Study on oxidation processes of 4H-SiC (0001) for investigation of the atomically flattening mechanism in plasma assisted polishing

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Abstract

In order to clarify the atomically flattening mechanism of 4H-SiC in plasma assisted polishing (PAP), a study on water vapor plasma oxidation of SiC was conducted. A cross-sectional transmission electron microscopy (XTEM) observation revealed that an atomically flat interface between the oxide layer and SiC was obtained. Three times of plasma irradiation and HF dipping were conducted on a diamond lapped surface, which completely removed the scratches, though an atomically flat surface was not obtained, due to the residual of silicon oxycarbide layer on the surface. It was considered that CeO_2 abrasives could remove both silicon oxide and silicon oxycarbide, therefore, a flat surface with well-ordered step/terrace structure could be generated by PAP.

1 Introduction

Single-crystal silicon carbide (SiC) is considered one of the most promising next-generation semiconductor materials owing to its excellent properties, such as high hardness, wide band gap, and high thermal conductivity. For atomically finishing of SiC, chemical mechanical polishing (CMP) proposed by Zhou *et al.* [1] is now widely used. In CMP process, 4H-SiC was polished by concentrated colloidal silica slurry in alkaline solution. The flattening ability of CMP was acceptable and less subsurface damages were introduced.

We proposed a novel finishing technique named PAP, which combines atmospheric pressure water vapor plasma irradiation and soft abrasive polishing [2]. Although the good smoothing ability of PAP was proved, the material removal rate (MRR) of PAP, which was about 80 nm/h, was not as high as we expected compared with that of

CMP (about 500 nm/h). Also, it is not clear why an atomically flat surface could be obtained after PAP using ceria abrasives. To clarify the atomically flattening mechanism of 4H-SiC in PAP, an investigation of the water vapor plasma oxidation process of 4H-SiC (0001) was conducted.

2 Experimental setup and parameters

Figure 1 shows the schematic of experimental setup for plasma oxidation. Table 1 shows the experimental parameters of plasma irradiation. A 4H-SiC (0001) wafer (n-type, on-axis, ρ=0.110 Ωcm), manufactured by Cree Inc., was set on the ground electrode. Helium-based water vapor was used as the process gas and was introduced to the space between the electrodes. The diameter of the powered electrode was about 8 mm, and it was made of steel. Atmospheric pressure water vapor plasma was generated by applying a 13.56 MHz RF power between the electrodes. The gap between the powered electrode and the grounded SiC wafer was 3 mm.

Diamond abrasive lapping was conducted using a lapping machine manufactured by Maruto Instrument Co. Ltd. The diameter of diamond abrasive was ranging from 5 μm to 15 μm. The concentration of HF solution for removing the oxide layer by dipping was 50 wt%. The thin specimens for XTEM observation were prepared using a focused ion beam (FIB) system (HITACHI FB-2100) and observed by TEM (JEOL JEM-2100).

3 Results and discussion

Figure 2 shows the XTEM image of a 4H-SiC (0001) surface irradiated by water vapor plasma for 1 h. The middle layer was the oxide layer which was covered by a carbon layer for protection in FIB sample fabrication process. As shown in the XTEM image, an oxide layer with a thickness about 80 nm was generated. Also, though the surface of the oxide layer was very rough, the interface between oxide layer and SiC was atomically flat. Therefore, we assumed that plasma oxidation was the key step for obtaining an atomically flat SiC surface.

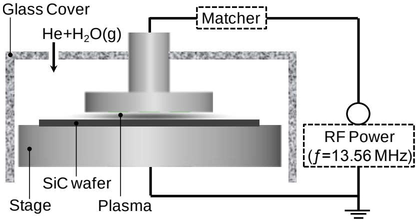

Figure 1: Schematic of experimental setup

Table 1: Experimental parameters

Parameters	Conditions
Specimen	φ50.8mm, n-type 4H-SiC (0001), 0.29°-off
Reactive Gas	He:H_2O = 98.62:1.38
Flow Rate	3.0 L/min
RF Power	18 W
Processing Time	1 h

To verify the assumed mechanism, the following experiments were conducted. A new specimen processed by CMP was firstly lapped by diamond abrasives, many scratches were introduced just as shown in Fig. 3(a). Then, this surface was irradiated by water vapor plasma for 1 h to oxidize the surface, and the oxide layer was etched off by HF dipping. After removal of oxide layer, the scratches introduced by diamond lapping become much shallower as shown in Fig. 3(b). Next, the second time of plasma irradiation and HF etching was conducted. As shown in Fig. 3(c), many deep scratches emerged, and they are considered as the subsurface damage layer introduced by diamond abrasive lapping. In the case of third time of plasma irradiation and HF cleaning were conducted, a scratches-free surface was obtained with a much better surface roughness as shown in Fig. 3(d). Also, this surface was observed using AFM. Though this surface was as flat as the surface processed by PAP, step/terrace structure, which reflects the crystallographic structure of 4H-SiC, could not be observed.

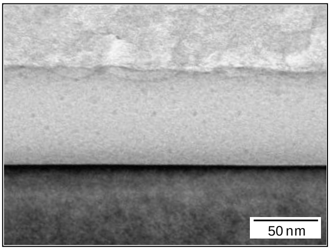

Figure 2: XTEM image of surface irradiated by plasma for 1h

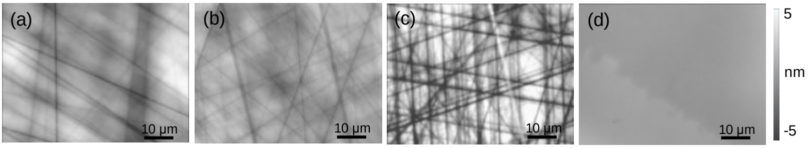

Figure 3: SWLI images of processed 4H-SiC surfaces (a) 11.14 nm p-v, 1.80 nm rms, (b) 6.65 nm p-v, 1.02 nm rms, (c) 18.39 nm p-v, 2.83 nm rms and (d) 2.45 nm p-v, 0.45 nm rms

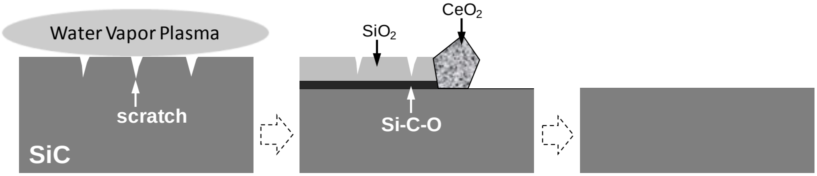

Figure 4: Probable mechanism of PAP

The composition of surfaces processed by plasma irradiation and HF dipping were analyzed using angle resolved X-ray photoelectron spectroscopy (ARXPS). Analyzing the results indicated that both SiO_2 and silicon oxycarbide were generated after plasma irradiation, and silicon oxycarbide couldn't be removed by HF dipping. Based on the above results, we proposed the atomically flattening mechanism in PAP. In the case of plasma oxidation followed by HF dipping, the HF solution removed the SiO_2 layer. However, the silicon oxycarbide layer remained on the surface. This is the reason why the step/terrace structure of SiC could not be observed. Figure 4 shows the probable atomically flattening mechanism in PAP. As it was mentioned, in the PAP process, due to the rotation of the polishing head and specimen, when an oxide layer was generated, it would be removed by abrasive scraping. Therefore, the duration time of oxidation was very short. In this case, both the thicknesses of SiO2 and silicon oxycarbide were very thin, and they were completely removed by ceria abrasives scraping. These combination process forms a atomically flat surface with well-ordered step/terrace structure without the residual of silicon oxycarbide layer.

Acknowledgments

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References:

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