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# Ultraviolet-based laser cutting of type Ib diamonds

Kakeru Koiso[1a], Akinori Yui[1b],Hirofumi Suzuki[2c],Kazuyuki Moriizumi[3d]

*[1]Kanagawa University, [2]Chubu university, [3]Jonan Diamond kougyo CO.*

*[a]r202170126ul@jindai.jp, [b]yui@kanagawa-u.ac.jp, [c]suzuki@isc.chubu.ac.jp, [d]info@jd-co.jp*

**Abstract**

Diamonds have superior cutting characteristics, owing to their extraordinary hardness and excellent thermal conductivity. On the other hand, processing of diamonds is very difficult, owing to the above-listed properties. Furthermore, the hardness of diamond crystals varies, depending on the crystal orientation and high-temperature carbonization. Therefore, diamond cutting is very important for manufacturing diamond-based tools. Here, the cutting performance of monocrystalline type Ib diamonds was investigated, using a nanosecond pulsed ultraviolet laser. The experimental results suggest that a 12-µm-deep grooving can be obtained for the 16 mm/s scanning speed. By controlling the focus point, sub-millimeter-depth groovings can be machined using a 30-kHz-frequency ultraviolet laser.

Keyword: Laser cutting, Diamond, Processing

## 1. Introduction

Recently, diamond tools have been introduced for machining non-ferrous metals such as aluminum alloys and copper alloys, as well as for machining parts and molds that require excellent shape and dimensional accuracies. Diamonds are among the hardest materials, have excellent thermal conductivity and wear resistance, and are resistant to the formation of component cutting edges. Recently, as machining has become more efficient and precise, a need has arisen to cut increasingly diverse and hard materials; consequently, the workpiece demand for diamond-based tools has been increasing.

Grinding and electrical discharge machining are two major methods for diamond-based shaping. Conventional diamond cutting edges are polished by craftsmen, making it impossible to machine complex shapes, thus lowering the machining efficiency. Electrical discharge machining also suffers from low machining efficiency.

Recently, laser-based machining has been used for diamond processing, owing to its high-speed performance and non-contact capability. However, in laser machining, the surface roughness is not sufficient, owing to the high irradiation temperature-induced diamond carbonization; thus, surface polishing becomes time-consuming. As a result, the cost of diamond-based tools has been high, and the processing time has been long. Therefore, by changing the laser conditions, it should be possible to improve the surface properties of the forming process, and thus reduce the time and cost of finish polishing.

In this study, we performed diamond cutting using a nanosecond pulsed ultraviolet (UV) laser, and investigated the conditions for high-efficiency processing.

## 2. 2. Experimental apparatus and methods

A monocrystalline synthetic diamond (type Ib) was used as the workpiece material. Figure 1 shows the optical transmission characteristics of the monocrystalline synthetic diamond. Table 1 lists the specifications of the utilized laser oscillator.

Figure 2 schematically shows the nanosecond laser oscillation system used in this study. The optical system of the laser processing system consists of a reflecting mirror, a beam expander, and a condenser lens. The minimal spot diameter that can be resolved by this optical system is 6.7 µm. An Nd:YVO laser (pulse width, 13 ns; oscillation frequency, 30 kHz; wavelength, 355 nm) was used for irradiating the workpiece. The focal length was adjusted using a position-adjustment stage, and the laser beam was scanned by an XYZ stage.

The material properties of the diamond used in these experiments are listed in Table 2. The surface of the monocrystalline diamond was irradiated using the nanosecond pulsed laser while varying the scanning speed and the number of scans. The groove depth of the machined grooves and the thermal effects around the grooves were evaluated.

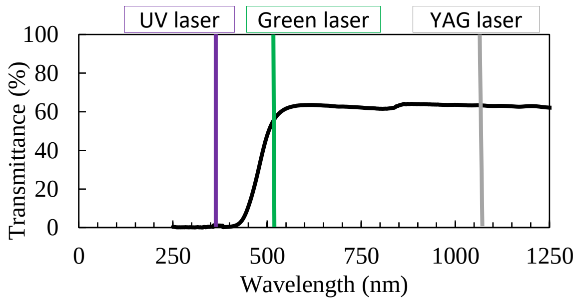


Fig 1. Optical transmission characteristics of the monocrystalline synthetic diamond

Table1 Specification of the laser oscillator

| | |
|---|---|
| Unit name | AONano 355 5-30-V (Advanced Optowave) |
| Laser source | Nd:YVO |
| Wavelength | 355 nm |
| Average power | ～5.7 W |
| Pulse width | 13～70 ns |
| Repetition rate | 30～300 kHz |
| Beam roundness | 90 % < |

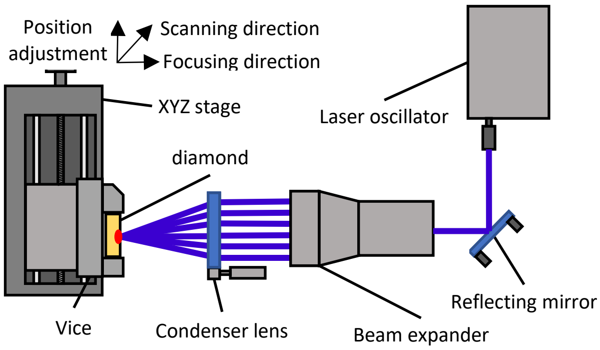

Fig 2. Schematic of the nanosecond laser processing system

Table2 Material characteristics

| | |
|---|---|
| Type of material | Monocrystalline Synthetic Diamond (Ib, PD1140, Sumi crystal) |
| Density | $3.515 \times 10^3$/m$^3$ (25℃) |
| Lattice constant | 3.567Å (25℃) |
| Young's modulus | 1050GPa |
| Coefficient of thermal expansion | $1.5\times10^{-6}$/K (78℃)<br>$3.5\times10^{-6}$/K (400℃) |
| Relative permittivity | 5.7 (1MHz) |
| Refractive index | 2.41 (λ=656.3nm) |
| Manufacturer | Sumitomo Electric Co., Ltd. |

## 3. Experimental results

### *3.1 Oscillation frequency change experiment*

Figure 3 shows the measured groove depth, for one-pass diamond scan and for the scanning speed of 1 mm/s; the laser oscillation frequency was varied in the 30–100 kHz range. The groove depth decreased as the oscillation frequency increased. In this experiment, the frequency that yielded the largest groove depth, 30 kHz, was used for achieving more efficient cutting.

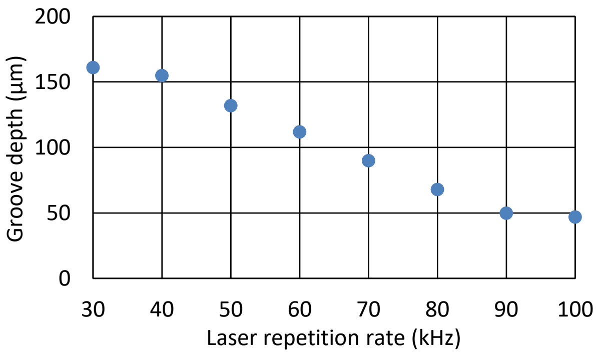

Fig. 3 Effect of the repetition rate on the groove depth

### *3.2 Scanning speed change experiment*

Figure 4 shows the machined groove depth for the scanning speed in the 0.2–16 mm/s range, for the average power of 4.0 W (oscillation frequency, 30 kHz). As the scanning speed increased, the groove depth decreased. Based on these results, the diamond scanning speed of 16 mm/s was used in the following.

### *3.3 Dependence on the number of machining operations*

When employing laser cutting in several steps, the focal length drifts as the processing depth changes. Therefore, it is necessary to change the focal length during grooving.

Figure 5 shows the change in the groove depth after 50 steps and 100 steps, as the focal length changed from 2 to 20 μm in the depth direction of the workpiece for each scan, for the oscillation frequency of 30 kHz and for the scanning speed of 16 mm/s.

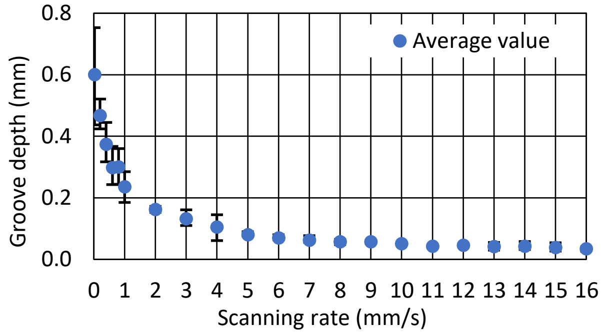

Fig. 4 Effect of the scanning speed on the groove depth

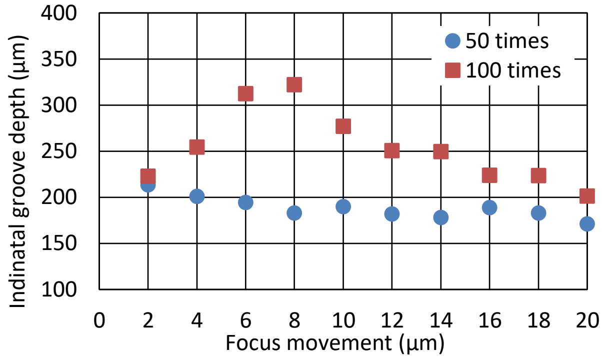

Fig. 5 Effect of the focus drift on the groove depth

The deepest machined groove was obtained for the focal point changing by 8 μm during each pass.

## Summary

Cutting of the type Ib diamond was performed using a nanosecond pulsed UV laser with the spot diameter of 6.7 μm. The following results were obtained:

1) Grooves with an average depth of 0.012 mm were produced under the irradiation conditions of 30 kHz oscillation frequency, 16 mm/s scanning speed, and one scanning frequency.
2) Under the above conditions, the focal length changed by 8 μm after 50 scans, and machining was performed for another 50 scans, resulting in a 0.32-mm-deep machined groove.

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