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Study of an on-line precision microgroove generating process on silicon wafer using a developed ultra-thin diamond wheel-tool☆☆

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ABSTRACT

This study presents a novel and economical method for precisely developing an ultra-thin diamond grinding wheel-tool and using the finished wheel-tool to on-line fabricate crisscross microgrooves on silicon wafer. The wheel-tool blank is made of diamond grain of 0–2 μm grade via a designed micro co-deposition. A non-continuous cathode design, in which current crowding effect can be suppressed, is used to obtain a diamond wheel-tool with good surface characteristics. With abrasive content of 8 g/l, a suitable interval chip-pocket of 2–3 μm can be generated. The grinding wheel blank is thinned and dressed simultaneously down to a thickness of 15 μm using micro wire Electro Discharge Dressing (w-EDD). The finished wheel-tool is directly utilized to grind the crisscross microgrooves on the silicon wafer using 'high-speed and fast-shallow grinding' technique. A grinding depth of 0.5 μm per stroke is exactly controlled to ensure that the removal mechanism transfers to a ductile grinding mode. The width, depth and surface roughness R_a of the microgrooves are 15 μm, 9 μm and 0.087 μm, respectively.

1. Introduction

Hard-brittle materials with fabricated microstructures have been widely employed in biomedical analyses such as the early diagnosis of diseases, in integrated circuit processes as dies separation by microgrooves array, and as optoelectronic products for filter and beam splitting. However, when machining the surface of hard-brittle material such as optical glass and silicon wafer, traditional machining methods cannot be employed since they require considerable amounts of mechanical and thermal energy for removing the material. Although non-traditional techniques have their distinctive features, some are hazardous, some require expensive equipment, and some have extremely low material removal rates [1–4]. 'Brittle–ductile transition' is an important removal mechanism that occurs in hard-brittle material during the machining process [5]. A hybrid process that combines micro co-deposition, wire electrical discharge dressing (w-EDD) with 'high-speed and fast-shallow grinding' is employed to make the precision microgrooves on a silicon wafer. The geometrical and dimensional accuracy and surface roughness of the microgrooves are estimated.

2. Methodology

Fig. 1 shows a schematic design of the proposed fabrication approach. A hybrid process combining micro co-deposition, micro w-EDD and micro grinding is employed to make precision microgrooves on hard-brittle material. In this process, a blank of a diamond grinding wheel is first formed and then on-line thinned to obtain a highly concentric shape. The finished wheel-tool is directly positioned beside a silicon wafer and operated on-line. The motion of the ultra-thin grinding wheel-tool is accurately controlled according to the CNC (Computerized numerical control) path, in which numerical values corresponding to the desired tool or control positions are generated by a computer, during the whole process of the truing and grinding. Therefore, the on-line grinding can be guaranteed the obtained machining accuracy to be kept within the positional accuracy of the machine tool (within 1 μm in our case).

3. The procedures

3.1. Co-deposition of a wheel-tool blank

Firstly, the wheel-tool blank is fabricated using electrochemical co-deposition. According to Faraday's law, the deposition rate is defined as the ratio of the deposition thickness to deposition time. The deposition thickness ***d*** can be expressed by the following equation [6]:

$$\frac{d}{t} = \eta \frac{M}{zF\rho} j \tag{1}$$

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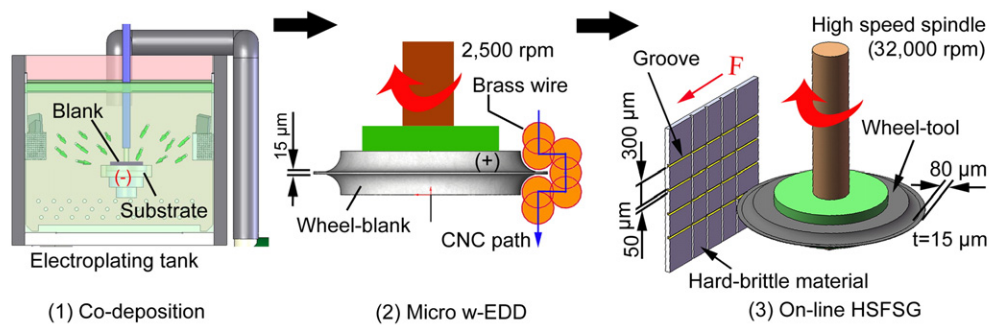

Fig. 1. The proposed approach.

where t is the deposition time; M, the molecular weight of the electrolyte; η, the current efficiency; z, the number of electrons participating in the electrochemical reaction; F, Faraday's constant; ρ, the density of the metal; and j, the current density. A so-called 'current crowding effect' is always observed at the sharp edge of the work-piece during the metal deposition process. Consequently, j appears as the maximum value at this edge. A cathode substrate of non-continuous design in which an insulator (Poly-methyl-methacrylate; PMMA) is inserted into the non-continuous region to interrupt current crowding generated in the region with the highest j is proposed and devised, as shown the top of Fig. 2a. In this case, a smooth layer can be deposited on the inner disk as shown in the bottom-left corner of Fig. 2a. On the contrary, at the outside edge of the work-piece, current crowding occurs, and this results in the formation of an uneven surface as shown in the bottom-right corner of Fig. 2a. Fig. 2b demonstrates the relationship concerning the diamond grits content in the electrolyte corresponding to the interval where it provides a function for storing chips temporarily. The average value of interval is obtained at 2.5 μm in a given interval when the diamond grains content is fixed at 8 g/l.

3.2. Thinning and dressing of the diamond wheel-tool

The co-deposited wheel blank comprising numerous diamond grits and nickel ions is mounted on a high speed spindle so as to be thinned and sharpened by micro w-EDD. A resistance capacitance (RC) circuit is employed as the electrical discharge power since it helps in achieving a discharge current with a short pulse and high peak [7], and thus, a very shallow and narrow discharge cavity is

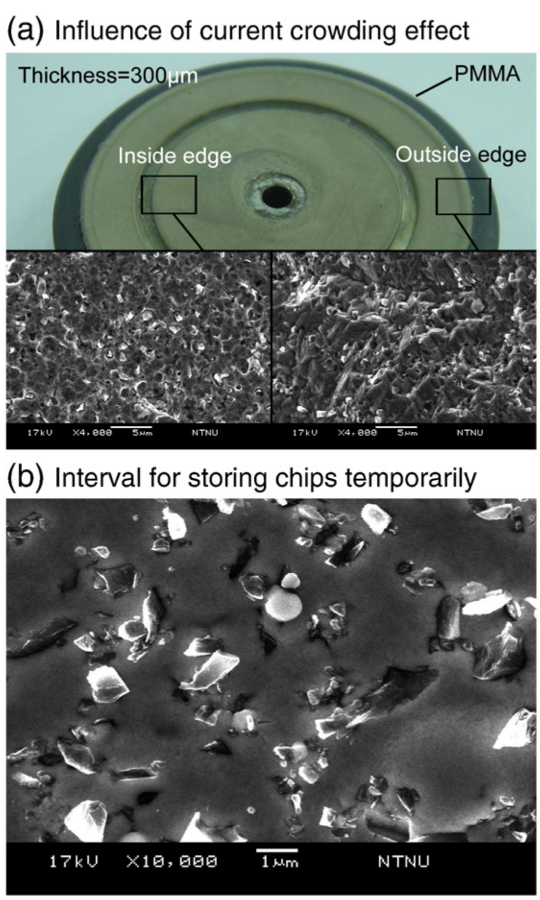

Fig. 2. Co-deposition of a wheel-tool blank.

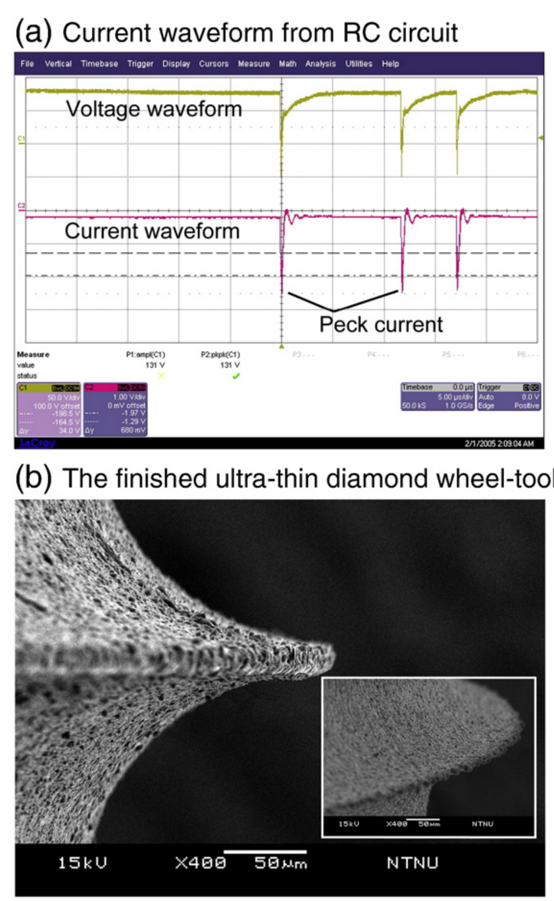

Fig. 3. Thinning and dressing of the diamond wheel-tool.