A newly developed polishing pad for achieving high surface flatness without edge roll off

T. Enomoto, U. Satake, T. Miyake, N. Tabata

1. Introduction

Design specifications of semiconductor devices are constantly being miniaturized; that is, the line width and spacing of the devices continues to shrink for increasing the integration density of the devices. Hence, this requires highly flat surfaces of silicon wafers as the starting materials of the devices [1,2]. Furthermore, wafer sizes have been increasing so that more devices can be produced from a single wafer [1,2], thus resulting in considerable increase in productivity and economic efficiency. In addition, with increasing wafer diameter, the number of device chips located at the wafer periphery increases dramatically.

However, surface flatness significantly deteriorates near the wafer edge because of edge roll off during polishing as the final stage of the wafer manufacturing process [1,3]. Thus, an edge exclusion region exists on the wafer surface where device chips cannot be placed. Reducing the edge exclusion region from the current size of 2–3 mm from the edge of the workpiece [2] to less than 1 mm is becoming necessary to enhance the yield from each chip.

The same demand for decreasing edge roll off has rapidly increased for polishing glass disks as the substrates of magnetic media disks. To increase the data storage density and capacity while decreasing the disk size, the flat region of the disk surface must be expanded to the immediate vicinity of the disk edge.

Many theoretical and experimental studies of edge roll off generation have been conducted [3–9], and polishing methods for suppressing edge roll off (e.g., the use of harder polishing pads and the application of a retaining ring) have been proposed [10]. These methods, however, have serious problems relating to low polishing efficiency, generation of defects, and difficulty in achieving the appropriate processing conditions [11].

In this study, we used finite element methods (FEM) to investigate polishing pad specifications required for decreasing edge roll off, i.e., uniform contact stress distribution near the workpiece edge. On the basis of the computational results, we developed double-layered polishing pads having an extra-fine fiber thin layer and a hard polymer layer. Polishing experiments on silicon wafers and glass plates showed that the developed polishing pads achieved high finishing efficiency and improved surface flatness near the edge.
Our solution to this difficulty was to develop a double-layered polishing pad. The upper layer was set to 0.2 mm, and the thickness, Young's modulus, and Poisson's ratio of the lower layer were 1.2 mm, 2.29 MPa and 0.35, respectively. As shown in Fig. 5, it was found that the larger Poisson's ratio of the upper layer \( (v_u) \) resulted in smaller stress concentration near the edge. Smaller values of the Young's modulus of the upper layer \( (E_u) \) decreased the stress concentration near the edge, contrary to the case of a single-layer pad. This is possibly because the properties of not only the upper layer but also the lower layer influence pad deformation in the double-layered pad. Thereby, smaller Young's modulus of the upper layer causes less force for the deformation of the pad at the workpiece edge.

### 3. Newly developed double-layered polishing pads

On the basis of the above FEM results, we have developed new double-layered polishing pads composed of a soft thin layer of extra-fine fiber as the upper layer (thickness 0.2 mm), and a hard polymer layer as the lower layer (thickness 1.2 mm). The use of extra-fine fiber is expected to improve finishing efficiency, because the fiber is very effective at holding abrasives owing to the large contact-specific surface area.

Table 2 shows the rubber hardnesses of the developed pad and two types of reference commercial polishing pads. Commercial pads A (Nitta Haas Inc., SUBA800) and B (Kokonoe Electric Co. Ltd.,
KSP66B) are a nonwoven pad used for silicon wafer polishing and a urethane foam pad containing ceria used for glass polishing, respectively. Two types of rubber hardnesses of the pads, namely, Asker C and Micro A were measured using a durometer (Kobunshi Keiki Co., Ltd., P1-C) and a microdurometer (Kobunshi Keiki Co., Ltd., MD-1), respectively.

As shown in Table 2, the hardnesses of the pads are almost identical according to the Asker C values. On the other hand, the hardness of the surface of the developed pad was lower than those of the commercial pads according to the Micro A values, because of the pad’s soft thin upper layer.

3.1. Viscoelastic properties of the developed polishing pads

In the preceding section, FEM analyses were conducted by considering only elastic properties of polishing model elements. However, it is well known that viscoelastic properties of polishing pads have a strong influence on the edge roll off. In particular, high elasticity and low viscosity result in small edge roll off [1,14]. Thus, we investigated the viscoelastic properties of the developed pad as compared to commercial pads.

We modeled the dynamic behavior of polishing pads based on a three-element viscoelastic model combining the Voigt component and the spring element in series (right side of Table 3) to obtain the viscoelastic properties. A noncontact viscoelastic measurement system was also developed to determine the viscoelastic parameters of each element, as shown in Fig. 6. The measurement system employed compressed air to apply a prescribed pressure on the indenter on the pad and a noncontact displacement sensor to measure the displacement of the indenter. The noncontact measurement system had more accurate pressure, resulting in more accurate estimation of the viscoelastic parameters, as compared to direct contact measurement systems such as indentation testers that have been widely used [14].

Table 3 shows the identified viscoelastic parameters of the three-element model from the time responses of the displacement to the step input of the applied pressure. The spring constants of the developed pad were larger than or equal to those of commercial pad A, and the viscous damping constant of the developed pad was smaller than that of the commercial pad A. This strongly suggested that using the developed pad, surface flatness at the edge can be improved.

Table 2
Rubber hardness of polishing pads.

<table>
<thead>
<tr>
<th>Types of hardness</th>
<th>Developed pad</th>
<th>Commercial pad A</th>
<th>Commercial pad B</th>
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<tbody>
<tr>
<td>Asker C</td>
<td>93</td>
<td>92</td>
<td>94</td>
</tr>
<tr>
<td>Micro A</td>
<td>70</td>
<td>82</td>
<td>90</td>
</tr>
</tbody>
</table>

Asker C: hemispherical indenter diameter 5.08 mm, max. load 8.4 N.
Micro A: cylindrical indenter diameter 0.16 mm, max. load 0.3 N.

3.2. Polishing characteristics of silicon wafers

Polishing experiments were conducted on silicon wafers using a single-sided polishing machine (Lapmaster Corp., LP-15F), as illustrated in Fig. 1. Table 4 lists the polishing conditions. Before the experiments, the surface of the reference commercial polishing pad A (nonwoven pad) was conditioned with a #170 diamond disk, whereas the developed polishing pads were used without pad surface conditioning. The obtained edge roll off was quantitatively evaluated by the roll-off amount (ROA), which is defined as the vertical displacement from the level line to the measured wafer profile at a position 1 mm from the wafer edge [15]. The level line was at 3–6 mm from the edge.

Fig. 7 confirms that surface flatness at the wafer edge was significantly improved using the developed polishing pad. The slight depression in the surface near the edge in the usage of the commercial pad A can be observed, whereas the developed pad shows a smooth surface near the edge.

Table 3
Spring constants and viscous damping constants for the three-element models of polishing pads.

<table>
<thead>
<tr>
<th></th>
<th>$k_s$ (N/mm)</th>
<th>$k_f$ (N/mm)</th>
<th>$c$ (N s/mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Developed pad</td>
<td>30</td>
<td>82</td>
<td>1.4</td>
</tr>
<tr>
<td>Commercial pad A</td>
<td>19</td>
<td>83</td>
<td>2.0</td>
</tr>
</tbody>
</table>

Fig. 8. AFM images of finished wafer surfaces.
developed pad is thought to be brought by the effect of viscoelastic properties of the pad. As for the surface roughness, the surface quality was as good as that obtained by polishing with the commercial pad, as shown in Fig. 8. Fig. 9 indicates that high finishing efficiency, which was improved by 1.1–1.3 times, was achieved with stability. This was possibly because the upper layer material of extra-fine fiber had high abrasive holding ability.

3.3. Polishing characteristics of glass plates

Polishing experiments were performed on glass plates using the conditions listed in Table 4. Before the experiments, the surface of the reference commercial polishing pad B (urethane foam pad) was conditioned with a #60 diamond disk.

Figs. 10 and 11 confirm that the glass polishing characteristics of the developed pad were also excellent, again exhibiting a significant decrease in edge roll off and increase in finishing efficiency by a factor of 2.

4. Conclusion

To reduce the edge roll off of a workpiece, double-layered polishing pads with an upper thin soft layer of extra-fine fiber and a lower hard layer were developed on the basis of an FEM analysis. Experimental results showed that the developed polishing pads significantly improved surface flatness at the workpiece edge and finishing efficiency in both silicon wafer and glass plate polishing.

References