Effect of the Doping and the Al Content on the Microstructure and Morphology of Thin $Al_xGa_{1-x}N$ Layers Grown by MOCVD.

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ABSTRACT

$Al_xGa_{1-x}N$ {x=30% (doped and undoped), 45% (doped)} thin films were grown by MOCVD on ~2 μm thick GaN layer using Al_2O_3 substrate. These films were designed to be the active parts of HFETs with $n_s\mu$ product of about $10^{16}(Vs)^{-1}$. The layers were then studied by means of transmission electron microscopy (TEM) techniques. In this paper, it is shown that the $Al_xGa_{1-x}N$ layer thickness was non-uniform due to the presence of V-shaped defects within the $Al_xGa_{1-x}N$ films. The nucleation of these V-shaped defects has taken place about 20 nm above the $Al_xGa_{1-x}N$/GaN interface. Many of these V-shaped defects were associated with the presence of the threading dislocations propagating from the GaN/Al_2O_3 interface. We show that the density of these V-shaped defects increases with the doping level and also with the Al mole fraction in the films. The formation mechanism of the V-shaped defects seems to be related to the concentration of dopants or other impurities at the ledges of the growing film. This suggestion is supported by high resolution TEM analysis. The growth front between the V-shaped defects in the lower Al concentration thin films was planar as compared with

the three-dimensional growth in the doped, higher Al concentration film. This interpretation of the origin of the V-shaped defects is consistent with the observed lowering of the Schottky barrier height in n-doped AlGaN/Ni Schottky diodes.

INTRODUCTION

In addition to applications in optoelectronics[1], GaN and related alloys are of interest for applications in high temperature, high frequency and high power electronic devices[2]. In many of these devices, the AlGaN layer is an active part of the device structure and the structural properties of this layer can affect the basic device characteristics. This has been demonstrated and inferred for example in the work of Shiojima, *et al* [3] who observed lowering of the Schottky barrier height and assigned it to the presence of the structural defects in the n-doped layer. In this work, several AlGaN/GaN HFET structures are analyzed using transmission electron microscopy (TEM).

EXPERIMENTAL

The GaN and the AlGaN layers were grown by low pressure MOCVD in a modified EMCORE D125 reactor system. Trimethylgalium (TMGa) and trimethylaluminum (TMAl) were used as column III precursors, while hydrogen-diluted silane (SiH_4) was used as the n-type dopant. High purity ammonia (NH_3) was used as the N source. The Al_2O_3 substrates were cleaned for 10 minutes in 10:1:1 H_2SO_4:H_2O_2:DI H_2O and then for 10 minutes in 2:9 HF:HNO_3. The cleaning was followed by a DI water rinse. Substrates were then loaded into the system and, after prepumping to a base pressure of 10^{-7} torr, were loaded into growth chamber. After a H_2 bake at 1050°C for 5 minutes, the substrates were cooled down and 25 nm-thick buffer layers were grown at 530°C. The wafers were then heated to 1050°C again and ~2 μm of GaN was grown in NH_3, H_2, and TMGa. A rapid switch to TMAl, TMGa, NH_3, and H_2 followed to grow undoped 30% AlGaN layers, as well as doped 30%

and 45% AlGaN layers. The samples were subsequently cooled to room temperature in H_2 and NH_3. TEM cross-sections were prepared along [11-20], and [1-1 0 0] directions normal to the growth direction [0001]. Tilting (bright field, weak beam and dark field) experiments were performed in the side entry stage JEOL 200 CX, while high resolution imaging was perform on JEOL ARM operating at 800 kV.

RESULTS

Figure 1 shows the low magnification image of the cross-section of an undoped 30% $Al_xGa_{1-x}N$ film. The $Al_xGa_{1-x}N$ layer was about 30 nm thick. Some undulation of the thickness of this layer was observed. These undulations were associated with the presence of the V-shaped defects, some of which extended almost halfway into the layer as shown in Fig. 2. Adding dopant to the $Al_xGa_{1-x}N$ layer while preserving the aluminum concentration at x=30% resulted in overall increase of the density of the V-shaped defects. Otherwise the morphology of the doped film was very similar to that of the undoped $Al_xGa_{1-x}N$ film. This is illustrated in Fig. 2 and Fig.3. By comparison, further increase in the concentration of Al to x=45% resulted in an increased density of the V-shaped defects, as well as in the changed morphology of the growth front from 2D to 3D. This is illustrated in Fig.5 and Fig.6.

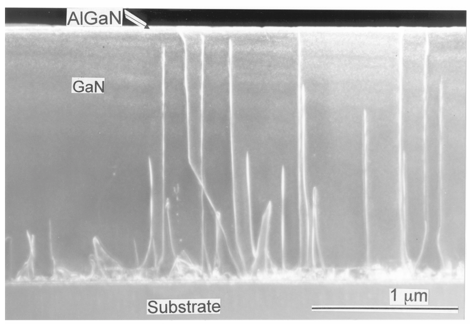

Fig. 1: Weak beam **g**=[0002] image of an undoped 30% AlGaN layer (sample **1170**) layer on about 1.7-2 µ GaN layer on a sapphire substrate. Note presence of V-shaped defects. In many cases these defects appear to be associated with the threading dislocations.

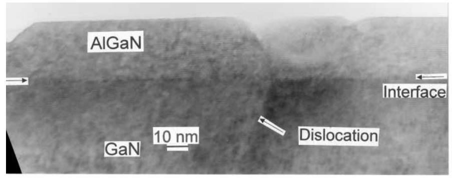

Fig. 2: High resolution image of an undoped AlGaN layer (sample 1170) layer on ~1.7-2.0 µm GaN on a sapphire substrate showing V-shaped defects. Note that the growth between V-shaped defects is planar (2D). The V- shaped defect to the left initiated about 200 nm away from the AlGaN /GaN interface.

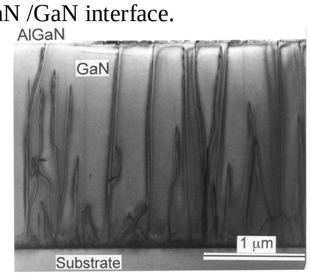

Fig. 3: TEM bright field image of the cross-section of a doped 30% AlGaN layer on ~2 µm GaN on a sapphire substrate (sample **1134B**).

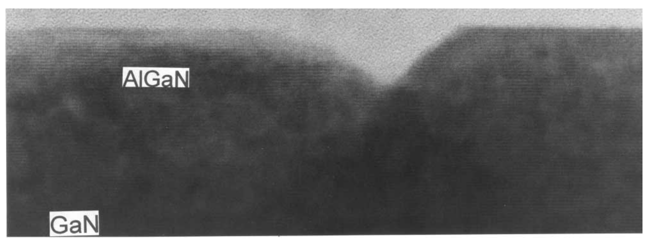

Fig. 4: High resolution TEM image of the cross-section of a doped 30% AlGaN layer on ~2 µm GaN on a sapphire substrate (sample **1134B**).

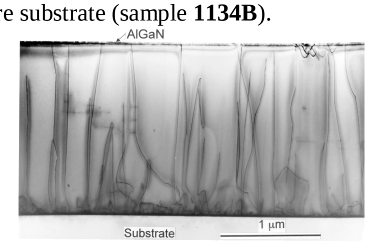

Fig.5: Bright field TEM image of the cross-section of a doped 45% AlGaN layer on ~2 µm GaN on a sapphire substrate (sample **1129A**).

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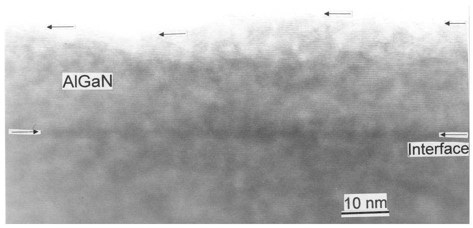

Fig. 6: High resolution TEM image of a doped 45% AlGaN layer on ~2 µm GaN on a sapphire substrate (sample **1129A**). Careful analysis of the growth front between V-shaped defects indicates 3D growth.

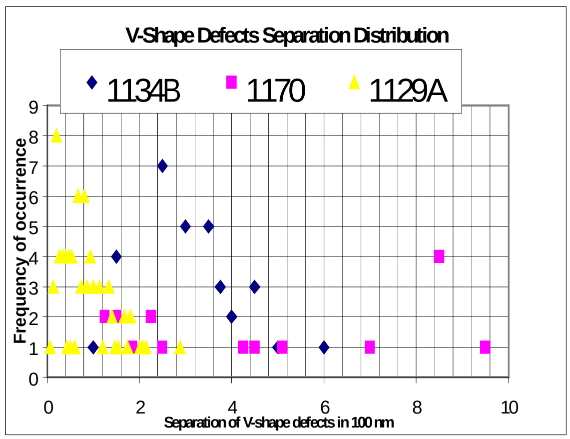

Fig.7: Frequency of the observation of the V-shaped defect as a function of the separation between two consecutive V defects is the highest for a doped sample with highest Al content and the lowest for the undoped lower Al content sample.

SUMMARY AND CONCLUSION

The density of the V-shaped defects increases with Al and dopant content. This is illustrated in Fig. 7 which summarizes the TEM results. This dependence on theAl concentration and on the dopant composition in the growing AlGaN film indicates that the poisoning of the ledges takes place and promotes V-shape defect formation. The local composition inhomogeniety due to poisoning of the ledges could be responsible for the observed lowering of the Schottky barrier height in n-doped AlGaN/Ni Schottky diode [3]. The role of threading dislocations in the formation of the V-shaped defects has to be further studied, because many, but not all, V-shaped defects were found in the proximity of these dislocations. The formation of the V-shaped defects presents a challenge for AlGaN/GaN electronic devices, as these defects will impact many electrical parameters and reduce device reliability. Therefore methods need to be developed to reduce the V-shaped defect density in AlGaN/GaN heterostructure.

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