Progress of N-polar GaN/AlN HEMT through N-polar AlN surface treatment and optimization of GaN channel

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Introduction

N-polar GaN/AlN High Electron Mobility Transistors (HEMTs) can generate a two-dimensional electron gas (2DEG) without the need for an AlN cap layer, and furthermore, by employing AlN as the underlying substrate, they offer the potential to achieve higher power, higher breakdown voltage, and high-temperature operation compared to the conventional AlGaN/GaN HEMT structure. In our laboratory, we have demonstrated the operation of N-polar GaN/AlGaN/AlN HEMTs grown by metalorganic vapor phase epitaxy (MOVPE) [1]. In this presentation, we will discuss the crystal growth of N-polar GaN/AlN HEMT structure on sapphire substrates and the device performances.

Results and Discussion

For growing N-polar AlN on sapphire substrates by MOVPE, maintaining a low V/III ratio is crucial. In addition, controlling the 2.0° off-cut angle is essential to achieve surface flatness [2]. At this condition, the root-mean-square (RMS) roughness measured by atomic force microscopy (AFM) was about 1 nm. To achieve further flattening, we developed a method called "hydrogen pulse etching," in which the N-polar AlN surface is etched by hydrogen during growth, enabling us to reduce the RMS roughness down to ~0.4 nm [3].

On the other hand, it is well known that nitride semiconductors grown on sapphire substrates typically exhibit a high density of threading dislocations, the N-polar AlN templates have also high dislocation densities. To address this issue, we successfully reduced the dislocation density of N-polar AlN on sapphire by employing a mechanism of dislocation annihilation via tiny-pits structures formed on Al-polar surfaces, combined with polarity inversion from Al-polar to N-polar [4].

After achieving flattening and crystal quality improvement of N-polar AlN on sapphire, we grew an N-polar GaN/$Al_{0.9}Ga_{0.1}N$/AlN HEMT structure. A 2-nm SiO_2 layer was deposited on the GaN channel surface, and the device was fabricated using Ti/Al/Ti/Au as source and drain electrodes, and Ni/Au as the gate electrode. The growth conditions of the GaN layer were found to be critical for realizing the N-polar GaN/$Al_{0.9}Ga_{0.1}N$/AlN structure, especially the growth temperature below 800 °C. Furthermore, reducing the impurity concentration in the GaN channel proved essential for performance improvement, with optimization of the V/III ratio, flow modulation method and the F-value (the H_2/N_2 carrier gas ratio) being particularly effective. Additionally, lowering the threading dislocation density contributed to increased drain current.

As a result, N-polar GaN/AlGaN/AlN HEMTs grown on sapphire substrates by MOVPE have achieved a maximum drain current exceeding 400 mA/mm as shown in Fig.1.

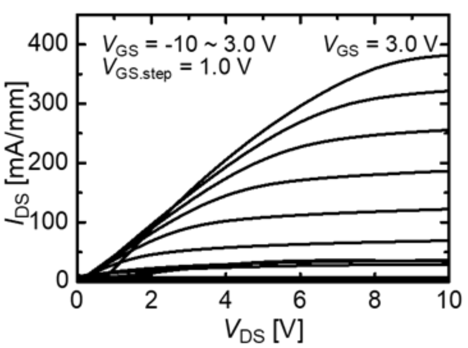

Fig. 1 I_D-V_{DS} static characteristic of N-polar GaN/AlGaN/AlN HEMT

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