Self-assembled Quantum Dots for Detectors and Emitters in the Long-wavelength Infrared

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Motivation—Self-assembled quantum dots (SAQD) have unique optical properties that make them promising for potential long-wavelength infrared (LWIR) applications. Unlike quantum well infrared photodetectors (QWIPs), detectors utilizing the electrons populating the conduction subband, introduced by doping the SAQD, can readily couple to surface-normal incident radiation. The electron promoted to a higher conduction band state can tunnel through potential barriers under applied voltage and be sensed as a photocurrent. Emitters require injection of electrons into an excited state and a radiative transition to the ground state of the SAQD. We are utilizing the intersubband transitions of SAQD to develop detectors and emitters. SAQD have several advantages over quantum well analogs. The quantum mechanical selection rules for a SAQD allows them to emit or sense radiation with all polarizations. For emitters this eliminates the need to engineer a grating structure to extract light out of a cascade laser based on quantum wells. This characteristic makes the detector structure sensitive to normal incidence radiation.

Accomplishment—We have undertaken the development of LWIR emitters. For efficient emitter operation, the ground state of the SAQD must be above the conduction bandedge of GaAs. The conduction band diagram in Fig. 1 shows this can be achieved by increasing the potential around the SAQD using an AlAs matrix. A prerequisite for SAQD growth is a smooth morphology of the underlying layer. While this has been reported by molecular beam epitaxy, this structure has not been reported by metal-organic chemical vapor deposition (MOCVD). Our use of a low decomposition temperature metal-organic precursor allowed us to achieve smooth AlAs surfaces at temperatures as low as 480°C (Fig. 2a). The root mean square roughness of the AlAs layer is 0.6 nm. The growth of InAs SAQD on AlAs challenged our paradigm developed for InAs SAQD on GaAs. For the InAs on GaAs system, a post-growth purge has been shown to be essential to facilitate the surface mass transfer needed for SAQD formation. The short post-growth purge of two seconds was found to have a negative influence on InAs SAQD grown on AlAs (Fig. 2b) resulting in large, faceted islands (20 nm high). Eliminating the post-growth purge from the growth sequence produced small (2 nm high), dense islands (Fig. 2c).

Significance—Success in finding appropriate conditions for InAs SAQD growth on AlAs provides an internal source of material for LWIR emitters and detectors. Future efforts will generate cavity structures to look at resonant cavities with and without two-dimensional photonic crystals etched into the surface. This success impacts not only emitter fabrication, but it extends the wavelengths over which detectors are sensitive. Shorter wavelength detector sensitivity should be achieved with InAs SAQD in high Al content AlGaAs matrices compared to current GaAs based designs. The long term goal of this effort is to demonstrate a surface emitting quantum cascade laser structure, which would be a significant advancement for this technology.

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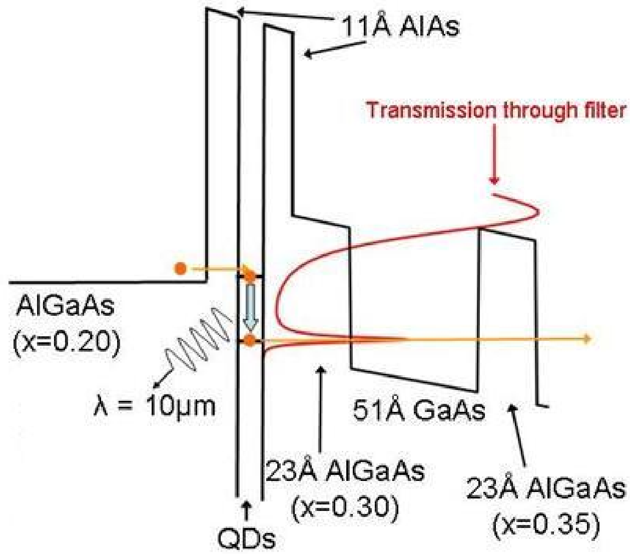

Figure 1. Conduction band diagram of intersubband emitter structure using SAQD as the active media. By placing the InAs SAQD between AlAs layers, the ground state is raised above the GaAs conduction bandedge, a necessary condition for depopulation of the ground state.

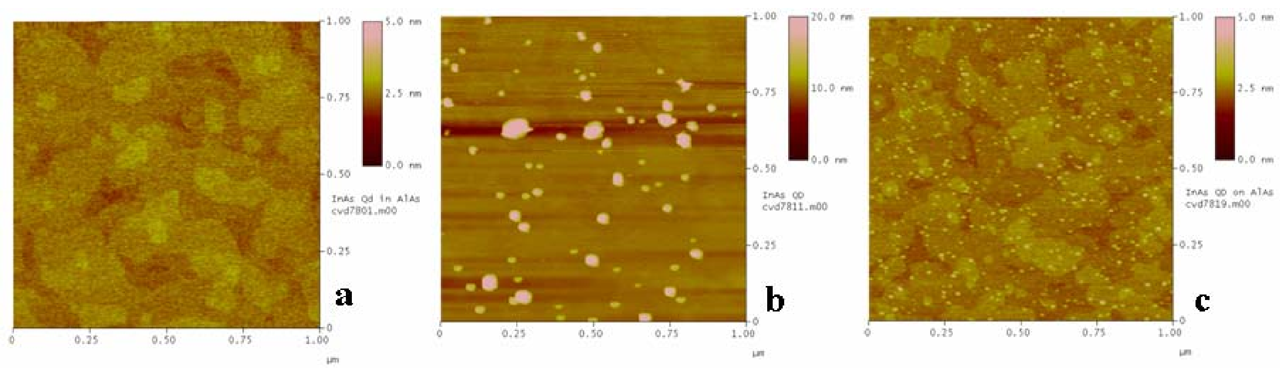

Figure 2. Atomic force microscopy images of surfaces: a) AlAs grown at 480°C with a RMS roughness of 0.6 nm, b) InAs SAQD on AlAs purged for 2 sec without AsH_3 present in growth chamber, c) InAs SAQD not subjected to any time without AsH_3 during their growth.