3 - 39 Damage to Epitaxial GaN Layer by $^{238}U^{32+}$-irradiation

Zhang Liqing, Zhang Chonghong, Gou Jie, Yang Yitao, Song Yin, Li Jianjian
Meng Yancheng, Ma Yizhun and Zhang Hengqing

GaN-based materials have a great potential used in high-temperature, high-power and high frequency electronic devices such as transistors, solid-state light sources and detectors etc. With the development of space technology, these devices are widely used to radiation environments. Devices are suffered from both particle and electromagnetic radiation, such as proton, electron, alpha particles, neutron, gamma ray, SHI, and so on. The optical and structural properties of the material can be modified with high energy ion beam radiation. The study of damage induced by SHI from the device fabrication and performance is very important though GaN is immune to various environments. Kucheyev, et al. have reported the nano-track formation in GaN by 190 MeV Au ions irradiation. V. Suresh Kumar, et al. have reported the formation of Ga_2O_3 and smoothening takes place on the GaN surface irradiated with MeV light ions of lithium and heavy ions of Silver and Gold. Reurings, et al. [1] have reported radiation induced defects in InN and GaN studied with positron annihilation and found that Ga vacancies are found and to recover in the annealing process. In recent years, It is reported that GaN layers were irradiated with 100 MeV silver and oxygen ions, 70 MeV nitrogen ions, 75 MeV tin ions, 80 MeV Si ions and 100 MeV Ni^{9+} [2] at room temperature and 70 MeV Si^{5+} [3] at liquid nitrogen temperature (77 K) to study the changes in the structural, optical and electrical properties due to irradiation damage. In this investigation, we present the surface morphology, structural change and optical properties of GaN epilayer irradiated by 290 MeV U^{32+} at room temperature using atomic force microscopy (AFM) and photoluminescence spectroscopy.

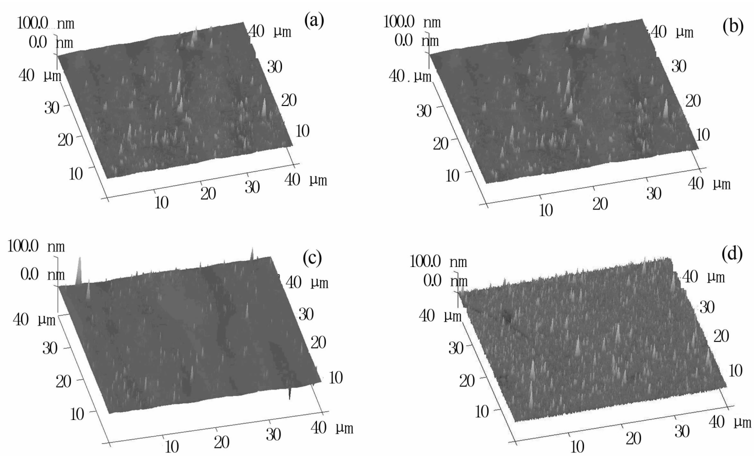

Fig. 1 Typical 3D AFM images of GaN irradiated by 290 MeV U^{32+} ions at different fluence.

Fig. 1 shows the typical 40×40 μm^2 3D AFM images of the pristine and the irradiated GaN samples. Image (a)~(d) is for Pristine, 1.0×10^9, 5.0×10^{10} and 1.0×10^{12} ions/cm^2 irradiation, respectively. As seen from Fig 1(a), the pristine GaN surface is not smooth, and some hillock-like defects on the sample surface can be observed. After irradiated with low fluence (1.0×10^9 ions/cm^2), the sample surface becomes flat, original defects disappear and wide terrace was formed as shown in Fig. 1(b). It is clear from the Fig. 1(c) that the hillocks of nano-dimensions appear on the sample surface and surface roughness increase obviously with an increase in ion fluence. For the highest fluence (1.0×10^{12} ions /cm^2), the irradiated GaN surface was covered with a large number of nano-hillocks, and the original GaN surface can not be seen. Moreover, the hillocks' height and diameter increase dramatically, shown as in Fig 1(d).

The RMS roughness of the pristine and irradiated sample is 12.1 nm, 9.26 nm (1.0×10^9), 9.3 nm (1.0×10^{10}), 10.5 nm (5.0×10^{10}), 14 nm (1.0×10^{11}), 27.6 nm (5.0×10^{11}), 36.1 nm (1.0×10^{12}), respectively, shown as in Fig. 2. It is interesting to note that the surface roughness for the samples irradiated with the fluence of 1×10^{10} has not been altered compared with 1.0×10^9 ions/cm^2, which may be attributed to the nano-hillocks formation. It eliminates the original surface defects and compensates the surface roughness. The changes in surface morphology were created due to electronic energy transfer and the deposition of large kinetic energy by the irradiated ions instantaneously on the GaN surface[4]. According to SRIM 2006 code, the electron energy loss of 290 MeV U^{32+} in GaN is $dE/dx = 408.8$ eV/nm[5]. The potential energy of U^{32+} is 500.11 keV[6]. There are 8.77×10^{22} ions/cm^3 for GaN, for so large electronic energy loss of the ion, a cylindrical zone of the order of several nanometers in diameter will form along the ions path, with high atomic mobility and reduced density. Therefore the irradiated region may be strikingly different from the pristine. This effect of the high temperature and high pressure on the surrounding material and also on the direct modification of the material in the track itself can create new potential gradients, which then act as a driving force for further modification and create nano-structures during ion irradiations[6]. That is, swift heavy ions initially transfer their energy to the electronic system of the target, leading to a localized region of high electronic excitation. This electronic excitation is subsequently transferred to the lattice atoms by electron phonon coupling, leading to pronounced lattice heating. The formation of surface hillocks can then be ascribed to a melting process[7].

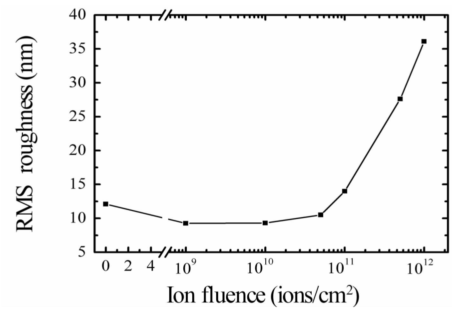

Fig. 2 RMS roughness of GaN epi-layer irradiated by 290 MeV U^{32+} as a function of ion fluence.

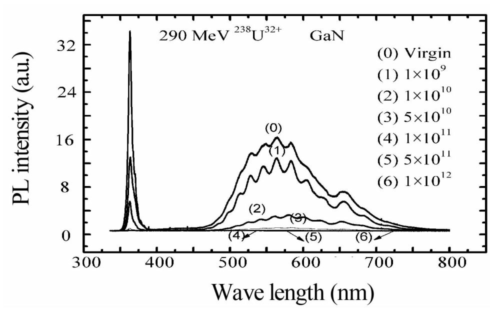

Fig. 3 PL spectra of the GaN irradiated by U^{32+} ions with different fluence at room temperature.

Fig. 3 shows the photoluminescence spectrum of the pristine and the irradiated GaN samples. Near band edge emission (NBE) occurs at 363 nm (3.413 eV) for pristine GaN epilayer. After irradiation, the NBE blue shifts to the 362 nm (3.422 eV) and broadens with an increase of ions fluence, which indicates the irradiated GaN epilayer experience the compressive strain[8]. This may be attributed to the formation of nano-hillocks as evident in the AFM images shown in Fig. 1(a～d) and subsequent defects evolution induced by ion irradiation. Broad yellow luminescence band emission (YL) was observed from 463 nm to 725 nm with centered at 563 nm (2.2 eV). After irradiation, the intensity of the NBE and the YL decrease evidently with increasing of ion fluence and finally they are completely quenched for higher fluence due to the defects act as "carrier killer"[9].

References

[1] F. Reurings, F. Tuomisto, W. Egger, et al., Phys. Status Solidi., A207(2010)1087.
[2] V. SureshKumar, J. Kumar, P. Puviarasu, et al., Physica, B406(2011)4210.
[3] S. Suresh, V. Ganesh, U. P. Deshpande, et al., J Mater Sci., 46(2011)1015.
[4] S. O. Kucheyev, H. Timmers, J. Zou, et al., J. Appl. Phys., 95(2004)3048.
[5] J. F. Ziegler, J. P. Biersack, U. Littmark, The Stopping and Range of Ions in Matter, Pergamon, New York, 1985.
[6] B. R. Gossick, J Appl Phys., 30(1959)1214.
[7] A. S. El-Said, R. A. Wilhelm, R. Heller, et al., Nucl. Instr. and Meth., B296(2011)1234.
[8] W. Rieger, T. Metzger, H. Angerer, et al., Appl. Phys. Lett., 68(1996)970.
[9] X. L. Xun, The University of Hong Kong, (1999)108.