$GaN/Gd_2O_3/GaN$ Single Crystal Heterostructure (Invited)

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It is fascinating to study the epitaxy of two dissimilar materials and to explore new applications and novel physical phenomena built on such heterostructures. The attainment of single crystal oxides epitaxially grown on semiconductors has been previously reported. Although it is more difficult to achieve good epitaxial growth of semiconductors on oxides, a notable example was found in the growth of single crystal GaN on sapphire. Rare earth oxides are among a group of oxides, which earlier were found to grow epitaxially on GaAs and Si. These oxides recently have attracted a lot of attention because of applications on passivating semiconductor surfaces. In the area of III-V compound semiconductors, deposition of Gd_2O_3 films on clean GaAs surfaces in UHV has produced a low interfacial density of states (D_{it}). This is essential in making metal oxide semiconductor field effect transistors (MOSFET's) with inversion in GaAs and its related compounds. Y_2O_3, Gd_2O_3, and Pr oxides on Si give low electrical leakage currents, a low D_{it}, and high dielectric constants, important aspects for replacing SiO_2 as gate dielectrics for Si-based transistors.

In this work, not only single crystal rare earth oxide films (Gd_2O_3) were grown epitaxially on single crystal GaN films, but also single crystal GaN films were shown to overgrow epitaxially on the rare earth oxide films. The GaN films grown on sapphire (Al_2O_3) (0001) have a wurtzite hexagonal close-packed (hcp) structure. RHEED patterns of the UHV-annealed GaN show six-fold symmetry (Fig. 1 (a)), in which the pattern on the left was taken along the <100> azimuthal and the one on the right along the <110> direction, with a 30° separation. During the initial growth of Gd_2O_3 on GaN, streaky RHEED patterns with a six-fold symmetry were observed. The two major in-plane directions of the oxide (Fig. 1 (b)) are aligned with those of GaN. This is very different from the two- and four-fold symmetry pattern observed in the growth of Gd_2O_3 on GaAs. The same heterostructure has also been obtained with another rare earth oxide of Y_2O_3 replacing Gd_2O_3. The Gd_2O_3 films grown on the GaN were, unexpectedly, found to have an hcp structure. The GaN epilayers overgrown by MBE on the rare earth oxide films have a wurtzite hcp structure.

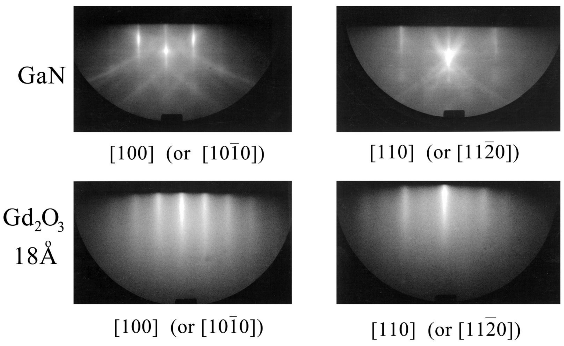

Fig. 1 (a) RHEED patterns of GaN surface and (b) RHEED of Gd_2O_3 film 18 Å thick deposited on GaN.

The XTEM micrographs (Fig.2) were taken using a [002] reflection, a condition used to reveal the screw and mixed dislocations in GaN layers. The bottom GaN layer shows a typical threading dislocation structure in a MBE grown GaN layer on sapphire substrate. However, growth of a thin Gd_2O_3 layer on such GaN layer is expected to terminate the threading dislocations due to a different crystal structure of Gd_2O_3. The distinct contrasts of the screw and mixed dislocations all terminate at the bottom interface of a thin Gd_2O_3 layer. Since the growth of the top GaN layer has to be re-initiated on the Gd_2O_3 surface, a different dislocation structure is expected to form. The wavy and tangle nature of the dislocation structure in the top GaN layer as seen in Fig. 2 does indicate a different nucleation process for GaN on Gd_2O_3.

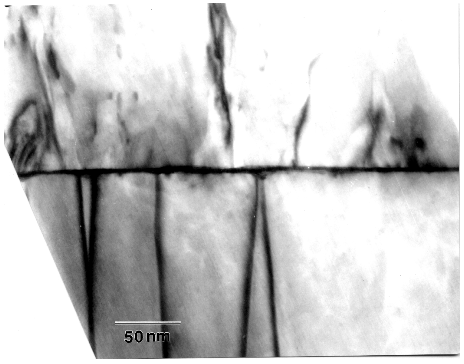

Fig. 2 XTEM showing the structure of $GaN/Gd_2O_3/GaN$.

It was unexpected that an hcp Gd_2O_3 single crystal would grow on GaN, considering that the hcp structure exists only at temperatures over 2000˚C. It was also surprised that the GaN single crystal would grow on the hcp rare earth oxides. In an ellipsometry study of hcp Gd_2O_3, a refractive index of 2.0-1.94 was measured in the wavelength range of 400-800 nm. The large refractive index difference between the rare earth oxide and GaN may find applications in photonic devices. We have also obtained a low D_{it} of $\sim 10^{11}$ $cm^{-2}eV^{-1}$ for the rare earth oxide/GaN interface. The attainment of a low interfacial density of states in the rare earth oxide single crystal thin films UHV-deposited on GaN may find applications in opto-electronic and electronic devices such as MOSFETs.