Chemical State Modification of 4H-SiC by Ultraviolet-Ray Aided Machining*

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(Received 12 January 2018; Accepted 11 May 2018; Published 16 June 2018)

An ultraviolet-ray aided machining (U-RAM), which attempts to add a chemical reaction through ultraviolet-ray irradiation to a mechanical polishing, is a promising procedure to obtain a flat surface of SiC in a short time. In order to investigate how chemical states change in the U-RAM process, we have performed X-ray absorption fine structure measurements. As a result, it was found that a mixed compound other than SiO₂ was produced on the SiC surface by the U-RAM. We think that polishing efficiency of U-RAM is better than ordinary mechanical polishing because of generating the mixed compound of Si-C-O. [DOI: 10.1380/ejssnt.2018.283]

Keywords: X-ray absorption spectroscopy; Surface chemical reaction; Silicon carbide

I. INTRODUCTION

A SiC has attracted much attention as a substrate for electronic devices. In order to efficiently obtain a flat surface of SiC, many polishing procedures have been performed [1, 2]. Among them, an ultraviolet-ray aided machining (U-RAM) [3] is a promising procedure to obtain a flat surface of SiC in a short time, where an irradiated photocatalyst and fluorescent substance would provide an electron and a hole to act as oxidation/reduction reactions to the surface and a photocatalyst would also scratch the surface mechanically with abrasive grit. Previous work on the U-RAM of Al has revealed the oxidation of the Al surface [4]. Although applying the U-RAM to 4H-SiC improves a polishing rate [5], it is not clear how the surface of SiC is oxidized. In order to study the chemical state modification, we have performed X-ray absorption fine structure (XAFS) measurements of SiC during each U-RAM procedure.

II. EXPERIMENTAL

We prepared a 4H-SiC with a flat surface (commercial SiC), whose Si-plane is finished with $R_a < 0.5$ nm using chemical mechanical polishing, and then sandblasted commercial SiC to obtain a SiC with a rough surface (sandblast SiC). An U-RAM of this sandblast SiC was performed using a TiO₂ particle ($\sim7$ nm) as a photocatalyst and a Cathilon dye as a fluorescent substance under the irradiation of UV lamp ($\lambda = 253.7$ nm) with diamond grit ($0-2$ μm), referred as U-RAM SiC. Furthermore, we continued two kinds of U-RAM procedures by exchanging grits; one with CeO₂ grit (U-RAM SiC further polished with CeO₂), the other with smaller-size diamond grit (5 nm) [U-RAM SiC further polished with Dia (5 nm)]. In order to see an effect of the slurry and the UV irradiation, we only immersed sandblast SiC and commercial SiC in the TiO₂ and the Cathilon dye (immersed sandblast SiC, immersed SiC) under UV irradiation (immersed sandblast SiC + UV, immersed SiC + UV). As a reference, SiO₂/Si sample was also prepared.

XAFS measurements were performed at the BL-8 of SR Center at Ritsumeikan University, equipped with a grazing incidence monochromator with a varied-line-spacing plane grating. In order to obtain the depth-resolved information, XAFS spectra of the samples were simultaneously collected by total electron yield (TEY) and total fluorescence yield (TFY) through a sample drain current and a micro-channel plate detector with retarding grids, respectively. TEY spectra have the information near the surface (1−5 nm), while TFY spectra have the information mainly inside the bulk (more than 10 nm). The retarding voltage was set to $-150$ V for Si L-edge. In addition, set-

* This paper was presented at the 11th International Symposium on Atomic Level Characterizations for New Materials and Devices '17, Aqua Kauai Beach Resort, Kauai, Hawaii, USA, December 3−8, 2017.
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FIG. 1. Si L-edge TEY XAFS spectra of 4H-SiC during each U-RAM procedure. A reference SiO₂/Si XAFS spectrum is also shown.
III. RESULTS AND DISCUSSION

Figure 1 shows the Si L-edge TEY spectra of commercial SiC, U-RAM SiC, sandblast SiC, and SiO$_2$/Si. For commercial SiC, the onset appears around 101.8 eV, which is a characteristic feature of 4H-SiC [6–8]. The TEY spectrum of U-RAM SiC is different from that of commercial SiC. A prominent feature appears around ~106 eV with a small shoulder structure starting at ~101 eV, as indicated in Fig. 1. This shoulder structure can be assigned to a component of SiC since the absorption onset nearly coincides with that of 4H-SiC. For sandblast SiC, the onset also appears around 101 eV and a prominent feature appears around 108 eV. As seen in the spectrum of SiO$_2$/Si, both the structures around 106 eV and 108 eV come from SiO$_2$ and the structure around 101 eV comes from Si [9]. From these results, the surface of sandblast SiC is mainly covered with SiO$_2$ due to the high energy collisions, and on the surface of U-RAM SiC exists not SiO$_2$ but other compounds besides SiC.

Figure 2 shows the Si L-edge TFY spectra of commercial SiC, U-RAM SiC, and sandblast SiC. The TFY spectra of U-RAM SiC is similar to that of commercial SiC, indicating that the chemical state of U-RAM SiC in the bulk is SiC. For sandblast SiC, two prominent features appear. One starting at ~101 eV, as indicated in Fig. 2, can be assigned to a component of SiC since the absorption onset nearly coincides with that of 4H-SiC. The other around ~108 eV can be assigned to a component of SiO$_2$. Thus the chemical state of sandblast SiC in the bulk is SiC, though the structures of SiO$_2$ (around 106 eV and 108 eV) still appear maybe due to the rough surface.

Since other compounds were found on the surface of U-RAM SiC, we further polished U-RAM SiC by exchanging grits. Figure 3 shows the Si L-edge TEY spectra of commercial SiC, U-RAM SiC further polished with Dia (5 nm), U-RAM SiC further polished with CeO$_2$, and U-RAM SiC. The TEY spectra of U-RAM SiC further polished with Dia (5 nm) and U-RAM SiC further polished with CeO$_2$ is similar to that of commercial SiC. The surfaces are confirmed to be 4H-SiC free from the newly formed compound. Because SiC is harder than CeO$_2$, CeO$_2$ grit could polish not SiC but the newly formed compound, suggested to be a brittle compound compared to SiC.

Figure 4 shows Si L-edge TEY spectra of sandblast SiC with the immersion and UV irradiation.

After the immersion and/or UV irradiation.
FIG. 5. Si L-edge PEY XAFS spectra of commercial SiC with the immersion and UV irradiation.

Figure 5 shows Si L-edge PEY spectra of commercial SiC, immersed commercial SiC, and immersed commercial SiC + UV. The spectra hardly change. This suggests that only rough SiC surfaces are affected by the immersion and/or UV irradiation. Then, further polishing with CeO$_2$ or smaller-size diamond grits does not produce the newly formed compound because of the flat surface.

Next, we consider the newly formed compound, which appears around ~106 eV in the TEY spectrum of U-RAM SiC (Figs. 1 and 3). We think that the compound is a mixture of Si, C, and O. Because, it is thought that oxidation occurs on the surface of SiC, and from the previous research [10] it is confirmed that mixed compounds of Si, C, and O are produced by a thermal treatment. Although the newly formed compound is not clear at present, we think that polishing efficiency of U-RAM is better than ordinary mechanical polishing because of produced mixed compounds of Si, C, and O on the surface.

IV. CONCLUSION

We have analyzed chemical state of 4H-SiC samples by XAFS. Not SiO$_2$ but mixed compounds exist after U-RAM. We think that polishing efficiency of U-RAM is better than ordinary mechanical polishing because of generating the mixed compound of Si-C-O.