INTERNATIONAL JOURNAL OF RESEARCH IN COMMERCE, IT, ENGINEERING AND SOCIAL SCIENCES (IJRCIESS) ISSN: 2349-7793
Vol. 4 No. 1 (2010): January
Double-Blind Peer Reviewed Refereed Open Access International Journal

Deep level defects in electron irradiated GaN based Light emitting Diodes

B. JAYASHREE
Department of Physics, APS College of Arts & Science,
Bangalore-560019, India

ABSTRACT

Indium gallium nitride (InGaN)-based devices are potential candidates for integration into Air Force communication and sensor platforms. In this study, the electrical and optical properties of 8 MeV electron irradiated Light Emitting Diode (LED) Chips are characterized for deep level defects using Deep Level Transient Spectroscopy (DLTS), I-V and spectral response measurements. The objective of the present study is to assess the radiation tolerance of LEDs when they need to be operated in a radiation rich environment. When InGaN is exposed to a beam of electrons, it is found that five different electron traps are generated with activation energies ranging from 0.2 - 2.0 eV. Three of these traps correspond to radiation-induced traps previously reported in GaN, and they are found to deepen significantly in the energy band gap with an increase in electron fluence. The total trap concentration increases with increase in electron fluence while the carrier lifetime is found to decrease with increase in fluence. I-V measurements indicate that 8 MeV electron irradiation does not have any significant effect on the operating voltage. There is no significant change in dominant wavelength of the emission spectra of LED chips, suggesting GaN-based LEDs seem to be radiation tolerant up to electron fluence of the order of 6.8x 10^{14} electrons/cm^2.

Key words: LED, electron irradiation, deep level defects, DLTS measurements, emission spectra.

1. INTRODUCTION

Indium Gallium nitride/gallium aluminium arsenide/gallium nitride (GaInN)-based materials have attracted considerable interest owing to their potential use in optoelectronic devices, such as light emitting diodes (LEDs) and laser diodes (LDs)[1-3]. Indium gallium nitride (InGaN)-based devices are attractive candidates for integration into future Air Force communication and sensor platforms, including those that must operate in harsh radiation environments[4]. It is generally known that devices operating in radiation environments display changes in the physical properties and electrical characteristics. It is useful to understand the radiation response of these devices to find better design strategies before employing them for specific applications. By regulating the defects formation, one-can optimize electrical characteristics of the device to the required leve1[5]. Also, the electrical properties of the device such as forward voltage drop, reverse recovery charge before and after irradiation is extremely helpful in estimating the lifetime of the devices working in radiation environment[6].

The present studies on high-energy electron irradiation induced effects in LED chips are carried out with an objective to investigate modifications in optical and electrical characteristics and to identify the defects, which could be responsible for the modification.

2. EXPERIMENTAL

The chips of green colour LEDs made out of p - and n-type layers of InGaN grown over sapphire substrate of thickness 100 ± 10 µm prepared by M/s. LED Rep. (Division of M/s. AXT, USA) were used in this study. The LED chips (without encapsulation) of area 375 x 325 μm^2 were selected for comparison. The die bonding (epoxy bonding) and wire (gold) bonding of the chips were done at M/s Bharat Electronics Ltd, Bangalore. Diameter of both n- and p- type gold contact pads is 90 ±10 µm and thickness of the gold pad is 0.5-1 µm.

I-V measurements of LEDs before and after electron irradiation were carried out using Keithley Source and Measurement Unit (SMU 236) interfaced to a computer. Emission spectra (Spectral response) at room temperature are obtained on the prepared samples using the set-up consisting of a SMU, a monochromatic grating and Ge/Si photo detector. The LEDs are powered up using a SMU and all the spectra were recorded at a constant current of 70 mA. The width of the emission line (FWHM) and dominant wavelength of LEDs before irradiation are determined. The samples are irradiated with a beam of 8 MeV electrons at room temperature to a fluence of 1.5 $x10^{14}$ e/cm^2, 4.2 $x10^{14}$ e/cm^2 and 6.8 x 10^{14} e/cm^2. Electron irradiation was carried out at Variable Energy Microtron Center, Mangalore University, Mangalore. The I-V and emission spectral measurements are performed after each fluence. DLTS spectra are recorded using IMS-2000 DLTS system (M/s. Lab Equip, India) for both unirradiated and irradiated LEDs of the same colour. The trap concentration; activation energy and capture cross-section of different deep levels are determined by DLTS spectra.

3. RESULTS AND DISCUSSION

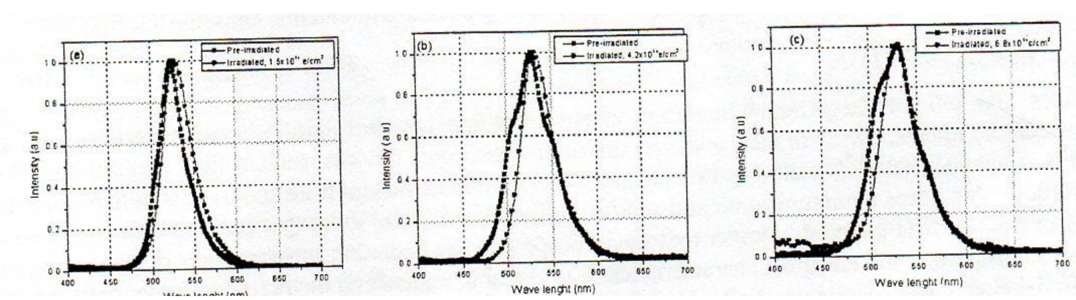
I-V measurements have been made on the LED chips before and after electron irradiation. However, no significant changes in the I-V characteristics are observed even after exposing the chips to highest electron fluence of the order of 10^{14} e/cm^2.

3.1 Spectral response

The Spectral response is one of the main optical techniques used to characterize the emission of LEDs. The emitting light will have certain wavelength, which corresponds to a certain colour. However, light emission from LED is not strictly monochromatic. There will be certain spreading in the spectral response distribution. For LED applications, it is useful to know the spread in spectral response. The emission linewidth (FWHM) and dominant wavelengths of LEDs before and after irradiation were determined. Fig.1 (a), (b) and (c) exhibit normalized emission spectra of LEDs before irradiation and after irradiation to three different electron fluences. The full width at half maximum (FWHM) of the emission spectra of green LED chip before and after irradiation is roughly the same. However, spectral responses of the post-irradiated devices show more uniformity compared to the pre-irradiated devices. A small shift observed in the peak wavelength suggests that electron irradiation might have introduced additional defect levels. A decrease in brightness, efficiency, and peak spectral intensity of the emission lines upon irradiation can be explained by a change in carrier lifetime where the light intensity for a linearly graded LED is given by[7]

$$L = C\,\tau \exp(qV/kT)$$

where C is a constant, τ is the carrier lifetime and all other symbols have usual meaning.



Fi… …s (a) 1.5 x
10

3.2. DLTS measurements

In principle any incident particle, such as high-energy electrons, can damage LEDs both through ionization and displacement[8]. Ionization is a surface effect whereas displacement damage is a bulk phenomenon which results in the creation of defects such as point defects (vacancy or interstitial) divacancy, Frenkel pair, vacancy-impurity complexes namely A-center, di-interstitial or higher order complexes called D-center and E-center (vacancy donor/acceptor)[9]. The deep level defects introduced due to the electron irradiation of LEDs are best characterized by using DLTS technique. DLTS is a high frequency capacitance transient thermal scanning method useful for observing a wide variety of deep level defects in semiconductor devices[10]. The DLTS spectrum is plot of difference in capacitance (δC) versus temperature. The trap concentration (N_T) can be determined by knowing peak height (δC_{max}) in the DLTS spectrum. In the DLTS characterization, the capacitance transients of p-n junction at different temperatures are recorded. The time constant (τ) for the given capacitance transient, activation energy (E_c - E_T) and capture cross section (σ) of the deep levels are related to each other as,

$$\tau T^2 = \frac{\exp[(Ec - ET/kT]}{\gamma\sigma}$$

where γ is the material coefficient and all other symbols have their usual meaning [11]. A plot of ln (τT^2) versus (1000/T) is known as Arrhenius plot, the slope of which yields the activation energy of the trap and intercept in [1/($\gamma\sigma$)] gives the capture cross section (σ). The DLTS spectrum recorded before and after electron irradiation exhibits five well behaved peaks corresponding to electron traps (spectrum not shown). Fig. 2 shows an Arrhenius plots for all five deep levels. Five minority carrier deep level defects labeled Ell, El2, E13, E14 and E15 are observed in the DLTS spectra of electron irradiated LED with fluence 1.5 x 10^{14} e/cm^2. Defects labeled E31, E32, E33, E34 and E35 are observed with electron fluence of 6.8x10^{14}e/cm^2. The identification of the deep

levels are made on the basis of their activation energy. The defect levels E11, E12, E31 and E34 correspond to activation energy of 0.30, 0.264, 0.578, and 0.993 eV respectively reported by C.D.Wang et al[12]. Three of these defect levels correspond to the radiation-induced traps previously reported in GaN, and they are found to deepen significantly in the energy band gap with increase in fluence.[13] As the fluence increases, the carrier lifetime decreases suggesting that the radiation-induced defects may act as scattering centers and cause the carrier mobility to decrease (Table 1). The radiation-induced levels in the bandgap can give rise to five processes: generation, recombination, trapping, compensation, and tunneling. In principle, any combination, or all, of these processes can occur through the same level. The role a particular level plays depends on variables such as carrier concentration, temperature, and the device region in which it resides[8].

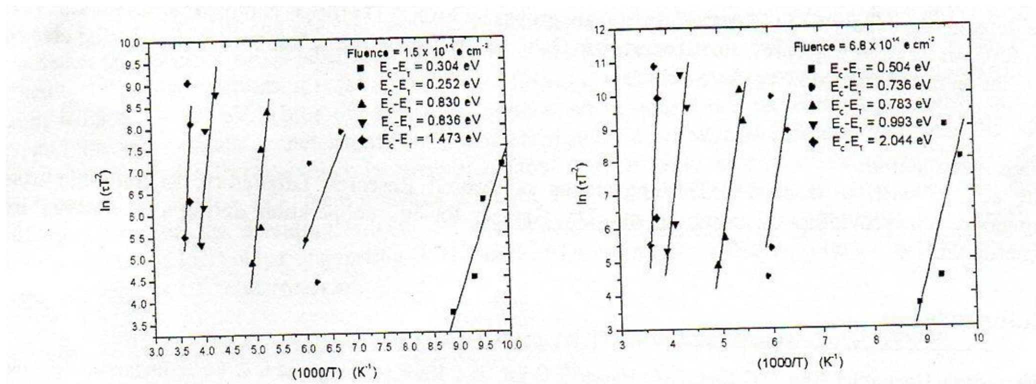


Fig.2. Arrhenius plot of emission rate and temperature for the five defect levels detected by DLTS. Activation energies are obtained from the slopes of the lines corresponding to each level.

Fluence (e/ cm^2)	Defect label	Activation Energy (eV)	Trap concentration n (cm^{-3})	Total trap concentration (cm^{-3})	Capture Cross section (cm^2)	Introduction rate η (cm^{-1})	Carrier life time (s)	Effective life time (s)
	E11	0.304	1.01E+12		2.74E-14	0.00673	5.26E-06	
	E12	0.252	6.76E+11		9.98E-17	0.00451	1.76E-03	
1.5 x 10^{14}	E13	0.83	1.27E+12	4.20E+12	2.66E-16	0.00847	3.20E-04	4.31E-06
	E14	0.836	6.51E+11		1.20E-16	0.00434	1.33E-03	
	E15	1.473	5.90E+11		5.39E-15	0.00393	2.64E-05	
	E31	0.504	1.01E+12		5.07E-14	1.40E-03	2.84E-06	
	E32	0.736	6.25E+11		1.38E-15	9.00E-04	1.38E-04	
6.8 x 10^{14}	E33	0.783	1.54E+12	4.98E+12	2.16E-13	2.30E-03	3.25E-07	1.19E-07
	E34	0.993	1.21E+12		2.64E-13	1.70E-03	3.26E-07	
	E35	2.044	5.92E+11		2.72E-13	9.00E-04	5.22E-07	

Table 1. DLTS data for electron irradiated LED for two different fluences.

The direct band gap energy of wurtzite GaN and InN are 3.4 and 0.8 eV respectively. This work essentially signifies that InGaN LED has trap levels within the band gap. The radiation induced trap level could be due to the tunneling of carriers through a potential barrier by means of defect levels. This defect-assisted (also called trap-assisted) tunneling process can cause device currents to increase in certain situations. For example, there may be a defect-assisted tunneling component of the reverse current in a p-n junction diode[8]. Nevertheless, the radiative defects within the space charge region must be insensitive to lifetime damage, and hence are unaffected by displacement damage effects until the radiation level is high enough to cause carrier removal. It can beconclude that at the injection levels (the density of minority carrier when the junction is forward biased) corresponding to typical regions where the LEDs considered in this study are operated, radiation recombination within the space charge region is not a significant factor. It may, however, affect device operation at low injection level, as well as at low temperature[14].

4. Conclusion

The 8MeV electron irradiation on GaN-based LED chips does not have any significant change in the I-V characteristics up to the fluence level of $6.8X10^{14}e/cm^2$, however emission spectra reveals that there are some defects which are present in the pre-irradiated samples as well as post- irradiated samples, which correspond to the defects which have been identified for n-GaN grown by MOCVD process and three of these traps correspond to radiation-induced traps previously reported in GaN. In addition to these, this work suggests that electron irradiation has introduced two more defects.

Acknowledgement

The author wish to thank Dr. Thirumavalavan of Central Research Laboratory, Bharath Electronics Ltd, Bangalore for providing the samples and Dr. Ganesh for his cooperation during the electron irradiation experiment.

References

1. Hung-Wen Huang, J T Chu, C C Kao, T H Hseuh, T C Lu, H C Kuo, S Cwang and C CYu , " Enhanced light output of an InGaN/GaN light emitting diode with a nano-roughened p-GaN, Surface Nanotechnology ," 16 , 1844-1848, 2005.
2. Nakamura S, Senoh M, Nagahama S. Iwasa N, Yamada T, Matsushita T, Sugimoto Y and Kiyok-u H, "Room-temperature continuous-wave operation of InGaN multi-quantum-well-structure laser diodes with a long lifetime," Appl.Phys.Lett.70 868-70 , 1997.
3. Nakamura S, Senoh M, Iwasa N and Nagahama S, " High-brightness InGaN blue, green and yellow light-emitting diodes with quantum well structures," Japan .J.Appl. Phys. 34 L797-9, 1995.
4. Nakamura S, Mukai T and Senoh M "Candela-class high-brightness InGaN/A1GaN double-heterostructure blue-light-emitting diodes ," Appl. Phys .Len. 64 (1687-9) 1994.
5. A. lonascut-Nedelcescu, C. Carlone, A. Houdayer, H.J. Von Bardeleben, J.LCantin and S. Raymond "Radiation Hardness of Gallium Nitrade, IEEE Tras.Nuc.Sci.,Vo1.49, No.6, Dec 2002.
6. Shyam M.khanna, Diego Estan, Alain Houdayer, Hui C.Liu and Richard Dudek, "Proton Radiation Damage at Low Temperature in GaAs and GAN Light-Emitting Diodes," IEEE Tras.Nuc.Sci..Vol.51,No.6,Dec 2004.
7. S. A. Goodman, F. D. Auret, F. K. Koschnick, J.M. Spaeth, B. Beaumontand P. Gibart, "Electrical characterization of defects introduced in n-ganduring high energy proton and He-ion irradiation," MRS Internet J. Nitride Semicond. Res. 4S1, G6.12, 1999.
8. J.R.Srour "IEEE, Nuclear and Space Radiation Effect Conference- Short Course," 17 July 1983
9. J. R. Srour, Cheryl J. Marshall, P.W. Marshall, "Review of displacement effects in Silicon Devices," IEEE Trans. Nucl. Sci. 50 (2003), 653.
10. D. V. Lang, "Deep Level Transient Spectroscopy of Zinc Oxide," J. App. Phy. 45 ,3023, 1974.
11. D. K. Schroder , "Semiconductor Material and Device Characterization," John Wiley & Sons, pp309, pp361-362, 1990.

12. C.D.Wang,L.S.Yu,S.S.Lau and E.T.Yu "Deep level defects in n-type GaN grown by molecular beam epitaxy", Appl.Phys.Lett.72,No.10,1998.
13. Hosed, Michael R. "Deep Level Defects in Electron-Irradiated Aluminum Gallium Nitride Grown by Molecular Beam Epitaxy", Doctoral thesis Apr 2003-Jan 2005 Accession Number : ADA431507
14. C.E.Barnes and J.J.Wiczer,"Radaition effects in optoelectronic devices,"Sandia National Laboratories,Albuquerque,NM,Tech.Rep. AND84-0771, May 1984.