

Characterization and Solar Cell Application of GaSb Quantum Dots

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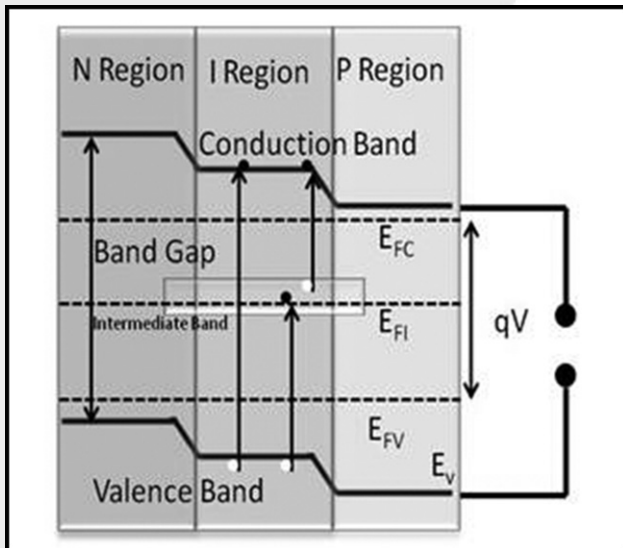


Figure 1: Ideal band diagram of the intermediate band solar cells.

Introduction:

Intermediate band solar cells (IBSC) can potentially overcome the Shockley-Queisser (SQ) conversion efficiency limit of photovoltaic devices. In addition to photocurrent generated by photons above the band gap, IBSC can utilize a “two-step” photocurrent, wherein sub-bandgap photons excite carriers from the valence to intermediate band, then intermediate to conduction band, depicted schematically in Figure 1.

Quantum dot heterostructures (QDs) are one method of realizing intermediate energy states within the band gap. Our interest is in structures with type II band alignment. In contrast to commonly used type I structures, in which both electrons and holes are confined in the narrow bandgap material, radiative recombination can be largely suppressed in type-II structures, which would be preferable for solar cell application, because losses due to radiative recombination can be reduced.

QD solar cells realized from gallium antimonite (GaSb) embedded in gallium arsenide (GaAs) are of interest an example of type-II band solar cells. By changing the GaAs barrier to aluminum gallium arsenide (AlGaAs), we expect the dot energy levels will be situated deeply enough to achieve

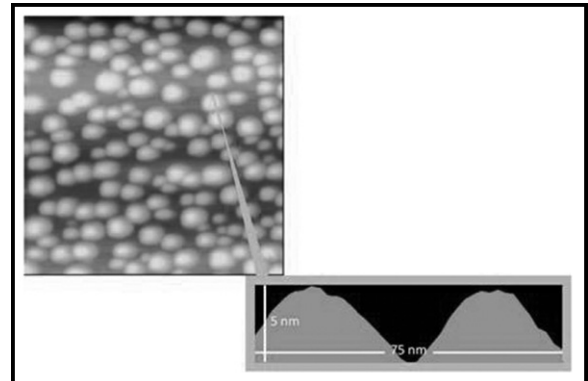


Figure 2: AFM micrograph of GaSb/AlGaAs QDs.

transition energies nearly matching the ideal IBSC configuration for highest efficiency proposed by Luque, et al. [1].

GaSb/GaAs QDs and GaSb/AlGaAs QDs were grown, and IBSC were fabricated using them. In this work, we determined the band alignment of GaSb/AlGaAs QDs, and then studied their solar cell applications.

Fabrication Procedure:

GaSb QDs embedded in GaAs and AlGaAs were grown on n-type GaAs <100> substrates using molecular beam epitaxy. We employed the Stranski-Krastanov growth mode, wherein growth is first layer by layer until the thickness reaches a critical value and growth continues through the coalescence of three-dimensional “islands.” Ten layers of QDs were separated by 20 nm thick barrier layers to decouple adjacent electronic states. We fabricated QD solar cells using photolithography and sputtering. A phosphoric acid, hydrogen peroxide, and water etch was used to electrically decouple the devices. Gold wires were then bonded from the device to a serial package.

Results:

Atomic force microscopy (AFM) revealed the average height of GaSb QDs (Figure 2) was 5 nm, regardless of barrier material. The density of GaSb/GaAs QD layers was $2.9 \times 10^{10}/\text{cm}^2$ and $5.6 \times 10^{10}/\text{cm}^2$ for GaSb/AlGaAs QDs. Photoluminescence

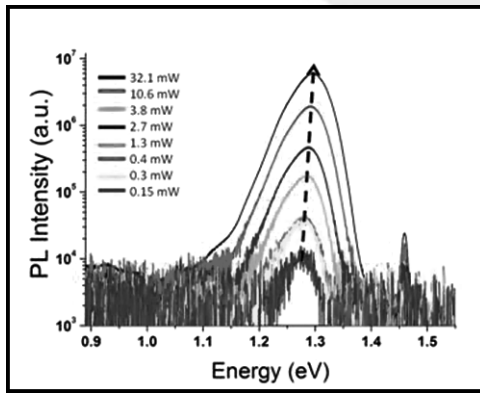


Figure 3: Blueshift of PL from GaSb/AlGaAs QDs with increasing laser power. (See full color version on page xxxvi.)

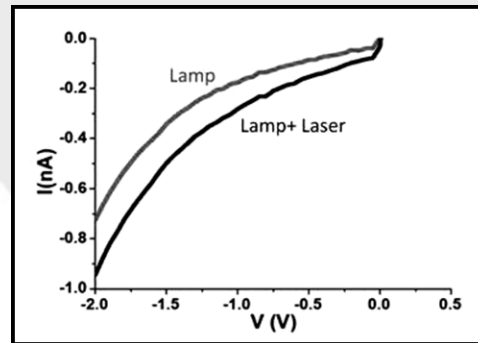


Figure 4: Two-step photocurrent generated by GaSb/AlGaAs QD solar cell.

(PL) measurements at 10 K revealed transitions at 1.09 eV for GaSb/GaAs QDs and 1.29 eV for GaSb/AlGaAs QDs from carriers occupying the QD layers. Hodgson, et al. [2] showed that increasing laser power results in a blueshift of the peak position of PL from type II QD heterostructures. PL from GaSb/GaAs QDs was blueshifted. Figure 3 shows this blueshift occurring in PL from GaSb/AlGaAs QDs. This revealed that GaSb/AlGaAs QDs has type II band alignment.

QD solar cells fabricated with GaSb/AlGaAs QDs revealed higher open circuit voltage and smaller short circuit current compared to that with GaSb/GaAs QD solar cells. This is explained by the higher band gap of AlGaAs and poor escape of photogenerated holes from the QDs due to an increase in the confinement energy.

Photocurrent spectroscopy at room temperature demonstrated the absorption of photons with energies below the band gaps of GaAs (1.5 eV) and AlGaAs (1.8 eV) corresponding to the QDs and wetting layers. The photocurrent decreased with increasing voltage, presumably due to the bias dependence of the escape efficiencies of holes from the QDs.

To observe two-step photocurrent, we used a 600 nm (2.1 eV) halogen lamp and a 1.55 μm (0.8 eV) laser. The lamp creates electron-hole pairs, whereas the 1.55 μm laser generates no carrier. Upon illumination with the laser, an increase in photocurrent, ΔI , was observed in solar cells fabricated from GaSb/GaAs QDs and GaSb/AlGaAs QDs (see Figure 4).

Conclusions and Future Work:

We successfully fabricated solar cells with ten layers of GaSb QDs embedded in GaAs and AlGaAs. We determined that GaSb/AlGaAs QDs has type II band alignment. We observed photocurrent generated from the QDs and wetting layers in

both GaSb/GaAs QDs and GaSb/AlGaAs QDs, and analyzed the current-voltage characteristics. We observed two-step photocurrent generation, the key operating mechanism for IBSCs. We observed reduced photocurrent by changing the barrier from GaAs to AlGaAs, which is explained by strong confinement in GaSb/AlGaAs QDs. These results demonstrate the potential of GaSb/AlGaAs QD solar cells in realizing ideal IBSC and overcoming the SQ limit.

Future work includes investigating the dependence of the two-step process on incident laser power among other experiments to study the fundamental physics of GaSb/AlGaAs QD solar cells.

Acknowledgements:

I would like to thank my principal investigators, Drs. Noda and Sakaki, mentor, Dr. Elborg, and the High Efficiency Solar Cell/Quantum Nanostructures Group for their great assistance and patience; and the National Institute of Materials Science, National Nanotechnology Infrastructure Network International Research Experience for Graduates (NNIN iREG) Program, and National Science Foundation for making this research possible.

References:

- [1] A. Luque and A. Martí. "Increasing the Efficiency of Ideal Solar Cells by Photon Induced Transitions at Intermediate Levels"; Physical Review Letters, v. 78, p. 5015-5017 (1997).
- [2] P.D. Hodgson, et al. "Blueshifts of the Emission Energy in Type II Quantum Dot and Quantum Ring Nanostructures"; Journal of Applied Physics, v. 114, p.1-6 (2012).

