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MOVPE high quality GaN film grown on Si (111) substrates using a multilayer AlN buffer

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High quality GaN films were successfully grown on Si (111) substrates using the MOVPE method and a multilayer AlN buffer. The buffer layer film quality and thickness are critical for the growth of the crack-free GaN film on Si (111) substrates. Cracks started to form on the single layer high temperature (HT) AlN film grown on Si (111) substrate as the AlN thickness was greater than 20 nm. However, a 100 nm crack-free AlN film can be obtained when multilayer buffer of HT-AlN/low temperature (LT)-AlN/HT-AlN was grown on the Si (111) substrate. By using multilayer AlN buffer, a 2 µm crack-free GaN film was successful grown on the 2” Si (111) substrate. Moreover, the GaN film (2µm thick) grown on Si with a GaN (004) Mosaic FWHM of only 0.12°.

1 Introduction In recent years GaN growth on Si substrate has attracted considerable attentions. This is mainly due to the fact that such substrates can be applied to light emitting diodes as well as high-temperature, high-frequency and high-power electronic devices [1]. Due to the considerable differences in lattice parameters and thermal expansion coefficients (CTE) between GaN and Si substrates, the growth of high quality GaN films on Si substrate poses serious difficulties. To obtain high quality GaN film on Si substrates, the design of the interlayer structure between the GaN and the Si substrate is crucial. Using a low temperature AlN interlayer contributes to a reduction in the growth stress [2-8]. This tensile stress effect can be reduced at high temperatures due to the compensation in stress effect caused by CTE mismatch which is compressive stress. However, the AlN film grown at a low temperature is of inferior quality as compared to the high temperature grown AlN, which influences the quality of the GaN film grown on top. Due to a significant lattice mismatch between AlN and Si, cracks and higher defect densities were formed in the high temperature (1100 °C) grown AlN epilayer. However, compressive stress can be generated on epitaxial GaN grown on high quality AlN due to the lattice mismatch between AlN and GaN which can compensate the tensile stress caused by the CTE mismatch [9]. In this letter, a series of GaN films grown on 2” Si (111) substrates using multilayer AlN buffers are investigated.

2 Experiment The AlN multi-layer buffers and GaN films were grown on 2” Si (111) wafers using an EMCORE D-180 MOVPE reactor. Trimethylgallium (TMGa), Trimethylaluminum (TMAl), and ammonia (NH_3) were employed as reactant source materials for the Ga, Al, and N, respectively. First, long baking at 1050ºC for 30 minutes in hydrogen was employed between each GaN deposition run to clean the reactor walls and to achieve a Ga-free susceptor. The Si (111) substrates were chemically cleaned before epitaxial growth to obtain a hydrogen-free surface [10]. The AlN growth commenced with an AlN seed layer grown around 1050 °C with a short Al-predeposition using TMAl before the application of ammonia. The LT-AlN films were grown at 800 °C and the HT-AlN films were deposited at 1050 °C. Afterwards, high-resolution X-ray diffractometry (HRXRD) measurements were then conducted using Panalytical diffracometer. The X-ray source

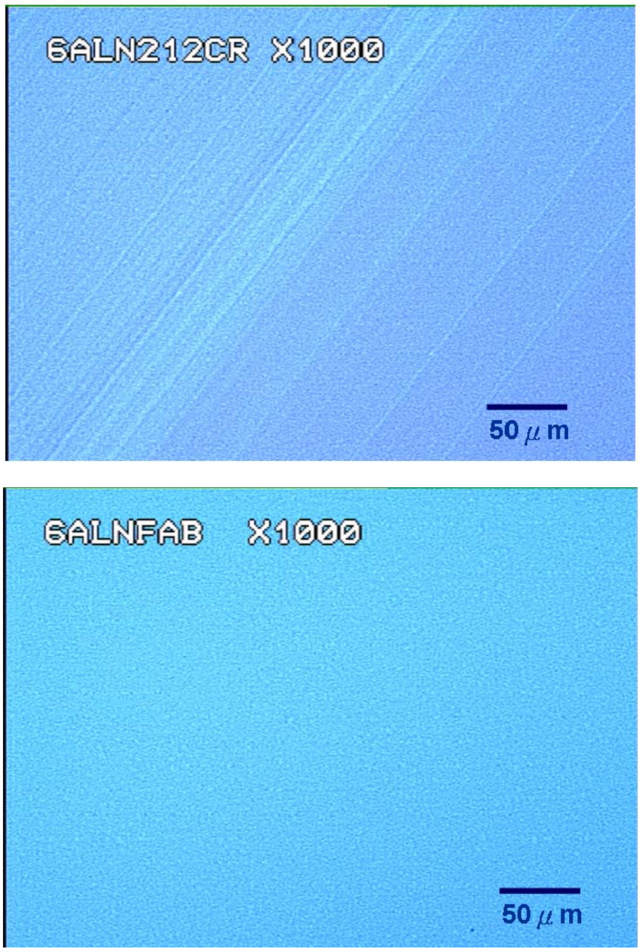

Figure 1 Optical images of AlN of the surface morphology of the AlN film on Si (111) substrate. (a) Single AlN film with a thickness of 30 nm. (b) Multilayer AlN film with a thickness of 100 nm.

is a copper anode, producing CuK_α radiation with a wavelength of 1.5406 Å. Typical operation is at 40 kV and 45 mA. SEM (scanning electron microscopy) was used to investigate the surface morphology and the cross-section of the samples. Finally, photoluminescence (PL) spectra was used to determine the GaN film quality.

3 Results and discussion A series of multilayer AlN films were grown to investigate the effect of AlN buffer on the GaN film quality. Figure 1(a) shows the surface morphology of a high temperature AlN layer grown on Si (111) substrate with a thickness greater than 30 nm, slight cracks appeared on the edge of the wafer surface. M.A.Mastro et al. reported that high temperature AlN films grown on Si with thickness greater than approximately 300 nm were heavily cracked [11]. Due to the fact that AlN has a 19% lattice mismatch and about a 15% thermal expansion efficient mismatch with the Si (111) substrates, tensile stress of about 6.269 GPa was generated on AlN upon cooling. In order to solve this problem, a multilayer

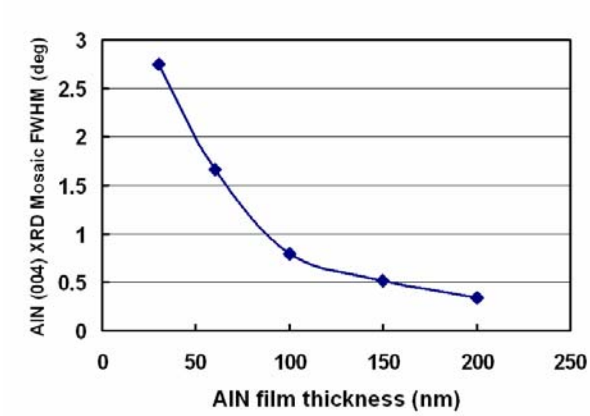

Figure 2 The relationship between AlN (004) XRD Mosaic FWHM and AlN film thickness.

was used for the growth the GaN on the Si substrates. Using the HT-AlN/LT-AlN/HT-AlN multilayer structure, over 100 nm crack-free AlN films were successful grown on 2” Si (111) wafers, as shown in Figure 1(b). The first layer of the HT-Al film with a thickness of about 20 nm was grown at 1050 °C, this layer was used to prevent the reaction of the Si with nitrogen. There were many defects and cracks formed on the first HT-AlN layer due to the relaxation of the stress in this layer. The second layer was LT-AlN film with a thickness of about 30 nm which was grown at 800 °C and acted as a nucleation layer for the growth of the top HT-AlN layer and was used to stop the cracks and defects in the first HT-AlN layer from propogation into the top HT-AlN layer [12] . In this study, multilayer AlN films up to 200 nm thick were grown on Si (111) substrates. Figure 2 presents the multilayer AlN (004) XRD Mosaic FWHM plotted against film thicknesses. The results show that the AlN film quality improved with increasing film thickness. In order to better understand the effect of the multilayer AlN buffer on the GaN stress evolution during the growth of the GaN layer, 2 μm GaN film was grown on 2” Si (111) substrates. Due to the lattice mismatch between the AlN and GaN films, compressive stress was generated on the GaN film during the epitaxial

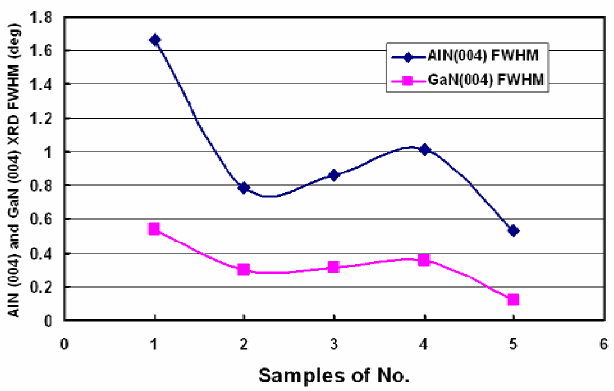

Figure 3 GaN (004) and AlN (004) XRD Mosaic data.

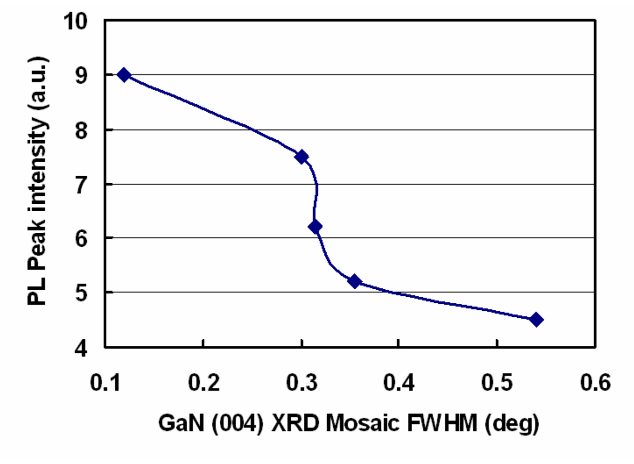

Figure 4 The relationship between PL band-edge peak intensity and GaN (004) XRD Mosaic FWHM data

GaN growth on AlN, which can be used to compensate the tensile stress due to the thermal expansion (CTE) mismatch between these two materials to make crack-free GaN films on Si substrates. From Fig. 3, the correlation between the XRD FWHM data of Mosasic GaN (004) peak and Mosasic AlN (004) peak is evident. High quality AlN buffer films are necessary for the growth of the high quality GaN film as judge from the data. Using AlN multilayer buffer, 2 µm crack-free GaN film grown on 2” Si (111) substrate with GaN (004) XRD Mosaic FWHM of only 0.12° was achieved. The band-edge PL intensity at 300 K versus GaN films FWHM is presented in Fig. 4. The band-edge PL intensity is consistent with XRD Mosaic FWHM data, which means high quality GaN films have a narrow XRD Mosaic FWHM value and possess a better optical quality. In short, the band-edge PL intensity also shows a better quality for the overgrown GaN film on multilayer AlN buffer. Moreover, it is believed that a multilayer AlN buffer could lead to the bending and termination of the threading dislocations and thus leads to the effective blocking of the dislocations at the interface of third HT-AlN layer.

4 Conclusion Based on this investigation, it can be concluded that with the application of a multilayer HT-AlN/LT-AlN/HT-AlN film structure as the buffer layer, high quality AlN can be successfully grown on Si. 2 µm crack-free GaN films were grown on 2” Si (111) substrates. The GaN films grown were also of very high quality with a GaN(004) Mosaic FWHM of 0.12°. Finally, it can be concluded that the thickness and quality of the AlN multi-layer buffer film have a significant influence on the quality of the GaN film grown on Si substrate.

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