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Enhancement-mode AlGaN/GaN HEMTs by selective area growth of AlGaN layer with Al_2O_3 deposition

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Abstract

An enhancement-mode (E-mode) AlGaN/GaN HEMT was successfully fabricated by selective area growth of an AlGaN layer with Al_2O_3 film deposition. The regrown AlGaN layer on a completely depleted AlGaN/GaN heterostructure generates two-dimensional electron gas. In addition, deposition of the Al_2O_3 film further increases carrier concentration. The fabricated HEMT shows a threshold voltage of +0.5 V, the high maximum drain density more than 400 mA/mm, and the maximum transconductance of 160 mS/mm.

1. Introduction

GaN based HEMTs have attractive for high power switching applications. Enhancement mode (E-mode) operation was one of major requirements for AlGaN/GaN HEMTs. However, realization of E-mode simultaneously with low on-resistance is difficult due to the existence of two-dimensional electron gas (2DEG) in heterointerface induced piezo and spontaneous polarization charges. Selective area growth (SAG) technique was considered to be one of solutions for E-mode operation [1, 2].

In this paper, we report E-mode AlGaN/GaN HEMTs with SAG of an AlGaN layer and deposition of an Al_2O_3 film on an AlGaN/GaN heterostructure designed to be completely depleted.

2. Epitaxial layer and access region design for E-mode HEMT

In an E-mode AlGaN/GaN HEMT, depletion of 2DEG under the gate and high carrier concentration at an access region must be realized. In order to simultaneously obtain these opposite characteristics in a single structure, we designed an AlGaN/GaN heterostructure fabricated by epitaxial growth with depleted 2DEG and used SAG and insulator deposition for carrier generation.

The initial epitaxial layer for E-mode operation consisted of a GaN channel layer, a 1-nm-thick AlN spacer and a 5-nm-thick $Al_{0.2}Ga_{0.8}N$ layer (Fig. 1(a)).

To confirm generation of a 2DEG at the interface between AlN and GaN, an AlGaN layer was regrown on the E-mode structure (Fig. 1(b)). Moreover, Al_2O_3 film was deposited on the regrown AlGaN layer by atomic layer deposition (ALD) (Fig. 1(c)).

An ohmic electrode was fabricated on all three structures for evaluation of their *I-V* characteristics.

Fig. 2 shows *I-V* characteristics for three devices with an ohmic electrode gap of 10 μm. For the device shown in Fig. 1(a) (only the initial growth structure), only 8.5×10^{-5} A/mm at 10 V was observed, which indicates that 2DEG is completely depleted as designed.

On the other hand, the regrowth structure (Fig. 1(b)) shows that a current density is significantly increased to 340 mA/mm at 10 V. Moreover, a combination of the regrown AlGaN layer and the ALD-deposited Al_2O_3 film increase the current density, resulting from further enhancement of the 2DEG concentration. Supposing that the regrown AlGaN and Al_2O_3 structure is used for the access region of the HEMT, we evaluated a sheet resistance (R_{sh}) of 650Ω/□ and a specific contact resistance (r_c) of 1.0 Ω·mm by transmission line measurement.

3. E-mode HEMT structure and its characteristics

Fig. 3 shows cross-sectional schematic of a fabricated E-mode AlGaN/GaN HEMT. The AlGaN layer was selectively regrown on the first epitaxial layer using a SiO_2 mask. An Al content of the regrown AlGaN layer was 20%. The gate length of the device is 3.7 μm, and both a source-to-gate and a drain-to-gate spacing are 2.5 μm. The gap between the regrowth AlGaN layer and the gate electrode, on which the Al_2O_3 film was deposited, is 0.7 μm.

An actual thickness of the selectively regrown AlGaN layer was confirmed to approximately 4 nm by atomic force microscopy (Fig. 4).

Fig. 5 shows typical drain *I-V* characteristics of the fabricated SAG AlGaN/GaN HEMT. A drain current density at a gate voltage of 2 V was 240 mA/mm. An on-resistance evaluated at V_g = 1.5 V was 8.4 Ω·mm.

Fig. 6 shows transfer characteristics of the SAG HEMT. E-mode operation was successfully confirmed with a threshold voltage of +0.5 V, which was extracted from a linear plot in transfer characteristics. The maximum drain current achieves as high as 400 mA/mm. The peak transconductance (g_m) was 160 mS/mm at a drain voltage (V_d) of 4 V.

4. Summary

The regrown AlGaN layer on the completely depleted AlGaN/GaN heterostructure generates two dimensional electron gas. Deposition of the Al_2O_3 film further increases carrier concentration.

Adopting AlGaN regrowth in a selective area (SAG) and Al_2O_3 film deposition for the access region of the HEMT, we successfully demonstrated E-mode operation of the AlGaN/GaN HEMT. The fabricated device showed the high maximum drain current density of 400 mA/mm with a threshold voltage of 0.5 V and a peak transconductance of 160 mS/mm.

References

[1] Y. Wen et al., Appl. Phys. Lett. **98** (2011) 072108.
[2] Y. Yao *et al.*, Appl. Phys. Express **7** (2014) 016502.

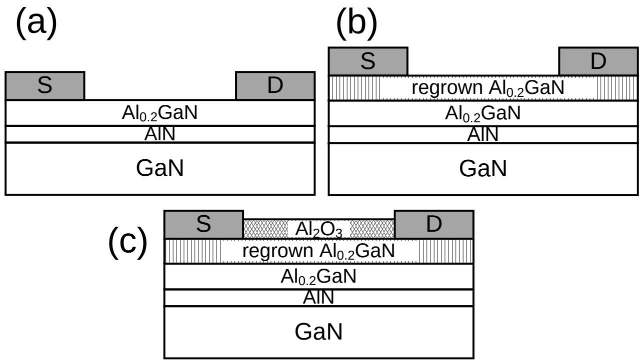

Fig. 1. Schematic cross sections for evaluation of AlGaN regrowth and Al_2O_3 deposition. (a) Initial epitaxial structure, (b) AlGaN regrown structure, and (c) AlGaN regrown and Al_2O_3 deposited structure.

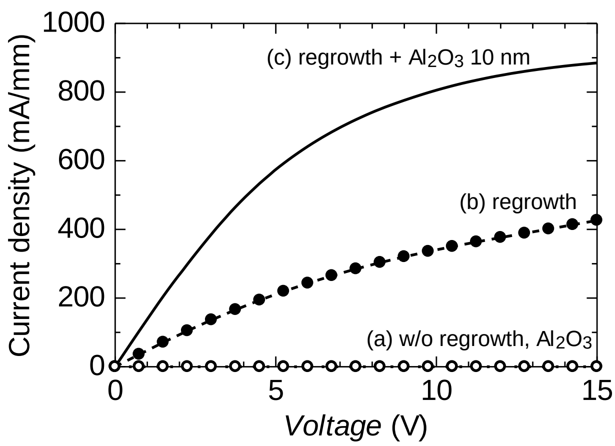

Fig. 2. Current-voltage characteristics for 3structuers as shown in Fig. 1. The ohmic contact spacing is 10 μm.

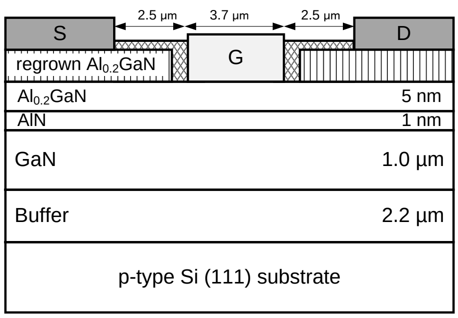

Fig. 3. Schematic cross-sections of SAG AlGaN/GaN HEMT with Al_2O_3 deposition.

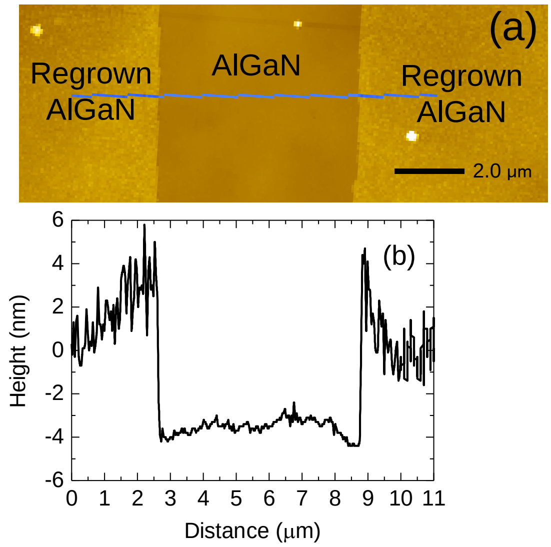

Fig. 4. (a) AFM image of a regrown AlGaN layer on the initial epitaxial layer of the AlGaN/GaN heterostructure. (b) cross-sectional profiles along the blue cut line in (a).

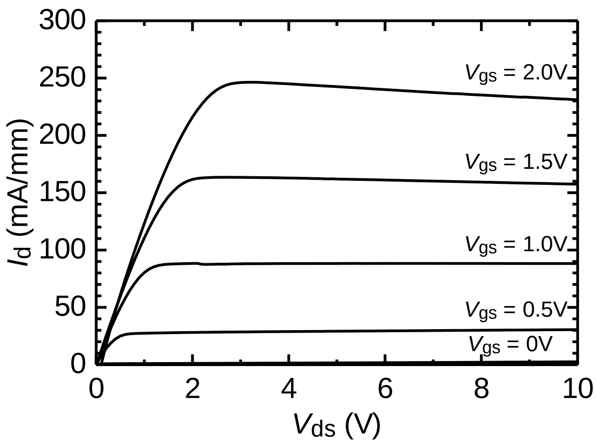

Fig. 5. Typical drain *I*-*V* characteristics of the SAG AlGaN/GaN HEMT.

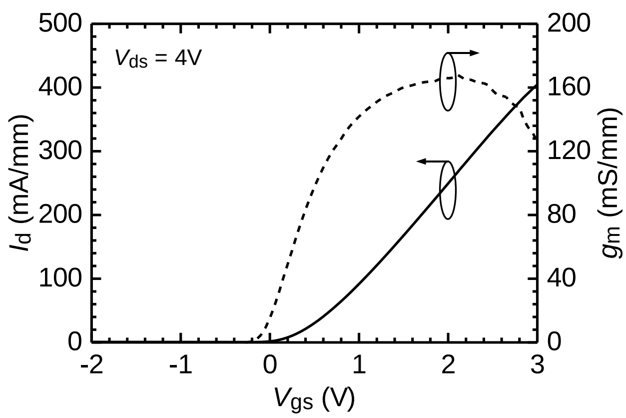

Fig. 6. Transfer characteristics of the SAG AlGaN/GaN HEMT.