High-Quality PECVD SiO\textsubscript{2} Gate Oxide for Use in Normally-off AlGaN/GaN Recessed MOS-HFETs

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Abstract

We have developed a high-quality SiO\textsubscript{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 (\(\sim 10^{-7}\) A/cm\textsuperscript{2} at 6 MV/cm) for the SiO\textsubscript{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 m\textOmega\cdot cm\textsuperscript{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\textsubscript{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\textsubscript{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\textsubscript{2} deposition process, the films were deposited on Si wafers using a PECVD system with SiH\textsubscript{4} and N\textsubscript{2}O gas mixtures as reactant gases. During the film deposition process, the chuck temperature was fixed at 350°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\textsubscript{4}/N\textsubscript{2}O (\(= 27/540\) sccm), a RF power of 100 W, a pressure of 2 Torr, and a deposition temperature of 350°C. The breakdown field was \(\sim 12\) MV/cm.

![Breakdown field and deposition rate as a function of the chamber pressure.](image)

Rearranged AlGaN/GaN-on-Si MOS devices were fabricated using the optimized SiO\textsubscript{2} deposition process. As shown in Fig. 2(a), a breakdown field of > 11 MV/cm with a leakage current level of \(\sim 10^{-7}\) A/cm\textsuperscript{2} at 6 MV/cm was achieved for the SiO\textsubscript{2} film deposited on a recessed GaN surface where a low damage BCl\textsubscript{3}/Cl\textsubscript{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 SiO2/GaN configuration [4]. The interface trap density extracted by a conductance method [5] was $1.17 \times 10^{12}$ cm$^{-2}$eV$^{-1}$ at 0.44 eV.

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 mΩ-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 $V_{ds} = 200$ V with 10 kHz switching operation as shown in Fig. 4.

Fig. 2. (a) Leakage current characteristics and (b) Fowler-Nordheim plot of the SiO2-on-recessed GaN.

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

The developed SiO2 deposition process was employed to fabricate normally-off AlGaN/GaN-on-Si recessed MOS-HFETs.