Development of Pin-type Vacuum Chuck for High-Precision Machining

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1. Introduction

The wafer machining that enables sophisticated higher-performance electrical and optical devices needs to be improved to handle larger and more complex wafers[1), 2)]. An important aspect of advanced machining is the chucking method. The vacuum chuck provides easy operation, high precision, and high reproducibility. However, dust such as abrasives decreases machining precision by intruding between the wafer workpiece and chuck plane. We have developed a pin-type vacuum chuck to solve this problem[3)]. In this presentation, we study the influence of pin-suspension for a wafer theoretically and experimentally in order to determine the optimum chuck design.

2. Pin-type vacuum chuck

The chucking plane that supports a wafer is made up of an array of many tiny pins that are 0.22 mm in diameter and 0.25 mm high. The chucking plane, which is made of alumina, is finished to a flatness of less than 0.2 μm. A very small contact-area ratio of 0.4% reduces the probability of dust existing between the wafer and the pin-heads. Even if there is some dust, it can be removed from the pin-heads by slightly sifting the wafer. This small ratio also enhances the clamping power available for flattening. In addition, the chuck includes a slurry invasion prevention mechanism.

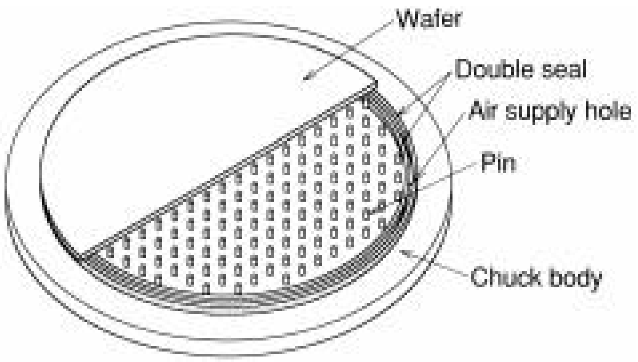


Fig.1 Schematic diagram of pin chuck.

However, if the wafer has low rigidity, for example because it is thin or the pins are too far apart, the wafer will deform between the pins. Such deformation leaves dimples on the _wafer after machining. Thus, we have studied wafer deformation between the pins and how it affected the flatness of the machined wafer. We calculated the Si wafers deformation using the finite element method and experimentally measured the deformation with a Fizeau-interferometer. We found that deformation of more than 0.02 μm occurred for wafers thinner than 100, 300 and 1100 μm when the pin pitches were 1, 2, and 5 mm, respectively, under a 1 a.t.m. clamping vacuum pressure. Our experimental results agreed with our calculated results.

3. Influence of pin suspension in wafer polishing

Next, we studied this dimpling in practical Si-wafer polishing. We used wafers having low rigidity because of their thinness and from being clamped with a wide-span pin-chuck. All wafers were finished to a thickness of 300 μm using a 5-mm-pitch pin chuck. The relative work speed was 45 m/min. Colloidal-silica-abrasive polishing was done with polishers having a rubber hardness of 61, 82, or 95 (ASKER-C). The 82- and 95-hardness polishers were cross-grooved with 2-mm-wide grooves and 15-mm spacing. We believe the dimpling-formation process was as follows. When we use an extreme soft polisher on a deformed wafer surface, the removal rate was the same throughout the plane and almost uniform machining pressure was applied. On the other hand, when polishers had certain hardness, convex regions of the wafer were polished faster, apparently because of a high polishing pressure. This caused dimpling. The dimples became larger ad polishing continued and the polishing rate difference became smaller. Eventually, the wafer surface being polished became flat, and then the polishing pressure on the wafer surface became uniform. However, the opposite surface of the wafer was deformed by the vacuum and polishing pressure. After polishing, when the wafer was removed form the chuck, this deformation caused dimpling of the polished surface. The dimpling depth was determined by the deformation that resulted from these two pressures. In other words, the dimpling depth changed with polishing pressure at a uniform vacuum chuck pressure.

Figure 2 shows the typical cross-sectional shape of dimpling on the polished surface of a Si wafer. The profile valleys corresponded to the pin positions. It revealed that the profile represents reversed suspended lines between two pins. Similar profiles were obtained from other parts of the polished wafer.

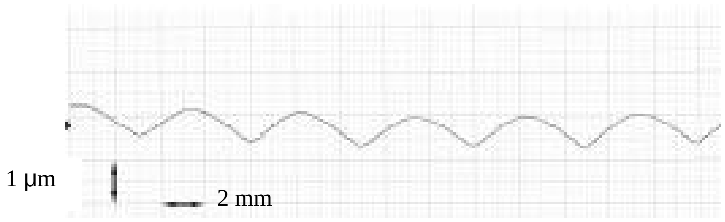
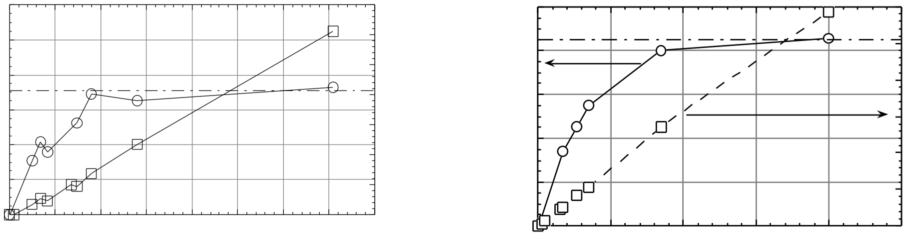


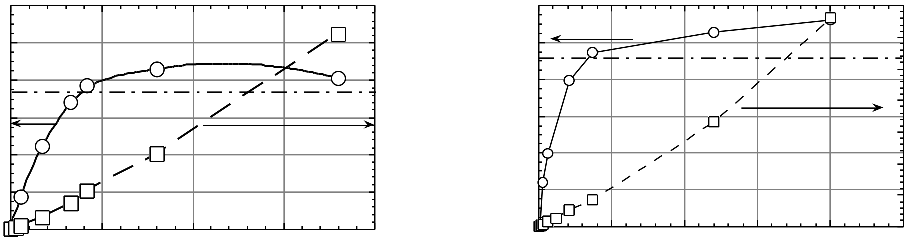
Fig. 2. Typical dimpling shape

Figure 3 shows the dimpling depth and stock removal as a function of polishing time for polisher hardness of 61, 82, and 95, and polishing pressure of 9.8 and 29.8 kPa. The calculated deformation is indicated by the dashed lines in Fig. 3. We took the grooves on the polisher into consideration when calculating the nominal contact area. We defined the force divided by this area the nominal pressure. The dimpling depths initially increased with polishing time, then saturated. This saturation occurred earlier for harder polishers and higher polishing pressures. The faster saturation seems to have been due to a larger removal-rate difference with unflat-



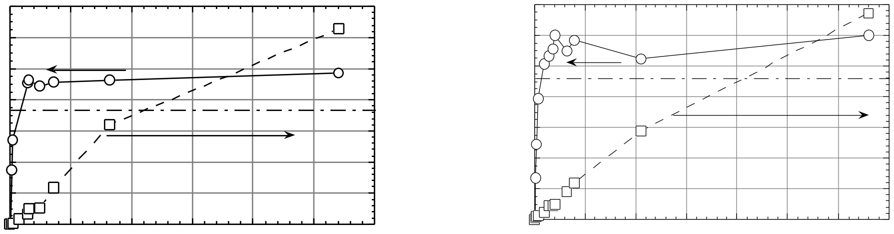
(a) Polishing pressure; 9.8 kPa (b) Polishing pressure; 29.4 kPa

(1) With 61-rubber hardness polisher



(a) Polishing pressure; 9.8 kPa (b) Polishing pressure; 29.4 kPa

(2) With 82-rubber hardness polisher



(a) Polishing pressure; 9.8 kPa (b) Polishing pressure; 29.4 kPa

(3) With 95-rubber hardness polisher

Fig. 3. Dimpling amount and stock removal as a function of polishing time

ness of the wafer surface under these conditions. We also found that the saturated values were higher than the calculated deformation when the polisher hardness was 82 or 95. It will be caused by the inhomogeneity of polisher surface. The polisher surface inhomogeneity such as the surface roughness and the grooves causes force distribution among pin spans. It is considered that the largest force of this distribution, which is larger than the force calculated by the nominal polishing pressure, decides the dimpling depth. Figure 4 shows the relationship between the dimpling depth and the nominal polishing pressure. The dimpling for all polishers increased at almost the same rate as the calculated value. This means the dimpling increased with an increase in wafer deformation caused by higher machining pressure. In our experiments, the dimpling depth was less than twice the calculated value, so we believe the dimpling depth with a 1-mm-pitch pin-chuck can be suppressed to less than 0.02 μm for Si wafers more than 200 μm thick.

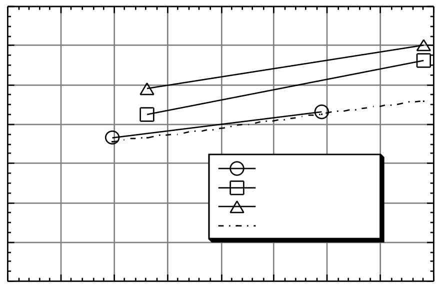


Fig. 4. Relationship between dimpling depth and nominal polishing pressure._____

4. Conclusion

We investigated the pin influence for practical wafer polishing in order to optimize the structure of the pin-type vacuum chuck that we developed for precision wafer machining. As a result, the dimpling depths caused by pins were less than One and half of the calculated values. Thus the dimpling depth with a 1-mm-pitch pin-chuck can be suppressed to less than 0.02 μm for Si wafers more than 200 μm thick for less than 50 kPa polishing pressure. The difference between experimentally results and calculated values were believed to be due to the inhomogeneity of polisher surface.

Reference:

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