Electrical Characterization of GaN

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Abstract— GaN based blue light emitting diodes were characterized, using deep level transient spectroscopy technique. Nine defects having ionization energies: 0.06, 0.08, 0.09, 0.14, 0.10 , 0.14, 0.14, 0.16 and 0.65 eV and corresponding capture cross-sections $(\sigma_\infty) 4.0 \times 10^{-14}$, 1.3×10^{-13}, 7.6×10^{-14}, 6.95×10^{-13}, 3.53×10^{-14}, 1.6×10^{-13}, 8.0×10^{-14}, 7.34×10^{-14} and $1.8 \times 10^{-5}\,\mathrm{cm}^2$ were identified. Respective concentrations were found to be 8.81×10^{13}, 8.56×10^{13}, 8.90×10^{13}, 8.68×10^{13}, 8.62×10^{13}, 8.56×10^{13}, 8.66×10^{13}, 8.57×10^{13}, 8.54×10^{13}, 8.68×10^{14}, and $8.46 \times 10^{14}\,\mathrm{cm}^{-3}$.

1. INTRODUCTION

GaN and associated alloys (III-N compounds) have been focus of research for more than three decades [1–4] due to their wide verity of applications in opto-electronic devices. Tunable band gap of these materials (0.7 to 6.1 eV) makes their use versatile in the fields of ultra-high frequency (RF) components [1, 5, 6]. The realization of hetero-structures out of these materials opened a new era in the field of telecommunication. High electronic mobility transistors (HEMT's) based on these materials, can support power densities ten times higher than those accessible with silicon and gallium arsenide [1, 7]. These materials are famous for their excellent optical properties such as laser diodes (LDs), high performance light emitting diodes (LEDs), and solar cells [8–12]. Laser diodes are used in high density optical processing systems like digital versatile disk random access memory (DVD-Ram, and DVDR) [13–16]. Deep level defects in these materials may act as non radiative recombination or trapping centers, which significantly decrease the radiative efficiency and increase the thresh hold current density, thus deteriorate device performance [13, 17, 18]. To improve the performance of such devices and, particularly, to increase the light intensity, it is, therefore, important to optimize growth conditions of each layer of the diodes by defect engineering [13, 19]. The knowledge of deep level defects is of primary importance for the improvement of performance of devices based on III-N compounds. The deep levels can be easily identified by deep level transient spectroscopy (DLTS), a powerful and well established technique for the investigation of electronic properties of deep level defects in semiconductors [20]. In this report we present a study of defects in GaN material by DLTS technique.

2. EXPERIMENTAL

High bright blue GaN based light emitting diodes imported from Hebei I.T, China [21] were used as our samples. The samples are single blue color emitting devices which have high bright output, low power consumption, high reliability and long life.

Capacitance-voltage characteristics of GaN based LEDs were measured to determine the quality of diodes using capacitance meter Boonton 7200. Typical capacitance-voltage characteristics have been shown in Fig. 1. The data points in plot, $1/C^2$ Vs applied voltage v, are found approximately fit on a straight line, indicating junction as a step junction [22]. However, a careful examination shows that two different straight lines can be fit in the voltage range 0–4 and 6–10 volts. The least square fitting show that shallow level concentration on p- and n-sides of the junction are nearly equal [23].

For DLTS [20] measurements, a deep level transient spectrometer DLS-83D, manufactured by Semi trap, Hungary was used. The spectrometer provides a quiescent reverse bias and filling pulse with a repetition rate from 0.1 Hz to 1 kHz and temperature accuracy of better than 1 K. Output of the sensor and spectrometer is fed to CPU through a data bus. Shielded cables were used to provide connections from the samples to the spectrometer. Sample is mounted in a sample holder of the cryostat with the help of two spring-loaded pins for this purpose.

Temperature of the sample is lowered to 77 K by slowly lowering the sample holder into liquid nitrogen container and raised to room temperature or above, by gradually lifting the sample holder or by increasing the current through a heater embedded inside the sample holder. The rate of

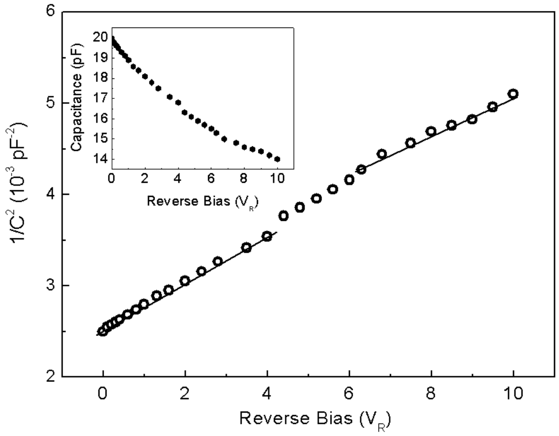

Figure 1: Typical $1/C^2$ verses reverse bias plot of GaN diodes, inset shows capacitance verses voltage graph.

emission of the charge carriers from deep levels is monitored by measuring change in capacitance of the diode under quiescent reverse bias using the above setup. Output of the spectrometer gives a scan. For maximum emission rate of a defect, scan shows a peak at a fixed temperature. DLTS scan exhibits different peaks for different defects. The DLTS scans were repeated at different emission-rate windows to obtain a data for estimating the energy-position of the traps in the band gap. Emission rates were plotted against the temperature (K) on the semi-logarithmic scale using the equation,

$$\ln\left(\frac{e_n}{T^2}\right) = \ln A + [-\Delta E/k_B T]$$

The slope of the best fit line of the Arrhenius plot, $\ln[e_n/T^2]$ Vs $1000/T$ gives activation energy of the deep levels [20]. The activation energies of different defects were obtained from such best-fit lines. Capture cross sections (σ_∞) for the corresponding levels were calculated from the y-intercept of $\ln[e_n/T^2]$ Vs $1000/T$ at $T = \infty$.

3. RESULTS AND DISCUSSION

A typical DLTS scan is shown in Fig. 2. At least fourteen peaks, $P1$–$P14$, have been noticed in the scans. Emission rate data for peaks $P1$, $P2$, and $P12$–$P14$ were not sufficient to get a reliable energy, therefore, not reported. Measured activation energies of the defects assigned to peaks $P3$–$P11$ are 0.06, 0.08, 0.09, 0.14, 0.10, 0.14, 0.14, 0.16 and 0.65 eV and corresponding capture cross-sections (σ_∞) are 4.0×10^{-14}, 1.3×10^{-13}, 7.6×10^{-14}, 6.95×10^{-13}, 3.53×10^{-14}, 1.6×10^{-13}, 8.0×10^{-14}, 7.34×10^{-14} and $1.8\times10^{-5}\,\text{cm}^2$. Respective concentrations are found to be 8.81×10^{13}, 8.56×10^{13}, 8.90×10^{13}, 8.68×10^{13}, 8.62×10^{13}, 8.56×10^{13}, 8.66×10^{13}, 8.57×10^{13}, 8.54×10^{13}, 8.68×10^{14}, and $8.46\times10^{14}\,\text{cm}^{-3}$. The data is also listed in Table 1.

Although, in literature [24–26], deep levels in this material have been studied, however, most of the investigations limited to electron trapping centers related to doping impurities such as Si and Se. Both electron and hole emitting deep levels need to be examined quantitatively to study the defects responsible for reduction of radiative efficiency. We performed DLTS measurements to study electron and hole emitting centers. It is reported in literature that inherent threading dislocation density in this material is of the order of 10^9–$10^{10}\,\text{cm}^{-2}$ [27, 28]. Such a high dislocation density could be attributed to the large difference in lattice constants and thermal expansion coefficient between the substrate and epitaxial GaN films. Characteristics of the devices could be strongly influenced by the high dislocation density and limit the performance by affecting life time, mobility and the quantum efficiency of radiative recombination.

Recent theoretical studies on native point defects in III–V nitrides [29, 30] show that nitrogen vacancies have the lowest formation energy in p-type GaN and can be produced in a significant concentration during the growth. We can, thus, speculate that defects reported in this work are nitrogen-vacancy related defects. Ionization energy, 0.65 eV, of a trap observed in this study is comparable to that reported by Dyba et al. [18] for trap E (0.63). This trap was identified with single vacancy or V_{Ga}-O complex [18, 31}. As DLTS signal from both sides is possible as a majority signal we are, therefore, of the opinion that energy state (0.65 eV) is due to vacancy or V_{Ga}-O complex [18, 31].

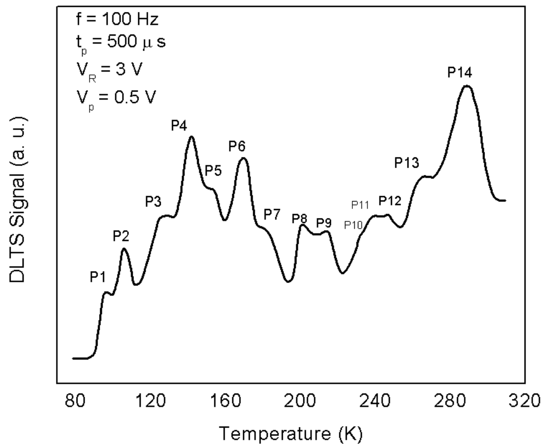

Figure 2: A typical DLTS scan of GaN-LEDs.

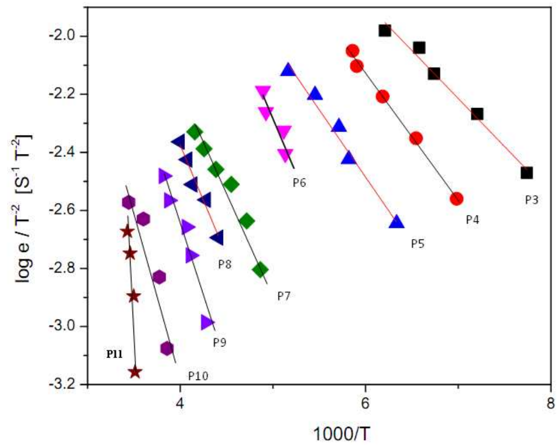

Figure 3: Emission rate data of defects corresponding to peaks $P3$ to $P11$.

Table 1: Characteristics of defects related to different peaks.

Peaks	**Activation Energy (eV)**	**Capture Cross-section (σ_∞) ($\mathbf{cm^2}$)**
$P3$	0.059	4.0×10^{-14}
$P4$	0.083	1.3×10^{-13}
$P5$	0.087	7.6×10^{-14}
$P6$	0.107	6.94×10^{-13}
$P7$	0.124	3.53×10^{-14}
$P8$	0.142	1.6×10^{-13}
$P9$	0.141	8.04×10^{-14}
$P10$	0.155	7.34×10^{-14}
$P11$	0.648	1.8×10^{-5}

REFERENCES

1. Charfeddine, M., M. Gassoumi, H. Mosbahi, C. Gaquiére, M. A. Zaidi, and H. Maaref, *Journal of Modern Physics*, Vol. 2, 1229–1234, 2011.
2. Khan, M. A., A. Bhattarai, J. N. Kuznia, and D. T. Olson, "High electron mobility transistor based on a GaN-AlX, Ga1-XN heterojunction," *Applied Physics Letters*, Vol. 63, 1214–1215, 1993.
3. Omling, P., E. R. Weber, L. Montelius, H. Alexander, and J. Michel, *Physical Review B*, Vol. 32, 6571–6581, 1985.
4. Kim, H., S. J. Park, and H. Hwang, "Design and fabrication of highly efficient ganbased light-emitting diodes," *IEEE*, Vol. 49, 1715–1721, 2002.
5. Semra, L., A. Teliaa, and A. Soltani, *Surface and Interface Analysis*, Vol. 42, 799–802, 2010.
6. Dumka, D. C., C. Lee, H. Q. Tserng, P. Saunier, and M. Kumar, *Electronics Letters*, Vol. 40, 1023–1024, 2004.
7. Dupuis, R. D., *Journal of Crystal Growth*, Vol. 178, 56–73, 1997.
8. Chu, M.-T., W. Y. Liao, R.-H. Horng, T.-Y. Tsau, T.-B. Wu, S.-P. Liu, M.-H. Wu, and R.-M. Lin, Vol. 32, 922–924, 2011.
9. Horng, R. H., Y. A. Lu, and D. S. Wuu, *IEEE Photon. Technol. Lett.*, Vol. 23, 54–56, 2011.
10. Hansen, M., J. Piprek, P. M. Pattision, J. S. Spech, S. Nakamura, and S. P. Den Baars, *Applied Physics Letters*, Vol. 81, 4275–4277, 2002.
11. Horng, R. H., M. T. Chu, H. R. Chen, W. Y. Liao, and D. S. Wuu, *IEEE Electron Device Letters*, Vol. 31, No. 6, 585–587, 2010.
12. Dahal, R., B. Pantha, J. Li, J. Y. Lin, and H. X. Jiang, *Applied Physics Letters*, Vol. 94, 063505, 2009.

13. Kima, D. S., K. C. Kima, Y. C. Shina, D. H. Kang, B. J. Kim, Y. M. Kim, Y. Park, and T. G. Kim, *Physica B*, Vol. 376–377, 610–613, 2006.
14. Yagi, T., H. Nishiguchi, Y. Yoshida, M. Miyashita, M. Sasaki, Y. Sakamoto, K. I. Ono, and Y. Mitsui, *IEEE J. Sel. Top. Quantum Electron.*, Vol. 9, 1260, 2003.
15. Shima, A., H. Tada, K. Ono, M. Fujiwara, T. Utakoji, T. Kimura, M. Takemi, and H. Higuchi, *IEEE Photon. Technol. Lett.*, Vol. 9, 413, 1997.
16. Xi, Y. and E. F. Schubert, *Applied Physics Letters*, Vol. 85, 2163–2165, 2004.
17. Domen, K., K. Sugiura, C. Anayama, M. Kondo, M. Sugawara, T. Tanahashi, and K. Nakajima, *J. Cryst. Growth*, Vol. 115, 529, 1991.
18. Dyba, P., E. Placzek-Popko, E. Zielony, Z. Gumienny, S. Grzanka, R. Czernecki, and T. Suski, *ACTA Physica Polonica*, Vol. 119, 2011.
19. Kaniewska, M., D. Krynska, and M. Wesolowski, *Opt. Mater.*, Vol. 17, 283, 2001.
20. Lang, D. V., *J. Appl. Phys.*, Vol. 58, 3023, 1974.
21. Data sheet Hebei I.T, China, LED, specification.
22. Neamen, D., *Semiconductor Physics and Devices*, 3rd Edition, University of Mexico, 2011.
23. Tsarova, T., T. Wosinski, A. M. Kosa, C. Skierbiszewski, I. Grzegory, and P. Perlin, *Acta Physica Polonica A*, Vol. 112, 331, 2007.
24. Nojima, S., H. Tanaka, and H. Asahi, *J. Appl. Phys.*, Vol. 59, 3489, 1986.
25. Watanabe, M. O. and Y. Ohba, *J. Appl. Phys.*, Vol. 60, 1032, 1986.
26. Sugiura, K., K. Domen, M. Sugawara, C. Anayama, M. Kondo, T. Tanahashi, and K. Nakajima, *JAP*, Vol. 70, No. 9, 4946–4949, 1991.
27. Elsner, J., R. Jones, P. K. Sitch, V. D. Porezag, M. Elstner, T. Frauenheim, M. I. Heggie, S. Oberg, and P. R. Briddon, *Phys. Rev. Lett.*, Vol. 79, 3672–3675, 1997.
28. Chu, M.-T. and W. Y. Liao, *IEEE Electron Device Letters*, Vol. 32, 922–924, 2011.
29. Tsarova, T., T. Wosinski, A. M. Kosa, C. Skierbiszewski, I. Grzegory, and P. Perlin, Vol. 112, 331–337, Institute of High Pressure Physics "unipress", Polish Academy of Sciences, 2007.
30. Van de Walle, C. G. and J. Neugebauer, *Appl. Phys.*, Vol. 95, 3851, 2004.
31. Ashgar, M., P. Muret, B. Beaumont, and P. Gibart, *Mater. Sci. Eng. B*, Vol. 113, 248, 2004.