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MAG-LEV SEMICONDUCTOR WAFER TRANSPORTER FOR ULTRA-HIGH-VACUUM ENVIRONMENT

(Application Development of Active Magnetic Bearing)

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Abstract

Magnetically levitated linear and tilting movement transfer equipment to operate in an ultra-high-vacuum was developed. This equipment will be used in semiconductor manufacturing equipment for Ultra-Large-Scale Integrated circuit such as dynamic random access memories (DRAMs) with capacities of tens of megabits. Regular electromagnet materials cannot be used in a high vacuum because they emit gases, so we keptthose parts on the outside of a metallic shield wall, with the vacuum inside the wall. It was not easy to develop magnetic bearing control through the conductive wall and across the wide bearing gap. The major problems were vibration of the long and thin transfer rod and axial oscillation of the rod and the floating body.

1. Introduction

It is well known that keeping the environment in a semiconductor manufacturing plant very clean is essential for maintaining high quality and high yield of integrated circuit.

To manufacture even more highly integrated circuits (such as 100 Megabit DRAMs) in the future, it is necessary to process the semiconductor wafers in an ultra-high-vacuum (UHV) to avoid unexpected reaction caused by humidity and impurities of the air.

Wafer transfer equipment, which carries the wafers between UHV process chambers, must not generate particles, release gases, and employ any lubricant.

In these circumstances, rolling or sliding contact bearings cannot be used, we developed a wafer transporter using active magnetic bearings as a contactless motion guide and actuator.

2. Structure of the equipment

Under UHV conditions [$1.33*10^{-6}$Pa ($1.33*10^{-8}$Torr) or lower pressure], ordinary materials for electromagnets such as magnetic steel sheets and enamel-insulated copper wires are cannot be used because they emit gases from their insulating films, contaminating the vacuum. To prevent this contamination we placed ordinary electromagnets outside the vacuum shield and placed the floating body for transportation inside of the shield.

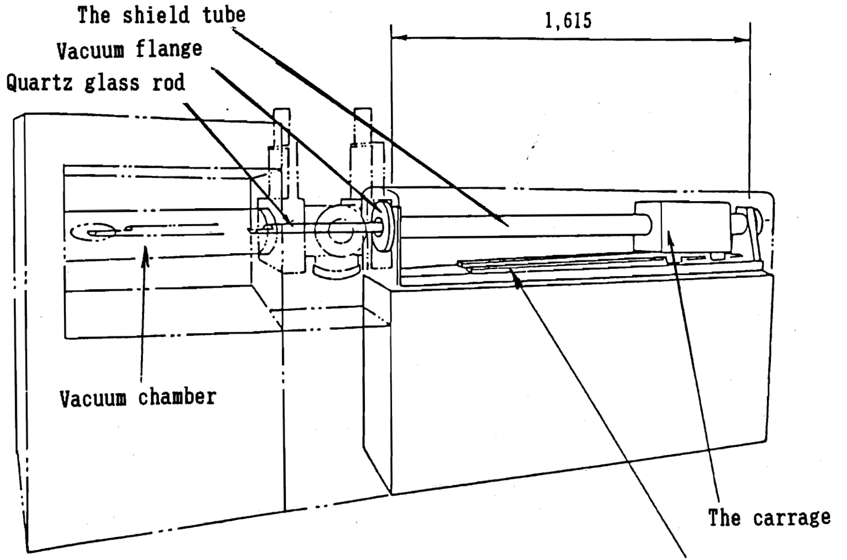


Fig.-1 Wafer transporter and vacuum chamber

Wafer transporter (Figure-1)

From the side wall of the semiconductor UHV chamber, the transfer rod projects into the chamber and moves horizontally. The flat part on one end of the rod scoops the wafer up from the relay point, transfers it to the process (fabricating) spot, unloads it to wait the fabricated wafer.

At the other end of the rod, the transfer rod is connected to the cylindrical floating body. The rod and the floating body are levitated in the middle of a vacuum shield tube which is connected to the vacuum chamber by a vacuum flange. The inside of the shield tube has the same vacuum conditions as the process chamber.

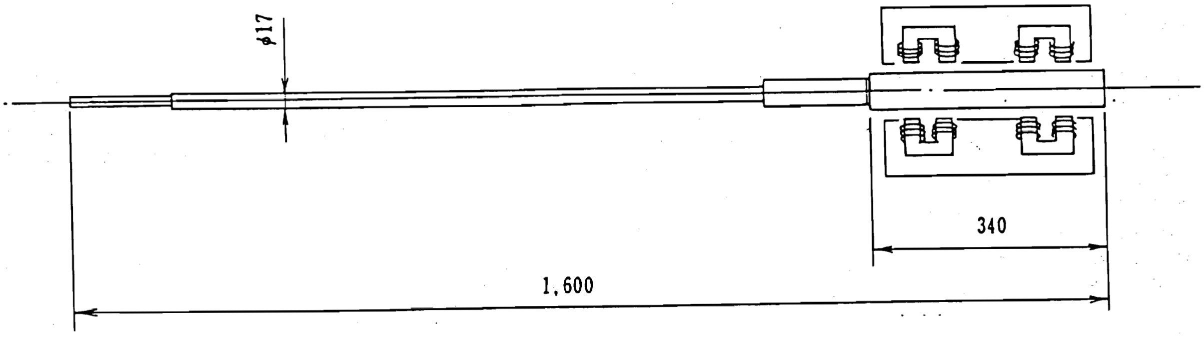


Fig-2 The transfer rod and electromagnets

The transfer rod (Figure-2)

The floating body, is made of magnetic material and is a cylinder about in 50 mm diameter and 340 mm long. The total length of the rod, flat scoop, and floating body is 1.6 meters. The floating body is supported by magnetic attraction through the thin wall of the shield tube.

The radial bearings (Figure-3)

The floating body fits inside the shield tube with a 1 mm gap all around. Four pairs (8 pieces) of electromagnets surround the shield tube, Two groups of two pairs define two points which define the center line of the floating body. The distance between the two groups is decided by the length of the floating body. Also four pairs of inductive position sensors are located on the side of the magnets to detect the radial position of the floating body. Using these sensor signals, four servo control loops keep the floating body and the transfer rod aligned on the center of the shield tube.

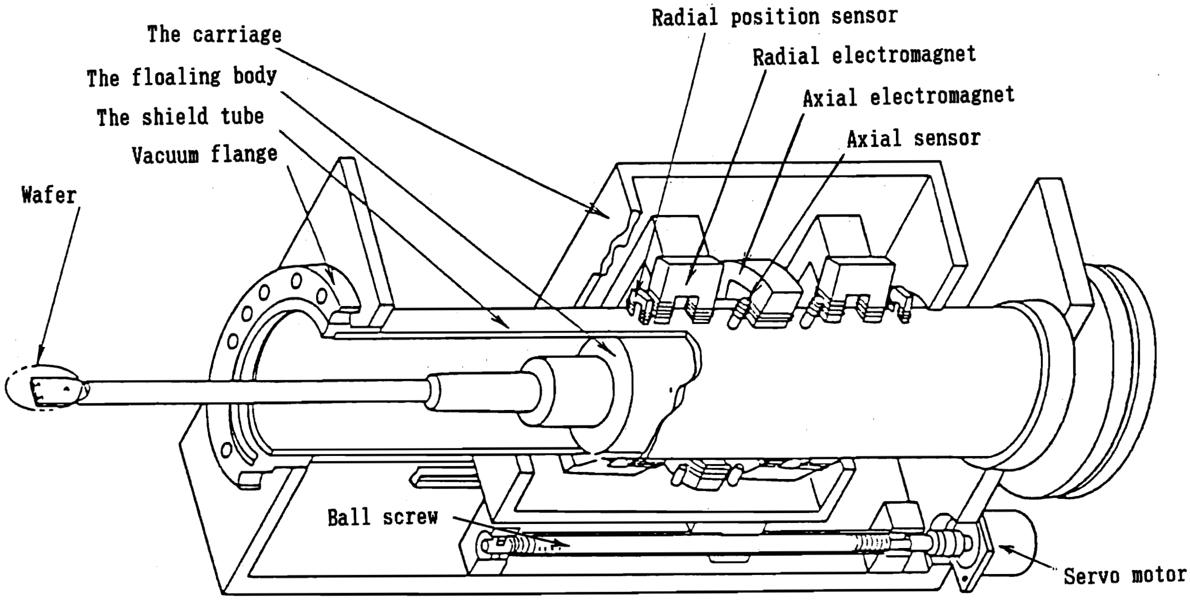


Fig.-3 The carriage and the floating body

Axial motion

The electromagnets and sensors are fixed to the carriage which travels horizontally along the shield tube. Around the floating body's cylindrical surface, 16 lands are formed to match the shape and face the locations of the pole shoes of the 8 electromagnets.

At the time of initial design, we expected that the transfer rod would follow the horizontal travel of the magnets but finally we had to add one control loop to damp axial oscillation at the time of start and stop of traveling.

Restriction of transfer rod rolling

Restoring force to stop the rod rolling is given passively by the radial electromagnets' pole shoes and facing lands on the floating body. When the floating body begins to roll, the electromagnets' pole shoes and the facing lands on the floating body are no longer centered on each other, so the magnetic force brings them back into alignment.

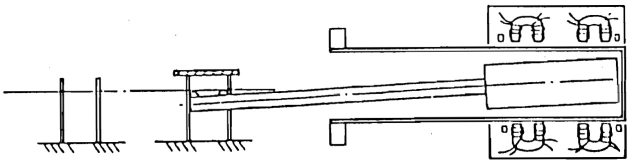
Horizontal motion

The carriage with eight radial electromagnets, their corresponding position sensors, and a set of electromagnets with sensors for damping axial oscillation (explained later), move coaxially with the shield tube. A ball screw and a servo motor drive the carriage guided by linear-motion ball bearings parallel to the shield tube. The levitated floating body and the connected transfer rod are dragged and follow the carriage's movement.

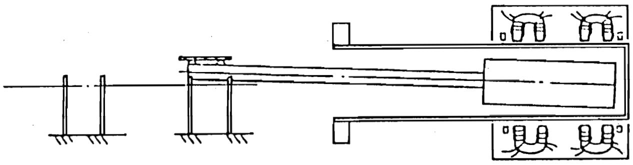
Pick and place motion (Figure-4)

When the floating body is tilted in the vertical plane (pitched), the flat part at the top of the transfer rod scoops up (picks) the wafer from the relay spot or lays down (places) at the process spot.

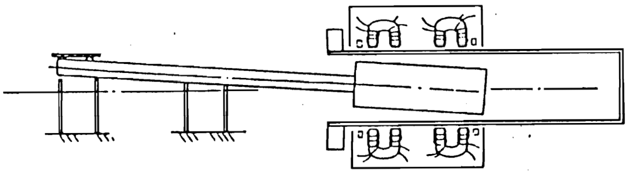
These movement are given by the input signal for the servo control loops for the radial bearings, and is sequentially changed with the carriage's travel position.



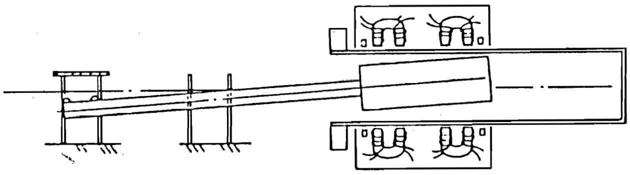
Picks up



Transfer



Places



Retreat

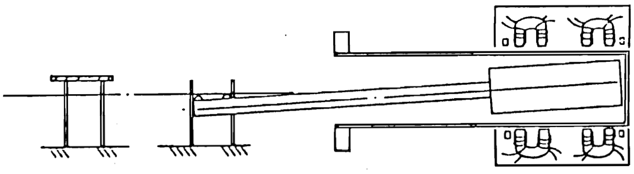


Fig.-4 Pick and Place

3. The subject in design process

Target design specifications and final results are listed in Table-1. The many problems were worked on by trial and error method. The major problem was deciding the bearing gap between the electromagnets and the floating body's lands. The factors for the bearing gap decision are listed below.

* Vertical motion amount (lift) of the flat part at the top of the rod for pick and place.

* Wafer fixture's height diffirence between relay point and process point.

* Geometrical accuracy of the shield tube. (straightness, roundness, taper and wall thickness uniformity)

* Stable control range of the floating body's tilt.

* Maximum payload.

We did not have enough data and experience to design a wide or fluctuating bearing gap, and the bearing was difficult to cotrol through the metal vacuum shield. So we could not optimize the gap, the lift and the size of the electromagnets. The minimum bearing gap was determined by the necessary lift (5 mm) and the estimated geometrical accuracy of the tube.

4 Prototype performance

Unforseen difficulties made it difficult to attain the target specifications. We describe how we overcome those difficulties and where we were obliged to compromise.

Table-1	Design target	Actual results
Transfer travel	1,000/500 mm	Unchanged
Transfer speed	100 mm/s	80 mm/s
Payload /Travel	100 g / 1,000 mm	14 g / 1,000 mm 1,000 g / 500 mm
Lift	5 mm	3.5 mm
Locating accuracy	+/- 0.5mm	+/- 0.1 mm
Vacuum shield (Leak test)	$1 * 10^{-8}$ Torr L/s	$2.7 * 10^{-10}$ Torr L/s

Travel speed

We had hoped to achieve 100 mm/s maximum speed, but had to lower that to 80 mm/s because of axial oscillation of the floating body and the cost of the carriage drive motor servo control system.

We did not adopt any axial control in the initial structure. With this structure, at the carriage's travel end, when the carriage decelerated from its top speed and stopped, the floating body overran and was pulled back by magnetic force. It then started to oscillate at about 2 Hz frequency without amplitude decrement (Figure-5a).

To suppress the oscillation, we put two extra electromagnets and sensors on the carriage and put notches and tapers on the floating body (Figure-6). We also add a control loop for this purpose.

The effect of the additional control is shown in Figure-5b. The oscillation at the carriage stop was damped in 1 second. We were unable to decrease the shock at the carriage travel end because of financial constraints. By using a servo motor with a wider speed range we will be able to increase the maximum transfer speed.

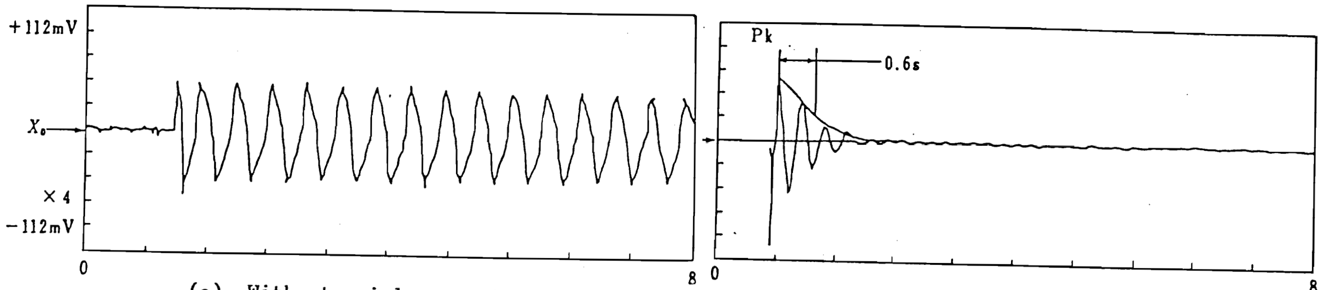
Payload

The main thing limiting the payload was the bending resonance of the transfer rod. When the rod resonates, the wafer falls off the flat part of the rod. Beside thin and long shape, the semiconductor manufacturing process requires that the transfer rod material be quartz glass . That and the rod's long, thin shape meant that it was frequently broken by violent resonance.

There are many resonance frequencies For example with the 1,000 mm distance transfer model, the first-order bending resonance was at 30 Hz and the second-order was at about 100 Hz. To suppress the resonance, we put phase-lead networks in every bearing control loop for the first resonance frequency, notch filters for the second resonance and high-order low-pass filters for the third and higher harmonics.

These countermeasures forced us to compromise and make do with a 14-gram payload instead of the 100 grams we had originally intended.

For bigger payload, we must made the rod stiffer. The model with 500 mm transfer distance reached 1,000 grams payload on a shorter aluminum rod of higher resonant frequencies.



(a) Without axial control (b) With axial control

Fig.-5 Effect of axial damping control

Lift amount

The wall thickness of the austinite stainless steel of the shield tube was 0.5 mm. The gap between the outside of the tube and the electromagnet was 0.2 mm on average. The gap between the inside of the tube and the lands on the floating body was 1.2 mm on average.

The total gap between the electromagnets' pole shoes and the lands on the floating body was 2.0 mm, including the tube thickness.

The geometrical accuracy of the tube was worse than expected, so we had to increase the bearing gap by 0.2 mm and the lift amount was only 3.5 mm, rather than the 5 mm we had planned.

We note that it is necessary to study the behavior of the inductive position sensor, which senses the magnetic material through the conductive shield.

To avoid lift motion shock, a ramp function for the control signal input was employed, To increase tilt stiffness, the control signal of the front and rear bearing was cross coupled.

Others

Horizontal locating accuracy (repeatability measured in the atmosphere) was better than expected, thanks to the low-friction magnetic bearing and the carriage's high locating accuracy of 0.01 mm.

The vacuum shield test was carried out by helium detecting. The internal surface of the shield tube was polished millor-smooth by an electro-chemical method so that the gases would be released easily from its surface and so that a high grade of vacuum would quickly be reached.

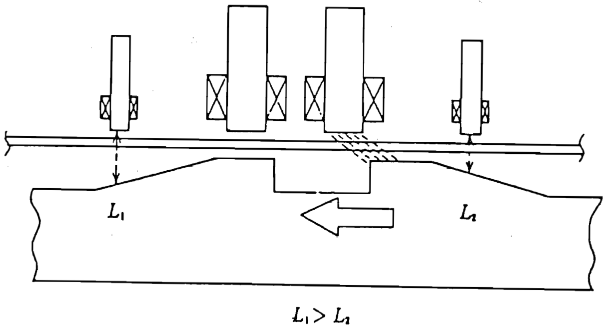


Fig.-6 Components layout for axial damping.
the Electromagnets, Sensors and the Floating body

5 Conclusions

We developed and built non-contact, non-lubricated, and dust-free semiconductor wafer transporter, which is levitated and driven by magnetic attraction through the metal vacuum shield.

This transporter can be used in a UHV and will be used in the manufacturing process equipment that will mass-produce 100 Mbit DRAMs in the near future.

* We gathered design data for the stainless steel shielded magnetic bearing including payload limit, gaps, and tilting controllability.

* Without any complicated structure, a wafer could be picked up and placed by tilting the floating body in the gap of the magnetic bearing.

*The suppressing method for axial oscillation of the floating body and the transfer rod was realized by active (controlled) magnetic damping through the metallic shield tube.

* The sensitivity and robustness of the position sensor through the metal vacuum shield must be improved.

* The data and experience gathered during this development are very important for the futures polar coordinate robot, which will work in a UHV.

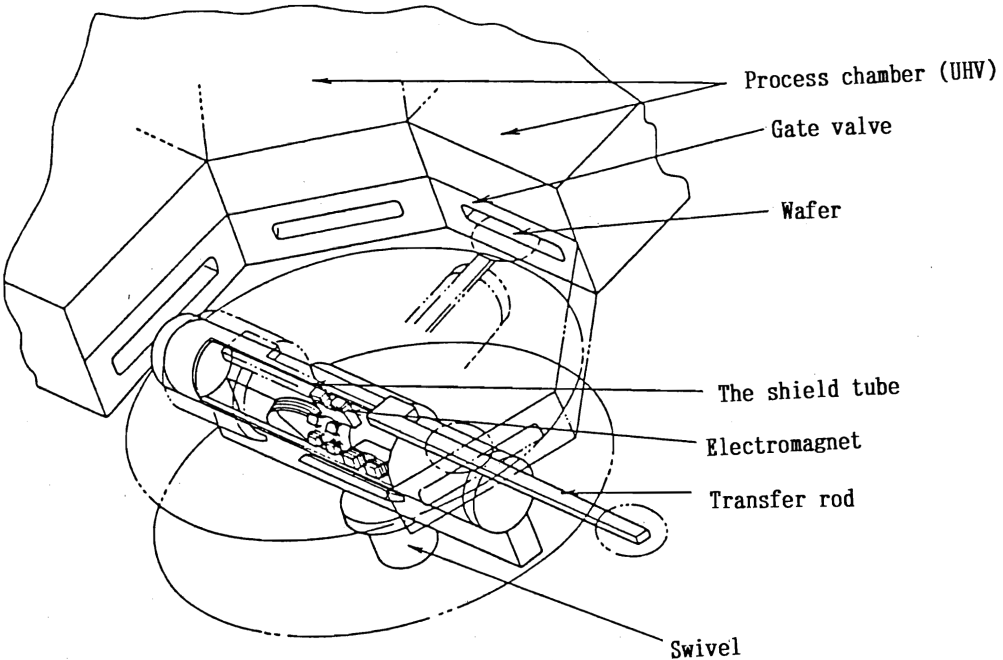


Fig.-7 Poler coordinate robot in UHV.

Acknowledgement

This equipment was developed under the guidance of Professor T. OHMI and Dr. M. MORITA of Tohoku University Electrocommunication Laboratory. The 1,000-mm transfer model was evaluated with an experimental oxidization furness for forming an insulating layer on silicon crystal. This furness, made by SEIKO Instruments, was operated in Tohoku University's famous super-clean room.