Studying The Oxidation Behaviour of InAlN Thin Films Using Aberration Corrected STEM and EELS.

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GaN based high mobility transistors (HEMT) are a promising alternative to Si-based power transistors due to higher operating voltages, higher operating temperatures, and a significant reduction in Ohmic loss at high frequencies. AlGaN-GaN HEMTS have gained attention due to the formation a 2-dimensional electron gas with a high charge carrier mobility at the AlGaN/GaN interface. Power efficiency, especially at high operating frequencies, can further be improved by replacing the AlGaN layer with lattice matched InAlN [1]. In order achieve a high switching frequency for GHz applications a narrow gate and a thin barrier height must be achieved. Recent studies have shown that the charge carrier density in the 2DEG for InAlN/GaN based HEMTs can be maintain for barrier thicknesses as low as 9nm, and optimal performance can be maintained for barrier thicknesses as low as 3nm [2]. This is an improvement upon AlGaN based devices who’s performance degrades at such thin barrier thicknesses.

One limiting aspect of the InAlN based HEMT is the high leakage current that occurs at the Schottky barrier between the metal gate and the InAlN surface [3]. Recent studies have shown that growing a thin oxide layer by thermally oxidizing the top surface of InAlN reduces the high leakage currents by suppressing thermionic and field emission to occur at low gate voltages [2,4]. These studies suggest that the growth of an oxide layer on the surface on InAlN films is a reaction limited process, and not a diffusion limited process previously observed for AlN sintered compacts [5].

In this study, we use aberration corrected scanning transmission electron microscopy (STEM) and electron energy loss spectroscopy (EELS) to study the oxidation kinetics of InAlN deposited on GaN. Latticed matched InAlN (In0.17Al0.83N) films were deposited on 2μm thick GaN layer by MOCVD, in a Veeco P-75 turbodisc reactor. The MOCVD growth of GaN was initiated on (0 0 1) sapphire substrates. The InAlN films oxidized by rapid thermal processing (RTP) for varying times in an Annealsys As-One RTP at 800 C in a pure oxygen ambient.

Contrary to previous studies, the initial growth of an oxide layer on top of InAlN was found to be reaction limited, not diffusion limited. This is evident by the O K-edge profile at the top of InAlN films annealed for less than 10 min (Fig. 1). For InAlN layers annealed longer than 10 min, the rate at which InAlN film is consumed by the oxidation process decreases (Fig. 1). This suggests that the growth kinetics of the oxide layer transitions form reaction limited to diffusion limited growth. The oxide layers were found to be non-stoichiometric and composed of N, In, Al, and O (Fig. 1). The termination of the lattice below the oxide layer in the HAADF images
and the lack of diffraction contrast in the STEM bright field images demonstrate that the newly formed oxide layer is amorphous (Fig. 2).

Figure 1. (a) HAADF image of the InAlN film annealed at 800 °C for 4 min. (b,c) Integrated EELS edge intensity profiles along the InAlN film in the region highlight by the blue line in (a). (d) HAADF image of the InAlN film annealed for 60 min. (e,f) Integrated EELS edge intensity profiles along the InAlN film in the region highlight by the blue line in (d). The green line signifies the original surface of the InAlN before annealing, and the white signifies the interface between the wurtzite crystal structure and the amorphous oxide layer.

Figure 2. (a) HAADF and (b) BF images of the InAlN film annealed at 800 °C for 4 min. (c) HAADF and (d) BF image of the InAlN film annealed for 60 min. at 800 °C. The green line signifies the original surface of the InAlN before annealing, and the white signifies the interface between the wurtzite crystal structure and the amorphous oxide layer.

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