Epitaxial Lateral Overgrowth of GaN on Si Substrate by Hydride Vapor Phase Epitaxy

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Silicon has been recently studied as an alternative substrate for GaN growth. The availability of large area, inexpensive substrates has the potential for the large-scale development of GaN. Both Molecular Beam Epitaxy and Metal-organic Vapor Epitaxy have been used to grow epitaxial GaN on Si substrates. In all cases, buffer layers with a GaN/AlN superlattice have been successfully applied to limit the crack formation due to the large differences in thermal expansion coefficient and lattice mismatch between the Si and GaN. Most recently, selective area GaN growth on Si has been used to improve material quality and limit crack formation. In general the class of growth processes utilizing epitaxial lateral overgrowth (ELO) has been proved to be useful in the growth of GaN with a reduced dislocation density and improved optical and electrical properties. Subsequent device performance using ELO GaN shows a substantial improvement when compared to devices fabricated on GaN grown directly on sapphire substrates. Some papers additionally report that the cracks prevalent in thick epitaxial GaN can be eliminated by ELO techniques.

In hydride vapor phase epitaxy (HVPE), the reaction between Si and the chlorine-based growth chemistry and ammonia leads to difficulties in the growth of high quality GaN on Si substrates, despite the use of AlN or GaN buffer layers. Previous reports, both from our laboratory and others, have shown that the high thermal expansion coefficient and lattice mismatch can cause the GaN layer to form cracks during growth exposing the underlying Si to reactive ambient. Reactions do occur once the cracks form, significantly degrading the surface morphology and materials quality of the subsequent GaN through the formation and incorporation of second phases, such as SiN_x.

We present recent results on the application of ELO to improve the HVPE GaN growth on Si substrates. The GaN buffer layers grown by MBE to the thickness of 0.7- 0.8 μm have been used as the ELO substrate. SiO_2 deposited by plasma enhanced chemical vapor deposition (PECVD) 300°C was used as a mask material. Stripe openings in the mask material were formed parallel to the $(1\underline{1}00)$ directions of GaN layers at the period of 12 μm with 6 μm windows. The substrate growth temperature was varied from 1000°C to 1075°C. The HCl flow rate to the Ga source controlled the growth rate that ranged from 0.5 to 4 μm/min. The NH_3 flow rates are varied from 90 to 740 sccm. A mixture of H_2 and N_2 was used as the carrier gas. For some samples, HCl has been directly introduced into the growth region, bypassing the Ga source boat, altering the ELO GaN growth.

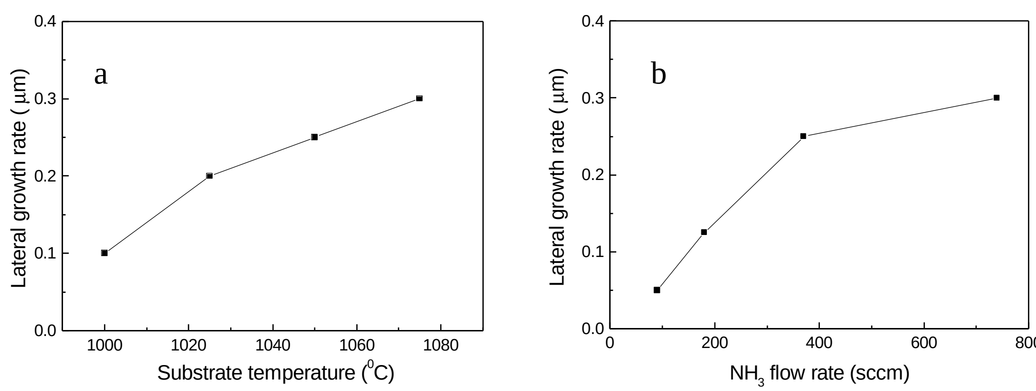

Figure 1: The lateral growth rate versus the growth conditions (a: substrate temperature, b: NH_3 flow rate)

The initial MBE GaN on Si layers were epitaxial with a broad (0002) double crystal x-ray diffraction rocking curve (DCXRD) possessing a full width at half maximum (FWHM) of 4000 arcsec. There is a significant improvement in the structural properties of the subsequent HVPE GaN grown to a thickness of 5 - 10 μm on these MBE GaN substrates. The FWHM of (0002) DCXRD curves of these layers was 800 - 1000 arcsec for both GaN growth on unpatterned (homoepitaxial) and patterned, ELO substrates. Fig.1a shows that the lateral overgrowth rate significantly increases with the substrate temperature, which is similar to the ELO results we obtained from samples grown on patterned MOVPE GaN on sapphire substrates. A lateral-to-vertical growth rate ratio is difficult to define due to the facetted growth seen under some growth conditions. The cracking and subsequent reaction with the Si, appearing as a form of 'corrosion', does occur on the growing surface at highest growth temperatures (higher than 1050°C) even on the uncoalesced ELO strips without large scale cracking being apparent. Extensive reactions with the underlying Si are not readily apparent at the lower growth temperatures (below 1050°C). These results suggests that the Si transport from inadvertently exposed areas such as the wafer backside or microcracks and pits in the GaN layer, through the gas phase or, less likely, the bulk diffusion of Si through the GaN layer is significantly enhanced at high temperatures leading to the degradation in surface morphology and structural properties. This degradation is shown by the increase of the FWHM of the (0002) DCXRD curve with the substrate temperature, over the range 1000-1075°C, from 850 to 1250 arcsec.

The detailed ELO behavior was also studied. The lateral overgrowth rate will increase with V/III ratio at the temperature of 1050°C, as is shown in Fig.1b. This dependence on V/III ratio was not observed for growth on patterned MOVPE GaN layers on sapphire at an albeit higher temperature of 1100°C. Both the increase in growth temperature and the incorporation of Si, in the case of growth on Si substrates, can influence the ELO behavior. The high temperatures will lead to an increased surface diffusion length which should in principle lead to smoother facets and higher chemical selectivity with respect to the masking materials. Previous work on impurity addition during ELO MOVPE GaN has also shown that Si produces changes in the ELO behavior affecting facet formation and changes in the lateral-to-vertical growth rates.

The introduction of HCl into the growth region significantly reduces the vertical growth rate leading to a high lateral-to-vertical growth ratio with flat top surface present on the ELO material. This is shown in the cross-sectional SEM images in Fig.2. Surprisingly, the additional HCl does seem to suppress the extent of the Si-based 'corrosion' that is observed.

Continued growth of the initial ELO material to form a coalesced layer is not uniform and can lead to a locally very high density of surface pits, as shown in Fig.2d. The origin of these surface pits, often seen in thick layer growth by HVPE, is uncertain. The presence of a rough sidewall to the ELO regions could lead to the formation of a larger scale defect, such as a pit, upon coalescence. Additionally, the formation of a second phase, such as SiN_x due to Si transport during growth, could disrupt the surface growth process and lead to a pitted surface. We have observed that the reduction in the stripe opening and mask period does lead to an improved surface morphology and structural quality. The surface pit density and size have been significantly reduced for the GaN ELO grown on a patterned substrate with the period of 6 μm, as shown in Fig.2e.

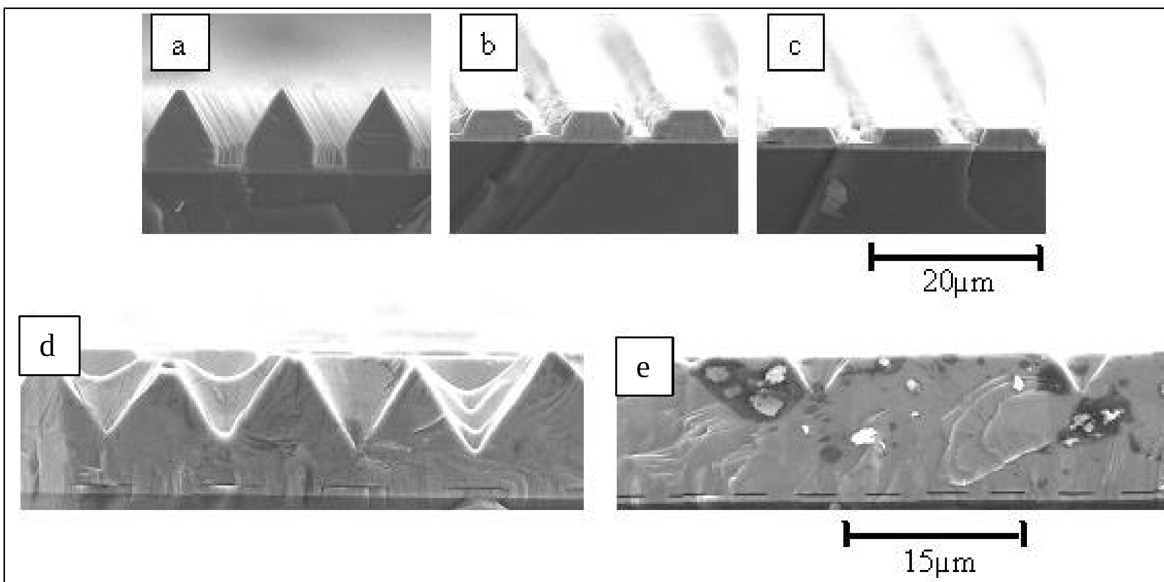

Figure 2: The SEM cross section pictures of the GaN ELO grown on Si substrate with MBE GaN buffer layers: uncoalesced (a: 0 sccm HCl; b: 10 sccm HCl; c: 20 sccm HCl); coalesced (d: pattern period 12 μm (6 μm space with 6 μm window), e: pattern period 6 μm (3 μm space with 3 μm window)).