A Comparative Study of Gate Oxides Grown in 10%-N_2O and in Dry Oxygen on N-type 4H SiC

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AComparativeStudyofGateOxidesGrownin10%-N_2OandinDryOxygen onN-type4HSiC

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Abstract

The electrical properties of gate oxides grown in two different processes, which are in 10% nitrous oxide (N_2O) and in dry oxygen, have been experimentally investigated and compared. It has been observed that the SiC-SiO_2 interface-trap density (*D*it) measured in nitrided gate oxide has been tremendously reduced, compared to the density obtained from gate oxide grown in dry oxygen. The beneficial effects of nitridation on gate oxides also have been demonstrated in the values of total near interface-trap density and of forward-bias breakdown field. The reasons of these improvements have been explained.

Key Words : SiC, Gate Oxide

1. Introduction

Silicon carbide is an attractive wide-bandgap material [1] that is suitable to fill the unmet requirements by other semiconductors in high power, high frequency, high temperature, and non-volatile memory applications [2], [3]. Unlike other wide-bandgap semiconductor, this is the only material that can oxidize thermally to form native oxide. However, the quality of the oxide, in terms of SiC-SiO_2 interface trap density (D_{it}), near interface-trap density and reliability, grown by dry or wet oxidations is poor [4]. It has been reported that carbon and its derivatives accumulated at the interface is the main contributor to the high interface-trap density [4]. Some report also suggested that the high D_{it} and near interface-trap density were attributed to dangling bond of Si and C, which is similar to the Pb center in Si-SiO_2 system [5]. In order to fabricate functional metaloxidesemiconductor (MOS)-based devices, it is extremely important to reduce the value of *D*it and improve the quality of oxide. These can be achieved by using nitridation techniques to grow gate oxides [6], [7]. In this paper, the electrical properties of gate oxides directly grown in diluted nitrous oxide (N_2O) has been experimentally investigated and compared with gate oxides grown in dry oxygen.

2. Experimental Procedures

MOS capacitors were fabricated on 10um thick epitaxial layer of n-type 4H SiC with doping concentration of 3.60×10^{15} cm^{-3}. The epitaxial layer was grown on (0001) Si-face, ~8° off axis, 4H-SiC wafers, which is heavily n-type doped, and was purchased from CREE Inc. Prior to oxidation and nitridation, the wafers were diced into 10x10 cm^2 and first cleaned in a mixture of H_2SO_4 and H2O2, followed by an RCA method. Immediately before oxidation, the wafers were dipped in 1% HF for 1 min.

The gate oxides were separately grown in dry oxygen and in 10% N_2O 90% N_2 at 1175°C for 155 and 420 min., respectively, in a horizontal furnace. The flow rate of dry oxygen was 4 l/min. While the flow rates of N_2O and N_2 were 1 and 9 l/min, respectively, which produced the required diluted-N_2O gas. After the oxidation and nitridation processes, the furnace was cooled down to 800°C in high-purity N_2 at the rate of 5°C/min before the samples were unloaded. Subsequently, aluminum was sputtered on the oxides to form gate electrodes. Then, the areas of MOS capacitors (*A*G) were defined by photolithography. Finally,a large area of aluminum back contact was sputtered on the n+ substrate.

Electrical characterization was performed by high frequency (100 kHz) and quasistatic capacitancevoltage (*CV*) measurements, using a computer-controlled Keithley 590 *CV analyzer* and 595 *Quasistatic CV meter.* The gate-oxide thickness, *t*ox, was deduced from the accumulation capacitance (*C*ox) of the high-frequency *CV* curve. The gate-oxide forward-breakdown strength was evaluated by an Agilent 4156B *Precision Semiconductor Parameter Analyzer,*measuring current as a function of ramping voltage (0.3 V/s) until an instantaneously increase of the current is observed.

3. Results and Discussion

Figure 1 shows the room temperature high-frequency *CV* curves measured from MOS capacitors with dry oxide and with nitrided oxide (labeled as 10% N_2O).

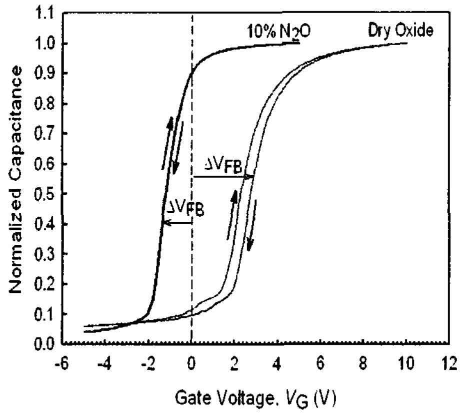

Fig. 1: Typical room temperature high-frequency *CV* measurements of MOS capacitors with nitrided (10% N_2O) and with dry oxides on n-type 4H-SiC. Arrows indicate gate-voltage sweeping directions.

The respective oxide thicknesses were 40 and 20 nm. The flatband-voltage shifts (VFB) of the measured *CV* curve from the theoretical *CV* curve are indicated in the figure. From this shift, the effective oxide charge (Q_{eff}) was calculated by the methodfrom ref. [8], after taking into consideration of the differences in respective oxide thickness. Both types of oxide have comparable Q_{eff} values The Q_{eff} values of dry oxide and of nitrided oxide are $1.41 x 10^{12}$ cm^{-2} and $+1.59 x 10^{12}$ cm^{-2}, respectively, but the polarity of the effective charges is different. In addition, it can be observed that the slopes of the *CV* curves, measured from near depletion to strong inversion levels, of nitrided gate oxide is steeper compared to the slope of the *CV* curve of dry oxide. This indicates that D_{it} of gate oxide grown in 10% N_2O is lower than in dry oxygen. Using *simultaneous hi-lo* technique, the distribution of D_{it} with traps level within the bandgap can be quantified. As shown in Fig. 2, the D_{it} extracted from the nitrided gate oxide is significantly reduced, especially near conduction band edge, *E*C. Besides D_{it}, the total near interface-trap density of nitrided gate oxide ($1.04 x 10^{11}$ cm^{-2}) was approximately five folds lower than that of dry oxide ($5.22 x 10^{11}$ cm^{-2}). These values were deduced from the high-frequency *CV* hysterisis (Fig. 1).

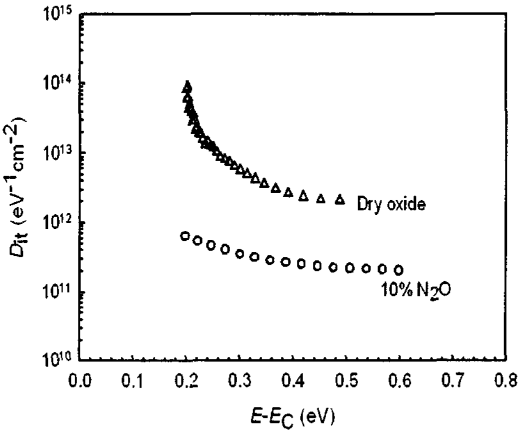

Fig. 2: Energy distribution of n-type 4H SiC-SiO_2 interface trap density obtained from dry (△) and nitrided (○) oxides.

The electric-field strength of 10% N_2O-grown oxide is approximately 30% higher than that of dry oxide (Fig. 3). This strength is strongly affected by the quality of the oxide and the density of interface and near interface-trap densities. In this work, we have found that the D_{it} and near interface-trap density of the nitrided gate oxide were considerably lower than that of dry oxide. Consequently, the former gate oxide recorded higher forward-bias breakdown strength.

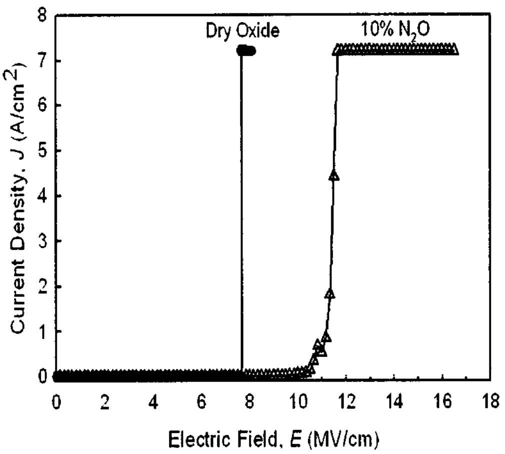

Fig. 3: Comparison of current density, *J*, as a function of electric field, *E*.

The beneficial effects of nitridation on gate oxide have been demonstrated in the above electrical-measurement results and it can be explained as follows. Nitrogen that is one of the decomposed products from N_2O gas, at high temperature, has dual important function, described by the 'nitridation model' [6]: (1) to passivate $SiC\text{-}SiO_2$ interface by forming SiN and (2) to remove carbon and its related compound, by forming CN, from the interface. These two positive effects cumulatively improve $SiC\text{-}SiO_2$ interface and oxide quality of the capacitors.

4. Conclusion

In summary, the superior quality of gate oxides grown in 10% N_2O on 4H SiC has been experimentally demonstrated. The improvement in the interface and near interface-trap contributed to the higher forward-bias breakdown field in nitrided gate oxide compared to that in dry oxide.

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