An Investigation into the Effects of Quantum Structures on the Carrier Dynamics of GaAs/GaNAs Solar Cells

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Abstract:

The addition of quantum wells (QWs) to solar cells is a potential method of implementing an intermediate band solar cell (IBSC). Three gallium arsenide (GaAs) solar cells containing ten differently doped gallium nitride arsenide (GaNAs) QWs are characterized, then compared to a reference GaAs solar cell via time-resolved photocurrent (TRPC) measurements. Carrier dynamics in QW solar cells is discussed.

Introduction:

The IBSC is a solar cell design with the potential to overcome the Shockley Quiesser efficiency limit for p-n solar cells. In these devices, the addition of an intermediate energy level within the band gap of the solar cell's host material allows the device to utilize a larger portion of the solar spectrum, resulting in an increased theoretical maximum efficiency of 63.1% [1]. This design can be implemented by the addition of nanostructures into the solar cell. A layer of material with a smaller band gap than the host material is added, creating wells in the band diagram. These QWs provide the intermediate energy states necessary for an IBSC.

Here we study how QW-originated states influence carrier transport properties. In this project we measure temporal evolution of photocurrent, which is generated by a nano-second laser.

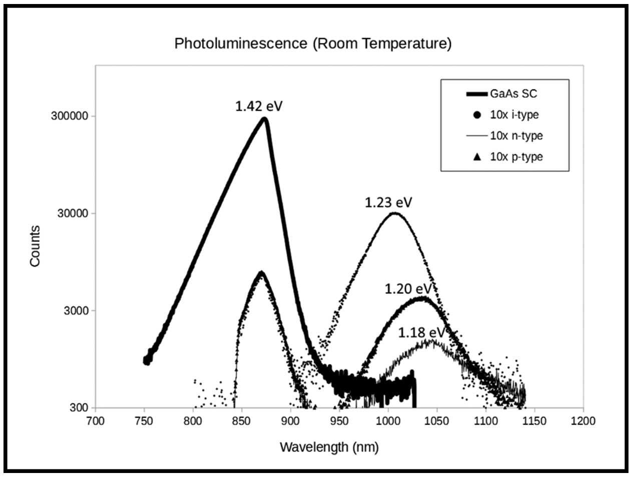

Figure 1: Photoluminescence spectrum at room temperature.

Experimental Procedure:

The four samples discussed here are a reference GaAs solar cell, and three GaAs solar cells containing ten GaNAs QWs. The three QW samples contain differently doped QWs, i-type, n-type, or p-type. Each sample was grown using molecular beam epitaxy (MBE), and, except for the presence or lack of QWs, they share the same dimensions. Following growth, each sample underwent an identical fabrication process in which electrical contacts are applied to each device.

Photoluminescence (PL) measurements were done to determine the nitrogen concentration and the depth of the GaNAs QWs. Each sample was illuminated with a 532 nm wavelength (2.33 eV) laser, and its photon emission spectrum was recorded. Current-voltage (IV) measurements were conducted on each device to characterize its performance under illumination by a solar simulator. The TRPC was measured for each device. The transient photocurrent signal was recorded with an oscilloscope under a single 2 ns pulse from a 532 nm, 40 µW laser. The power is controlled by filter and optical setup.

Results and Conclusions:

Figure 1 shows PL spectra of all samples at room temperature. A peak observed at 872 nm is shared between all samples, corresponding to the expected GaAs band gap of 1.42 eV at 300 K. Another peak in the PL spectrum was observed at around 1030 nm (1.20 eV), which originates from the GaNAs QWs. The nitrogen composition and QW depth were determined to be 2%, and 0.22 eV, respectively, using the model for GaNAs band gap derived in [2]. Here we ignore the valence band discontinuity. Additionally, the relative intensities of the GaNAs peaks in the QW samples are indicative of the level of recombination in that sample, with the highest being i-type, lowest being n-type.

Figure 2 shows the IV curves obtained from each device. Rather than the expected increase in photocurrent, each QW sample showed a decrease in both short circuit current, and open circuit voltage, resulting in reduced efficiency.

The results of the TRPC measurements are shown in Figure 3. Table 1 lists the photocurrent decay time constants and the total number of extracted carriers, both obtained from the TRPC curves. The TRPC results for each QW sample vary. These differences must be due to recombination, as the only difference between each device is doping. The extracted carriers in the i-type QWs are the lowest, while those in the n and p-type QWs are comparable to those in the reference sample. Hence, recombination in the i-type QWs is higher than in the n and p-type QWs. This is consistent with PL results, as PL from the QW in i-type sample is higher than others.

We next discuss the time constant, τ, of photocurrent decay. The i-type sample exhibits a shorter time constant than other samples including the reference sample, which is reasonable because large re-combination diminishes photogenerated carriers quickly. The fact that the n-type and the reference sample have very close τ, suggests that addition of QWs has little effect on carrier transport. In the p-type sample, the PC decay is characterized by two τ's. Although further work is necessary, our observation will be useful in understanding carrier transport in solar cell devices.

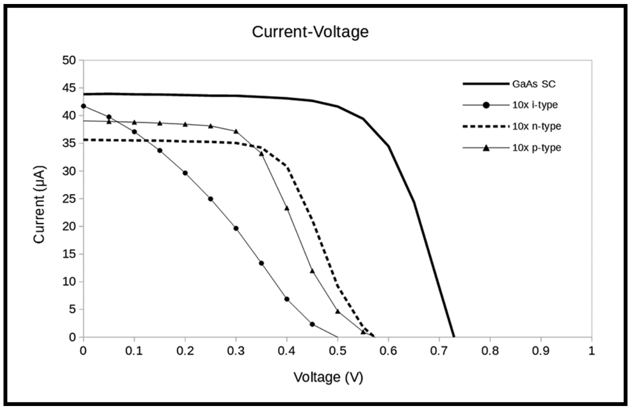

Figure 2: Light IV curves.

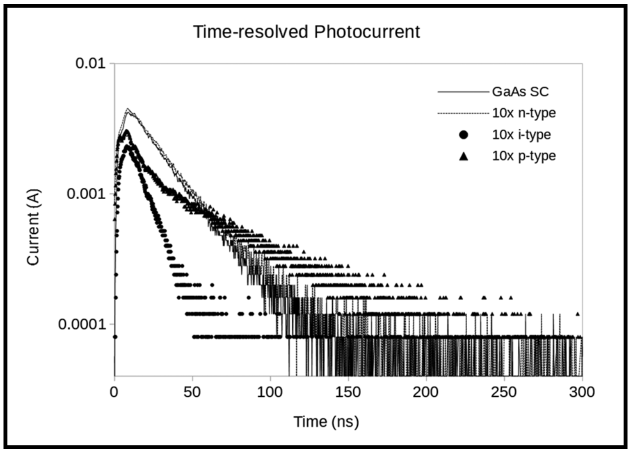

Figure 3: TRPC signals under single laser pulse.

	Time Constant (ns)	Extracted Carriers
GaAs SC	30.3	3.84E+18
10 i-type QWs	19.2	1.16E+18
10 n-type QWs	35.7	4.29E+18
10 p-type QWs	23.8, 66.7	3.57E+18

Table 1: Photocurrent decay time constants, and total number of extracted carriers.

Future Work:

Future experiments should measure TRPC in devices with the same QW doping, but varying number of QWs, to clarify the effect of trapping in devices with similar levels of recombination.

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References:

[1] A. Luque and A. Marti, Phys Rev. Lett., 78, 26 (1997).

[2] W. Walukiewicz, et al., PV 99-11, p. 190, The Electrochemical Society Proceedings (1999).