Polishing characteristics of single crystal SiC assisted by plasma oxidation using different kinds of abrasives

H. Deng[1], K. Endo[1], K. Yamamura[1]
[1] *Research Center for Ultra-precision Science and Technology, Graduate School of Engineering, Osaka University, Japan*
yamamura@upst.eng.osaka-u.ac.jp

Keywords: 4H-SiC, Plasma, Polishing, Abrasive

Abstract

For the flattening of some difficult-to-machine materials, such as 4H-SiC, GaN, diamond and so on, we proposed a precision polishing technique named plasma assisted polishing (PAP), which combined the irradiation of atmospheric pressure water vapor plasma and soft abrasive polishing. For the optimization of the abrasive material in PAP, the polishing characteristics of different abrasives such as CeO_2, SiO_2, Al_2O_3 and diamond are evaluated in this work. In the case of polishing using CeO_2 and SiO_2 slurry, step-terrace structure of SiC was generated and that on the CeO_2 slurry polished surface was much more uniform. In contrast, scratches were introduced on the surfaces polished by Al_2O_3 and diamond slurry due to the high hardness of the abrasive materials.

1. Introduction

4H-SiC is considered one of the most promising next-generation semiconductor materials owing to its excellent mechanical and electrical properties, such as high hardness, wide band gap, and high thermal conductivity, and so on. To make these properties to sufficiently good use, an atomically flat and damage-free surface is essential. We proposed a novel polishing technique named PAP, which combines modification by atmospheric pressure water vapor plasma and polishing using soft abrasive [1, 2]. Although the good smoothing ability of PAP was already proved, the material removal rate (MRR) of PAP was very low. In order to increase the MRR of PAP, optimization of the modification process and polishing process in PAP is essential. In this paper, the polishing characteristics of 4H-SiC (0001) using different abrasives such as CeO_2, SiO_2, Al_2O_3 and diamond are evaluated.

2. Experimental setup and parameters

Fig. 1 shows the experimental setup for water vapor plasma oxidation. The 4H-SiC specimen was set on the ground electrode. Helium-based water vapor (1.5 standard liters per minute) was used as the process gas and was introduced into the space between the electrodes. The diameter of the aluminum alloy powered electrode was 4 mm. Atmospheric-pressure helium-based water vapor plasma was generated by applying a 13.56 MHz RF power between the electrodes. The RF power was 45 W with a duty ratio of 10%. The gap between the powered electrode and the SiC wafer was 1 mm. The polishing process was conducted using a slurry polishing system. The specimen was immersed into slurry and the polishing pad scanned on it. Table 1 shows the conditions of slurry polishing.

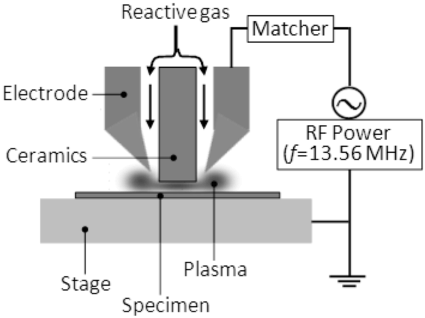

Figure 1: Experimental setup of water vapor plasma irradiation.

Table1: Experimental conditions of slurry polishing.

Parameters	Conditions
Load	50 g
Polishing pad	K0017 (FILWEL Co. Ltd.) (ϕ=10 mm)
Abrasive material	CeO_2 (ϕ=190 nm), SiO_2 (ϕ=80 nm), Al_2O_3 (ϕ=100 nm), diamond (ϕ=100 nm)
Polishing time	3 h
Rotation speed	2000 rpm
Slurry concentration	CeO_2 (1.0 wt%), SiO_2 (1.0 wt%), Al_2O_3 (10.0 wt%), diamond (0.4 wt%)

3. Results and discussion

Figure 2 shows an atomic force microscopy (AFM) image of a SiC (0001) surface processed by plasma oxidation followed by slurry polishing. An atomically flat surface with a well-ordered step-terrace structure is obtained. This result indicates that combination of plasma oxidation and CeO_2 abrasive polishing is a very useful method for surface flattening of 4H-SiC.

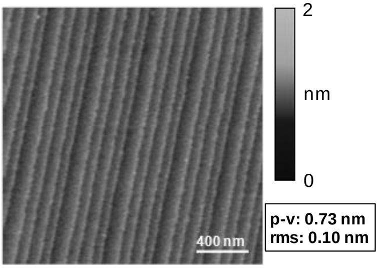

Figure 2: AFM image of a SiC (0001) surface processed by plasma oxidation followed by slurry polishing.

In a PAP process, when an oxide layer is generated, it will be immediately removed by abrasive polishing. After the oxide layer was removed, polishing of the bulk SiC will be conducted. Therefore, the surface morphology obtained by PAP was determined by the oxide-SiC interface and the abrasive polishing characteristic of 4H-SiC. Therefore, polishing of 4H-SiC (0001) using different abrasives such as CeO_2, SiO_2, Al_2O_3 and diamond were respectively conducted without previous plasma oxidation.

Figure 3 shows the AFM images of SiC (0001) surfaces processed by polishing using different abrasives. When CeO_2 and SiO_2 slurry was used, step-terrace structure of SiC was generated. Although the hardness of CeO_2 and SiO_2 is much lower than that of SiC, SiC is oxidized by chemical reactions in slurry and the oxide layer can be removed by CeO_2 and SiO_2 abrasives. The interaction between chemical reaction and mechanical polishing greatly affect the morphology of the step-terrace structure. Because the oxidation rates of the four SiC bilayers in one unit cell of 4H-SiC are different whereas the mechanical removal rates of these bilayer are supposed to be the same. In the case of CeO_2 slurry polishing, well-ordered step-terrace structure is observed, thus, the mechanical removal rate should be higher than the oxidation rate in this process because the MRR of SiO_2 by CeO_2 slurry polishing is high. In contrast, when SiO_2 slurry was used, a step-terrace structure with alternations of four kinds of terraces is observed. It means that the oxidation rate in this process is higher than the mechanical removal rate. And this is why a periodic step-terrace structure is generated. It can be found that the terrace-edge is not uniform and it is considered that a very small amount of oxide exist at the terrace-edge.

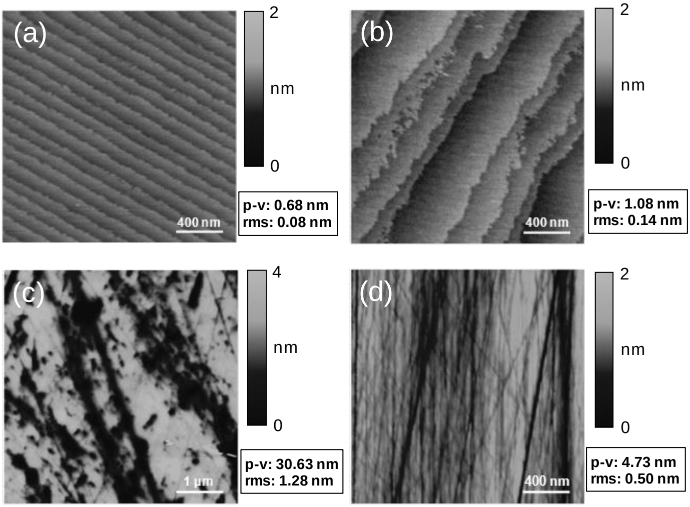

Figure 3: AFM image of a SiC (0001) surface processed by polishing using different abrasives. (a) CeO_2, (b) SiO_2, (c) Al_2O_3, (d) diamond.

When Al_2O_3 and diamond slurry are applied, many scratches are introduced as shown in Figure3 (c) and (d). This is due to the high hardness of Al_2O_3 and diamond

4. Conclusions

The polishing characteristics of CeO_2, SiO_2, Al_2O_3 and diamond were evaluated in this study. No scratches were introduced when CeO_2 and SiO_2 were used. CeO_2 was very useful for the generation of a well-ordered step-terrace structure.

Acknowledgments

This work was partially supported by Adaptable and Seamless Technology Transfer Program through Target-driven R&D, JST, a Grant-in-Aid for Scientific Research A (25249006) from the Ministry of Education, Culture, Sports, Science and Technology, Japan (MEXT) and a Grant-in-Aid for JSPS Fellows (25-518 2013).

References:

[1] K. Yamamura, T. Takiguchi, M. Ueda, H. Deng, A.N. Hattori and N. Zettsu, Ann. CIRP **60** (2011) 571.

[2] H. Deng and K. Yamamura, Ann. CIRP **62** (2013) 575.