The Effect of Re-nitridation on Plasma-Enhanced Chemical-Vapor Deposited SiO_2 /Thermally-Nitrided SiO_2 Stacks on N-type 4H SiC

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Abstract

In this paper the importance of re-nitridation on a plasma-enhanced chemical-vapor deposited (PECVD) SiO_2 stacked on a thermally grown thin-nitrided SiO_2 on n-type 4H SiC have been investigated. Without the final re-nitridation process, the leakage current of metaloxidesemiconductor (MOS) was extremely large. It is believed that water and carbon, contamination from the low-thermal budget PECVD process, are the main factors that destroyed the high quality thin-buffer nitrided oxide. After re-nitridation annealing, the quality of the stacked gate oxide was improved. The reasons of this improvement are presented.

Key Words : re-nitridation, stacked gate oxide, PECVD, nitrous oxide

1. Introduction

One of the key technology issues limiting the performance of silicon carbide (SiC)-based electronic devices is that of SiC surface passivation. Commonly, SiC is passivated with its native oxide via thermal oxidation or nitridation processes. It has been reported that the gate oxide quality passivated with dry or wet oxide demonstrated high SiC-SiO_2 interface and near interface trap densities, which cause huge leakage current and extremely low channel mobility in metal oxide semiconductor (MOS) based devices [1]-[3]. These adverse phenomena can be minimized by passivating SiC surface with oxide grown by nitridation techniques [3]-[8]. One report even claimed that these techniques enable industrial-grade gate oxide to be produced [9]. However, oxides grown by nitridation techniques have two drawbacks: (1)

slow growth rate and (2) high thermal budget. So, it is extremely difficult to grow thick oxide, which is essential in power devices, with oxide quality comparable to thin oxide. In order to overcome these problems, alternative dielectric materials and deposition techniques have been investigated [10], [11]. In this paper, we are reporting on the experimental results of SiO_2 deposited by plasma-enhanced chemical vapor deposition (PECVD) on n-type 4H SiC. Comparisons are made between MOS capacitors after underwent re-nitridation annealing in samples with and without a thin nitrided gate oxide sandwiched between the PECVD oxide and the Si

2. Experimental Procedures

N-type 4H-SiC wafers with 10um thick epilayer doped with (4~8)x10^{15} cm^{-3} of aluminum were used to fabricate the MOS capacitors. The 8ooff (0001) oriented wafers were purchased from CREE Research Inc. (USA). The wafer cleaning process prior to nitridation and the subsequent steps for MOS-capacitor fabrications have been described elsewhere [4]. Two sets of 1um thick PECVD oxides were prepared. The first set of PECVD oxide was deposited on a 10unm thick, 10%-N_2O thermally nitrided oxide on the wafers (labeled as NB1) and the other set was deposited on wafers without the thin nitrided oxide (labeled as NCO1). The growth of nitrided oxide has been reported elsewhere [12] and the PECVD oxide was deposited using SiH_4, N_2, N_2O sources at 300°C with RF power of 60 W. Electrical characterization was performed by 100-kHz capacitancevoltage (*CV*) and currentvoltage (*IV*) measurements, using a computer-controlled Keithley 590 *CV* analyzer and Agilent 4156B *Precision Semiconductor Parameter Analyzer.* After completed the initial electrical characterization, the thicknesses of PECVD oxides were reduced, by etching in buffer HF, and then were re-nitrided at 1175°C for 3.5 hours in 10% N_2O. After re-nitridation, similar electrical characterization were carried out.

3. Results and Discussions

Figure 1 shows typical high-frequency capacitanceconductancevoltage (*CGV*) measurement results of samples with as-deposited PECVD oxide stacked on a thin nitrided oxide (NB1) and with solely PECVD 2.1 V in NB1 and NCO1 samples, respectively. Based on the results presented in Fig. 2, it is significant that re-nitridation improves the quality of PECVD-based oxides.

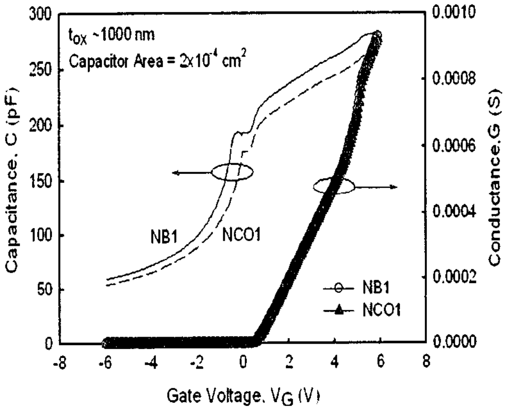

Fig. 1: Typical room-temperature high-frequency *CGV*curves obtained from as-deposited NB1 and NCO1 samples.

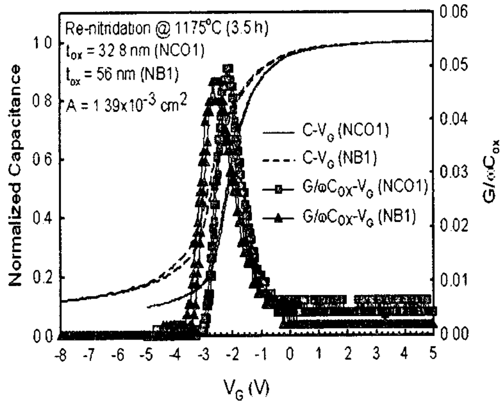

Fig. 2: Typical CGV measurements for samples underwent re-nitridation process.

In order to further reaffirm the positive effect of re-nitridation, time-zero breakdown test was conducted as follows. The gate current as a function of ramping voltage(0.3 V/s) until an instantaneously increase of the current is measured and compared between the two samples after re-nitridation. Gate voltage that demonstrated a sudden increase of current is defined as oxide breakdown voltage. The *currentvoltage* plot is also transformed into *current density* (*J*)*electric*

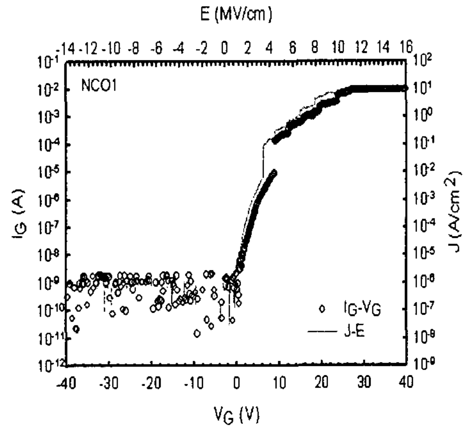

Fig. 3: Typical gate currentgate voltage and gate current densityelectric field plots obtained from NCO1 sample.

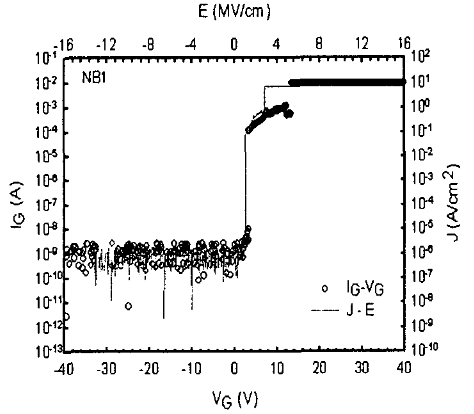

Fig. 4: Typical *gate currentgate voltage* and *gate current densityelectric field* plots obtained from NB1 sample.

field (*E*) plot, as presented in Figs. 3 and 4 representing samples NCO1 and NB1. The breakdown field for NCO1 and NB1 were 3.1 MV/cm and 3.3 MV/cm, respectively. For non re-nitridated samples, the time-zero breakdown was not measurable as the oxide leakage was too high. After re-nitridation, the leakage current of PECVD-based oxide has been reduced. It is believed that nitrogen from the re-nitridation process contributed to this positive effect. Previous report demonstrated that nitrogen is successfully passivated SiC-SiO_2 interface by forming SiN and nitrogen is promoting carbon removal, from the interface region, by forming CN [4]. As a result, the interface and near interface trap densities are reduced and leakage current is minimized [4]. However, the improvement of the PECVD-based oxide quality has yet to be optimized. The concentration of N_2O gas, the length of re-nitridation time, the source/gas of re-nitridation and the re-nitridation temperature are the factors that remain to be examined.

4. Conclusions

In conclusion, the high quality of initial thin nitrided oxide has been destroyed by PECVD process. The quality of leaky PECVD-based oxides has been reduced by re-nitridation technique. The re-nitridation process has yet to be optimized. Therefore, more works need to be done, in order to utilize this type of oxide as SiC surface-passivation material.

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