Cutting of polished single-crystal silicon by wire electrical discharge machining using anti-electrolysis pulse generator

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Abstract

Polished single-crystal silicon plates were cut in water by wire electrical discharge machining (WEDM) with an anti-electrolysis (AE) pulse generator to investigate the effect of cutting on their surface quality. Experimental results show that although the surfaces near the cut sections were roughened, the rough areas were smaller than those obtained by WEDM with a unipolar power supply. The use of water with a higher specific resistance in WEDM results in the reduced size of the rough areas. The results of elementary analysis suggest that the rough areas were formed by the reactions of Cu, Zn, and O with the surfaces. Cu and Zn are probably generated from the wire electrode.

1. Introduction

Optics with various contours are expected to be fabricated by the following procedure using single-crystal silicon blocks as blanks. The silicon blocks are polished smoothly and are then cut by wire electrical discharge machining (WEDM) to the desired contour. This procedure requires that the smoothness of the polished surface be degraded as little as possible by WEDM to achieve superior optical performance. In our previous work [1], polished silicon plates were cut in water by WEDM with a unipolar power supply. This experiment revealed that the surfaces near cut sections are extremely rough.

In recent years, WEDM using an anti-electrolysis (AE) pulse generator has been proposed to reduce the amount of corrosion of workpiece surfaces. The AE pulse generator uses a bipolar power supply, which leads to the workpiece alternately becoming an anode and a cathode during WEDM. This reduces the time-averaged gap voltage to almost zero during WEDM, suppressing the electrolysis of workpiece surfaces. Thus, in the present study, we investigated the effectiveness of WEDM using an AE pulse generator in the cutting of polished silicon surfaces.

2. Experimental

We used single-crystal silicon plates with a resistivity of 0.02 Ωcm as workpieces [2]. One side of the plates was polished to an optical surface. Then, the plates were cut in water by WEDM using an AE pulse generator. The cutting was conducted such that the workpiece was incised, as shown in Fig. 1. The wire electrodes used in the machining were 200 µm in diameter. To minimize the damage to the polished surfaces caused by WEDM, the cutting conditions were set such that the cutting energy was as low as possible. After the cutting, we observed the polished surfaces using a Nomarski microscope.

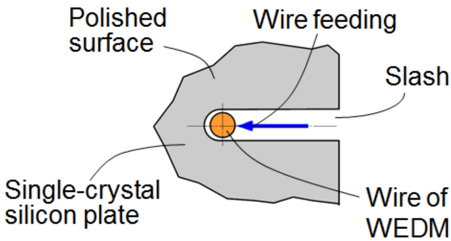

Figure 1: Experimental method. One side of single-crystal silicon plates was smoothly polished. The plates were cut by WEDM.

3. Results and discussion

3.1 WEDM using an AE pulse generator

Before cutting the polished silicon workpieces, we performed a cutting experiment on polished steel plates to investigate the effectiveness of the AE pulse generator. Figure 2 shows an image of a polished surface after cutting. As shown in Fig. 2, no rough areas were observed near the cut section, demonstrating the effectiveness of WEDM using an AE pulse generator for cutting steel.

An image of a cut silicon plate is shown in Fig. 3. From Fig. 3, the surface near the cut section was found to be roughened. The width of the rough areas increased

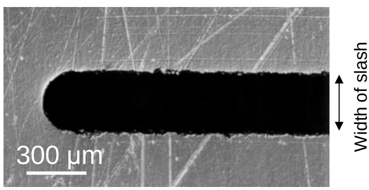

Figure 2: Image of the polished steel surface near a cut section: AE pulse generator.

with increasing pulse energy in WEDM (not shown here). The profiles of the rough areas were measured with a contact surface profiler, revealing areas of roughness that reached a height of approximately 0.5 µm on above the smooth surface.

For comparison, a surface cut by WEDM with a unipolar power supply is shown in Fig. 4. Here, the cutting conditions were also set such that the cutting energy was as low as possible. From the comparison of Figs. 3 and 4, the size of the rough area was found to be decreased by using the AE pulse generator. This indicates that electrolysis on the single-crystal silicon surface was suppressed by the AE pulse generator, reducing the amount of corrosion of the surface.

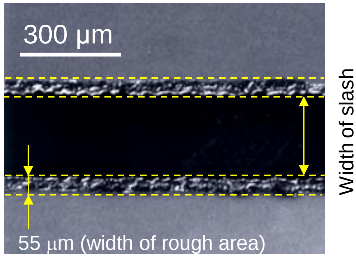

Figure 3: Image of the polished silicon surface near a cut section: AE pulse generator.

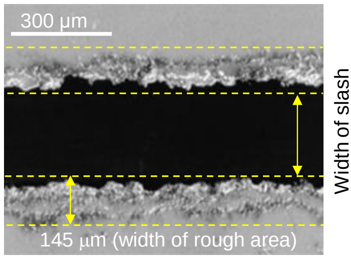

Figure 4: Image of the polished silicon surface near a cut section: Non AE pulse generator.

3.2 Cutting in water with higher specific resistance

It is well known that, in WEDM, increasing the specific resistance of water reduces the corrosion of workpiece surfaces caused by electrolysis. Thus, we performed a cutting experiment in water with a higher specific resistance of 600 kΩcm; in section 3.1 the cutting was performed in water with a specific resistance of 70 kΩcm. The other conditions were similar to those in section 3.1.

Figure 5 shows the experimental results. From Fig. 5, the surface near the cut section was also found to be roughened. However, comparing Fig. 5 with Fig. 3, it was found that the rough areas are reduced in size by increasing the specific resistance of water:

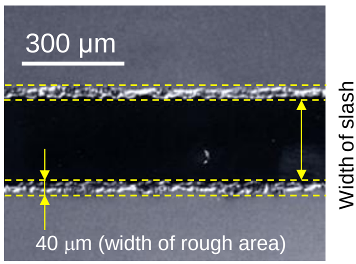

Figure 5: Image of the polished silicon surface near a cut section. The surface was cut in water with a specific resistance of 600 kΩcm: AE pulse generator.

the widths of the rough areas near the edge are 55 μm and 40 μm for water with specific resistances of 70 kΩcm and 600 kΩcm, respectively.

3.3 Elementary analysis of the polished surfaces after cutting

To obtain more detailed information about the rough areas, we conducted elementary analysis of a rough area by energy-dispersive X-ray analysis (EDX). Figure 6 shows the obtained EDX spectrum, in which Cu, Zn, O, and Si were detected. This suggests that the rough areas were formed by the reaction of these chemical species with the surfaces. During the WEDM process using an AE pulse generator, the electric potential of the workpiece was alternately changed between positive and negative. Thus, it is likely that Cu and Zn react with the silicon surface when the workpiece is negative and that oxygen reacts with the surface when the workpiece is positive. Cu and Zn are probably yielded from the electrode, which is made of brass.

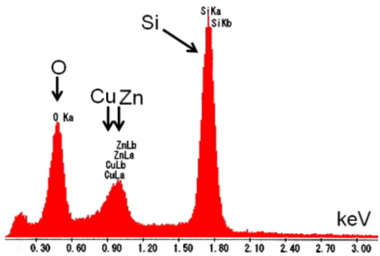

Figure 6: EDX spectrum of a rough area on a polished surface after cutting.

4. Conclusions

We cut polished single-crystal silicon plates by WEDM using an AE pulse generator. Although the surfaces near the cut sections were found to be roughened, the rough areas were smaller than those formed by WEDM with a unipolar power supply. Moreover, by increasing the specific resistance of water, the rough areas were reduced in size. Elementary analysis of the rough areas indicates that they were formed by the reactions of Cu, Zn, and O with the surfaces.

References:

[1] Takino H, Ichinohe T, Tanimoto K, Yamaguchi S, Nomura K, and Kunieda M 2004 Cutting of polished single-crystal silicon by wire electrical discharge machining *Prec Eng* 28, 3 pp 314–319.

[2] Okada A, UnoY, and OkamotoY 1998 A new slicing method of monocrystalline silicon ingot by wire EDM *Proc. 12th Int. Symp. for Electro Machining* pp 417–424.