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Design of a contactless handling system using compliant surface elements

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Abstract

Handling thin, fragile substrates is a challenging and critical task in semicon industry, where any physical contact between substrate and system is a risk. Thus, handling systems without any physical contact are needed. Based on the active air-bearing working principle, contactless handling systems have previously been developed requiring high supply pressure and deep vacuum air, in which the handling performance is proportional to the pressure difference. In other words, a high pressure difference is desired for better dynamic response resulting in higher acceleration for rapid substrate transport and positioning. In the previous research, a deep vacuum pressure p_v was required to obtain a high pressure difference and thus a high traction force. However, a deep vacuum supply is expensive and it is hard to maintain. Therefore, in order to make the best use of the vacuum source, a new air-bearing surface design with compliant surface elements has been developed in which a high pressure difference is realised without requiring a deep vacuum supply. According to the simulation results using COMSOL, the new surface design has pushed the boundary of the actuation performance further with the same vacuum air pressure. The optimized contactless handling and positioning system is capable of driving a 100-mm silicon wafer with over 0.3 g acceleration.

Contactless, Handling, Air-bearing, Vacuum.

1. Introduction

As high-end electronics industries advance, the optimization and continual reduction of integrated chip feature sizes are pursued to attain lighter and more compact configurations. In semiconductor manufacturing, microchips are crafted on thin silicon substrates, with efforts directed towards decreasing substrate thickness to lower production costs. Nevertheless, when substrate thickness falls below 200 µm, the substrates become highly fragile, posing a risk of easy damage during manufacturing processes [1].

Thus, how to handle this kind of substrate for achieving miniaturization and higher productivity simultaneously has become a fundamental issue. Using the active air-bearing working principle, contactless handling systems have previously been developed requiring high supply pressure and deep vacuum air [2]. In the previous research, a deep vacuum pressure p_v was required to obtain a high pressure difference and thus a high traction force due to the pressure equilibrium condition.

Nonetheless, a deep vacuum supply proves to be costly and challenging to sustain. To optimize the utilization of the vacuum source, an innovative approach has been introduced. This involves the development of a new air-bearing surface design featuring compliant surface elements, which achieves a high pressure difference without the need for a deep vacuum supply.

2. Compliant Design

A contactless handling system has been proposed with a deformable air-bearing surface by Vuong [2]. As implied by the name, this design has the capability of deforming or tilting the air-bearing surface by actuating the bottom plate to generate viscous force for driving substrates. However, the developed system has an issue concerning manufacturability. In detail, each actuator cell contains more than five individual parts, posing a big challenge for assemblage. In addition, the corresponding high pressure difference relies on the deep vacuum supply due to the surface configuration.

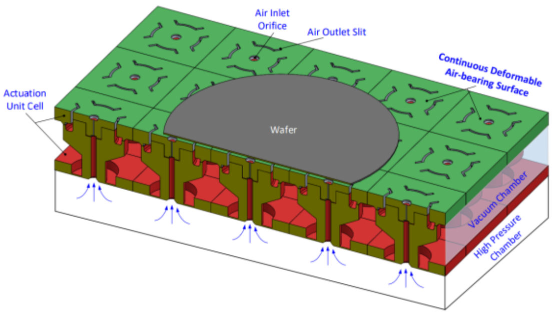

Figure 1. Cross-section view of the designed contactless actuator for handling system with compliant elements implemented.

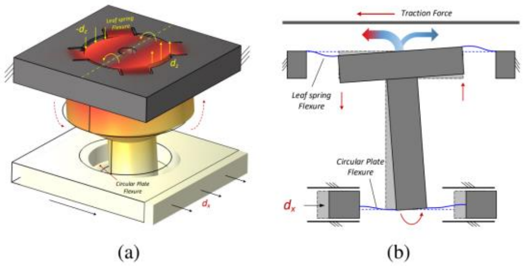

Figure 2. Working principle of single unit cell with the deformable air-bearing.

Given this challenge, a novel compliant deformable air-bearing surface is designed, which consists of many compliant-based actuation unit cells. This whole mechanical structure contains two monolithic parts, the top part with a deformable surface and the middle part with air supply channels. It can be seen that the mechanical structure is compact and easy to assemble. Compared with the original deformable surface concept, in the new system all the deformable air-bearing surfaces of the actuation unit cells are integrated into one monolithic component. This monolithic mechanical feature enables the whole system to be built with much less effort and cost.

In addition to the good manufacturability, the new design features a different pressure configuration of the air bearing surface, which enables the system to have higher pressure difference without deep vacuum supply. Specifically, it has two independent regions including the deformable one and the outer vacuum one for each unit cell (see Figure 3), where the outer vacuum region makes a huge pressure bias for the pressure equilibrium condition.

For the design without the vacuum area:

$$\int p_a dA \approx \int \frac{p_{in} + p_m}{2} dA.$$

where A is the total area, p_a is the pressure of ambient air, p_{in} is the inlet high pressure, p_m is the outlet vacuum pressure.

Then we can get the pressure difference:

$$\Delta p_1 = p_{in} - p_m \approx 2(p_a - p_m).$$

For the new design with the vacuum area:

$$\int p_a dA \approx \int p_m dA_v + \int \frac{p_{in} + p_m}{2} dA_d.$$

where A_v is the vacuum area and A_d is the working deformable area.

As shown in Figure 3, the equation can be re-written as follows:

$$p_a l^2 \approx p_m(l^2 - \pi r^2) + \frac{p_{in} + p_m}{2} \pi r^2.$$

where l is the length of the whole square, r is the radius of the deformable circle.

Then we can get the pressure difference:

$$\Delta p_2 = p_{in} - p_m \approx 2(p_a - p_m)\frac{l^2}{\pi r^2} = \frac{l^2}{\pi r^2}\Delta p_1.$$

It can be seen that Δp_2 is bigger than Δp_1 with a same vacuum supply p_m, which means the new configuration have more potential for driving performance.

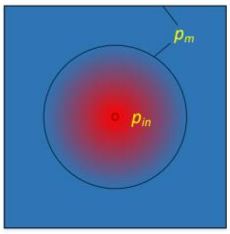

Figure 3. Pressure distribution of the top surface with simplified boundary condition.

3. Simulation and Evaluation

In order to validate the pressure distribution and the traction force performance, COMSOL Multiphysics has been used. Firstly, the vacuum pressure is set to 80 kPa (absolute) based on the results from the pretests, and the high pressure for the air inlet is calculated as 270 kPa according to the floating pressure equilibrium condition. With these specific settings, the pressure distribution profiles are simulated and obtained. As shown in Figure 4, it shows the pressure distribution difference between the condition without displacement input. It is worthwhile mentioning that a modular design has been adopted for 100-mm wafer with seven unit cells in hexagon shape.

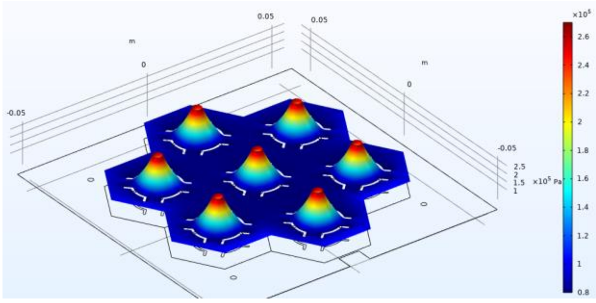

Figure 4. Pressure distribution of the air-bearing surface with seven unit cells.

Given the pressure distribution profiles, the traction force can be generated by having some displacement inputs (the displacement d_x in Figure 2b). As shown in Figure 5, the traction forces with different displacement inputs are collected, which shows that 34 mN actuation force is achieved with 20-µm input. For 100-mm wafer, it can provide more than 0.3g acceleration.

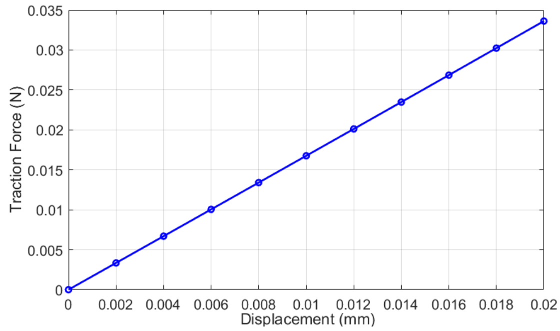

Figure 5. Simulation results of traction force performance with different displacement inputs.

4. Conclusion

Contactless handling systems have great potential for handling fragile substrates carefully. Substrates can be transferred, actuated, and positioned in a mechanical contact-free manner to prevent breakages and contamination. In this work, a contactless handling system integrated with a novel compliant active air-bearing surface has been proposed, where the compliant elements ensure a good manufacturability and high pressure difference for high actuation force without deep vacuum needed. Finally, the simulation result shows that a maximum actuation force of 34 mN is validated for 100-mm wafers.

References

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[2] P. H. Vuong, “Air-based contactless actuation system for thin substrates: The concept of using a controlled deformable surface,” Ph.D. dissertation, Delft University of Technology, 2016.