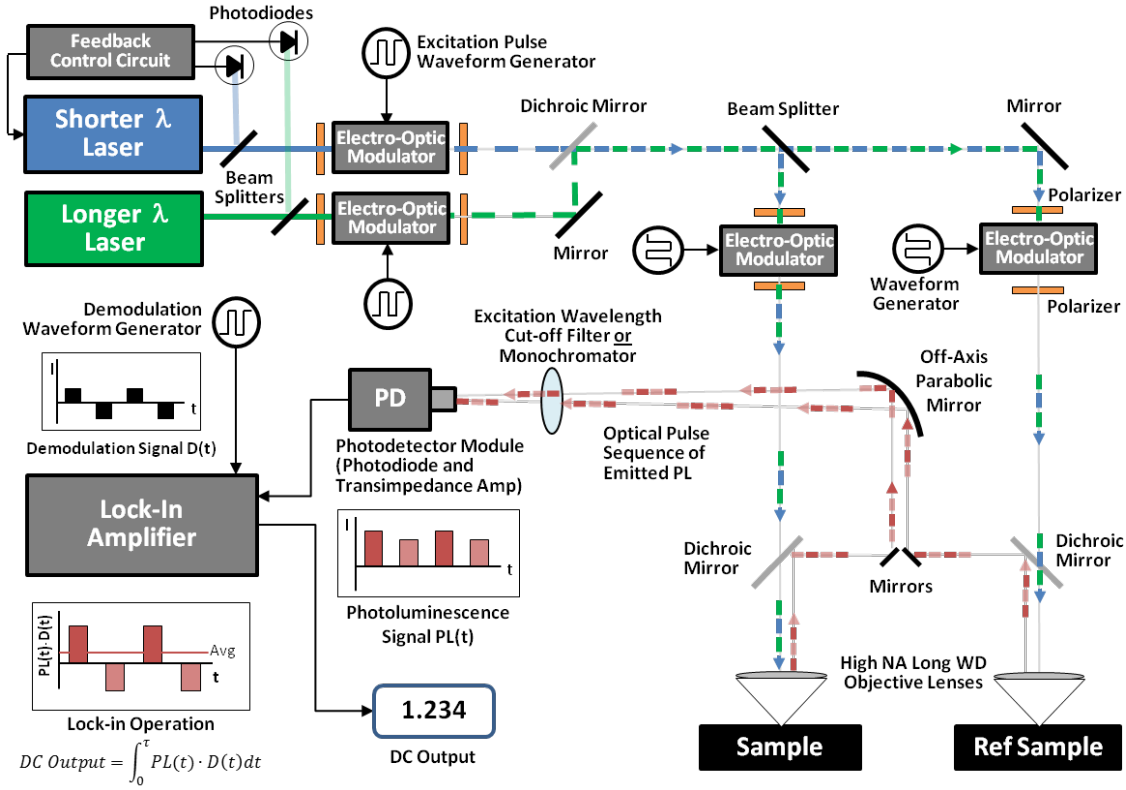
**BAPVC Annual Project Report**

**Project Title:** Development of Multicolor Lock-in Photoluminescence Methods for In-Situ Process Monitoring and Ex-Situ Mapping of Solar Cell Absorber and Interface Quality

**PI:** Hugh W. Hillhouse
**E-mail:** h2@uw.edu

**Summary:**
The goal of the project is to develop a new photoluminescence technique to interrogate surfaces and buried interfaces that is robust in a manufacturing environment and will generate easily interpretable output so that it can be correlated to product quality or even integrated into a process control scheme. We have completed a prototype of the instrument and collected data sets on various semiconductors including GaAs, InP, and CdTe. The difference PL spectra show that the surface of InP is high quality (as expected) while GaAs and CdTe have high surface recombination.

**Key Accomplishments:**
We have completed a prototype instrument. The schematic of the full instrument set-up is shown in Figure 1. The current prototype uses two laser beams (640 nm and 514 nm) that are pulsed and interlaced before illuminating the sample. The time-modulated steady state PL is collected, passed through a monochromator, detected, and demodulated.




$$DC\ Output = \int_0^{\tau} PL(t) \cdot D(t)dt$$

**Figure 1.** Schematic of a standalone modulated Multicolor Lock-in PL instrument that is robust to drift, fouling, and noise. The optical path from the exit of the last electro-optical modulator to the sample to the detector may be fiber coupled to avoid alignment issues.

The instrument is calibrated such that the number of photons in the 640 nm pulse is the same as the number of photons in the 514 nm pulse. Since the penetration depth is larger for the 640 nm light, the photoexcited carriers are spread out over a larger area and the injection level is lower. If the effective rate of recombination at the surface is the same as the bulk, the PL intensity from the 514 excitation should be higher. However, if the surface recombination is high then the PL intensity from the 640 should be higher. For both the GaAs and CdTe, then difference in PL intensity (614 nm excitation minus 514 nm excitation) is positive, indicating high surface recombination. However, for InP the opposite is observed. This is commensurate with expectations for InP (see Figure 2).

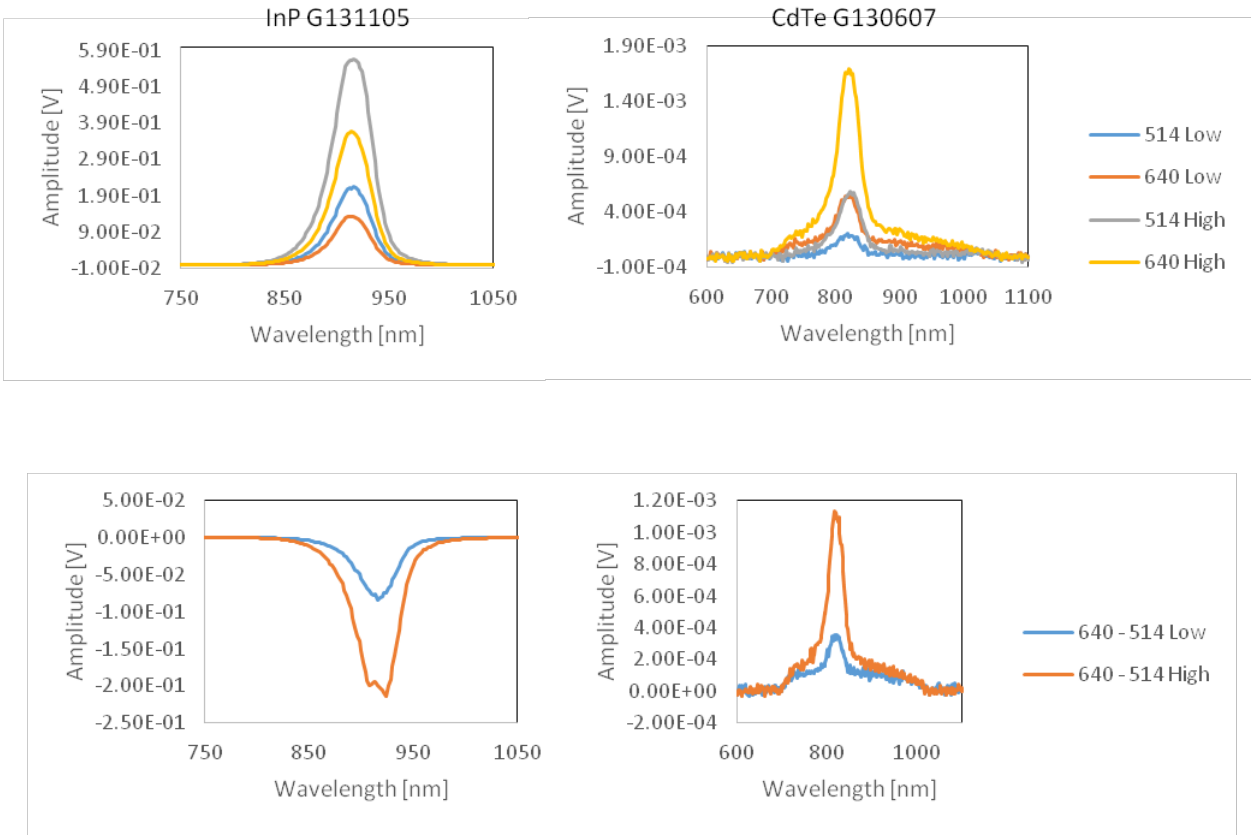



**Figure 2.** Demodulated PL signals from InP (left column) and CdTe (right column). The top row shows the PL spectra for both 640 and 514 excitation for two different excitation intensities. The bottom row shows the demodulated difference spectra. ***NOTE: All these data are extracted in tens of milliseconds from the modulated beam arriving at the detector***. The data show that the InP surface is passive while the CdTe surface has high surface recombination velocity.

**Future Work:**

We are now collecting data from different materials (GaAs, CdTe and CIGS) and conducting surface treatments to illustrate the capability of the tool. In addition, we are working towards adding a reference sample.