

Mid-IR HgTe Colloidal Quantum Dots

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BIOGRAPHY

Sean Keuleyan: Sean is a fourth year graduate student in the Chemistry department at the University of Chicago, where his work focuses on the development of colloidal materials for applications in the mid-infrared. He graduated with a B.S. in Chemistry with a second major in Film and Media Arts from Temple University in 2008.



TECHNICAL ABSTRACT

The past two decades have seen incredible interest and development of colloidal quantum dots (CQDs) in the visible and near-IR for light sources, detection, photovoltaics, and labeling. Colloidal nanocrystals though, may have a great unrealized potential in the mid-infrared, where solution preparation and processing enable low-cost devices, and an attractive alternative to photodetectors in the 3-5 μm range of wavelengths for some applications. Mid-infrared-active nanocrystals though are quite underdeveloped, due in part to poorly-controlled chemistry of the particle growth. By improving the chemical preparation of HgTe colloidal quantum dots, we have enabled the first studies of these materials into the mid-IR and their potential in mid-infrared detection and emission.

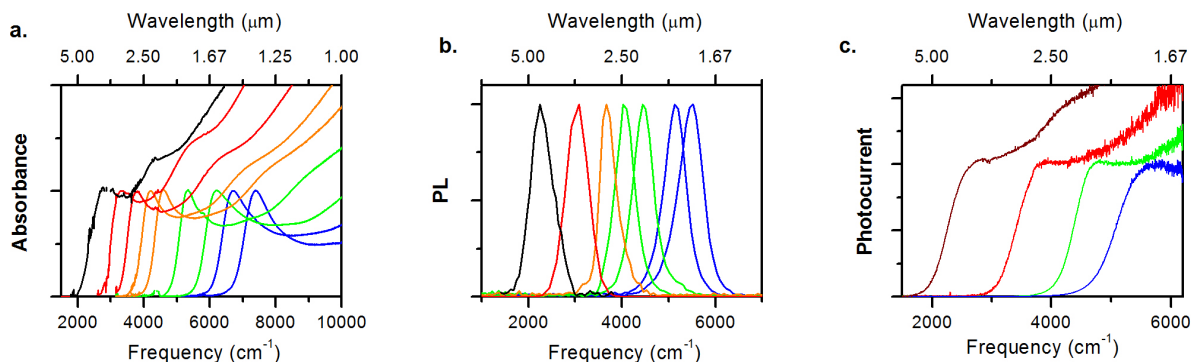


Figure: Absorption, photoluminescence, and photocurrent spectra for HgTe quantum dots of different sizes.

The synthesis of HgTe CQDs is a simple injection-based method using relatively low-toxicity (compared to organo-mercury compounds) mercury salts and phosphine tellurides at moderate temperatures (60-150 $^{\circ}\text{C}$). The method results in particle sizes (edge to edge) ranging from about 6 to 15 nm, tuning the material band-gap through the wavelength range of 1 to 5 μm with sharp edge features seen in absorption photoluminescence, and photocurrent spectra. A rational trend with size is given for both the particle band-gap and cross-section and compared to k-p calculations. Film absorption lengths turn out to be similar to bulk HgTe, beneficial to the use of thin films for devices.

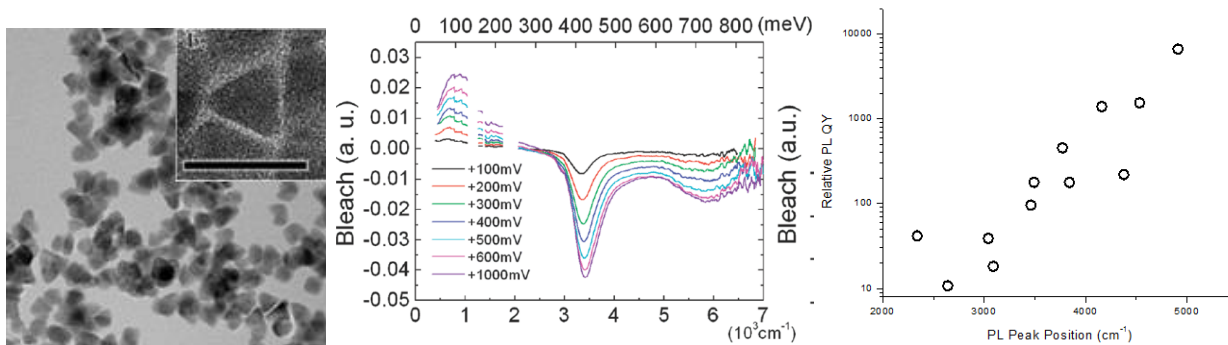


Figure: Left: TEM image of large HgTe particles, inset shows single particle with lattice fringes. Middle: absorption bleach spectrum on electrochemical p-doping. Right: relative PL quantum yields as a function of particle band-gap.

Photoconductive detectors based on drop-cast thin films of this material have tunable room temperature photoresponse to beyond $5 \mu\text{m}$, reaching $7 \mu\text{m}$ at low temperature. We have investigated the electronic structure, majority carrier, and effects of charge-doping, using field-effect and electrochemical gating. Temperature dependence of the material band-gap is of great importance from basic as well as applied perspectives. A positive shift with increasing temperature is described by the Varshni equation, with a size dependence attributed to electron-phonon effects.

Furthermore, as fluorescent inks, the colloidal solutions or solids could be used in labeling and infrared sources. We show narrow emission from solutions and films of HgTe nanoparticles across the mid-IR. Photoluminescence is investigated as a function of energy, temperature, and material processing. The simple synthetic control of the material band-gap and solution processing present an unrealized potential for new low-cost alternatives for mid-infrared photodetection and emission.

Keywords: colloidal quantum dots, HgTe, mid-IR, detection, mercury telluride, solution-processing, emission