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High-Quality PECVD SiO_2 Gate Oxide for Use in Normally-off AlGaN/GaN Recessed MOS-HFETs

Hyun-Seop Kim[1], Jae-Gil Lee[2], Sung-Hoon Park[1], Sang-Woo Han[1], Kwang-Seok Seo[3], and Ho-Young Cha*[1]

[1] Hongik University
Electronic and Electrical Engineering
94 Wausan-ro, Mapo-gu, Seoul, Korea 121-791
[2]University of Texas at Dallas
Department of Materials Science and Engineering
800 W Campbell Rd, Richardson, TX 75080, USA
[3] Seoul National University
Department of Electrical and Computer Engineering
1 Gwanak-ro, Gwanak-gu, Seoul, Korea 151-015
*Phone: +82-2-320-3062 E-mail: hcha@hongik.ac.kr

Abstract

We have developed a high-quality SiO_2 deposition process using a plasma enhanced chemical vapor deposition system for the gate oxide film of AlGaN/GaN metal-oxide-semiconductor heterostructure field-effect transistor (MOS-HFET). A breakdown field of > 11 MV/cm was achieved with a very low leakage current (~10^{-7} A/cm^2 at 6 MV/cm) for the SiO_2 film deposited on a recessed GaN surface. The fabricated device exhibited outstanding characteristics; a threshold voltage of 3.2 V, a maximum drain current density of 246 mA/mm, a specific on-resistance of 4.64 mΩ·cm^2, and a breakdown voltage of 810 V.

1. Introduction

AlGaN/GaN heterostructure field-effect transistors (HFETs) are promising candidates for high-power and high-efficiency switching applications due to high breakdown field and high electron mobility. High-quality gate insulators are strongly demanded in AlGaN/GaN HFETs to reduce the leakage current and implement normally-off operation [1]. Though the metal-insulator-semiconductor (MIS) gate has advantages of low leakage current and threshold voltage controllability, many AlGaN/GaN MIS-HFETs still suffer from poor dynamic characteristics, which are mainly associated with the interface and bulk quality of the gate insulator. In this work, we developed a high-quality SiO_2 deposition process using a plasma enhanced chemical vapor deposition (PECVD) system for the gate insulator of AlGaN/GaN metal-oxide-semiconductor -HFETs (MOS-HFETs) that employed recessed-MOS gate configuration. SiO_2 is a promising candidate as a gate insulator for (Al)GaN due to its large bandgap energy and conduction band offset from (Al)GaN. The advantages using PECVD are low temperature process, low pinhole density, and good step coverage.

2. Experiments and Discussion

In order to optimize the SiO_2 deposition process, the films were deposited on Si wafers using a PECVD system with SiH_4 and N_2O gas mixtures as reactant gases. During the film deposition process, the chuck temperature was fixed at 350^{o}C. The reactant gas flow rate, RF power, and chamber pressure were varied to optimize the deposition conditions. As the chamber pressure increased, the breakdown field increased with the decreased deposition rate while the refractive index was almost constant as shown in Fig. 1. The optimum deposition conditions were determined as follows: a reactant gas flow rate of SiH_4/N_2O (= 27/540 sccm), a RF power of 100 W, a pressure of 2 Torr, and a deposition temperature of 350^{o}C. The breakdown field was ~12 MV/cm.

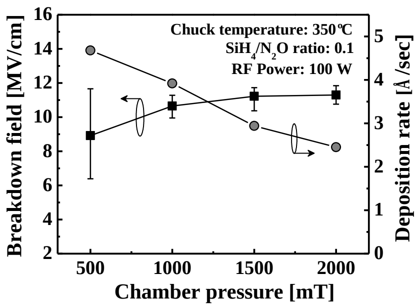

Fig. 1. Breakdown field and deposition rate as a function of the chamber pressure.

Recessed AlGaN/GaN-on-Si MOS devices were fabricated using the optimized SiO_2 deposition process. As shown in Fig. 2(a), a breakdown field of > 11 MV/cm with a leakage current level of ~10^{-7} A/cm^2 at 6 MV/cm was achieved for the SiO_2 film deposited on a recessed GaN surface where a low damage BCl_3/Cl_2 based inductively coupled plasma reactive ion etching process was carefully optimized. The Fowler-Nordheim tunneling plot [2, 3] for the gate leakage characteristics resulted in a conduction band offset of 3.26 eV as shown in Fig. 2(b), which is close to the theoretical value for SiO_2/GaN configuration [4]. The interface trap density extracted by a conductance method [5] was 1.17×10^{12} $cm^{-2}\cdot eV^{-1}$ at 0.44 eV.

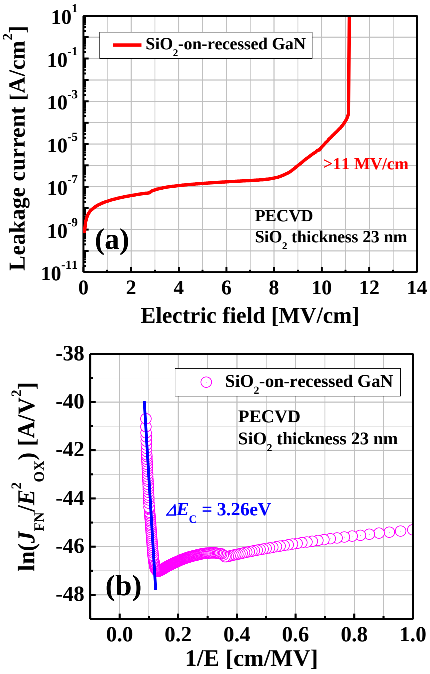

Fig. 2. (a) Leakage current characteristics and (b) Fowler-Nordheim plot of the SiO_2-on-recessed GaN.

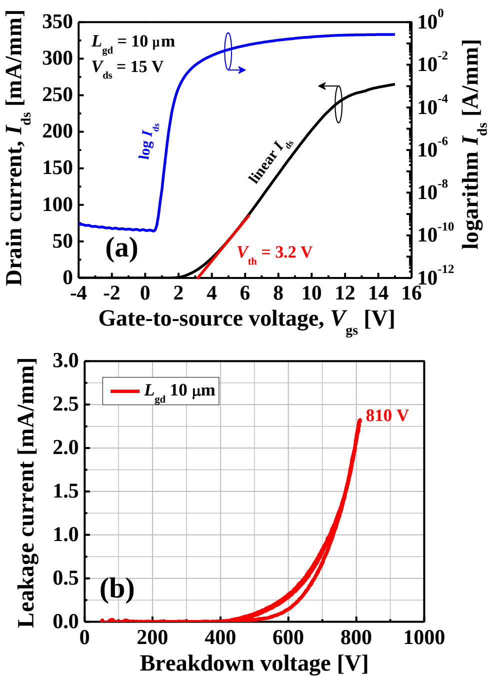

Fig. 3. (a) Transfer characteristics and (b) breakdown voltage of normally-off AlGaN/GaN-on-Si recessed MOS-HFET.

The developed SiO_2 deposition process was employed to fabricate normally-off AlGaN/GaN-on-Si recessed MOS-HFETs. The AlGaN layer under the gate region was fully recessed to make sure the normally-off characteristics. The gate metal was Mo/Au and a post-metallization was carried out at 400°C for 10 min for stabilization. The fabricated device with the gate length of 2 μm and the gate-to-drain distance of 10 μm exhibited a threshold voltage of 3.2 V, a maximum current density of 246 mA/mm, and a specific on-resistance of 4.64 $m\Omega\cdot cm^2$, as shown in Fig. 3(a). A breakdown voltage of 810 V was achieved with the gate overhang length of 1 μm as plotted in Fig. 3(b). The dynamic on-resistance was increased by 1.5 times at V_{dd} = 200 V with 10 kHz switching operation as shown in Fig. 4.

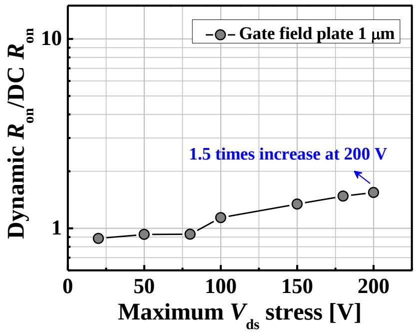

Fig. 4. Dynamic on-resistance characteristics of fabricated normally-off AlGaN/GaN-on-Si recessed MOS-HFET using the optimized PECVD SiO_2 process.

3. Conclusions

We have developed a high-quality SiO_2 film deposition process using a PECVD system for the gate insulator of AlGaN/GaN MOS-HFET. Normally-off AlGaN/GaN-on-Si recessed MOS-HFETs were successfully fabricated using the optimized PECVD SiO_2 process. The fabricated devices exhibited excellent characteristics; a threshold voltage of 3.2 V, a maximum drain current density of 246 mA/mm, a specific on-resistance of 4.64 $m\Omega\cdot cm^2$, and a breakdown voltage of 810 V.

Acknowledgements

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