

Experiment study on electroplated diamond wire saw slicing single-crystal silicon

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ABSTRACT

This paper conducted the slicing experiments of single-crystal silicon using a reciprocating electroplated diamond wire saw. The machined wafer topography and wire wear were observed by using scanning electron microscope (SEM). The influences of process parameters and cutting fluids on single-crystal silicon wafer surface roughness (SR), subsurface micro-crack damage (SSD) depth, total thickness variation (TTV) and warp were investigated. The bonded interface sectioning technique was used to examine the cut wafers SSD depth. Study results show that a higher wire speed and lower ingot feed speed can produce lower wafer SR and SSD; the lower warp of wafer needs lower wire speed and ingot feed speed; and low wafer TTV can be obtained by an appropriate matching relationship between wire speed and ingot feed speed. The synthetic cutting fluid has a better total effect to improve the wafer quality. The pulled-out of diamond abrasives is the main wear form of wire, which indicates that more research on improving the abrasives retaining strength on wire surface should be investigated in fixed-abrasive wire manufacturing process, in order to improve the wire life and wire saw machining process.

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1. Introduction

Nowadays, semiconductors are widely used in microelectronic applications, such as computer systems, automobiles, industrial automation, consumer electronics and control systems. Semiconductor devices are the foundation of the electronics industry, which is the largest industry in the world. So far, the majority of semiconductors are still built on silicon wafers [1,2]. A typical manufacturing process flow of high-quality integrated circuit chips based on silicon wafers usually includes the following major processes: crystal growth, slicing, flatting, etching, polishing, cleaning, developing circuit on the front side of silicon wafer, back grinding, dicing and packaging, etc. [3]. Wafer slicing process is a key machining procedure, and the wafer surface and subsurface quality in slicing can directly affect the workloads and costs of next processes.

The wire saw machining technology has been applied to slicing single-crystal silicon wafers since the mid-1990s, using loose abrasive slurry and bare wire, which is called free abrasive wire saw machining technology [4,5]. During this machining process, the cutting action is finished by cone-shaped abrasives rolling between the wire and the ingot, which forms a three body

abrasion [5]. In recent years, the fixed-abrasive diamond wire sawing technology has a rapid development and application for slicing of brittle-hard materials including silicon crystalline, sapphire and SiC. Instead of using the slurry including the super-hard abrasives for cutting agents, the cut tool used in fixed-abrasive diamond wire sawing is a stainless steel wire with diamond abrasives fixed on its surface by using the method of plating or resin bonding. The material removal mechanism of these two kinds of processing technology using loose abrasive slurry and fixed-abrasive wire is different, and the material removal is finished by two body wear when using a fixed-abrasive wire, which will bring a series of advantages such as a higher processing efficiency and a smaller cut kerf Fig. 1.

Smith et al. [7], Tokura et al. [8] and Ishikawa et al. [9] conducted the early wire saw machining experiments using a diamond plated wire in 1990s. Shih et al. [10–12] studied the fixed-abrasive diamond wire cutting wood, foam ceramics and silicon carbide (SiC). The process monitoring and influences of process parameters on machined surface roughness and cutting forces were researched, the machined surfaces microscopic examination and wire wear were also presented. Since 1970s, there have been hundreds of patents about wire saw technology, and most of the breakthroughs in wire saw technology are documented as patents. Watanabe et al. [13] studied the multicrystalline silicon slicing using a resin bonded diamond wire, and the results show that the fixed abrasive wire saw has a higher throughput and a lower

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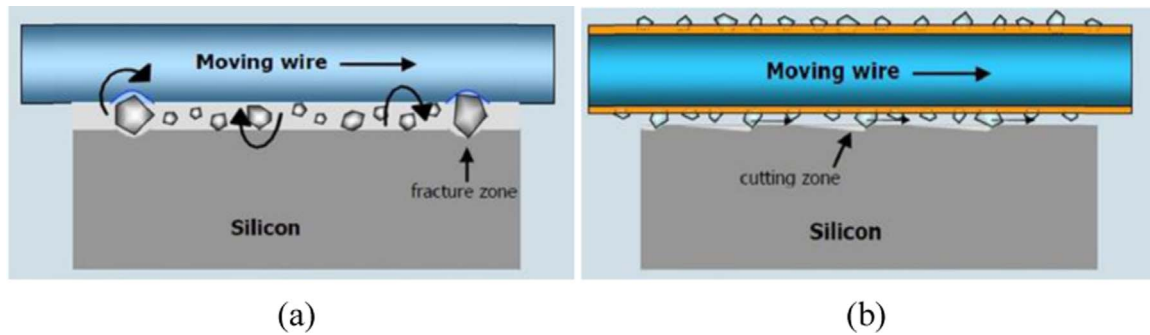


Fig. 1. Schematics of the material removal process: (a) free abrasive wire saw, and (b) fixed-abrasive wire saw [6].

subsurface damage layer depth, compared to the free abrasive wire sawing. Wu et al. [14] and Yu et al. [15] also presented that the better mechanical strength and surface roughness of silicon wafers can be produced by fixed-abrasive wire sawing. At present the fixed-abrasive wire used in industry mainly includes two kinds of electroplating diamond wire and resin bonded diamond wire. The resinoid bond diamond wire has a lower wear and heat resistance comparing to the electroplated diamond wire that can meet the requirements of practical application better, especially for cutting high hardness materials such as SiC and sapphire [12,16–18].

Chung et al. [19] theoretically proposed a model to calculate the material removal rate considering diamond distribution density on the wire surface. Li et al. [20] presented a force modeling in electroplated diamond wire sawing of SiC Monocrystal Wafer. Wurznner et al. [21] presented the influences of the wire speed on the surface damage of diamond wire sawn multicrystalline silicon wafers, and the research results show that a faster wire speed leads to lower crack depth value. Besides, there are other cut processes for silicon wafer slicing such as wire-EDM [2,22], which

has not been widely used in industry.

As a kind of hard-brittle material, the key technical challenges for fixed-abrasive wire saw (FAWS) slicing single-crystal silicon are wafer surface integrity and shape accuracy, including the wafer surface topography, surface roughness, subsurface damage depth, wafer warp and total thickness variation, etc. In the semiconductor processing industry, the quality of processed silicon wafer in wire saw silcing is a widely concerned problem. The research goals of this paper are to investigate the influences of process parameters on sliced silicon wafer quality of FAWS machining. This paper presents an experimental study on FAWS machining single-crystal silicon by using a reciprocating wire saw machine and electroplated diamond wire. The silicon wafer surface topography is observed by using SEM and analyzed combining with material removal mechanism, and the influences of wire speed and ingot feed speed on wafer SR, TTV, warp and SSD depth are studied. Influences of different cutting fluids on the sliced silicon wafer quality are also analyzed. The wire wear mechanism is also analyzed by observing the wire micrographs using SEM. These researches can

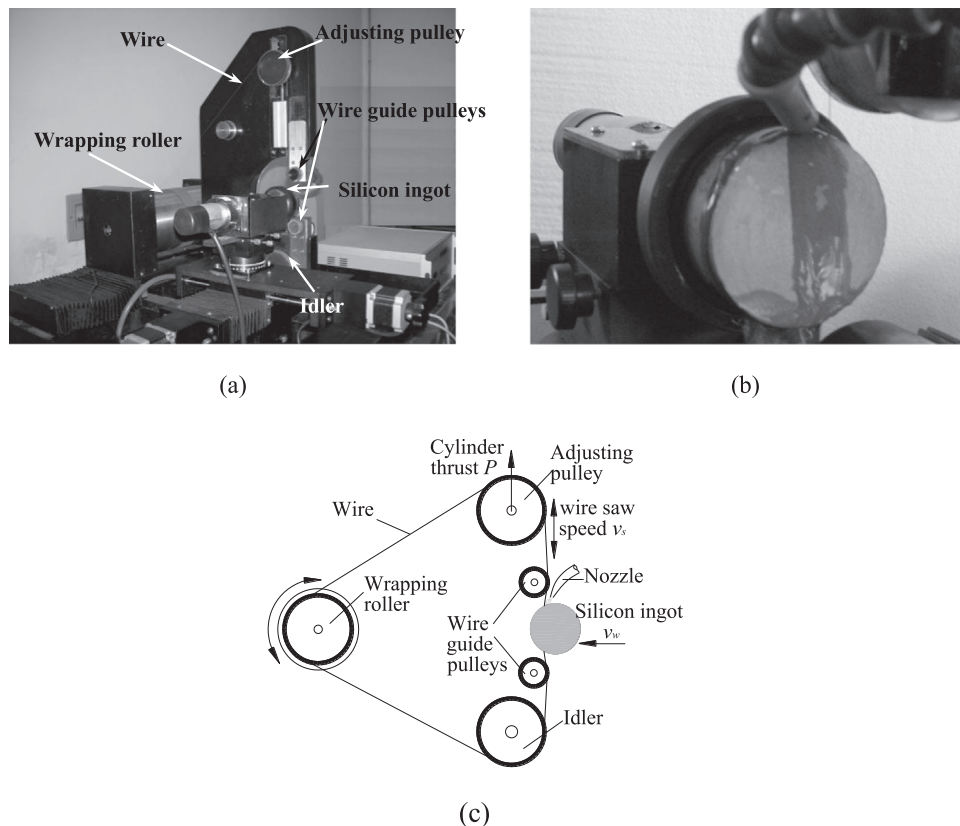


Fig. 2. Reciprocating wire saw apparatus for slicing experiments: (a) appearance, (b) close-up view of cutting part, and (c) schematic.

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