Development of Atmospheric-Pressure-Plasma-Assisted High-efficient and High-integrity Machining Process of Difficult-to-Machine Materials

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Abstract

A novel machining method utilizing an irradiation of atmospheric pressure plasma is proposed for finishing of difficult-to-machine materials. The irradiation of helium-based water vapor atmospheric pressure plasma efficiently oxidize the surface of single-crystal 4H-SiC, and a ball-on-disc test using an alumina ceramic ball revealed that the wear rate of plasma irradiated SiC surface is 20 times larger than the surface without plasma irradiation. Similar effects were also observed in the cases of polycrystalline CVD-SiC and cemented carbide material. A scratch-free 4H-SiC surface was obtained by CeO_2 abrasive lapping assisted by the irradiation of water vapor plasma.

1 Introduction

The materials of die for precision glass lens molding are difficult-to-machine because of its hardness and chemical inertness. Polycrystaline CVD-SiC and cemented carbide are typical materials for molding die, and those are polished by applying micro diamond abrasives. Therefore, micro-scratches and subsurface damages, which deteriorate surface integrity, are inevitably generated on the workpiece surface. In contrast, chemical mechanical polishing (CMP) techniques are being developed for finishing the surface of single-crystal SiC and/or GaN substrate, which are promising materials as the next-generation semiconductor power device. However, polishing rate of single-crystal SiC is very low (less than 0.5 μm/h), and it is generally difficult to obtain an adequate level of surface integrity for epitaxial growth in commercially available SiC and GaN wafer because these are hard and chemically-inert materials [1, 2].

To resolve these issues, we propose a new machining technique, which utilizes an assist of atmospheric-pressure-plasma irradiation, to realize high-efficient and high-

integrity finishing of difficult-to-machine materials. The irradiation of plasma modifies the mechanical and/or chemical properties of the surface of the hard material to remove easily.
In this paper, we describe the machining properties, such as the removal rate, the surface roughness and the subsurface damage, of the newly proposed plasma-assisted machining technique.

2 Experimental setup

Fig. 1 shows schematic of experimental apparatus. This apparatus consists of plasma generation part and mechanical removal part, and these parts are separately installed to investigate basic removal mechanism. Atmospheric pressure plasma is generated by applying a high-frequency (f=13.56 MHz) electric power, and the helium containing water vapor (2.3%) is supplied as a process gas (1.5 L/min). Copper electrode is covered with a quartz glass to prevent an arc discharge by generating a dielectric barrier discharge. In the mechanical removal part, ball-on-disc test with an alumina ball (φ6.35 mm) or lapping test with a lapping film (φ8 mm) can be performed by changing the tool head. The test sample is installed on the rotary table, and the surface modification by plasma irradiation and mechanical removal by alumina ball or lapping film are sequentially performed.

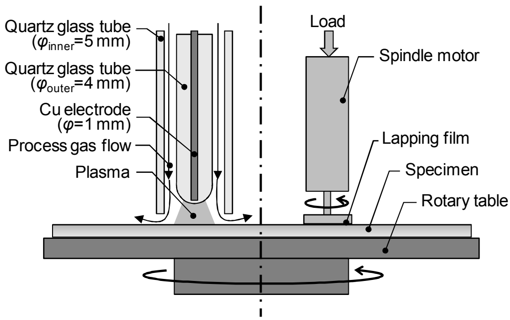


Figure 1: Schematic of experimental apparatus (Lapping configuration)

3 Results and discussion

Fig. 2 shows ball-on-disc test result of 4H-SiC (Si-face). The load, rotating speed of the specimen and processing time were 100 g, 120 rpm and 30 min, respectively. The wear rate of the SiC surface with the irradiation of water vapor plasma is 20 times greater than that of the surface without plasma irradiation. Fig. 3 shows the XPS spectra of the 4H-SiC surface. Strong peak due to the Si-O bond (532.5 eV) is observed from the surface irradiated by water vapor plasma, while the weak peak due to hydroxide (531.8 eV) is observed from the as-received surface. This result indicates that irradiation of the water vapor plasma strongly oxidizes the surface of the SiC. Figs. 4(a) and (b) show the hardness of 4H-SiC and WC, which were measured with a nanoindenter with a Berkovich indenter. The hardness of SiC and WC irradiated by water vapor plasma were decreased in about one order of magnitude. These results indicate that the irradiation of the water vapor plasma is effective to modify the hardness of the difficult-to-machine materials to soft. The 4H-SiC (Si-face) irradiated with the water vapor plasma was processed by the lapping film with CeO_2 abrasives (φ0.5 μm). Rotating speed of the rotary table and the spindle motor and the load were 120 rpm, 10,000 rpm and 30 g, respectively. These experimental parameters are preliminary which are not optimized.

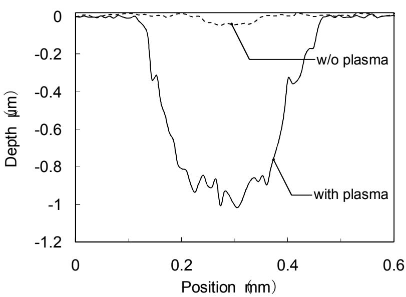


Figure 2: Ball-on-disc test results of 4H-SiC (Si-face)

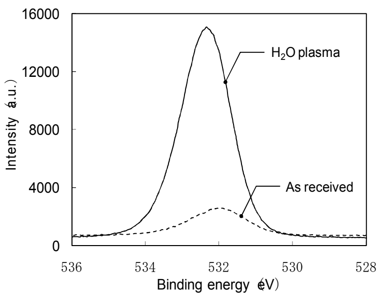
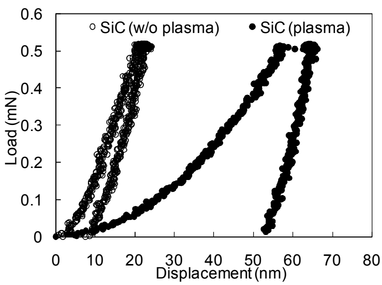
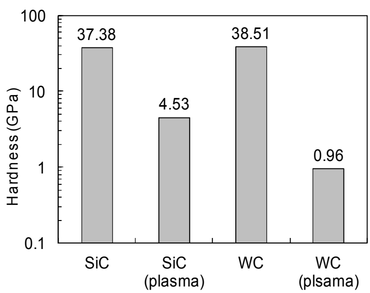


Figure 3: XPS spectra of O1s peak of 4H-SiC (Si-face)



(a) Load-displacement curve (4H-SiC)



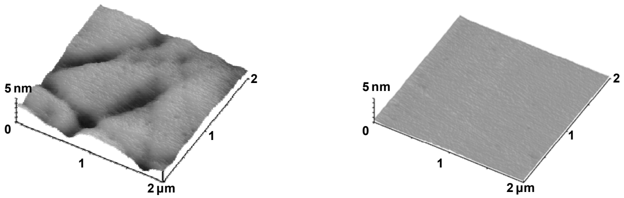
(b) Calculated hardness

Figure 4: Nanoindentation test results of 4H-SiC (Si-face) and WC

(a) As-received surface
4.41 nm p-v, 0.621 nm rms

(b) Plasma-assisted lapped surface
1.889 nm p-v, 0.280 nm rms

Figure 5: Surface profiles of 4H-SiC measured with microscopic interferometer



(a) As-received surface
3.648 nm p-v, 0.495 nm rms

(b) Plasma-assisted lapped surface
1.319 nm p-v, 0.060 nm rms

Figure 6: AFM images of 4H-SiC

Figs. 5 and 6 show the surface roughness of 4H-SiC (Si-surface, 8° off-axis) measured with a microscopic interferometer and an AFM, respectively. These results show that the plasma-assisted lapping enables us to obtain a scratch-free surface of SiC substrate. As for the evaluation of crystallinity, the relaxation of strain, which existed in the as-received surface, was observed by reflection high energy electron diffraction (RHEED) analysis. This result indicates that plasma-assisted lapping never introduces the crystallographic strain to the SiC surface. Furthermore, it is presumed that there is little oxidized layer on the SiC surface because very clear image of RHEED pattern was observed. The HF dipping can easily remove off the residual slight oxidized layer. Therefore, it is concluded that plasma-assisted lapping/polishing technique has great potential to improve the surface integrity of difficult-to-machine materials.

Acknowledgments

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[2] V. D. Heydemann, et al., Materials Science Forum, **457-460** (2004) 805.