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Polishing characteristics of CVD-SiC in plasma-assisted polishing

Hui Deng[1], Katsuyoshi Endo[1], Kazuya 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

Abstract

CVD-SiC coated substrate is a very promising material for glass molding and space telescope mirror because of its excellent chemical and mechanical properties. To make use of CVD-SiC as a molding, scratch-free and damage-free finishing are essential for decreasing the light scattering of optical device and for improving the durability of mold. However, polishing of SiC is very difficult since SiC have a very high hardness and a chemical inertness. Plasma assisted polishing (PAP) was proposed by the author to realize the high-efficiency and high-integrity finishing of difficult-to-polish materials such as single crystal SiC, reaction sintered SiC, sapphire, tungsten carbide, and diamond. In the case of PAP finishing of SiC substrate, combination process, which consists of irradiation of atmospheric pressure water vapor plasma and polishing using a soft abrasive such as ceria, is applied. The irradiation of water vapor plasma oxidizes the SiC surface, and the subsequent ceria abrasive polishing preferentially removes the oxidation layer. In our previous research, we have obtained an atomically smooth and damage-free 4H-SiC (0001) surface by applying PAP. Polycrystalline CVD-SiC substrate has structural differences, such as the grain boundary, surface orientation and impurities, in comparison with the single-crystal SiC. In this paper, CF_4 plasma etching for the removal of scratch and subsurface damaged layer and PAP using a CeO_2 grindstone for surface flattening were applied to a CVD-SiC substrate.

Keywords: Plasma-assisted polishing, CVD-SiC, Mold, Oxidation, Dry polishing

1. Background

Materials of high hardness, light weight and high thermal conductivity are very suitable for mirror and mold applications. Therefore, CVD-SiC is widely considered as one of the most promising materials for glass molding and space telescope mirror [1]. Conventional manufacturing processes such as grinding, polishing and CMP are widely used for the processing of CVD-SiC [2-4]. However, when diamond abrasives are used, scratches and subsurface damaged layers, which deteriorate the properties of SiC, are inevitably introduced. On the other hand, when CMP is used for finishing of CVD-SiC, the material removal rate is extremely low. Moreover, the use of slurry is not environmentally friendly and increases the cost of CMP.

For the finishing of some difficult-to-polish materials, plasma-assisted polishing (PAP), in which surface modification by plasma irradiation and removal of modified layer by dry polishing using soft abrasives are combined, has been proposed [5]. In our previous research, PAP using CeO_2 as an abrasive was successfully used to flatten single-crystal SiC and reaction-sintered SiC ceramic, and scratch-free and damage-free surfaces were obtained. In particular, in the case of single-crystal SiC, an atomically smooth surface with a well-ordered step-terrace structure was obtained [6-8].

In this work, CF_4 plasma etching and water vapor-based PAP were applied to CVD-SiC. Scratches and subsurface damaged layers of CVD-SiC were quickly removed by CF_4 plasma etching. PAP using a CeO_2 grindstone was conducted to improve the surface roughness.

2. Experimental setups

CVD-SiC with a thickness of 3 mm grown on 2 inch reaction sintered SiC substrates were used in this study. Fig. 1(a) shows the experimental setup used for plasma irradiation. A mixture of helium gas with CF_4 was supplied through the space between the electrode and the coaxially arranged ceramic cover. The flow rates of He and CF_4 were 1.0 slm and 25 sccm, respectively. A CVD-SiC specimen was set on the stage. The gap between the electrode and the substrate was 1.1 mm. The diameter of the powered electrode, which was made of aluminium alloy, was 3 mm. An impedance matcher was used to maximize the transfer of power from the power source to the plasma. The applied power was increased from 10 W to 30 W. Atmospheric-pressure He-based CF_4 plasma was generated by applying a 13.56 MHz radio frequency (RF) power between the electrode and the stage. The duration for plasma etching was 5 min.

Figure 1 (b) shows the experimental setup used for PAP. A CeO_2 grindstone was fixed under the electrode with a center offset of 4 mm. The applied power was 18 W. Helium gas containing water vapor (494 ppm) was supplied from circumference of the electrode with a flow rate of 3.0 slm. Helium based atmospheric pressure water vapor plasma was generated around the grindstone by applying a 13.56 MHz RF power between the electrode and stage. With rotation of the electrode with a constant load of 80 g and rotation speed of 320 rpm, plasma modification and abrasive polishing were simultaneously conducted.

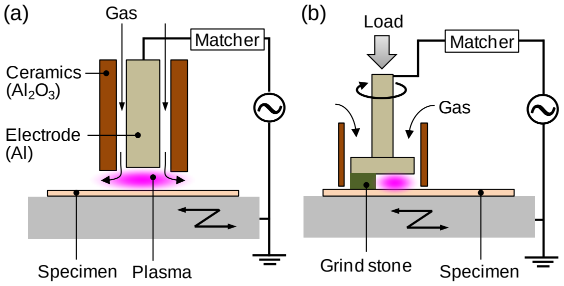

Figure 1. The experimental setups used for plasma irradiation (a) and PAP (b).

2. Results and discussion

To remove the scratches and subsurface damaged layers of CVD-SiC introduced by diamond abrasive lapping, CF_4 plasma etching with different applied power was conducted. Figure 2 shows the scanning white light interferometer (SWLI) images of CVD-SiC surfaces etched by CF_4 plasma irradiation for 5 min. On the as-received diamond abrasive lapped surface, many scratches could be observed. After this surface was etched with an applied power of 10 W, these scratches were almost disappeared as shown in Figure 2(b). In the case of the applied power of 20 W, the etching depth became thicker and many deep scratches as shown in Figure 2(c) were emerged. These scratches were considered originated from the subsurface damaged layers in CVD-SiC. When the applied power was increased to 30 W, the etching rate was also greatly increased. Owing to the different etching rates of different SiC surface orientations in CVD-SiC, a very rough surface was obtained as shown in Figure 2(d). It was proved that for the etching of CVD-SiC, a low applied power, which resulted in a low etching rate, was necessary to avoid the increase in surface roughness.

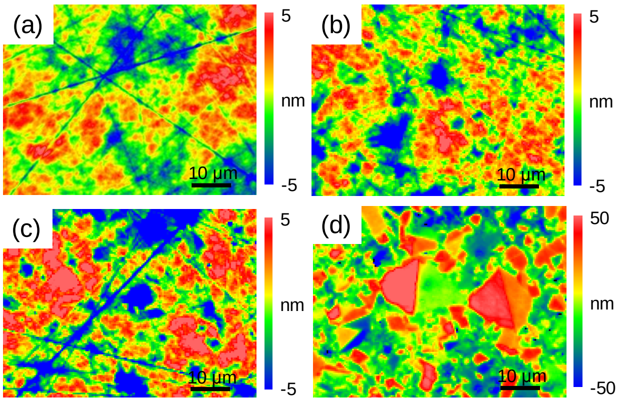

Figure 2. SWLI images of CF_4 plasma etched surfaces. (a) as-received surface (Sz: 22.16 nm, Sq: 2.18 nm), (b) applied power of 10 W (Sz: 18.79 nm, Sq: 2.48 nm), (c) applied power of 20 W (Sz: 44.14 nm, Sq: 4.05 nm), (d) applied power of 30 W (Sz: 439.04 nm, Sq: 25.19 nm).

To decrease the surface roughness of CVD-SiC, PAP using a CeO_2 grindstone was conducted. Figure 3 shows a scanning electron microscope (SEM) image of the surface of the grindstone. Many small CeO_2 grains of micrometer size can be observed. The CeO_2 grains in the grindstone are held together by resin, which is very soft, as the bonding material.

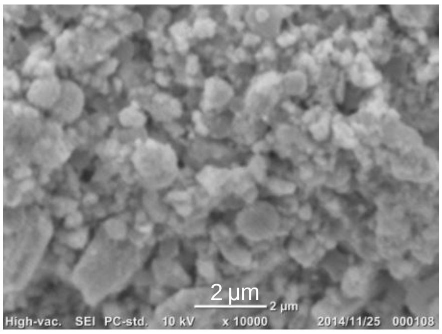

Figure 3. SEM image of the surface of resin-bonded CeO_2 grindstone

Before the application of PAP, polishing of CVD-SiC without plasma modification was conducted under the same polishing conditions. Figure 4(a) shows the SWLI image of the polishing results. The surface roughness greatly increased. Many dropouts of SiC grains were observed on the polished surface. In the case of reaction sintered SiC, Si, as the bonding material, existed around SiC grains. However, no bonding materials existed in CVD-SiC. Therefore, owing to the impacts between CeO_2 abrasives and SiC grains, dropouts of SiC grains frequently occurred, which increased the surface roughness.

Figure 4(b) shows the SWLI image of the CVD-SiC surface processed by PAP. A smooth surface with an root mean square roughness less than 1 nm was obtained. Also, no dropouts could be observed on the polished surface. In PAP, surface modification (oxidation) and CeO_2 abrasive polishing were simultaneously occurred. SiC grains in CVD-SiC were oxidized to SiO_2, which was much softer than SiC and much easier to be polished. The generated oxide layer was removed by CeO_2 abrasive, which was very suitable for the polishing of glass. Therefore, the impacts between CeO_2 abrasives and SiC grains were avoidable and a smooth surface could be obtained. The above results proved that PAP using CeO_2 grindstone was very useful for the smoothing of CVD-SiC.

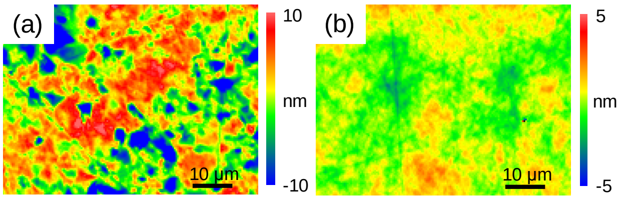

Figure 4. SWLI images of polished surfaces. (a) CeO_2 grindstone polishing without plasma modification (Sz: 47.05 nm, Sq: 5.49 nm), (b) PAP (Sz: 7.56 nm, Sq: 0.78 nm)

4. Conclusions

Atmospheric-pressure CF_4 plasma etching and plasma-assisted polishing using a CeO_2 grindstone were applied to the smoothing of CVD-SiC. In the case of CF_4 plasma etching, it was found that a low etching rate was necessary to remove the scratches and subsurface damaged layers without the increase in surface roughness. In the case of PAP combined water vapor plasma modification and CeO_2 grindstone polishing, a smooth surface without dropouts of SiC grains was successfully obtained.

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