Experimental Investigations of Silicon Wafer Grinding

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Abstract. The majority of integrated circuits are built on silicon wafers. To manufacture high-quality silicon wafers, a series of processes are needed. After a wire sawing process slices silicon ingots into wafers, grinding processes can be used to flatten the sliced wafers. This paper reports three experimental investigations on wafer grinding. The first investigation was to study the effectiveness of soft-pad grinding in removing the wire-sawing induced waviness. The second was to explore the capability of grinding in achieving super flatness. The third was to study the effects of grinding parameters on wafer flatness.

Introduction

Semiconductor devices are the foundation of the electronics industry [1,2], and the majority of semiconductors are built on silicon wafers [2]. The feature sizes of integrated circuits will continue to decrease and this will require increasingly flatter wafers [3]. Furthermore, the falling price of silicon wafers has created great pressure on silicon manufacturers to develop more cost-effective processes.

The lapping-based manufacturing method currently used for silicon wafers is shown in Fig. 1 [4]. In spite of its dominant role in today’s manufacturing of silicon wafers, the lapping-based manufacturing method has the following drawbacks [5]: (a) labor intensive; (b) expensive (due to consumable slurry), and (c) time consuming. Besides, the wet etching and long polishing processes involved in the lapping-based method make it difficult to meet the increasingly stringent flatness requirement [6]. Consider all of these, innovative manufacturing methods are necessary to produce flatter wafers at an affordable cost.

A grinding-based manufacturing method, as shown in Fig. 2, was proposed to replace lapping, etching, and the major portion of rough polishing [6]. The advantages of the grinding-based method over the lapping-based method include the following [6,7].

1) Grinding is fully automatic.

2) The grinding process does not involve any wet etching process and has much less polishing.

3) Grinding uses fixed-abrasive wheels instead of loose abrasive slurry; hence the cost of consumables per wafer is lower. Furthermore, fixed-abrasive grinding wheels are more benign to the environment than lapping slurry.

4) Grinding cuts one wafer at a time instead of batch processing. In batch operations, the work in process (WIP) inventory is higher; and once problems occur in production, more defects will be produced before the problems are fixed. Furthermore, a thickness-sorting step is often needed before lapping to ensure that only wafers with small wafer-to-wafer thickness variation are put on the same lapping machine.

5) Grinding has higher throughput than lapping.

Two major challenges associated with the grinding-based method are wafer waviness and grinding marks. A wafer with obvious waviness is shown in Fig. 3. Conventional wafer grinding
using a rigid chuck, as shown in Fig. 4, cannot effectively remove wire-sawing induced waviness [7]. The waviness will negatively affect wafer flatness. So, although grinding has several advantages over lapping process, its success in replacing lapping depends critically on whether the wire-sawing induced waviness can be removed. Another problem is the grinding marks appear on the ground wafers. Fig. 5 shows two examples of wafer surfaces. A typical feature of the grinding mark can be seen clearly on the wafer surface shown in Fig. 5 (b). Both wafers in the figure have gone through fine grinding followed by polishing. Removing grinding marks is one of the purposes of the polishing process after grinding. For wafer A, all grinding marks have been removed by sufficient polishing, while for wafer B, the polishing has not removed enough material from the ground surface. Since polishing is an expensive process, when a smaller polishing removal amount is used the polishing cost will be decreased. In order to achieve substantial cost reduction in wafer manufacturing, polishing should be used to remove the least amount of wafer surface. Since polishing is an expensive process, when a smaller polishing removal amount is used the polishing cost will be decreased. In order to achieve substantial cost reduction in wafer manufacturing, polishing should be used to remove the least amount of waviness induced by wire-sawing.

(a) Wafer A without grinding marks (b) Wafer B with grinding marks

Fig. 5 Two examples of wafer surfaces.
This paper reports three experimental investigations on the grinding-based manufacturing method. The first investigation was to study the effectiveness of soft-pad grinding in removing the wire-sawing induced waviness. The second was to explore the capability of grinding in achieving super flatness at low cost. The third was to study the effects of grinding parameters on wafer flatness.

Experimental conditions and procedures
The grinding experiments were conducted at Strasbaugh Inc. (San Luis Obispo, CA) on a Model 7AF grinder. Fig. 6 illustrates the wafer grinding process. The grinding wheels are diamond cup wheels. The workpiece (wafer) is held on a porous ceramic chuck by means of vacuum. For soft-pad grinding, a perforated soft pad is inserted in between the wafer and the ceramic chuck. The rotation axis for the grinding wheel is offset by a distance of the wheel radius relative to the rotation axis for the wafer. During grinding, the grinding wheel and the wafer rotate about their own rotation axes simultaneously, and the wheel is fed towards the wafer along its axis.

Grinding wheels used were resin-bonded diamond wheels with a diameter of 280 mm. The grit size for the coarse wheel was mesh #320. The grit size for the fine wheel was mesh #2000. Single crystal silicon wafers having a diameter of 200 mm and the (100) planes as major surfaces were used. During grinding, deionized (purified) water was used to cool the grinding wheel and the wafer surface.

Effectiveness of soft-pad grinding in removing the waviness
Soft-pad grinding [8] is a newly patented approach that involves using a ‘soft pad’ or a resilient pad. It was invented to reduce or eliminate the waviness. The process is illustrated in Fig. 7 [7]. When grinding the first side of a wire-sawn wafer, a perforated resilient pad is inserted in between the wafer and the ceramic chuck. The pad holds the wafer in an undeformed condition. As a result, the waviness of the top surface is removed effectively by grinding. This ground surface will be the flat reference plane for grinding the other side of the wafer on a conventional ceramic chuck. In this investigation, a set of experiments have been conducted to study the effectiveness of
soft-pad grinding in removing the waviness.

Six wafers were used in the experiments and all of them were sliced (by wire sawing) at the same time from one ingot hence had similar waviness (wavelength and height). The test wafers were separated into two groups. One group was ground following the “flip once” sequence, and another group of wafers were ground following the “flip twice” sequence. When using the “flip once” sequence, the following steps are followed. First, coarse and fine grind the first side of the wafer on a soft pad. Then, flip the wafer. After that, coarse and fine grind the second side of the wafer on a rigid chuck. For the “flip twice” grinding process, coarse grinding is performed on the first side of the wafer on a soft pad. After flipping the wafer, coarse and fine grinding are performed on the second side of the wafer on a rigid chuck. Then flip the wafer again. The final step is fine grinding the first side of the wafer on a rigid chuck. Two types of soft pads (A and B) were tested, and the major difference between the two pads was the arrangement of the perforated holes.

The experimental results are summarized in Table 1. It can be seen that neither of the wafers ground on soft pads A and B show any waviness, while there is obvious waviness on the wafer ground without a soft pad. Therefore, a conclusion can be drawn that both pads (A and B) were effective in removing wire-sawing waviness.

However, the problem with soft-pad grinding is that the wafers after soft-pad grinding (wafer #2-4 in Table 1) exhibit non-uniform patterns (“clouds” patterns). These “clouds” patterns are the reflection of surface undulations and are probably caused by the non-uniformity of the soft pads. From the experiment result, it looks like that the “clouds” patterns on the wafers (#2 and #4) ground by the “flip twice” sequence are less severe than those on wafers (#1 and #3) ground by the “flip once” sequence. This indicates that changing the sequence of the grinding process might reduce or eliminate the “clouds” patterns induced by soft-pad grinding. However, this observation is not conclusive and further investigation is needed.

**Wafer flatness after grinding**

Wafer flatness is critical to electronics industry. It will directly impacts device line-width capability, process latitude, yield, and throughput [9,10]. The flatness requirements in recent years are shown in

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<tr>
<th>Table 1</th>
<th>Experimental results.</th>
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<tr>
<td></td>
<td>Flip once</td>
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<tr>
<td>Soft pad A</td>
<td><img src="image1" alt="Image" /></td>
</tr>
<tr>
<td>Wafer #1</td>
<td><img src="image3" alt="Image" /></td>
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<tr>
<td>Soft pad B</td>
<td><img src="image5" alt="Image" /></td>
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<tr>
<td>Wafer #3</td>
<td><img src="image7" alt="Image" /></td>
</tr>
<tr>
<td>No soft pad</td>
<td><img src="image9" alt="Image" /></td>
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<tr>
<td>Wafer #5</td>
<td><img src="image11" alt="Image" /></td>
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</tbody>
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<tr>
<th>Table 2</th>
<th>Flatness requirements for silicon wafers. (year 2004 to 2006)</th>
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<tr>
<td>Flatness Parameter</td>
<td>2004</td>
</tr>
<tr>
<td>Global flatness (GBIR) for 300 mm wafers</td>
<td>&lt; 1 μm</td>
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<tr>
<td>(also known as total thickness variation TTV)</td>
<td></td>
</tr>
<tr>
<td>Site Flatness (SFQR) (26 mm x 33 mm)</td>
<td>&lt; 90 nm</td>
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Table 2 [11]. Site flatness is the sum of the maximum positive and negative deviations of the surface in a certain area of the wafer from a theoretical (least squares best fit) reference plane. The area used in this experiment is 26 mm × 33 mm. Wafers that do not meet the specifications are often rejected, causing high yield loss. In order for the grinding-based manufacturing method to succeed, it has to be able to produce flat wafers.

![Fig. 8 Global flatness data for ground wafers.](image)

![Fig. 9 Thickness map of a ground wafer.](image)

![Fig. 10 Site-flatness map for a ground wafer.](image)

This investigation used 14 slices of single crystal silicon wafers. Fig. 8 shows the experimental data for global flatness. It can be seen that the global flatness is less than 0.5 μm for all the ground wafers except one wafer. Fig. 9 shows a thickness map for a ground wafer and Fig. 10 shows its site flatness. The results show that the site flatness on the ground wafers is less than 90 nm for all the sites except a few sites at the wafer center. These results indicate that the grinding-based method can achieve much better flatness than the lapping-based method and has the potential to manufacture very flat silicon wafers.

Some of the ground wafers were polished with a removal amount of 7 μm, and no grinding marks are visible on any of these wafers. Fig. 11 shows the result on grinding marks on one of these wafers.

This investigation has also demonstrated the necessity of future research on two fundamental issues. First of all, full potential of the grinding-based method will not be utilized if the required polishing removal amount is more than 5μm. Therefore, further polishing test with different removal amounts (1, 3, and 5μm) will be conducted to find out what is the minimum polishing removal amount required to eliminate the grinding marks. Another challenge is how to improve the flatness at the wafer center.

**Effects of grinding parameters on wafer flatness**

The intention of the third experiment was to study the effects of process variables in fine grinding. In this investigation, the course grinding variables were kept constant for all the grinding tests in this study. For fine grinding, a $3^2$ (two variables, three levels) full factorial design was employed to systematically change the feedrate and chuck speed. Under each grinding condition, five or more wafers were ground. Two wafers from each grinding condition were randomly chosen for double-side polishing.

The peak-to-valley (PV) value for a wafer is the

![Fig. 12 Effects of feedrate and chuck speed on the PV value over the entire wafer surface.](image)
height difference of the highest point and the lowest point on the entire wafer surface. It can be seen from Fig. 12 that no consistent trends can be observed on changes in the PV values as federate or chuck speed changes. For example, as the federate increases, the PV values on the wafers with the chuck speed of 0.28 rev s\(^{-1}\) increase. But the PV values on the wafers with other chuck speeds do not have the same trend. The above observation indicates that the feedrate and chuck speed in fine grinding are not the determining factors for the PV values over the entire wafer surfaces.

Summary

Three experimental investigations have been reported in this paper. The following conclusions can be drawn.

1) Soft-pad grinding can effectively remove wire-sawing waviness. (But it will induce “clouds” patterns which will negatively affect the wafer flatness.)

2) The grinding-based method can generate very flat wafers (except at the wafer center).

3) Federate and chuck speed do not have determining effects on the PV values over the entire wafer surfaces.

Acknowledgments

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References


