Optical Characterization and Solar Cell Application of GaAs/$Al_{0.8}Ga_{0.2}As$ Quantum Wells

Lauren M. Otto

Physics and Mathematics, Bethel University
Electrical Engineering, University of Minnesota-Twin Cities

NNIN iREU Site: National Institute for Materials Science (NIMS), Tsukuba, Ibaraki, Japan
NNIN iREU Principal Investigators and Mentors: Prof. Hiroyuki Sakaki, President of Toyota Technological Institute, NIMS Fellow; Dr. Takeshi Noda, Photovoltaic Materials, NIMS
Contact: lauren-otto@bethel.edu, h-sakaki@toyota-ti.ac.jp, noda.takeshi@nims.go.jp

Abstract:

The theoretical efficiency limit of current single p-n junction solar cells is ~ 33%. Intermediate energy states in the solar cell's band gap allow low energy photons to induce carrier excitations, increasing efficiency [1]. Quantum well solar cells contain such states, but carriers excited in the barrier often relax into the wells where they become trapped and recombine, reducing efficiency. Because of a large momentum difference, the use of an indirect material may suppress carrier trapping and recombination, resulting in greater solar cell efficiency. Using GaAs/$Al_{0.8}Ga_{0.2}As$ quantum well structures, we find that carriers trapped in our quantum wells cannot easily escape, and current measurements show no significant recombination among carriers generated in the indirect barrier region. Our data suggest that the trapping of these carriers may indeed be suppressed, but further investigation is necessary.

Introduction:

Solar cells (SCs) convert solar energy to electricity. Current SCs only utilize part of the solar spectrum, so room for improvement remains. Intermediate band (IB) SCs are a possible solution because they allow low energy photons (< SC's band gap) to excite carriers from the valence band (VB) to the conduction band (CB) [1]. Quantum well (QW) IB SCs are easy-to-fabricate layers of different band gap materials, leading to finite potential wells in the VB and CB, each having discrete hole and electron states [2]. Unfortunately, barrier-excited carriers often relax into the well, become trapped, and recombine. The SC's efficiency is reduced because these carriers do not contribute to the current.

Indirect barrier QW structures are expected to suppress the trapping of barrier-excited carriers. Unlike a direct barrier, the Γ-state of indirect $Al_xGa_{1-x}As$ ($x > 0.45$) has the greatest energy, and the X-state has the least. Indirect barrier-excited carriers were expected to thermally relax to the X-state. Then, conservation of momentum and narrow QW width would increase probability of carrier contribution to the current. Since the lattice constant is not dependent on Al composition, GaAs/$Al_{0.8}Ga_{0.2}As$ QWs were grown to study the possible application of indirect barrier QWs as SCs and were characterized using photoluminescence (PL), photocurrent (PC), and voltage dependent current (I vs. V) experiments.

Fabrication:

Two sets of samples were fabricated.

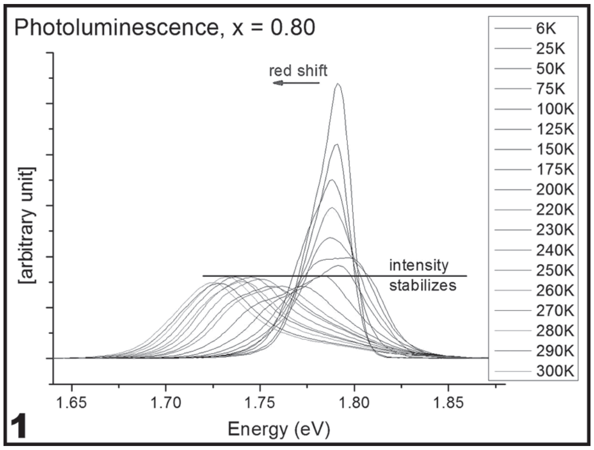
First, two undoped, ~ 3 nm wide, 10-QW structures were grown with molecular beam expitaxy (MBE) for PL measurements. A low Al content $x = 0.3$ sample served as a traditional, direct barrier reference sample for a high Al content $x = 0.80$ sample. Second, two high Al content ($x = 0.80$), doped SCs were grown using MBE. A 0-QW sample served as a reference for a ~ 3 nm wide, 10-QW sample. Photolithography and sputtering were used to create devices for PC and I vs. V measurements.

Results and Discussion:

PL occurs when excited carriers recombine and emit a photon [3]. After excitation with a 532 nm laser, the spectrum emitted is observed with a charge-coupled device detector. For the reference sample, temperature increase showed a red shift in peak energy and a decrease in intensity [4]. Quantitative analysis showed that direct sample carriers "see" the lowest energy Γ-state as barrier. Indirect barrier PL stabilized at 125 K as seen in Figure 1. Carrier recombination still occurred, and qualitative analysis predicted high AE. Indirect sample carriers likely "see" the highest energy Γ-state as barrier. Since carriers were not likely to escape to the X-state, they were less likely to relax into the well from the X-state.

PC collected across the visible light spectrum showed carrier excitation energies, including below the band gap. This information was used to determine the exact Al composition and well thickness as labeled in Figure 2 [5].

I vs. V measured from reverse to forward bias with photons above and below the $Al_{0.8}Ga_{0.2}As$ Γ-state band gap of 2.56 eV show carrier trapping and recombination effects. At low voltage, a steep band profile contributed to easy well-



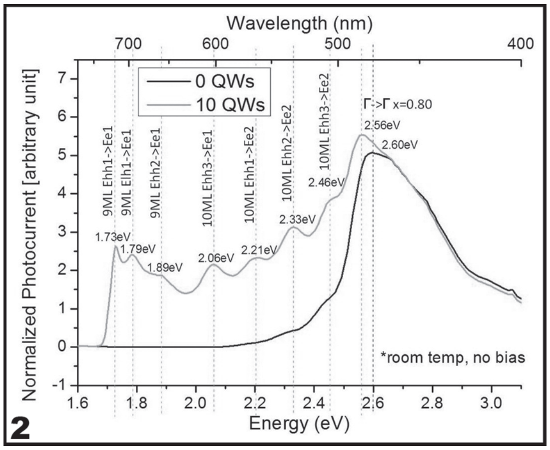
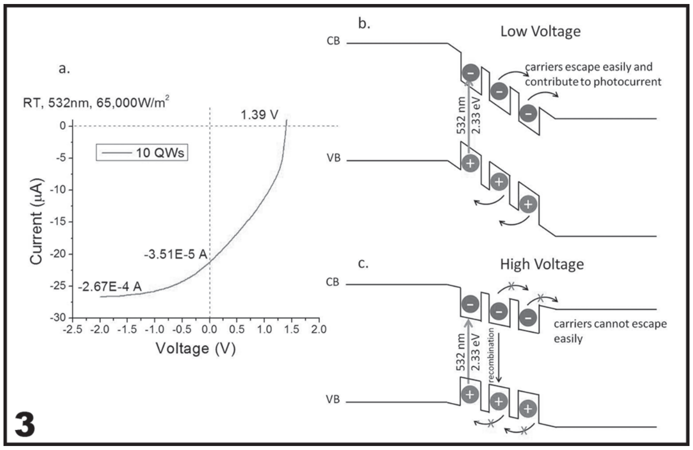


Figure 1, top: Temp. dependent photoluminescence.

Figure 2, bottom: Photocurrent spectra.



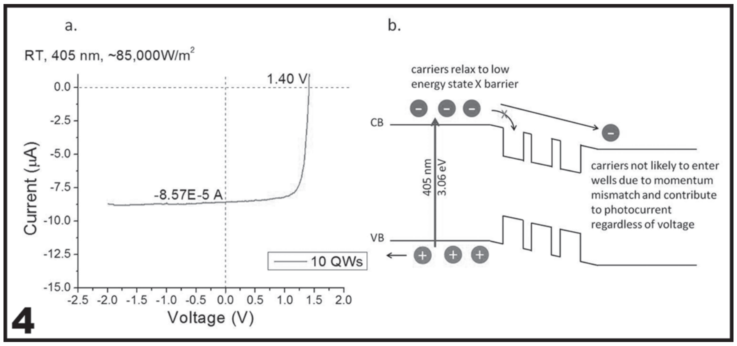


Figure 3, top: I vs. V with well-excited carriers.

Figure 4, bottom: I vs. V with barrier-excited carriers. No significant voltage dependence was observed.

generated carrier escape, and current was high as seen in Figure 3. A higher voltage yielded a flatter band profile, so carriers could not escape and contribute to the current. This voltage dependence agreed with high AE. Figure 4 shows that barrier-excited carriers were not likely to relax into the wells, and contribution to the current regardless of voltage was expected. No voltage dependence was observed, which is consistent with expectations, but further study is required to prove that carrier trapping is suppressed.

Summary:

PL showed high confinement and AE in high Al content, 10-QW sample. I vs. V confirmed this high confinement for well-excited carriers and suggested that the trapping of barrier-excited carriers may be suppressed. Further investigation includes measuring PC at different voltage biases and I vs. V at low temperature. A 1-QW sample will also be to more purely study carrier trapping and escape.

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