3 - 40 Influence of Highly Charged $^{209}Bi^{33+}$ Irradiation on Stress Accumulation in GaN Epi-layer

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While a HCI impact on solid surface, the high density of electronic excitation produced by potential energy release of HCI is comparable to that produced by high power laser pulses or swift heavy ion. However, its potential energy deposition was confined in a nanometer-sized volume close to the surface and occurs on a femtosecond time scale, which can leads to nano-structure deformation in various materials, such as hillocks (LiF, CaF_2, mica, HOPG,)[1,2], pits (KBr, BaF_2)[3], craters (Si (1 1 1)(7 - 7))[4], caldera like structures (TiO_2(1 1 0)) and ripples (Si). Furthermore, the potential energy conversion may result in permanent local changes of the electronic structure or changes in the topography of semiconducting materials (Si and GaAs). The potential energy is released mainly in electronic exchange interaction, some permanent damages and defects are produced on the surface. Correspondingly, HCIs have been proposed as a tool for surface modifications and analysis on the nanometer scale. Recently, we found highly charged ions can induce nanometer scale deformation on GaN surface and Ga-rich damage layer was generated. In order to gain a better understanding of the creation mechanism for HCI-induced GaN surface modifications, in this work, we study stress properties of GaN layer irradiated by highly charged $^{209}Bi^{33+}$ ions using Raman scattering spectroscopy.

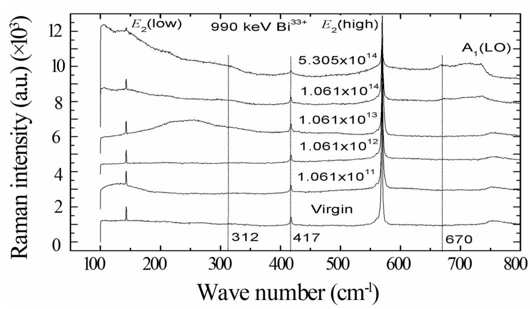

Fig. 1 Raman spectra of GaN after 990 keV Bi^{33+} irradiation at room temperature at different fluences, indicated in units of cm^{-1}.

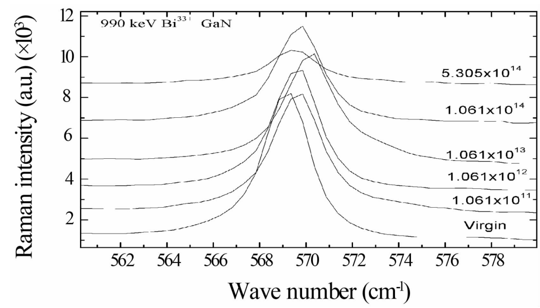

Fig. 2 E_2(high) phonon band of GaN after 990 keV Bi^{33+} irradiation at room temperature at different fluences, indicated in units of cm^{-1}.

The room temperature Raman scattering spectra of the GaN epilayer irradiated with 990 keV Bi^{33+} at different fluences and un-irradiated GaN epilayer are displayed in Fig. 1. In the spectrum of all the samples, the peak at 417 cm^{-1} comes from sapphire substrate. The peak at 144, 570, 740 cm^{-1} are the first-order phonon frequencies of E_2(low), E_2(high) and A_1(LO), respectively. The strong E_2(high) phonon line reflects the characteristics of the hexagonal crystal phase, even though GaN epilayer irradiated with highest fluence (5.305×10^{14}).

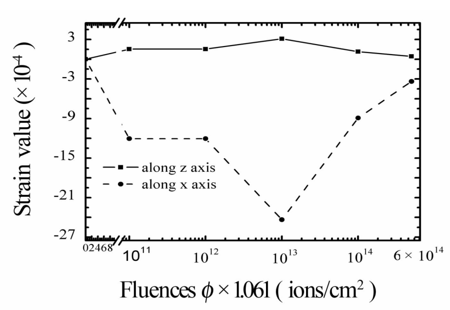

Fig. 3 Strain values as a function of fluences along the z and x axis, respectively. Positive donates the compressive stress, while negative donates the tensile stress.

After irradiation with successive increasing fluence, the strain-related E_2(high) phonon band is redshifted and broadens in full width half maxium (FWHM) gradually, shown as in Fig. 2 and Fig. 1. Which indicates Ga is rich and N is deficient in the irradiated samples. The A_1(LO) phonon band is blueshifted and broadens with asymmetric line shape. This effect is similar to that observed in implanted GaAs, where downward frequency shifts of the LO phonon were explained by a reduction of the ionic plasma frequency (i. e. the LO TO splitting) due to the interstitials and antisites introduced by the ion bombardment. This effect is obvious in GaN because it has a much higher TO LO splitting. Strains introduced by the implantation may also account for part of the frequency shifts. The enhancement and broadening of the A_1(LO) bands from highest fluence irradiated sample (5.305×10^{14}) can be attributed to a disorder induced by increasing Ga content. It cannot be ruled out that this band has an important contribution from the B_1 silent mode. Similar results have been reported in disordered III-nitride samples in other literatures. Moreover, two new broad bands appear located at ~312 and ~670 cm^{-1} with an increase of fluence. The broad band at 312 cm^{-1} has been observed in previous works[5, 6] and has been attributed to a disorder-activated acoustic mode reflecting the phonon density of states in this frequency region[7]. The broad band near 670 cm^{-1} is related to vacancy-related defects[5].

The strains could also play an important role in the shift of Raman scattering band. It is known that E_2(high) phonon band toward a higher frequency can be correlated with the increase of the lattice constant c. The observed E_2(high) mode shift indicates the presence of compressive or tensile stress due to radiation damage to lattices. Kozawa et al. and Katsikini et al. reported the following relationship between the frequency shift ($\Delta\omega$ in cm^{-1}) and biaxial stress (σ in GPa) for GaN films[8, 9].

$$\Delta\omega = 6.2\sigma$$

Where 6.2 is the pressure coefficient, σ denotes the stress expressed in Gpa. With Hook's law, $\sigma=\varepsilon_{zz}E/\nu$, the relation can be written as $\sigma=526.3\ \varepsilon_{zz}$. For this, the bulk modulus E and the Poisson ratio ν are taken as 200 GPa and 0.38, respectively. The strain value along the z- and x-axis are

$$\varepsilon_{zz} = \frac{\Delta\omega(E_2)}{3263.2},\ \varepsilon_{xx} = \frac{C_{33}}{2C_{13}}\varepsilon_{zz}$$

Where C_{13} and C_{33} are the shear elastic constants of bulk GaN ($C_{13}=103$ and $C_{33}=405$ GPa).

For the irradiated GaN samples with different fluences, the strain value along the z- and x-axis is shown in Fig. 3. The irradiated GaN samples experience compressive stress along the z axis (//c), and undergo the tensile stress along the x axis ($\perp$c). Moreover, the tensile stress is larger than the compressive stress at the same influence due to biaxial compressive (z and y) and uniaxial tensile stress (x). With the increase of the fluences, the stress first increase and then decrease, at the 1.061×10^{13} ions/cm^2, the stress is up to the largest. This maybe infers the separation of the neighboring lattices planes along the z direction and generation of dislocations.

References

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