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Improved mobility in InAlN/AlGaN two-dimensional electron gas heterostructures with an atomically-smooth heterointerface

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Abstract

An InAlN/AlGaN two-dimensional electron gas (2DEG) heterostructure with an "regrown AlN initial layer" was grown on AlN/sapphire template by metalorganic chemical vapor deposition, and their structural and electrical properties were investigated. It was confirmed that the prepared sample had an atomically-smooth heterointerface and exhibited an improved 2DEG mobility of 242 cm^2/Vs compared to the sample without the regrown AlN layer.

1. Introduction

In addition to conventional AlGaN/GaN two-dimensional electron gas (2DEG) heterostructures, modified 2DEG heterostructures, such as AlGaN/AlGaN or InAlN/GaN, have also been attracting much attention, owing to their extremely high breakdown voltages [1] or large 2DEG densities [2]. We have also reported the growth and characterization results about InAlN/AlGaN heterostructures [3] as well as heterostructure filed-effect transistors (HFETs) [4]. Consequently, it was found that there are a few issues to be solved for considering the practical use of InAlN/AlGaN HFETs [4]. As for the 2DEG mobility, one of the most important issues, we have confirmed that the interface roughness scattering significantly suppressed it [5]. In this study, therefore, we attempted to improve the 2DEG mobility in InAlN/AlGaN 2DEG heterostructures by achieving an atomically-smooth heterointerface.

2. Experiments

Samples were grown by a horizontal metalorganic chemical vapor deposition (MOCVD) system with conventional precursors. A 2-inch-diameter AlN template, which had a 1-μm epitaxial AlN film on a *c*-face sapphire, was used as an underlying substrate. Fig. 1 shows a schematic of the InAlN/AlGaN heterostructure employed in this study. The heterostructure consisted of, from bottom to top, a 2-μm-thick AlGaN channel layer, a 1-nm-thick AlN interlayer, and a 15-nm-thick InAlN barrier layer. During the MOCVD growth of the heterostructure, a "regrown AlN layer" was initially formed on the AlN template. This is the most distinctive point in this study to achieve an atomically-smooth AlGaN surface. The regrown AlN layer contains a few different-growth-rate AlN layers (see Fig.1). To analyze the AlGaN surface by atomic force microscopy (AFM), an additional sample without the top AlN and InAlN layers was also prepared. Then, electrical characteristics of the heterostructure were evaluated using the Hall effect and *C*-*V* measurements.

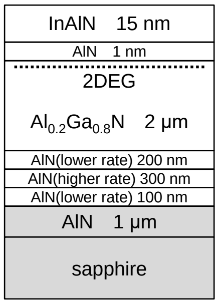

Fig. 1. Schematic cross section of the InAlN/AlGaN heterostructure with a regrown AlN layer.

3. Results and discussion

Figs. 2(a) and 2(b) show AFM images of the AlGaN surfaces with and without the regrown AlN layer, respectively. Here, the latter sample is the same as that shown in our previous study [3]. As obvious in these images, the sample with the regrown AlN layer exhibited a smoother surface with clear atomic steps than that of the other sample. Also, the measured root mean square (RMS) roughness was significantly reduced from 1.2 nm to 0.26 nm. Then, an InAlN/AlGaN 2DEG heterostructure with the regrown AlN layer was prepared, and their electrical characteristics were evaluated. Table I summarizes the room-temperature 2DEG properties of InAlN/AlGaN heterostructures, which also shows their precise alloy compositions determined by X-ray diffraction measurements. The obtained results revealed that the sample with the regrown AlN layer exhibited a high 2DEG mobility of 242 cm^2/Vs and a similar 2DEG density of $2.6 \times 10^{13}/cm^2$ compared to our past samples [3]. Consequently, the present sample showed a low sheet resistance of 998 Ω/sq, which is much closer to that of the conventional AlGaN/GaN 2DEG heterostructures than those of our past samples.

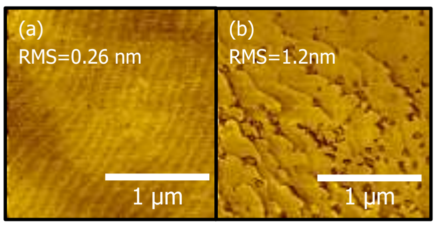

Fig.2. AFM images of the AlGaN surface morphologies for samples (a) with and (b) without the regrown AlN layer.

Table I Room-temperature 2DEG density (N_S), mobility (μ), and sheet resistance (R_{sh}) values of InAlN/AlGaN HFET structures measured by Hall effect measurements

Sample structure		N_S (cm^{-2})	μ (cm2/Vs)	R_{sh} (Ω/sq)
w/o regrown	$In_{0.14}Al_{0.86}N/Al_{0.1}Ga_{0.9}N$	3.0×10^{13}	165	1,267
AlN layer	$In_{0.12}Al_{0.88}N/Al_{0.21}Ga_{0.79}N$	2.8×10^{13}	162	1,477
(Ref.[3])	$In_{0.1}Al_{0.9}N/Al_{0.34}Ga_{0.66}N$	2.5×10^{13}	130	1,919
w/ regrown	$In_{0.17}Al_{0.83}N/Al_{0.15}Ga_{0.85}N$	2.6×10^{13}	242	998
AlN layer	$In_{0.17}Al_{0.83}N/Al_{0.15}Ga_{0.85}N$ (77 K)	2.6×10^{13}	375	631

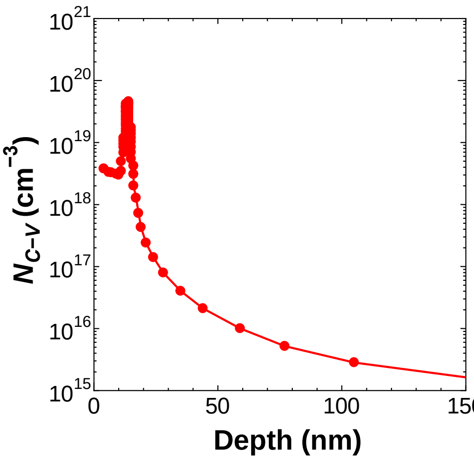

Fig. 3. *C-V* depth profiling of 2DEG in the InAlN/AlGaN heterostructure with regrown AlN layer.

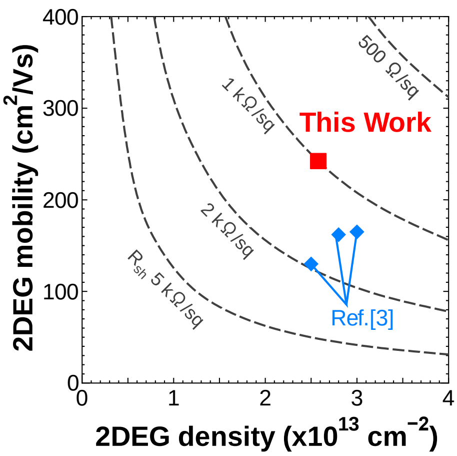

Fig. 4. Relationship between the measured 2DEG densities and mobilities for InAlN/AlGaN HFET structures. The dashed lines represent constant sheet resistance lines.

Fig. 3 shows the result of the *C-V* depth profiling. As the figure clearly shows, electrons were highly concentrated at a depth of approximately 15 nm that corresponds to the InAlN barrier thickness. Thus, it was confirmed that the electrons were two-dimensionally generated at the InAlN/AlGaN heterointerface. Fig. 4 shows the relationship between the measured 2DEG densities and mobilities. Also, Fig. 5 shows the relationship between Al content in AlGaN channel and the 2DEG mobilities. These figures obviously indicate that the 2DEG mobility of the InAlN/AlGaN 2DEG heterostructure was considerably improved with the introduction of the regrown AlN layer.

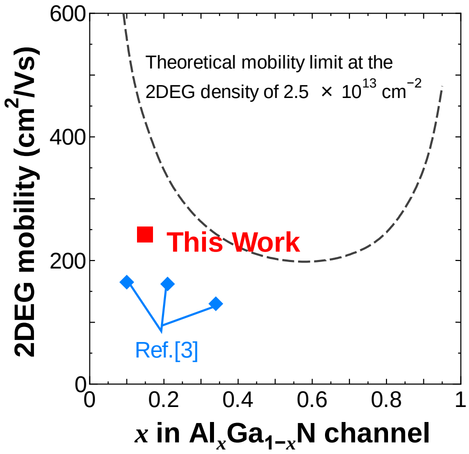

Fig. 5. Relationship between Al content in AlGaN channel and the 2DEG mobilities. The dashed line presents the theoretical mobility limit [5] at a constant 2DEG density of 2.5 x 10^{13} cm^{-2}

4. Conclusion

We attempted to improve the 2DEG mobility in InAlN/AlGaN 2DEG heterostructures by achieving an atomically-smooth heterointerface. It was confirmed that the introduction of a “regrown AlN layer” can improve the AlGaN surface roughness and thereby results in a high 2DEG mobility. An InAlN/AlGaN heterostructure with the regrown AlN layer showed an improved 2DEG mobility of 242 cm^2/Vs with a 2DEG density of 2.6 × 10^{13}/cm^2.

Acknowledgements

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