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Photoluminescence Imaging of Semiconductors

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The development of energy-related devices requires new materials and fabrication processes that enable both an enhancement in performance and a decrease in manufacturing cost. Polycrystalline semiconductors are promising for photovoltaic applications because they can be grown at low temperatures on inexpensive substrates. Metamorphic epitaxy of semiconductor alloys on lattice-mismatched substrates is also increasingly used to access new semiconductor alloys for visible light emitting diodes used in high efficiency solid-state lighting. With these advancements, defects play a progressively more prominent role in device performance, and it is important to be able to probe their behavior in order to understand and ultimately control their effects. Information about the spatial distribution of extended defects and compositional fluctuations as well as their influence on carrier transport is particularly crucial for materials engineering efforts. Characterization techniques must therefore be able to provide real time feedback with micron-scale spatial resolution. We present a novel photoluminescence (PL) imaging technique with both of these capabilities and discuss the information that can be obtained in a number of semiconductor systems.

The general configuration of the PL imaging setup is shown in Fig. 1a. Photoluminescence excited with either a defocused or focused laser beam is collected with an objective lens and is projected onto a Si CCD camera, enabling real-time imaging with diffraction-limited spatial resolution. Narrow regions of the spectrum can also be imaged separately by inserting a tunable liquid-crystal optical filter into the beam path. Coupled with a tunable excitation source, this is an exceedingly simple yet powerful technique that is ideal for a number of different material and defect studies.

As a demonstration of the concept, Fig. 1b shows a composite PL image of an $Al_{0.34}In_{0.66}P$ epilayer grown metamorphically on a GaAs substrate, revealing strain-induced compositional fluctuations around threading dislocations. The image has been false colored to show the spatial variation of the bandgap energies. The density of both threading and misfit dislocations can rapidly be measured with this tabletop setup.

The capabilities of this technique extend beyond spatially resolving the location of defects or alloy compositions across a sample and provide a way to detect how extended defects affect carrier transport. Because the configuration allows us to photo-inject carriers into one region of the sample with a focused laser beam and simultaneously spatially resolve PL emission from a much larger area, we can observe how far carriers travel before they recombine [1]. Figure 2 displays PL images taken from a polycrystalline CdTe sample. A focused laser beam (diameter ~ 1 μm) was placed in the center of the grain marked "v", and PL was imaged over a ~ 150 x 150 μm^2 area. Additionally, the tunable liquid crystal filter was used to separate band edge PL (Fig. 2a) from PL originating from impurity states (Fig. 2b). Detection of PL from adjacent grains as well as from impurity states far from the point of injection provides information about how the grain boundaries and impurities in this material influence carrier transport [2].

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References:

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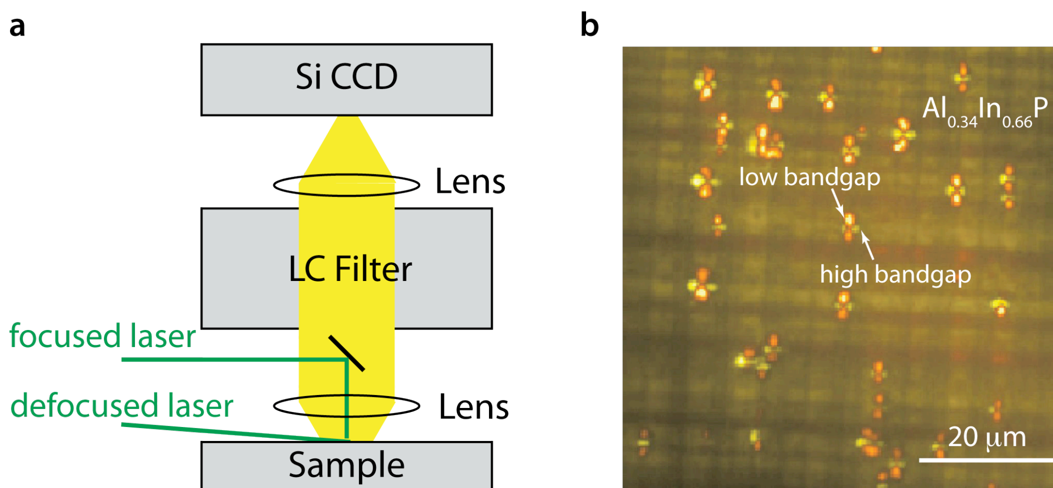

Figure 1. (a) Configuration of the PL imaging measurement setup. (b) PL image of strain-induced compositional variation around threading dislocations in metamorphically-grown $Al_{0.34}In_{0.66}P$. The image has been false colored based on the emission energies.

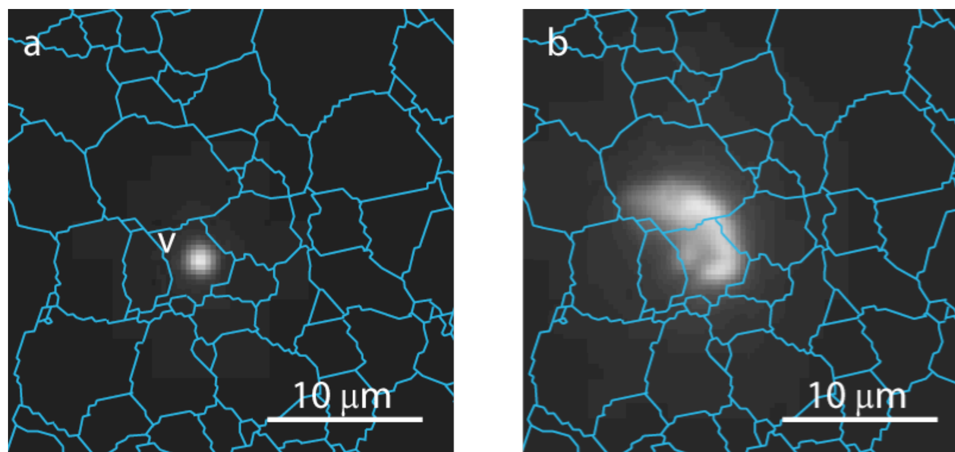

Figure 2. PL images of a polycrystalline CdTe sample. The positions of the grain boundaries, marked in light blue, were determined by electron backscatter diffraction measurements (EBSD). A focused laser (diameter ~ 1 μm) is used to inject carriers into the center of the grain marked "v". Images are shown for PL emitted from (a) the band edge (782 nm) and (b) impurity states (865 nm).

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