Development of Mag-Lev Polar Coordinate Robot Operated in Ultra High Vacuum

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ABSTRACT

The polar coordinate robot in the vacuum in which magnetic bearings were used was developed. This robot is used as transporter of the wafer in the multi- chamber manufacturing system for the semiconductor. The floater (transfer rod) is supported by magnetic bearings and is driven by a linear motor. The electromagnets of the magnetic bearings and the linear pulse motor are encapsulated in the shield tube. Because the gas from the coil and the yoke are not discharged in the vacuum in this structure, the semiconductor wafer is not polluted by the gas.

The deformation of the shield tube, caused from internal pressure, was evaluated because this robot will be installed in the vacuum. The extent of the actual deformation did not cause the bad effect on the movement of the robot because the FEM(Finite Element Method) deformation simulation was used during the design procedure. Moreover, the heat problem was a concern in a tube-encapsulated structure, but the electromagnets and linear motor in the shield tube were cooled by the air flow.

1. INTRODUCTION

We developed mag-lev transfer equipment for transporting wafer containers between the semiconductor manufacturing process equipment in 1986[1]. We also developed the liner wafer transporter in the ultra-high vacuum in 1988[2]. Recently, the sample shipment of 16MDRAM will start. Development of 64MDRAM, with a 0.3 micro meter rule, has been announced and 256M and 1GDRAM are in the research phase. The three following conditions are necessary in the manufacturing processes for above mentioned future semiconductor[3].

(A) Super-clean process atmosphere.
(B) Super-clean wafer surface.
(C) Complete control of process parameter.

To fulfill the condition of (A), it is necessary to make gas, water,and the chemical clean, and to make the manufacturing equipment clean. This means all the processes must be operated in a vacuum chamber.

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To fullfill the condition (B), it is necessary that the wafer not be exposed to air. It is necessary, too, to transport the wafer in the vacuum or in the inert gas, such as pure nitrogen. To fulfill these conditions (A) and (B), the best method is to make a multi-vacuum chamber processing system that can process almost all kinds of manufacturing, and to make the robot transfer the wafers between multi-chambers. We think magnetic bearings are best for this robot. The reasons follow

-- No dust generation
The moving member is levitated without contact, and neither dust nor particles are generated.

-- No lubrication
Because lubrication is not necessary, no gas evaporates from the lubricant, such a grease or oil.

-- Long life
Because there is no contact or sliding part in the vacuum, there is no wear, and the equipment lasts a very long time.

-- No leakage
There is no leakage of air or gas from the equipment to the vacuum because of the metallic tube shield.

-- Shock-free
Because of the magnetic levitation, the moving part is shock-free from the outside.

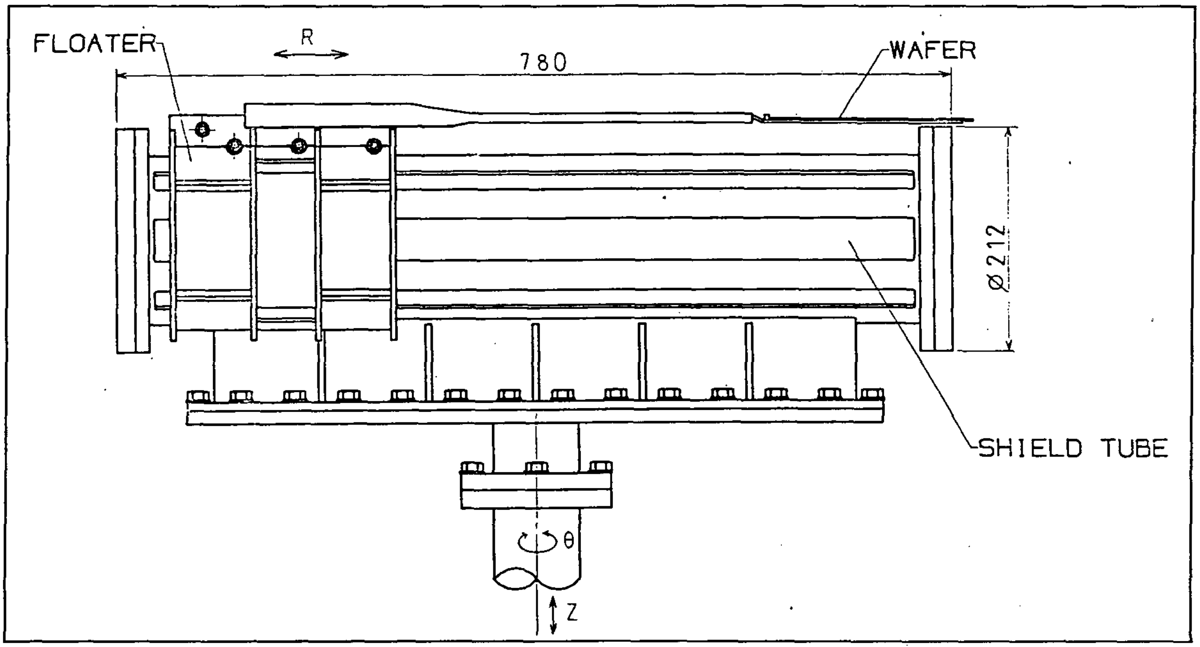

Figure 1 Mag-Lev Robot

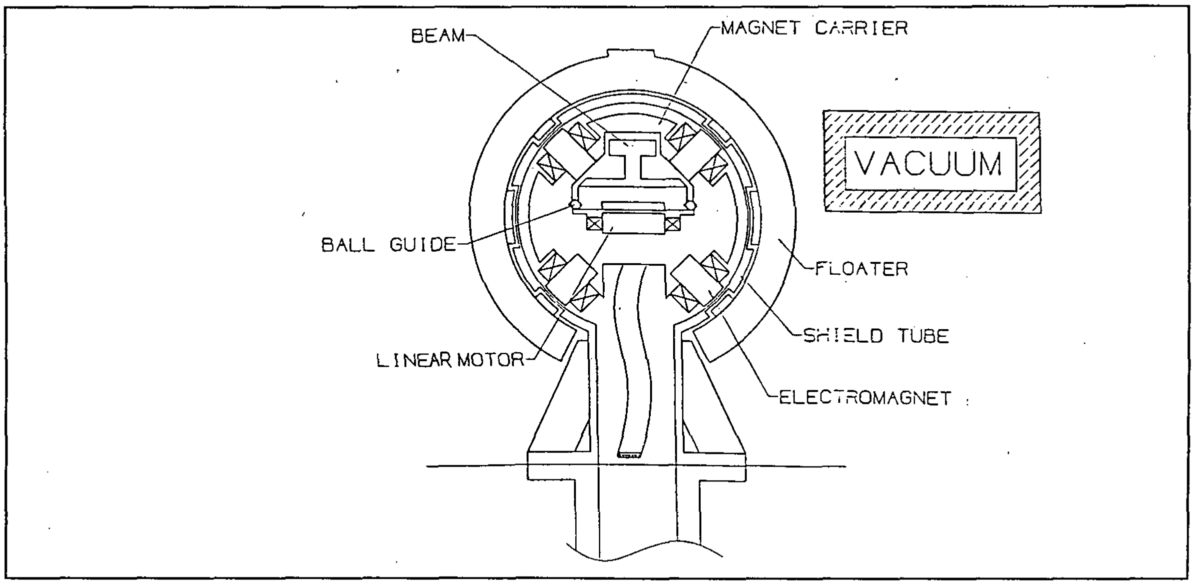

Figure 2 Cross Section of The Shield Tube

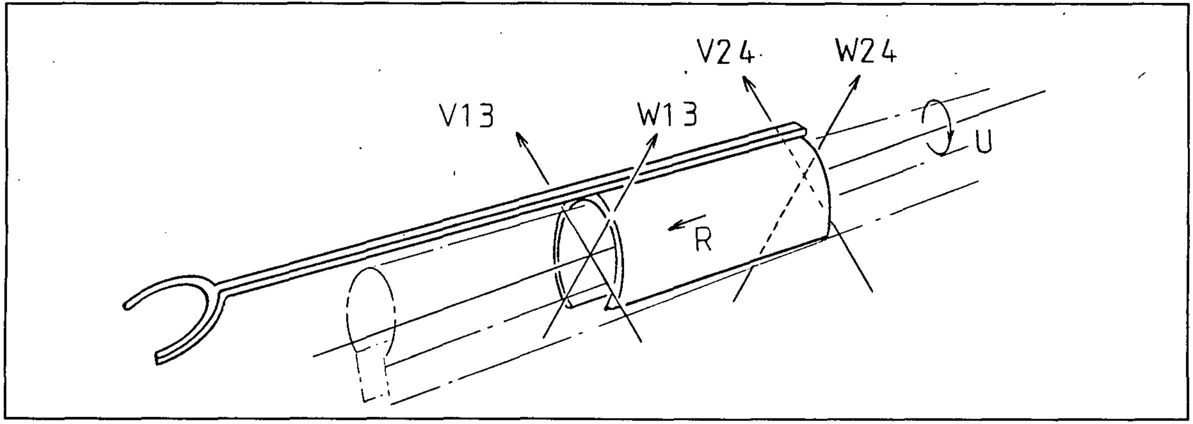

Figure 3 Electromagnets Arrangement

2. STRUCTURE

This robot is composed of radial part R, which moves horizontally, the swing part theta, which moves in the horizontal plane, and the Z part, which moves vertically.

(1) Part R

The appearance of part R is shown in Figure 1. The section is shown in Figure 2. The server which receives the wafer and the arm are fixed to the floater. This floater is levitated by a magnetic force. This floater moves horizontally along the shield tube.

This shield tube structure was adopted by the experience of our previous development of the linear wafer transporter in the UHV [1]. Reasons are following. There are few metal shielded magnetic bearing applications, most of them are rotary bearing applications. (for example X-ray tube[4] and canned motor pump[5]). Only one metal shielded linear magnetic bearing application is known which guides 10mm axial motion and step motor and bearing combination[6]. We have only one reference of long travel linear metal shielded application of our previous development.

As shown in Figure 2, the linear motor rack (platen) and the ball guide are fixed along the beam in the shield tube. The magnet carrier is being supported by this ball guide. On this magnet carrier, there are electromagnets of magnetic bearings and the linear motor stator(forcer). The floater is levitated by these magnetic bearings.

(2) Magnetic bearings

The electromagnets' arrangement to support the floater is depicted in Figure 3. To levitate the floater, there are four pair of magnets (V13,W13,V24,W24). One pair (U) suppresses the floater's rolling motion. An other pair is for controlling the back and force motion at the start and stop of the linear motor. Six pairs of electromagnets are used in all.

The electric circuit system is composed of the sensor, the PID circuit, the power amplifier, and the electromagnets. The floater's position is detected through the shield tube by the inductive sensor. To lower the eddy current effect from the shield tube on the sensor signal, the carrier frequency is one third of the regular carrier frequency(51kHz), which is used for nonshielded regular bearing.

The control circuit is composed of normal analog PID circuit. The notch filters are used to damp mechanical resonance of the floater and the server.

(3) Drive part

The linear pulse motor (LPM) is used for driving the magnet carrier horizontally. The LPM rack and liner ball guideway are fixed on the beam. The LPM forcer and carrier with electromagnets are mounted on the linear bearing unit. The carrier is driven smoothly by LPM with micro-step control.

(4) Shield tube

To prevent contamination of the vacuum, all the gas-emitting materials are shielded by a thin austenite stainless tube. These gas-emitting materials are the lubricant for the guide, the insulator of the coil wire, steel sheets for magnet core, and other plastic material. Under the shield tube, there is space for moving cables to feed power to bearings, the linear motor, and the sensor signal.

(5) Drive theta and Z

The shield tube is swung in the horizontal plane and around the vertical axis. Bearings of this rotation are regular ball bearings, which are sealed from the vacuum by ferrofluid seal. Direct drive motor controls swing the angle, and all of these mechanism, are driven vertically (Z) by a pneumatic cylinder.

Power and sensor cables for magnetic bearings and the linear motor are connected from their controllers through the hollow tube in the center of the mechanism.

3. PROBLEMS AND THEIR SOLUTIONS

In the plan and design stage several problems were expected. These problems were evaluated, and solutions were applied in the design stage. Unexpected or unevaluated problems, however, were solved experimentally by trial and error method in the evaluation stage.

(1) Rolling motion damping

The round shield tube was selected because it is easier to manufacture. The floater was supported by eight radial electromagnets controlled by four servo loops and axial damping was applied by an additional control loop, as in the previous report[2]. Rolling motion of the floater is predicted at the time of the robot's swing motion. We found that the former variable reluctance structure is not good enough to damp this rolling movement, and so prepared a sixth servo loop and magnets to control the motion.

(2) Manufacturing shield tube

The thinner the shield tube wall, the better the bearing performance, but the tube wall must be thick to manufacture it easily. We compromised by using a tube wall of 0.5mm thickness. The problem, however, is the difficulty in keeping the tube's shape within 0.1 mm cylindricity in the manufacturing stage and in the vacuum. In the welding process, when attaching the cable-moving space case to the round thin shield tube, the tube's original shape will be come deformed.

The solution to this problem is to use a tube with walls 5mm thick to avoid welding deformation. We must, however, machine complex shape to maintain 0.5 mm thickness in the wall area where the electromagnets and the sensors travel. As a result, the desired shape was obtained in the necessary area after welding process.

(3) Deformation of the shield by the vacuum

Inside the shield tube is the ambient pressure, and on the outside is the vacuum. This internal pressure deforms the shield tube nonuniformly, because the shape of cross section of the tube and cable case is not a circle. This nonuniform deformation troubles the tuning process of the magnetic bearing controller, as we must operate this robot both in the ambient and in the vacuum with the same tuning value. We estimated a maximum of approximately 1 mm deformation by FEM simulation.

By applying reinforcement ribs on the cable case and by repeating simulation, we reached a maximum of 0.1 mm deformation, with proper rib thickness and spacing along the entire length of the tube.

(4) Heat problem

In the shield tube there are heat-generating components magnetic bearing coils and LPM's stator coil. There are also many plastic materials of low permissible temperature. The temperature of LPM's plastic mold material, in particular, must be kept at 60 degrees centigrade. A heat

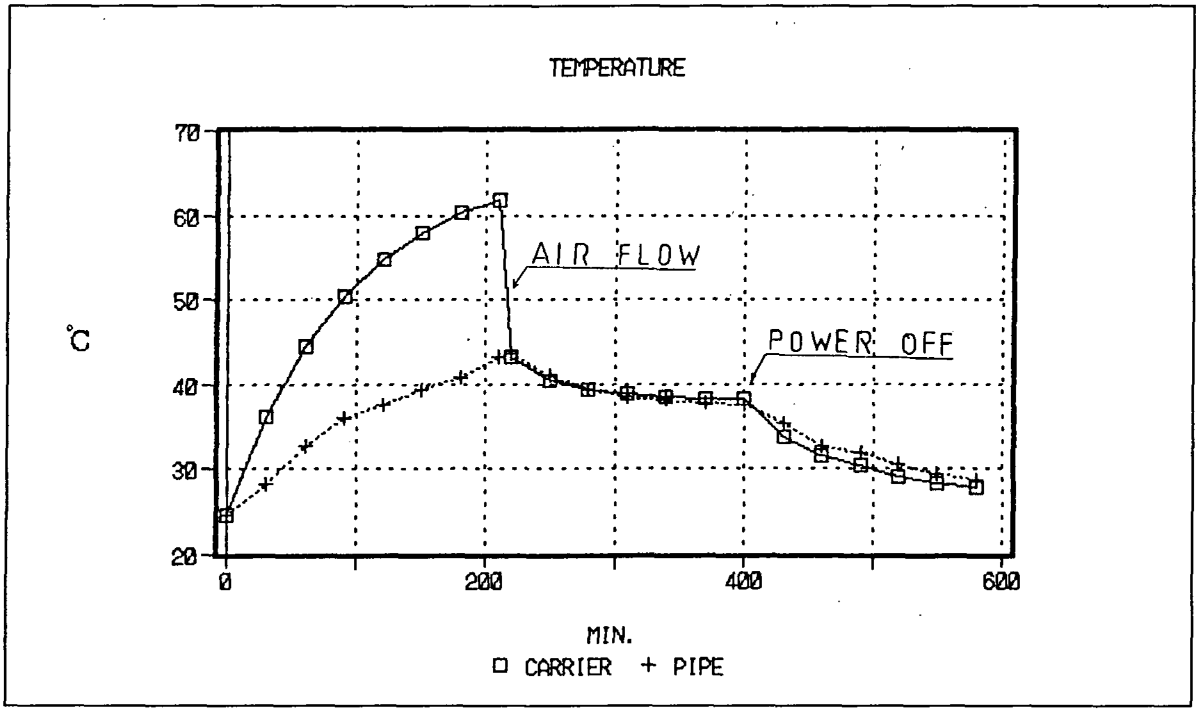

Figure 4 Temperature of The Shield Tube

problem is expected. Low thermal conductivity of the vacuum space causes low heat emission from the shield tube surface, which in turn causes a rise in temperature over the permitted level. Heat generation of the magnetic bearing is 24 watts, and that of the LPM is 9 watts.

The solution to this problem is to cool these components using the air flow in the tube. In Figure 4, the rise in temperature of the shield tube surface and the magnet carrier is illustrated. The air flow efficiently cools these components, and keeps the temperature of all the parts below 40 degrees centigrade.

(5) Mechanical resonance of the structure

Every structure must be stiff enough so as not to be resonated by the feedback control circuit, but we must use a long and light weight transfer rod that has a low mechanical resonance frequency. Another long but slim structure, is the beam that supports all the moving weight - including the magnet carrier, the floater, the transfer rod, the server, and the LPM forcer - on the linear bearing.

The resonance frequency of the original design's levitated part was 40 Hz, and we could not achieve satisfactory bearing stiffness and failed to make a stable bearing, because the bearing resonance and mechanical resonance were too close. Finally, we had to raise the resonance frequency to 120 Hz by shaving off the weight of the transfer rod and the server without losing mechanical stiffness.

4. RESULT

The design specifications and the attained data values are indicated in Table I. And some measured values with load and without load on the server are shown in Table II. It shows that the load effect is small on the performance of this robot.

Table I Result

	Design target	Actual result
Transfer travel	500mm	500mm
Transfer speed	300mm/sec	130mm/sec
Payload	100g	100g
Locating accuracy	+/- 0.2mm	<+/- 0.1mm
Ambient pressure	10µ Pascal	100µ Pascal #
		# without baking

Table II Load Effect

Payload	0g	100g
Levitated server position	---	-0.03mm
Settling time	1.5sec	1.5sec
Locating accuracy	<+/- 0.1mm	<+/- 0.1mm

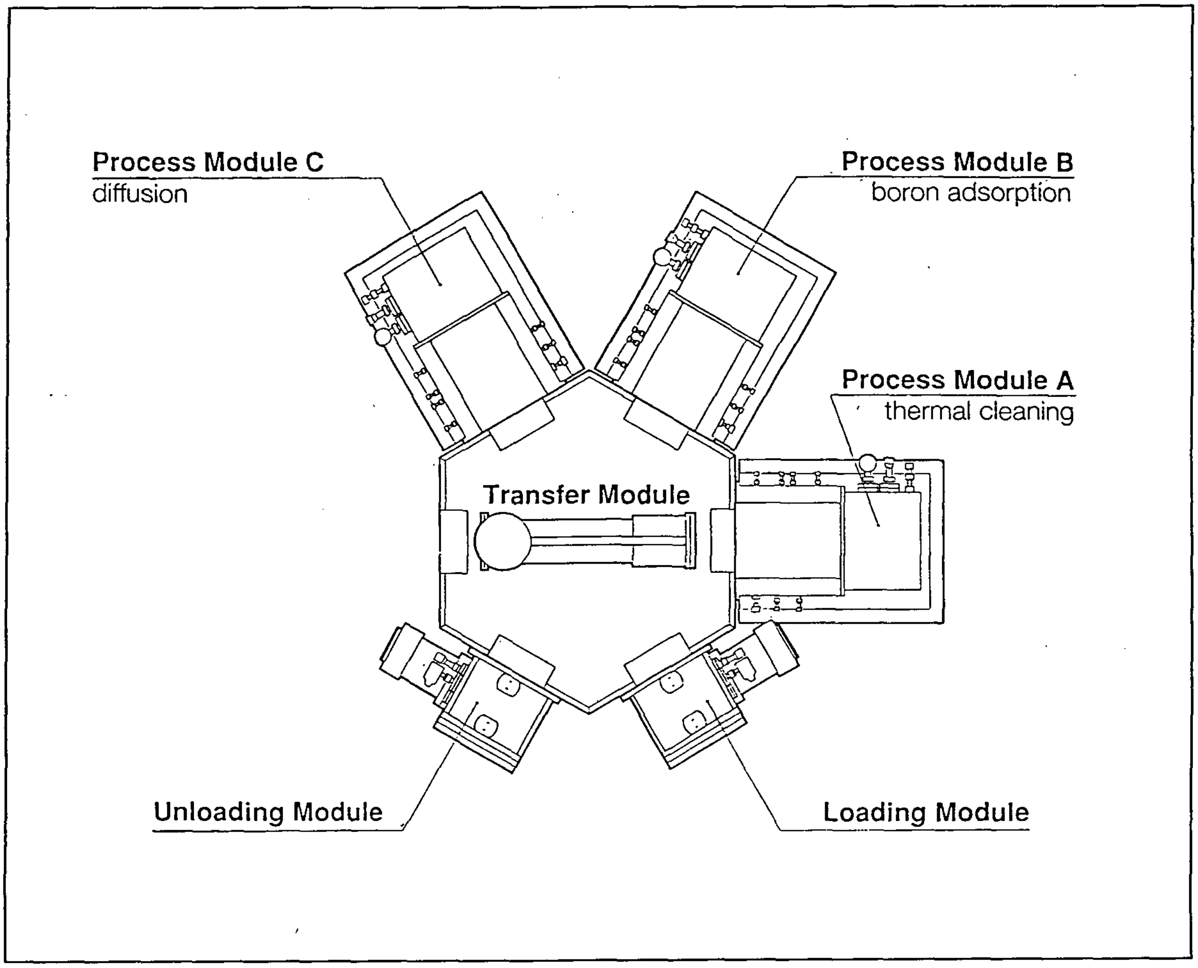

Figure 5 Multi-chamber Semiconductor Manufacturing Equipment

5. CONCLUSION AND PLAN FOR THE FUTURE

-- A noncontact, nonlubricated, dust-free polar-coordinate robot, which transports semiconductor wafers in an ultra-high vacuum, was developed.

-- This robot can be operated in an ultra-high vacuum environment. (100μ Pascal)

--The planned vacuum shield tube had to be reinforced to minimize the deformation in the vacuum.

-- This robot is installed in multi-chamber semiconductor manufacturing equipment, which is developed by Seiko Instrument Incorporated. In Figure 5 the reliability and durability of this robot is evaluated.

-- Improvements can be made by making smaller structures, to achieve quicker motion in operation and shorter evacuation time when starting up the equipment.

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