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# Investigation on mirror surface grinding characteristics of SiC materials

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**SiC materials such as sintered SiC, CVD-SiC, and monocrystalline SiC are hard-to-difficult to grind, and they are expected to be applied for optical elements, structural components, dies and molds, and semiconductors. The authors investigated the mirror surface grinding characteristics of these SiC materials. A comparison on mirror surface grinding characteristics between polycrystalline SiC and monocrystalline SiC has been conducted. Metal-bonded diamond grinding wheels and a rotary grinding method have been applied under a variety of grinding conditions. As a result, very high quality of mirror surfaces has been successfully achieved on both materials using high mesh sized grinding wheels.**

**Keywords: SiC, Mirror surface grinding, In-feed grinding, ELID grinding.**

## Introduction

Silicon carbide (SiC) materials have some excellent mechanical and electrical properties such as high hardness, high strength at elevated temperatures, better thermal conductivity, wide band gap, etc. [1]. Therefore, SiC materials have increasingly been applied in a wide range of industries. For example, polycrystalline SiC is used for structural components, automobile parts, in a space telescope, as an X-ray mirror, etc.. Monocrystalline SiC is used as a next-generation semiconductor. However, SiC materials have difficulties in super-smooth finishing due to their hard and brittle features. In addition, the number of cases that reported about grinding SiC materials is very small.

We investigated the grinding characteristics of SiC materials with high precision by using the electrolytic in-process dressing (ELID) grinding method [2, 3]. In this study, polycrystalline SiC and monocrystalline SiC were used as specimens, and their surface properties were determined.

Monocrystalline SiC has some polytypes that are usually expressed by a number and a letter. The number shows atomic stacking sequences along the c-axis and the letter shows the crystal system. For instance, “4H” stands for atoms crystallized in the hexagonal system and a unit consists of 4 atoms. Fig. 1 shows crystal structures of 4H-SiC and 6H-SiC. In Japan, more numbers of 4H-SiC are relatively produced because 4H-SiC has less anisotropy and a higher electron mobility than the other types of SiC [1]. Fig. 2 shows typical crystallographic planes of 4H-SiC. In the case of the crystallographic planes, $(11\bar{2}0)$ has less electrical resistance than other crystallographic planes. So, the workpiece we used was a 2-inch (50 mm) 4H-SiC wafer and the crystallographic plane was $(11\bar{2}0)$.

## Experimental conditions

Fig. 3 shows the surface roughness before machining

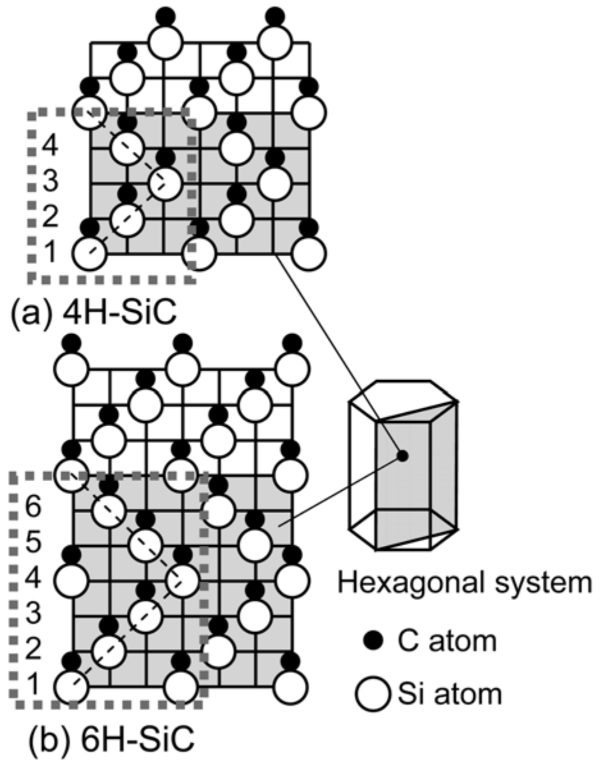


**Fig. 1.** Crystal structures of 4H-SiC and 6H-SiC.

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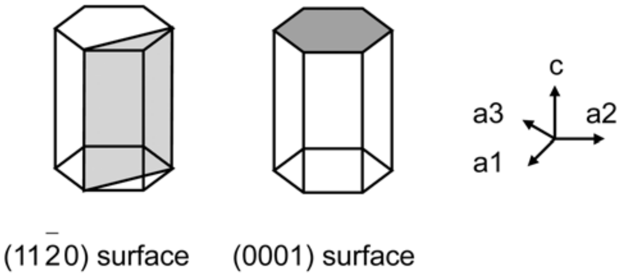


**Fig. 2.** Typical crystallographic planes of 4H-SiC.

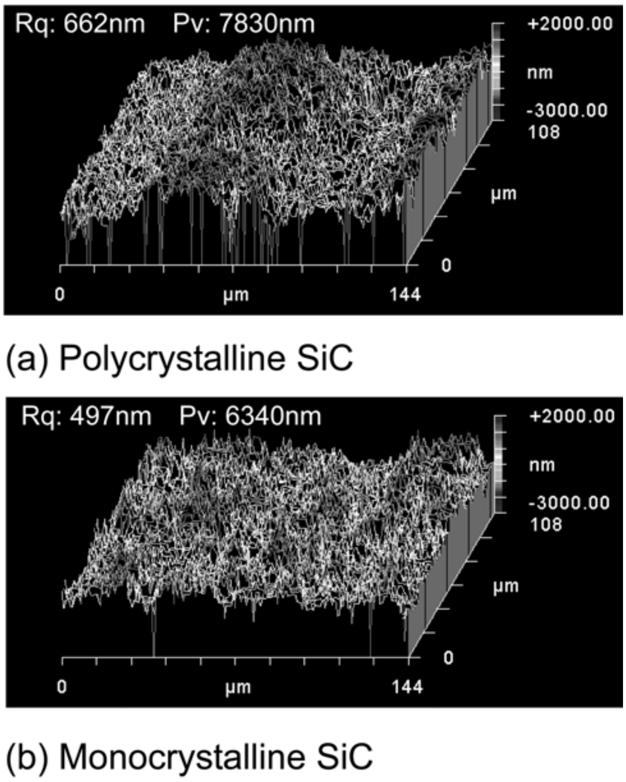


**Fig. 3.** Surface roughness before machining.

by an optical profiler: NewView [zygo corp.]. The roughness of polycrystalline SiC and monocrystalline SiC was Pv 6000 to 8000 nm. A #1200 wheel was used at first for machining. Table 1 shows the experimental conditions. With the #1200 and #4000 wheels, the feed rate was set as 1.0 µm·minute$^{-1}$. With #8000 and #20000 wheels, the feed rate was set as 0.5 µm·minute$^{-1}$ for finishing grinding. Incidentally, the average sizes of abrasive grains were 12 µm, 4.1 µm, 1.8 µm and 0.51 µm. The rates of wheel rotations were selected according to feed rates and abrasive grain sizes. When each machining was finished, the surface roughness was evaluated by an optical profiler, and the surface property was observed by a scanning electron microscope (SEM).

Fig. 4 shows an external view of the rotary in-feed grinding machine and Fig. 5 shows the principle of the ELID grinding method. ELID is composed of a metal-bond grinding wheel and an electrolytic dressing process.

**Table 1.** Experimental conditions

| | |
|---|---|
| Workpiece | Polycrystalline SiC<br>(40.0 × 40.0 × 0.7 mm)<br>Monocrystalline 4H-SiC (11$\bar{2}$0)<br>(ϕ 50.8 × 0.4 mm) |
| Grinding machine | Rotary in-feed grinding machine:<br>HGS-10A2 |
| Grinding wheels | Cast iron bonded diamond wheel:<br>SD#1200, SD#4000<br>Average sizes of abrasive grains:<br>12 µm, 4.1 µm<br>Concentration 100<br>(ϕ 143 × W 3 mm cup)<br>Metal-resin bonded diamond wheel:<br>SD#8000, SD#20000<br>Average sizes of abrasive grains:<br>1.8 µm, 0.51 µm<br>Concentration 100<br>(ϕ 143 × W 3 mm cup) |
| Grinding conditions | Wheel rotation:<br>1000, 1500, 2000, 2500 minute$^{-1}$<br>(Circumferential velocity:<br>449, 674, 898, 1120 m·minute$^{-1}$)<br>Workpiece rotation: 300 minute$^{-1}$<br>Feed rate: 0.5, 1.0 µm·minute$^{-1}$ |
| Power supply | NX-ED911 |
| Electrical conditions | Open voltage: 60, 90 V<br>Peak current: 4, 6, 8, 10 A<br>Pulse timing (on/off): 2 / 2 µs |

**Fig. 4.** External view of the grinding machine.

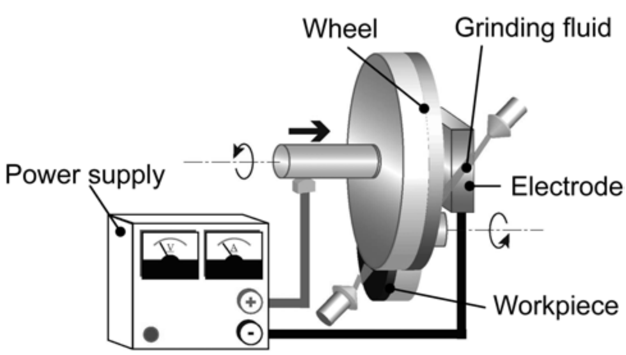


**Fig. 5.** Schematic illustration of ELID in-feed grinding.

The wheel serves as a positive electrode and a negative electrode is fitted in near the wheel. In addition, a specific pulse generator of which the voltage and the electric current are variable is used. In the situation that a chemically-soluble grinding fluid is supplied, electrolysis occurs under the application of electric current. Thus, the wheel is stably dressed by electrolysis.

## Experimental results

Fig. 6 and Fig. 7 show the surface roughness with using the same profiler (NewView). As the mesh size became finer, the surface roughness was improved in general. Although the root mean square height (Rq) of monocrystalline SiC with the #8000 wheel was not better than one with the #4000 wheel, it would be possible to improve the smoothness with more appropriate wheel rotations and electrical conditions.

According to previous experience, as the abrasive grain size became finer, the wheel rotation should have been set slower for a better surface finish [4]. When the wheel rotation was set slow, it was difficult to slip for wheel on the workpiece. In addition, the electrical conditions usually must be turned down because a slower wheel speed increased the intensity of the electrolysis per unit time. The appropriate conditions were demanded by such outlines.

Fig. 8 and Fig. 9 show the SEM [JEOL Ltd.] images after grinding with the #4000 and #20000 wheels. There were some grinding traces in a ductile mode on each surface after grinding with the #4000 wheel. However, there were features of fracture in a brittle mode on each surface. A situation that mingles the brittle mode and ductile mode after grinding with the #4000 wheel was observed.

On the other hand, there were few grinding marks in the brittle mode on each surface after grinding with the #20000 wheel. Comparing polycrystalline SiC and monocrystalline SiC, the former had some shades from place to place. This suggests that grain boundaries appeared.

Fig. 10 shows the surface roughness with the #20000 wheel using the same profiler, NewView. Rq values on both polycrystalline SiC and monocrystalline SiC were less

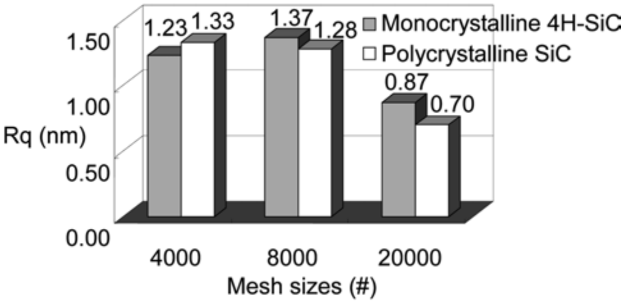


**Fig. 6.** Root mean square height (Rq) after machining with each mesh size.

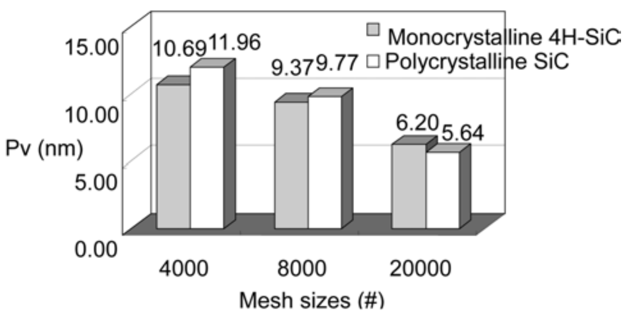


**Fig. 7.** Peak to valley roughness (Pv) after machining with each mesh size.

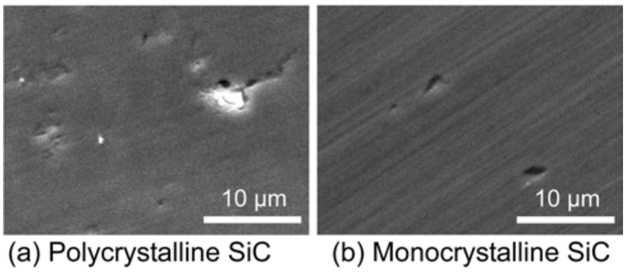


**Fig. 8.** Observation by SEM ground by #4000.

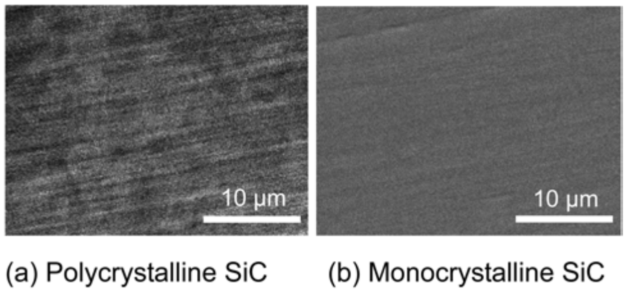


**Fig. 9.** Observation by SEM ground by #20000.

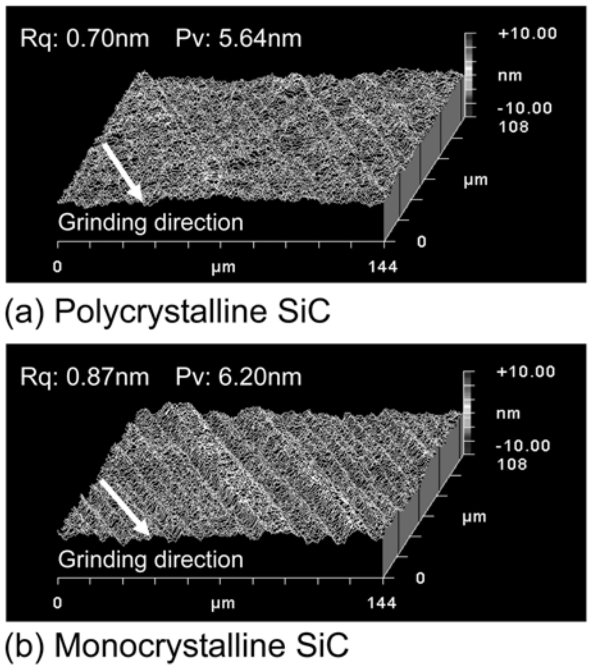


**Fig. 10.** Surface roughness ground by #20000.

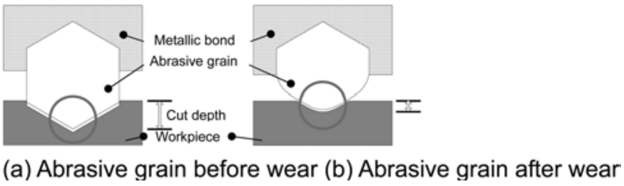


**Fig. 11.** Schematic illustration of the relationship between wear of abrasive grains and surface roughness.

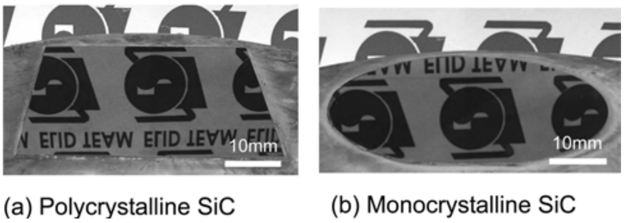


**Fig. 12.** External view of workpiece ground by #20000.

than 1.00 nm. Comparing both workpieces, monocrystalline SiC had uniform grinding traces. In general, monocrystalline SiC has a single crystal orientation toward the grinding surface and it tends to equalize the load of the grinding surface. So, it appeared that the uniform grinding traces were mainly formed on the ground surface of the same crystal orientation.

On the other hand, polycrystalline SiC did not exactly have uniform grinding traces. It had various orientations of crystal grains toward the grinding surface. So, it appeared that the nonuniform grinding traces were mainly formed on the ground surface of the different orientations of crystal grains.

In addition, polycrystalline SiC has a nonuniform hardness toward the grinding surface because of the different orientations of crystal grains. When a crystal grain was harder than monocrystalline SiC, the wear rate of the wheel tended to be increased. As a result, the cut depth of abrasive grains became shallower while the surface roughness was improved. Fig. 11 shows the relationship between the wear of abrasive grain and the surface roughness. The more abrasive grain was finer, the more brittle-ductile transition was increasing and surface roughness was improved. It suggested that the surface roughness of polycrystalline SiC was better than monocrystalline SiC after grinding with the #20000 wheel.

Fig. 12 shows an external view of polycrystalline SiC and monocrystalline SiC after grinding with the #20000 wheel. Both workpieces had mirror-surfaces and were super-smooth finished. These results will help to reduce the time of next process such as chemical and mechanical polishing (CMP) or plasma chemical vaporization machining (PCVM) [5].

## Conclusions

SiC materials have increasingly been needed in a wide range of industries. In this paper, we ground polycrystalline SiC and monocrystalline 4H-SiC. As the result, we acquired the following findings.

(1) Surface roughness of 0.87 nm and 0.70 nm in Rq were obtained in the grinding of monocrystalline 4H-SiC and polycrystalline SiC by using a rotary in-feed grinding machine with a #20000 wheel and 0.5 $\mu$m·minute$^{-1}$ feed rate.

(2) There were grinding marks in the ductile mode on the surfaces of each material, and suitable surface conditions were observed.

In the future, we will investigate other crystallographic planes of monocrystalline 4H-SiC and the appropriate grindings conditions for each plane.

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