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Al2O3-Dielectric AlGaN/GaN Enhancement-Mode MOS-HEMTs by Using Ozone Water Oxidization Technique

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Abstract : AlGaN/GaN high electron mobility transistors (HEMTs) have been intensively studied due to their intrinsic advantages of high breakdown electric field, high electron saturation velocity, and excellent chemical stability. They are also suitable for ultra-violet (UV) photodetection due to the corresponding wavelengths of GaN bandgap. To improve the optical responsivity by decreasing the dark current due to gate leakage problems and limited Schottky barrier heights in GaN-based HEMT devices, various metal-oxide-semiconductor HEMTs (MOS-HEMTs) have been devised by using atomic layer deposition (ALD), molecular beam epitaxy (MBE), metal-organic chemical vapor deposition (MOCVD), liquid phase deposition (LPD), and RF sputtering. The gate dielectrics include MgO, HfO2, Al2O3, La2O3, and TiO2. In order to provide complementary circuit operation, enhancement-mode (E-mode) devices have been lately studied using techniques of fluorine treatment, p-type capper, piezoneutralization layer, and MOS-gate structure. This work reports an Al2O3-dielectric Al0.25Ga0.75N/GaN E-mode MOS-HEMT design by using a cost-effective ozone water oxidization technique. The present ozone oxidization method advantages of low cost processing facility, processing simplicity, compatibility to device fabrication, and room-temperature operation under atmospheric pressure. It can further reduce the gate-to-channel distance and improve the transocnductance (gm) gain for a specific oxide thickness, since the formation of the Al2O3 will consume part of the AlGaN barrier at the same time. The epitaxial structure of the studied devices was grown by using the MOCVD technique. On a Si substrate, the layer structures include a 3.9 μm C-doped GaN buffer, a 300 nm GaN channel layer, and a 5 nm Al0.25Ga0.75N barrier layer. Mesa etching was performed to provide electrical isolation by using an inductively coupled-plasma reactive ion etcher (ICP-RIE). Ti/Al/Au were thermally evaporated and annealed to form the source and drain ohmic contacts. The device was immersed into the H2O2 solution pumped with ozone gas generated by using an OW-K2 ozone generator. Ni/Au were deposited as the gate electrode to complete device fabrication of MOS-HEMT. The formed Al2O3 oxide thickness 7 nm and the remained AlGaN barrier thickness is 2 nm. A reference HEMT device has also been fabricated in comparison on the same epitaxial structure. The gate dimensions are 1.2 × 100 μm 2 with a source-to-drain spacing of 5 μm for both devices. The dielectric constant (k) of Al2O3 was characterized to be 9.2 by using C-V measurement. Reduced interface state density after oxidization has been verified by the low-frequency noise spectra, Hooge coefficients, and pulse I-V measurement. Improved device characteristics at temperatures of 300 K-450 K have been achieved for the present MOS-HEMT design. Consequently, Al2O3-dielectric Al0.25Ga0.75N/GaN E-mode MOS-HEMTs by using the ozone water oxidization method are reported. In comparison with a conventional Schottky-gate HEMT, the MOS-HEMT design has demonstrated excellent enhancements of 138% (176%) in gm, max, 118% (139%) in IDS, max, 53% (62%) in BVGD, 3 (2)-order reduction in IG leakage at VGD = -60 V at 300 (450) K. This work is promising for millimeter-wave integrated circuit (MMIC) and three-terminal active UV photodetector applications.

Keywords : MOS-HEMT, enhancement mode, AlGaN/GaN, passivation, ozone water oxidation, gate leakage
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