High Performance Self-aligned AlN/GaN MISHEMT with In-situ SiNx Gate Dielectric and Regrown Source/Drain

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Ultra-thin barrier AlN/GaN high electron mobility transistors (HEMTs) offer better performance over conventional AlGaN/GaN devices because of its relatively large two-dimensional electron gas (2DEG) concentration and the good carrier confinement using AlN barrier. However, the ultra-thin AlN barriers suffer from surface sensitivity and large gate leakage currents unless they are well protected. In-situ SiNx grown by MOCVD has been demonstrated to be advantageous over other ex-situ deposited insulators for AlN/GaN HEMTs, such as better surface passivation effects and the elimination of process- and growth- related defects [1], [2]. On the other hand, the high potential barrier of AlN makes it difficult to form low contact resistance to the channel. One emerging alternative device design is incorporating regrown source/drain for ohmic contact [3]. In this work, in-situ SiNx gate dielectric and selectively-regrown source/drain were applied in self-aligned AlN/GaN MISHEMTs grown on sapphire substrates, as shown in Fig.1. The sub-micron gated device have exhibited drain current exceeding 1700mA/mm with a low on-resistance of 1.61 Ω-mm and an on/off ratio of over 10^7.

We developed a gate-last self-aligned process for the fabrication of MISHEMTs with in-situ SiNx gate dielectric and regrown source/drain. The SiO2 dummy gate with SiNx spacers was firstly formed on the as-grown in-situ SiNx/AlN/GaN MISHEMT sample as regrowth mask, the source/drain regions were exposed by dry etching down to the GaN buffer layer. Heavily n-doped GaN source/drain regions were regrown in an AIXTRON2000HT MOCVD system. Mesa etching was then performed for device isolation. After source/drain metal (Cr/Au) deposition, BCB planarization process was conducted to expose the SiO2 dummy gate. Finally, the dummy gate was removed by BOE and replaced with the Ni/Au metal gate. The process flow is depicted in Fig.2. Fig. 3 shows an AFM image of the as-grown MISHEMT sample.

With transmission-line modeling (TLM) measurement, the 180nm thick regrown n+-GaN showed a sheet resistance of 157 Ω/□ and the contact resistance of metal on regrown-GaN is 0.312 Ω-mm. The DC output and transfer characteristics of a 0.4 μm gated MISHEMT are shown in Fig.4 and Fig. 5. The device exhibited a maximum drain current of 1702 mA/mm and the on-resistance was as low as 1.61Ω-mm. The off-state breakdown voltage at VGS = -5 V (Id = 1 mA/mm) was 21.2 V for the device with gate-to-n⁺ GaN spacing of 55 nm. The peak transconductance was 372 mS/mm at VDS = 6 V and VGS = -0.5 V. A low gate leakage current of 2.5×10⁻⁵ mA/mm and a high on/off ratio of over 10⁷ were achieved.

Fig. 1 Schematic diagram of self-aligned AlN/GaN MISHEMTs.

Fig. 2 Schematic diagram of the self-aligned process.

Fig. 3 AFM image of the as-grown MISHEMT sample. RMS value is 1.07 nm across a 5 μm × 5 μm scanned area.

Fig. 4 DC output characteristic of the 0.4 μm gated MISHEMT.

Fig. 5 Transfer characteristic of the 0.4 μm gated MISHEMT.