Development of vertical-spindle rotary surface grinding machine for large-scale silicon-wafers

–static stiffness of grinding spindle and worktable–

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Abstract
The development of the next generation, large-scale silicon-wafer surface grinding machine for the semiconductor industry is necessary. High loop stiffness is indispensable for putting the grinding machines into practical use for large-scale silicon wafers. The authors developed a vertical spindle rotary surface grinding machine, as shown in Fig.1, and investigated its performance. Hydrostatic water bearings are used for the worktable and wheel spindle to enhance loop stiffness. Furthermore, the number of machine components and its guide-ways have been minimized as much as possible to eliminate losing loop stiffness. A grinding head is not used, so the wheel spindle shaft creates both rotary and axial infeed motion. In addition, the worktable and the wheel spindle components are rigidly connected using kinematic couplings. This results in the measured loop stiffness of the developed grinding machine being 163N/m.

1. Introduction
The international technology road map for semiconductors¹) indicates that surface grinding machines for 450mm diameter silicon wafers are to be commercialized before 2016. Therefore the development of the next generation, large-scale, silicon wafer surface grinding machine for the semiconductor industry is necessary. The grinding force of 450mm wafers under an
infeed rate of 100-200 m/min during rough grinding is estimated at up to 300N. The total thickness variation of the ground wafer must be smaller than a micrometer. To satisfy the requirement, loop stiffness of the grinding machine must be higher than 100N/μm.

The authors designed a vertical-spindle surface grinding machine equipped with a rotary worktable that is sustained by water hydrostatic bearings and a wheel spindle shaft which creates both rotary and axial feed motion. Both the worktable and wheel spindle components are rigidly connected using kinematic couplings. This paper investigates the design and loop stiffness of the developed grinding machine for large-scale silicon wafers.

2. Rotary worktable sustained by hydrostatic water bearing

Figure 2 shows a schematic of the rotary worktable that is axially sustained by single-recess type constant flow hydrostatic water bearings. The bearing pad is optimally designed to realize the necessary sustaining force and static stiffness of the worktable. Water is supplied to each bearing with a constant flow rate \( Q = 60 \text{ mL/min} \) by using a micro gear pump. Neodymium magnets \( F = 7,750 \text{ N} \) are installed in the table base to attract the worktable in an axial direction and thus reinforce the bearing stiffness.

The radial bearing is comprised by a constant-pressure hydrostatic water bearing. These bearing systems are eco-

### Table 1 Specifications of rotary worktable

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter of worktable</td>
<td>500mm</td>
</tr>
<tr>
<td>Rotational speed</td>
<td>0 - 500 rpm</td>
</tr>
<tr>
<td>Water flow rate for each bearing, ( Q )</td>
<td>0 - 60 mL/min</td>
</tr>
<tr>
<td>Attraction force of neodymium magnets, ( F )</td>
<td>7,750 N</td>
</tr>
<tr>
<td>Mass of worktable rotational parts</td>
<td>300 kg</td>
</tr>
<tr>
<td>Gap of axial bearing</td>
<td>0 - 0.01 mm</td>
</tr>
</tbody>
</table>

Fig. 3 Effect of \( Q \) on \( K \)

![Fig.2 Schematic of rotary worktable](image-url)
friendly, since the working substance of the bearings is water and they have low energy consumption.

**Figure 3** shows the measured static stiffness, $K_1$, of the worktable under variable water flow rates, $Q$. $K_1$ is effected under $Q$; the measured $K_1$=1,960N/°m and measured sustaining force was 2,970N while $Q=30$mL/min.

In the case of wafer grinding, the grinding point is not at the table’s center, eccentric forces act both on the worktable and the grinding wheel. Therefore, the table incline angle under table eccentric load is measured, resulting in 55N·m/° as shown in **Fig.4**. As the result, measured static stiffness of the table grinding point was 909N/°m.

### 3. Wheel spindle where spindle shaft creates both rotary and infeed motion

**Figure 5** shows a schematic of the wheel spindle. The spindle shaft creates both rotary motion and axial feeding motion. Rotary motion is generated by a built-in motor; axial motion is generated by a linear actuator. The axial spindle position is fed back to the linear actuator by using a capacitance-type gap sensor. The axial spindle position can then be precisely controlled even when a variety of axial forces are loaded during the grinding operation. The wheel spindle, on the other hand, is radially sustained by constant pressure water hydrostatic bearings.

**Fig. 6** shows measured static stiffness of
the wheel spindle. Static stiffness of the spindle was 1,036N/m.
The rotary table and the wheel spindle are rigidly mounted using 3 kinematic
couplings whose total static stiffness is 7,100N/mm. Static stiffness of the other
components of the machine is estimated to be 10 times higher than the rotary table or
spindle. As a result, the measured loop stiffness of the developed machine was
163N/m.

4. Conclusions
The next generation vertical-spindle rotary surface grinding machine for large scale
silicon-wafers was developed and its static stiffness investigated. The following
conclusions were obtained:
1. Static stiffness of the worktable, wheel spindle, and kinematic couplings
were 1,960N/m, 1,036N/m and 7,100N/m, respectively. The static stiffness of
the table grinding point was 909N/m.
2. Measured loop stiffness of the machine was 163N/m, which is high
enough to grind 450mm wafers.

References:
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