PHOTOEMISSION STUDY OF GATE DIELECTRICS ON GALLIUM NITRIDE

Seiichi Miyazaki, Graduate School of Engineering, Nagoya University
miyazaki@nuee.nagoya-u.ac.jp
Nguyen Xuan Truyen and Akio Ohta, Graduate School of Engineering, Nagoya University

Key Words: photoemission, GaN, defects, dielectric function, energy band alignment

In the development of gallium nitride (GaN) power devices, gate dielectric technology on GaN is of great importance and includes major scientific and technological issues to be solved for required device performance and reliability[1]. In particular, characterization of electronic defects in dielectrics and at their interfaces with GaN as well as energy band profiles has been imperative to gain a better understanding of physics of dielectrics/GaN heterostructures. In this work, we have demonstrated how useful the analysis of energy loss signals of photoelectrons [2] is to characterize dielectric functions of dielectrics on GaN and how powerful photoelectron electron yield spectroscopy [3] is to quantify the energy distribution of electronic defect states in dielectric/GaN heterostructures.

After wet-chemical cleaning of a GaN epitaxial layer with an Si concentration of $1.5x10^{16}cm^{-3}$ on sapphire (0001) and subsequent dipping in a 4.5% HF solution, as a representative dielectric, SiO_2 layers in the thickness range of 5-50nm were deposited at 500 ºC by remote plasma CVD, in which the decomposition of SiH_4 was induced by remote plasma of Ar/O_2 gas mixture to suppress ion dimages. AFM images confirm uniform depositon of SiO_2 on GaN. In XPS measurements using monochromitzed AlKa radiation, Ga3d and N1s spectra from ~5nm-thick SiO_2/GaN show no detectable interfacial oxidation and no change in stoikiometry near the SiO_2/GaN interface. Also, in Si2p, O1s and valence band spectra from deposited SiO_2, no difference from thermally-grown SiO_2 was detectable. From the analysis of valence band spectrum taken for the ~5nm-thick SiO_2/GaN, the valence band offset was determined to be 2.2 eV, from which the conduction band offsetwas derived to be 3.35eV in consideration of energy bandgap values of GaN and SiO_2. The energy bandgap of deposited SiO_2 was directly measured to be 8.95eV within an accracy of 50meV, being identical to the value measured for thermally-grown SiO_2, from the onset energy of energy loss signals of O1s photoelectrons.

For further information about electronic structures, taking into acount the relationship among energy loss spectrum, dielectric function and optical constants (n and k values) and using Kramers-Kronig relations for the real and imaginary parts of complex functions such as dielectric function and refractive index, elaborately measured energy loss signals of O1s and Si2p3/2 photoeelectrons were convered into the dielectric finction below ~30eV, in which the contribution of surface plasmon into the measured energy loss signals was first eliminated by difference signals between the cases taken at photoelectron take-off angles of 15 and 30º. As a result, peaks in k values corresponding to characteristic transitions including excitonic transition reported in SiO_2 glass were discerned.

For quantification of electronic defects in SiO_2/GaN heterostructures without additional process steps, photoelectron yield spectra in the incident photon energy region of 3 -10eV, in which Xe arc and high brightness D_2 lamps were used as light sources, were measured at each step of SiO_2 thinning in a dilute HF solution. Occupied states located in energy region deeper than the conduction band edge of GaN were clearly detected although photoemissions from the GaN valence band became significant in the photon energy region over ~7eV with progressive SiO_2 thinning. When measured photoelectron yield spectra were normalized with the yield from mainly from the GaN valence band for photons over ~9eV, almost no change in the yield due to defects was detectable until the SiO_2 thickness was reduced down to ~1.5nm. With further SiO_2 thinning, a marked decrease in the yield for defects was observed. The results indicates occupied defect states are located within ~1.5nm from the SiO_2/GaN interface. Since the energy derivatives of the measured yield spectra lead us to energy distribution of occupied defect state density in consideration of density of states of the GaN valence band, measured photoelectron yield from the GaN valence band and photoelectron escape depth. As a result, occupied states as many as $\sim 3x10^{11}$ $cm^{-2}eV^{-1}$ were detected even at the energy corresponding to the midgap of GaN near the SiO_2/GaN interface.

Acknowledgements
This work was supported in part by NEDO through a co-operative research with AIST. Authors wish to thank Assoc. Prof. K. Makihara and Dr. M. Ikeda for their supports about sample characterization and Prof. Amano's Laboratory, Nagoya Univ. for the preparation of epitaxial GaN on sapphire substrate.

References

[1] Z. Yatabe et al., J. Phys. D: Appl. Phys. 49 (2016) 393001. [2] T. Yamamoto et al., ECS Trans. vol.75, No.8 (2016) 777. [3] S. Miyazaki et al., Microelectro. Eng., 48 (1999) 63.