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MOVPE growth of nonpolar a-plane GaN with low oxygen contamination and specular surface on a freestanding GaN substrate

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ABSTRACT

We investigated unintentionally doped nonpolar a- and m-plane GaN layers grown by metalorganic vapor phase epitaxy under several sets of conditions on freestanding a- and m-plane GaN substrates. Oxygen contamination in a-plane GaN is greatly reduced by increasing the V/III ratio during growth. As a result, a high-resistivity GaN buffer layer for an AlGaN/GaN heterostructure field-effect transistor was realized.

1. Introduction

Nonpolar group III nitride semiconductors have attracted significant attention for use in optical and electronic device applications because of their lack of spontaneous and piezoelectric polarization fields [1]. Most III-nitride heterostructure field-effect transistor (HFET) devices are grown on c-plane [2–7] and have two possible operation modes; depression mode (D-mode) and enhancement mode (E-mode). D-mode HFETs are already practically applied in high-frequency circuits, whereas E-mode HFETs are expected to be used in future fail-safe circuits with low power dissipation.

In the case of HFET devices in the nonpolar GaN, the two-dimensional electron gas (2DEG) density in the channel layer can be controlled by intentional doping in the barrier layers [8]. Therefore, E-mode operation can be expected with a comparatively easy device fabrication process. However, there are several problems in the use of a nonpolar plane for HFET devices. First, heteroepitaxially grown nonpolar GaN films have a high density of dislocations and stacking faults [9,10]. This problem can be solved by performing growth on a freestanding GaN substrate [11]. Second, nonpolar planes are chemically active. Therefore, contamination by oxygen is a serious problem [12]. Oxygen acts as a shallow donor in GaN [13], making the fabrication of HFETs with a high breakdown voltage difficult [14]. Fe-doping in polar and nonpolar HFETs has been used to compensate for the oxygen [15,16]. Although this is effective for reducing the leakage current, it tends to degrade the device performance through Fe segregation [17,18].

In this study, we investigated the residual oxygen contamination in nonpolar GaN by varying the growth temperature and V/III ratio during the growth of GaN by low-pressure metal organic vapor phase epitaxy (MOVPE). In particular, we characterized the surface morphology and oxygen contamination for each set of conditions.

2. Experimental details

All samples were grown by MOVPE. Trimethylgallium (TMGa), trimethylaluminum and ammonia (NH_3) were used as the source gases. As the substrates, we used +c-, m- and a-plane freestanding GaN films grown by the Na-flux method [19]. The threading dislocation density and stacking fault density of these GaN substrates were determined to be less than $5\times10^{6}\,cm^{-2}$ and less than $2\times10^{3}\,cm^{-1}$, respectively. These substrates were sliced with an

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offset angle of $0 \pm 0.5^{\circ}$ and then subjected to chemical mechanical polishing. By using these freestanding GaN substrates, a GaN buffer with a specular surface morphology and good crystalline quality can be realized [20,21].

3. Results and discussion

Table 1 shows the growth conditions, the root mean square (RMS) surface roughness obtained by atomic force microscopy (AFM) and the oxygen concentration in the top GaN buffer obtained by secondary ion microprobe mass spectrometry (SIMS). Sample 1 was grown on a +c-plane GaN substrate. This sample was prepared as a reference for comparison. After 10 min thermal annealing at 1050 °C in NH_3 and hydrogen, an unintentionally doped GaN layer was grown. The growth conditions of GaN were as follows: V/III ratio: 1000, growth temperature: 1050 °C, reactor pressure: 200 hPa, TMGa flow rate: 150 μmol/min, NH_3 flow rate of 3 slpm. Samples 2 and 3 were grown on m- and a-plane Na-flux GaN substrates, respectively. After 10 min thermal annealing at 1030 °C in NH_3 and hydrogen, an unintentionally doped GaN layer was grown. In the growth of a- and m-plane GaN, the surface morphology can be improved by performing growth under a low V/III ratio of as low as 200 and at a low growth temperature of 1030 °C [22,23]. The growth conditions for a- and m-plane GaN were as follows: V/III ratio: 250, growth temperature: 1030 °C, reactor pressure: 100 hPa. Next, an unintentionally doped GaN layer was grown at a V/III ratio of 1000, a growth temperature of 1030 °C and a reactor pressure of 100 hPa. Samples 4 and 5 were grown on m- and a-plane Na-flux GaN substrates, respectively. After 10 min thermal annealing at 1060 °C in NH_3 and hydrogen, an unintentionally doped GaN layer was grown. The growth temperature and pressure were fixed at 1060 °C and 100 hPa, respectively. The V/III ratio was increased from 250 to 1000 and then 2000. Note that the growth rate on each plane is different under the same growth conditions and that the total thickness is not exactly the same for all samples. For example, the growth rate of sample 1 (+c-plane) was approximately 3 μm/h. In a growth temperature of 1030 °C (sample 2 and

Table 1
Growth conditions, surface roughness and oxygen concentration of epitaxial GaN.

	Plane	1st GaN layer		2nd GaN layer		3rd GaN layer		Surface roughness $5 \times 5\ \mu m^2$ RMS (nm)	Epi-GaN of oxygen concentration (each top layer)
		Temperature (°C)	V/III ratio	Temperature (°C)	V/III ratio	Temperature (°C)	V/III ratio		
Sample 1	+c	1050	1000	–	–	–	–	0.29	Detection limit
Sample 2	m	1030	250	1030	1000	–	–	0.16	2×10^{18}
Sample 3	a	1030	250	1030	1000	–	–	0.19	1×10^{17}
Sample 4	m	1060	250	1060	1000	1060	2000	0.82	3×10^{17}
Sample 5	a	1060	250	1060	1000	1060	2000	0.24	Detection limit

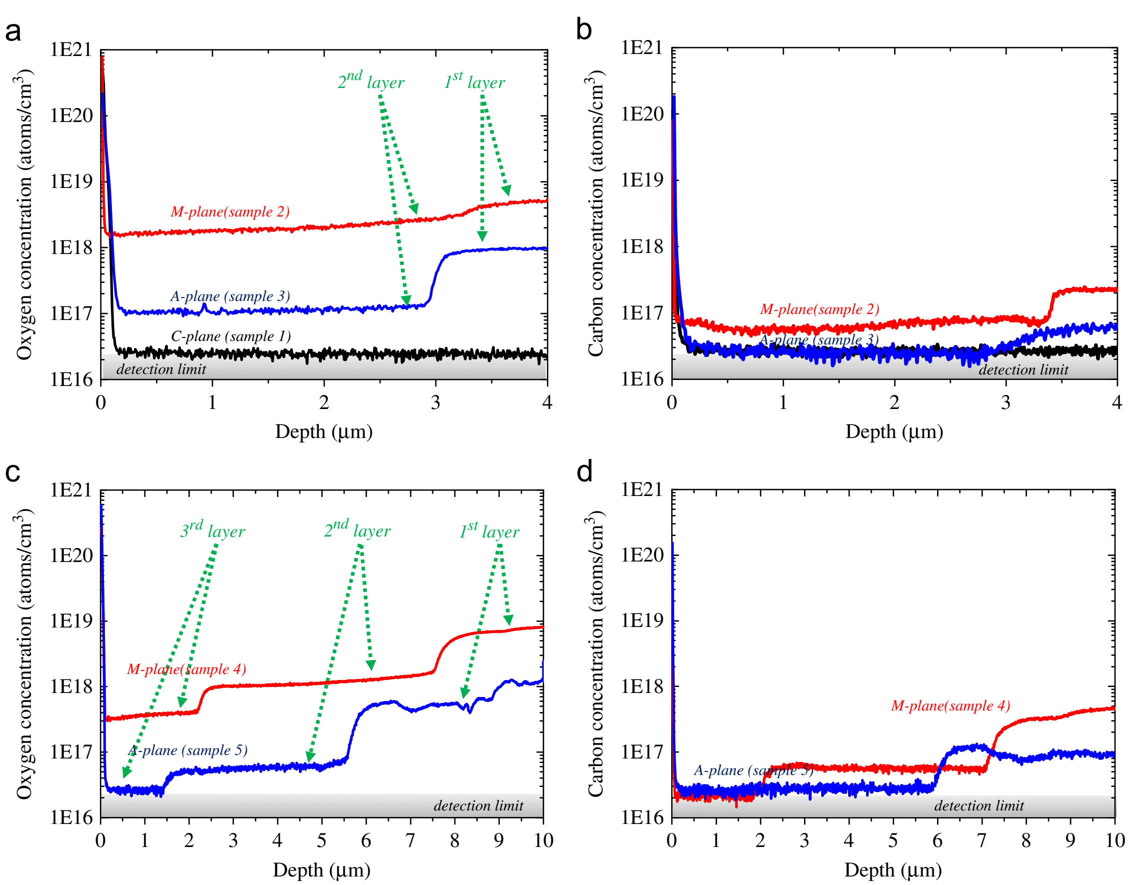

Fig. 1. Impurity profiles of epitaxial GaN layers measured by SIMS. (a, c) and (b, d) show the oxygen and carbon concentrations in samples 1–5, respectively.