Thermoelectric Effect Spectroscopy of Deep Levels in Semi-Insulating GaN

U. V. Desnica
M. Pavlovic
Z-Q. Fang
David C. Look

Wright State University - Main Campus, david.look@wright.edu

Follow this and additional works at: https://corescholar.libraries.wright.edu/physics

Part of the Physics Commons

Repository Citation
https://corescholar.libraries.wright.edu/physics/149

This Article is brought to you for free and open access by the Physics at CORE Scholar. It has been accepted for inclusion in Physics Faculty Publications by an authorized administrator of CORE Scholar. For more information, please contact library-corescholar@wright.edu.
Thermoelectric effect spectroscopy of deep levels in semi-insulating GaN

U. V. Desnica and M. Pavlović
Rudjer Bošković Institute, Bijenicka 54, P. O. Box 1016, 10000 Zagreb, Croatia
Z.-Q. Fang and D. C. Look
Semiconductor Research Center, Wright State University, Dayton, Ohio 45435
(Received 14 March 2002; accepted for publication 12 July 2002)

The report of thermoelectric effect spectroscopy (TEES) applied on semi-insulating GaN was presented. The type of TEES setup, especially suitable for film-on-substrate samples, was devised. TEES enabled determination of sign of observed deep traps. Using TEES and thermally stimulated current spectroscopy measurements in combination with the simultaneous multiple peak analysis formalism all important trap parameters were determined. The shallowest identified electron and hole traps had activation energies $E_e - 0.09$ eV and $E_v + 0.167$ eV, respectively. Results indicate that both these traps, oppositely charged are present in the studied material in relatively high concentrations causing the electrical compensation and high resistivity. © 2002 American Institute of Physics. [DOI: 10.1063/1.1504168]
negative peak covers a narrower T range, and the peak maximum is shifted towards lower T in comparison to the maximum of A in the TSC spectra. This agrees with the notion that for lower β the thermoelectric-effect driven separation of electrons and holes becomes less effective, giving rise to a more intense recombination of liberated electrons and holes.

Solely from the shape of TSC peak A, Look et al.\(^9\) concluded that A has to be a multicomponent peak and extracted activation energies \(E_A^1 = 0.09 \pm 0.01\) eV and \(E_A^2 = 0.17 \pm 0.05\) eV for two of its main components. In this article we have applied simultaneous multiple peak analysis (SIMPA)\(^{12,17}\) to the whole TSC spectrum to determine all components of peak A. As shown in Fig. 2, we have successfully fitted peak A with three deep traps \(A_1, A_2,\) and \(A_3,\)

The sign of the TEES spectra indicates that \(A_1,\) the lowest-energy trap contributing to the A peak, is an electron trap, and the highest-energy trap, \(A_3,\) is a hole trap. As the TEES signal changes its sign just in the T range corresponding to the \(A_2\) trap, it is not possible to determine its sign with certainty. Namely, the activation energies of all three \(A_1 – A_3\) traps are relatively close, and the TEES signal from the \(A_2\) trap might be overpowered either by electron trap \(A_1\) or by hole trap \(A_3.\) The SIMPA analysis gives the following trap parameters:

\[
E_{A_1} = E_C - (0.090 \pm 0.004)\text{ eV}, \quad \sigma_{A_1} = (4.5 \pm 1.5) \times 10^{-22}\text{ cm}^2, \quad E_{A_2} = E_V + (0.167 \pm 0.008)\text{ eV}, \quad \sigma_{A_3} = (5.0 \pm 1.5) \times 10^{-19}\text{ cm}^2.
\]

The value of \(\sigma_{A_2}\) comes out either \(9.4 \times 10^{-19}\) or \(6.7 \times 10^{-19}\) cm\(^2\), depending on whether \(A_2\) is an electron or a hole trap. The product \(N\tau\mu,\) where \(N\) is trap concentration, \(\tau\) is a free-carrier lifetime, and \(\mu\) is the carrier mobility, is \(7.8 \times 10^{13}, 2.5 \times 10^{13}, 3.1 \times 10^{13}\) cm\(^2\) V\(^{-1}\), for traps \(A_1, A_2,\) and \(A_3,\) respectively. This suggests high concentrations of all three traps, in the \(10^{17}\) cm\(^{-3}\) range.

The temporal evolution of \(I_{PC}(t)\) during constant-intensity white-light illumination at 86 K is presented in Fig. 3. \(I_{PC}\) shows clear photocurrent quenching (PCQ) in the early stage of the transient. Since photogeneration constantly supplies new \(n\) and \(p\), the observed decrease of \(I_{PC}(t)\) can be explained if there is a sudden switch between the dominant type of carrier in \(I_{PC}\) during illumination. Then considerable changes in \(p\) and \(n\) concentrations, their recombination rate and mobility would take place. Computer simulations have shown\(^{18}\) that such a switch—and the resulting PCQ—will occur in samples having “fast” and “slow” traps of opposite sign but comparable concentrations, due to preferential trapping of either electrons or holes during the early stages of illumination. An analogous quenching of \(I_{PC}\) was observed previously in SI GaAs during low-T illumination\(^{14,19,20}\) in samples which also contained both electron and hole deep traps with quite different cross sections.\(^{14}\)

Having now determined not only the energy but also the sign of the observed deep levels, the question of microscopic
origin of donor level at $E_v - 0.09$ eV and acceptor level at $E_v + 0.167$ eV, as well as the nature of the compensation mechanism can be analyzed with more plausibility. Based on the comparison of trap parameters, the most probable candidate for the electron trap $A_1$ is a defect related to the N vacancy. From the temperature-dependent Hall data, the thermal activation energy ($E_T$) for the N-vacancy donor, induced by electron irradiation (EI) has been determined to be 0.07 eV. In addition, a broad, low-temperature DLTS peak ($E_D$), induced by 1 MeV EI, has an apparent activation energy of 0.18 eV.$^{22}$ However, detailed DLTS fitting shows that (i) $E$ consists of $ED1$ and $ED2$; (ii) both centers have the same $E_T$, 0.06 eV, which is very close to the 0.07 eV found for the EI-induced N-vacancy donor; and (iii) both centers have different and small capture cross sections ($1-3 \times 10^{-20} \text{cm}^2$ for $ED1$ and $5-8 \times 10^{-19} \text{cm}^2$ for $ED2$), with that of $ED2$ being temperature dependent and having an activation energy ($E_a$) of 0.06 eV.$^{23}$ We speculate that the hole trap ($A_3$) is due to the Ga vacancy, which is often the dominant acceptor in undoped GaN, especially that grown by hydride vapor phase epitaxy, as confirmed by positron annihilation studies.$^{24,25}$ According to theoretical calculations,$^{26}$ (i) the N vacancy (a donor) has the lowest formation energy in $p$-type GaN, and the Ga vacancy (an acceptor) in $n$-type GaN; and (ii) the isolated Ga vacancy in the negative charge state is triply occupied, with levels close to the valence band. There are many reports about deep levels related to impurity acceptors [such as Mg (Refs. 27 and 28)], however, so far there are no reports about any DLTS centers related to the Ga vacancy. It is possible that the TSC/TEES trap $A_3$ at $E_v + 0.167$ eV is related to Ga vacancy. Since this activation energy is close to the reported activation energies for Mg (such as 136 meV by admittance measurements,$^{27}$ 135–155 meV by Hall effect measurements, and 80–115 meV by admittance measurements$^{28}$ respectively), we should not rule out the possibility that $A_3$ is due to Mg, owing to possible contamination and memory effect during MBE growth. To clarify this issue, further TEES studies on high-resistive or semi-insulating GaN samples grown by other techniques are necessary.

The authors thank Dr. H. Morkoč for providing the MBE-grown SI–GaN. This research was supported by the Ministry of Science and Technology of Croatia. Z-Q.F. and D.C.L. were supported under AFOSR Grant No. F49620-00-1-0347.