1500 V AlGaN/GaN MIS-HEMTs Employing LPCVD-Si3N4 as Gate Insulator

Authors: Zhili Zhang, Guohao Yu, Xiaodong Zhang, Shuxin Tan, Dongdong Wu, Kai Fu, Wei Huang, Yong Cai, Baoshun Zhang

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Abstract

An AlGaN/GaN metal-insulator-semiconductor high electron mobility transistors (MIS-HEMTs) on Si substrates was obtained with 18 nm Si3N4 grown by low pressure chemical vapor deposition (LPCVD) as gate insulator, The MIS-HEMTs show high Idss of 16.8 A@Vg=3 V, high breakdown voltage of 600 V and a low specific on-resistance of 2.3. The power device figure of merit V2BV/Ron=157MW·cm-2. Furthermore, the good insulation effects of LPCVD-Si3N4 were also demonstrated by the low gate leakage current of below Ig=154 nA@Vds=600 V and Vgs=-14 V. The high Idss, low specific on-resistance and high breakdown voltage show the potential and advantages of GaN MIS-HEMTs for power switching applications.

Full Text

1500 V AlGaN/GaN MIS-HEMTs Employing LPCVD-Si N as Gate Insulator

Zhili Zhang[1], Guohao Yu[1], Xiaodong Zhang[1], Shuxin Tan[1], Dongdong Wu[1], Kai Fu[1]*, Wei Huang[2], Yong Cai[1], and Baoshun Zhang[1]

[1]Key Laboratory of Nanodevices and Applications, Suzhou Institute of Nano-tech and Nano-bionics, Chinese Academy of Sciences, Jiangsu Suzhou, China
[2]Wuxi Jingkai Technology Co., Ltd., Jiangsu Wuxi 214061, China
*E-mail: kfu2009@sinano.ac.cn

AlGaN/GaN metal-insulator-semiconductor high-electron-mobility transistors (MIS-HEMTs) on Si substrates were fabricated with 18 nm Si N grown by low-pressure chemical vapor deposition (LPCVD) serving as the gate insulator. The MIS-HEMTs exhibit a high saturation drain current (I_dss) of 16.8 A at V_g

= 3 V, a high breakdown voltage of 600 V, and a low specific on-resistance of 2.3 m$\Omega \cdot$cm^2. The power device figure-of-merit V^2_BV/R_on reaches 157 MW$\cdot$cm ^{2}. Furthermore, the excellent insulating properties of LPCVD-Si N are demonstrated by the low gate leakage current of less than I_g = 154 nA at V_ds = 600 V and V_gs = -14 V. The high I_dss, low specific on-resistance, and high breakdown voltage reveal the potential and advantages of GaN MIS-HEMTs for power switching applications.

Introduction

AlGaN/GaN high-electron-mobility transistors (HEMTs) are emerging as promising candidates for next-generation power electronic devices due to their outstanding material advantages, including large critical electric field, high electron saturation velocity, and high-density two-dimensional electron gas (2DEG) at the heterojunction. These devices have attracted significant research attention [1-3]. However, Schottky-gate HEMTs suffer from large gate-leakage current and face reliability degradation issues, which limit device performance. MIS-HEMTs are strongly preferred over Schottky-gate HEMMTs for high-voltage power switches because of their suppressed gate leakage and enlarged gate swing. Various dielectric materials have been adopted for the gate insulator, such as Al O deposited by atomic layer deposition (ALD) [4-6], PECVD-SiN [7], PE-ALD SiN [8], TiO deposited by nonvacuum ultrasonic spray pyrolysis [9], and CeO films deposited by RF sputtering [10].

Nevertheless, it remains challenging to achieve low and stable gate leakage characteristics while simultaneously suppressing current collapse effects. Silicon nitride (SiN) has been widely applied as passivation films in AlGaN/GaN HEMTs to reduce current collapse because of its excellent interface properties [11-12], which suggests that high-quality thin SiN film is a good candidate for an interfacial MIS dielectric for GaN. In this paper, we investigate the effects of Si N gate insulator deposited by low-pressure chemical vapor deposition (LPCVD) on the electrical properties of MIS-HEMTs, achieving excellent performance including high breakdown voltage, high drain current, and low specific on-resistance.

Experiments

AlGaN/GaN heterostructure epitaxial materials were grown by MOCVD on a 2-inch Si (111) substrate. The epitaxial stack consists of, from bottom to top, a 2.9-µm-thick carbon-doped GaN buffer layer, a 100-nm channel layer, a 1-nm AlN spacer layer, a 25-nm undoped Al . Ga . N barrier layer, and a 2-nm-thick GaN cap layer. Hall measurements using a standard van der Pauw geometry on 1 × 1 mm^2 samples of the as-grown epitaxial material yielded an electron mobility of 1,661 cm^{2}V^{1}s^1 and a sheet charge density of 6.2 × 10^{12} cm^2 at room temperature.

Fig. 1a [Figure 1: see original paper] shows a cross-sectional view of the MIS-HEMT structure with an 18-nm LPCVD-Si N layer serving as both gate insulator and passivation layer. The LPCVD-Si N layer was deposited prior to ohmic and gate metal deposition because no metal can be introduced into the furnace to avoid potential contamination. The device fabrication process began with mesa isolation by ion implantation. Subsequently, ohmic contacts for the source and drain were formed by e-beam evaporation of a Ti/Al/Ni/Au (20 nm/130 nm/50 nm/150 nm) metal stack and a lift-off process, followed by annealing of the entire sample at 890 °C for 30 s under N atmosphere. The contact resistance of ~1.12 Ω · mm was extracted from linear transmission line method (TLM) patterns.

The gate was then formed by depositing Ni/Au (50 nm/150 nm) and lift-off. A 300-nm-thick SiN dielectric layer was deposited at 350 °C in a PECVD system. Contact windows were opened by RIE dry etching, and thick pad electrodes were formed by depositing 2 µm of aluminum metal. The gate-to-source spacing is 2 µm, and the gate-to-drain spacing is 10 µm. The gate width and length are 48.3 mm and 2 µm, respectively, and the active area of the device is 0.67 mm^2 (excluding the ohmic contact area, source, and drain). A photograph of the fabricated LPCVD-Si N /AlGaN/GaN MIS-HEMTs is shown in Fig. 1b.

Experimental Results and Discussion

Fig. 2 [Figure 2: see original paper] shows the transfer characteristics of the MIS-HEMT device measured using an Agilent B1505A parameter analyzer with the gate voltage swept forward from -15 V to 3 V. The threshold voltage (V_th) is determined to be -7.7 V according to the definition in [13]. The maximum drain current reaches 16.8 A at V__gs = 3 V (I__ds = 348 mA/mm) and 15.6 A at V__gs = 0 V (I__ds = 323 mA/mm), respectively. The maximum transconductance (G_m) is 2.32 S at V__gs = -5.4 V (G_m = 48 mS/mm).

Fig. 3a [Figure 3: see original paper] shows the output characteristics measured with V_ds stepped down and up between -9 V and 3 V in increments of 2 V. A maximum drain current of approximately 16.8 A (348 mA/mm) was obtained at a gate voltage (V__gs) of 3 V and a drain voltage (V__ds) of 10 V. The specific on-state resistance, defined for the active area of 0.67 mm^2 with an on-state resistance of 346 mΩ, was 2.3 mΩ · cm^2. No obvious differences were observed in the output curves between gate step-down and step-up measurements.

As shown in Fig. 3b, a breakdown voltage (BV) of 601 V is achieved at a drain leakage current of 1 µA/mm for a device with a specific on-resistance R_on,sp of 2.3 mΩ · cm^2, resulting in a figure-of-merit (FOM = V^2_BV/R_on) of 157 MW · cm ^{2}. For power switching applications, low gate leakage current can increase the off-state breakdown voltage and improve the reliability of GaN HEMTs. The LPCVD-Si N gate insulator demonstrates excellent insulation performance with a low gate leakage current of I_g = 154 nA at V_ds = 600 V and V_gs = -14 V.

Conclusions

A 2-µm gate-length, 48.3-mm gate-width AlGaN/GaN/Si MIS-HEMT with 18-nm LPCVD-Si N as the gate dielectric is demonstrated. The device exhibits a low specific on-resistance of 2.3 mΩ · cm², a large maximum saturated drain current of 16.8 A, and a high breakdown voltage of 600 V. These characteristics offer great potential for LPCVD Si N /AlGaN/GaN/Si MIS-HEMTs in high-power switching applications.

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