Micro Raman Spectroscopy of Annealed Erbium implanted GaN

Agam Prakash Vajpeyi[1], Soo Jin Chua[1,3], Eugene Fitzgerald[1,4] and S.Tripathy[2]

[1] AMM&NS, Singapore-MIT Alliance, 4 Engineering Drive 3, Singapore 117576
[2] Institute of Material Research and Engineering, 3 Research Link, Singapore 117602
[3] Department of Electrical and Computer Engineering, NUS, 4 Engineering Drive 3, Singapore 117576
[4] Department of Material Science and Engineering, MIT, Cambridge, Massachusetts, USA 02139

Abstract— **Wurtzite GaN epilayers grown by metal organic chemical vapor deposition on sapphire substrates were subsequently ion implanted with Er to a dose of 5×10^{15} cm^{-2}. The implanted samples were annealed in nitrogen atmosphere at different temperatures to facilitate recovery from implantation related damage. In this paper we report the annealing behavior of Erbium implanted GaN by using micro Raman spectroscopy and optimized annealing condition. We have observed almost full damage recovery of the crystalline quality of Er implanted GaN after annealing at 1000^{0}C for 2 minute. This observation is further confirmed by using AFM images.**

Index Terms—**Annealing, Damage recovery, Erbium implantation, , Raman spectroscopy.**

I. INTRODUCTION

GaN and other III- Nitrides are promising material for optoelectronic applications. III-Nitride semiconductors extend the field of application from visible to UV region due to their wide band gap. These III-Nitrides have attracted considerable attention also due to their application in high temperature and high power devices. The thermal, chemical, and mechanical stability of III-Nitrides make them a desirable material for fabrication of optoelectronic devices [1]. These III-Nitrides are successfully used for blue/green lasers diodes and light emitting diodes [2-4]. Rare earth implantation in GaN film offers alternate way to produce full color flat panel display. Wilson et al [5] reported the first observation of optical emission from Er ions implanted GaN films grown on GaAs and on sapphire substrate.
In this paper we report the annealing behavior of Er implanted GaN using Raman spectroscopy

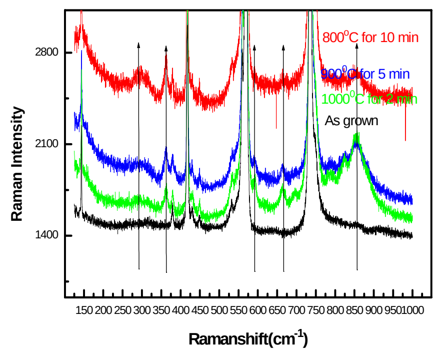
Agam.P.Vajpeyi is PhD student under Singapore-MIT Alliance, Advanced Materials for Micro- and Nano-Systems Programme, 4 Engineering Drive 3, Singapore 117576 (e-mail: smap1031@nus.edu.sg).
Dr. S. Tripathy is with Institute of Material Research and Engineering, 3 Research Link, Singapore 117602
Soo Jin Chua is with National University of Singapore. He is now with the Department of Electrical and Computer Engineering, National University of Singapore, 4 Engineering Drive 3, Singapore 117576 (e-mail: elecsj@nus.edu.sg).
Eugene Fitzgerald is with the Department of Material Science and Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts, USA 02139 (e-mail: eafitz@mit.edu).

II. EXPERIMENT:

Micro Raman spectra are recorded at room temperature from the top surface of as-implanted and annealed Er implanted undoped GaN film in backscattering Z(X, X)-Z geometry with z direction along the c axis. The 514 nm line of a Ar^+ laser is used as an excitation source and spectral resolution of the Raman set-up is 0.2cm^{-1}. The GaN film investigated in this study is 2μm thick deposited on sapphire substrate by metal organic chemical vapor deposition and implanted with a dose of 5×10^{15} cm^{-2}. Er is implanted with a 200 keV energy beam. The samples are annealed at 800^{0}C, 900^{0}C and 1000^{0}C in a nitrogen atmosphere for 10 min, 5 min and 2 minute respectively.

III. RESULTS AND DISCUSSION:

Raman scattering is an inelastic scattering which provides information on the vibrational states of a crystal or a semiconductor. It tracks noninvasively the crystalline quality, the stress, and the free carrier concentration in the sample. The E_2 phonon line width can be used to monitor the crystalline quality of the GaN film, while its frequency can be used to monitor the stress [6].



We present the Raman spectra of as grown and Er implanted annealed GaN films .

Raman peaks are observed in Fig 1. at the following wave numbers = 300 cm^{-1}, 362 cm^{-1}, 380 cm^{-1}, 418 cm^{-1}, 449 cm^{-1}, 533 cm^{-1}, 592 cm^{-1}, 663 cm^{-1}, 735 cm^{-1}, 824 cm^{-1} and 850 cm^{-1}. The broad band at 300 cm^{-1} is attributed to the amorphous component [7]. Since implantation results in high defect density, the wave vector conservation in the Raman scattering process can break down and phonons from the entire Brillouin zone can be observed under such a condition. Thus Raman spectra reflect the total phonon density of states. The phenomenon is called disorder activated Raman scattering. The peak at 362 cm^{-1} may be due to vibration from vacancy mode as this peak is observed in Be implanted GaN and Zn implanted GaN as well [7]. The modes at 380 cm^{-1}, 418 cm^{-1} and 450 cm^{-1} are due to sapphire substrate. The peak at 663 cm^{-1} is due to zone boundary phonon mode which appears after annealing. The peak at 824 cm^{-1} and 854 cm^{-1} may be due to combinational modes. We observe a new peak at 592 cm^{-1} after implanting Erbium. The origin of this peak is not very clear but this peak may be due Er related mode. We did a theoretical calculation to show that 592 cm^{-1} is a combinational mode of Erbium. In calculating the Raman peaks due to Erbium implantation, we used the fact that Er substitutes Ga atom. This fact is confirmed by Rutherford back scattering (RBS) experiment and reported by several researchers [8]. When Er replaces Ga, new Raman peaks are observed due to the difference in mass and electro negativity. The calculation for the Raman peaks arising from Er implantation is shown below.

$$\omega = \sqrt{\frac{k}{m^*}}$$

Where ω = vibration frequency and κ is force constant.

$$m^*_{Er-N} = \frac{m_{Er} \times m_N}{m_{Er} + m_N} = 12.918 a.m.u$$

$$m^*_{Ga-N} = \frac{m_{Ga} \times m_N}{m_{Ga} + m_N} = 11.659 a.m.u$$

$r_{Ga\text{-}N}$ = 1.95 Å, $r_{Er\text{-}N}$ = 2.42 Å

$$F \propto \Delta\chi$$

Where F is vibration force and $\Delta\chi$ is difference in electro-negativity of two atoms.

$$\Delta\chi_{Er-N} = 3.1 - 1.1 = 2.0$$

$$\Delta\chi_{Gar-N} = 3.1 - 1.8 = 1.3$$

$$\frac{\omega_{Er-N}}{\omega_{Ga-N}} = \sqrt{\frac{m^*_{Ga-N} \times r_{Ga-N} \times \Delta\chi_{Er-N}}{m^*_{Er-N} \times r_{Er-N} \times \Delta\chi_{Ga-N}}}$$

$$\frac{\omega_{Er-N}}{\omega_{Ga-N}} = 1.05$$

$$E_2(low) = 1.05 \times 144 = 151.2 cm^{-1}$$

$$E_2(high) = 1.05 \times 569 = 597.4 cm^{-1}$$

$$A_1(TO) = 1.05 \times 533 = 559.6 cm^{-1}$$

$$A_1(LO) = 1.05 \times 735 = 771.7 cm^{-1}$$

$$E_1(TO) = 1.05 \times 561 = 589.1 cm^{-1}$$

$$E_1(LO) = 1.05 \times 743 = 780.2 cm^{-1}$$

Where 144 cm^{-1}, 569 cm^{-1}, 533 cm^{-1}, 735 cm^{-1}, 561 cm^{-1} and 743 cm^{-1} are standard phonon frequencies for GaN sample. Raman peak at 592 cm^{-1} is deducted to be a combinational mode of $E_1(TO)$ and $E_2(high)$.

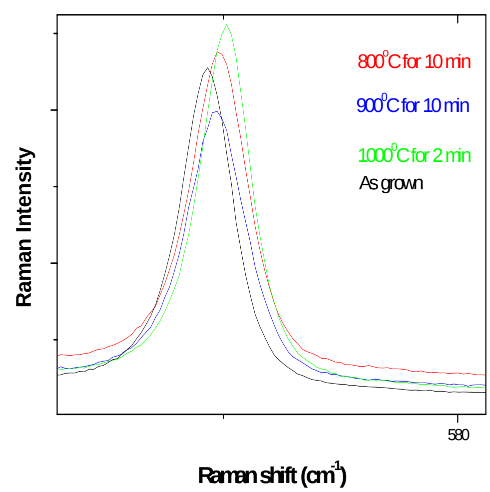


Fig 2. Effect of annealing on E_2 Intensity and Raman frequency shift.

Fig 2. shows the effect of annealing on the E_2 intensity and its frequency behavior. The optimum annealing condition for the Er implanted GaN sample the dose 5×10^{15} cm^{-2} is found to be 2 mins at 1000^{0}C. The E_2 peak shows the highest intensity at this condition.

This conclusion is further confirmed by observing the E_2 line width variation, under different annealing conditions, which is a measure of the crystalline quality of the sample. We show the E_2 line width variation with different annealing condition in Fig (3). The E_2 line width after 2 min annealing at 1000^{0}C is 2.45 cm^{-1}, while as-grown GaN has line width of 2.49 cm^{-1}. Therefore we can say annealing at 2 min for 1000^{0}C removes almost all the damage created by Er implantation and recovers the crystalline quality of the as-grown sample. The E_2 frequency shift is a measure of stress induced in the film. Since the E_2 frequency shifts towards higher wave number indicating that the film is getting compressively stressed.

The magnitude of compressive stress can be calculated from shift in E_2 frequency by using the following expression

$$\Delta\omega = K\,\sigma$$

Where K is linear stress coefficient and its value for GaN/sapphire system is 2.56 cm^{-1}/ GPa [9].

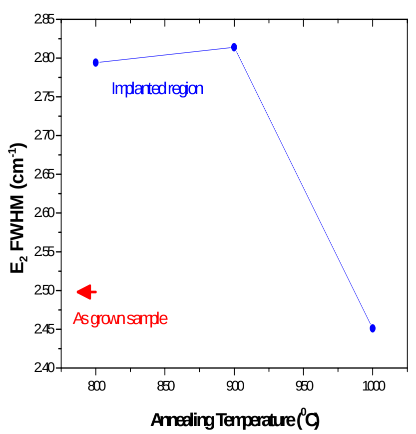


Fig 3.
Variation of E_2 line width with different annealing conditions annealed at 1000^{0}C for 2 minute.

The AFM picture of as grown, sample is shown below-

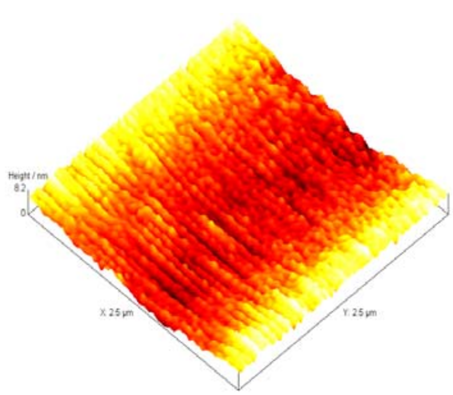


Fig 4. 3-D image of as-grown undoped GaN

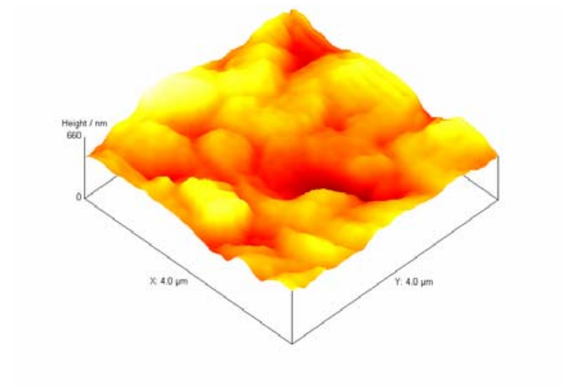


Fig 5. 3-D image of as-implanted undoped GaN

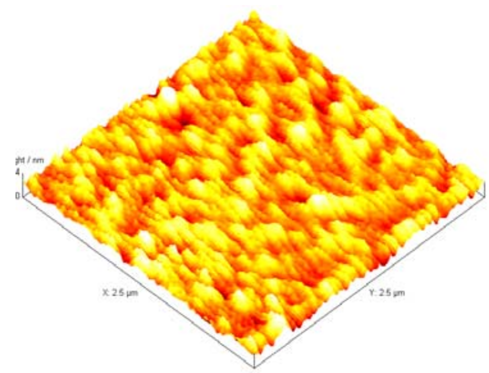


Fig 6. 3-D image of Er-implanted undoped GaN

Annealing temperature(C)	Annealing time(minute)	Surface-roughness(n m)
As grown	----------------------	1.46
As-implanted	----------------------	57.1
800	10	11.3
900	5	1.93
1000	2	1.76

Table 1. Comparison of surface roughness under different annealing conditions

From this Table, it is evident that the as-grown sample has a surface roughness of 1.46nm. After implantation the surface becomes very rough due to implantation damage. To remove implantation damage post implantation annealing is required. After annealing at 1000C for 2 minuts surface is smooth again and surface roughness is 1.76nm which is very close to the as -grown sample.

In summary we have reported optimum annealing condition for Er implanted undoped GaN by using Raman spectroscopy and this observation is further confirmed by AFM images

IV. References:

1. M. Rubin, N. Newman, J. S .Chan, T .C .Fu and J. T. Ross, Appl. Phys. Lett. 64, pp. 64-66, (1994).

2. S. Nakamura, T. Mukai, and M. Senoh, Appl. Phys. Lett. 64, pp. 1687-1689, (1994).

3. S. Nakamura, T. Mukai, and M. Senoh, Jpn. J. Appl. Phys. 30, pp. 1998-2001, (1991).

4. S. Nakamura, M. Senoh, S. Magahama, N. Iwasa, T. Yamada, T. Matsushita, H. Kiooku, and Y. Sugimoto, Jpn. J. Appl. Phys. Lett. 74, pp. 1998-2000, (1996).

5. R. G. Wilson, R. N. Schwartz, C. R. Abernathy, S. J. Pearton, N. Newman, M. Rubin, T. Fu, and J. M. Zavada, Appl. Phys. Lett. 65, pp. 992-994, (1994)

6. M. Kuball, Surf. Interface anal. 31, pp. 987-999, (2001)

7. W. Limmer, W. Ritter, R. Sauer, B. Mensching, C. Lu, and B. Rauschenbach, Appl. Phys. Lett. 72, pp. 2589-2591, (1998)

8. E.Alves, M.F.Dasilva, J.C.Soares, J.Bartels, R.Vianden, C.R.Abernathy, and S.J.Pearton, MRS Internet J.Nitride Semicond. Res., 4S1, G11.2 (1999)

9. J. M. Wagner and F. Bechstedt, Appl. Phys. Lett. 77, pp. 346-348, (2000)