English
Research Express@NCKU Volume 5 Issue 5 - August 15, 2008
[http://research.ncku.edu.tw/re/articles/e/20080815/2.html]

AlGaN/GaN Metal-Oxide-Semiconductor High-Electron Mobility Transistors Using Oxide Insulator Grown by Photoelectrochmical Oxidation Method

Li-Hsien Huang, Shu-Hao Yeh, Ching-Ting Lee*, Haipeng Tang, Jennifer Bardwell, and James B. Webb.

Institute of Microelectronics, Department of Electrical Engineering, National Cheng-Kung University
Email: ctlee@ee.ncku.edu.tw

IEEE Electron Device Letters, 2008, 29, 284.

In recent years, III-V nitride-based materials have arouse many interests due to their high electron mobility, direct energy bandgap, better thermal stability and chemical stability. They are used widely in electronic and optoelectronic devices, such as high-electron mobility field-effect transistors (HEMTs), metal-oxide-semiconductors high-electron mobility field-effect transistors (MOS-HEMTs), light-emitting diodes (LEDs), photodetectors (PDs), and laser diodes (LDs).

Comparing GaN-based HEMTs with GaN-based MOS-HEMTs, the latter has better performances in high-power and high-frequency applications in microwave systems and communication systems because they have small gate leakage current, large breakdown voltage, and large gate-voltage-swing (GVS). There are many dielectrics have been used for GaN-based MOS-HEMTs. However, these insulators deposited externally and not similar to growing SiO_2 on Si wafer using wet oxidation or thermal oxidation method. According to the reasons mentioned above, oxidize semiconductors directly to form insulators for MOS devices is an important issue.

A photoelectrochemical (PEC) oxidation method was used to oxidize GaN and AlGaN successfully. The interface-state density of GaN MOS diodes and AlGaN MOS diodes with gate insulators grown using PEC oxidation method was $2.53\times10^{11}cm^{-2}eV^{-1}$ and $5.1\times10^{11}cm^{-2}eV^{-1}$, respectively. The forward breakdown field and reverse breakdown filed were larger than 2.2MV/cm and 5.8MV/cm, respectively. Those results show that PEC oxidation method can be a promising method to grow oxide layer for GaN-based MOS devices. In this study, the PEC oxidation method was used to oxidize AlGaN directly to form gate insulators for AlGaN/GaN MOS-HEMTs.

Figure 1 shows the schematic configuration of HEMTs structures used in this study, consisted of a 20 nm AlN nucleation layer, a 1.5 μm carbon-doped GaN buffer layer, a 0.3 μm GaN layer and an 100 nm AlGaN layer on sapphire substrate, grwon using molecular-beam epitaxy (MBE) system. This structure has sheet carrier concentration of 6.93×10^{12} cm^{-2} and Hall mobility of 1240 cm^2/Vs.

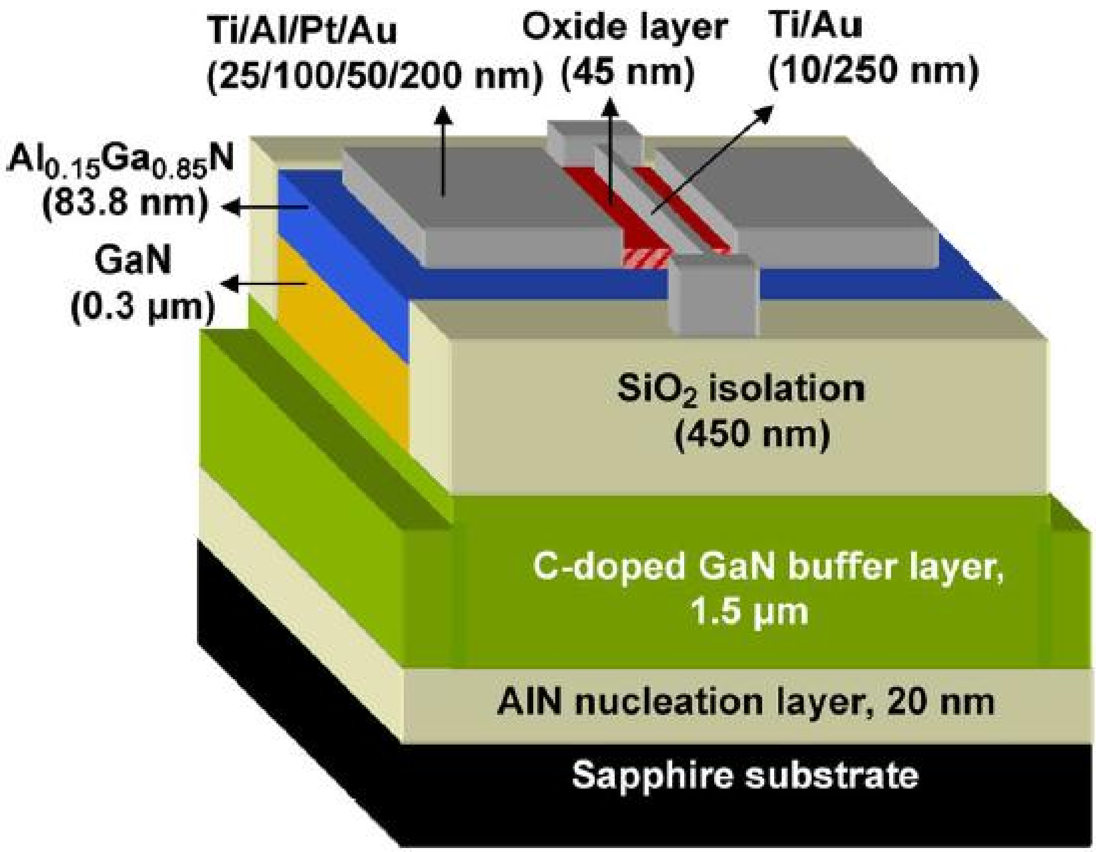

Figure 1. The schematic configuration of AlGaN/GaN MOS-HEMTs.

Ni/Au (50/600 nm) metal mask and reactive ion etching system were used to define mesa patterns. Then, SiO_2 (450 nm) were deposited to flatten surface and avoid breaking gate pads using a plasma-enhanced chemical vapor deposition (PECVD) system. A surface $(NH_4)_2S_x$-treatment was used to remove native oxide layer on AlGaN surface before depositing Ti/Al/Pt/Au (25/100/50/200 nm) to form ohmic metals. The ohmic properties were performed at 850 ˚C in N_2 ambient for 2 mins using a rapid thermal annealing system and can be maintained after annealing at 750 ˚C in N_2 ambient for 10 hrs. To grow gate insulators, the PEC oxidation method was used in this experiment. An He-Cd laser with a wavelength of 325 nm and H_3PO_4 chemical solutions with PH value of 3.5 were used in PEC process. The growth rate and thickness of as-grown oxide films was 10 nm/min and 65 nm, respectively. As the oxide films were grown, the thickness of AlGaN layer decreased minutely and the thickness of the remainder AlGaN layer was 83.8 nm. However, it was difficult to use as-grown oxide films in device process because they dissolved easily in developer, acid solutions and alkaloid solutions. After annealed the oxidized AlGaN films at 700 ˚C in O_2 ambient for 2 hrs, the annealed oxide films exhibited β-Ga_2O_3 and α-Al_2O_3 crystalline phases and can not be dissolved easily in developer, acid solutions and alkaloid solutions. The thickness of the annealed oxide films was 45 nm. Finally, Ti/Au (10/250 nm) were deposited on defined gate pad regions with gate length and gate width of 3 µm and 300 µm, respectively.

DC characteristics of AlGaN/GaN MOS-HEMTs were measured at room temperature using an HP 4145B semiconductor parameter analyzer. Figure 2 shows the output characteristics of resultant MOS-HEMTs with 45-nm-thick gate insulators. The MOS-HEMTs fabricated in this study are normally-on devices. When the gate-source bias decreased, the depletion regions extended and the drain-source current decreased. It can be seen that the drain-source current became almost zero when the $V_{GS}=-5$ V. This phenomenon means the MOS-HEMTs cut-off at $V_{GS}=-5$ V and the threshold voltage is −5 V. The drain-source current in saturation region (I_{DSS}) at $V_{GS}=0$ V is 200 mA/mm. Figure 3 shows the extrinsic transconductance (g_m) as a function of gate-source voltage at $V_{DS}=10$ V. This parameter means the ability of the gate-source voltage control the drain-source current. The maximum g_m value of 50 mS/mm obtained at $V_{GS}=-2.09$ V. To analyze the function of the annealed oxide films grown using PEC oxidation method, the gate-source current as a function of gate-source voltage was measured at room temperature using an HP 4145B semiconductor parameter analyzer. At $V_{GS}=-10$ V and $V_{GS}=10$ V, the gate leakage current was only 2 pA and 50 pA, respectively.

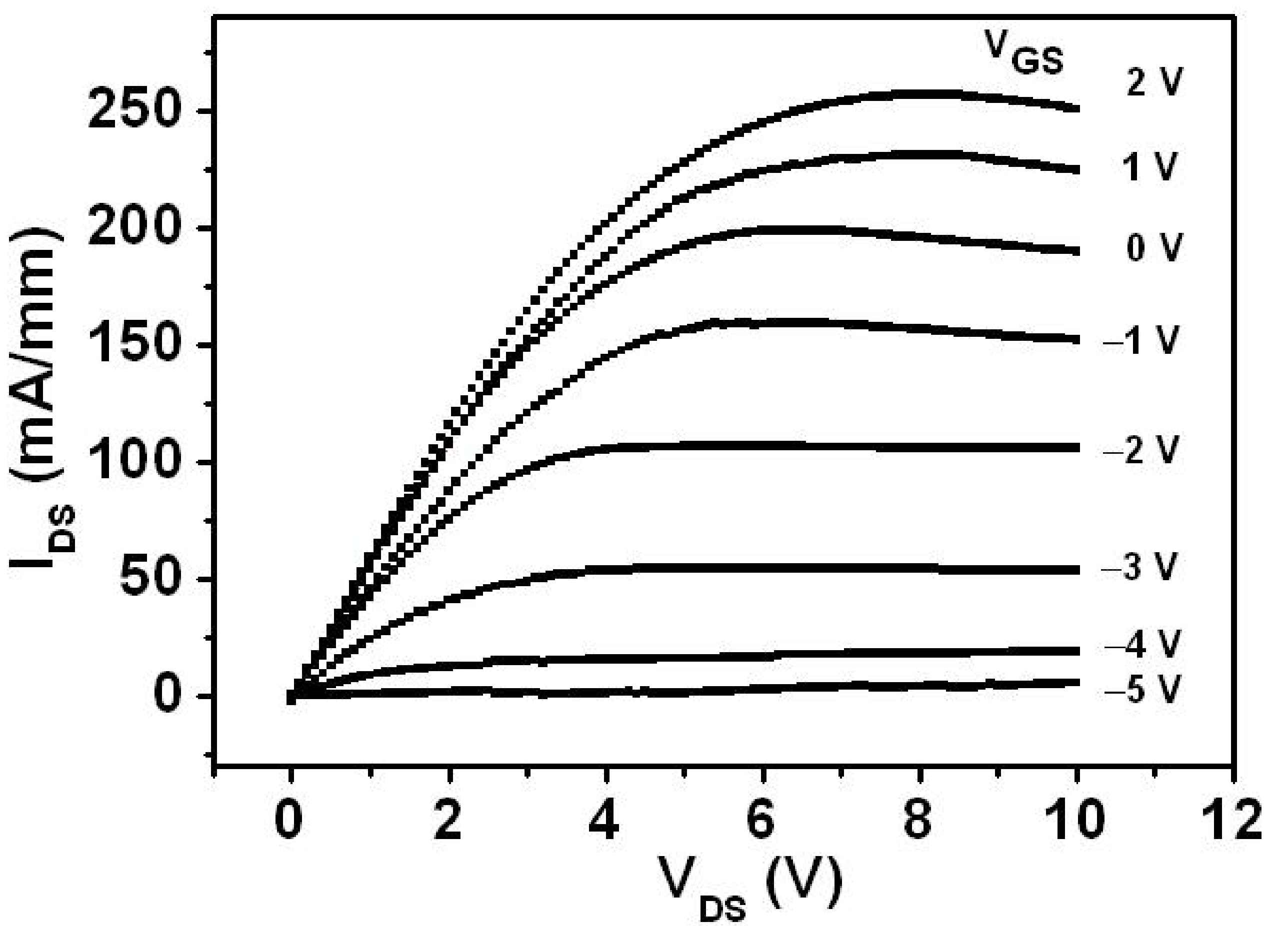

Figure 2. The output characteristics of AlGaN/GaN MOS-HEMTs.

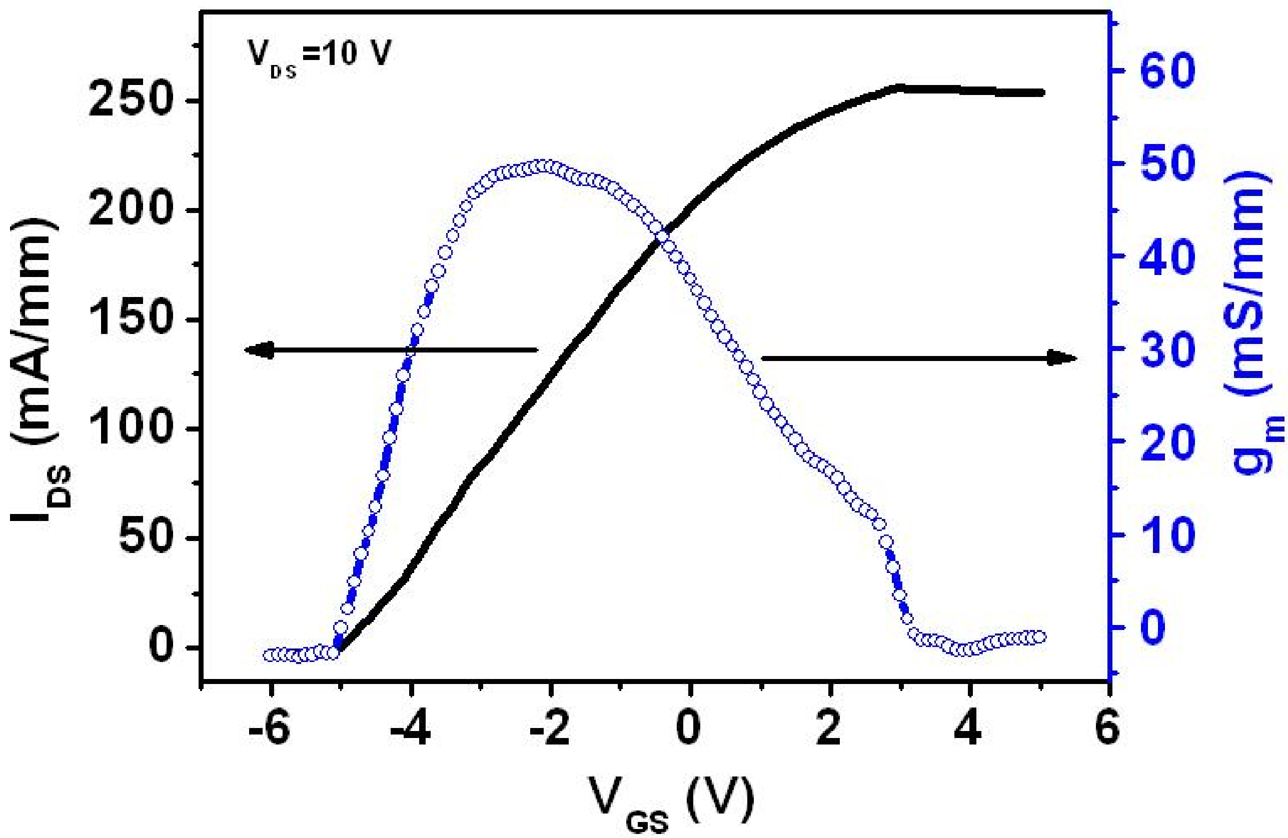

Figure 3. The drain-source current (I_{DS}) and transconductance (g_m) as a function of gate-source voltage (V_{GS}) of AlGaN/GaN MOS-HEMTs.

The PEC oxidation method can oxidize AlGaN successfully to form gate insulators for AlGaN/GaN MOS-HEMTs. The oxide films exhibited β-Ga_2O_3 and α-Al_2O_3 crystalline phases and interface-state density of $5.1\times10^{11}cm^{-2}eV^{-1}$ after annealed at 700 ˚ C in O_2 ambient for 2 hrs. The I_{DSS} and $g_{m(max)}$ of AlGaN/GaN MOS-HEMTs was 200 mA/mm and 50 mS/mm, respectively. The gate-source leakage current was only 2 pA and 50 pA at V_{GS}=–10 V and V_{GS}=10 V. According to the DC performances measured in this work, PEC oxidation method can be a promising technique to fabricate high performance III-V nitride-based MOS-HEMTs in the integrated circuits in the future.