Fundamental Study on Multi-wire EDM Slicing for Monocrystalline Ingot

- Effects of Supply Method of Working Fluid and Wire Speed on Machining Characteristics -

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Summary

A new slicing method of monocrystalline silicon ingot using wire electrical discharge machining was proposed for high efficiency and high quality slicing instead of inner diameter blade or multi-wire method. The effects of supply method of working fluid and wire speed on machining characteristics were experimentally investigated. It is clarified that the immersion method is superior than the nozzle supply method and the wire speed over 200 m/min is desirable for stable machining. Besides, mounting of wire sub-guide is useful for obtaining better kerf shape.

Key words: Multi-wire, Electrical discharge machining, Slicing, Monocrystalline silicon

1. Introduction

Recently the diameter of silicon wafer becomes larger to increase the number of chips per one wafer. It is difficult to slice a large diameter ingot by the conventional inner diameter blade method, because of the difficulties in making the corresponding blade size and low efficiency. Nowadays the slicing is mainly done by using multi-wire method, in which a thin long wire is used with slurry. With this method, several hundreds of wafers could be sliced at the same time. However there are still problems remaining, such as large cracks, slurry treatment, contamination and so on. Therefore we proposed a new slicing method of monocrystalline silicon ingot using wire electrical discharge machining (wire EDM). The specific conductivity of silicon wafer used for epitaxial growth becomes lower to the order of $10^{-2} \Omega \cdot \text{cm}$ that is possible to do EDM⁽¹⁾⁻⁽³⁾. In this method, the cracks on the machined surface might be reduced, since the machining force in wire EDM is extremely small compared to that in the conventional methods. Also, it is expected that the working environment could be improved, because deionized water is used as the working fluid in wire EDM, so the contamination might be reduced. However obtaining high efficient process with this process is difficult, since the conventional wire EDM technique can slice only one wafer at one time. Therefore a multi-wire EDM slicing equipment with a multi-EDM power supply unit was newly developed to increase the efficiency of wafer slicing. In this paper, fundamental machining characteristics for monocrystalline silicon ingot by the newly developed multi-wire EDM equipment were experimentally investigated.

2. Experimental procedures

Figure 1 shows the schematic diagram of the newly developed multi-wire EDM equipment. The electrode wire is wound spirally on wire guides many times. The wire is fed reciprocally by reversing the direction of feed when the wire comes to the end. Conductivity pieces used to give power to the electrode wire were set at inner part or outer part between two wire guides. In this experiment, the wire pitch is set to 1.1mm. Wire tension is controlled by the tension loading weight where the maximum tension can be adjusted to 40N.

Main machining conditions are listed in Table 1. The polarity is set as (-) for the electrode wire and (+) for the workpiece. Molybdenum wire of 180 μm in diameter was used as the wire electrode.

3. Results and discussion

3.1 Supply method of working fluid

Electrode wire is fed through two wire guides mounted near the machining area under a certain wire tension. At first, we were supplying the working fluid by nozzle method. In this case, the kerf is not stable and it changes greatly from place to place because of surface tension of working fluid. Therefore we changed the supply method of working fluid into the immersion method. In this case, the kerf is almost constant and the wire pitch is kept at the setting value of 1.1mm. Therefore we used the immersion method hereafter.

3.2 Effect of wire speed

Even in the immersion method, there are some irregularities and they become larger with the cutting length as shown in Fig.2(b). It is considered that this phenomenon is due to the difficulties in debris exclusion. In order to solve the problem, the wire speed is changed from 100 m/min to 200, 300, 400 m/min. Figure 3 shows the variations of removal rate and surface roughness with wire speed. It can be seen from the figure that the removal rate increases, whereas the surface roughness decreases with increasing wire speed.

Fig.1 Schematic diagram of multi-wire EDM equipment

Table 1 Machining conditions

Electrode	Mo ($\phi 180\mu\text{m}$)
Specific resistance of workpiece	$\rho_s = 10^{-2} \Omega \cdot \text{cm}$
Polarity	Electrode (-)
Gap voltage	$V_o = 100\text{V}$
Wire tension	$F = 15\text{N}$
Discharge current	$i_e = 8 - 15\text{A}$
Discharge duration	$t_e = 3 - 20 \mu\text{s}$
Duty factor	$\tau = 30 \sim 60\%$
Wire speed	$W_s = 100 - 400\text{m/min}$
Max. table speed	$F_{t\text{max}} = 1 - 5 \text{ mm/min}$
Dielectric working fluid	Deionized water
Specific resistance of dielectric working fluid	$\rho_w = 3 \times 10^5 - 10^6 \Omega \cdot \text{cm}$

Fig.2 Difference in kerf shapes according to working fluid supplying method (a) nozzle supply (b)immersion

Fig.3 Variations of removal rate and surface roughness with wire speed

Fig.4 Kerf shapes for various wire speeds

Fig.5 Effect of wire sub-guide

Figure 4 shows the kerf shapes for various wire speeds. As shown in the figure, the kerf becomes more stable with increasing wire speed. It is considered that the debris exclusion becomes smoother with the wire speed.

3.3 Mount of wire sub-guides

Even in Fig.4, there are some irregularities in the kerf shape. It is due to the vibration of electrode wire. Therefore we mounted two wire sub-guides between two conductivity pieces. Figure 5 shows the kerf shapes in the cases without sub-guide and with sub-guide. It can be seen that the kerf shape is more stable when the wire sub-guide is mounted.

3.4 Efficiency in multi-wire EDM

Figure 6 shows the variations of removal rate and surface roughness for single wire, twin wire and triple wire. The removal rate per wire and surface roughness are almost the same regardless of wire number. This means that there is no energy loss even in the case of multi-wire EDM. In other words, many electrical discharges occur on one wire at the same time.

3.5 Slicing of 8" silicon ingot

Here we tried the slicing of 8" silicon ingot. Figure 7 shows the schematic illustration of ingot and beam which is the holder of ingot. They are joined with special paste. The slicing is done from bottom side to the upper side. Figure 8 shows the relationship between displacement of workpiece(silicon ingot) and machining time. As shown in this figure, stable machining was done until the machining time 1230 minutes that corresponds to the sliced depth of about 195mm. After this point, the slicing rate decreases greatly because the beam is made of steel and this part is difficult to slice compared to the silicon ingot. Figure 9 shows the variations of removal rate with machining time. The removal rate is fairly constant until 1230 minutes, which means the stable machining was done during this period.

Fig.6 Variations of removal rate and surface roughness with number of wire electrode

Fig.7 Schematic illustration of ingot and beam

Fig.8 Relationship between displacement of workpiece and machining time

Fig.9 Variation of removal rate with machining time

4. Conclusions

A new slicing method of monocrystalline silicon ingot with multi-wire EDM was proposed for high efficiency and low contamination. Main conclusions obtained are as follows;

- (1) Slicing performance in immersion method is superior than that in nozzle supply method, because the machining state is stable.
- (2) Wire speed over 200m/min is desirable for stable machining because the exclusion of debris is easy.
- (3) Mounting of wire sub-guide is useful for obtaining better kerf shape.
- (4) There is no energy loss even in the case of multi-wire slicing, which means that high efficient slicing of ingot is possible.
- (5) Slicing of 8" silicon ingot was possible in this equipment with the newly developed equipment.

This paper made not only clear that the slicing of monocrystalline ingot by wire EDM is possible, but also that high efficient slicing is possible with this process. In the next stage, we will try multi-wire slicing of silicon ingot with more than 3 wire electrodes.

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