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Oxidation Mechanism of 4H-SiC in Dilute N_2O Ambient

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Abstract—**Oxidation mechanism of 4H-SiC in diluted N_2O ambient is studied at various temperatures and various N_2O flow rate and N_2/N_2O flow ratio. It is observed that the collision partner, N_2 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 $1x\ 10^{16}\ cm^{-3}$. 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_2O or Diluted N_2O, 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_2O and N_2 flow rates in slm, respectively.

3. RESULTS AND DISCUSSION

Fig.1 shows the oxide thicknesses of Si and SiC substrate oxidized in pure N_2O 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_2O 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_2/N_2O 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_2O oxidation but the main collision partner M becomes N_2 molecular. N_2 is a more efficient collision partner than the other molecular so that the N_2O decomposition and thus the oxidation is enhanced by adding N_2. At 1300 °C, the thermal decomposition of N_2O dominates the decomposition chemistry so that the oxidation is almost independent on the N_2 flow rate. Fig.5 and Fig.6 show the D_{it} 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_{it} is reduced.

4. CONCLUSION

This work provide deep understand of the oxidation mechanism of SiC in N_2O-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^{-2} can be achieved by N_2O oxidation using N_2 as collision partner. With more efficiency collision partner, lower D_{it} at lower temperature could be expected.

REFERENCES
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[4]   K. A. Ellis and R. A. Buhrman, *Appl. Phys. Lett.*, **68** (1996), 1696.

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.

Sample ID	Oxidation Temperature (°C)	Oxidation Time (hour)	N_2O Flow Rate (slm)	N_2 Flow Rate (slm)	N_2O/N_2 Flow Ratio
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	1, 2, 6	0.05, 0.2, 0.5, 1	0.5, 1, 2, 2.5, 5	1:1, 1:5, 1:10, 1:100

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_2 enhance oxidation while NO retards oxidation.

$$N_2O + M \rightarrow N_2 + O + M \quad \text{(R1)}$$
$$N_2O + O \rightarrow 2NO \quad \text{(R2)}$$
$$N_2O + O \rightarrow N_2 + O_2 \quad \text{(R3)}$$
$$O + O + M \rightarrow O_2 + M \quad \text{(R4)}$$
$$NO + O + M \rightarrow NO_2 + M \quad \text{(R5)}$$
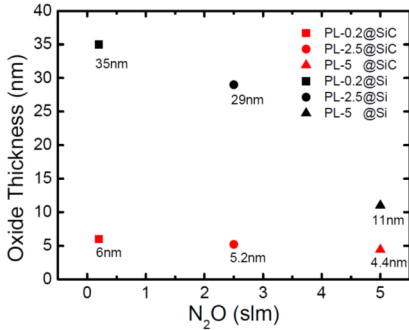$$NO_2 + O \rightarrow NO + O_2 \quad \text{(R6)}$$

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.
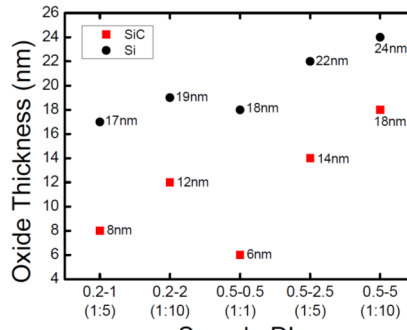

Fig.2 Oxide thickness of Si and SiC oxidized in diluted N_2O ambient at 1000 °C for 1 hour with various N_2O and N_2 flow rate. The oxidation rate of SiC is enhanced by adding N_2 gas while the oxidation rate of Si is suppressed. Increasing N_2 flow rate results in higher oxidation rate, which indicates that N_2 is a more efficient collision partner.
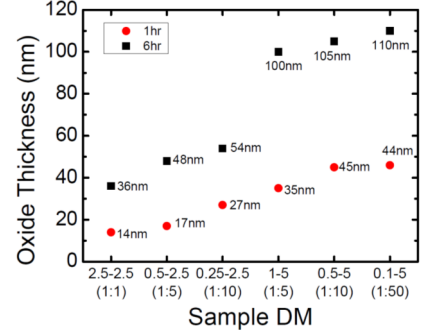

Fig.3 Oxide thickness of SiC oxidized in diluted N_2O ambient at 1200 °C for 1 hour and 6 hours with various N_2O and N_2 flow rate. Similar to the results in Fig.2, the oxidation rate of SiC is enhanced by adding N_2 gas.
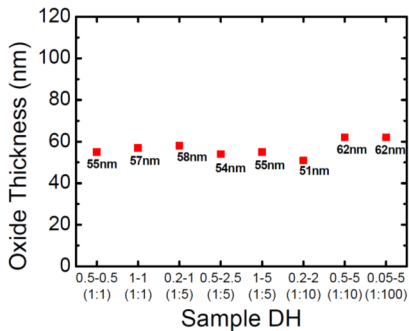

Fig.4 Oxide thickness of SiC oxidized in diluted N_2O ambient at 1300 °C for 1 hour with various N_2O and N_2 flow rate. The oxide thickness distributes in the range of 51~62 nm and shows no gas flow dependence. It is suspected that the decomposition of N_2O at this temperature is dominated by thermal decomposition. Thus, the collision partner plays minor role.
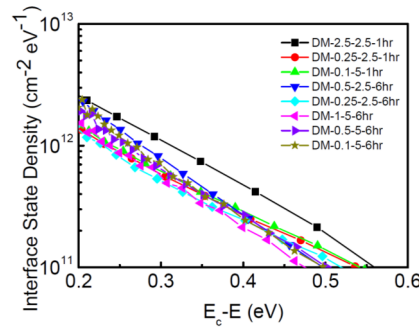

Fig.5 Interface state density of the MOS capacitors with gate oxide grown in diluted N_2O ambient at 1200 °C for 1 hours and 6 hours. The he interface state density at E_c-0.2 eV is higher than 1×10^{12} eV^{-1}cm^{-2} in each sample and the difference between samples is not significant
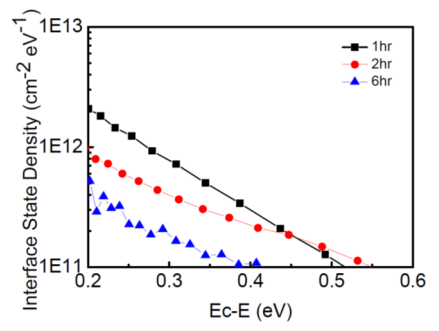

Fig.6 Interface state density of the MOS capacitors with gate oxide grown in diluted N_2O ambient at 1300 °C for 1, 2, and 6 hours. Apparent improvement occurs with elongated oxidation time. Interface state density at E_c-0.2 eV as low as 4~5×10^{11} cm^{-2}eV^{-1} can be achieved.