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Electron Traps Detected in P-Type GaAsN Using Deep Level Transient Spectroscopy

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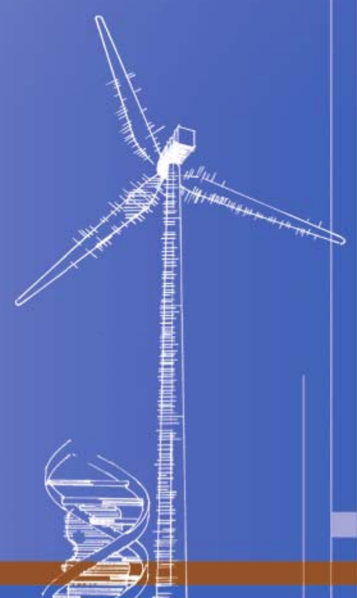

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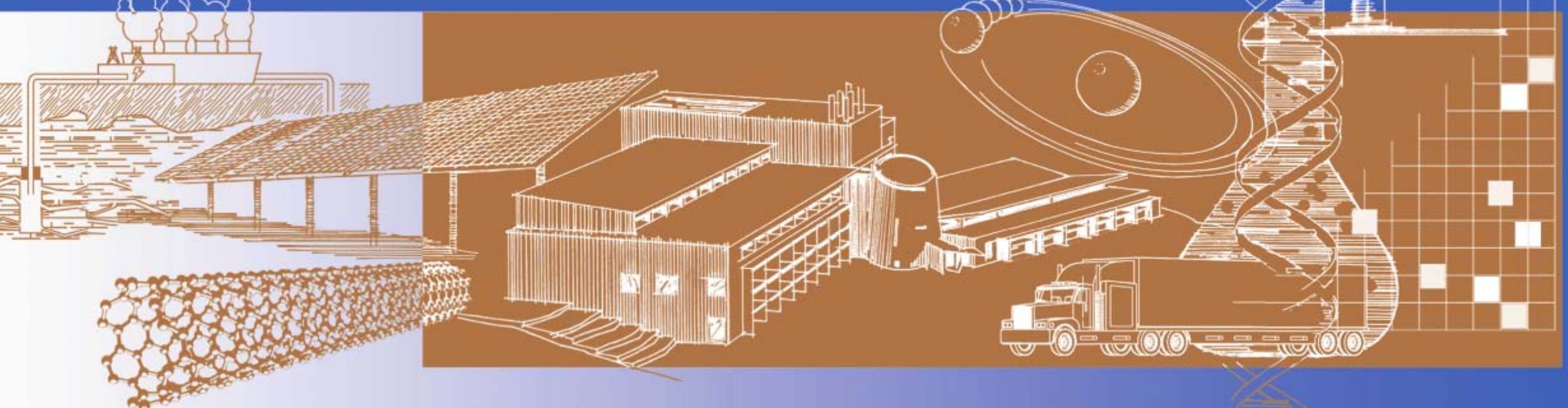

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ABSTRACT

The GaAsN alloy can have a band gap as small as 1.0 eV when the nitrogen composition is about 2%. Indium can also be added to the alloy to increase lattice matching to GaAs and Ge. These properties are advantageous for developing a highly-efficient, multi-junction solar cell. However, poor GaAsN cell properties, such as low open-circuit voltage, have led to inadequate performance. Deep-level transient spectroscopy of p-type GaAsN has identified an electron trap having an activation energy near 0.2 eV and a trap density of at least 10^{16} cm^{-3}. This trap level appears with the addition of small amounts of nitrogen to GaAs, which also corresponds to an increased drop in open-circuit voltage.

1. Objectives

The long-term objective of this project is a 40% efficient GaInP/GaAs/InGaAsN/Ge solar cell that could be used in a concentrator module. The specific objective of this project is to better understand the GaAsN alloy by identifying and characterizing defects using deep-level transient spectroscopy (DLTS) that correlate to reduced solar-cell performance.

2. Technical Approach

The growth conditions of GaAs solar cells were adjusted so that DLTS measurement showed no peaks. Nitrogen was then added to the active layers of these solar cells so that resulting DLTS data could be used to identify a detrimental defect level.

3. Results and Accomplishments

The addition of a small amount of nitrogen led to a positive peak in the DLTS spectra that was not seen in GaAs with no N added. As shown in Fig. 1, the peak increases in magnitude with increasing N content, (from sample MF057 to MF166). This peak's appearance with added N also corresponded to a reduction in open-circuit voltage. The inset of Fig. 1 shows nearly linear data points on an inverse capacitance squared versus voltage plot (CV), and thus illustrates the uniform p-type doping density over the bias range used for the DLTS measurement (-1 V to 0 V). Linear fits of the data give majority hole concentrations in the mid-10^{16} cm^{-3} for all samples.

The DLTS data represented by Fig. 1 is plotted in an Arrhenius plot in Fig. 2. Fits of the data for each sample give an electron trap activation energy of about 0.2 eV. The electron trap concentration values at saturation also increase with increasing N content.

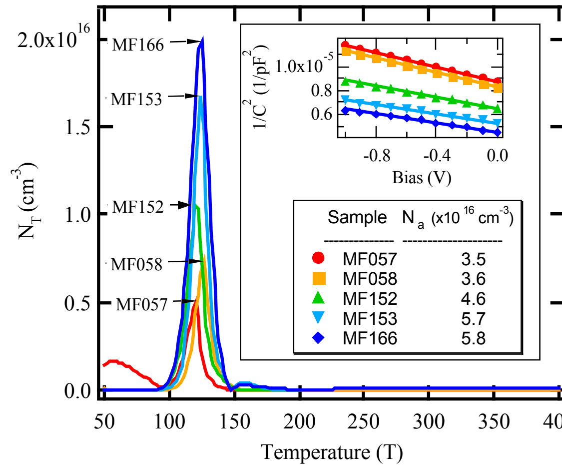

Fig. 1. DLTS spectra using a 100-ms time window and long signal-saturating filling pulses (1 to 10 s) for GaAsN pn junction samples with increasing amounts of N. The positive peak corresponds to an electron trap. Capacitance-voltage data plotted in the inset shows uniform majority hole concentrations.

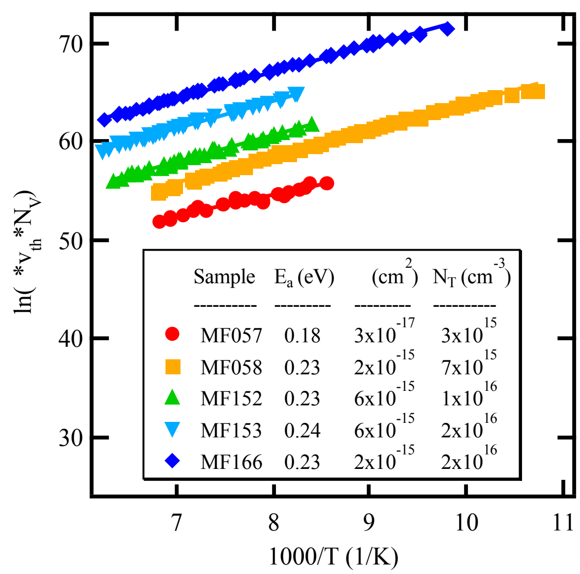

Fig. 2. Arrhenius plot created from DLTS data of Fig. 1. The curves are vertically offset by +3 for clarity.

A Schottky-barrier GaAsN sample having about 2% N was similarly measured and characterized. Although minority-carrier traps are not expected to be detected when applying only reverse bias, and perhaps even less expected with a Schottky barrier, we nonetheless observed a similar electron trap. This Schottky sample was biased in 1-V increments from -4 V to -1 V as shown in Fig. 3. The left inset shows the majority hole-concentration from CV. The right inset shows the electron trap signal from optical DLTS when using a flash lamp for trap filling. Additionally, we verified the positive signal was not due to high series resistance by adding a known series resistance that did invert the signal.

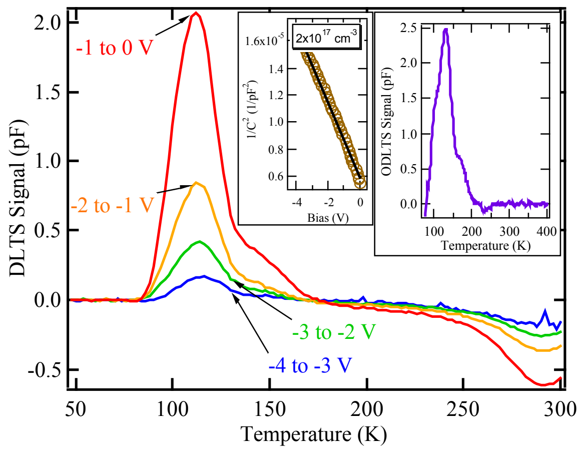

Fig. 3. DLTS spectra using a 100 ms time window, long signal-saturating filling pulses, and varying bias conditions for a Schottky barrier GaAsN sample. The left inset shows the majority hole concentration from CV. The right inset shows optical DLTS results for a similar time window.

The DLTS data of Fig. 3 is plotted in an Arrhenius plot shown in Fig. 4. The resulting parameters, including an activation energy near 0.2 eV, are similar to those seen in the pn junction samples.

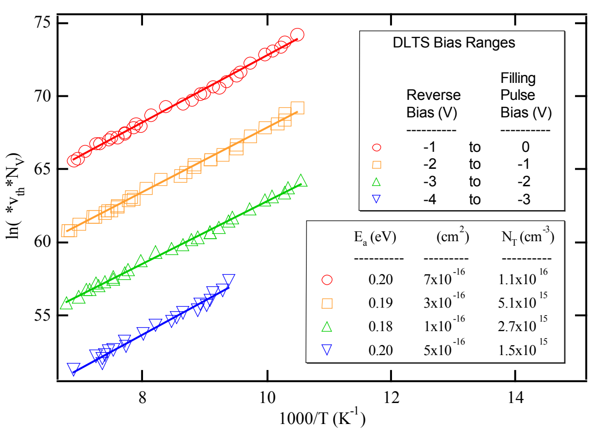

Fig. 4. Arrhenius plot created from DLTS data of Fig. 3. The curves are vertically offset by +5 for clarity.

We modeled the band diagrams in order to illustrate the source of the electrons for filling the electron traps when only reverse bias is applied. Fig. 5 shows the band diagrams for 0 V and 1 V applied reverse bias. The electron density is highest near the metal interface and depends upon the Fermi level position related to material parameters and defect states. A Schottky barrier was estimated from CV data. When less reverse bias is applied, a larger electron occupation is probable.

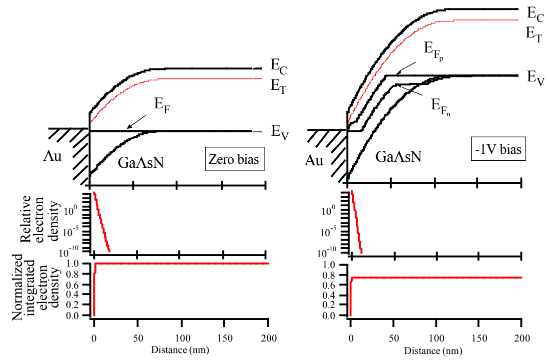

Fig. 5. Modeled band diagram and electron concentration for zero-bias and 1 V reverse bias.

Figure 6 summarizes the model by showing smaller steps of 0.2 V from -4 V to 0 V. The amplitude of the DLTS signal at saturation (shown in the left inset) is proportional to the number of filled electron traps. The data points, represented by filled circles, are shown to closely follow the model and support the speculation that electrons travel by thermionic emission from the metal or n-type material up and over a portion of the increasing-energy conduction band. A sample that included a 100-nm p-type GaAs layer between the GaAsN and the metal was also measured and showed reduced electron trapping by requiring higher temperature and less applied reverse bias. See right inset and filled triangles of Fig. 6.

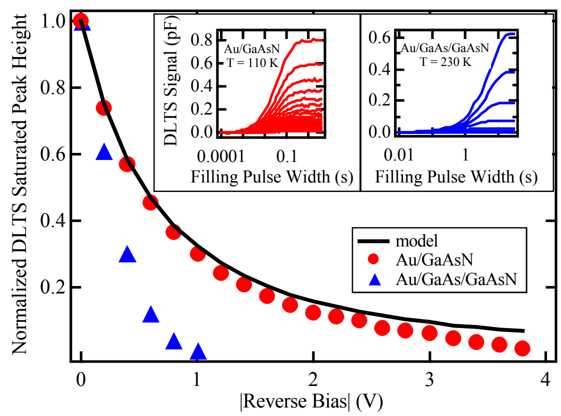

Fig. 6. Measured DLTS signal magnitude versus the modeled electron concentration. The left inset shows trap filling data for the Schottky barrier GaAsN sample. The smallest signal represents biasing of -4 V to -3.8 V. The right inset shows similar data for a GaAsN Schottky sample with a 100-nm GaAs barrier layer included.

4. Conclusions

Electron traps were observed in GaAsN material using DLTS with only reverse applied bias. DLTS data fit a model that suggested electrons could surmount a potential barrier and fill traps near the interface.

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15. SUBJECT TERMS
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