# Oxidation Mechanism of 4H-SiC in Dilute N<sub>2</sub>O Ambient

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Abstract—Oxidation mechanism of 4H-SiC in diluted N<sub>2</sub>O ambient is studied at various temperatures and various N<sub>2</sub>O flow rate and N<sub>2</sub>/N<sub>2</sub>O flow ratio. It is observed that the collision partner, N<sub>2</sub> in this work, plays important role on the oxidation rate and N-incorporation. According to the proposed oxidation mechanism, low interface state density with low oxidation temperature is possible with high efficiency collision partner.

# **1. INTRODUCTION**

It is well known that oxidation in NO or  $N_2O$  ambient is an effective method to reduce the interface state density ( $D_{it}$ ) and then improves channel mobility of the SiC MOSFET [1, 2]. Although the oxidation mechanism of Si in  $N_2O$  ambient has been widely investigated, as our knowledge, the oxidation mechanism of SiC in  $N_2O$  has not been studied thoroughly. In this work, we investigate the oxidation mechanism of (0001)-oriented 4H SiC in  $N_2O$  ambient. Both pure  $N_2O$  and  $N_2$  diluted  $N_2O$  ambient are used. Various  $N_2O/N_2$  flow rate ratio and total flow rate are studied.

# **2. EXPERIMENTAL CONDITIONS**

Simple MOS capacitors without field oxide were fabricated on a (0001)-oriented 4H SiC epi-wafer. The epi-layer is 5-µm-thick and is doped to  $1 \times 10^{16}$  cm<sup>-3</sup>. A 300-nm-thick aluminum film was deposited by a thermal evaporator coater and was patterned by wet etching as gate electrodes. Table 1 lists the sample ID and the main process conditions. The sample ID is in the form of XY-G1-G2. The first character is either P or D, which represents pure N<sub>2</sub>O or Diluted N<sub>2</sub>O, respectively. The second character Y may be L, M, or H which represent oxidation temperature is 1000, 1200, or 1300 °C, respectively. The digits G1 and G2 are the N<sub>2</sub>O and N<sub>2</sub> flow rates in slm, respectively.

#### 3. RESULTS AND DISCUSSION

Fig.1 shows the oxide thicknesses of Si and SiC substrate oxidized in pure N<sub>2</sub>O ambient at 1000 °C. The higher the flow rate is, the slower the growth rate is. This trend is consistent with those reported in literature on Si substrate and has been explained by the reactions of N<sub>2</sub>O decomposition chemistry as summarized in Table 2 [3, 4]. The slower oxidation rate of SiC than Si is due to the

strong Si-C covalent bond. However, the trend changes in diluted  $N_2O$  ambient. The oxidation rate of SiC increases by adding  $N_2$  gas as shown in Fig.2. The higher the  $N_2/N_2O$  flow rate is, the higher oxidation rate is. Increasing the total flow rate also increases the oxidation rate. This trend is observed on Si substrate, too. As the oxidation temperature increases to 1200 °C, the trend is still reserved as shown in Fig.3.

Once the oxidation temperature increases to 1300 °C, the oxide thickness distributes in the range of 51~62 nm independent of the N<sub>2</sub>/N<sub>2</sub>O flow ratio and the total flow rate as shown in Fig.4. It is proposed that the reactions listed in Table 2 are still valid for diluted N<sub>2</sub>O oxidation but the main collision partner M becomes N<sub>2</sub> molecular. N<sub>2</sub> is a more efficient collision partner than the other molecular so that the N2O decomposition and thus the oxidation is enhanced by adding N2. At 1300 °C, the thermal decomposition of N<sub>2</sub>O dominates the decomposition chemistry so that the oxidation is almost independent on the N2 flow rate. Fig.5 and Fig.6 show the D<sub>it</sub> extracted by high-low CV method of the samples oxidized at 1200 °C and 1300 °C, respectively. It is observed that thermal decomposition at high temperature can incorporate sufficient N so that the D<sub>it</sub> is reduced.

# 4. CONCLUSION

This work provide deep understand of the oxidation mechanism of SiC in N<sub>2</sub>O-based ambient. It is observed that the collision partner plays important role on the oxidation rate and N-incorporation.  $D_{it}$  lower than  $5x10^{11}$  cm<sup>-2</sup> can be achieved by N<sub>2</sub>O oxidation using N<sub>2</sub> as collision partner. With more efficiency collision partner, lower D<sub>it</sub> at lower temperature could be expected.

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N20 Oxidation. E, W, and Trepresent 1000, 1200, 1500 C, respectively. OT is the N20 now rate and O2 is the N2 now rate.					
Sample ID	Oxidation	Oxidation Time (hour)	N <sub>2</sub> O Flow Rate (slm)	N <sub>2</sub> Flow Rate (slm)	N <sub>2</sub> O/N <sub>2</sub> Flow Ratio
	Temperature (°C)				
PL-G1-G2	1000	1	0.2, 2.5, 5	0	NA
DL-G1-G2	1000	1	0.2, 0.5	0.5, 1, 2, 2.5, 5	1:1, 1:5, 1:10
DM-G1-G2	1200	1,6	0.1, 0.25, 0.5, 1	2.5, 5	1:1, 1:5, 1:10, 1:50
DH-G1-G2	1300	126	0.05 0.2 0.5 1	0512255	1.1 1.5 1.10 1.100

Table 1 Sample ID and the oxidation conditions used in this work. In the sample ID, P represents pure  $N_2O$  oxidation, D represents diluted  $N_2O$  oxidation. L, M, and H represent 1000, 1200, 1300 °C, respectively. G1 is the  $N_2O$  flow rate and G2 is the  $N_2$  flow rate.

Table 2 Main reactions of  $N_2O$  decomposition chemistry [1, 2]. The M in R1 is a collision partner. In the early stage of pure  $N_2O$  oxidation, M is  $N_2O$  itself and then the products from the other reactions contribute collision. In diluted  $N_2O$  oxidation, M is  $N_2$  in our experiments. In these reactions, O and O<sub>2</sub> enhance oxidation while NO retards oxidation.

$$N_2 O + M \rightarrow N_2 + O + M$$
(R1)  

$$N_2 O + O \rightarrow 2NO$$
(R2)  

$$N_2 O + O \rightarrow N_2 + O_2$$
(R3)  

$$O + O + M \rightarrow O_2 + M$$
(R4)  

$$NO + O + M \rightarrow NO_2 + M$$
(R5)  

$$NO_2 + O \rightarrow NO + O_2$$
(R6)



Fig.1 Oxide thickness of Si and SiC oxidized in pure  $N_2O$  ambient at 1000 °C for 1 hour with various  $N_2O$  flow rate. High flow rate results in slower oxidation rate because  $N_2O$  decomposes nearer heat region so that more NO molecular are produced.



Fig.2 Oxide thickness of Si and SiC oxidized in diluted N<sub>2</sub>O ambient at 1000  $^{\circ}$ C for 1 hour with various N<sub>2</sub>O and N<sub>2</sub> flow rate. The oxidation rate of SiC is enhanced by adding N<sub>2</sub> gas while the oxidation rate of Si is suppressed. Increasing N<sub>2</sub> flow rate results in higher oxidation rate, which indicates that N<sub>2</sub> is a more efficient collision partner.



Fig.3 Oxide thickness of SiC oxidized in diluted N<sub>2</sub>O ambient at 1200 °C for 1 hour and 6 hours with various N<sub>2</sub>O and N<sub>2</sub> flow rate. Similar to the results in Fig.2, the oxidation rate of SiC is enhanced by adding N<sub>2</sub> gas.



Fig.4 Oxide thickness of SiC oxidized in diluted N<sub>2</sub>O ambient at 1300 °C for 1 hour with various N<sub>2</sub>O and N<sub>2</sub> flow rate. The oxide thickness distributes in the range of  $51\sim62$  nm and shows no gas flow dependence. It is suspected that the decomposition of N<sub>2</sub>O at this temperature is dominated by thermal decomposition. Thus, the collision partner plays minor role.



Fig.5 Interface state density of the MOS capacitors with gate oxide grown in diluted N<sub>2</sub>O ambient at 1200 °C for 1 hours and 6 hours. The he interface state density at Ec-0.2 eV is higher than  $1 \times 10^{12} \text{ eV}^{-1} \text{cm}^{-2}$  in each sample and the difference between samples is not significant



Fig.6 Interface state density of the MOS capacitors with gate oxide grown in diluted N<sub>2</sub>O ambient at 1300 °C for 1, 2, and 6 hours. Apparent improvement occurs with elongated oxidation time. Interface state density at  $E_c$ -0.2 eV as low as 4~5x10<sup>11</sup> cm<sup>-2</sup>eV<sup>-1</sup> can be achieved.