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High quality and uniformity GaN grown on 150 mm Si substrate using in-situ NH_3 pulse flow cleaning process

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By using in-situ NH_3 pulse flow cleaning method, we have achieved the repeated growth of high quality and uniformity GaN and AlGaN/GaN high electron mobility transistors (HEMTs) on 150 mm Si substrate. The two dimensional electron gas (2DEG) mobility is 2200 cm^2/Vs with an electron density of 7.3×10^{12} cm^{-2}. The sheet resistance is 305 ± 4 Ω/□ with ±1.3% variation. The achievement is attributed to the fact that this method can significantly remove the Al, Ga, etc. metal droplets coating on the post growth flow flange and reactor wall which are difficult to clean by normal bake process under H_2 ambient.
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1. Introduction

GaN based high electron mobility transistors (HEMTs) grown on large size (>150 mm) silicon substrates, owing to large wafer size, low cost, high thermal conductivity, high carrier mobility, high critical electric field, show potential in a wide range of applications from high power switching, radiofrequency amplification, to potential integration with Si-based CMOS technologies have attracted much attention [1–5]). But GaN-on-Si technology still facing reproducibility and reliability issues due to several reasons: (1) Ga meltback etching of Si at the interface of Si substrate will penetrate into GaN layers; [6]) (2) high dislocation density (>10^8 cm^{-2}) due to the large lattice mismatch between GaN and Si substrate; and (3) tensile stress generated during the post growth cooling down process leads to cracks in GaN layers due to the large thermal mismatch (~54%) between GaN and Si substrates. Several complicated stress control technologies such as patterned Si substrate, [7]) LT-AlN, [8] AlN/GaN superlattice, [9,10] and graded AlGaN interlayer [11,12]) have been proposed to achieve high quality GaN based heterostructures.

To avoid Ga meltback etching, AlN nucleation layer is commonly used as crystallographic and morphological templates for the subsequent epitaxy of GaN layers. Before deposition of the AlN nucleation layer, trimethylaluminum (TMAl) preflow [13–16] is often used to wet the Si surface without the introduction of ammonia (NH_3) to prevent the formation of an

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amorphous SiN_x layer [17,18]. The conditions for TMAl preflow (such as time, TMAl flow, and temperature) are critical in affecting the Si/AlN interface, which can determine the structural quality, surface morphology of AlN layer and the subsequent grown GaN layers [19–21]. The duration time of the TMAl preflow, usually from 10 to 30 s, means it is very essential and should be carefully optimized on individual process. The flow rate of TMAl preflow also needs to be carefully optimized. So it is great challenge to achieve the reproducibility and uniformity with the critical TMAl preflow conditions. Except for AlN, GaN, etc. particles, there are Al, Ga, etc. metal droplets coating on the post growth flow flange and reactor wall, which will deposit onto the Si substrate together with the TMAl preflow. The metal droplets coating on the post growth flange and reactor wall will vaporization at high temperature are difficult to clean by normal in-situ bake process. That will further increase the difficulty to realize the reproducibility and quality. However, there are few reports discussing this issue. Here we develop a new in-situ NH_3 pulse flow cleaning process to clean both the AlN, GaN, etc. particles, and Al, Ga, etc. metal droplets. By using this method, high quality and uniformity GaN on 150 mm Si substrates with good reproducibility have been obtained.

2. Experimental

The epitaxy process is carried out in 6 × 5″ multi-wafer Veeco TurboDisc K465i MOCVD systems equipped with a DRT-210 in-situ process monitor (integrated pyrometer-reflectometer unit) for wafer temperature and reflectance measurements. Two samples prepared without and with in-situ NH_3 pulse flow cleaning process were grown with the same structure, named sample A and sample B. First the 6″ Si (111) substrate was annealed at 1100 °C under H_2 ambient for about 10 min to remove native oxide from the surface. Next, 200 μmol/min of TMAl was pre-deposition for 30 s. The buffer layers consist of a 150 nm AlN nucleation layer and two $Al_xGa_{1-x}N$ intermediate layers, with $x = 0.40$, 0.20, named AlGaN1 and AlGaN2 respectively. Following, a 2–3 μm highly resistive carbon-doped GaN buffer layer, and 300 nm high crystal quality GaN channel layer were deposited. To verify the reproducibility, sample C with the same structure was grown also with in-situ NH_3 pulse flow cleaning process. The in-situ reflectance of epitaxial layers along with pyrometer temperature control are measured by the reflectometer with wave length of 930 nm. The crystalline quality of GaN layer and Al compositions are characterized by high resolution X-Ray Diffraction (HRXRD). The thickness of the epilayer is measured by white light interference. The surface morphology is studied by Atomic Force Microscope (AFM). To further investigate the reproducibility and quality, GaN (1 nm)/$Al_{0.20}Ga_{0.80}N$ (22 nm)/AlN (1 nm)/GaN HEMTs grown on GaN template based on sample B and C were named sample D, a 1 nm GaN cap layer was grown in-situ on top of the AlGaN barrier layer to minimize the current collapse by passivating surface states/traps.

3. Results and discussions

Fig. 1(a) and (b) show the in-situ epitaxial reflectivity curve with monitoring wavelength of 930 nm during the growth of samples A, B, C. Oscillation amplitude of sample A declines rapidly with increase of the GaN layer thickness, which indicates a rough surface morphology. Samples B and C have nearly the same epitaxial reflectivity curve, with no damping of the oscillation amplitude indicating a two dimensional growth mode and good surface morphology. Fig. 2 shows the optical microscopy images of samples A, B. It is found that a network of cracks are generated on the surface of sample A, while sample B are crack-free and have good surface morphology. The different epitaxial reflectivity curves and optical microscopy images of samples A, B, C indicate that the reactor cleaning process has great impact on the GaN crystal quality on Si.

The surface morphology of the GaN grown on AlN/AlGaN buffers is further studied by AFM. For sample A, as shown in Fig. 3(a), the root mean square (RMS) roughness is 0.384 nm in a scanned area of 5 μm × 5 μm. Many pits can be observed on

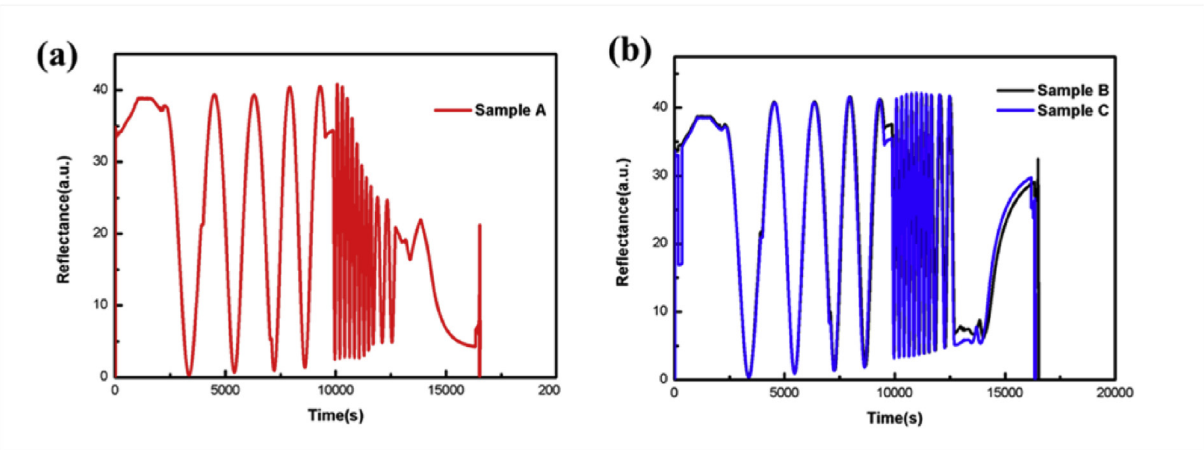

Fig. 1. The in-situ epitaxial reflectivity curve with monitoring wavelength of 930 nm. (**a**) sample A; (**b**) sample B and sample C.

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