

Hybrid Nanomaterials for Multi-spectral Infrared Photodetection

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Abstract

Quantum dot infrared photodetectors (QDIPs) using Stranski-Krastanow (S-K) quantum dots (QDs) grown by strained-layer epitaxy have demonstrated low dark current, multi-spectral response, high detectivity, high operating temperature, and infrared (IR) imaging. However, achieving near room-temperature, multi-spectral operation is still a challenge in simple QDIP heterostructures due to random fluctuations in QD properties. The ability to control dopant incorporation is especially important since charge carrier occupation influences dark current and IR spectral response. In this work, dopant incorporation is investigated in two classes of QDs; S-K QDs embedded in epitaxial semiconductors, and colloidal QDs (CQDs) synthesized by chemical reactions and embedded in polymers. The long-term goals of this work are to optimize each QD type for IR spectral response in different atmospheric windows and to combine them in a single device heterostructure, thereby enabling hybrid nanomaterials for multi-spectral IR photodetection.

The following topics will be presented: 1) unique properties of QDs beneficial for IR photodetection, 2) electrical and optical characterization of S-K QDIPs, and 3) optical characterization of CQD/polymer nanocomposites deposited on semiconductor substrates. In the case of S-K QDIPs, dark current-voltage (Figure 1) and Fourier transform IR (FT-IR) absorption (Figure 2) characteristics for different doping schemes (modulation- vs. delta-doping) and doping concentrations (1, 2, and 3 electrons/dot) provide a comprehensive picture of dopant incorporation for device optimization. In the case of CQD/polymer nanocomposites, FT-IR absorbance spectra for different semiconductor substrates (Figure 3) demonstrate a method for controlling charge transfer in hybrid heterostructures. It is important to note that while near-IR sensitivity has been demonstrated in CQD/polymer nanocomposites using interband transitions [Leatherdale et al., *Phys.Rev.B*, **62**,2669(2000); McDonald et al., *Appl.Phys.Lett.*, **85**,2089(2004)], this work is unique in that mid- and long-wave-IR absorption in such materials are achieved through *intraband* transitions. Such transitions have been predicted theoretically [Binks, *IEEEJ.Quant.Electron.*, **40**,1140(2004)] and observed experimentally in CdSe/MEH-PPV nanocomposites deposited on GaAs [Stiff-Roberts et al., *MRS*, April, 2006].

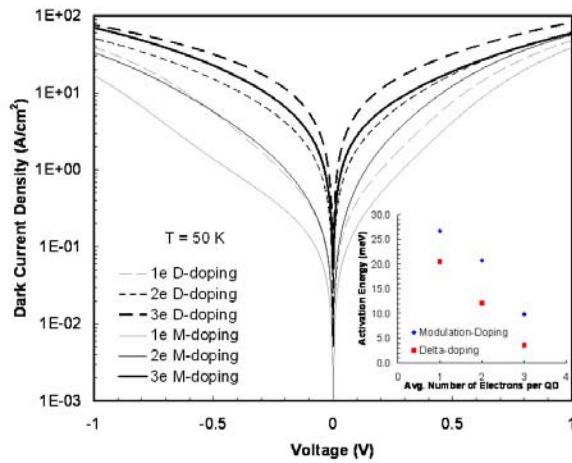


Figure 1. Dark current density ($T = 50$ K) vs. bias voltage for InAs/GaAs S-K QDIPs featuring different doping techniques and concentrations. The inset shows bias corresponding activation energies determined by Arrhenius plots.

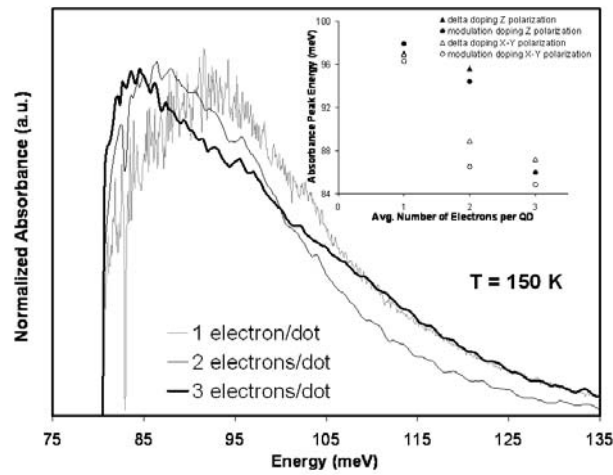


Figure 2. FT-IR absorbance spectra ($T = 150$ K) for X-Y polarization in modulation-doped, InAs/GaAs S-K QDIPs featuring different doping concentrations. The inset shows the FT-IR peak energies for the full range of samples.

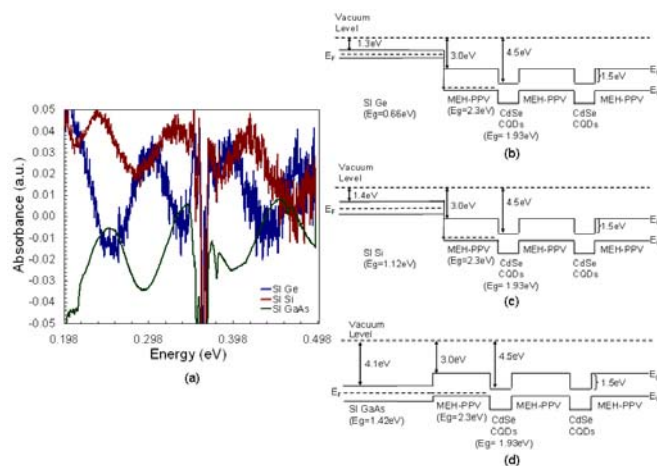


Figure 3. (a) FT-IR absorbance spectra for CdSe/MEH-PPV CQD nanocomposites deposited on semiconductor substrates, and the corresponding interfacial band line-ups for semi-insulating (b) Ge, (c) Si, and (d) GaAs.