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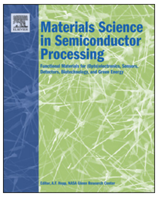

Discharge cutting technology for specific crystallographic planes of monocrystalline silicon

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ABSTRACT

Crystallographic planes were detected with X-ray crystal orientation instrument to study wire-cut electrical discharge machining (WEDM) technology for specific crystallographic planes of monocrystalline silicon. The unidirectional conductivity of monocrystalline silicon was analyzed. The contact potential barrier was decreased by preparing Ohmic contact to the surface discharging of the input terminal. Finally, the high-precision discharge cutting of the specific crystallographic planes of monocrystalline silicon was validated. Finished silicon products with specific crystallographic planes were prepared by WEDM, and the cutting efficiency, surface quality, crystal orientation precision, and qualified rate were determined. With cutting thickness of 200 mm, the cutting efficiency reached 100 mm^2/min, and the precision of crystal orientation reached 3′ or less.

1. Introduction

Monocrystalline silicon has specific crystallographic planes, which can colorize the original light ray by diffraction. The monocrystalline silicon obtains only a specific wavelength ray after it was colorized. The colorized ray has good monochromaticity and continuously adjustable energy. For example, the colorized X-ray energy ranges from 20 keV to 100 keV. Johnson et al. [1] indicated the significant advantages of silicon active pixel sensors of neutron scattering, where the silicon is used as monochromator. Šaroun et al. [2] showed the crystallographic plane in a monochromator required high precision. The accuracy of the angle of the crystallographic plane needs to reach 3′ or less in some precise crystals. The specific crystallographic planes can be determined by the following methods: mechanical method, optical method, and X-ray method. Mechanical method damages the crystal, and optical method has relatively poor accuracy. X-ray method measures the deviation of the crystallographic planes well, because it does not damage the crystal and has higher accuracy than the first two methods.

Inamura et al. [3] demonstrated that monocrystalline silicon has high hardness and brittleness, and it is prone to crack or fracture because of the cleavage phenomenon in general mechanical machining. Thus, the machinability of monocrystalline silicon is poor. Mechanical cutting is the traditional crystal-cutting method. Mechanical cutting generally uses a modified precision grinder with 3D motion, because no special equipment for this task is available. Mechanical cutting has complicated machining processes. The size of the crystal is less than 100 mm; the rigidity and accuracy requirements of the machine and the cost are very high as reported by Xie et al. [4]. Wire-cut electrical discharge machining (WEDM) uses the instant high temperature of spark discharge to melt or vaporize the workpiece. It is suitable for cutting brittle monocrystalline silicon because of its very small macroscopic mechanical force. Luo et al. [5] proved the feasibility of

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monocrystalline silicon machining by WEDM. Kunieda et al. [6] improved the EDM efficiency of monocrystalline silicon machining by using Ohmic contact. This article presents the discharge cutting technology for specific crystallographic planes. Theoretically, any crystallographic planes of monocrystalline silicon in space can be cut by WEDM and the orientation detection of XRD.

2. Detection and cutting principles of crystallographic planes

2.1. Bragg diffraction theory

As described by Zhou and Guo [7], Bragg's law is the basic principle of the XRD of crystallographic plane detection. When parallel monochromatic X-ray (Wavelength is λ, angle of incidence is θ) is present on the crystal surface, the optical path difference of adjacent parallel crystal plane reflection is $2d\sin\theta$, as shown in Fig. 1. Bragg's law holds that the diffraction phenomenon occurs when the optical path difference is appropriate to an integer multiple of the wavelength.

Bragg's law is represented by the following formula:

$$2d\ \sin\ \theta = n\lambda \tag{1}$$

where d is the spacing of adjacent parallel planes; $2d\sin\theta$ is the optical path difference, which is the length of AO+BO in Fig. 1; n is an integer, which is greater than zero; θ is the incident angle of X-ray, which is also known as the Bragg angle; and λ is the wavelength of the incident X-ray. The spacing d differs among crystallographic planes corresponding to different Bragg angles θ. Therefore, specific crystallographic planes can be measured by detecting the corresponding Bragg angle.

2.2. Detection principle of X-ray crystal orientation instrument

Fig. 2 shows the detection principle of X-ray crystal orientation instrument. The workpiece was set on the reference surface by an air pump to ensure that the silicon workpiece surface is parallel to the reference. The incident X-ray was generated by the high voltage on X-ray source (Cu-target). The Bragg angle of the ideal specific crystallographic plane is the angle θ, which is between the X-ray and the reference surface. The stage can rotate around the axis O. The specific crystallographic plane is parallel to the reference surface when the stage turns δ, and thus the diffraction condition is met. The Geiger counter receives the maximum intensity of X-rays, whereas the Microampere meter pointer deflects to a maximum value. The δ, which is the angle between the measured and ideal plane, can be read out. Afterward, the position of the specific crystallographic plane can be calculated indirectly. Fig. 3 shows the crystal orientation instrument.

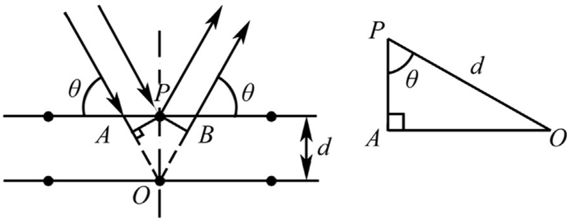

Fig. 1. Schematics of Bragg's law.

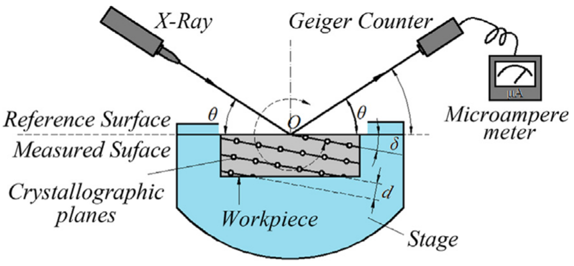

Fig. 2. Detection principle of X-ray crystal o rientation instrument.

2.3. Specific crystallographic plane-cutting principle by WEDM

Fig. 4 shows the principle of cutting a specific crystallographic plane of monocrystalline silicon by WEDM. The requirements of WEDM machine is a taper cutting function with four-axis (i.e., X, Y, U, and V axis) control, shown in Fig. 5. The lower wire frame is stationary. The relative motion between the upper and the lower wire frame can be achieved by the stepper motor of U, V axis. For example, the stepper motor of U axis can achieve micron grade motion. The center distance between the upper and the

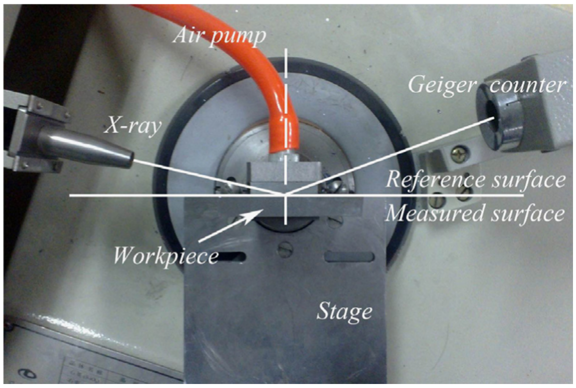

Fig. 3. X-ray crystal orientation instrument.

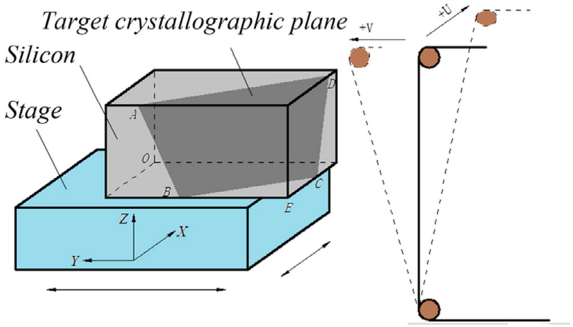

Fig. 4. Principle of cutting a specific crystallographic plane of monocrystalline silicon by WEDM.