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Experimental study and modeling of the effect of mixed size abrasive grits on surface topology and removal rate in wafer lapping

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ABSTRACT

The semiconductor industry has continued to increase the diameter of wafers in recent years, which poses a challenge in the lapping of prime wafers as the processing time is proportional to the square of the diameter, and the surface quality is a function of the features generated in the lapping process. As a free abrasive machining (FAM) process, where the abrasive grits act as third-body particles, lapping is influenced by abrasive size distributions; however, past studies focus on a single abrasive or size distribution, where the effects of mixed size abrasive distributions on surface feature generation are still unknown. In this study, lapping experiments are conducted on silicon by mixing two SiC abrasive grits, with different mean sizes and at various ratios, under two normal loadings. Lapped surfaces are examined by optical microscopy, where the number and size of critical surface feature types are characterized quantitatively with image processing. The results are correlated with the material removal rate (MRR) by modeling a lapping quality index (LQI) to evaluate different mixed abrasive ratios, where it is shown that lapping performance can be improved by mixing abrasives at high loadings.

1. Introduction

The rapid development of the semiconductor industry presents a need for increasing the diameter of wafers [1,2]. This trend makes it more challenging to achieve good surface quality of wafers with high manufacturing efficiency. In order to control defects, it is important to analyze the microscopic surface topology in manufacturing processes. Bullis [3] reviewed various kinds of silicon defects. Young et al. [4] investigated the surface features of silicon wafers under various parameters in lapping and grinding. Much research has been conducted on the methodology of automatic recognition based on feature characterization. Udupa et al. [5] studied surface topology for unpolished wafers and proposed to use shearography to detect several kinds of features such as swirl shapes and groups of particles. Yuan et al. [6] employed Bayesian inference procedure for parametric pattern recognition. Hwang and Kuo [7] and Yuan and Kuo [8] proposed model-based clustering approaches to simultaneously identify defect clusters and their spatial patterns on the wafer. Chen and Liu [9] used neural networks for spatial defects pattern recognition. As a popular method of characterization, fuzzy clustering algorithms were also studied [10–12]. However, there has lacked research analyzing the results statistically for different settings of manufacturing parameters.

Parameters of the lapping process have been widely studied [13–15], but the impact of abrasive size distributions was rarely involved. Bhagavat et al. [16] first showed that the mixed abrasives result in higher material removal rate (MRR) than the single-sized abrasives. Chung et al. [17] further identified that maximum removal rate is achieved at 1:1 mixing ratio of two different sizes of abrasive grits. However, the papers only presented the impact on average surface roughness, without statistical results of microscopic topology.

In this study, two different sizes of silicon carbide abrasives, F-400 and F-600, were mixed at five different mixing ratios, with the ratio of the abrasives to the carrier fluid (de-ionized water) kept the same, and two different loadings, 2.3 kg and 4.1 kg, were applied separately for each mixing ratio. Still photos of lapped wafer surfaces at each mixing ratio and loading were taken using an optical microscope. Image processing was employed to detect the numbers and sizes of several types of surface features that may result in defects. A model integrating surface topology and removal rate was utilized to evaluate the performance in different settings of mixing ratios and loadings. The result can provide a good reference for the parameter optimization of the free abrasive machining (FAM) process.

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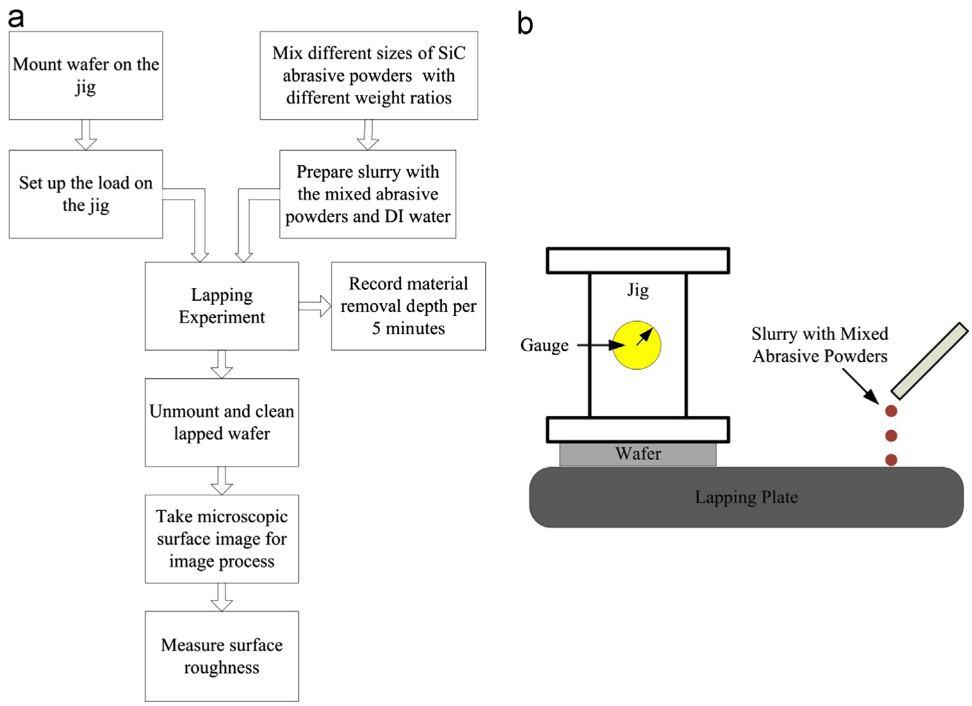

Fig. 1. (a) Flow chart of the experimental procedure and (b) schematic of the lapping process used.

Table 1
FEPA grading chart of F-400 and F-600 SiC powders (μm).

SiC powder	*D3%*	*D50%*	*D94%*
FEPA F-400	32	17.3 ± 1.5	8
FEPA F-600	19	9.3 ± 1	3

2. Experimental setup of lapping and macroscopic results

2.1. Experimental setup

Lapping experiments were carried out on (111) silicon wafers with a diameter of 76 mm and a Logitech PM5 one-sided lapping machine was employed (see Fig. 1). A grooved cast iron plate was used as the lapping plate. The wafers were wax-mounted onto glass plates, which in turn were vacuum-chucked to a Logitech PP6GT lapping jig. The jig also provided a constant normal load on the wafers during lapping. The dial gauge mounted on the jig measured the material removal depth in real time.

Two different grades of silicon carbide abrasives, F-400 and F-600, as shown by Table 1, were used in the experiments. The median sizes of F-400 and F-600 are 17.3 μm and 9.3 μm, respectively. Five different ratios of the weight of F-400 powder, W_{400}, to the total weight of abrasives, W_{total}, were employed: $W_{400}/W_{total}=0$, 0.25, 0.5, 0.75 and 1. The ratio of the total weight of abrasives to the weight of de-ionized carrier fluid, C, was kept at a constant value of 0.154. Two different normal loads, 2.3 kg and 4.1 kg, were applied on the jig. Overall, there were 10 different settings with five mixing ratios and two loads.

The experiment of each setting lasted for 30 min. The angular velocity of the cast iron lapping plate was kept at 70 RPM. The depth of material removal was recorded without interrupting the process every 5 min. After lapping, the wafer was cleaned by de-ionized water, and the wax was melted to remove silicon wafer from the glass plate. The average Root-Mean-Square (RMS) surface roughness after lapping was measured by an XP2 profilometer with a diamond probe at eight randomly selected locations. Fig. 1 shows the flow chart of the experimental procedure and schematic of the lapping process.

2.2. Summary of macroscopic results

The material removal depth, as shown in Fig. 2(a), is nearly linear with respect of time. The average MRR is defined as the total removal depth divided by the operation time of 30 min. The average MRR and RMS surface roughness at different mixing ratios and under different loadings are listed in Table 2. Fig. 2(b) shows that higher MRR comes with the consequence of higher surface roughness under the same loading. $W_{400}/W_{total}=0.5$ with the half–half mixed abrasive slurry has the highest MRR and surface roughness under the same loading, and $W_{400}/W_{total}=0$ with only the small grits has the lowest. The result applies to both 2.3 kg and 4.1 kg loadings [17].

3. Analysis of surface topology

In order to statistically study the microscopic surface topology, we present the methodology for the image capturing of lapped wafer surfaces and the characterization with image processing techniques. Images of lapped surfaces (see Fig. 3) were taken using a digital optical microscope (Keyence VHX-500) with magnification of 500×. Images were taken for each wafer along two perpendicular lines from center to edge of the wafer as shown in Fig. 3(b). Typical images before and after mixed-abrasive lapping are shown in Fig. 3(a) and (c), respectively. There were approximately 175 images taken along each line. Only the first 150 images were analyzed because the images taken near the edge had poorer image quality.

The topology of lapped wafers shows typical surface features such as cracks, indentations, and scratches under the microscope. Based on characteristics of different feature types, the ones that may exacerbate into defects after lapping are identified as target features by image analysis.