Development of Micro Grinding Process using Micro EDM trued Diamond Tools

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Abstract
Micro mechanical and optical devices that have high precision and ultra-micro shapes are highly important to achieving Broadband digital-networks. These devices require sub micron-level accuracy, nanometer-order surface roughness and complex three-dimensional microstructure. There are many fabrication technologies such as etching, LIGA and micro EDM[1]. But, these technologies have limited material, shape and machining accuracy. This paper describes a micro grinding method using a Poly Crystalline Diamond (PCD) micro tool scanning on a high accuracy 3 axis machine platform. An accurate tool can be shaped using micro EDM. The EDM process can produce many tool shapes, therefore complex three dimensional microstructures can be realized. Experiments show that evaluation of EDM machining conditions results in a fine surface roughness, Ry=9nm.

Keywords: micro EDM, Poly Crystalline Diamond, micro grinding, micro optics

Introduction
With optical and electronic devices becoming ever smaller and more complex, the demand for higher precision micro machining has been growing. Sub micron-level accuracy of form and nanometer-order surface roughness are required in devices such as optical wave-guides, micro lens arrays, and fiber-optic connectors. There are many technologies for the fabrication of microstructure such as etching, LIGA, and micro EDM. But, the drawbacks to these technologies are limited material, shape and machining accuracy.

A new grinding method is developed using a polycrystalline diamond (PCD) tool which is trued by micro EDM. Micro-PCD tools of any shape can be easily fabricated using micro EDM, therefore processing high-precision complex microstructures, such as V-grooves can be realized. In this study, we investigated the potential application of micro grinding of Tungsten Carbide using a cylinder-shaped PCD tool. Machining conditions are evaluated to discover the optimal condition.

Experimental setup
A 3 axis machine platform (Precitech) was developed to process the micro grinding method. Figure 1 is a picture of the machine setup.

Fig 1: Precitech 3 axis machine platform

A PCD tool with a particle size of 0.5 µm (DA200, Sumitomo Electric Industries, Ltd.) is shaped using a micro electro discharge machine (MG-ED72, Matsushita Electric Industrial Co., Ltd.). The tool rotation accuracy is very important to achieve a high accuracy tool without run out. Therefore the same bearing system is used for the grinding machine and the micro EDM machine.

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The surface roughness of the tool can be varied by changing the electric discharge energy conditions for tool shaping. A grinding experiment was performed on the 3 axis machine platform. The tool was driven by a DC motor at 3000 rpm. Figure 2 is a diagram of the experimental setup.

![Experimental setup diagram]

**Figure 2: Experimental setup**

**Evaluation of Grinding Characteristics of the Micro PCD Tool**

**Effect of the tool's surface roughness on grinding efficiency**

Using tools 100µm in diameter, we ground into Tungsten Carbide (FB20 micro-particle Tungsten Carbide, DIJET Industrial Co., Ltd.) using the tool's side while changing the feed rate of the tool, and measured the grinding depth to evaluate the grinding efficiency. Figure 3 is a diagram of the experimental method. Table 1 indicates the electro discharge conditions for shaping the tools used and the measurement results of their surface roughness (measured with an optical 3D profilometer, Keyence).

![Experimental method diagram]

**Figure 3: Experimental method**

<table>
<thead>
<tr>
<th>Tool No.</th>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacitance of capacitor</td>
<td>10pF</td>
<td>3300pF</td>
</tr>
<tr>
<td>Processing voltage</td>
<td>70V</td>
<td>110V</td>
</tr>
<tr>
<td>Tool's surface roughness (Ra)</td>
<td>0.20µm</td>
<td>0.78µm</td>
</tr>
</tbody>
</table>

The contact length of the tool's side and the work was 150 µm and the predetermined grinding depth of the work was 30 µm. Figure 4 shows the result of grinding depth. When the tool’s feed rate is high, the desire grinding depth is not reached. And it is realized that grinding efficiency of Tool 2 is higher than Tool 1.

![Result of grinding depth graph]

**Figure 4: Result of grinding depth**

**Evaluation of Microground Surface Roughness**

To measure the surface roughness of the surfaces ground with the micro-PCD tools, we performed surface grinding of Tungsten Carbide using the bottom surface of PCD tools 2 mm in diameter shaped with the electro discharge conditions indicated in Table 1. Figure 5 shows the experimental method. We then measured the surface roughness of the ground surface using a stylus-based surface roughness meter (Nanostep 2, Taylor Hobson). Figure 6 shows the measurement results, which indicate that the surface machined with Tool 1 is good with a Ry = 9 nm or less.

![Measurement results graph]

**Figure 6: Measurement results graph**
Profiling in Tungsten Carbide

Figure 7 shows an example of Tungsten Carbide machined using a 95µm diameter PCD tool made under the same electro discharge conditions as Tool 1. The grooves have a pitch of 100 µm, a length of 90 µm, and a depth of 35 µm. For the machining, the work was first ground with the side of the tool which was moved horizontally at a rate of 0.1 µm/s. The tool was then raised vertically at 5 µm/s to prevent the tool's surface roughness from being transferred to the machined surface, thus making the surface smoother. It is clear that use of this method allows microstructures to be machined to a mirror finish with high shape accuracy.

V-groove machining method and examination of machining mechanism

V-groove on Ni spherical surface

V-groove machining consists of using a cone-shaped PCD tool to carry out successive microgrinding by mechanically moving the rotating tool across a work piece at a fixed speed. By arbitrarily moving the tool on the work, you can obtain an arbitrary processing pattern. Figure 8 is an SEM image of the tool.

Figure 9 shows the result of machining on spherically electroless plated Ni. In the center of the spherical surface of R = 10 mm, V-grooves with a groove width of 30 µm were cut to form a cross pattern. The tool was passed at a speed of 10 µm/s in the plane direction; and the work was processed in oil with a uniform cutting depth of 1 µm/s for the rough machining and 0.1 µm/s for the last 1µm finishing. It is clear that this machining enables the formation of smooth surfaces with very sharp edges.
Examination of processing mechanism

Figure 10 shows a conceptual diagram of the V-groove machining method and its mechanism. V-groove machining consists in using a cone-shaped PCD tip as the machining tool, cutting the work to the depth D with the tool revolving at the rotational speed R and mechanically removing the work area by moving the tool around at the feed rate F. By adjusting the vertex angle of the cone-shaped tip, V-grooves of any angle can be machined.

When performing ultra-accurate cutting of brittle materials, such as silicon, a common problem is the damage caused by ductile/brittleness transition. It is reported, as a solution for this problem, that controlling the cutting depth with the cutting edge enables specular finishing in the ductile cutting mode. In this method, it is considered that the process develops through microscopic grinding caused by the surface roughness of diamond particles. The cone-shaped tool is an assembly of diamond-particle cutting edges, which perform numerous microscopic cuttings at the work surface as a result of the rotational motion of particles and feed movement of the tool itself. It is considered that, if the stress of the work surface during cutting exceeds a certain limit, the brittle fracture mode predominates, resulting in defects.

The volume V of work removed by each particle during one revolution of the tool is independent of the cutting depth of the tool but is given by the following equation using the tool feeding rate F and rotational speed R. It is considered that, if V exceeds a certain value, the cutting mode changes from the ductile cutting mode to the brittle cutting mode, which would cause defects in the work surface.

\[ V = k \cdot F / R \]  

(1)

To verify the above equation, we performed a V-groove machining experiment with different feeding rates and rotational speeds of the tool and checked for occurrence of defects after machining. As the sample, we used single-crystal silicon wafers (Sumitomo Metal Industries, Ltd.). The worked surface was (1,0,0), and the sample was machined in stationary oil in the orientated flat and horizontal directions. We performed V-groove machining five times with cutting depth D=5 \( \mu \)m for a cutting length of 100 \( \mu \)m and determined the number of defects.

Figure 11 shows the relationship between the tool-feeding rate F and the number of defect occurrences at different rotational speeds R. It is realized that the greater the tool feeding rate F or the smaller the rotational speed R, the more often defects may occur: this agrees with the characteristics of the above equation.

Conclusions

In consideration of the above described results, the micro grinding process using micro EDM trued diamond tools can be explained utilizing general grinding theory and is an acceptable method for fabricating micro optical devices.

Reference