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Advanced Lapping and Polishing Methods for Planarizing a Single-Crystal 4H-Sic Utilizing Fe Abrasive Particles

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Abstract. We have developed advanced lapping and polishing methods for silicon carbide (SiC) substrates using an Fe abrasive particles and hydrogen peroxide (H_2O_2) solution. In this method, a SiC surface is oxidized by hydroxyl radicals (OH*), which was generated by Fe catalyst reactions, and the oxide layer on the SiC is mechanically and/or chemically removed by Fe abrasive particles and solution [1-4]. In this study, we applied this planarization method for lapping and polishing SiC surface, in which catalytically generated hydroxyl radicals were utilized to oxidize the surface of a SiC wafer. The processed surfaces were observed by optical interferometric microscope, Nomarski differential interference contrast. These observations showed that surface roughness and flatness of a SiC substrate were markedly improved and scratch-free SiC surface was obtained. These results provide useful information for preparing a high-efficiency and high-accuracy SiC substrate.

Introduction

To make an ultrasmooth and defect-free 4H-SiC wafers is strongly demanded in the next-generation power semiconductor devices. However, such SiC substrates are relatively difficult to machine because of their mechanical hardness and marked chemical inertness. A currently used planarization method for 4H-SiC substrates is mechanical polishing (lapping) using diamond abrasives with a hard lapping plate. However, the lapped 4H-SiC surface remains on the damaged layer and has innumerable scratches. To reduce the surface damage and surface roughness, a chemical mechanical polishing (CMP) using silica powder particle has been developed extensively. However, the process parameters, such as the condition of slurry and polishing pads, pressure and temperature, are so difficult to control that damage-free and scratch-free surfaces cannot be obtained easily. Accordingly, a novel planarization method which can suppress the damaged layer and surface roughness on the processed SiC substrate is highly required.

This research investigates new lapping and polishing methods for planarizing 4H-SiC substrate utilizing Fe abrasive particles and hydrogen peroxide solution. This method uses catalytically generated hydroxyl radicals (OH*) to oxidize the SiC substrates. OH* are generated by the decomposition of hydrogen peroxide on the surface of the Fe abrasive particles. Generated oxide layer on the SiC substrate is mechanically and/or chemically removed by Fe particles and solution, finally, smoothed and damage-free SiC surface will be obtained.

Experimental procedure

In this study, samples were commercially available as-sliced 4H-SiC (000-1) on-axis substrates from Nippon Steel Co., Ltd. and were cut into a size of 1 cm × 1 cm square. Before the experiment, the samples were treated with sulfuric acid and hydrogen peroxide mixture solution (SPM) for 15 min to remove organic contaminants. And then, they were dipped into 50% hydrofluoric acid solution for 10 min to remove the oxide layer, finally they were rinsed with pure water for 1 or 2 min.

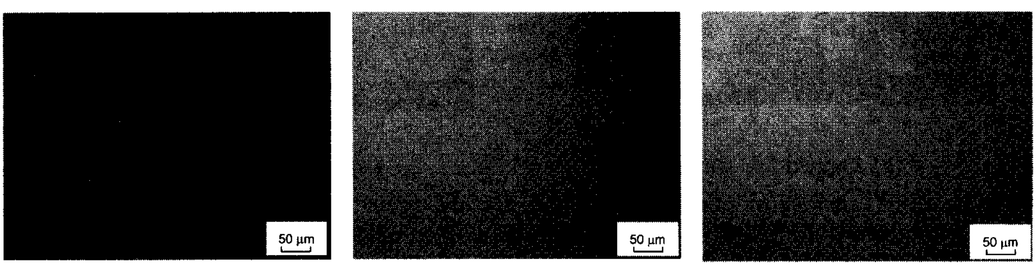
First of all, we demonstrated the planarization of SiC surface by lapping method. The lapping setup has a catalytic plate made of Fe that is placed on a rotational table. Sample was attached onto the sample folder with electron wax and is placed on the Fe plate at a controlled pressure of 0.09 MPa. The rotating speed of the Fe plate was 50 rpm, while that of the sample holder was 50 rpm. The slurry was supplied to the sample/Fe plate surfaces in a drop with a flow rate of 2 ml/min. The slurry was made of a concentration of 30% hydrogen peroxide solution and Fe abrasive particles (3 wt%). Processing time was 2 h.

After the lapping process, we conducted the polishing experiment. The SiC substrate processed in the previous lapping process was adopted as a sample. The polishing setup has a rotational table covered with a polishing pad (Rohm and Haas's IC1000 pad). The rotating speeds of the table and sample stage were fixed at 30 rpm. The polishing slurry consists of Fe abrasive particles 10 wt% and a concentration of 30% hydrogen peroxide solution. Slurry is provided to the surface of the polishing pad by pumping. A flow rate of slurry was 2 ml/min. The contact pressure between sample and polishing pad was set to be 0.03 MPa, processing time was 2.5 h.

The morphology and scratches on the obtained surfaces were measured and evaluated using an optical interferometric microscopy (Veeco Instruments, Inc., Wyko NT3300) and Nomarski or differential interference contrast (NDIC) microscopy (Nikon Corp., ECLIPSE LV150).

Results and Discussion

To clarify surface morphological changes before and after processing, the preprocessed and processed surfaces were observed by NIDIC microscopy. Figure 1 shows images of (a) preprocessed surface (commercially available as-sliced SiC surface), (b) lapped SiC surface and (c) polished SiC surface. As observed in Figs. 1, numerous surface asperities on the preprocessed surface are completely removed, and the roughness is improved markedly. The result clearly shows that scratch free surface is obtained by proposed lapping and polishing methods.



(a) Preprocessed surface (b) Lapped surface (c) Polished surface

Fig.1 NIDIC images of (a) preprocessed surface (b) lapped surface and (c) polished surface.

To reveal the improvement of surface flatness, the surface waviness of a commercially available mirror finished SiC surface and lapped SiC surface was evaluated. Figure 2 shows cross-sectional profiles of the commercially available mirror finished SiC surface and lapped SiC surface obtained by an optical interferometric microscope. Compared with cross-sectional profiles, it turns out that the flatness of the lapped surface is higher than that of commercially available mirror finished SiC surface. This result is probably due to use of soft pad during the mirror SiC substrate manufacturing processing.

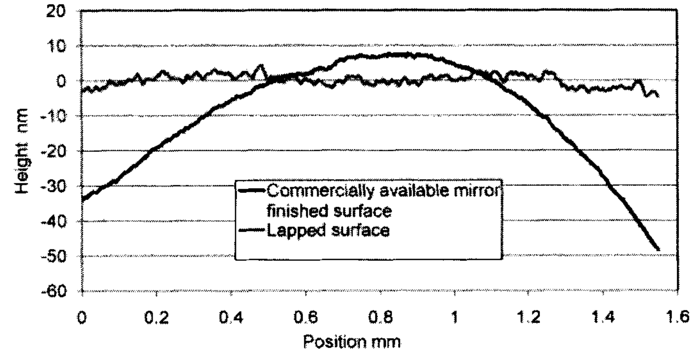
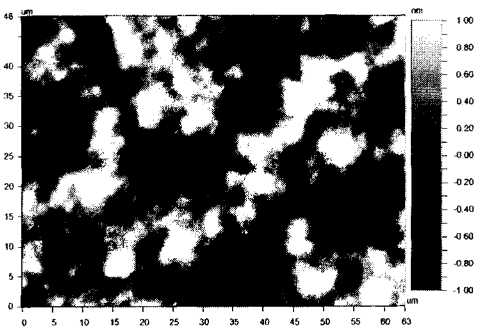
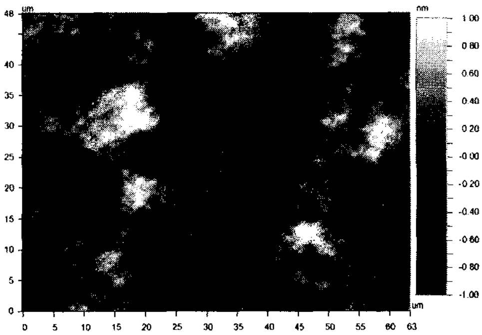


Fig. 2 Comparison of surface figuration of (a) commercially available SiC mirror surface and (b) lapped SiC surface.

Figure 3(a) shows an optical interferometric image of lapped SiC surface, and Figure 3(b) shows that of polished SiC surface. The measurement area is 64 μm × 48 μm. The maximum height of irregularity (Rz) and root-mean-square roughness (Rrms) on the lapped SiC surface are 6.11 nm and 0.97 nm, respectively. On the other hand, the roughness of polished SiC surface is 0.38 nm Rms and 2.66 nm Rz, respectively. As seen in Figs.3, it is clear that surface roughenss is improved during polishing procedure.



(a) Lapped SiC surface



(b) Polished SiC surface

Fig. 3 Phase-shift interferometric images of (a) lapped SiC surface and (b) polished SiC surface. The surface roughness is (a) 0.97 nm Rms, 6.72 nm Rz and (b) 0.38 nm Rms, 2.66 nm Rz, respectively. The measurement area is 64 μm × 48 μm.

To characterize the surface waviness in specific spatial wavelength, the lapped SiC surface and polished SiC surface were evaluated through the power spectral density analysis. Figure 4 shows the power spectral density spectra of the surface profile measured using an optical interferometric microscope. These spectra show that the surface is smoothed in the spatial wavelength range from 1 μm to 100 μm during polishing process. Figs. 3 and Fig.4 indicate that proposed polishing method is effective in removing and smoothing a SiC surface. Moreover, polished surface was measured and analyzed using atomic force microscopy (AFM), it is found that a polished SiC substrate has an atomic flatness and scratch-free surface.

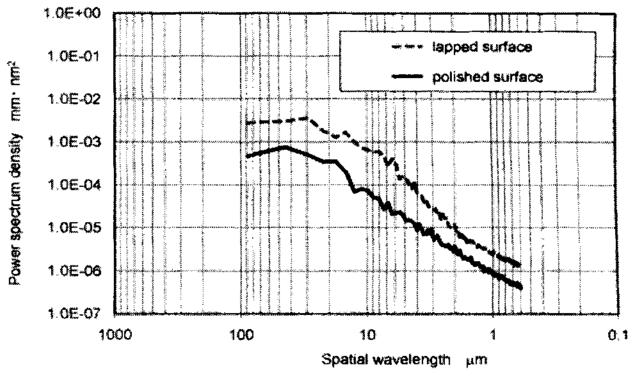


Fig. 4 Power spectrum density spectra of lapped SiC surface and polished SiC Surface.

Summary

Advanced lapping and polishing methods for planarization of single-crystal 4H-SiC utilizing Fe abrasive particles has been described. Planarization of SiC surfaces was conducted using an Fe plate and Fe abrasive particles immersed in a hydrogen peroxide solution. The processed surfaces were observed by an optical interferometric microscope, Nomarski differential interference contrast and atomic force microscope. The results obtained show that lapping and polishing methods, we propose, give a good surface quality. Moreover, the power spectral density analysis shows that the polished surface is smoother than lapped surface in the spatial wavelength range from 1 µm to 100 µm. However, further studies are needed to obtain an atomically flat and damage free SiC surfaces while controlling the optimal process conditions, and to clarify the removal mechanism of SiC substrate.

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