrating sphere. The sample is excited using an LED white light source. The inset shows the schematic illustration of the PL measurement experiment, depicting red excitation wavelength.

For the upcoming year, we will perform PLQY measurements and obtain the spatial photon recycling efficiency of different materials and solar cells. For future development of the technique we intend to place the sample on a 2D translation stage and obtain a depth profile of the photon recycling efficiency at multiple points in the sample. This would allow us to create detailed 3D maps of different loss mechanisms throughout the material or device. Our results would contribute to further understand of loss mechanisms and to promote the development of better performance solar energy conversion devices.

References:

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3. Boriskina, S. V *et al.* Roadmap on optical energy conversion. (2016).
4. Segev, G. *et al.* The Spatial Collection Efficiency of Charge Carriers in Photovoltaic and Photoelectrochemical Cells. *Joule* **2**, 210–224 (2018).
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