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Removal of subsurface damage of 4H-SiC wafer by plasma assisted polishing

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Abstract

4H-SiC is considered one of the promising next-generation semiconductor power-device materials because of its high electronic performances, such as wide band gap, high breakdown field, high thermal conductivity. An atomically smooth 4H-SiC surface without subsurface damage (SSD) is essential for epitaxial growth or applications in electronic devices. Subsurface damage is inevitably formed on the surface during grinding and lapping process due to their mechanical removal mechanism such as plastic deformation and brittle fracture. Chemical mechanical polishing (CMP) is widely used for the finishing process of device grade SiC wafer to decrease the surface roughness and to remove the SSD. To improve the productivity of SiC wafer, optimization of grinding and lapping process, which form SSD, is essential because polishing rate of SiC by CMP is very low. We proposed a highly efficient damage-free polishing technique named plasma assisted polishing (PAP), which combine the irradiation of plasma for surface modification and removal of modified layer by using soft abrasive, was proposed for the finishing of difficult-to-polish materials such as 4H-SiC, GaN, sapphire, diamond, and so on. In the case of which PAP was applied to 4H-SiC, SiC was oxidized by irradiation of water vapour contained plasma. After oxidation by irradiation of plasma, modified layer could be removed by polishing using soft abrasives, such as ceria or silica. In this paper, SSD formed on the lapped 4H-SiC (0001) was observed by cross-sectional TEM (XTEM) and differences in oxidation rate between lapped and CMP-finished 4H-SiC (0001) surface were evaluated by X-ray photoelectron spectroscopy (XPS).

Grinding, Lapping, Subsurface damage, Plasma assisted polishing, 4H-SiC, Damage-free

1. Introduction

Single-crystal silicon carbide (SiC) is one of the most promising semiconductor materials for power device owing to its excellent properties, such as wide band gap, and high thermal conductivity. Manufacturing process of SiC wafer for electronic device use consists of slicing by wire saw, flattening by grinding or lapping and smoothing by chemical mechanical polishing (CMP). In the case of grinding or lapping process, subsurface damage (SSD), which deteriorates electronic property of SiC, is inevitably formed on the surface because of their mechanical removal process such as plastic deformation and brittle fracture. Material removal rate (MRR) of CMP is very low (*ca.* 1 μm/h). Therefore, development of highly efficient finishing process is strongly required for improving productivity of device grade SiC wafer. We proposed plasma assisted polishing (PAP), which consists of surface softening process by plasma irradiation and removal of modified layer by soft abrasive compared to base material, for finishing difficult-to-polish materials. In our previous study, atmospheric pressure plasma was used for surface oxidation or fluoridation, and atomically smooth surfaces without formation of SSD for 4H-SiC (0001) and GaN (0001) [1-3]. However, MRR of PAP was low because plasma generation area and supplied electric power were restricted to relatively small for maintain stable glow discharge. To increase the plasma generation area and supplied electric power, vacuum type PAP was proposed. In this paper, oxidation of 4H-SiC (0001) was demonstrated by applying vacuum type PAP apparatus, and comparison of the oxidation rate between wafer with and without SSD was conducted.

2. Experimental setup

Fig. 1 shows schematic of vacuum type PAP apparatus. This apparatus consisted of an upper electrode and a lower electrode, a rotation table for holding a wafer, a rotary head for installing a fixed abrasive, and a pressurizing mechanism for applying polishing pressure. Center of the rotary head was set with an offset of 15 mm from the center of the rotary table. Inside of the vessel between the upper electrode and the lower electrode, where covered by quartz glass window, was evacuated by rotary pump, and gas pressure in the vessel was controlled by flow rate of the process gas and pumping speed. Mass flow controller (MFC) controlled the flow rate of water vapour contained Ar gas, and the concentration of water vapour was measured by dew point meter (DPM).

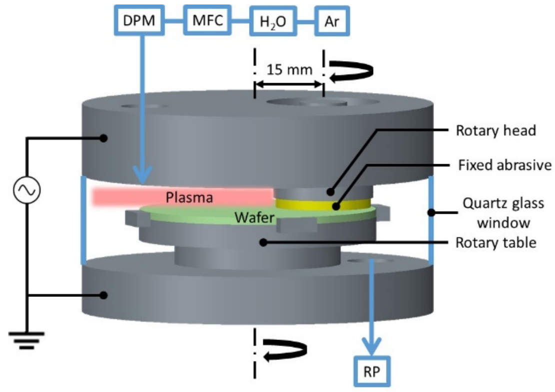

Figure 1. Schematic of vacuum type PAP apparatus.

Ar based low pressure plasma was generated between the upper electrode and the rotary table or lower electrode by applying RF (*f* = 13.56 MHz) electric field. Gap distance between upper electrode and rotary table was 15 mm.

3. Results and discussion

Surface modification rate decides the MRR of the workpiece in PAP process. To compare the oxidation rate of 4H-SiC (0001) with and without SSD, two kinds of specimens were prepared. One was a surface lapped using a vitrified grinding stone, and the other one was a commercially available CMP processed surface. Lapping pressure, abrasive material, and grain size range were 19.6 kPa, diamond, and 0-0.5 µm, respectively. Fig. 2 shows cross-sectional transparent electron microscope (XTEM) image of lapped surface. It is found from Fig. 2, SSD with a thickness of 100 - 200 nm was observed on the lapped surface, even though the surface roughness was 0.6 nm Ra. Therefore, removal depth of greater than 0.5 µm at least is needed to this specimen to use as a substrate for power device fabrication. Oxidation experiments used the apparatus showed in Fig. 1 were conducted to both the CMP processed surface and the lapped surface with same experimental conditions as shown in Table 1. Both specimens were put on the rotary table at the same time, and were irradiated with plasma without rotating the table. Fig. 3 shows optical emission spectrum of Ar based RF plasma used in this study. Emission from hydroxyl radical (λ = 309 nm) was observed in the OES. Hydroxyl radical has very large oxidation potential. So, it is assumed that hydroxyl radicals are main oxidation species in PAP process. In the case of PAP, surface modification by plasma irradiation and removal of modified layer are simultaneously occurred. Therefore, initial oxidation rate of newly exposed SiC surface is main factor that dominates MRR in PAP. To evaluate the initial oxidation rate, short time oxidation experiments for 1 min were conducted. Oxidation rates of SiC were calculated from Si2p spectra measured by X-ray photoelectron spectroscopy (XPS) using monochromatized AlKα (1486.6 eV) with a take-off angle of 45°. Fig. 4 shows Si2p XPS spectra of the oxidized SiC surface with and without SSD. Peaks of 100.5 eV and 102.9 eV correspond to Si-C and Si-O bonds, respectively. Thickness of oxide layer (d) is calculated by using equation:

$$d = \lambda_{\mathrm{OX}} \cdot sin\theta \cdot ln\left[\left(\frac{N_{\mathrm{m}}}{N_{\mathrm{OX}}} \cdot \frac{\lambda_{\mathrm{m}}}{\lambda_{\mathrm{OX}}}\right) \cdot \frac{I_{\mathrm{OX}}}{I_{\mathrm{m}}} + 1\right], \qquad (1)$$

where λ_m and λ_{ox} are escape depth of photoelectron in base material and oxide; N_m and N_{ox} are volume densities of atoms in base material and oxide; θ is take-off angle of photoelectron; I_m and I_{ox} are intensities of photoelectron peaks of base material and oxide [4]. In the case of SiC and its oxide, λ_m ($\approx\lambda_{ox}$), N_m, and N_{ox} are 3.3 nm, 4.8 ×10^{22} /cm^3, and 2.2 ×10^{22} /cm^3, respectively.

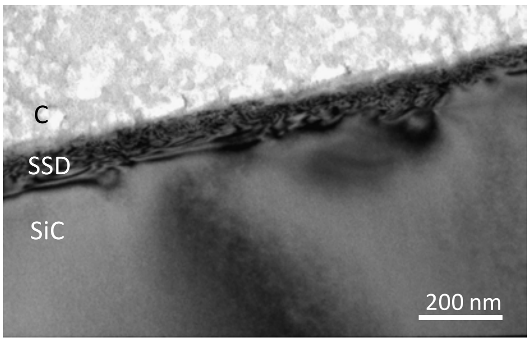

Figure 2. XTEM image of lapped 4H-SiC (0001).

Table 1 Experimental parameters in plasma oxidation.

Specimen	n-type 4H-SiC (0001)
RF power	130 W
Ar flow rate	14.1 sccm
Gas pressure	1.2 kPa
Concentration of water vapor	3.05%
Plasma irradiation time	1.0 min

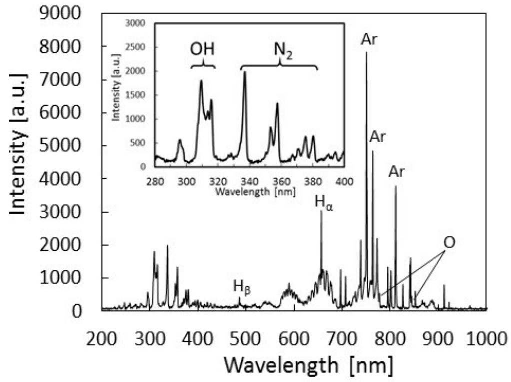

Figure 3. Optical emission spectrum of Ar based RF plasma.

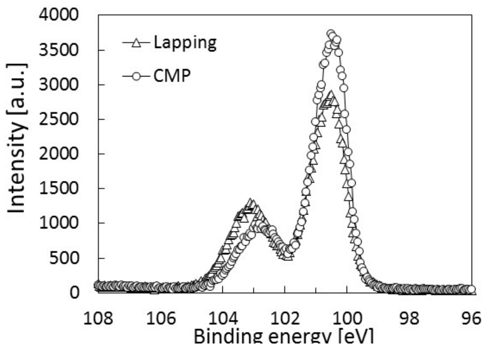

Figure 4. Si2p XPS spectra of SiC after plasma irradiation for 1 min.

Thickness of the oxide layers formed on the CMP processed surface and lapped surface were 1.06 nm and 1.62 nm, respectively. This result showed that oxidation rate of the surface with SSD was more than 1.5 times greater compared to the surface without SSD. It is assumed that strain and/or defects in the SSD promoted oxidation of the lapped SiC surface.

4. Conclusions

Vacuum type PAP was newly proposed and oxidation rates of 4H-SiC (0001), which dominate the MRR in PAP, were evaluated by XPS measurements. Results show that oxidation rate of lapped surface with SSD was more than 1.5 times greater compared to CMP processed surface. Therefore, highly efficient removal of SSD and finishing of SiC wafer will be expected.

Acknowledgments

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References

[1] Yamamura K, Takiguchi T, Ueda M, Hattori A N and Zettsu N 2011 *Annals of CIRP* **60** 571
[2] Deng H, Endo K and Yamamura K 2015 *Annals of CIRP* **64** 531
[3] Kageyama C, Deng H. Endo K and Yamamura K 2016 *Proceedings of 16th International Conference of the euspen* P7.12
[4] Strohmeier R. B 1990 *Surf. Interface Anal.* **15** 51