Student Paper

Enhancement-Mode GaN MOS-HEMT with Quaternary InAlGaN-Barrier

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Gallium nitride (GaN) has wide-bandgap (3.4eV) and the high critical electric field (up to 3 MV/cm) useful for high-voltage power devices. Conventional AlGaN/GaN HEMT is depletion-mode due to two-dimensional electron gas (2DEG) induced spontaneous and piezoelectric polarization effects [1]. In order to apply to minimize the stand-by power consumption and the high-power switching, the requirement of normally-off for the devices is necessary [2]. The threshold voltage (V_{th}) of the HEMTs depends on epitaxial structure with Al composition, barrier thickness, and work function of gate metal [3]. Besides, the devices structure relates to the V_{th} to achieve normally off operation are gate recess [4], fluoride-based plasma treatment [5], and InGaN capping layer [6]. The bandgap of indium nitride (InN) and aluminum nitride (AlN) with values are 0.87 and 6.2 eV, respectively [7]. In this work, we proposed an InAlGaN-barrier GaN MOS-HEMT with enhancement- mode (E-mode) operation. Lowing conduction band offset (ΔEc) at the $Al_xGa_{1-x}N$/GaN interface may cause the V_{th} positive shift, and add Indium (In) for the barrier layer to decrease ΔEc to complete E-mode MOS-HEMT.

The nitride-based heterojunction was grown on 2-inch sapphire substrate by Metal Organic Chemical Vapor Deposition (MOCVD). The quaternary InAlGaN was grown on 2μm-thick GaN buffer layer with 30nm and the composition are $In_{0.02}Al_{0.25}Ga_{0.73}N$. The sheet resistance of the structure was about 680Ω/sq., and the prior to treatments the surface was cleaned with hydrochloric acid solution [8]. For the MOS-HEMT fabrication process, the gate-last process was carried-out in this work (Fig. 1). After all cleaning, the Ohmic S/D contacts were placed by the liftoff technique using Ti/Al (25/125nm) and rapid thermal annealing at 600°C for 30sec in N_2 ambient. Then, deposition of 8nm TiO_2 gate dielectric by atomic layer deposition (ALD) at 250°C. Gate electrode was patterned by lithography and evaporated with Ni/Au (30/30nm) by electron-beam. The oxide on S/D region was removed by inductively coupled plasma reactive ion etching (ICP-RIE) with CHF_3 gas.

Measured reciprocal space mapping (RSM) (Fig. 2) and Rocking-curve by High-Resolution X-ray Diffraction (HR-XRD) (Fig. 3) for epitaxial quality was indicated the peaks for InGaN, GaN, and AlGaN, and confirmed the composition for quaternary. Due to relax in InAlGaN/GaN interface may induce lower the 2-DEG concentration and lower mobility in channel by RSM analyze. The DC characteristics of the devices were performed by Agilent B1500A. The specific contact resistance was $1.74\times10^{-4}\Omega cm^2$, which extracted from transmission line model (TLM) measurement. The transfer characteristics (I_{DS}-V_{GS}) was shown the feature of normally-off at V_{GS}=0V with V_{DS}=10V, and V_{th}=0.65V (Fig. 4). The smaller driving current is due partial relaxation occurred in InAlGaN as compare with previous study of quaternary nitride-based HFET (heterojunction FET) [9]. The positive polarity of V_{th} was obtained with gate length 3-30μm and short channel effect was observed. The property of normally-off operation was displayed for high-power switching and reduction the power consumption during stand-by state.

In conclusion, the quaternary InAlGaN-Barrier GaN MOS-HEMT with E-Mode operation was demonstrated. Lowing ΔEc at the $Al_xGa_{1-x}N$/GaN interface may cause the V_{th} positive shift, and add indium for the barrier layer to decrease ΔEc to complete E-mode MOS-HEMT. Measured Rocking- curve RSM for epitaxial quality was confirmed the composition for quaternary. The MOS-HEMT with L_G=15μm and L_{GD}=20μm has V_{th}=0.65V. The positive polarity of V_{th} was obtained with gate length 3-30μm and short channel effect was observed. The potential quaternary InAlGaN-barrier GaN MOS-HEMT may be as a candidate to pave a way for future power applications.

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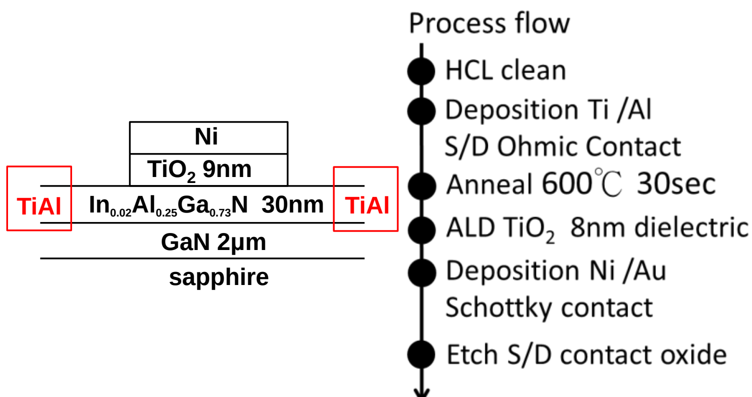

(a) (b)

Fig. 1 (a) Cross-section schematic of quaternary InAlGaN-barrier GaN MOS-HEMT. (b) The fabrication process flow.

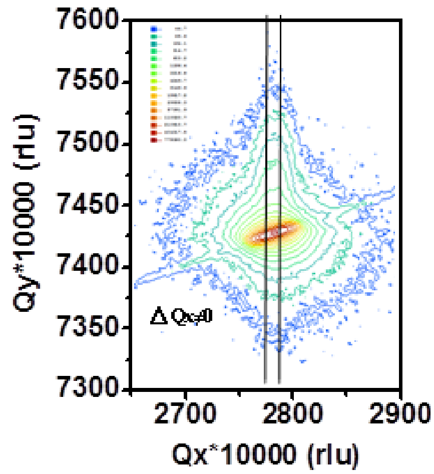

Fig. 2 The reciprocal space mapping of the (105) reflection for quaternary InAlGaN-barrier GaN.

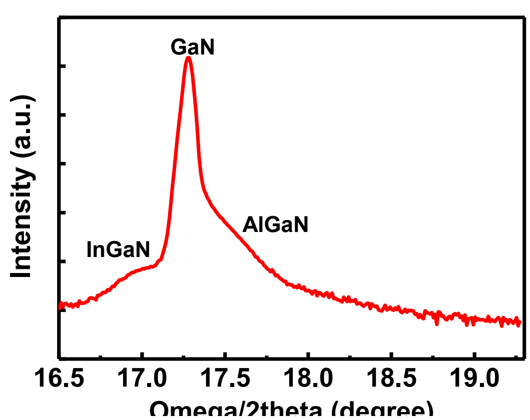

Fig. 3 HR-XRD scans for (002) of quaternary InAlGaN-barrier GaN.

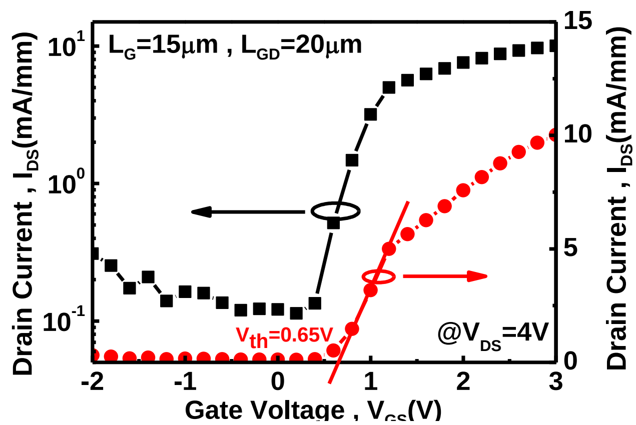

Fig. 4 The transfer characteristics (I_{DS}-V_{GS}) was shown the feature of normally-off at V_{GS}=0V with V_{DS}=10V.