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EFFECT OF Li ION IRRADIATION (OF 20 MeV) ON RELIABILITY OF AlGaN/GaN HIGH ELECTRON MOBILITY TRANSISTORS

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ABSTRACT

In this study, AlGaN/GaN heterostructure based HEMT (High electron mobility transistor) devices have been irradiated from 20MeV Li ions having fluences of 5e11/ cm^2 and 5e12/cm^2. The effect of irradiation on structural, optical and electrical characteristics have been studied after the irradiation and compared with unirradiated one. It has been found that the irradiated fluences do not show any change in the FWHM of the material as found from the x-ray rocking curve measurement. The photoluminescence study showed a quenching effect in the optical intensity up to 80% at the higher fluence of the irradiation. A positive shift of the HEMT threshold voltage has been found from the C-V measurement on the irradiation. The carrier concentration has been found to decrease with the increase of irradiation fluence. The study shows the degradation of the device for the higher dose of the irradiation.

Keywords: GaN, AlGaN, HEMT, radiation, reliability

I. INTRODUCTION

AlGaN/GaN heterostructures based HEMT (high electron mobility transistors) are promising candidates for high power high frequency civilian as well as military applications, such as radars and satellites communication systems due to their high breakdown voltage and high carrier mobility properties [1, 2]. Electronic systems used for these applications constantly face different type of radiations from cosmic rays, Van Allen belts and solar flares etc. This consists of electromagnetic radiations as well as particles such as protons, gamma ray, neutrons, electrons and alpha particles etc. Thus radiation reliability of these devices and materials for space applications is a crucial issue prior to their practical applications. Varied degrees of reliability studies have been reported for these systems [3-12].

In this report, GaN/AlGaN heterostructure based high electron mobility transistors have been subjected to 20 MeV of Li ion irradiation for 5e11/ cm^2 and 5e12/cm^2 fluences. Structural, optical and electrical characteristics have been compared before and after the irradiation to investigate the changes in the characteristics for radiation reliability evaluation.

II. EXPERIMENTAL DETAILS

The schematic cross-section of the fabricated HEMT device on the MOCVD (Metal Organic Chemical vapour Deposition) grown layered structure, used in the study, is shown in figure 1. For the device fabrication, the photolithographically defined ohmic contacts were formed with Ti/Al/Ni/Au deposition with lift-off technique and then alloying was done with rapid thermal annealing. This was followed by mesa isolation which was achieved with the help of dry etching. The Schottky gate was formed with Ni/Au metal layers with the help of photolithography and lift-off technique.

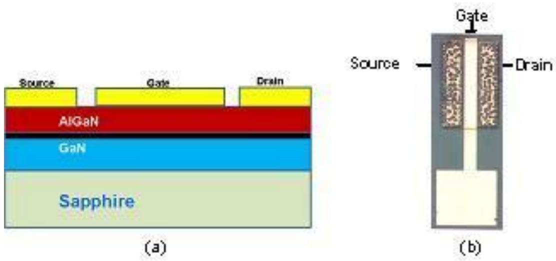

Figure.1 : (a) Cross-section schematic of device & (b) a typical fabricated HEMT device

The electrical characterization on fabricated HEMT with a gate length of 20 µm and gate width of 150 µm *(*Fat field effect transistor*)* was done before the irradiation. The peak transconductance value of 54.92 mS/mm for the device was found. The schottky measurements for forward and reverse characteristics were also performed. The capacitance-voltage measurement of the devices was carried out and a peak capacitance value of 12.8 pF was measured. For the structural property of the material x-ray rocking curve measurement was performed (FWHM =0.138 degree). The optical characteristics were studied using photoluminescence technique.

For the irradiation experiment the facility at Inter University Accelerator Center, New Delhi was used. The 20MeV Li ion at two fluences of 5e11/cm^2 and 5e12/cm^2 were exposed to unprocessed materials and fabricated devices .After irradiation, electrical measurements were repeated on the same devices. The x-ray rocking curve measurement and photoluminescence characteristics were performed on similar material pieces.

III. RESULTS AND DISCUSSION

The x-ray rocking curve comparison of the device material (AlGaN/GaN), before and after the irradiation is shown in fig 2. It has been found that FWHM of the material system has not been changed on the irradiation. This shows that the used fluences of the Li ions do not change the crystalline order of the material on irradiation.

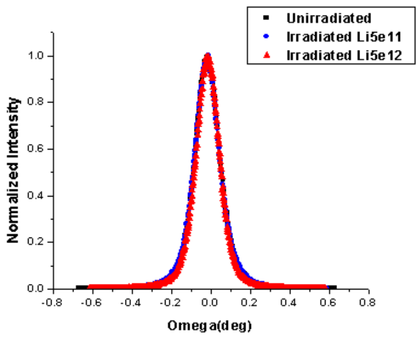

Figure 2.: X ray rocking curve comparison of unirradiated vs. Li irradiated samples

The Schottky diodes characteristics (of the HEMT device) comparisons in forward and reverse biases on the irradiation are shown in fig 3 for the used Li ions fluences.

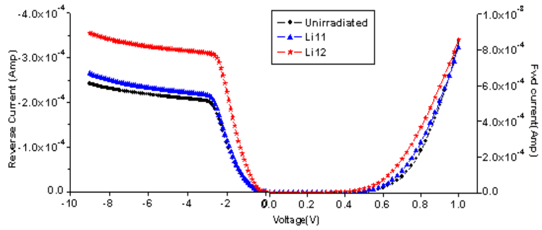

Figure.3 : Schottky diode characteristics comparison

For Li ion irradiation of 5e11 /cm^2 dose, the schottky diode characteristics for forward and reverse biases were found remain unchanged after the irradiation. This indicates that the irradiation does not alter the schottky junction characteristics for any perceptible change .Table 1 shows the estimated barrier height which has not change for the irradiation dose of 5e11/cm^2. For the irradiation dose of 5e12/cm^2, a decrease in the barrier height and increase in reverse current has been observed.

Table 1: Schottky diode characteristics

Parameter	**Unirradiated Devices**	**Irradiated with Li ion 5e11/cm^2 dose**	**Irradiated with Li ion 5e12/cm^2 dose**
Barrier height φ_B (eV)	1.05	1.05	1.03
I_{rev}@-3V (Amp)	-2.02X10^{-4}	-2.1X10^{-4}	-3.1X10^{-4}

The decrease in the barrier height may be due to the introduction of irradiation induced defects at the metal-semiconductor interface, which eventually also increases the reverse current. Thus it is observed that schottky diode degradation occurs for the Li ions of 5e12/cm^2 fluence which shall also limit the performance of HEMT at high voltages.

The comparison of capacitance-voltage characteristics of HEMT devices shows no change for the $5e11/cm^2$ irradiation dose while for $5e12/cm^2$ irradiation dose, a positive shift in the threshold voltage of the device has been observed as shown in fig 4.

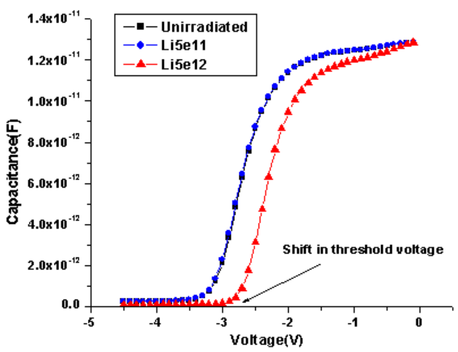

Figure .4.: C-V comparison of unirradiated vs. Li irradiated devices

This shift in the HEMT threshold voltage of the device can be explained by the model of Rashmi et al [13], which shows that;

$$V = \varnothing_B - (qNt^2 \div 2\epsilon) - (\Delta E_C \div q) - (\sigma_{pol} t \div \epsilon) \quad (1)$$

where V is threshold voltage of HEMT

Φ_B is schottky barrier height of gate

N is the doping in the AlGaN film

t is the thickness of the AlGaN film

ΔE_C is the AlGaN-GaN conduction band discontinuity

σ_{pol} is the interface charge

Relation (1) clearly shows that any change in the barrier height or carrier concentration shall lead to a change in the threshold voltage of the device. The data is listed in table 1 and it is found that the change in the barrier height is small but carrier concentration changes significantly on higher dose of irradiation as shown in fig 5. The 2DEG (two dimensional electron gas) concentration has been calculated and it is shown in table 2.

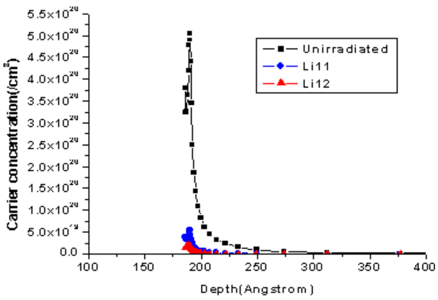

Figure 5 :. Carrier concentration vs. depth comparison

Table 2: Change in 2DEG

HEMT device type	Calculated $2DEG/cm^2$
Unirradiated	5.8e13
Irradiated with $5e11/cm^2$	5.6e12
Irradiated with $5e12/cm^2$	4.6e12

Thus the observed change in the threshold voltage on the irradiation of the device seems to be due to the change of the carrier concentration of the device on the irradiation. This change is attributed to irradiation induced defect centers in the device which can trap the carriers to degrade the electrical characteristics for limiting the performance of the HEMT device.

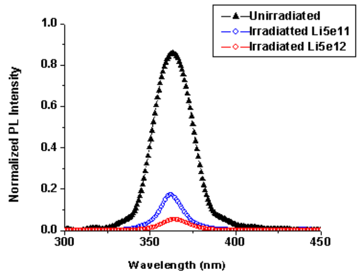

Figure 6.: Photoluminescence comparison of unirradiated vs. Li irradiated samples

The near band edge transition PL (photoluminescence) spectra comparison, for before and after the irradiation, revealed the quenching of the PL intensity with the increased fluence of Li ions. For 5e11/cm^2 fluence of the irradiation, an 80% decrease has been observed while more than 90 % quenching was observed for Li 5e12/cm^2 dose (fig 6). This may be because of creation of non-radiative centres in the material which leads to the quenching of optical intensity and thus degrading the optical characteristics of the material.

IV. CONCLUSIONS

The Li ion irradiation study of 5e11/cm^2 and 5e12/cm^2 doses has been carried out on AlGaN/GaN heterostructure HEMT device. The structural, electrical and optical characteristics have been compared before and after the irradiation. It has been found that there is no change in the crystalline quality of the material on the irradiation but there is degradation in the electrical and the optical characteristics for the irradiated fluences of the Li ions. A reduction in the carrier concentration and a shift in the threshold voltage of the device have been observed, showing the degradation of the device. The optical quenching has been observed as found by the photoluminescence study. The observed degradation has been understood in the realm of irradiation induced defects.

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