Development of a Vertical-spindle Rotary Surface Grinding Machine for Large Scale Silicon-wafers – Machine Specifications and Performance of Rotary Work Table

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Abstract

The development of a next generation surface-grinding machine for 450mm diameter silicon-wafers is required from the semiconductor industry. Loop stiffness of the grinding machine has to be high enough to sustain high grinding force because of the large contact area between the grinding wheel and the wafer. To increase the loop stiffness of the machine, each machine component should have high stiffness; the number of the components should be as small as possible and, thus, the machine construction should be simple. The authors developed a new vertical-spindle surface grinding machine equipped with a rotary work table sustained by water hydrostatic bearings, a wheel spindle equipped with a wheel infeed system and a kinematic cupping system that firmly fixes the wheel spindle head against the base of the work table[1)]. This paper describes the specifications of the developed grinding machine and investigates the results of static stiffness and rotational accuracy of the work table. Measured static stiffness of the work table was 2.5kN/μm under water flow rate of Q=10mL/min and rotational accuracy was 0.25μm under 120rpm.

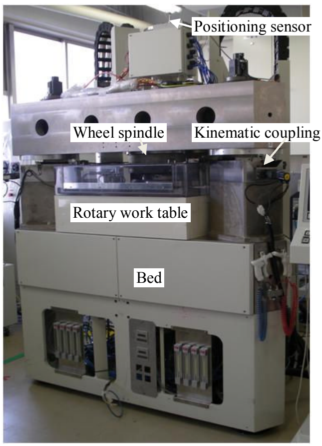

Fig.1 Photograph of developed grinding machine for 450mm diameter

1 Machine specification and construction of rotary table

Figure 1 shows a photograph of the developed

Table 1 Specifications of developed rotary surface grinding machine

Main Body	Machine size	2000×2000×2400 (mm)	
	Wafer diameter	450mm	
	Bearing type	Hydrostatic bearing	
	Working fluid	Pure water	
Work table	Table diameter	500mm	
	Table mass	300kg	
	Table rotational speed	0-500rpm	
	Bearing type	Thrust	Constant flow hydrostatic, Q=10-50mL/min
		Radial	Constant pressure hydrostatic, P=1.2MPa
	Wafer clamping method	Vacuum porous chuck	
Wheel spindle	Rotational speed	0-2500rpm	
	Feed stroke	1.5mm	
	Feed speed	0.010-0.999mm/min	
	Minimum increment	10nm	
	Bearing type	Thrust	Linear motor
		Radial	Constant pressure hydrostatic, P=1.2MPa

grinding machine and Table 1 shows the specifications of the machine. Constant water flow is supplied to the thrust bearings of the work table using micro-gear pumps, and constant water pressure is supplied to both the radial bearings of the work table and the wheel spindle. The wheel spindle is axially sustained by a linear motor. The hydrostatic bearings are earth-friendly, because the working fluid of the bearings is pure water. A porous chuck is installed on the table to vacuum hold a silicon-wafer.

Figure 2 shows a schematic of the rotary work table which is axially sustained by a single recess type constant flow hydrostatic water bearing[2)3)]. Strong neodymium magnets are installed under the rotary table to preload the table in an axial direction (6kN) and thus reinforce the bearing stiffness. The bearing pad is optimally designed to realize the necessary sustaining force and the static stiffness of the rotary work

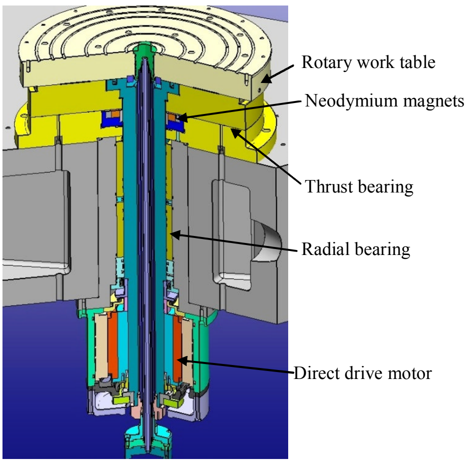

Fig.2 Schematic of rotary work table equipped with a water hydrostatic bearing

table. Flow rate of each bearing Q can be changed by adjusting the rotational speed of the micro gear pump. The rotary table is radially sustained by constant water pressure hydrostatic bearings (the pressure P=1.2MPa) and the rotational speed is controlled using a direct-drive servo motor.

2 Experimental results of work table performance

Figure 3 shows the effect of flow rate Q of each bearing on bearing gap h. The measured data is plotted in Figure 3 with the curve being the derived value from equation (1).

$$Q = \mathrm{C}h^3 = \mathrm{C}(h_0 + h')^3 \qquad (1)$$

where C is a constant given from table mass, bearing preload, viscosity and effective bearing pad size, h_0 is gap margin and h' is effective bearing gap. In this system, the table does not float (h'=0) until Q=0.8mL/min. This is due to the assumption that some water leakage occurs from the bearing surface. Therefore, h_0 must be considered in calculating the real bearing gap h.

Fig. 4 shows the effect of Q on static stiffness K of the work table. Weights of 18.5kg mass are placed on the table one by one and the vertical displacement of the table is measured using three electric micrometres. Lower Q results in higher K, and the measured K under Q=10mL/min (h'=6µm) was 2.5kN/µm. The bearing stiffness is high enough to compose the high precision grinding machine table.

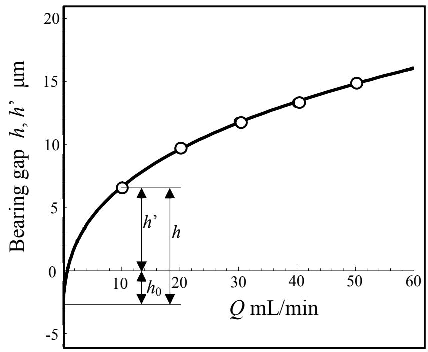

Fig.3 Effect of flow rate Q on bearing gap h

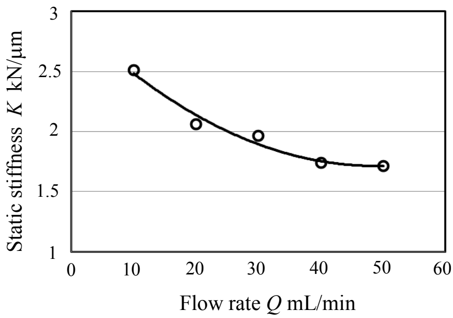

Fig.4 Effect of flow rate Q on static stiffness K

In the case of rotary

grinding of silicon-wafers, normal grinding force is not applied on the center of the rotary table, but it is applied eccentrically. Fig.5 shows the effect of eccentric force on table inclination angle θ. When a moment of 181N·m is applied on the table under Q=50mL/min, measured θ was 3.94". This shows that when the load of 100N is applied to the outskirts of the table (table radios=250mm), the loading point will sink 0.61μm, which is stiff enough to grind silicon wafers.

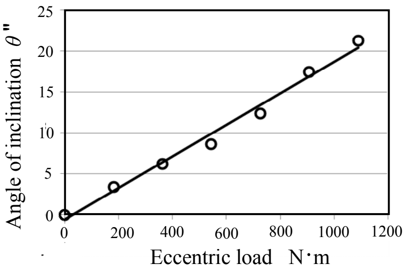

Fig.5 Effect of eccentric force on table inclined angle θ (Q=50mL/min)

Figure 6 shows a radial motion-deviation of the work table under 120rpm and Q=10mL/min. The radial deviation is measured using a master ball (0.055μm roundness in a measuring plane) and electric micrometers, which are set perpendicularly in the measuring plane. Measured rotating accuracy was 0.25μm.

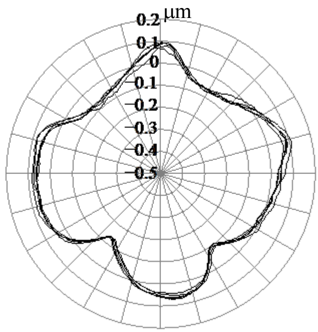

Fig.6 Radial motion deviation of rotary table (120rpm, Q=10mL/min)

3 Conclusions

A next generation precision grinding machine for 450mm diameter silicon-wafers is developed and performance of the work table is investigated. Measured static stiffness of the table was 2.5kN/μm under Q=10mL/min, and rotational accuracy was 0.25μm under 120rpm.

References:

[1] G.Rothenhöfer, A.H.Slocum, M.Paone, X. Lu, A. Yui: Proc. of 11th euspen International Conference, (2011.5) pp.260-266.
[2] G.Rothenhöfer, A.H.Slocum, A. Yui: Proc. of 10th euspen International Conference, (2008.5) pp.509-513.
[3] A.Yui, S.Okuyama, T.Kitajima, E.Fujita, A.H.Slocum and G. Rothenhöfer: Proc. of the 9th euspen International Conference, (2009.6) pp.248-251.