Low Temperature Growth of GaN on Sapphire by Remote Plasma Enhanced Metalorganic Chemical Vapor Deposition

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GaN and related III-V nitrides are the most promising materials for the optoelectronic applications in visible to ultraviolet spectral regions. Successful heteroepitaxial growth of the device-quality GaN on sapphire comes from two-step growth using low-temperature buffer layers [1,2]. The high interfacial energy between GaN and sapphire results in three dimensional growth behavior in its early stage, and it is believed that low-temperature buffer layers promote the two-dimensional growth of subsequent high-temperature GaN epilayers. The initial stages of nucleation and growth of the buffer layers is strongly affected by *in situ* nitridation steps. Recently, it was reported that the structural and optical properties of the buffer layers and the subsequent thick GaN epilayers were affected by initial nitridation of sapphire substrates [3-6].

In this study the nitridation of sapphire substrates and its effects on GaN buffer layer growth were studied in a remote plasma enhanced metalorganic chemical vapor deposition (RPE-MOCVD) system. Sapphire substrates were first cleaned *in situ* by hydrogen plasma at 100 W, 700 °C, and 0.2 Torr for half an hour. After the hydrogen plasma pretreatment a streaky reflection high energy electron diffraction (RHEED) pattern was observed. Some sapphire substrates were nitridated further by nitrogen plasma at 120W, 700 °C, and 0.5 Torr. Then, GaN buffer layers and subsequent GaN layers were grown at 500 °C and 750 °C, respectively. An AlN layer was formed on the sapphire substrate after nitridation by nitrogen plasma for an hour, as confirmed by *in situ* RHEED and X-ray photoelectron spectroscopy (XPS) analysis. The presence of the AlN layer affected the growth behavior of low-temperature GaN buffer layers, as shown in Fig. 1. Fig. 1(a) shows that a typical three-dimensional island growth with rough surfaces was prevalent when the substrate was not nitridated. However, the GaN buffer layer on the AlN layer formed by initial nitridation had a smooth surface and larger grain size, as shown in Fig. 1 (b).

Changes in surface morphology and growth behavior of the GaN buffer layers were studied in detail by cross section transmission electron microscopy (XTEM). It was observed that GaN grew on a non-nitridated sapphire in three-dimensional growth mode, as shown in Fig. 2 (a). Furthermore, some of the GaN islands were found to have different crystallographic orientations from that of the substrate, as shown in the selective area diffraction pattern (SADP) in Fig. 2 (a). On the other hand, GaN buffer layers grown on nitridated sapphire substrates had larger grains with flat top surfaces, suggesting that the two-dimensional growth was enhanced. The AlN layer formation by nitrogen plasma nitridation is believed to reduce the lattice mismatch and the chemical dissimilarity between sapphire substrates and GaN buffer layers. Furthermore, GaN islands on nitridated sapphire substrates were oriented in the same crystallographic orientation. The shape of the GaN islands on nitridated sapphire substrates was a truncated hexagonal pyramid similar to the shape reported for high-quality GaN epilayers grown by MOCVD at high temperatures (>1000 °C) [7,8]. The truncated hexagonal pyramid is known as an equilibrium shape in hexagonal crystal system when partially wetted. It is believed that the near-equilibrium shape of the low-temperature (500 °C) GaN results from the reduced interfacial energy by AlN formation and the increased surface diffusion of adatoms by the bombardment of energetic particles during RPE-MOCVD growth. Effects of nitridation parameters on the initial stages of nucleation and growth of GaN epilayers on sapphire will be presented in detail.

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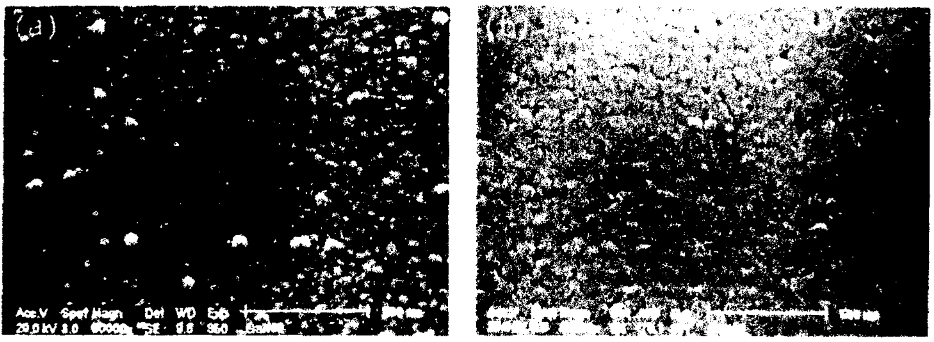

Fig. 1. SEM micrographs of 20 nm GaN buffer layers grown (a) on a non-nitridated sapphire substrate, and (b) on a nitridated sapphire substrate. Nitridation was made at 120W, 700 °C, and for an hour.

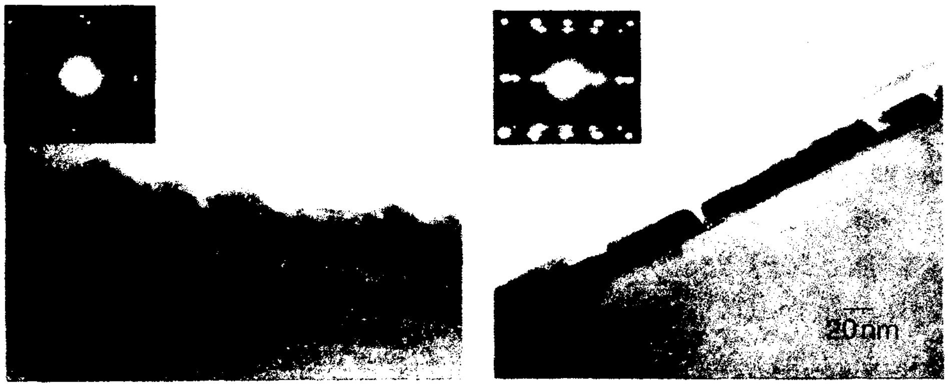

Fig. 2. XTEM micrographs and SADP of 20 nm GaN buffer layers (a) on a non-nitridated sapphire substrate and (b) on a nitridated sapphire substrate. Nitridation was made at 120W, 700 °C, and for an hour.