Growth and Characterization of High-Density Quantum Dots for Solar Cell Applications

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Abstract:

We have demonstrated the growth of high-density GaAs/AlGaAs quantum dots (QDs) by droplet epitaxy on a (311)A substrate. The QDs were found to not only be uniform and highly dense, but also structurally consistent among multiple stacked layers. Optically, the QD peak position is found to follow a clear trend across different barrier thicknesses and QD layer numbers, demonstrating interactions between the QDs. Preliminary solar cells were also fabricated and characterized.

Background:

Traditional solar cells consist of semiconductor material and can absorb photons from the sun that have energy equal to or greater than their bandgap. Introducing intermediate states to a solar cell allows for photons with lower energies to also be absorbed, as seen by the band structure in Figure 1. One way to fabricate intermediate band solar cells is by embedding QDs into the cell, which creates discrete states due to QD confinement properties. Since the absorption coefficient is proportional to the number of QDs, higher densities of QDs result in more photons being absorbed and, therefore, improved efficiency.

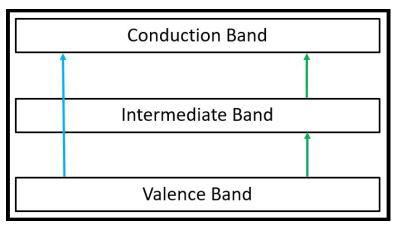

Figure 1: Simplified band structure of an intermediate band solar cell.

Summary of Research:

We were able to grow high-density QDs by droplet epitaxy. Unlike Stranski-Krastanov growth, the most common method for growing QDs, droplet epitaxy allows us to use a lattice-matched system. Using a strain-free material system allows us to grow many closely stacked QD layers without degraded material quality. We investigated the stacking process of QDs on a (311)A substrate using GaAs and AlGaAs. We first characterized these materials structurally and optically. Atomic force microscopy (AFM) showed higher dot densities for samples grown on (311)A substrates and showed consistent structures among varying layers of QDs. Photoluminescence (PL) measurements were used to investigate the relationships between QD layer number and/or barrier thickness and material properties, such as peak position. Then, preliminary solar cells were fabricated and their performance was analyzed.

Results and Conclusions:

Figure 2 shows an AFM scan of QDs grown on a (311) A substrate. QDs on (311)A are approximately 20 nm in diameter and 5 nm high with densities of 1000/ μm^2. The structure of surface QDs was found to be consistent across various numbers of QD layers. This consistency is promising for successful stacking of QD layers, which is necessary to achieve a densely stacked structure. Figure 3 shows a PL plot of QDs grown on a (311)A substrate. The obvious peak at approximately 770 nm is due to the GaAs QDs. The QD peak is clearly at a shorter wavelength than bulk GaAs, which is because of the confinement properties of quantum structures. Further PL measurements were performed to study structures with various barrier thickness (1 nm, 2 nm, and 3 nm) and consistent QD layer numbers and structures with various QD layer numbers (1, 2, and 3) and consistent barrier thickness. Both studies showed clear trends for the QD peak position, demonstrating that there must be interactions (such as coupling) between the QDs. Solar cell device experiments clearly showed that the cell's currents increased with illumination, which is promising. However, the performance of the devices could likely be greatly improved by optimizing the growth of the doped layers. On the (311)A substrate, the window for optimal doped layer growth is very small indicating that future research in this area is necessary.

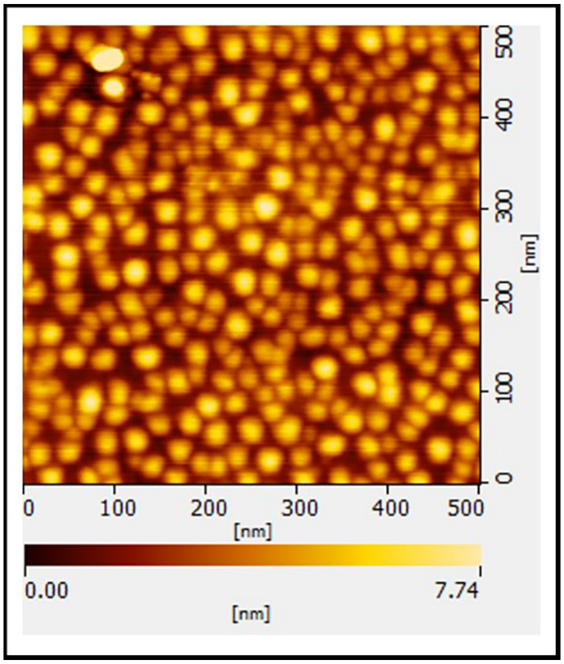

Figure 2: AFM results of QDs grown on a (311)A substrate.

Future Work:

Next steps include further investigation of coupling between quantum dots and optimizing the solar cell device.

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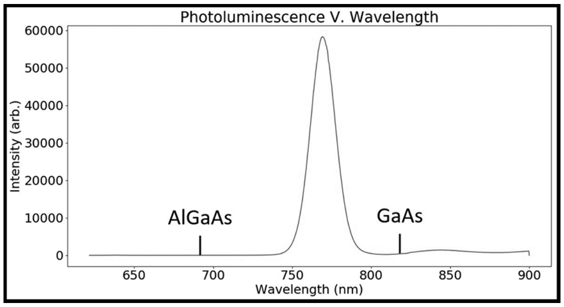

Figure 3: Photoluminescence results at 10K of QDs grown on a (311)A substrate showing a strong peak due to GaAs QD confinement with GaAs and AlGaAs bulk energies labelled.

References:

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