Influence of UV-ray irradiation on constant-pressure grinding for SiC

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Abstract. Silicon carbide (SiC) is a promising next-generation semiconductor material for high-temperature, high-frequency and high-power devices due to its excellent properties, such as high thermal conductivity, high carrier mobility and high chemical stability. However, SiC is difficult to machine because it has high mechanical hardness and high chemical inertness. Generally when diamond abrasive grains are used for grinding of SiC, it takes much time and high quality surface cannot be obtained due to a occurrence of damaged layer such as crack. Therefore, high efficiency with high quality processing technology is now required. Then the authors developed ultraviolet-ray assisted constant-pressure grinding method. In the latest study, it was clarified that the surface roughness was improved by UV-assisted grinding with mechano-chemical composited diamond wheel with mean abrasive diameter of 6 µm. In this method, superabrasive wheel, that contains submicron diamond abrasive grains with mean abrasive diameter of 0.5 µm, is used and ultraviolet-ray (UV-ray) irradiates for assisting material removal by photochemical reaction. In this study, the influences of UV-ray irradiation on processing characteristics were considered. As a result, it was clarified that surface roughness and processing time can be improved by UV-ray irradiation. Finally we obtained nano meter order specular surface with this method.

Introduction

Silicon carbide (SiC) has excellent characteristics and is expected to be used as a next-generation semiconductor instead of silicon (Si). However, SiC is difficult to machine because it has high mechanical hardness and chemical inertness. In general, ingots of SiC are cut into wafers by slicing process. Then, the wafers are ground or lapped then polished, and finally finished by Chemical Mechanical Polishing (CMP). A long time and a high cost are required for polishing and to remove the damaged layer by CMP. Thus, it is important to reduce the damaged layer in the lapping and grinding processes before polishing and CMP and to reduce the processing time of CMP.

The authors developed UV-assisted grinding [1]. Figure 1 shows a schematic diagram of UV-assisted grinding. An oxidized layer, which is softer than SiC, is generated on a SiC surface by photochemical reactions induced by UV-ray irradiation [2]. Moreover, the critical depth of cut of SiC is expanded by generating an oxidized layer [3]. In the latest study, the infeed grinding was used for UV-assisted grinding. As a result of UV-assisted grinding with a fixed-abrasive wheel, which contains diamond abrasive grains with a mean diameter of 6 µm and SiO_2 abrasive grains, surface roughness and removal rate were improved. This method

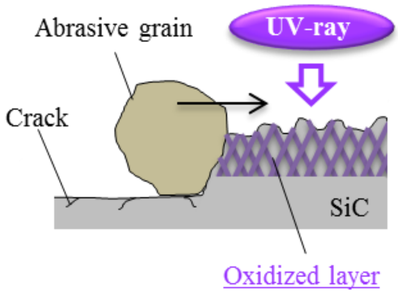


Fig. 1 Schematic diagram of UV-assisted grinding

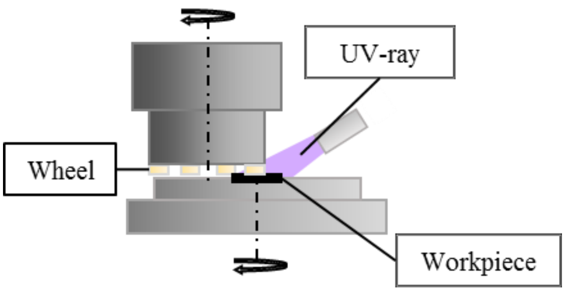
however was not crack-free method, because the effect of the cutting capacity of diamond abrasive grains with a mean diameter of 6 µm was larger than that of UV-ray irradiation.

In this study, we adopted UV-assisted grinding as a finishing process using diamond abrasive grains with a mean diameter of 0.5 µm and a constant-pressure method. Then, the influences of UV-ray irradiation on processing characteristics were investigated.

Experimental method and conditions

In this experiment, the pellet-type wheel shown in Figure 2, which contains diamond abrasive grains with a mean diameter of 0.5 µm, was used. And the multifunction polishing machine that can apply a constant pressure or a constant depth of cut was used. Figure 3 shows the experimental setup. The upper spindle has a wheel and the lower spindle has a workpiece on the constant-pressure jig, and the center of the wheel pellet passes through the center of the workpiece. UV-rays were irradiated at an angle to the workpiece surface. The lapped Si-surface with a surface roughness *Sa* of approximately 75 nm was used as a workpiece. The experimental conditions are shown in Table 1. However, when the processing time has passed 30 min, the wheel was dressed with a WA wheel.

Fig. 2 Pellet-type wheel



(a) Schematic diagram

(b) Photograph

Fig. 3 Experimental setup

Table 1 Experimental conditions

Workpiece		4H-SiC (Si-surface)
Workpiece size		20 mm × 20 mm × t 0.38 mm
Wheel		MD #20000
Wheel size	Base	ϕ 100 mm
	Pellet	ϕ 6 mm × 24
Rotation speed	Wheel	300 min^{-1}
	Workpiece	100 min^{-1}
Pressure		50 kPa
Processing time		60 min
Coolant		0 ml (dry)
UV-ray	Wavelength	200 ~ 500 nm
	Power	1700 mW/cm^2

Influence of UV-ray irradiation

Figure 4 shows optical microscopic images of the workpiece surface after grinding, observed by using a optical microscope (STM-6LM, Olympus Co.). It can be seen that the asperity left by a lapping process was reduced with processing time with or without UV-ray irradiation. However, it can also be seen that the rate of asperity reduction with UV-ray irradiation was higher than that without UV-ray irradiation. It is considered that more oxides were generated with UV-ray irradiation than without UV-ray irradiation. As a result, diamond abrasive grains more efficiently removed the workpiece surface by UV-ray irradiation. Also this result indicates that the removal rate is improved by UV-ray irradiation.

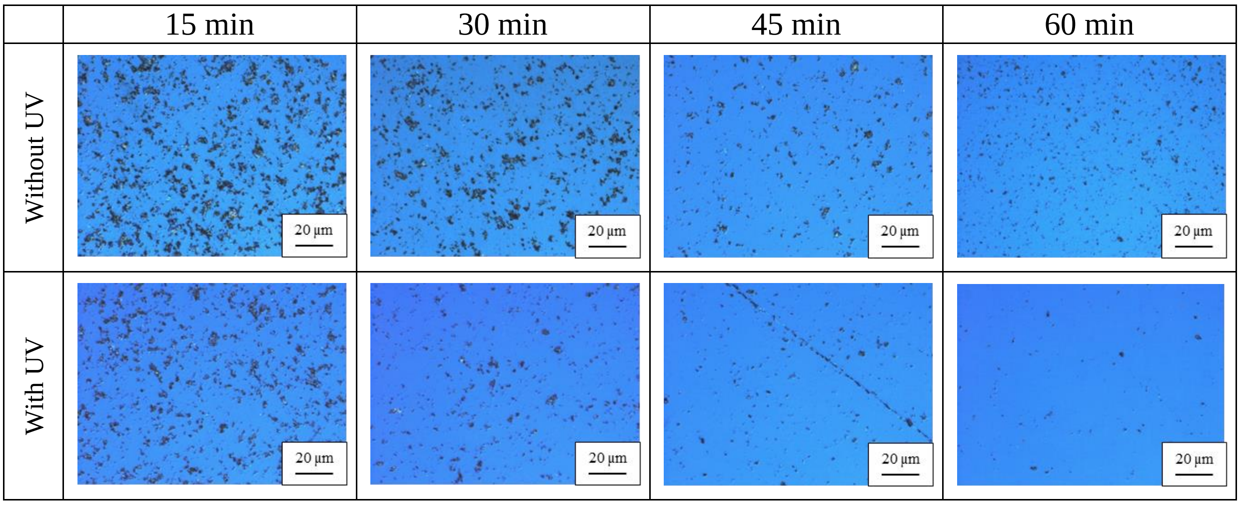


Fig. 4 Optical microscopic images of workpiece surface after grinding

Figure 5 shows interferometric images of the workpiece surface after grinding, measured by using a 3D optical surface profiler (New View 8200, Zygo Co.). At any processing time, the surface roughness was improved on the workpiece with UV-ray irradiation. As also can be seen in Figure 4, it is considered that convex parts left by a lapping process were more efficiently reduced by generating oxidized layer with UV-ray irradiation.

Particularly after a 15 minute grinding with UV-ray irradiation, the surface roughness *Sa* was 5.72 nm. On the other hand, the surface roughness *Sa* was 20.66 nm without UV-ray irradiation at the same processing time. The surface roughness was markedly improved with UV-ray irradiation compare to without UV-ray irradiation at the initial process.

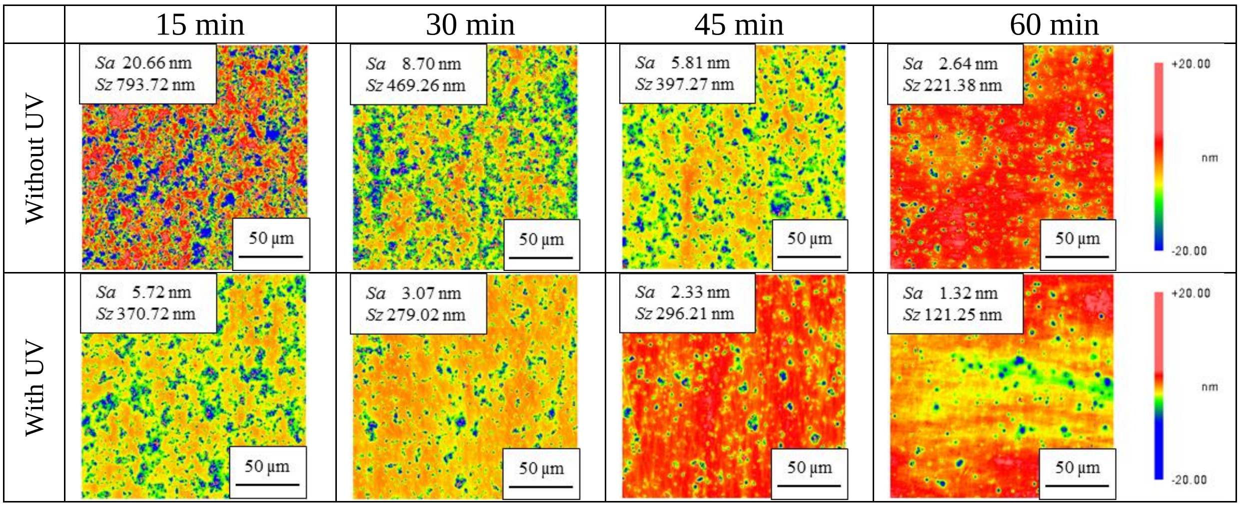


Fig. 5 Interferometric images of workpiece surface after grinding

Figure 6 shows the temporal transition of the average surface roughness of three arbitrary points on the workpiece surface after grinding. In the 15 minute grinding, the surface roughness *Sa* of the workpiece was improved with UV-ray irradiation considerably compare with that without UV-ray irradiation. Even after 15 min, the surface roughness *Sa* was slightly improved with UV-ray irradiation at the same processing time.

After reaching a surface roughness *Sa* of less than 10 nm, the improving rate suddenly decreased regardless of UV-ray irradiation. The time required to reach a surface roughness *Sa* of less than 10 nm was 10 minutes with UV-ray irradiation. On the other hand, it was 20 minutes without UV-ray irradiation. It was reduced to half with UV-ray irradiation. This result also indicates that the removal rate is improved and the time to reach the attained surface roughness is reduced with UV-ray irradiation.

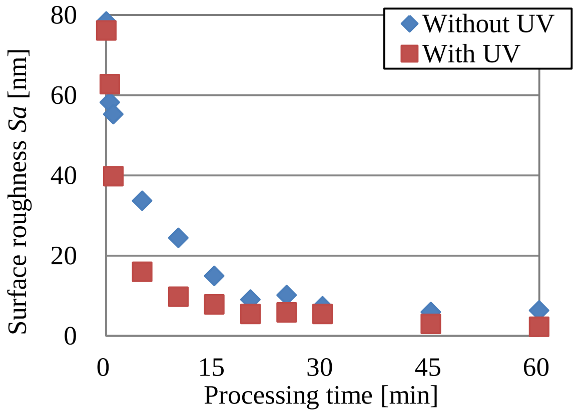


Fig. 6 Temporal transition of surface roughness of workpiece

Figure 7 shows the temporal transition of the average surface roughness of three arbitrary points on the wheel surface after grinding. It was also measured by using a 3D optical surface profiler (New View 8200, Zygo Co.).

Before grinding, the surface roughness *Sa* was approximately 5 μm. When the processing time has passed 30 minutes, the wheel was dressed with a WA wheel and then the surface roughness *Sa* was initialized to approximately 5 μm. In the case of without UV-ray irradiation, the surface roughness *Sa* suddenly decreased after first 1 minute process and subsequently remained roughly constant. In the case of with UV-ray irradiation, on the other hand, the surface roughness *Sa* decreased with increasing processing time. It can be considered that there is a potential reason that the chip composition has changed by UV-ray irradiation. So in regards to the reason of this result, we plan to observe the chips by using a Scanning Electron Microscope and to analyze these chemical compositions by using a X-ray Photoelectron Spectroscopy in our future work.

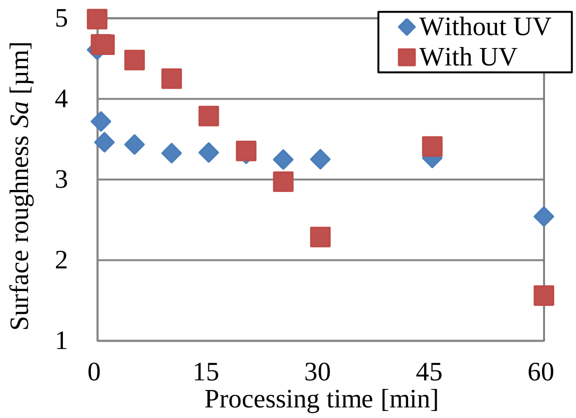
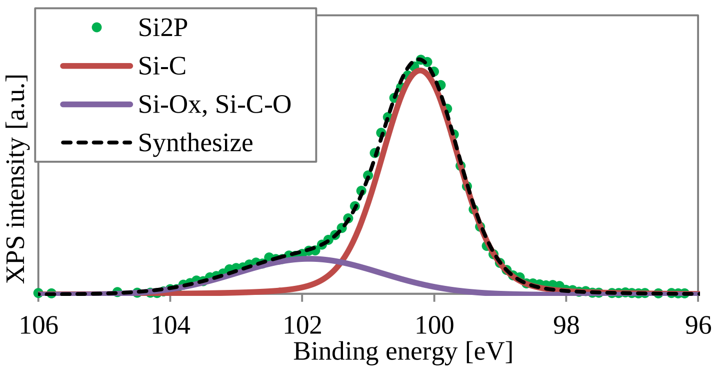
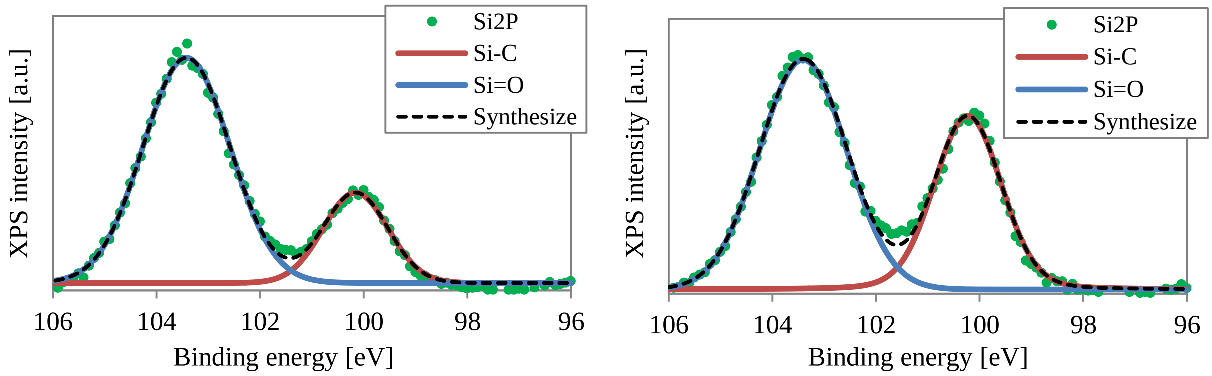


Fig. 7 Temporal transition of surface roughness of wheel

The chemical composition of the workpiece surface was analyzed by using a X-ray Photoelectron Spectroscopy (XPS: JPS-9010MC/SP, JOEL Co.) to determine the influences of UV-ray irradiation. Figure 8 (a), (b) and (c) show the XPS spectrum of Si2P on workpiece surface before grinding, after 30 minutes grinding without UV-ray irradiation and after 30 minutes grinding with UV-ray, respectively. Before grinding, there is no peak at approximately 103.6 eV. After grinding, however, there is a peak at approximately 103.6 eV, which indicates the SiO_2 bond, regardless of UV-ray irradiation. This result means that oxide was generated during the process regardless of UV-ray irradiation. Therefore, it is considered that the workpiece surface was oxidized by not only photochemical reactions induced by UV-ray irradiation but also tribochemical reactions [4] [5] of fine diamond abrasive grains. However, the peak intensity ratio of SiO_2 and SiC differed between the surface with UV and that without UV. When grinding with UV-ray irradiation, UV-ray was shut off just before process has done because of the machine architecture. It's assumed that this is a reason of the result.



(a) Before grinding



(b) After grinding without UV (c) After grinding with UV

Fig. 8 XPS spectrum of Si2P on workpiece surface

Conclusions

The following conclusions were acquired from the experiment on constant-pressure grinding with UV-ray irradiation of SiC.

1. The surface roughness was improved by UV-ray irradiation. And it is expected that the removal rate can be improved and the time to reach the attained surface roughness can be reduced by UV-ray irradiation.
2. With UV-ray irradiation, the surface roughness *Sa* of the wheel surface decreased with increasing processing time. On the other hand, it suddenly decreased at the initial stage of the process without UV-ray irradiation.
3. It is considered that workpiece surface was oxidized by tribochemical reactions induced by constant-pressure grinding using diamond abrasive grains with a mean diameter of 0.5 µm. Moreover, it was revealed that a surface with a comparable chemical composition can be obtained after grinding regardless of UV-ray irradiation.

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