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Effect of AlN buffer thickness on stress relaxation in GaN layer on Si (1 1 1)

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Abstract

The characteristics of GaN epitaxial layers grown on silicon (1 1 1) substrates by metalorganic vapor phase epitaxy have been investigated. The AlN thickness was found to decrease the stress sufficiently to avoid crack formation in a subsequent thick (2.6 μm) GaN layer. X-ray diffraction and photoluminescence measurements were used to determine the effect of AlN thickness on the strain in the subsequent GaN layers. Strong band edge photoluminescence of GaN on Si (1 1 1) was observed with a full width at half maximum of the bound exciton line as low as 17 meV at 13 K. The narrow (437″) linewidth on the (0 0 2) X-ray rocking curve also attests to the high crystalline quality of GaN on Si (1 1 1).

Keywords: Stress; Crack; Silicon (1 1 1); AlN buffer; Metalorganic chemical vapor deposition

1. Introduction

Recently, the growth of nitrides on silicon is of great interest due to the numerous advantages of this substrate, which are low cost, large scale availability with high quality, and good thermal and electrical conductivities. Regardless of many advantages, the reason why silicon substrates cannot be applied to the growth of GaN is cracks in GaN. The large lattice mismatch and the difference in thermal expansion coefficients between GaN and silicon lead to the formation of cracks when the thickness of the grown layer exceeds a critical value. Many researchers use a buffer layer of AlN [1], 3C–SiC [2], AlAs [3] and HfN [4] to obtain crack-free surface and high quality of GaN, instead of low-temperature (LT) GaN because LT-GaN buffer layer caused meltback etching of Si and deteriorated a quality of thin films on Si [5]. Among the buffer layers, most researchers use an AlN buffer layer to obtain a GaN film of high quality due to the high-thermal stability of AlN. Watanabe et al. [1] reported that a thin single crystal of AlN is an effective buffer layer for the growth of single crystalline GaN on Si substrate. Rehder et al. [6] reported that the physical structure of metalorganic vapor phase epitaxy (MOVPE)-grown AlN on Si (1 1 1) is sensitive to both substrate temperature and V/III ratio.

In this article, we report on the change of crack density and crystalline quality of metalorganic chemical vapor deposition (MOCVD)-grown GaN on Si (1 1 1) with AlN buffer thickness.

2. Experimental procedure

The GaN films were grown by MOCVD in an Emcore SpectraBlue™ multiwafer Turbodisk system (D180 GaN). (1 1 1) oriented Si substrates (n-type, 0.001 Ω cm) were used for GaN growth. To obtain oxide-free, hydrogen-terminated Si surface, the wafer was first annealed in a dry-oxidation furnace to form a SiO_x layer with a thickness of 1000 Å and then this oxide was removed with buffered

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HF [7]. The AlN growth and the GaN growth were performed at pressures of 76 and 200 torr at temperatures of 1070 and 1045 °C, respectively, by using TMAl, TMGa and NH_3 as precursors and H_2 as a carrier gas. First, the Si (111) substrate was annealed in H_2 ambient at 1090 °C. Then, the temperature was lowered to 1070 °C for AlN buffer layer growth. Before any growth of AlN, TMAl was preflowed for 10 s to prevent Si substrate from passivation. The AlN buffer layer was grown to a nominal thickness of 35, 65, and 80 nm. The growth of about 2.6 μm of GaN at 1045 °C followed the AlN buffer.

The crack density of GaN with AlN thickness is observed by Normalski microscopy (×50). Atomic force microscopy (AFM) was used to characterize the surface morphology of the samples and threading dislocations density. A Philips Xpert crystal X-ray diffractometer was used to determine the structure of grown films. Photoluminescence (PL) was carried out at 13–300 K using a Spectra Pro PL system with a 25 mW He–Cd laser operating at 325 nm as the excitation source.

3. Results and discussions

Fig. 1 is a photomicrograph that shows the surface feature of a 2.6 μm thick film with different AlN buffer thicknesses. All of the samples show mirror-like surface. With increasing AlN buffer thickness, the crack density of GaN films was clearly decreased. In the case of 80 nm, we obtain a nearly crack-free surface. This indicates that cracks of GaN on Si are seriously affected by the thickness of the AlN buffer. In general, the cracks of GaN on Si are generated by stress, so these results are due to relaxation of GaN stress with increasing AlN buffer thickness. We measured that crack density for 35 nm, 65 nm, and 80 nm was 300/cm, 40/cm, and 7/cm, respectively. In our case, there was no change in the crack density for samples with less than 50 nm AlN thickness but there was significantly change above 50 nm. Using an 80 nm AlN buffer layer, crack-free GaN is obtained for a 1 μm thick GaN layer (Fig. 1(d)).

Fig. 2 show the XRD traces measured using a θ-2θ scan mode for GaN films with AlN buffer thickness on Si (111) substrate. In all of GaN films, only a strong peak which is related to the GaN (0002) plane is observed at diffraction angles around $2\theta = 34°$. These results suggest that the GaN films, without respect to AlN buffer thickness, have a high preferred orientation (*c* plane) and a high quality. Also, Fig. 2 show that the peak intensity of AlN (0002) plane is strong with increasing AlN buffer thickness.

An AFM image of the surface morphology of the sample for 80 nm AlN buffer thickness with threading dislocations is shown in Fig. 3. The smooth surface similar to GaN on sapphire substrate is observed. Terraces are clearly visible on the AFM image of the surface. The roughness of the GaN layer is slightly improved with increasing AlN buffer thickness. The roughness measured on a $4 \times 4\ \mu m^2$ scan is about 0.4–0.5 nm. These values are comparable to

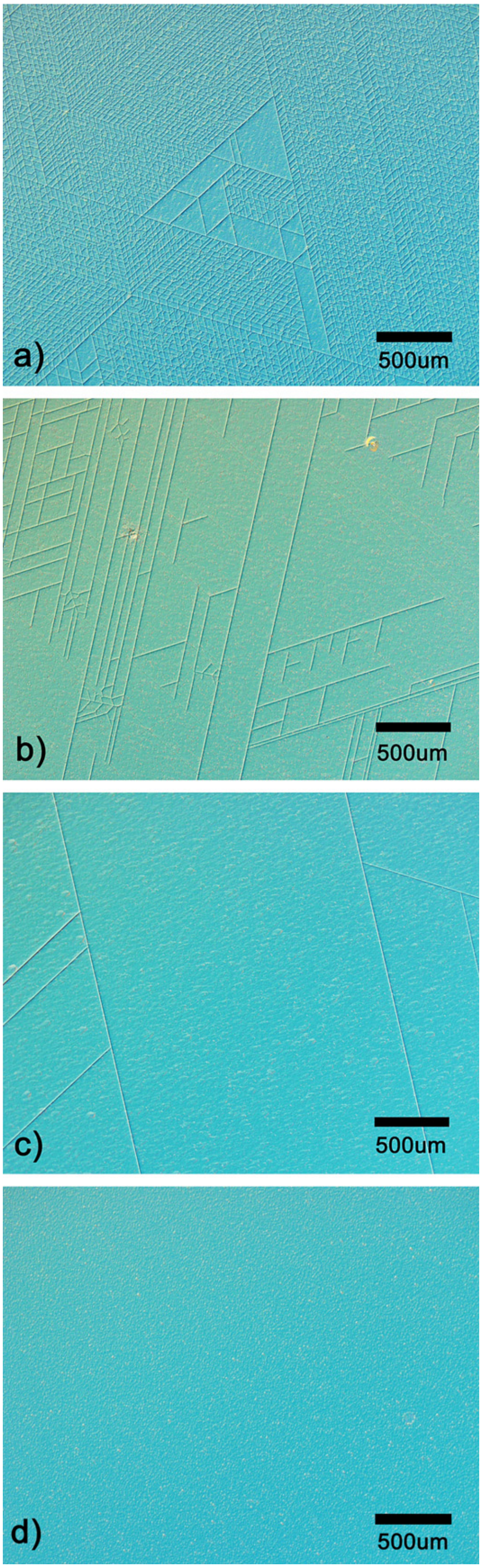

Fig. 1. Photomicrograph of a 2.6 μm-thick GaN surface with an AlN buffer thickness: (a) 35 nm, (b) 65 nm, (c) 80 nm and (d) photomicrograph of an 1 μm-thick GaN surface with an 80 nm AlN buffer. Crack density with 35 nm, 65 nm, and 80 nm AlN buffer is 300/cm, 40/cm, and 7/cm, respectively.