Optoelectronic Analysis of MBE Grown Symmetric and Asymmetric 1 eV Dilute Nitride Quantum Well Solar Cells

K. Kharel[1], M. Fitchette[1], K. Shervin[2], W. Wang[3] & A. Freundlich[1]
[1] *Department of Physics, University of Houston, Houston TX, 77204, USA*
[2] *Currently at Alta Devices, San Jose, CA*
[3] *Currently at First Solar, San Jose, CA*

In order to minimize the effects of the degraded minority carrier transport properties of bulk dilute nitride GaAs, we have demonstrated that by incorporating MBE grown symmetric or asymmetric (i.e. resonantly coupled) dilute-nitride-GaAsN/GaAs multiple quantum wells (MQW's) into the intrinsic region of a p-i-n GaAs photovoltaic device (see figure 1) enables a significant sub-GaAs-bandgap photocurrent generation while maintaining a high open-circuit voltage (V_{oc}) [1]. In fact, for the case of a 1 eV resonantly coupled MQW cell, the V_{oc} (the figure of merit for the performance of a solar cell) showed a record setting performance approaching the near ideal radiative limit (i.e. W_{oc}=Eg-V_{oc} ~ 0.4 V) [2].
To gain a better understanding of the photo-generated carrier escape and recombination mechanisms for these MQW devices, we examine their optical and electrical properties using the following characterization techniques: temperature dependent photoluminescence spectroscopy (PL), modulated photoreflectance spectroscopy (PR), photo-current spectroscopy (i.e. the spectral response-SR or External Quantum Efficiency- EQE) under different applied bias and temperatures), and the temperature dependence current-voltage (IV) while the cell is under either dark or illuminated conditions.
The bias dependent EQE analysis, performed at room temperature, shows 30X faster carrier escape times for the RTT devices than those of the conventional MQWs cell (0.2 ns and 6.38 ns, respectively). Similarly, the activation energies (which correspond to the effective barrier to electron extraction from the QW's) were determined from temperature dependence PL measurements are significantly lower (35meV and 75meV) than those of the conventional periodic MQWs cell (269meV); this contributes to the improvement in the carrier extraction for the RTT structure. The temperature dependent analysis enabled us to modulate, and even freeze out, the carrier thermalization phenomena. While the simultaneous measurement of the photogenerated current (SR) and radiative recombination (PL), as a function of the applied load (bias), enabled us to probe the correlation between the evolution of I-V characteristics and the physics at play. Finally, the electronic temperature of the photo-generated minority carriers' were extracted from the measured PL intensities which show a significantly high and unusual carrier temperature for a given lattice temperature; and this suggests the presence of a significant hot carrier effect.

1) D. Dang, G. Vijaya, A. Mehrotra, A. Freundlich, & D. J. Smith, Journal of Vacuum Science & Technology B. 34 (2016)
2) S. Shervin, W. Wang, K. Kharel, M. Fitchette & A. Freundlich, 33rd NAMBE, 2017, Galveston, TX

Supplementary Information:

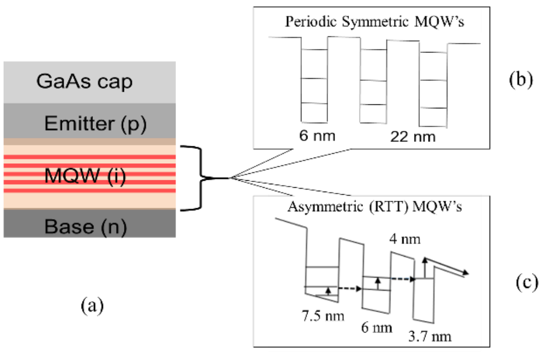

Figure 1: Device Structure for the GaAs p-i-n solar cells considered in this study. (a) Host device consists of a Si doped GaAs (n-type) Base layer and a Be doped GaAs (p-type) Emitter layer sandwiching an undoped (intrinsic GaAs) region containing the dilute nitride MQW's structure which is either a periodic series of: (b) 15 symmetric/identical QW's or (c) 3 coupled asymmetric RTT QW's repeated 4 times (total of 12 wells).

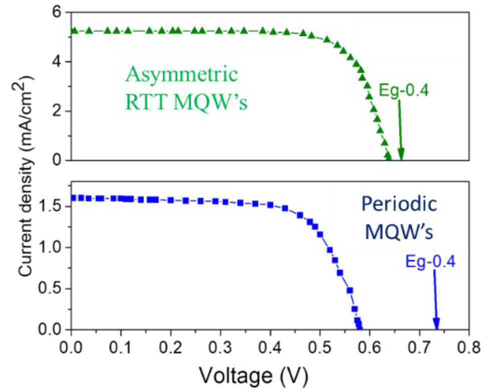

Figure 2: Measured current-voltage for the periodic MQW solar cell (bottom) compared to the RTT MQW solar cell (top) shows a significant improvement in both the short circuit current and open circuit voltage. The RTT cell's Voc is very close to the radiative limit.

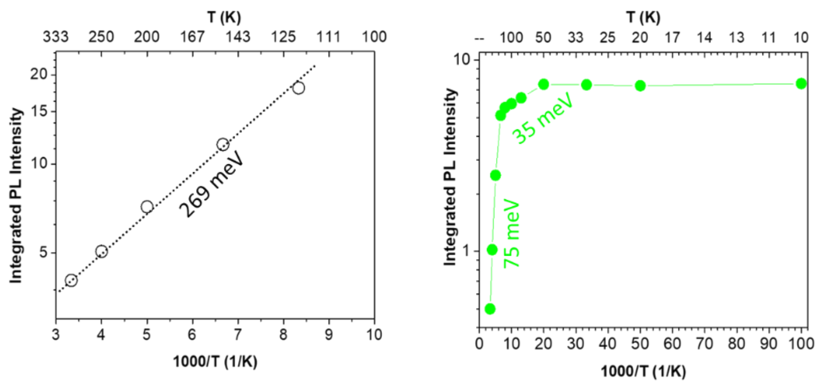

Figure 3: Plot of integrated PL intensity of 1.07 eV well as a function of the inverse of temperature and fitted with Arrhenius curve to extract the activation energy for the Symmetric MQW device (left) and the RTT device (right).

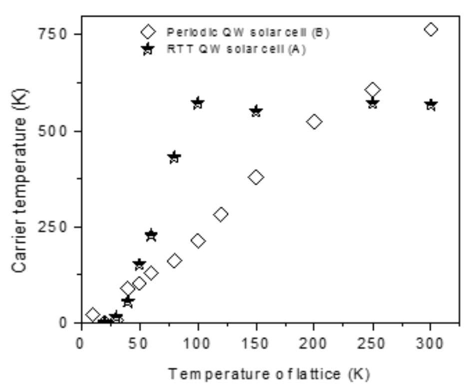

Figure 4: Difference between carrier temperature and lattice temperature of photogenerated carriers extracted from the wells for the periodic QW structure (diamonds) and RTT cell (stars) suggesting the existence of hot carrier effects. Note the presence of carrier temperature plateau for lattice temperatures of 100-300K for the RTT cell.