ANALYSIS ON GEOMETRY AND SURFACE OF 150 µm SILICON WAFER AFTER BACKGRINDING AND WET ETCHING PROCESS

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ABSTRACT

This paper examines the warpage on the backside of silicon wafer after thinning process. The thinning process includes after backgrinding (BG) and after wet etching (WE). The results on wafer warpage were linked to transmission electron microscopy analysis. This is purposely to explain the correlation between warpage and depth of damage. Results showed that deep backside damage would induce high wafer warpage, hence reduced wafer strength and create difficulty during handling. Further study on surface roughness and topography of each surface finish is obtained by atomic force microscopy and scanning electron microscopy techniques. They indicated that low surface roughness is determined by the smooth surface condition, which goes to after wet etching process.

INTRODUCTION

Semiconductor industries are driving towards miniaturization, multifunctional and high density packages, especially for portable electronic devices. The thrust to achieve those goals is wafer thinning technology, which the main subject of this paper. In this paper, the key technology enabler of wafer thinning is the mechanical backgrinding process. The main purpose of the mechanical backgrinding is the thinning of wafer to the required thickness. In addition, the bulk silicon removal technique is identified the most cost effective process method. The process is extremely applied in assembly industries due to the strength of low cost and mature

Despite of the positive outlook, there is a negative aspect of mechanical grinding. That aspect is the derivation of warp when the wafer is thinned down. Warp can be influenced by the different stress exerted by the different film deposited onto the wafer. However, the main focus of this study is the effect of the mechanical grinding on bare silicon wafers. Applying mechanical stress and heat during the backgrinding process will induce damage in the wafer backsurface that can lead to crack.

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propagation, growth and fracture [2]. It has been experimentally shown that the amount of silicon damage relates to wafer warp [3,4]. This warpage is not desirable for thin wafer handling, and therefore, it is important to further understand and control the surface damage from the grinding process. The damage of the wafer, due to mechanical grinding, follows the Hadamovsky model [5]. This model consists a surface polysilicon zone, a crack zone, a transition zone and a crystal dislocation stress zone.

![Hadamovsky model of subsurface damage](image)

Figure 1: The hadamovsky model of subsurface damage.

The interest of this study is to understand the severity of the microcrack in the crack zone when a standard grinding recipe is applied. Grind only processes can be optimized for lowering warp and surface damage however a silicon wet etch process is often necessary to completely remove the damaged layer. Most conventional backgrinding systems use the two-step process. The rough grinding process and the fine grinding [6-8]. The rough grinding is significant for bulk material (silicon) removal and there is high stock removal rate of bulk material which is about 90% of removal thickness. An abrasive grinding wheel (typically 320-500 grit) was used to rapidly remove material but it is also to greatly damage the backside surface of the silicon layer [7,8]. The second process is followed by the fine grinding process. It is used to accurately grind the wafer to the required thickness, removes most of the damage left by the rough grinding [9] and reduces it surface roughness using the abrasive diamond (typically 1200-3000 grit). In order to completely remove the damage layer, there is a need for stress relief process by applying chemical wet etch.
etching on the ground wafer. Wet etching used an acidic compound containing etchants such as hydrofluoric acid (HF), nitric acid (HNO₃), sulphuric acid (H₂SO₄) and phosphoric acid (H₃PO₄) [2,6]. Each acid in the acidic compound has its own function, such as:

a. Hydrofluoric acid, HF 50%: etch SiO₂.
b. Sulphuric acid, H₂SO₄ 96%: to react with H₂O to prevent diluted chemical mixture.
c. Nitric acid, HNO₃ 65%: oxidation to create SiO₂.
d. Phosphoric acid, H₃PO₄ 85%: for pH control (supplying H⁺ to the chemical mixture).

This paper describes efforts to characterize both the geometry (deformation) and surface finish of 150 µm substrates as a function of the wafer thinning process. Transmission Electron Microscopy, Scanning Electron Microscopy and Atomic Focus Microscopy characterization show the surface morphology and damage depth differences between the conventional backgrinding and the chemical wet etching process.

MATERIALS & METHODOLOGY

Bare silicon wafers of 8 inches diameter, 725 µm thickness and <100> orientation were used in this study. For the mechanical backgrinding, of the rough grinding step, the abrasive diamond wheels with grit size mesh #320 were used, while the wheels with mesh #1500 grit size were employed in the fine grinding step. After the backgrinding process, some wafers undergo the surface recovery by chemical wet etching at a standard removal rate. The end thickness of wafers from backgrinding process only was 185 µm while for wafers undergoing stress relief process was 150 µm. The grinding conditions are listed in Table 1 and chemical wet etch conditions are tabulated in Table 2.

Table 1: Grinding parameter used in the current study (machine model DISCO DFG8540).

<table>
<thead>
<tr>
<th>Grinding Parameter</th>
<th>Coarse grinding</th>
<th>Fine grinding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grit size</td>
<td>#320</td>
<td>#1500</td>
</tr>
<tr>
<td>Chuck speed (rpm)</td>
<td>80</td>
<td>50</td>
</tr>
<tr>
<td>Spindle speed (rpm)</td>
<td>5000</td>
<td>6000</td>
</tr>
<tr>
<td>Feed-rate (µm/s)</td>
<td>3.00</td>
<td>0.30</td>
</tr>
</tbody>
</table>

The experimental work to measure wafer warpage of both processes was conducted using metrology tool, MX 204-8-21-VR automatic wafer geometry gauge. Wafer thickness was checked and total warp was measured automatically. A simple concept for the understanding of warpage measurement is described in Figure 2.

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Table 2: Stress relief process (WE) parameter (machine model SEZ 203 spin processor).

<table>
<thead>
<tr>
<th>Process parameter</th>
<th>Chemical wet etch</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemicals</td>
<td>HF + H₂SO₄ + HNO₃ + H₃PO₄</td>
</tr>
<tr>
<td>Etch rate (µm/s)</td>
<td>0.69</td>
</tr>
<tr>
<td>Method</td>
<td>Spin etch</td>
</tr>
</tbody>
</table>

Figure 2: Manual warpage measurement of Si wafer; distance from bottom flat surface to the edge (maximum point) of the wafer.

Damage depth characterizations for samples of both processes were done using FEI Tecnai F20 transmission electron microscopy. Backside of each sample was deposited with 200 nm titanium (Ti) as a protective layer to check the thickness of the damage depth. The captured images were saved and the length of damage depth was measured using Digital Image Processing System 2.6 (DIPS 2.6) software. The surface roughness measurements were performed using Atomic Focus Microscopy nanoscope, multimode in scanning probe microscope (SPM)-IIIa controller. Average surface roughness (Ra) was collected over the entire measured array and it was usually used as surface finish roughness parameter. For each sample, the results of surface finish are presented in the 3D view and roughness analysis showing surface topography of each sample.

**RESULTS AND DISCUSSIONS**

*Effect of wafer back processing towards wafer warpage*

Wafer warpage is highly influenced by the type of back processing implemented during thinning process. Results the both processes are shown in Table 3. For after
the BG process, the warpage value is higher than after the WE process. This is driven by the mechanical stress induced by the BG process onto the backside of wafer, which utilizing abrasive particles to take out most of the wafer thickness. The BG process leaves severe backside damage in a form of micro-cracks. These micro-cracks contribute to high warpage. On the other hand, the WE process is implemented to remove the microcracks left by the BG process. This led to low wafer warpage after the WE process, hence, to increase the mechanical strength of the wafer.

Table 3: Warpage measurement of thinning process.

<table>
<thead>
<tr>
<th>Process</th>
<th>Warpage (µm)</th>
<th></th>
<th></th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional BG</td>
<td>222.5</td>
<td>220.7</td>
<td>219.4</td>
<td>220.9</td>
</tr>
<tr>
<td>Chemical wet etch</td>
<td>18.0</td>
<td>16.8</td>
<td>20.1</td>
<td>18.3</td>
</tr>
</tbody>
</table>

Correlation of wafer warpage with backside damage depth

The warp of silicon wafer can be increased by the depth of the microcrack. A cracked location, in its physical form, is already increased in the lateral length as compared to the undamaged surface on the other face of the wafer. This delta in length induced stress on the wafer backside and in order to compensate for the stress, the wafer is warped so that a balance state can be reached. As a result, the deeper the backside damage is, the higher the wafer need to warp to reach the equilibrium state. Figure 3 shows the result of depth of damage for both processes using transmission electron microscopy. BG process left deeper backside damage with visible micro-crack of 0.23 µm as shown in Figure 3(a) if compared to after WE process with no visible micro-crack can be seen, see Figure 3(b). From these findings, it is suggested that high warpage influenced by deep backside damage.

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Figure 3: TEM images of wafer backside micro crack: (a) Damage depth after BG process, (b) Damage depth after WE process.

**Effect of wafer back processing towards surface roughness (R\text{a})**

Surface roughness of wafer backside is also determined by the thinning method used. Fig. 4(c) and 5(c) show the surface roughness (R\text{a}) of wafer backside after the BG and WE processes. The result indicates there is a rise in surface roughness after the BG process with R\text{a} value 0.18 nm. In contrast, the WE process provides low surface roughness, R\text{a} of 0.12 nm due to smooth surface finish produced on the wafer backside. This is caused by the backside surface defects have been recovered by the stress relief removal process.
Figure 4: After BG process: (a) SEM micrograph, (b) AFM topographic image, (c) AFM roughness analysis.

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Figure 5: After WE process: (a) SEM micrograph; (b) AFM topographic image; (c) AFM roughness analysis.

Effect of wafer back processing towards surface topography

Figure 4 and 5 show different surface finish after both thinning processes by SEM micrograph and AFM. Figure 4 (a) indicates traces of fine grinding marks across the whole wafer surface. These grinding marks are results of abrasive grinding wheel that rotates while in contact with the wafer backside. Therefore, the grind marks are seemed as long, parallel lines and can clearly be seen with naked eyes. For the chemically etched wafer as shown in Figure 5, smooth surface condition is observed at the silicon back surface. According to this, it can be described that the
microcracks left by the BG process have been removed but still leaves minor damage. No small or large pits can be seen on the wafer backside showing that the WE process is properly done, hence yield in quality wafer backside condition.

CONCLUSION

In this research, it was found that there is a direct relationship between wafer warpage and backside damage depth. Higher damage depth contributes to higher wafer warpage. Further study on surface finish of wafer backside gave a clear view that smooth backside finish led to low surface roughness after backside processing. From the chemical wet etch analysis, suggested that the surface needed further treat in order to remove the damage layer left by mechanical backgrinding. The process is crucial to produce quality wafer in terms of their structure and mechanical integrity.

ACKNOWLEDGEMENT

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