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Temperature-Dependent Carrier Lifetime in GaNAs Using Resonant-Coupled Photoconductive Decay

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Temperature-Dependent Carrier Lifetime in GaNAs Using Resonant-Coupled Photoconductive Decay

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ABSTRACT

Temperature-dependent lifetime measurements can further characterize trapping and recombination mechanisms beyond a room-temperature-only measurement. The reduced bandgap material produced by adding N to GaAs is a potentially useful absorber layer in multi-junction photovoltaic devices. Lifetime measurements have been performed on a $GaN_{0.025}As/GaAs$ double heterostructure sample grown by metal-organic chemical vapor deposition. The lifetime is calculated from the photoconductive decay signal that is obtained using the resonant-coupled photoconductive decay measurement technique. Decay curves are recorded from approximately 77 K to room temperature, and an optical pulse of 1100 nm in wavelength excites carriers in the sample. The decay times are shown to vary from 50 µs at low temperature to 0.06 µs at higher temperatures. An Arrhenius plot of the data produces an activation energy of 0.14 eV and an apparent capture cross section of 4×10^{-14} cm^2. These results are compared to optical deep-level transient spectroscopy data recorded from similar samples, where electron traps having activation energies from 0.13 to 0.17 eV were observed.

1. Introduction

The efficiency of multi-junction solar cells depends on the number of junctions and how well each captures its designed portion of the solar spectrum. In a four-junction design, an ideal air mass zero efficiency of 41% requires a near-1eV bandgap material that can be grown lattice-matched between Ge and GaAs [1]. The alloy $GaAs_{1-x}N_x$ can be grown epitaxially in this configuration, and for x values of 2 to 3%, the bandgap is reduced to near 1 eV [2]. Characterization of the electrical properties of this layer is therefore important for understanding the resulting solar cell's performance.

2. Experiment

The minority-carrier lifetime can be an important indication of material quality. It gives a measure of the rate of recombination that may take place in the solar cell, thus limiting its efficiency. However, the experimentally-measured lifetime may not be a true measure of the recombination rate if carriers are trapped before recombination. By measuring the emission rate of carriers from these defects as a function of temperature, we can calculate the trap's energy level within the bandgap. We measure the minority-carrier lifetime by using a contactless, photoconductive decay technique called resonant-coupled photoconductive decay (RCPCD) [3]. By assuming that the recombination event occurs quickly compared to the time the carrier is trapped, we can estimate the emission rate as the inverse of the measured photoconductive decay lifetime. Excess carriers are created by a pulsed laser with a wavelength of 1100 nm.

Another measurement technique for characterizing trap levels within the bandgap is deep-level transient spectroscopy (DLTS). We use a DLTS apparatus from Sula Technologies [4] that is based on the principles from Lang [5].

The samples were produced by growing epitaxial layers of $GaAs_{1-x}N_x$ ~1µm thick on a GaAs substrate using metal-organic chemical vapor deposition (MOCVD). Dimethylhydrazine is used as the nitrogen source, and the nitrogen content is approximately 2 to 3%.

3. Data and Analysis

Figure 1 shows the photoconductive decay curves as a function of temperature. The low-injection lifetime is approximately 50 µs at low temperatures. Between the tem-

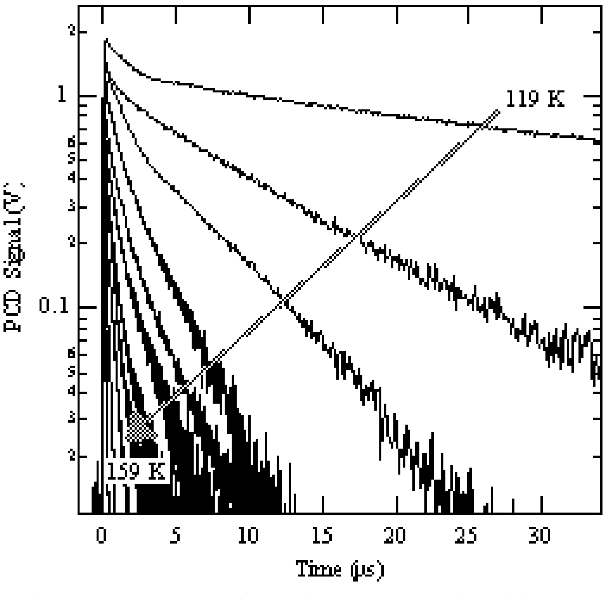

Fig 1. Temperature-dependent RCPCD signal for sample grown on semi-insulating substrate.

perature of 119 and 159 K, the lifetime quickly decreases to 0.06 µs. These lifetime values are then plotted on an Arrhenius plot as shown in Figure 2. Here, the activation energy of the trap level is extracted from the linear fit to the data and gives an apparent activation energy of 0.14 eV. The apparent cross section of the trap is calculated from the y-axis intercept and is $4\text{x}10^{-14}$ cm^2.

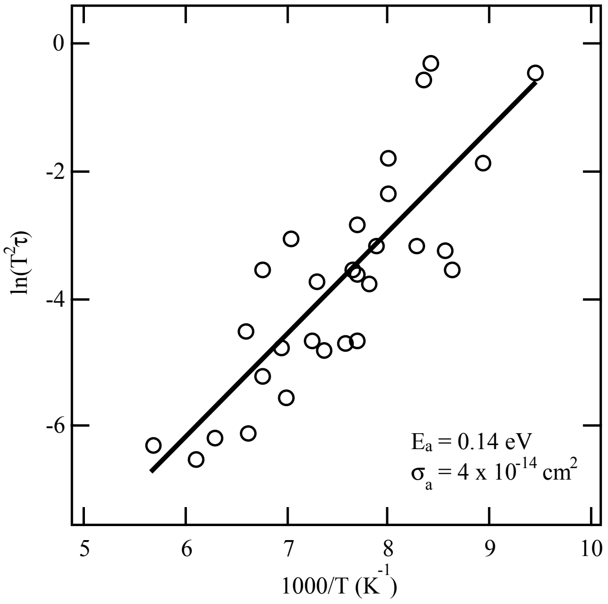

Fig 2. Arrhenius plot of temperature-dependent RCPCD data for sample grown on semi-insulating substrate.

For DLTS measurement, samples were grown on conducting substrates. Two samples were measured, both containing ~2 to 3% N (MD317 and MD319). Sample MD319 additionally had ~2% In added for better lattice matching to the GaAs substrate. Optical-DLTS data was taken using a Xe flash lamp to create excess free carriers. Capacitance-voltage measurements on the samples were used to obtain the doping concentration of the DLTS samples. Each sample was doped p-type with a density of $\sim 2\text{x}10^{17}$ cm^{-3} and had a built-in voltage of 0.8 V. The DLTS data showed positive peaks corresponding to a net minority-carrier trapping, or electron trapping. For both samples, trap levels are seen with energy levels that closely correspond to that found from the lifetime measurement. See the Arrhenius plots of Figures 3 and 4. The activation energies ranged from 0.13 to 0.17 eV. The cross sections ranged from $5.9\text{x}10^{-18}$ to $1.6\text{x}10^{-16}$ cm^2. Using the doping and peak values from the DLTS data, trap densities were calculated between $4.1\text{x}10^{13}$ and $1.4\text{x}10^{15}$ cm^{-3}.

4. Summary

Temperature-dependent lifetime data and optical-DLTS data both showed similar activation energy levels (~0.14 eV) for traps within the bandgap of similar $\text{GaAs}_{0.975}\text{N}_{0.025}$ epitaxial MOCVD samples.

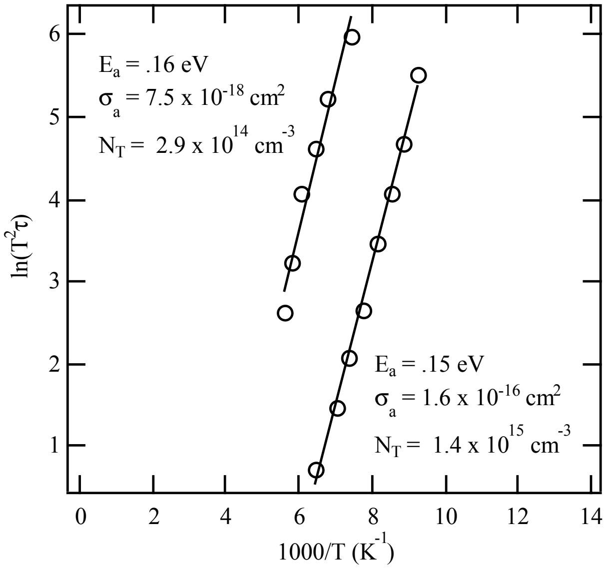

Fig 3. Arrhenius plot of ODLTS data for sample MD317 ($\text{GaAs}_{0.975}\text{N}_{0.025}$).

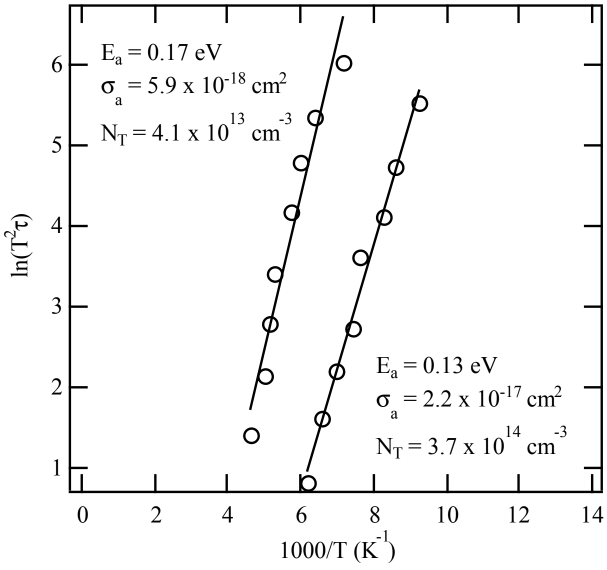

Fig 4. Arrhenius plot of ODLTS data for sample MD319 ($\text{Ga}_{0.98}\text{In}_{0.02}\text{As}_{0.975}\text{N}_{0.025}$).

5. References

[1] S.R. Kurtz, D. Myers, and J.M. Olson. 26th IEEE Photovoltaic Specialists Conference, IEEE, 1997, pp. 875-878.

[2] A.B. Chen and A. Sher. *"Semiconductor Alloys Physics and Materials Engineering,"* Plenum Press, New York, 1995.

[3] R.K. Ahrenkiel and S. Johnston. Solar Energy Materials & Solar Cells **55** (1998) 59-73.

[4] Sula Technologies. PO Box 963, Ashland, OR 97520 USA

[5] D.V. Lang. J. Appl. Phys. 45 (1974) 3023-3032.