Accurate TEM analysis of electron beam induced defects in GaN combined with defect-eliminated specimen preparation technique

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Evaluation of density and nature of defects in compound semiconductors, gallium-nitride (GaN), gallium-arsenic (GaAs) and other materials in electric devices, is very important for development of high efficiency and reliable devices. [1] Especially, needs for actual device analysis, i.e., analysis of microscopical region of interest, are increased.
It has been difficult to make a thin and defect-free specimen foil of such compound materials by focused ion beam (FIB) technique for transmission electron microscopy (TEM), because the artifacts were induced by gallium ion beam irradiation as an amorphous layer, crystal defects, deposition of sputtered debris, etc. Therefore, detailed defect analysis of GaN crystal by TEM is troublesome since the distinction between the native and the induced defect by specimen preparation is difficult. Moreover, careful consideration of the electron beam induced damage is required. For example, “charge collecting microscopy” such as STEM-EBIC [2] is strongly required damage-free specimen foil and irradiation condition of electron beam, since the induced defect would be a recombination site like native defects.
We demonstrated appropriate damage-eliminated and ultra-thin specimen preparation by FIB with low-energy gallium ion beam. The total thickness of specimen foil was about 20 nm and the thickness of surface damage layer was less than 5 nm. TEM observation was performed by a field-emission TEM (Hitachi HF2000). Fig. 1a, 1b and 1c show high resolution images of different acceleration voltage conditions, 200, 150 and 100 kV, respectively. The FIG. 1c shows almost defect-free structure, whereas the 1a and 1b show defective structure, i.e., agglomeration of point defects like dislocation loops. The micrograph in Fig. 1a and 1b were recorded after few minutes irradiation. In contrast, irradiation of several tens of minutes under 100 kV condition induces no obvious crystal defects (Fig. 1c). Fig. 1c indicates that the above-mentioned specimen preparation technique effectively eliminates the introduction of crystal defects. On the other hand, Fig. 1a and 1b indicate that high-voltage electron beam easily induces point defects in GaN crystal. In other words, threshold voltage of the introduction of knock on damage in GaN is between 100 and 150 kV at room temperature.
In conclusion, we demonstrated defect-eliminated specimen preparation for GaN based crystal by FIB, which enables us to evaluate accurate defect analysis for actual devices. Furthermore, analysis of threshold voltage for the formation of Frenkel defect based dislocation loops can be accurately performed by using defect-eliminated TEM specimen foils, which is effective for the determination of appropriate experimental conditions for STEM-EBIC and/or other precise analyses. Detailed threshold voltage of GaN crystal will be discussed.

References

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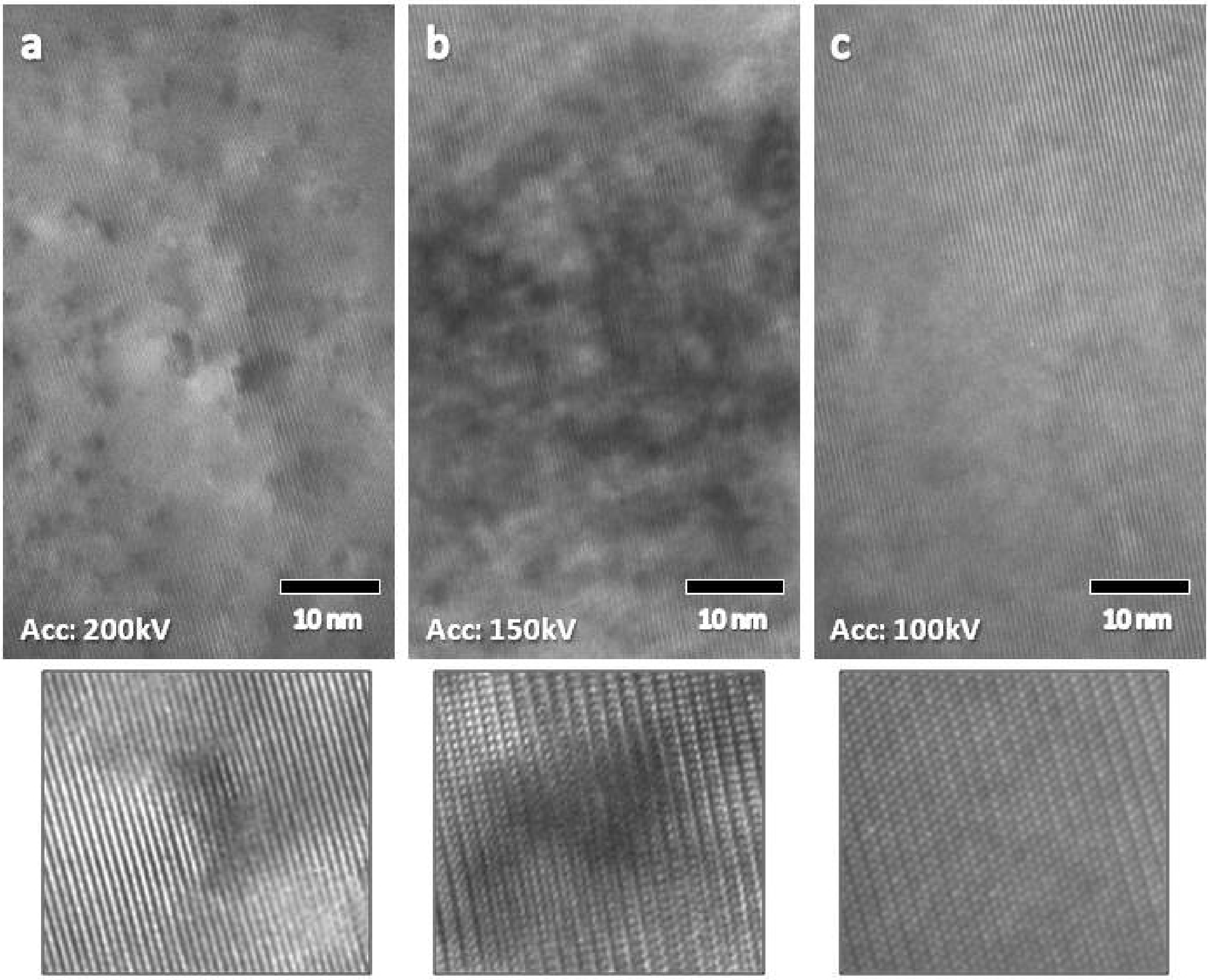

FIG. 1 TEM observed images. a) High resolution image of GaN crystal of actual device at 200 kV. b) High resolution image at 150 kV. c) High resolution image at 100kV. In this condition, defects were not appeared for several tens of minutes.