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Evolution of Threading Dislocations in GaN Films Grown on (111) Si Substrates with Various Buffer Layers

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Compared to commonly used sapphire and SiC, (111) Si offers several advantages as a substrate for Group-III nitride growth including high quality, low cost, large wafer size, and the potential integration of nitride devices with Si microelectronics. Therefore, growth of GaN on (111) Si is of great interest at the present time. In order to prevent the reaction between Ga and Si and improve the wetting properties of the film, a thin (~100 nm) AlN layer is often used as the buffer between the GaN film and the Si substrate. Due to the tensile coefficient of thermal expansion (CTE) mismatch stress and the additional tensile growth stress arising from island coalescence and lateral grain growth, cracks often form in thick (>~250 nm) GaN films grown on Si using thin AlN buffer layers. For example, a crack is evident in Fig. 1 (a), a bright-field cross-sectional transmission electron microscopy (TEM) image of a GaN/Si heterostructure with a thin AlN buffer layer. By using a compositionally graded $Al_{1-x}Ga_xN$ buffer layer instead of the AlN buffer, a compressive lattice mismatch stress can be induced to offset the tensile CTE mismatch stress and growth stress, thus suppressing the cracking [1-4]. In this work, the effects of $Al_{1-x}Ga_xN$ buffer layers and $Al_{1-x}Ga_xN$/GaN/AlN buffer combinations on the evolution of threading dislocations (TDs) in GaN films are studied.

Figure 1 (b) is a cross-sectional TEM image of a 500 nm GaN film grown on a 1 μm $Al_{1-x}Ga_xN$ buffer layer, collected under the multi-beam diffraction condition to reveal all types of TDs. It is evident that significant bending and annihilation of TDs occur in the top half of the $Al_{1-x}Ga_xN$ buffer layer. The TD densities of the GaN films were determined using plan-view TEM images collected from 10 different regions with a total area of ~20 μm^2. Figures 2 (a) and (b) are typical plan-view images for GaN films grown directly on thin AlN buffers and on $Al_{1-x}Ga_xN$ buffer layers, respectively. A reduced TD density of $(1.1\pm0.2)\times10^{10}$ cm^{-2} in GaN films grown on $Al_{1-x}Ga_xN$ buffer layers was achieved, in comparison with $(1.5\pm0.3)\times10^{10}$ cm^{-2} for those grown directly on AlN buffer layers. This TD density reduction is apparently due to the bending and annihilation of TDs in the compositionally graded $Al_{1-x}Ga_xN$ buffer layer shown in Fig. 1 (b).

Due to the high lattice mismatch (-19% for x=0 at the interface) between the $Al_{1-x}Ga_xN$ buffer layer and the Si substrate, the initial TD density in the $Al_{1-x}Ga_xN$ buffer layer near the $Al_{1-x}Ga_xN$/Si interface is very high. This is illustrated in Fig. 1 (b), where individual TDs cannot be distinguished near the buffer/Si interface. Reducing this initial TD density in the $Al_{1-x}Ga_xN$ buffer layer may further reduce the TD density in the overgrown GaN film. Thus, an AlN buffer and a GaN base layer were grown before the growth of the compositionally graded $Al_{1-x}Ga_xN$ buffer layer in order to reduce the lattice mismatch and the initial TD density in the $Al_{1-x}Ga_xN$ layer. Figure 1 (c) shows a cross-sectional TEM image of the $Al_{1-x}Ga_xN$/GaN/AlN buffer combination. Clearly, the initial TD density in the $Al_{1-x}Ga_xN$ buffer layer near the $Al_{1-x}Ga_xN$/GaN interface is significantly lower than that near the $Al_{1-x}Ga_xN$/Si interface shown in Fig. 1 (b), as a result of the much lower lattice mismatch (-2.5% at x=0) between $Al_{1-x}Ga_xN$ and GaN than that between $Al_{1-x}Ga_xN$ and Si. Figure 2

(c) is a typical plan-view TEM image of a GaN film grown on such an $Al_{1-x}Ga_xN$/GaN/AlN buffer combination. The TD density of this GaN film is $(6.1\pm1.4)\times10^9$ cm^{-2}, ~45% lower than that grown on a single $Al_{1-x}Ga_xN$ buffer layer.

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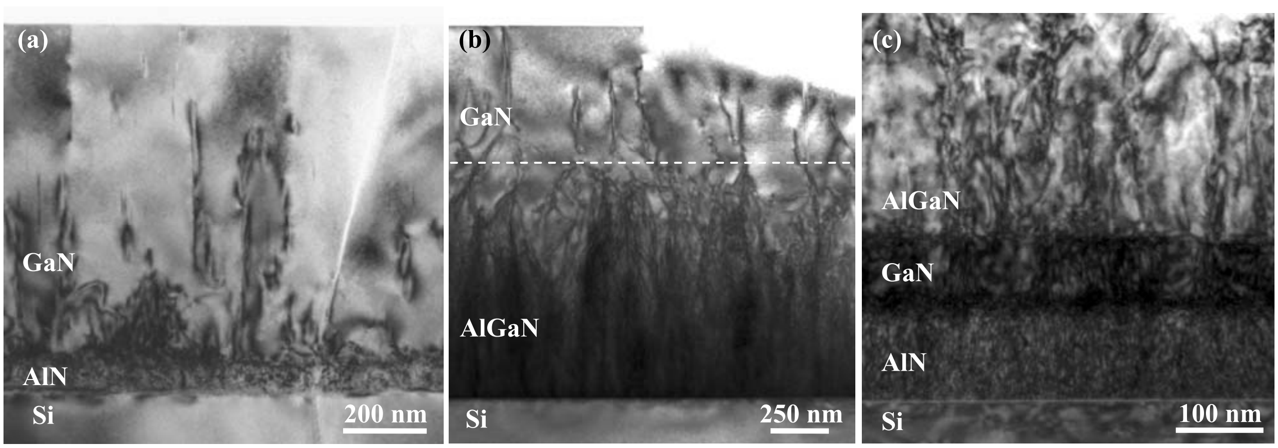

Fig. 1. Bright-field cross-sectional TEM images of GaN/Si heterostructures with (a) a thin AlN buffer layer, (b) a linearly graded $Al_{1-x}Ga_xN$ buffer layer, and (c) an AlN/GaN/AlGaN buffer combination. All the images were collected under multi-beam diffraction condition near the GaN $[1\bar{1}00]$ zone axis. The dashed line in (b) indicates the approximate position of the GaN/ $Al_{1-x}Ga_xN$ interface.

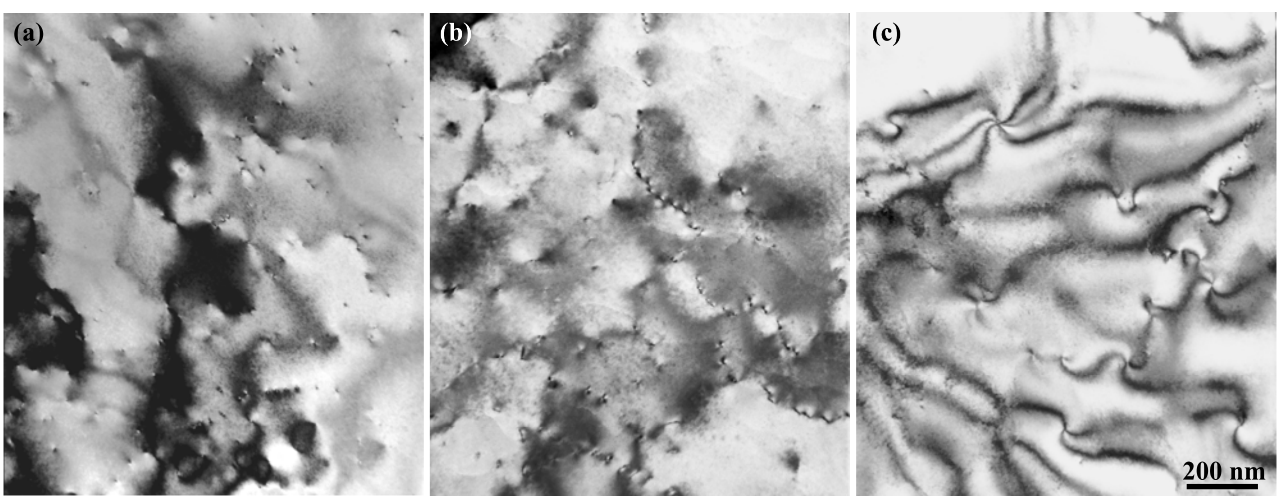

Fig. 2. Bright-field plan-view TEM images of GaN film grown on (a) a thin AlN buffer layer, (b) a linearly graded $Al_{1-x}Ga_xN$ buffer layer, and (c) a buffer combination. All the images were collected under multi-beam diffraction condition near the GaN [0001] zone axis.

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