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Original Research Article

High-energy electron irradiation induced effects in LED chips

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ABSTRACT
Devices based on indium gallium nitride (InGaN) could be included into Air Force communication and sensor platforms. Using Deep-Level-Transient-Spectroscopy (DLTS), I-V, and spectral response quantification, the electrical and optical characteristics of Light Emitting Diode (LED) Chips exposed to 8 MeV electrons are assessed for deep level defects in this study. The goal of the current study is to evaluate LEDs' radiation tolerance when operating in a radiation-rich environment. It has been discovered that five distinct electron traps having activation energy in the range 0.2 to 2.0 eV are produced when InGaN is subjected to an electron beam. Three of these traps are radiation-induced traps that were previously described in GaN, and it is discovered that as electron fluence rises, their energy band gaps deepen dramatically. While the carrier lifespan is shown to decrease with increased electron fluence, the total trap concentration is observed to increase. I-V measurements show that the operating voltage is not significantly affected by 8 MeV electron irradiation. The primary wavelength of the emission spectra from LED chips does not significantly change, indicating that GaN-based LEDs appear to be radiation-tolerant up to electron fluences of the order of 6.8×10^{14} electrons/cm^2.

1. Introduction

Because they might be used in optoelectronic devices like light-emitting diodes (LEDs) and laser diodes (LDs), materials based on indium gallium nitride/gallium aluminium arsenide/gallium nitride (GaInN) have garnered significant interest [1-3]. Future Air Force communication and sensor platforms, especially those required to function in extreme radiation conditions, are a good fit for Indium gallium nitride (InGaN)-based devices [4].

Devices working in radiation settings are known to exhibit changes in their physical and electrical characteristics. Before using these devices for particular purposes, it is helpful to understand how they respond to radiation in order to develop better design techniques. One can adjust the electrical characteristics of the device to the desired level by controlling the fault generation [5]. Moreover, electrical characteristics of the device, such as forward voltage drop and reverse recovery charge before and after irradiation, are highly useful in determining how long a device will last in a radiation environment [6].

The current research on the impact of high-energy electron irradiation on LED chips aims to explore changes in optical and electrical properties as well as to pinpoint any potential flaws that may be to blame.

2. Experimental

The p- and n-type layers of InGaN grown over a sapphire substrate with a thickness of 100 ± 10 μm produced by M/s. LED Rep. (Division of M/s. AXT, USA) were employed. For comparison, the 375×325 μm^2 LED chips (without encapsulation) were chosen. At M/s Bharat Electronics Ltd, Bangalore, the die bonding (epoxy bonding) and wire bonding (gold bonding) of the chips were completed. Both p- and n-type gold contact pads possess the diameter ~ 90 ±10 μm and a thickness ~ 0.5 - 1 μm.

The Keithley Source and Measurement Unit (SMU 236) was interfaced to a computer to do I-V measurements on LEDs before and after electron irradiation. The setup, which consists of an SMU, a monochromatic grating, and a Ge/Si photo detector, is used to obtain the prepared samples' emission spectra (also known as spectral response) at room temperature. A SMU is used to power the LEDs, and a steady current of 70 mA was used to record all of the spectra. Prior to illumination, the dominant wavelength and emission line width (FWHM) of LEDs are calculated.

At room temperature, the samples are exposed to beams of 8 MeV electrons with fluences of 1.49×10^{14} e/cm^2, 4.19×10^{14} e/cm^2 and 6.8×10^{14} e/cm^2. Furthermore, electron irradiation was done.

Following each fluence, I-V and emission spectrum measurements are made. IMS-2000 DLTS system (M/s. Lab Equip, India) is used to record DLTS spectra for both un-irradiated and irradiated LEDs of the same colour. Calculations of the trapping concentration, the energy of activation, and capturing cross-sectional area of different levels of depth are done using DLTS spectroscopy.

3. Results and discussion

On the LED chips, I-V measurements were taken both before and after electron irradiation. However, even after subjecting the chips to the maximum electron fluence on the order of 10^{14} e/cm^2, no discernible changes in the I-V characteristics were seen.

3.1 Spectral response

One of the primary optical methods for describing LED emission is the spectral response. The light that is emitting will have a specific wavelength that correlates to a particular colour. LED light emission is not wholly monochromatic, though. The dispersion of the spectral response will undoubtedly spread. It is helpful to understand the spread in spectral response for LED applications. We calculated the emission linewidth (FWHM) and prominent wavelengths of LEDs both before and after illumination. LEDs' normalised emission spectra before and after being exposed to three different electron fluences have been depicted in Figures 1(a), (b), (c). Before and after exposure, FWHM of emission spectrum from green LED chips is essentially the same. In contrast to the pre-irradiated devices, the post-irradiated devices' spectrum responses exhibit greater homogeneity. It is possible that additional defect levels were introduced by electron irradiation based on the slight shift in peak wavelength that was detected. A change in carrier lifetime, where the light intensity for a linearly graded LED is given by [7], can be used to explain a drop in brightness, efficiency, and peak spectrum intensity of the emission lines following irradiation.

$$L = C\tau \exp\left(\frac{qV}{kT}\right) \tag{1}$$

where C is a constant, τ is the carrier lifetime and others have their usual meanings.

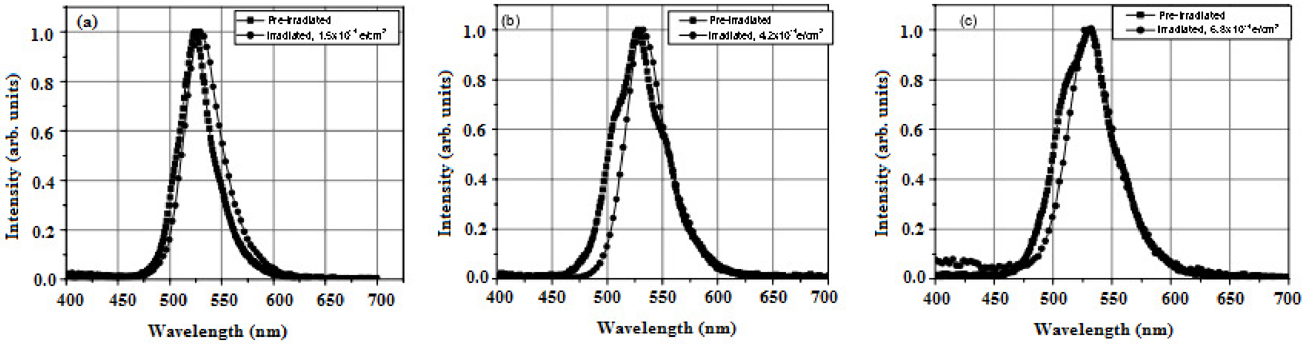

Figure 1: LED chip emission spectra before and after electron irradiation at various fluencies: (a) 1.49×10^{14} e/cm^2, (b) 4.19×10^{14} e/cm$^{2'}$ and (c) 6.8×10^{14} e/cm^2.

3.2 DLTS measurements

In theory, any impacting particle, even high-energy electrons, can harm LEDs by ionising them or by dispersing them [8]. Ionisation is an exterior impact, while relocation destruction is a bulk process that results in imperfections such as interstitial fluid or vacant positions imperfections, quando-vacancy, Frenkel combination, vacancy-impurity structures identified as A-centers, and greater order structures identified as D-centers and E-centers (vacancy donor/acceptor) [9]. The DLTS approach is the most effective way to characterise the deep level faults brought by by the electron irradiation of LEDs. The large frequency capacitor transient thermal scanning technique called deep level defect tracking (DLTS) is beneficial for spotting various deep level faults in various structures [10]. In DLTS spectrum, the capacitance difference (δC) is plotted against temperature. The peak height (δC_{max}) in DLTS spectrum can be utilized in the determination of trap contents (N_T). The p-n junction's capacitance transients at various temperatures are captured during the DLTS characterization. For the specific capacitance transient , the time constant (τ), capture cross section (σ), and the activation energy (E_C - E_T), are connected to one another as follows:

$$T^2\tau = \frac{\exp\left(\frac{E_c - E_T}{kT}\right)}{\sigma\gamma}, \tag{2}$$

where γ may be regarded as the material's constant and all other symbols have the same meaning as they would normally [11]. The Arrhenius plot is a plot of ln (τT^2) versus (1000/T), whose slope gives rise the value of activation energy of trap and its intersection, i.e. ln [1/($\sigma\gamma$)] gives rise the capture cross section (σ). Five well-behaved peaks that correspond to electron traps can be seen in the DLTS spectra that was recorded before and after electron irradiation (spectrum not shown). All five deep layers are represented by Arrhenius plots in Figure 2. The DLTS spectra of an electron-irradiated LED with fluence 1.5×10^{14} e/cm^2 show five minority carrier deep level defects named E11, E12, E13, E14, and E15. Electron fluence of 6.8×10^{14} e/cm^2 is used to observe defects labelled E31, E32, E33, E34, and E35. The deep levels are determined by their activation energy. According to C.D.Wang et al. [12], the defect levels E11, E12, E31, and E34 have corresponding activation energies of 0.30, 0.264, 0.578, and 0.993 eV. Three of these defect levels are the radiation-induced traps in GaN that were previously described, and it is discovered that as fluence increases, these defect levels drastically narrow the energy band gap. The fact that the carrier lifespan decreases with fluence suggests that radiation-induced flaws may serve as scattering foci and lower carrier mobility (Table 1). Five processes can result from radiation-generated energy levels in the bandgap structure: generation, recombination, trapping, compensation, and tunnelling. In theory, these procedures could all occur at the same level. The function a specific level performs is influenced by factors like device region in which it is located, the temperature, and the carrier concentration [8].

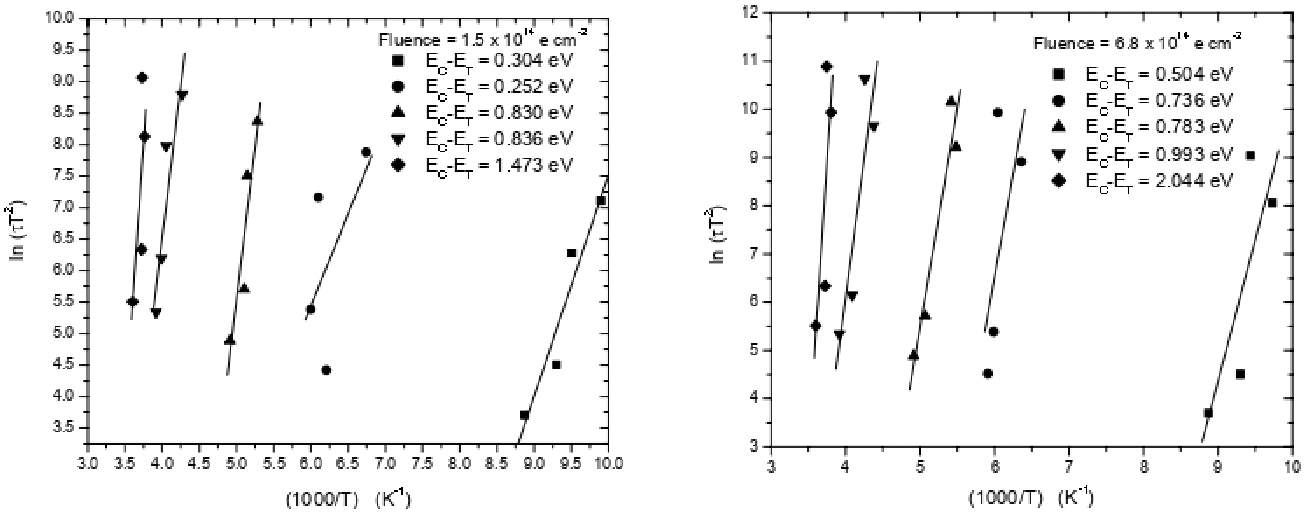

Figure 2: Temperature and rate of emissions plotted as an Arrhenius function for every one of the five levels of defects identified by DLTS. The activation energies are calculated from the gradients of the lines belonging for every level.

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

Fluence (e/cm^2)	Defect label	Activation energy (eV)	Trap conc. n (cm^{-3})	Total trap conc. (cm^{-3})	Capture cross-section (cm^2)	Introduction rate η (cm^{-1})	Carrier life time (s)	Average lifetime (s)
1.5×10^{14}	E11	0.305	1.02×10^{12}	4.20×10^{12}	2.72×10^{-14}	6.72×10^{-3}	5.24×10^{-6}	4.31×10^{-6}
	E12	0.253	6.75×10^{11}		9.99×10^{-17}	4.52×10^{-3}	1.74×10^{-3}	
	E13	0.832	1.26×10^{12}		2.64×10^{-16}	8.48×10^{-3}	3.22×10^{-4}	
	E14	0.835	6.50×10^{11}		1.21×10^{-16}	4.35×10^{-3}	1.30×10^{-3}	
	E15	1.475	5.92×10^{11}		5.40×10^{-15}	3.92×10^{-3}	2.61×10^{-5}	
6.8×10^{14}	E31	0.505	1.02×10^{12}	4.98×10^{12}	5.06×10^{-14}	1.41×10^{-3}	2.82×10^{-6}	1.19×10^{-7}
	E32	0.735	6.22×10^{11}		1.37×10^{-15}	9.02×10^{-4}	1.39×10^{-4}	
	E33	0.782	1.52×10^{12}		2.15×10^{-13}	2.32×10^{-3}	3.26×10^{-7}	
	E34	0.994	1.22×10^{12}		2.66×10^{-13}	1.72×10^{-3}	3.22×10^{-7}	
	E35	2.045	5.91×10^{11}		2.71×10^{-13}	9.02×10^{-4}	5.19×10^{-7}	

Wurtzite InN and GaN have straight band gaps of 0.8 and 3.4 eV, respectively. This paper effectively shows that the band gap of an InGaN LED has trap levels. The radiation-induced trap level might result from carriers using defect levels to tunnel through a potential barrier. Device currents may occasionally increase as a result of this defect-assisted (also known as trap-assisted) tunnelling process. In a p-n junction diode, for instance, the reverse current could have a defect-aided tunnelling component [8]. However, radiating faults inside the charged space zone need to be unresponsive to lifetimes damaging therefore they are not impacted by relocation damaging impacts until the amount of radiation becomes significant in order to result in carriers loss. We may infer that at injecting rates (the concentration of the minority carrier when the junction itself is forward biassed), which approximate to normal operating areas for the LEDs examined in this work, radiation mixing inside the space charge zone is not a serious issue. Nonetheless, it might have an impact on a device's performance at low injection levels and low temperatures.

4. Conclusions

I-V and spectrum absorption tests performed on InGaN LEDs exposed to 8 MeV electron irradiation show that neither the electrical properties nor the emission spectral response of the LEDs are significantly impacted by the irradiation. Nevertheless, electron irradiation causes displacement damage, which creates a number of deep level electron traps that may interfere with the operation of LEDs at low injection levels.

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