Plasma-assisted MBE Growth of GaN on GaN/sapphire Templates Grown in situ by Ammonia-MBE

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For many years, the GaN MBE research community has divided itself into two camps according to the two different nitrogen sources used for growth, i.e. the nitrogen plasma source versus the ammonia source. Communication between the two camps has been difficult because the growth phenomena are indeed very different with the two techniques. With the recent advances in both the ammonia- MBE and plasma-assisted MBE (PAMBE) techniques, it becomes increasingly apparent that each technique has its advantages and shortcomings, and that a combination of the two techniques can potentially open new opportunities. The PAMBE technique offers growth at lower temperatures (550 C – 800 C) and can achieve atomically flat surfaces under Ga rich growth conditions. But it generally needs to grow on high quality GaN templates made by MOCVD to achieve best results. In contrast, the ammonia- MBE technique grows at higher temperatures (850 C – 900 C) and readily obtains high electron mobility GaN layers on sapphire and SiC substrates. High quality semi-insulating GaN:C layers can also be grown by ammonia- MBE using a methane ion source for carbon doping. But these layers exhibit large surface roughness due to strong surface faceting inherent to the ammonia- MBE processes.

In the present work, we study GaN growth by PAMBE on semi-insulating GaN/sapphire templates prepared in situ by ammonia- MBE. Growth is carried out in an SVT N35S MBE system equipped with both a nitrogen plasma source and an ammonia injector. Highly insulating templates are used to ensure unambiguous characterization of the electrical transport properties of the PAMBE layers.

A remarkable result from this study is that the PAMBE growth can be significantly smoother than the ammonia-MBE grown GaN templates. The AFM images in Fig. 1 compare the surface morphology of the starting template layer and the surface after the PAMBE growth under Ga rich conditions. The ammonia- MBE template shows significant roughness (RMS roughness of 29 nm) with a pronounced faceted grain structure. Following growth by PAMBE, however, the surface becomes very smooth (RMS roughness of 0.78 nm) with clearly resolved atomic terraces.

The background electron concentrations in the PAMBE grown layers decrease strongly with increasing growth temperature. At the highest growth temperature used of 800 C, a background electron concentration of $1x10^{16}$ cm^{-3} with a mobility of 360 cm^2/vs is observed, indicative of good crystalline quality of the PAMBE layer grown on the ammonia- MBE templates. SIMS studies find that the background carrier concentrations are correlated with the oxygen incorporation levels.

Semi-insulating GaN layers with carbon doping have also been obtained by PAMBE growth on carbon-doped GaN templates grown by ammonia- MBE. The PAMBE carbon-doped layers exhibit atomic steps on the surfaces, significantly smoother than the ammonia- MBE templates.

AlGaN/GaN and InGaN/GaN superlattice structures have also been grown by PAMBE on the ammonia- MBE GaN templates. Good surface and interface quality is observed by AFM and x-ray diffraction studies.

Finally, InGaN quantum well LED structures have been grown by a combination of ammonia- MBE and PAMBE techniques. The InGaN/GaN quantum wells were grown by PAMBE on the n-type GaN template grown by ammonia- MBE. The top p-type layer was then grown again by ammonia- MBE. The LEDs show bright emissions with the peak wavelengths in the blue to green region tunable by the In concentration in the wells.

In conclusion, ammonia- MBE grown GaN layers can be used as in situ templates for PAMBE growth of GaN epilayers and device structures with good surface and interface quality. Such templates, both conducting and semi-insulating, offer an alternative to commercial MOCVD GaN templates commonly used for PAMBE growth.

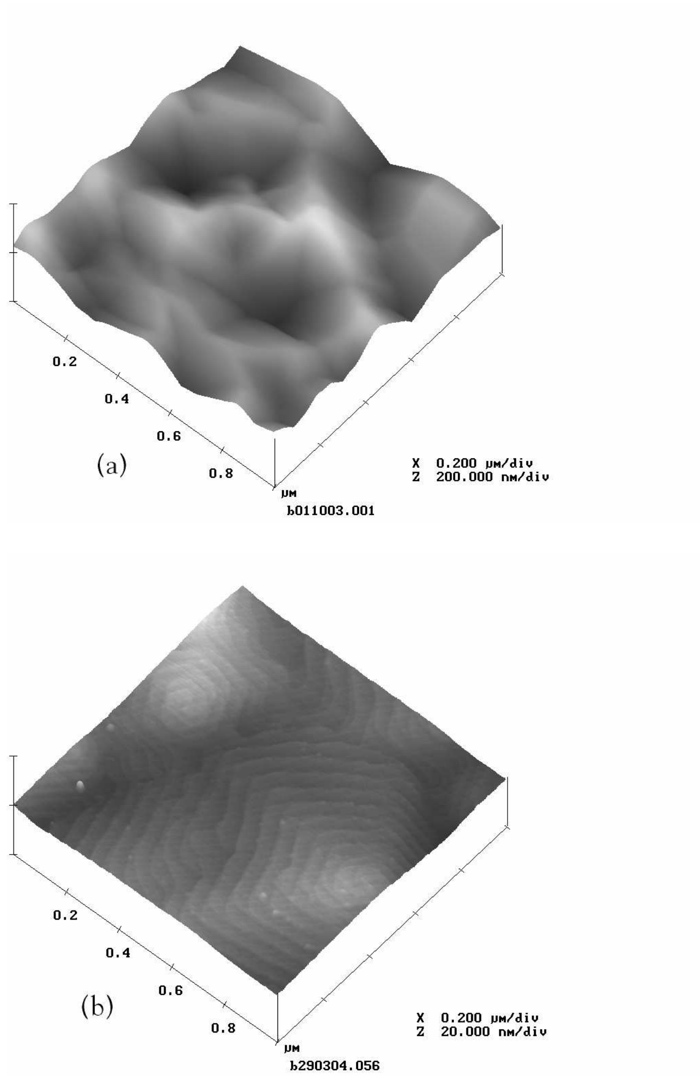

Fig. 1. AFM surface images of (a) a carbon-doped GaN on sapphire template grown by ammonia- MBE, and (b) a GaN layer (1 μm thick) grown on the template by plasma-assisted MBE.