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Correlation of DLTS and Performance of GaInNAs Cells

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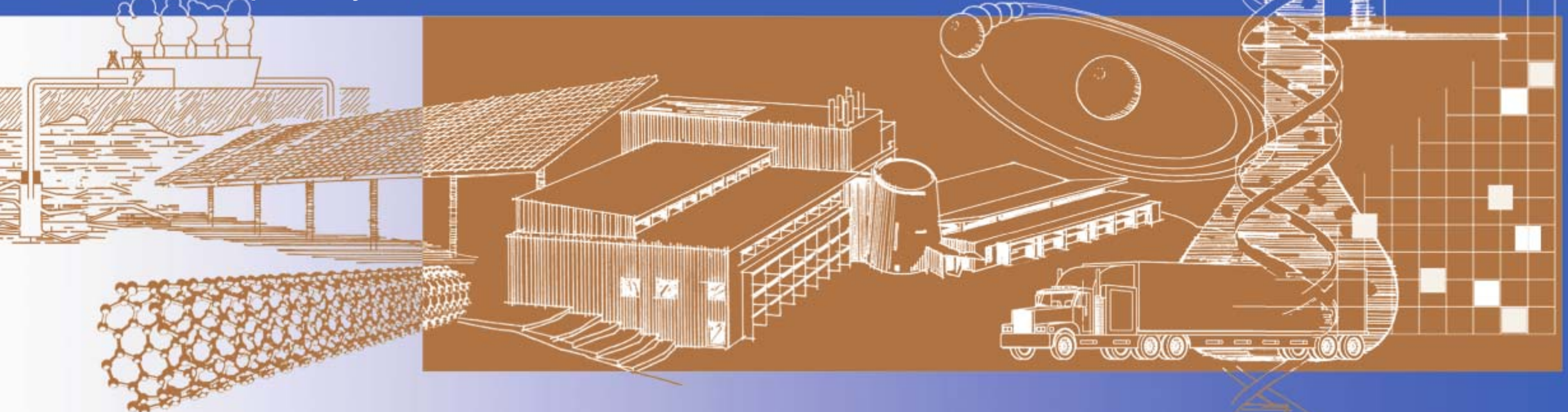

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ABSTRACT

A four-junction GaInP/GaAs/GaInAsN/Ge solar cell should be able to reach 40% efficiency if each of the junctions can be made with a quality similar to that demonstrated for GaAs. However, the GaInAsN subcell has shown poor performance. Deep-level transient spectroscopy (DLTS) can elucidate recombination centers in a material and could help identify the problem with the GaInAsN. So far, DLTS studies of GaInAsN have shown many peaks. In this paper we compare the performance of the GaInAsN solar cells with the DLTS spectra to identify which DLTS peak is correlated with the device performance.

1. Objectives

The long-term objective of this project is a 40% efficient GaInP/GaAs/GaInNAs/Ge solar cell that could be used in a concentrator module. The specific objective of this project is to better understand the alloy GaInNAs: its defects and how these affect solar-cell performance.

2. Technical Approach

The growth conditions of GaAs solar cells were adjusted so that the measurement of deep-level transient spectroscopy (DLTS) showed no features. Nitrogen was then added to the active layers of these solar cells and the resulting devices were characterized both for their photovoltaic performance and by using DLTS.

3. Results and Accomplishments

The addition of a small amount of nitrogen increased the dark current of the Ga(N)As solar cells dramatically, as shown in Fig. 1.

The DLTS spectra for Ga(N)As solar cells are shown in Fig. 2. The existence of a DLTS feature around 150 K is correlated with the addition of nitrogen and with the higher dark current observed in Fig. 1.

The open-circuit voltages (Voc) of GaAs, GaNAs, and GaInNAs solar cells are plotted as a function of band gap in Fig. 3. The dramatic decrease in Voc with the addition of a very small amount of nitrogen reflects the increase in dark current observed in Fig. 1. The degradation in Voc is seen even for nitrogen concentrations that don't reduce the band gap.

The decrease in Voc is caused by a reduction in the quasi-Fermi level for the electrons in illuminated GaNAs. The reduction of the quasi-Fermi level is approximated by the depth of the trap, as explained in the manuscript submitted to *Applied Physics Letters*.

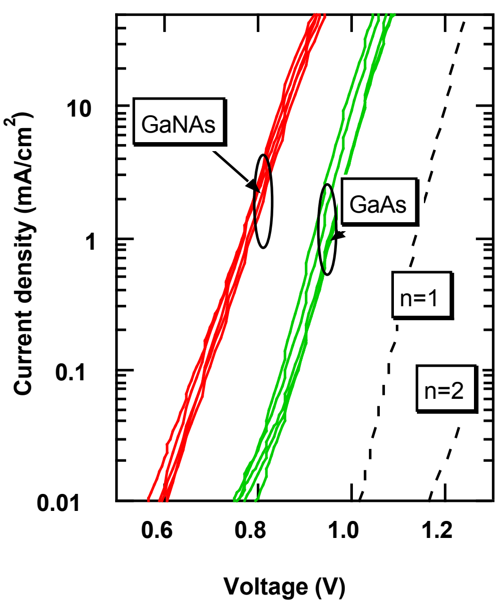

Fig. 1. Dark current-voltage curves for GaNAs and GaAs cells. The addition of a small amount of nitrogen dramatically increases the dark current density.

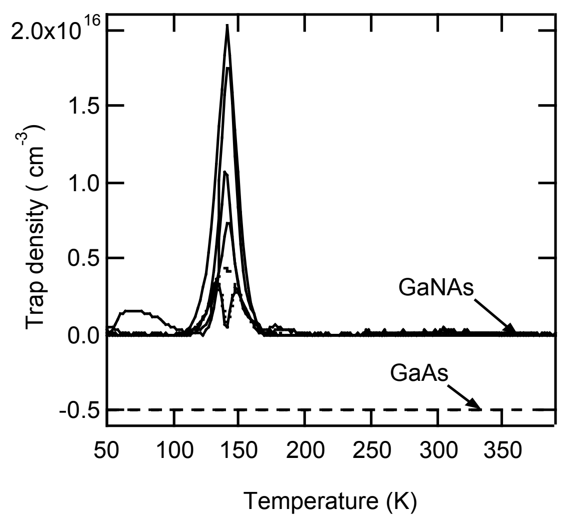

Fig. 2. DLTS data for GaNAs and GaAs cells. The addition of a small amount of nitrogen causes a DLTS feature around 150 K.

The addition of nitrogen also decreases the photocurrent in GaNAs solar cells as shown in Fig. 4. The diffusion length decreases much faster (see Figs. 5 and 6) than is expected for an isoelectronic alloy. The rate of decrease in the diffusion length is closer to what is observed for a donor or acceptor in GaAs (see Fig. 6).

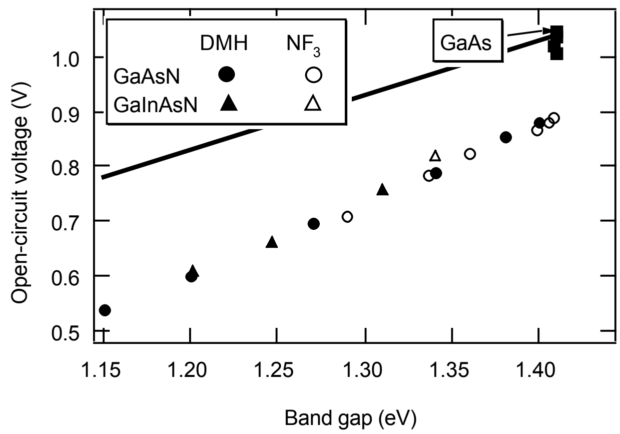

Fig. 3. Open-circuit voltage of GaAs, GaNAs, and GaInNAs cells as a function of band gap. A small amount of nitrogen degrades the Voc even before the band gap is reduced.

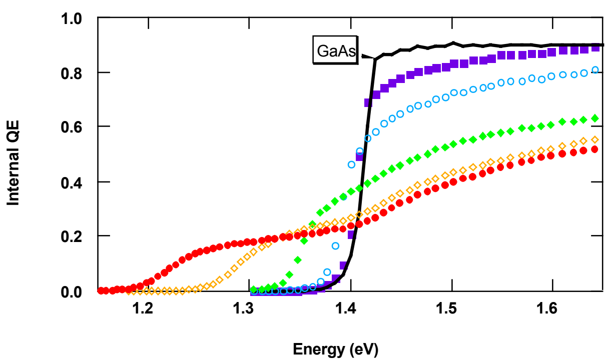

Fig. 4. Quanum efficiency (photocurrent) as a function of wavelength for GaAs and GaNAs cells. The amount of nitrogen is reflected by the decreasing band edge. A small amount of nitrogen decreases the photocurrent slightly; a greater amount decreases the photocurrent more dramatically.

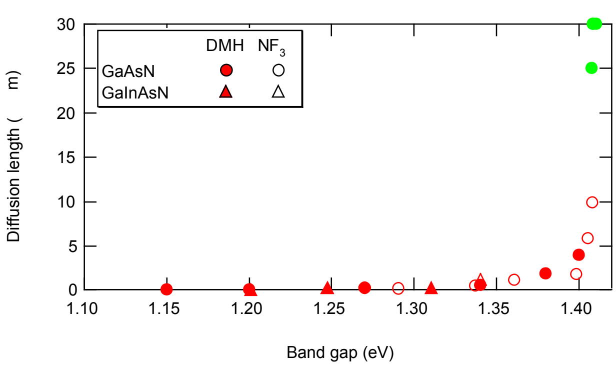

Fig. 5. Modeled diffusion length as a function of band gap for GaAs, GaNAs, and GaInNAs cells.

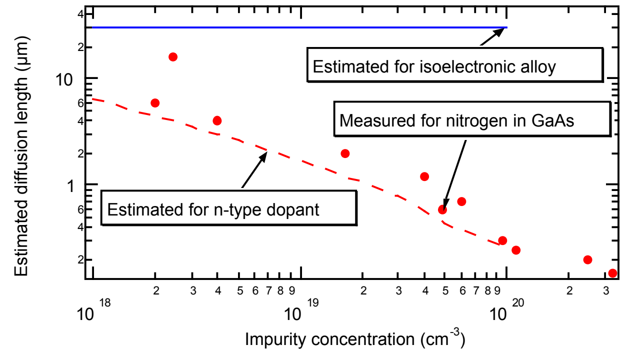

Fig. 6. Measured diffusion length as a function of nitrogen concentration (dots). The measured data are compared with two models: the expected effect for an isoelectronic alloy (solid line) and for an n-type dopant type of impurity.

4. Conclusions

This work shows that the addition of nitrogen causes a decrease in performance of GaNAs solar cells and that this decreased performance is correlated with a DLTS feature around 150 K. More studies may allow for identification of the microstructure of the implicated defect.

MAJOR FY 2004 PUBLICATIONS

S. Kurtz, S. Johnston, and H. Branz, “Capacitance-spectroscopy identification of a key defect in N-degraded GaInNAs solar cells,” submitted to *Appl. Phys. Lett*.

S. Kurtz, J. Geisz, D. Friedman, and A. Ptak, “Effect of nitrogen concentration on the performance of Ga(In)As(N) solar cells,” submitted to *31st IEEE Photovoltaic Specialists' Conference,* Lake Buena Vista, FL, Jan. 3-7, 2005.

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14. ABSTRACT *(Maximum 200 Words)*
A four-junction GaInP/GaAs/GaInAsN/Ge solar cell should be able to reach 40% efficiency if each of the junctions can be made with a quality similar to that demonstrated for GaAs. However, the GaInAsN subcell has shown poor performance. Deep-level transient spectroscopy (DLTS) can elucidate recombination centers in a material and could help identify the problem with the GaInAsN. So far, DLTS studies of GaInAsN have shown many peaks. In this paper we compare the performance of the GaInAsN solar cells with the DLTS spectra to identify which DLTS peak is correlated with the device performance.

15. SUBJECT TERMS
PV; deep-level transient spectroscopy (DLTS); solar cells; device performance; open-circuit voltage (Voc); photocurrent

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