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RF Power Characteristics of the AlGaN/GaN HEMTs with Molecular Beam Deposition CeO_2 as Gate Insulator

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Abstract

Molecular beam deposition (MBD) cerium-oxide (CeO_2) was applied to AlGaN/GaN high-electron-mobility transistors (HEMTs) as a gate insulator for RF-power applications. The C-V curves was shown clear accumulation and depletion behaviors with a small hysteresis (ΔV= 10 mV). A CeO_2 MOS-HEMT with 0.5 µm gate length was demonstrated an output power of 25.5 dBm, a power gain of 20.7 dB and a power-added-efficiency of 24.5%, whereas the gate leakage current density is six orders of magnitude lower than a conventional GaN HEMTs. The high-performance sub-micrometer MOS-HEMT is highly promising for microwave power amplifier applications.

1. Introduction

GaN HEMTs is considered as a promising candidate for the next generation of microwave power devices due to its excellent physical properties.[1)]

In conventional AlGaN/GaN HEMTs with Schottly metal gate, high gate leakage current and current collapse are usually observed in microwave or high voltage applications. Several methods are proposed to improve performance of the devices, one of the methods, high-κ dielectric materials are applied on AlGaN/GaN HEMTs as the gate dielectric and/or passivation layer. Recently, high-κ cerium-based oxides are very attractive materials for technological applications.[13-15)] The CeO_2 has excellent material properties, such as a high permittivity of ~26, a high band gap of ~6 eV, and a high critical electrical field of 4.9 MV/cm.[2-4)]

In this study, the DC and microwave characteristics of CeO_2/AlGaN/GaN MOS-HEMTs were investigated. The CeO_2 as gate dielectric was prepared by MBD grown on the AlGaN/GaN heterostructures. The DC characteristics and microwave properties of the CeO_2 MOS-HEMTs are compared with the conventional AlGaN/GaN HEMTs.

2. Experimental procedure

The AlGaN/GaN HEMTs structure were grown by MOCVD on Si. The epitaxial structure consisted of 2 µm-thick GaN buffer, ~1 nm AlN spacer, 22 nm $Al_{0.22}$GaNN barrier, and 2 nm GaN cap. All the layers are un-doped.

The Ti/Al/Ni/Au were deposited first as ohmic contacts by electron-beam gun (E-Gun) and then annealed at 800℃ for 60s. The active region was defined by the BCl_3/Cl_2 plasma etcher. A 14 nm CeO_2 film was applied as a gate dielectric for the AlGaN/GaN structure by MBD. Post-deposition annealing (PDA) was carried out at 400°C for 10 min. The ZEP/PMGI/ZEP was used for gate formation by JEOL electron-beam system. Ni/Au was deposited as gate metal by E-Gun. Devices with the gate length of 0.5 µm and the gate width of 200 µm were prepared. The Schottky gate of AlGaN/GaN HEMTs was fabricated for performance comparison.

3. Experimental procedure

Figure 1 shows the C-V hysteresis effect of the MIS capacitor with a diameter of 50 μm measured at 10 kHz. A tiny C-V hysteresis (ΔV= 10 mV) of the MIS capacitor was observed in CeO_2 film at 10 kHz. It indicates fewer bulk traps in the dielectric.

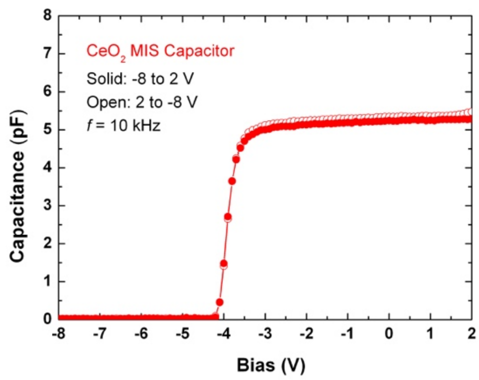

Fig. 1. The C-V hysteresis effect of the CeO_2 MIS capacitor was measured at 10 KHz with a diameter of 50 μm

Figure 2 shows the current density-voltage curves of the CeO_2 MIS capacitor and the Schottky diode. It is seen that

CeO_2 MIS capacitor exhibits a significantly reduced gate leakage current compared to the Schottky diode. At the forward bias (V_{FB}= 2 V), a six orders of magnitude lower gate leakage was obtained in the CeO_2 MIS capacitor as compared to the device with the Schottky gate.

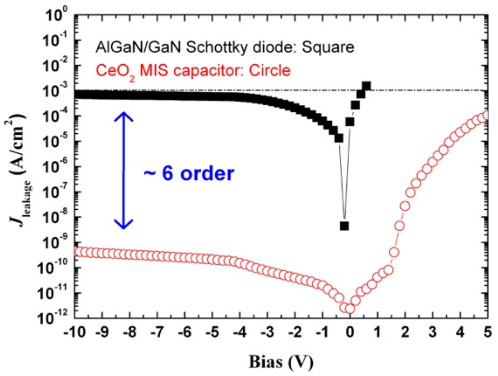

Fig. 2 Comparison of gate leakage characteristics for CeO_2 MIS capacitor and Schottky diode.

Figure 3 shows the DC characteristics of the MOS-HEMT and conventional GaN HEMT devices. From the I_{DS}-V_{DS} properties, the saturation drain-current (I_{DSS}) of CeO_2 MOS-HEMT was 580 mA/mm, while the I_{DSS} of GaN HEMT was 595 mA/mm. From the I_{DS}-V_{GS} properties, the extrinsic transconductance (g_m) of CeO_2 MOS-HEMT and GaN HEMT were 150 and 165 mS/mm, respectively. The threshold voltage of CeO_2 MOS-HEMT and GaN HEMT was -3.9 and -4.2 V, respectively. It indicates that the threshold voltage shift was reduced with increasing dielectric permittivity when the thickness of the insulator layer was fixed.[4]

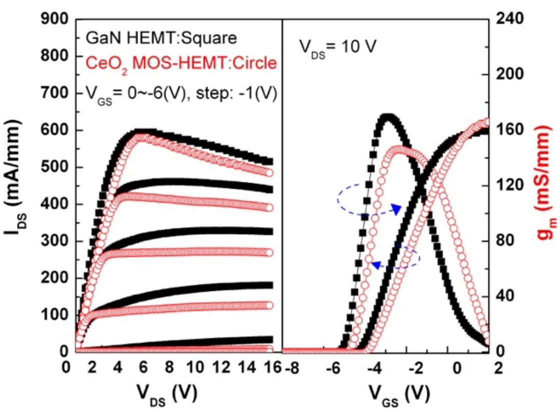

Fig. 3. Comparison of I_{DS}-V_{DS} characteristics and I_{DS}-V_{GS} characteristics.

Figure 4 shows the RF power characteristics of the device with the dimension of 0.5 ×200 μm^2. The microwave measurement of the devices was measured at 2.4 GHz with V_{DS} of 30 V. The devices were operated at a class AB. As can be seen in this figure, the maximum output power density and maximum power-add efficiency were 25.5 dBm and 24.5% for CeO_2 MOS-HEMT, which was better than the GaN HEMT with measured values of 22.7 mm and 18.5%, respectively. The power gain of the CeO_2 MOS-HEMT and GaN HEMT were 20.7 dB and 18.9 dB. The result indicates that the DC- and RF-characteristics of the device performances were obviously improved by inserting the dielectric layer.[5]

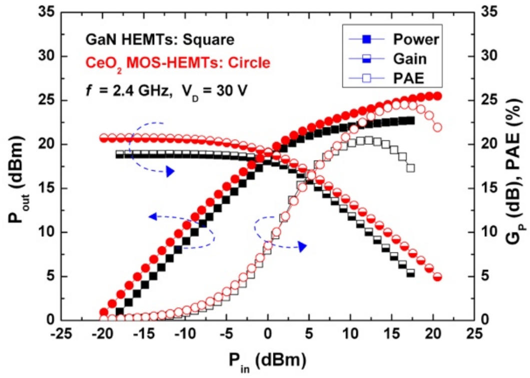

Fig. 4. Comparison of the RF power characteristics for 0.5 ×200 μm^2 devices measured at 2.4 GHz for both CeO_2 MOS-HEMT and GaN HEMT.

3. Conclusions

The DC- and microwave-power characteristics of high-κ CeO_2 dielectric as a gate insulator on AlGaN/GaN HEMT was investigated. The hysteresis of the C-V curve of the CeO_2 MIS capacitor was extremely small (~10mV). A reduction of the leakage current by six orders for the CeO_2 MIS capacitor was achieved. A maximum output power density of 1.8 W/mm and a power-added-efficiency of 24.5% were improved by the AlGaN/GaN HEMTs with the CeO_2 film. Based on the device performances, the results illustrated that low gate leakage and low surface state CeO_2 MOS-HEMTs demonstrate a high potential for RF-power applications.

Acknowledgements

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