Contactless 6 DoF Planar Positioning System Utilizing an Active Air Film

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Abstract

This paper discusses a 6 DoF positioning system that utilizes a thin air film to directly position flat substrates. Such a positioning system can be applied in the production of electronic devices, such as integrated circuits, flat panel displays and solar cells. All these devices are manufactured on a flat base substrate, e.g. a silicon wafer or glass plate. Precision positioning stages are used during exposure, inspection, alignment, etc. We present a planar positioning system where only the product mass is driven and without mechanical contact. This system has two main advantages: a moving mass of 2 to 3 orders of magnitude smaller, since the carrier stage is eliminated and the absence of mechanical contact reduces the chance of contamination or damage.

1 Working principle

Several actuation methods for contactless substrate positioning have been researched, for instance by using electrostatic forces [1] or air impulse jets [2]. Our principle of actuation utilizes viscous shear from air flow for improved proportional position control and can be explained as follows (refer to Figure 1 and also [3]). Compressed air flows from an inlet under the substrate, through a pocket towards an outlet, where the pressure is below ambient. At the product surface, the air creates a viscous shear, providing a lateral force for the motor function. To reduce undesired backflow between adjacent actuators, a small dam is introduced between them.

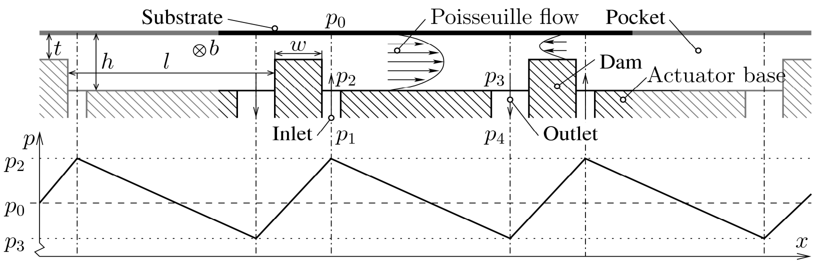

Figure 1: Overview of the working principle (above) and pressure curve (below)

The lateral force per actuator is only dependent on dimensions and pressure:

$$F_A = \tfrac{1}{2}\left(h - t\right)\left(p_3 - p_2\right)b$$

The bearing function works similar to a conventional air-bearing, meaning vertical stiffness is generated by introducing a restriction at the inlet. The outlet serves as a vacuum preload to reduce the thickness of the air-film, resulting in an increased vertical stiffness and a reduction in air flow.

2 Six Degrees of Freedom actuation

To control all six DoFs, the actuator configuration is modified slightly. Each square actuator pocket has two inlet and two outlet points placed diagonally in each corner (Figure 2). The resulting pressure distribution in the cell then takes a saddle shape, where zero lateral force is produced in the equilibrium situation. By varying pressure at each of the two inlet points, the flow inside the cell can be biased bidirectionally.

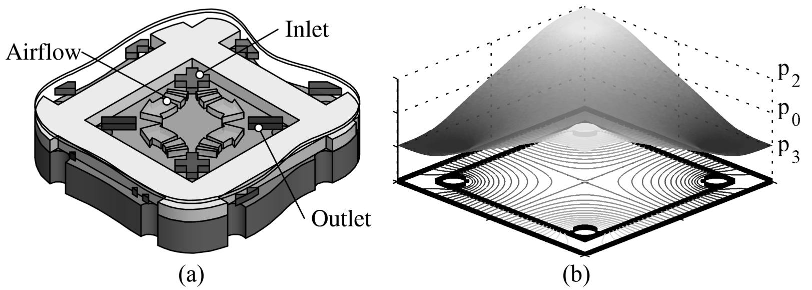

Figure 2: Actuator configuration for bidirectional motor function (a). Resulting pressure distribution in the actuator air film (b).

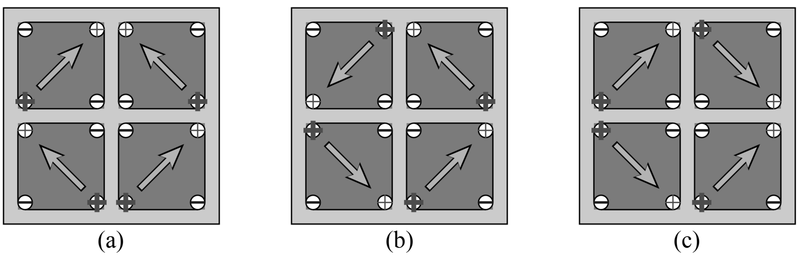

Figure 3: Inlet pressure variations for forces in *x* (a), *y* (b) and torque around *z* (c).

By combining four such cells in a fully symmetric configuration, all in-plane DoFs can be actuated (see Figure 3). Although the out-of-plane DoFs are passively stable, they can also be controlled by controlling the average pressure in each pocket.

Because the four cell configuration can actuate linearly in all degrees of freedom, superposition can be used to tile it into an array. By doing so the total traction on the substrate is increased and the vertical stiffness is distributed more evenly.

3 Experimental setup

The present study extends the previous work in [3] with a new setup (see figure 4), which has the ability to accurately position a 100 mm wafer in the xyθ-plane and align it in the out-of-plane DoFs. A total of 36 actuator cells are combined with 8 proportional valves to provide pressure control. The complex flow routing for these control channels is realized using a 3D printed manifold. Reflectance based optical sensors use edge detection to position the substrate in closed loop control. The system is designed for accelerations up to 1 m/s^2 in both x and y for a 500 µm thick wafer.

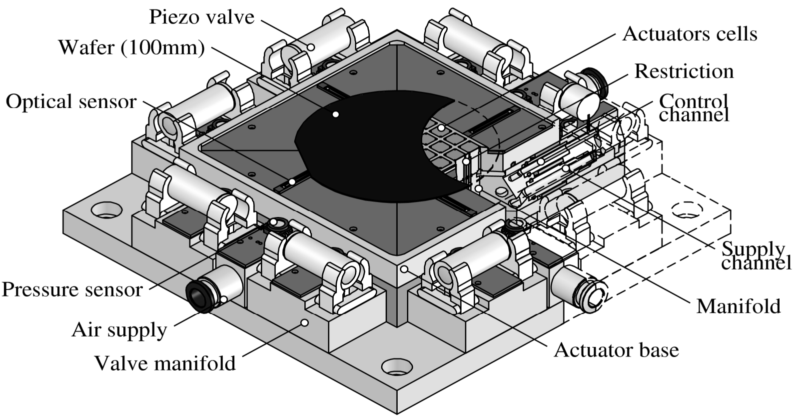

Figure 4: Waferstage test setup for 6 DoFs positioning.

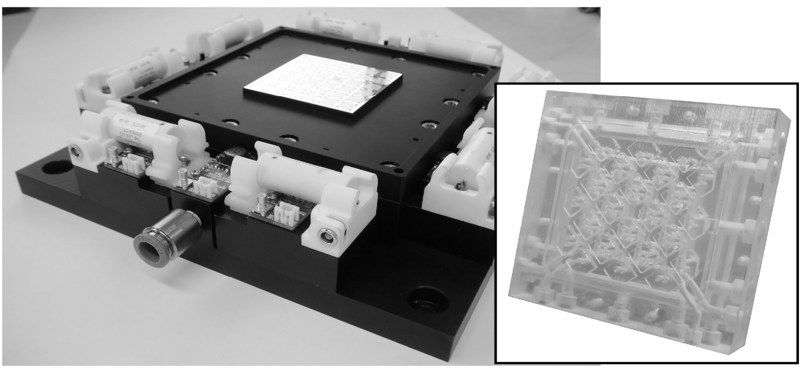

Figure 5: Photo of the experimental setup and 3D printed air supply manifold (insert).

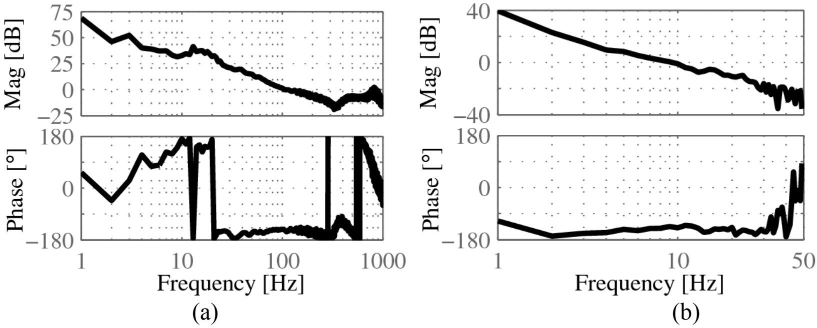

Figure 6: Open-loop frequency response of measured system with controller, for pressure (a) and position (b).

4 Results and discussion

The setup has been realized (see figure 5). Initial experiments show an open-loop bandwidth of 100 Hz for pressure control and 10 Hz for in-plane position control (figure 6). The servo error at standstill is less than 3 µm (1σ). The positioning bandwidth and error are currently limited by saturation of the actuator in combination with sensor noise. By increasing the operating pressure., the saturation will be improved.

5 Conclusions

This paper discusses a new contactless planar position system which uses air flow to provide a motor and bearing function for flat substrates. An experimental setup has been designed and realized with a positioning bandwidth of 10 Hz and a servo error of 3 µm.

Acknowledgement

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References

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