doi: 10.1017/S1431927609092046
Microsc Microanal 15(Suppl 2), 2009

Microstructure of ion-irradiated GaN and its thermal evolution

In-Tae Bae,* Weilin Jiang,** Yanwen Zhang,** William J. Weber,** and Chongmin Wang**

**The Small Scale Systems Integration and Packaging Center, The State University of New York at Binghamton, P.O. Box 6000, Binghamton, 13902, USA*
***Pacific Northwest National Laboratory, P.O. Box 999, Richland, Washington 99352, USA*

Gallium nitride (GaN) is an important wide bandgap semiconductor for application in advanced optoelectronic and microelectronic devices [1]. For device fabrication purposes, ion bombardment is a crucial processing technique for several technological steps, such as spatially selective n-type and p-type doping, dry etching, electrical isolation, quantum well intermixing, and ion cutting [2-4]. Since the ion implantation technique inevitably produces lattice disorder that deteriorates device performance, post-implantation annealing is usually adopted in the semiconductor manufacturing industry. It is also known that the upper limit on the practical implantation dose is generally determined by the onset of amorphization and the impurity solubility level for compound semiconductors [5]. Thus, the study of high-dose irradiation-induced damage and its thermal annealing behavior in GaN is not only important to understand fundamental defect evolution behavior in solids, but also essential for GaN device fabrication.

In this study, detailed microstructural features and atomistic volume expansion in Au-irradiated GaN at 150 K are characterized, and their evolution during thermal annealing are investigated using transmission electron microscopy (TEM) and electron energy loss spectroscopy (EELS).

A single crystalline (0001) GaN film grown on sapphire was irradiated 60° off the surface normal with 2 MeV Au^{2+} ions to a fluence of 3.3×10^{15} cm^{-2} at 150 K. Thermal annealing of the irradiated sample was performed at 973 K for 1 h using a vacuum furnace. Cross-sectional samples for TEM analysis were prepared by a combination of mechanical polishing and Ar ion milling. TEM analysis was performed using a JEOL JEM-2010 electron microscope operated at 200 keV. For elemental and structural analyses of nano-sized local area, nano-beam energy dispersive spectroscopy (NBEDS) and nano-beam electron diffraction (NBED) techniques were employed with probe sizes ranging from ~10 nm to ~20 nm in diameter. EELS measurements were performed using a Gatan Imaging Filter 2000.

For the 2 MeV Au-irradiated GaN sample at 150 K, electron diffraction and BF TEM images indicate that a ~305 nm thick amorphous layer with nitrogen bubbles is formed as a result of the irradiation. Detailed investigation using high-resolution TEM (FIG. 1) and NBED analyses combined with structure factor simulations reveals that Ga nanocrystals with the diamond structure, which is not the naturally occurring stable configuration for Ga, are embedded in the amorphous layer. Chemical disorder induced by Au^{2+} irradiation at cryogenic temperature is proposed as a possible mechanism for the Ga nanocrystal formation. During thermal annealing at 973 K, partial recrystallization of the amorphous material occurs. In addition, NBED analyses combined with structure factor simulations indicates that the Ga nanocrystals transform to a mixture of cubic and hexagonal GaN by reacting with nitrogen or nitrogen molecules released by the collapse of the nitrogen bubbles. The shifts in the GaN plasmon loss peaks measured by EELS (FIG. 2) suggest that the atomic-level volume expansion of the amorphous state after irradiation is ~18.9 %. After thermal annealing, this atomic-level volume expansion decreases to 7.7 %. Partial recrystallization and structural relaxation in the remaining amorphous GaN are proposed as possible mechanisms for the densification observed after the thermal annealing [6].

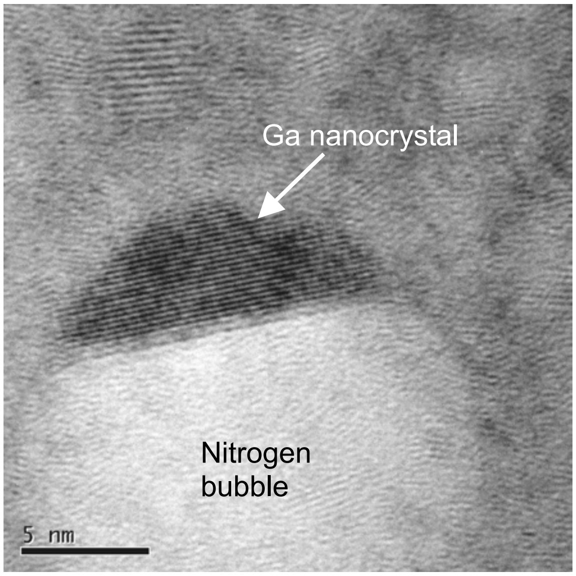

FIG.. 1 High-resolution TEM image showing a Ga nanocrystal located next to a nitrogen bubble.

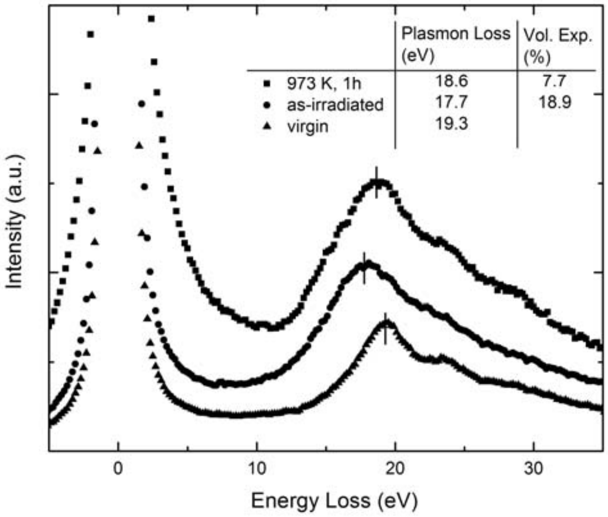

FIG. 2 Low energy loss spectra obtained from the virgin, as-irradiated, and annealed samples using EELS, showing a volume expansion of 18.9% after Au-irradiation and 7.7 % after subsequent annealing at 973 K.

References

---

[1] S. J. Pearton et al., *J. Appl. Phys.* 86, (1999) 1.
[2] S. O. Kucheyev et al., *Mater. Sci. Eng. R* 33, (2001) 51.
[3] C. M. Wang et al., *J. Mater. Res.* 17, (2002) 2945.
[4] W .Jiang et al., *Appl. Phys. Lett.* 89, (2006) 021903.
[5] J. C. Zolper et al., *Appl. Phys. Lett.* 70, (1997) 2729.
[6] The financial support from Empire State Development program is gratefully acknowledged.