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Very Smooth SiO_2/SiC Interface Formed by Supercritical Water Oxidation of Low Temperature

T. Futatsuki[1,2], T. Oe[2], H. Aoki[1], N. Komatsu[1], C. Kimura[1] and T. Sugino[1]
[1]Graduate School of Engineering, Osaka University, 2-1 Yamadaoka, Suita-Shi, Osaka 565-0871, Japan
[2]Organo Corporation, 1-2-8, Shinsuna, Koto-ku, Tokyo 229-0012, Japan
Mail: futats-t@organo.co.jp

1. Introduction

Silicon Carbide (SiC) is a promising material for the field effect transistor (FET) devices in high power, high frequency, and high temperature operation. An insulating film SiO_2 can be grown by oxidation of SiC surface, taking advantage of well-established process technologies of Si-FET devices. However, a carbon rich region is generated near the SiO_2/SiC interface during the conventional thermal oxidation of SiC. It is thought to be a source of interfacial states and a poor carrier mobility performance of SiC-FET. It is reported that such carbon rich regions are not laterally homogeneous but nucleated, generating SiO_2/SiC interface microroughness. [1] They are generated during high temperature oxidation process and can be reduced by reoxidation at lower temperature [2].

We considered that the interface microroughness generation will be suppressed if SiC can be oxidized at lower temperature than conventional thermal oxidation. We have achieved to form SiO_2 layer on SiC surface by supercritical water (SCW) oxidation at much lower temperature 400°C and revealed that SCW oxidation suppresses the formation of the SiO_2/SiC interface microroughness compared with conventional thermal oxidation at 1100°C.

2. Experimental

Fig.1 shows temperature-pressure phase diagram of high pressure water. Around its critical point (374 °C, 22 MPa), water shows marked changes in its density, dielectric constant, hydrogen bonding, and other physical properties, which makes it a good medium for oxidation reaction. In this study, we have evaluated SiC surface oxidation in SCW at 400°C, 25MPa, comparing with conventional thermal oxidation at 1100°C.

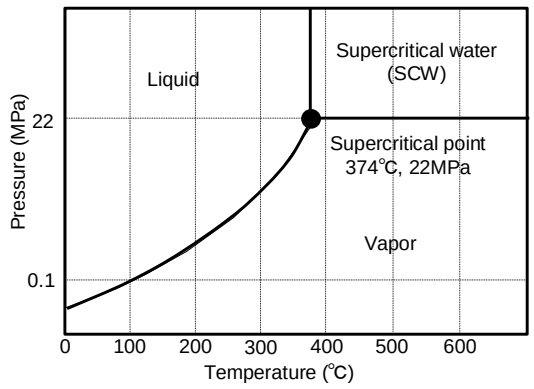

Fig.1 High pressure high temperature water

SCW oxidation was performed using a batch type high pressure reactor. Silicon-faced (0001) n-type 4H-SiC substrates with epitaxial layer were set in the reactor. An appropriate volume of pure water and hydrogen peroxide aqueous solution were introduced into the reactor, which was then sealed. Hydrogen peroxide was used as the oxygen source for SiC oxidation. The reactor was heated up to 400°C, kept at 400°C for SCW oxidation, and cooled down naturally. By controlling the water volume in the reactor, the pressure in the reactor was kept at 25MPa during SCW oxidation. Other SiC substrates were oxidized in a furnace tube at 1100°C.

Atomic force microscopy (AFM) observation was performed. Both the surface of the SiO_2 films and the surface of the SiC substrates after oxide removal by a 5% HF aqueous solution were observed. The latter surface represents the SiO_2/SiC interface.

3. Results and discussion

Table 1 summarizes the oxide thickness after various oxidation conditions for SiC substrates. Oxide thickness was calculated by the depth profile of the atom composition ratios measured by X-ray photoelectron spectroscopy (XPS) analysis with Ar-ion etching. A SCW oxide at 400°C for 6 min is as thick as a thermal oxide at 1100°C 120 min. This rapid oxidation at lower temperature is achieved by the high density of oxidant (oxygen: 400 mol/m^3) in high-pressure SCW environment, compared with 8 mol/m^3 in thermal dry oxidation at 1100°C.

Table 1 Oxide thickness

Sample	O_2 conc. (mol/m^3)	Time (min)	Tox (nm)
SCW 400°C, 25 MPa	400	6	10
SCW 400°C, 25 MPa	400	60	50
Thermal O_2 1100°C, 0.1MPa	8	120	15

Fig. 2 and Fig. 3 show the AFM images of SCW-oxidized SiC substrates before and after etching the SiO_2 film by 5% HF. After etching the SiO_2 film (Fig 3), slight increase of peaks is observed. They are thought to be carbon clusters and/or silicon oxycarbides generated as the results of incomplete oxidation of SiC in the SiO_2/SiC interface region. Those carbonated compounds are HF-resistant and remain after the HF etching as illustrated in Fig 5-(a). Fig 4 shows the AFM image

of thermally oxidized SiC substrate after etching. Vertically and horizontally larger peaks are observed than those found in SCW oxidized sample. As shown in Fig 5-(b), it is thought that long oxidation time at high temperature has grown larger HF-resistant compounds uniting the small peaks observed in the SCW case.

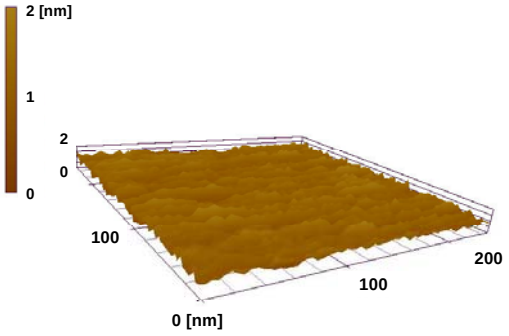

Fig.2 AFM image of the surface of the SCW oxide

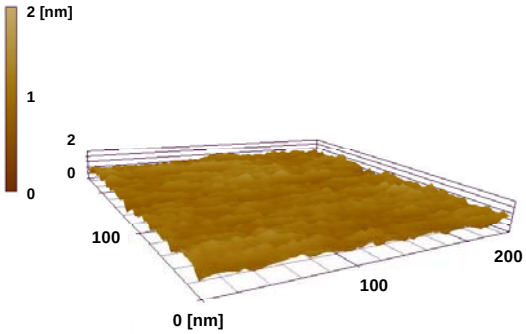

Fig.3 AFM image of the surface of the SiC after removal of the SCW oxide

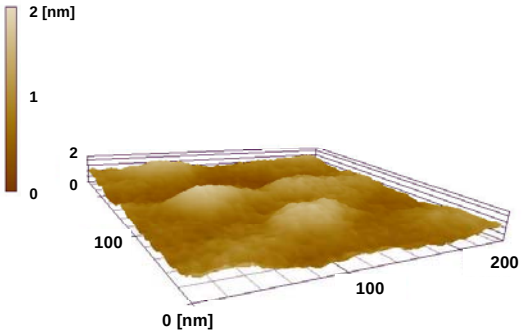

Fig.4 AFM image of the surface of the SiC after removal of the thermal 1100°C oxide

Average roughness index (Ra) and average peak-height index (Rc) of the AFM images are summarized in Table 2. Ra is not a proper index for the finding of this study. On the other hand, Rc represents the differences observed in the AFM images.

Reduction of the carrier scattering in SiO_2/SiC interface is essential for the mobility performance of SiC-FET. Fig 6 illustrates the carrier scattering model in the FET channel. The nucleated peaks of incomplete oxide near the interface may cause not only coulomb scatterings but also physical scatterings of the carrier. The SCW oxidation process at low temperature will effective to reduce the mobility degradation.

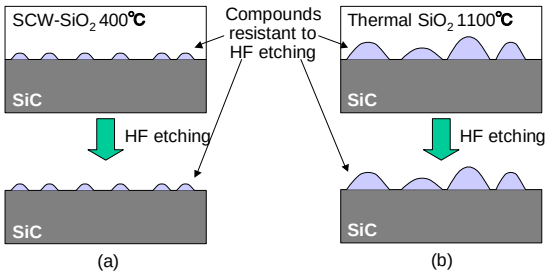

Fig. 5 Roughness formation model of SiO_2/SiC

Table 2 Summary of microroughness index

Sample	Ra (nm)	Rc (nm)
SCW 400°C before HF etching	0.2	0.7
SCW 400°C after HF etching	0.2	0.9
Thermal 1100°C after HF etching	0.3	1.5

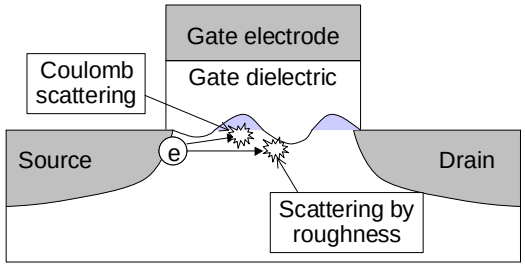

Fig. 6 Carrier scattering model of FET

4. Conclusion

We have revealed that SCW oxidation at 400°C forms very smooth SiO_2/SiC interface compared with conventional thermal oxidation at 1100°C. Smaller microroughness is achieved by the lower oxidation temperature owing to the high density of oxidant in SCW condition. The low temperature oxidation process will contribute to improve the mobility performance of future SiC-FET's.

Aknowledgement

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