euspen's 22nd International Conference & Exhibition, Geneva, CH, May/June 2022
www.euspen.eu

A hydrogen valve enabling overlay and throughput for EUV

Radu Donose [1], Christian Liedecke [1], Marc Dassen [2], Tao Yang [3], Ece Ozkaya Oge [4], Fer van Maasakkers [5]

[1]ASML Mechanical Development & Engineering, Precision Mechanics group, in the lead of this precision mechanics/mechatronics module
[2]ASML Mechanical Development & Engineering, Mechatronics Wafer Stage Control, responsible for the dynamic simulations and position control
[3]ASML Mechanical Development & Engineering, Mechatronics Wafer Stage Actuators, responsible for the Lorentz motor optimization
[4]ASML Mechanical Development & Engineering, Thermal Analysis, responsible for the structural, thermal and dynamic finite element analysis
[5]ASML Development & Engineering, Test & Measurement Facilities, responsible for the low impact setpoint optimization and for testing

radu.donose@asml.com

Abstract
This paper describes the engineering behind the development of a fast switching and accurate valve for the control of a hydrogen gas intended for temperature conditioning within EUV semiconductor lithography machines. Commonality was a main driver for the design, with the valve being used in all EUV machines of latest generation and in two different applications. The functionality of the valve is explained with emphasis on the design principles that are used to meet the engineering challenges. Lorentz actuation on flexure parallel guiding mechanism with frictionless movement is driving this valve to achieve high bandwidth motion control and no particles generation. The valve is meeting all performance and reliability requirements, with over 200 valves installed inside the EUV lithographic machines and with no reported failures.

Keywords: EUV, semiconductor lithography, hydrogen valve, fast switching, Lorentz actuation, wafer stage

1. Introduction

Developments in the semiconductor industry [1] that is responsible for the design and fabrication of all our electronics play an essential role in the technological advancement of our society. As the largest manufacturer of chip making equipment, ASML is pushing the Moore's law [2] into the next decade by innovating technology that produce semiconductor devices that are evermore performant and economical [3, 4].

A more economical microchip is not only defined by its architectural simplicity but also on how fast it can be manufactured. On the other hand, the performance of the chip is driven by the number of transistors that can fit inside it. As each chip is manufactured by successive exposures of several layers, it is the positioning accuracy of these layers on top of each other that determines the ability to miniaturize the transistors such that more of them can fit in the same area.

The valve presented in this paper is targeting both challenges. For the first application, the production costs are lowered by increasing the wafer throughput. This is realized by reducing the time it takes to swap the wafers. For the second application, the chip performance is improved by improving the overlay which is the positioning accuracy of each layer. This is realized by temperature conditioning at the wafer level with hydrogen gas to reduce the drift introduced by heat loads from various sources. The development of this valve illustrated in Figure 1 has been done from scratch, with no prior history from previous designs. A literature review revealed that there are no valves available on the market that could meet all the requirements for our applications.

The next chapter will describe the main engineering challenges of this design and our development approach. Chapter 3 will reveal the design principles and the benefits they bring. The main qualification results will be shown Chapter 4. Chapter 5 will highlight the main achievements and conclusions.

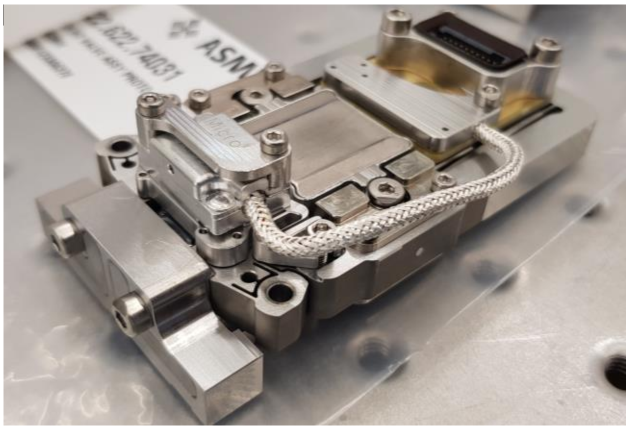

Figure 1. Picture of the developed hydrogen valve.

2. Engineering challenges

The valve had to be developed with a high degree of commonality. It is a business priority because it drives the cost of goods down, minimizing the number of unique parts and the time it gets to bring a new product to market. To keep the high commonality, we had to find solutions for partially contradicting requirements. On one hand the valve must be fast, accurate and in synchronization with the EUV light, on the other hand it must be robust and reliable to withstand the accelerations and magnetic cross talk from the wafer stage. The valve is attached to the wafer stage and thus it has to be as light as possible and as stiff as possible to have a minimum impact on the dynamics.

Conflicting requirements, however, finally led to a partly modular design, where the valve needs different configurations to serve its desired function. Two valve types are distinguished. The first configuration shown in Figure 2 is for wafer throughput improvement. It is 'open loop' actuated because of the existing infrastructure that is without connectivity to a position sensor.

Valve cooling is also not available, thus, a low heat dissipation is required. It operates with end-stop contact, held in position by magnetic force.

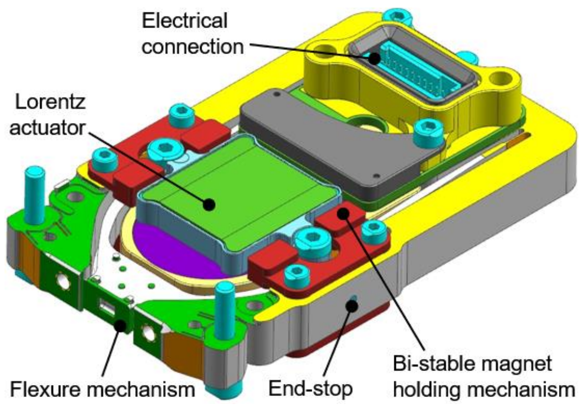

Figure 2. Valve configuration for wafer stage application.

The second valve configuration displayed in Figure 3 is for the wafer temperature conditioning application. An optical encoder is used for closed loop control of the mechanism position. There is no physical contact between the moving parts, enabling fast and accurate switching. The switching frequency of around 30Hz, leads to high actuator heat generation, which is then dissipated into a heatsink.

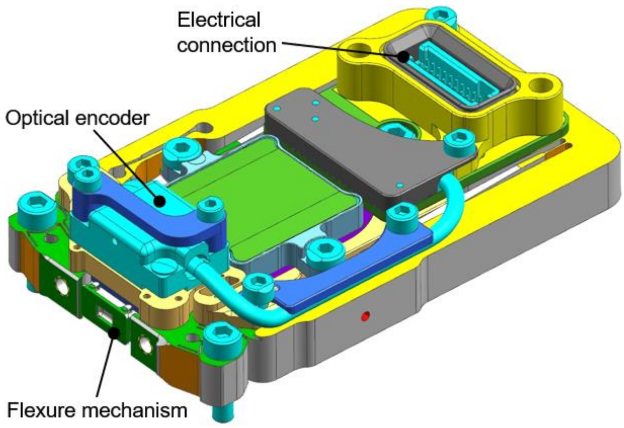

Figure 3. Valve configuration for wafer temperature conditioning.

The main function of the valve is to switch hydrogen supply on and off to two different modules in the wafer stage of all EUV machines of latest generation.

3. Design principles

The main function of the valve is to switch hydrogen supply on and off to two different modules in the wafer stage of all EUV machines of latest generation

3.1. Valve switching principle

A 3/2 valve principle that couples 3 ports with 2 states was chosen. In the supply position illustrated in Figure 4 top panel, the supply chamber is coupled to the channel that goes to the wafer. In the vent position shown in Figure 4 bottom panel, the gas is released to a venting chamber, allowing the gas to escape through an orifice with much lower flow resistance than through the manifold going to the wafer. Switching speed is increased by reducing the valve stroke. In this configuration the supply chamber is closing at the same time with the opening of the venting chamber.

The flow path is kept clean with a contactless seal. Inflow of particles is prevented by maintaining overpressure in the system. Overlap is added in all directions around the contactless seal area to make the flow insensitive to the position disturbances from the actuation or manufacturing and assembly tolerances.

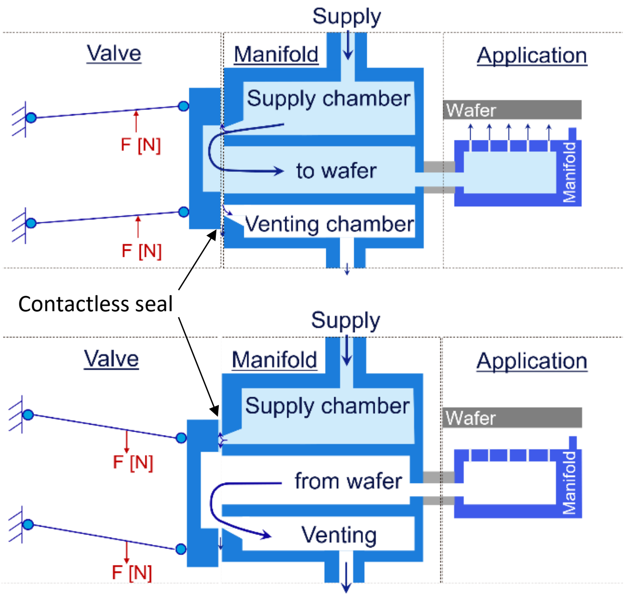

Figure 4. Valve operation principle. Top picture: 'Open' position. Bottom picture: 'Closed' position.

3.2. Valve mechanism design principle

The parallel guiding design principle with flexures is used for the valve movement for an accurate and contactless flow switch. The flexure indicated by the compliant beam in Figure 5 is designed with a nonlinear radius for an uniform stress distribution. The moving part of the valve, indicated by the guiding plate, is the complete area highlighted with red. Stavax material was chosen because it provides the best fatigue resistance for this application. The mid-section between the hinges is reinforced to achieve a high control bandwidth.

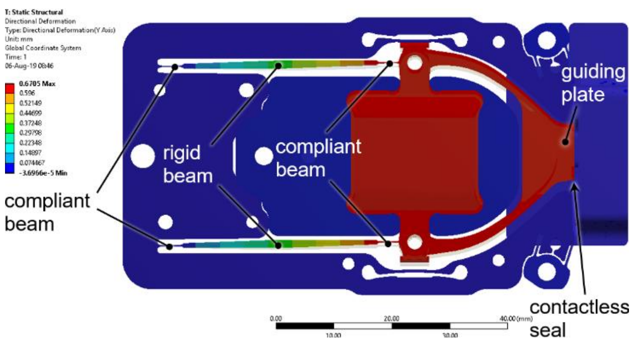

Figure 5. Valve moving mechanism.

To fit in the available space in the wafer stage, the valve must have a compact, light and planar design. Most interfaces were embedded into a single monolithic structure highlighted in Figure 6 that is optimized for manufacturing.

The flexures are made from the same part as well. The interfaces are designed to be machined as much as possible in the same clamping and in the same machining step. This way tight tolerances are achieved at reduced cost.

The compact, light, planar design could not be achieved without the use of stiffening by closing the box design principle. Having the valve mechanism at the center of the valve, created a C-shape structure that is too compliant. The manifold was attached directly to it, stiffening the design while keeping the mass and volume low. The same principle was applied to the valve mechanism. The compliancy between the two guiding beams is still too high to secure the seal gap uniformity. This was solved by adding stiffness directly by the structure of the magnet yokes.

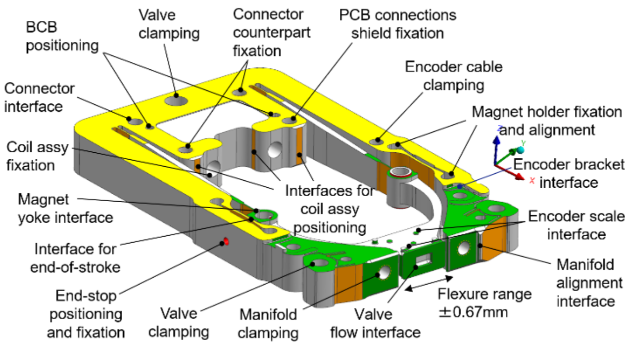

Figure 6. Valve interfaces in one monolithic structure.

Also, to maintain the seal gap uniformity, the thermal center clamping principle was used. The bolts connections at the back of the valve provide a rigid fixation for dynamics. The two interfaces at the front of the valve are decoupled by flexures to accommodate for the differential expansion between the valve and the attachment interface during transport and operation. The flexures are oriented 90° towards the rigid interface.

3.3. Valve actuation

Lorentz actuation principle presented in Figure 7 was chosen because it provides high stroke, high bandwidth for position control while maintaining a compact size. The choice to have a non-moving coil was taken to allow water cooling. The principal and moving magnets thus are moving. The magnetic flux generated by the magnets is compressed by the back irons to reduce mass and increase actuation efficiency.

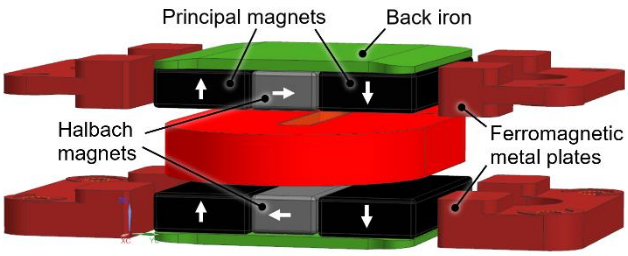

Figure 7. Lorentz actuator design.

For the wafer stage the same actuator is used with the addition of 4 ferromagnetic metal plates. The magnetic fields from the magnets are closing through these plates and this way the magnetic position locking function is realized. This addresses the low heat dissipation requirement by not powering the valve in between switches.

As the valve operates in between end stops, the impact load needs to be reduced to reduce wear, particles generation and improve lifetime. The smart switching setpoint indicated in Figure 8 as 'Low Impact Speed Current Profile' has been developed for this purpose.

After an initial pulse to trigger valve movement, a break pulse is applied in 2 stages to slow the valve down. In the end, a longer uniform pulse is applied to prevent the valve from bouncing back. The setpoint is tuned to be robust for most disturbances including valve manufacturing tolerances.

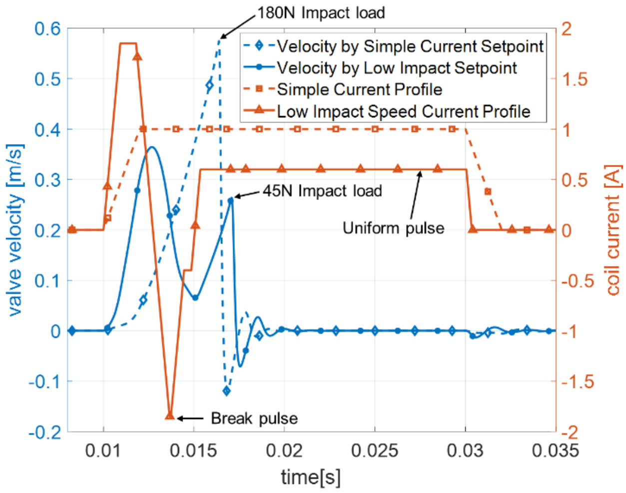

Figure 8. Valve switching velocity and the switch current setpoint profile.

The valve switching velocity plotted in Figure 8 has been measured with the optical encoder attached to the valve. The switching behavior with the simple current profile is plotted with dashed line and the low impact setpoint profile with solid line. The impact load is calculated from the moving mass of the valve known by design, multiplied by the acceleration extracted from the valve position measurement. The smart setpoint reduced the impact load by a factor 4.

Figure 9 shows the voltage on the coil, the current and power dissipation during a switching cycle for the wafer temperature conditioning application.

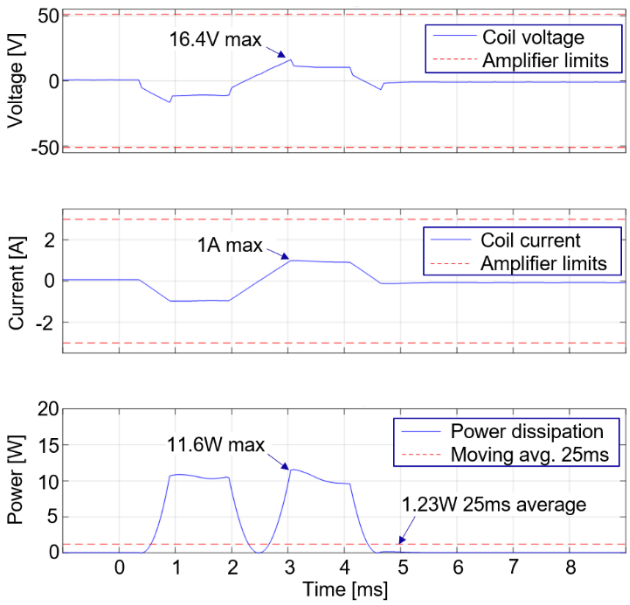

Figure 9. Actuator performance.

Most power is generating during switching to achieve the high acceleration of the valve mechanism and magnet yokes. In between switches, the actuator is also powered to maintain a constant and repeatable position. The average power dissipation over a switching cycle is 1.23W.

For the closed loop position measurement of the valve, an encoder is used. It is designed to respect the Abbe measurement principle. It measures very close to the point of interest achieving a minimum position error. The encoder head attached to the fixed part of the valve and the scale is glued to the moving mechanism. The center of force is very close to the center of gravity. There is a low rotation error because the flexures are far apart and a high tilt stiffness given by the closed box principle explained above.

Very critical for the flow switch uniformity is the valve position at the end of the stroke. The maximum position error is 1um within 5ms from the start of the position change as can be seen in Figure 10.

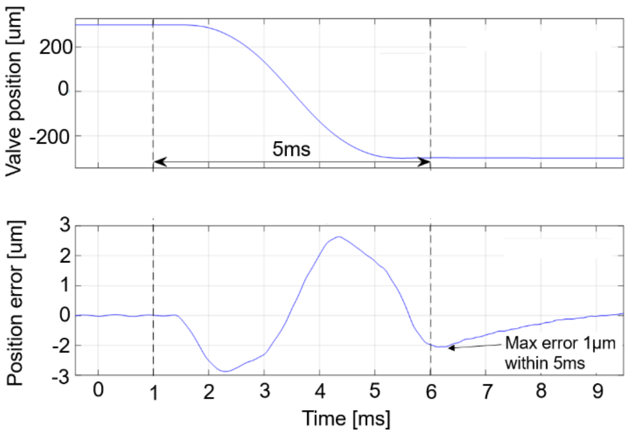

Figure 10. Valve position in closed loop control.

4. Measurement results

For the wafer temperature conditioning application, the flow pressure switching behavior characterization has been done with hydrogen gas in a lab setup environment replicating similar flow geometry and pressure conditions as in the real machine. As the machines operate in vacuum it is the pressure switch timing that is relevant for the temperature conditioning performance and not the flow itself. The area of interest is indicated by the small arrows below the wafer from Figure 4 top.

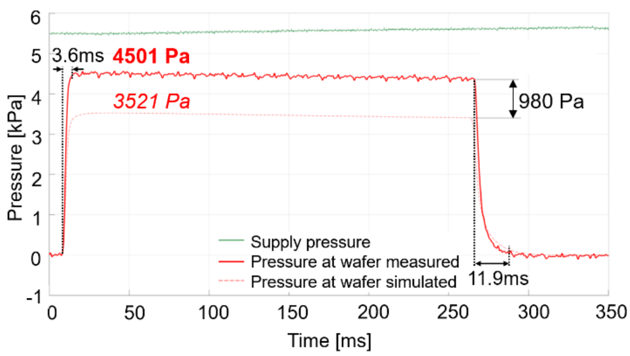

Figure 11. Flow pressure switching behaviour for wafer temperature conditioning application.

The optimization of the system as well as the valve dimensioning has been done with a flow model. Measurements displayed in Figure 11 of the flow switch time for both opening and closing are in good agreement with the model. There is a pressure offset however between the model and measurements of 980 Pa. This value can be easily corrected in the machine by adjusting the pressure at inlet to the desired value.

For the wafer stage application, the flow characterization has been done in the actual machine with and without the newly developed valve. The valve is directly contributing to the wafer throughput improvement by shortening the time it takes to reduce the hydrogen pressure. Figure 12 plots the pressure versus time when the valve is closing the hydrogen circuit. A gain of over 1.2s is measured for every wafer exchange, bringing a significant contribution to the manufacturing time of the microchips.

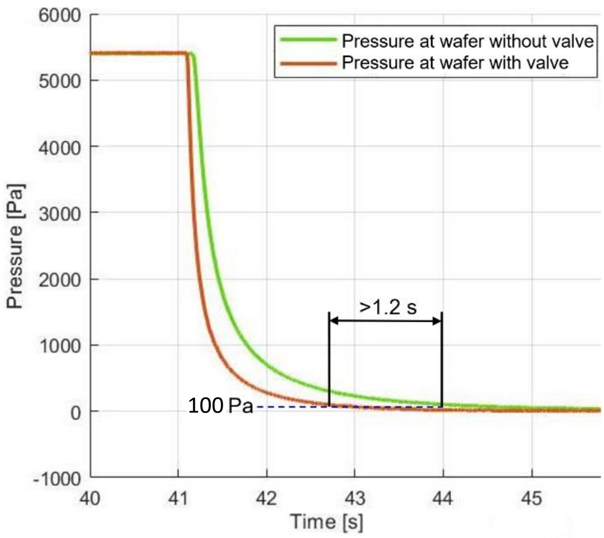

Figure 12. Flow pressure switching behaviour for wafer stage application.

Reliability of the valve has been proven with accelerated lifetime testing on several valves with 200x increase of switching frequency and 20% increase in current. The valves have been tested to over 10x the required number of cycles during a lithographic machine lifetime. No failures have been observed.

5. Conclusions

A valve for switching hydrogen gas has been designed, manufactured and tested for EUV semiconductor machines. Aiming for a first-time right design we achieved a fast development time, one year from sketch to operation at customers machines. Commonality has been achieved by a partially modular design that reduced costs and development time. The valve is designed with no contact between moving parts to prevent contamination of the hydrogen gas. The Lorentz actuator design and optimization for low mass, enables the valve to achieve very high switching speeds of less than 5ms. For the wafer stage application, a very stable position control is achieved by using a measurement system with closed loop control, reaching maximum 1µm position error within 5ms. For the wafer temperature conditioning, an end stop design with magnetic locking is keeping the valve in stable open or close position with an average power dissipation of <30mW. A smart setpoint control has been developed to reduce the impact load on the end stops during switching from 180 to 45N. A throughput improvement of 9 wafer per hour is achieved. At the moment there are more than 200 valves installed at the customers machine with no failure reported so far.

In the future the valve will be integrated in the wafer temperature conditioning application to secure the overlay reduction roadmap that will continue Moore’s law into the next decade.

References

[1] https://irds.ieee.org/topics/future-of-semiconductor-performance, *IEEE IRDS™*

[2] Moore G 1965 Cramming more components onto integrated circuits *Electronics* **38** 8

[3] ASML https://www.asml.com/en/company/about-asml

[4] Raaijmakers R 2018 ASML’s architects *Techwatch Books*