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Highly efficient flattening and smoothing process for Poly Crystalline Diamond substrates by combining laser-trimming and plasma-assisted polishing

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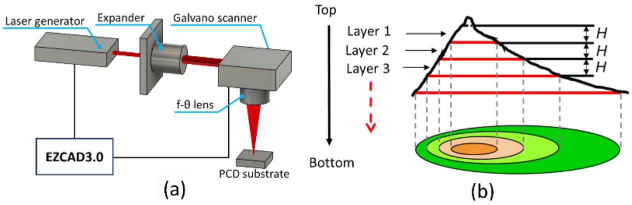
Abstract

Semiconductor power devices are expected to be applied to electric vehicles and power generation technology because of their high energy efficiency. However, performance degradation due to self-heating is a serious problem. Therefore, it has been proposed to bond a power device to a diamond substrate, which has the highest thermal conductivity in all materials can improve the heat extraction from power device and lower temperature of the device. To bond a diamond substrate and a power device, it is necessary to polish the diamond substrate to an atomic level smoothness. However, diamond is the hardest material and a surface of diamond substrate after CVD growth has large waviness, so it requires a very long polishing time. Therefore, we applied a laser-trimming process to remove large waviness efficiently. In this process, a Poly Crystalline Diamond (PCD) substrate whose shape has been measured in advance is subjected to numerically controlled processing for each contour line in units of ablation depth to remove the undulations and flatten the substrate. By applying laser-trimming, we succeeded in reducing the low-frequency waviness component of approximately 150 µm p-v existed on the surface of the PCD substrate to approximately 50 µm p-v. Then, we smoothed the PCD substrate after the laser-trimming by plasma-assisted polishing (PAP). As a result, the PCD substrate, which was *Sa* 9.6 µm after CVD growth, was polished to less than *Sa* 11 nm. It was also confirmed that the surface layer that had been graphitized by laser-trimming was removed by PAP. In this paper, we report the results of our work on a planarization and smoothing process for PCD substrates by combining laser-trimming and PAP.

Keywords: Diamond, Finishing, Laser, Polishing

1. Introduction

Poly crystalline diamond (PCD) has very high thermal conductivity and high mechanical strength. In addition, it is cheaper than single-crystal diamond and can be easily made into large size. To bond a power device to a PCD for heat dissipation, the PCD surface must be made atomically smooth. Currently, Scaife polishing and CMP are widely used for diamond polishing, but Scaife polishing involves high polishing pressure, which introduces damage to the surface. On the other hand, CMP requires a long process time due to its low polishing rate. In addition, the slurry used in CMP is very costly. Therefore, a highly efficient damage-free polishing technique that does not use slurry is desired. Plasma-assisted polishing (PAP), a dry polishing technique that combines surface modification by plasma irradiation and removal of the modified layer by ultra-low pressure or using polishing plate, has been successfully applied to polish difficult-to machine materials such as SiC, GaN, and SCD [1-3]. However, since the PCD substrate produced by CVD growth has a very large waviness component, a very long polishing time is required even if PAP is applied.



(a) (b)

Figure 1. Schematic of laser-trimming setup

To solve this problem, laser-trimming, which removes the waviness component of the substrate by laser ablation, was introduced as a pre-polishing process. In this report, we present the results of smoothing of PCD substrates synthesized by CVD growth by laser-trimming and then applying PAP to the substrates.

2. Experimental Setting

2.1. Laser-trimming

Figure 1(a) shows the schematic of laser trimming setup. It is mainly consisted of a laser generator, a beam expander, a Galvano scanner, an f-theta lens, and software EZCAD3.0 for controlling laser scanning path. A fiber laser with a 1064 nm wavelength and a constant pulse duration of approximately 100 ns, supplied by Raycus Co. Ltd, was used in the following experiments. The following is an overview of the laser trimming process. First, the 3D shape of the PCD substrate was measured with SWLI (SWLI, NewView 8300 Zygo). Next, a 2D contour map was created from the measured 3D shape image using EZCAD3.0. An appropriate reference at the top areas is set and the points with H from the reference are connected to form a closed curve, which is the contour of the first layer of laser trimming (Layer 1), where H is the depth to be removed by the laser irradiation. The points with 2H from the reference are connected to form a closed curve, which is the contour of the second layer of laser-trimming (Layer 2), and so on, until the suitable points at bottom areas. Then, the substrate is flattened by removing each layer divided by the laser. Table 1 shows the parameters of laser-trimming of this experiment.

Table 1 Experimental parameters of laser-trimming

Power density	9.1 W
Spot size on target	40 µm
Repetition frequency	80 kHz
Scanning speed	600 mm/s
Filling space	7.5 µm

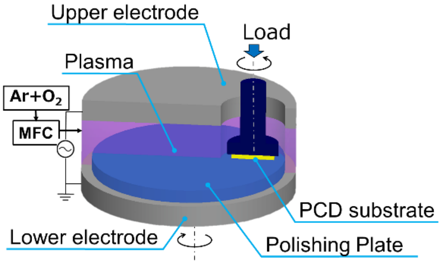


Figure 2. PAP experimental setting

2.2. Plasma-assisted Polishing

Figure 2 shows a schematic diagram of the PAP setup. It is composed of plasma generation and mechanical removal parts. Both parts are installed in a vacuum chamber, where the process gas composition and pressure are controlled. Plasma generation part is consisted of an upper electrode and lower rotary table, both made of aluminum alloy. The polishing plate made of quartz glass is fixed on a rotary table and PCD substrate is fixed on a rotating sample holder. The experimental parameters are shown in Table 2.

Table 2 Experimental parameters of PAP

Rotation speed	PCD substrate: 26 rpm, Polishing plate: 300 rpm (until 19h), 200 rpm (after 19h)
Polishing pressure	224 kPa
Flow rate	Ar: 200 sccm, O_2: 30 sccm
Chamber pressure	7 torr
RF power	100 W

3. Results and discussion

Figure 3 shows the scanning white light interferometer (SWLI) image and its cross-sectional profile of the entire PCD substrate before and after laser trimming. The initial shape of the PCD substrate was a concave shape with a p-v of about 150 µm in the cross section A1-A1'. By applying laser trimming for 1 m 59 s, the PCD substrate was flattened, and the p-v value was reduced to 50 µm. However, the surface of the PCD substrate turned into graphite, and high-frequency roughness component remained.

Next, we applied PAP to remove graphite component and high-frequency roughness component on the PCD substrate. PAP was performed on PCD substrates without and with laser trimming. Figure 4 shows the transition of the SWLI image of the surface when PAP was applied to PCD substrate without laser trimming and with laser trimming. Comparing Fig. 4(b) and (d), the PCD substrate without laser trimming had deep depressions after 26 hours of PAP (Fig. 4(b)). On the other hand, when applying laser trimming, the depressions disappeared at 26 hours of PAP (Fig. 4(d)). In addition, the surface was successfully improved from Sa 9.6 µm to Sa 11.0 nm after laser trimming (Fig. 4(c)(d)). These results indicate that the combination of laser trimming, and PAP is very useful for highly efficient smoothing of PCD substrates.

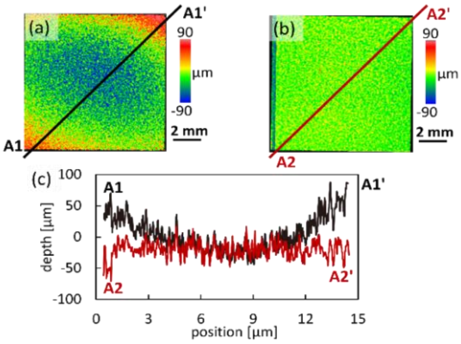


Figure 3. (a)(b) SWLI image of entire PCD substrate (a) initial (b) after laser-trimming, (c) cross-section of A1-A1' and A2-A2'.

Figure 5 shows the results of Raman spectroscopy evaluation of the crystal structure of the PCD substrate in its initial state, after laser trimming, and after 26 hours of PAP after laser trimming. Initially, a peak around 1332.5 cm^{-1} was observed, indicating the presence of a diamond structure. As a result of the graphite phase transition on the surface of the PCD substrate caused by laser irradiation, the peak of the diamond structure weakened, and a peak at 1580 cm^{-1} appeared, indicating the graphite structure. On the other hand, no graphite peak was observed on the PCD substrate after PAP, and only a diamond structure peak was observed. These measurement results suggest that laser trimming does not affect the polishing of the PCD substrate because the graphite layer is completely removed by PAP.

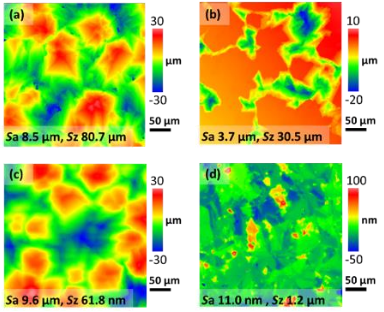


Figure 4. SWLI images of PCD surface (a) initial surface (b) surface after PAP for 26 h w/o laser-trimming, (c) surface after laser-trimming, (d) surface after 26 h of PAP w/ laser-trimming.

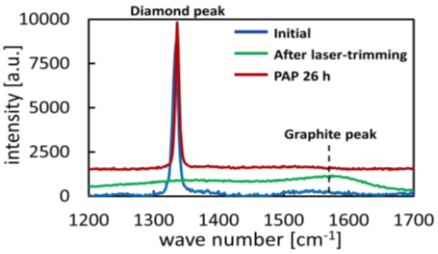


Figure 5. Raman spectra of the PCD surface of initial, after laser-trimming and after 26 h of PAP.

4. Conclusions

In this report, the following conclusions were obtained.

1) The p-v value was reduced from about 150.0 µm to 50 µm by applying laser-trimming for 1 m 59 s to a 10 mm square PCD substrate.
2) Plasma-assisted polishing was applied to 10 mm square PCD substrates that had been roughly flattened by laser-trimming. Comparison with untreated substrates showed that the time required for planarization and smoothing of PCD substrates was significantly reduced by the application of laser-trimming.

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