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Multi-discharge EDM coring of single crystal SiC ingot by electrostatic induction feeding method

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ABSTRACT

A new technique of EDM coring of single crystal silicon carbide (SiC) ingot was proposed in this paper. Currently single crystal SiC devices are still of high cost due to the high cost of bulk crystal SiC material and the difficulty in the fabrication process of SiC. In the manufacturing process of SiC ingot/wafer, localized cracks or defects occasionally occur due to thermal or mechanical causes resulted from fabrication processes which may waste the whole piece of material. To save the part of ingot without defects and maximize the material utilization, the authors proposed EDM coring method to cut out a no defect ingot from a larger diameter ingot which has localized defects. A special experimental setup was developed for EDM coring of SiC ingot in this study and its feasibility and machining performance were investigated. Meanwhile, in order to improve the machining rate, a novel multi-discharge EDM coring method by electrostatic induction feeding was established, which can realize multiple discharges in single pulse duration. Experimental results make it clear that EDM coring of SiC ingot can be carried out stably using the developed experimental setup. Taking advantage of the newly developed multi-discharge EDM method, both the machining speed and surface integrity can be improved.

1. Introduction

With the further development of electronic devices, silicon semiconductor is approaching its performance limit due to intrinsic material properties, especially in application related to high-power, high temperature and high frequency devices. On the other hand, single crystal silicon carbide (SiC), which is an extremely hard and inert material, has superior electrical and physical properties over Si, namely wider band-gap, larger critical electric field, higher thermal conductivity, etc. Due to these attractive features, SiC has been regarded as able to function well under very hostile environments such as high temperature and high radiation conditions at which conventional semiconductors cannot work adequately [1]. It has been expected that the performances of a wide variety of applications and systems can be improved significantly by utilizing SiC-based electronics. However, due to the high cost of SiC, currently Si still dominates nearly all semiconductor applications for economic reasons. SiC has little chance of being used unless its cost is the same as or lower than that of Si [2]. To reduce the cost of SiC and extend its applications, development of SiC manufacturing technology is considered to be of great importance.

In the fabrication process of single crystal SiC ingot/wafer, cracks or defects are generated occasionally due to thermal or mechanical causes resulted from the manufacturing process, for example, bulk crystal growth, multi-wire saw process and the like. In order to maximize the material utilization and save the no defect part of ingot/wafer, coring of SiC ingot is proposed in this paper. On the other hand, due to the super high hardness of SiC, EDM is being developed to process SiC material instead of conventionally used mechanical machining methods [3]. Wire electrical discharge machining (WEDM) was considered as an applicable method for coring an undamaged SiC cylinder from a damaged wafer/ingot. However, due to the high residual stress distributed in the peripheral region of the ingot, breakage of ingot along cleavage planes of SiC will occur easily when wire electrode is cutting into the ingot from the circumference of ingot. Therefore, this study was proposed to realize coring of SiC ingot by EDM utilizing a rotatory coring tool electrode.

2. EDM coring of SiC ingot by conventional pulse generator

2.1. Experimental setup

For coring the SiC ingot, a tubular tool electrode (like coring bit) is necessary. However, manufacturing of a tubular copper tool electrode with a small wall thickness has great difficulty.

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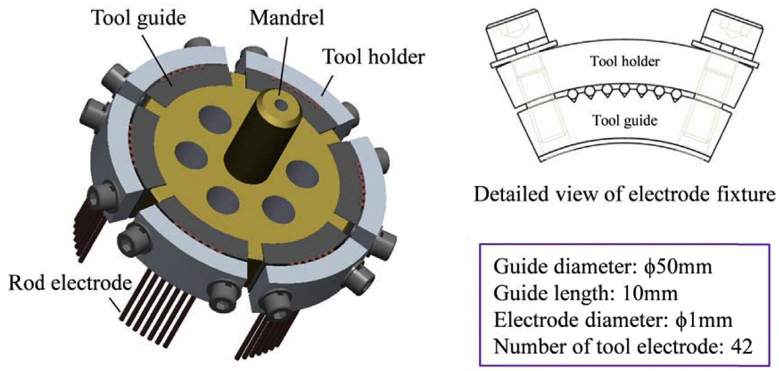

Fig. 1. Structure drawing of coring tool electrode setup.

Meanwhile, the flushing condition will become worse with increase of the cut depth when using a whole piece of tubular tool electrode. Therefore, the authors proposed a new rotatory tool electrode setup specifically designed for coring SiC ingot, as shown in Fig. 1. Copper rod is selected as the tool electrode due to its simplicity and easy accessibility. The rod electrode is fixed by a specially designed tool fixture of which the detailed structure is shown on the right side of Fig. 1. The tool electrode fixture mainly consists of 3 components: mandrel, circular electrode guide with V-shape grooves and the outside circular holders. The circular electrode guide is divided into six segments so that separate feeding of electricity can be realized which will be described in detail in later section. Rod electrodes are positioned along the V-shape groove guides and clamped tightly towards the guides by the outside circular holders using bolt screws along the radial direction. When the tool fixture is rotated, the trajectory of the rod tool electrodes will be a circle. By feeding the rotating tool electrodes towards the workpiece at the same time, a cylinder can be cut out.

The advantage of this design is that the tool electrode can be easily replaced after being worn. In the event of collision between the rod tool electrodes and the workpiece, only the bent rod needs to be replaced by a new one, while in the case of the tubular tool the whole electrode should be replaced. Another strong point of the setup is that it can provide better flushing effect and better gap condition compared with one whole piece of tubular electrode, owing to the interspace between any two rod electrodes.

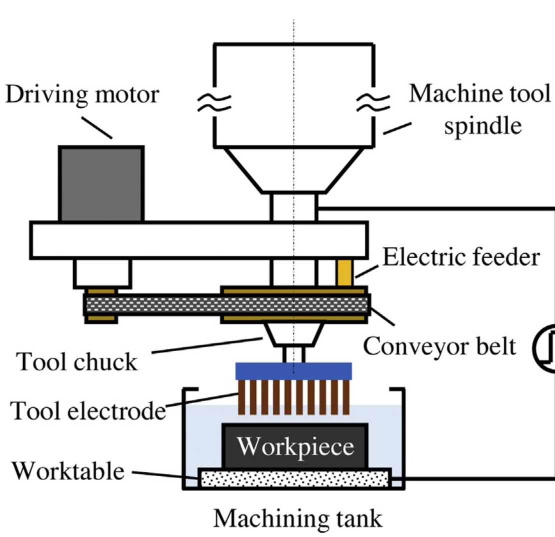

Fig. 2. Schematic diagram of experiment setup for EDM coring of SiC ingot using rotatory tool electrode.

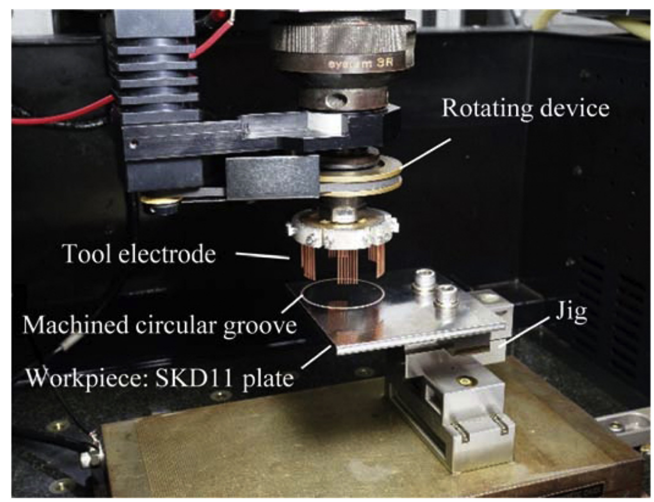

Fig. 3. Machining example of EDM coring of steel plate (SKD11).

Fig. 2 shows the schematic diagram of the developed experimental setup for EDM coring. A rotating apparatus (range of rotating speed: 50–250 rpm) consisting of a drive motor, timing pulley and conveyor belt is installed on the tool spindle of sinking EDM machine tool (Sodick C32) to rotate the tool electrode during machining. The tool electrode is fixed to the rotating device by a collet chuck. The electricity is fed to the tool electrode by utilizing two carbon brush feeders. Fig. 3 shows a photograph of the machining example by utilizing this setup (workpiece: cold tool steel SKD11 plate).

2.2. Machining stability

The experimental conditions for machining SiC are shown in Table 1. In order to avoid collision between rotating tool electrode and workpiece during feeding, an auxiliary high-voltage power source with large impedance was connected to the gap in parallel with the conventional EDM pulse generator to enlarge the discharge gap and improve the discharge condition. In addition, since

Table 1
Experimental conditions.

Workpiece	SiC ingot
Tool electrode [mm]	Copper rod, ϕ1
Open voltage [V]	120
High-voltage synchronization [V]	240
Measured discharge current [A]	16
Cut depth [mm]	2
Tool revolution number [rpm]	100