Power device, Heat spreader, Diamond tool

High-efficiency ultra-precision polishing technique for diamond substrates using plasma

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Abstract

Diamond is a promising material in the field of next-generation semiconductor power devices because it has excellent electrical and thermal properties such as low dielectric constant, high breakdown voltage, and high thermal conductivity. However, diamond is difficult to process because of its high hardness and chemical inertness. Our group has developed a new process for finishing diamond substrates with high efficiency and without damage using a ``Plasma-assisted Polishing technique'' that combines ``chemical action'' and ``mechanical action.'' This process achieved a polishing rate that is more than 10 times higher than that of conventional chemical mechanical polishing (CMP), and successfully achieved subnanometer-order surface roughness with no grain boundary steps on polycrystalline diamond substrates.

Background & Results

Currently, Scaife polishing using diamond abrasive is commonly used to polish diamond substrates, but this results in the formation of scratches and damaged layers, which deteriorates thermal conductivity and electronic properties. Furthermore, although chemical mechanical polishing (CMP) does not introduce damage, the polishing rate is too low to be practical. Therefore, we investigated the application of plasma-assisted polishing (PAP) as a new damage-free and highly efficient planarization/smoothing method for diamond substrates.

Figure 1(a) shows a 20 mm square single-crystal diamond substrate fabricated by the mosaic method, and large waviness with a height of over 100 μm can be seen, but after PAP, as shown in Figure 1(b), a flatness of less than 0.5 μm was achieved. At this time, under rough polishing conditions, a polishing rate of up to 13 μm/h, more than 10 times higher than that of CMP, was obtained. Furthermore, after PAP, a surface roughness on the order of 0.3 nm was obtained.

Polycrystalline diamond (PCD) substrates are being considered for use as heat spreaders for power devices because they can be made larger in size than single crystals. However, when mechanical polishing techniques are applied to PCD polishing, it is difficult to obtain a smooth surface because grain boundary steps are formed due to the dependence of the polishing rate on crystal plane orientation and crystal plane direction. Figure 2 shows the results of polishing a 2-inch PCD substrate using PAP. After PAP for 2 hours, the convex structures observed on the CMP surface disappeared, and after PAP for 5 hours, a surface roughness of 0.16 nm with no grain boundary steps was achieved. Therefore, by applying PAP processing, even a polycrystalline substrate can achieve a surface roughness on the order of subnanometers, providing a surface sufficient for bonding power devices at room temperature.

Figure 3 is a scanning transmission electron microscope (STEM) image of the (100) surface of single-crystal diamond polished by PAP. It can be seen that the crystal structure is maintained all the way to the outermost surface, and there is no damage at all.

Significance of the research and Future perspective

Research into using diamond substrates as heat spreaders for power devices has been conducted for several years. However, since diamond is a difficult-to-process material, a process that achieves both a high polishing rate and a high-quality surface has not yet been realized. The ``Plasma-assisted Polishing technique'' has made it possible to manufacture high-quality diamond substrates at low cost, and it has the significance of breaking through the conventional limits toward the widespread use of diamond substrates for semiconductor device applications. It is also expected to improve the performance of power-saving, high-performance power devices and high-frequency devices, leading to the early realization of a low-carbon society.

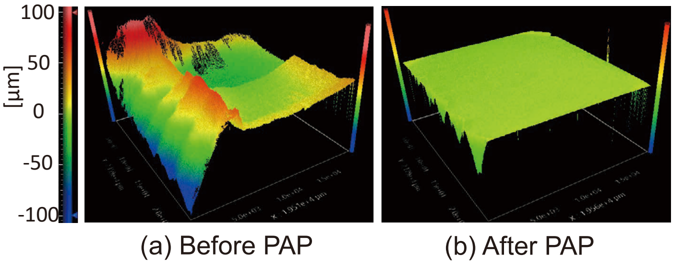

Fig. 1 Flatness of single crystal diamond substrate

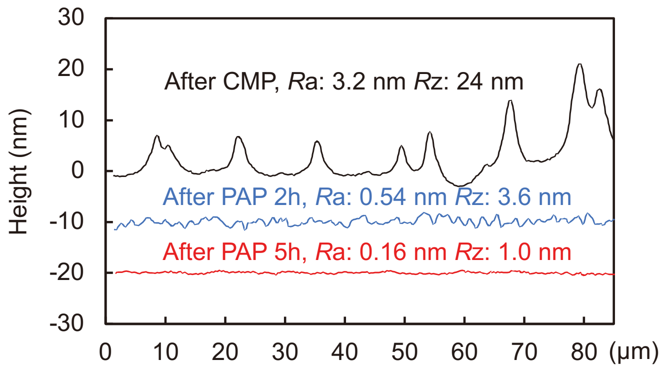

Fig. 2 Surface roughness of polycrystalline diamond substrate

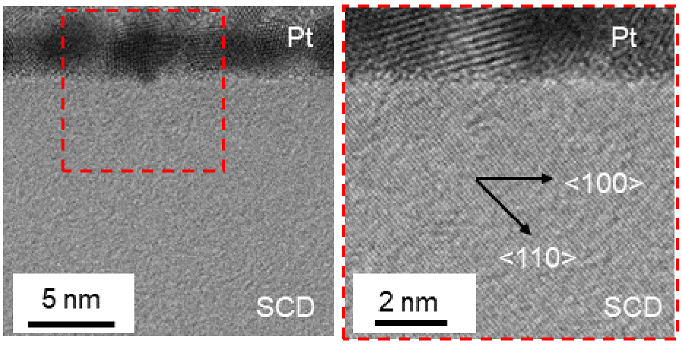

Fig. 3 STEM image of SCD after PAP

Patent	Japanese Patent Application No.2022-125662, Japanese Patent No.5614677
Treatise	Liu, Nian; Yamamura, Kazuya et al. Highly efficient finishing of large-sized single crystal diamond substrates by combining nanosecond pulsed laser trimming and plasma-assisted polishing. Ceram. Int. 2023, 49, 19109-19123. doi: 10.1016/j.ceramint.2023.03.038 Liu, Nian; Yamamura, Kazuya et al. Effects of polishing pressure and sliding speed on the material removal mechanism of single crystal diamond in plasma-assisted polishing. Diam. Relat. Mater. 2022, 124, 108899. doi: 10.1016/j.diamond.2022.108899 Liu, Nian; Yamamura, Kazuya et al. Damage-free highly efficient plasma-assisted polishing of a 20-mm square large mosaic single crystal diamond substrate. Sci. Rep. 2020, 10, 19432. doi: 10.1038/s41598-020-76430-6
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