Quantum Dot Infrared Photodetectors (QDIPS)

by **J. G. Cederberg**

Motivation—Quantum Dot Infrared Photodetectors (QDIPs) utilizing electronic transitions of self-assembled quantum dots (SAQD) are candidates for infrared detection from 3 to 30 µm (40-400 meV). Electrons in the populated conduction band of the SAQD are photoexcited to a higher energy state (Fig. 1). Potential advantages of QDIPs over existing detectors lies in the zero-dimensional characteristics of SAQD: sensitivity to normal incidence radiation, increased responsivity due to increased excited carrier lifetime, and higher temperature operation due to reduced overlap of the SAQD density of states with the Fermi distribution. Under the influence of an electric field the photoexcited carriers are detected as a photocurrent (Fig. 1). The three-dimensional confinement of the SAQD modifies the symmetry selection rules allowing the SAQD to couple to normal incidence radiation. The increased carrier lifetime in SAQD (tens of nanoseconds compared with tens of picoseconds for quantum wells) is attributed to reduced carrier-phonon coupling, termed the "phonon bottleneck". Higher operating temperature should result from the reduced overlap of the SAQD density of states with the carrier Fermi function.

Accomplishment—In collaboration with Prof. Sanjay Krishna, with the University of New Mexico's Center for High Technology Materials, an InAs SAQD QDIP has been demonstrated. The device shows tunable photocurrent response between 7.7 and 9.9 µm with response persisting up to 90 K. (Fig. 2) The device incorporates strain balancing techniques to minimize strain in the layers that result in performance degrading defects in the material. InAs SAQD are buried by compressively strained $In_{0.15}Ga_{0.85}As$ forming a dots-in-a-well (DWELL) structure. The compressive strain is balanced by tensile $GaAs_{0..8}P_{0.2}$. This demonstration provides a path to increasing the detectivity of QDIPs by increasing the number of SAQD layers in the structure. Almost all the devices investigated to date have utilized a small number of repeat periods (typically 10 or less) to limit the introduction of dislocations into the active region. This represents a path to higher performing mid-wavelength and long wavelength IR sensors.

Significance—Infrared sensing has long been a distinguishing technology for military and intelligence communities. QDIP sensors can positively impact this technology by providing detectors with higher operating temperatures or with functionality that is not presently achievable. Since QDIPs are fabricated in III-V materials, they have the potential to be monolithically integrated with other optical and electronic components for engineering sensing systems. These systems also have applications in chemical identification for environmental monitoring and process control. This demonstration highlights the unique applications for SAQD in optoelectronics.

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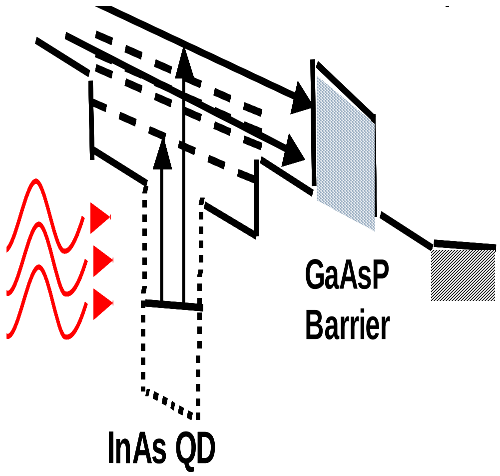

Figure 1. A single period of the conduction band diagram for a strain balanced QDIP device.

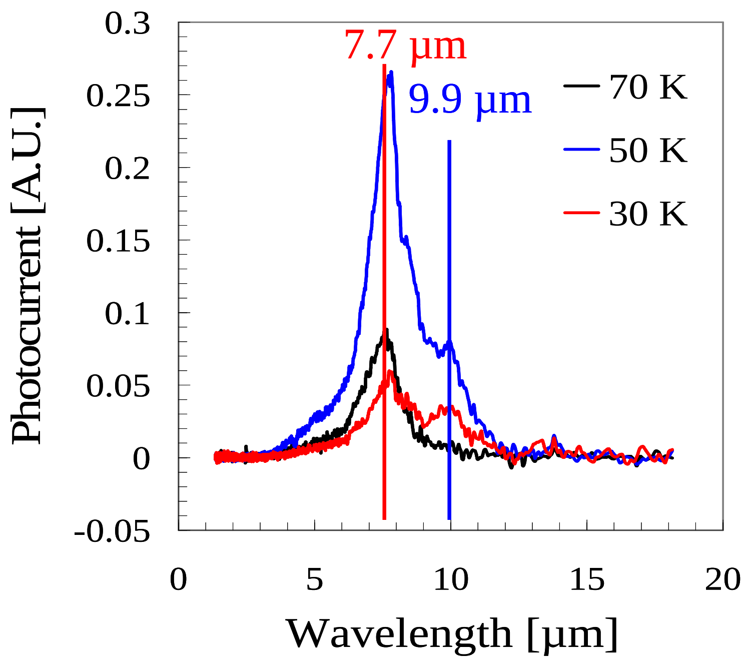

Figure 2. Photocurrent response from an InAs SAQD strain balanced QDIP.