Progress Report for the Boris Mints Institute – January 2020

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

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Summary: For the past five months, we have designed an experiment for measuring the photon recycling efficiency for characterizing materials and devices for solar energy conversion. To define the requirements and components' properties, we preformed preliminary experiments on an InP wafer. Using the results, we then compared and searched different possible instruments and products that are suitable for the experimental demands. For the next year, after setting up the experiment, we plan 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 point in the device to contribute to the photoluminescence emission 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 define the experiment and instruments requirements, we first turned to test the photoluminescence of sample wafers. We positioned the sample on an integrating sphere, which is an internally coated sphere with diffusive and almost perfectly reflective material. The integrating sphere 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. A 1 mW, 635 nm laser was used as an excitation source, incident on an InP sample wafer. We then preformed multiple tests to assess the required sensitivity of the measuring device. Figure 1 shows the results from a preliminary experiment using an undoped InP wafer. It can be seen that the PL signal is much weaker than the power of the exciting laser and potentially requires sensitive measuring devices for a reliable result.

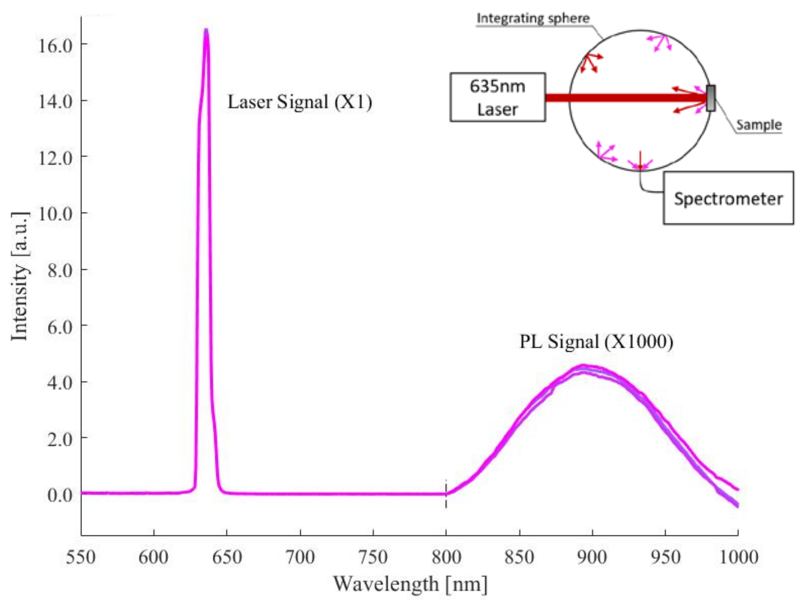

Figure 1 – Laser and PL signal results from preliminary experiments showing a number of measurements of InP undoped sample excitation, using an integrating sphere. The excitation laser signal can be seen centered at 635nm, together with the photoluminescent excited signal centered at 900nm. The PL signal (800-1000nm) is scaled by X1000 for convenience and the noise levels are smoothed. The inset shows the schematic illustration of the PL preliminary experiment.

To investigate the performance of a sample over a range of wavelengths, we decided to use a powerful light source, coupled to a monochromator. Figure 2 shows the designed set-up layout. The output light from the monochromator, with a chosen wavelength is directed into the integrating sphere with a set of mirrors and lenses, illuminating the sample that is mounted on a side port of the sphere. 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. Our design also includes a different optical path for the measurement of a reflectance standard and the throughput of the system, using a calibrated power meter.

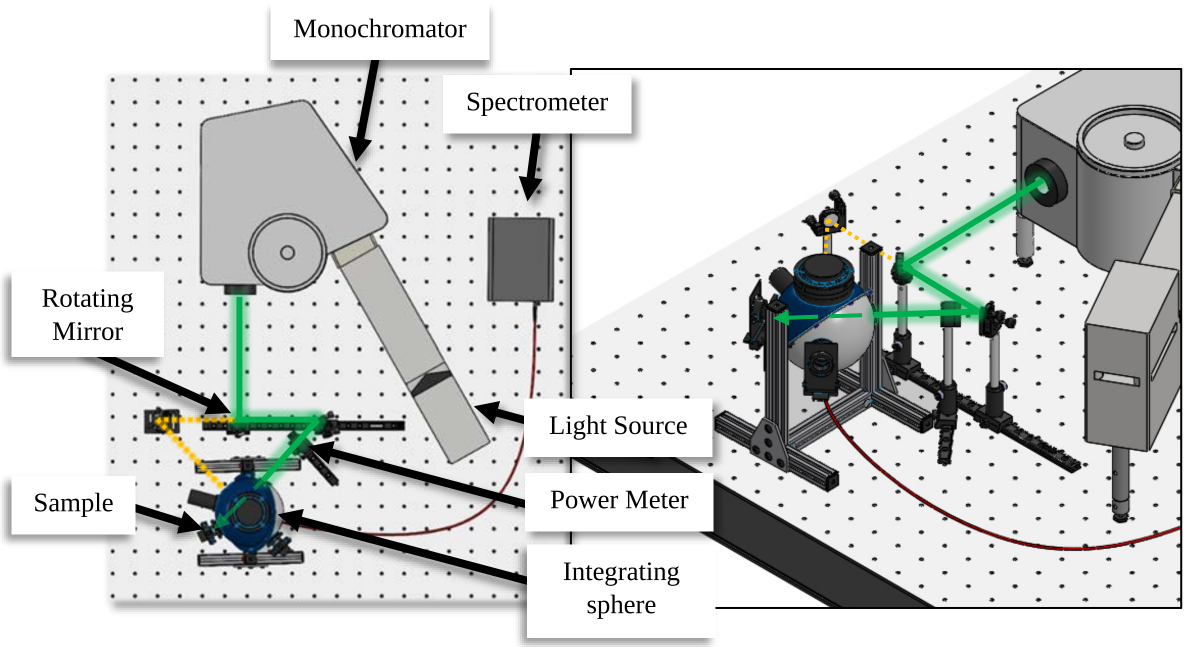

Figure 2 – Designed photoluminescent experiment layout, with top view on the left. The layout depicts the light (green) from the monochromator output to the sample on the integrating sphere. The PL signal is collected with a fiber at the bottom of the integrating sphere to spectrometer. The second light path (orange) corresponds to the measurement of a reflectance standard.

For the next 6 months, we will build and calibrate our setup. 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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