Progress Report for the Boris Mints Institute – Jan 2021

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

Student: Tamir Yeshurun, Faculty of Electrical Engineering, Physical Electronics Department
Advisor: Dr. Gideon Segev, Faculty of Electrical Engineering, Physical Electronics Department

Summary: Our research focuses on extracting the photon external luminescence efficiency for characterizing materials and devices for solar energy conversion. We constructed a photoluminescence quantum yield measuring system, preformed and measured the incident wavelength dependent photoluminescence quantum yield of an InP wafer. Over the next year, we will build an optical model, simulate, and compare the spatial photon external luminescence efficiency extracted from measurements for different materials and various solar devices. This year we will also be collaborating with the Hameiri group at UNSW, Australia, expanding possible experiments using various characterization techniques.

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.

The transport of photogenerated charge carriers and their recombination processes define the efficiency of photovoltaic cells. These recombination processes 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 external luminescence efficiency (SELE). Obtaining SELE 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 SELE 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 PLQY over a wide range of incident wavelengths. From the analysis of the wavelength dependent PLQY, together with optical modeling, we extract and compute the SELE profiles, as previously shown in a similar analysis.[4,5]

In order to investigate the photoluminescence properties of the sample over a range of excitation wavelengths, 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 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.

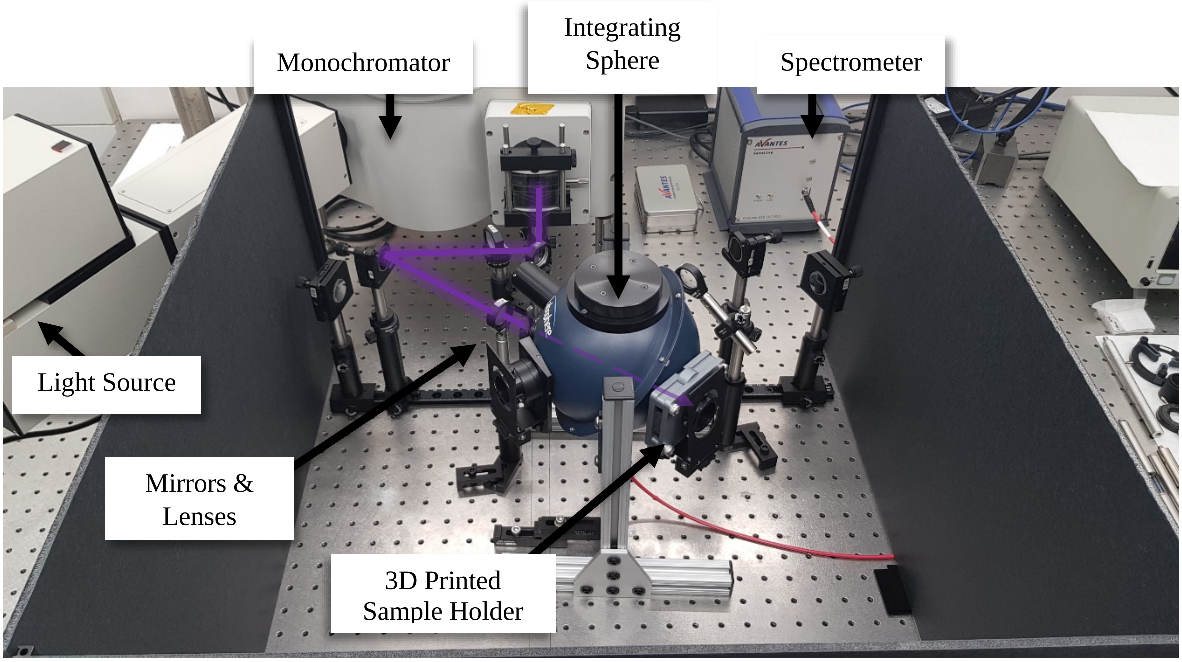

Figure 1 – PLQY Experiment layout. The image depicts the light (purple line) from the monochromator output to the sample inside the integrating sphere. The light is focused on the sample via a set of lenses and mirrors. The PL signal is collected with an optical fiber at the bottom of the integrating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

We have performed measurements of photoluminescence signal when the sample is excited by various wavelengths. Figure 2 shows measured photoluminescence quantum yield results from the measurements using an undoped InP wafer, with different excitation wavelengths.

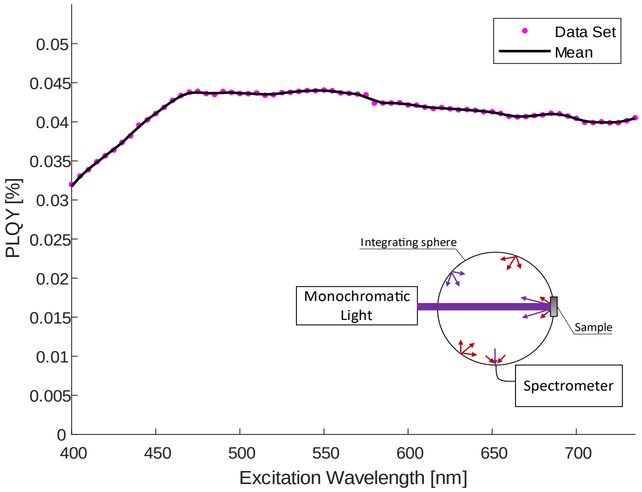

Figure 2 – Photoluminescence quantum yield measurements results using various excitation wavelengths on an undoped InP sample, positioned on an integrating sphere. The inset shows the schematic illustration of the PLQY measurement experiment, depicting monochromatic excitation wavelength.

For the upcoming year, we will perform PLQY measurements, model and simulate the spatial external luminescence 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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