Micro-fluidic Thermoactuator Exhaust Valve with Electrostatic Latching

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Abstract:

This paper presents the design, fabrication, and analysis of a microfluidic exhaust valve leveraging thermal actuator arrays and electrostatic forces to address common challenges of fluid leakage in MEMS devices. The thermal actuators, adapted from the work of Comtois and Bright (1997), are configured into a yoke array to deliver a sufficient force, ensuring secure blockage of the fluidic channel. An electrostatic latching mechanism, inspired by the Scratch Drive Actuator (SDA) concept by Akiyama, Collard, and Fujita (1997), enhances the seal by applying a voltage-controlled force on the metal layer. Utilizing the MUMPS process, the device incorporates a gold chromium metal layer to facilitate electrostatic attraction for precise fluid control. This approach demonstrates the integration of thermal and electrostatic actuation to achieve robust sealing in microfluidic devices.

I. Introduction

Microfluidics has been fundamental in both the development and functionality of Microelectromechanical systems (MEMS). Having precise handling of fluids at the micron scale has revolutionized the application across various fields, from healthcare to industrial monitoring. The integration of microfluidics into MEMS devices has enabled compact, efficient, and multifunctional systems such as the ability of sensing, actuating, and having fluidic control all in a single microscale device. An example of these microscale devices in MEMS include the inkjet printer heads, highlighting the impact of microfluidics on a large-scale commercial setting. The versatility of microfluidic control using microfluidic valves and pumps plays a vital role in the evolution and application of MEMS.

Our project will focus on the utilization of thermal actuator arrays for the actuation of an exhaust valve. We will use a thermal actuator array structure adapted from the work of Comtois and Bright (1997), who demonstrated the application of electro-thermal actuators in various micromechanical devices, including actuator arrays and micromotors. We also utilized electrostatic forces to act as a latching mechanism to help eliminate the issue of fluid leakage, a major issue that all microfluidic devices must consider. We will use a similar technique for maintaining electrostatic attraction found in the work done by Akiyama, Collard, and Fujita (1997), who developed a scratch drive actuator that was used to create small precise movements and later was used within micro-robotics and optics.

II. Concept, Principle

Attached to the six thermal actuator array structure will be an extended beam with a triangular tip. The triangular tip will be utilized to plug the microfluidic channel, which we are interested in exhausting.

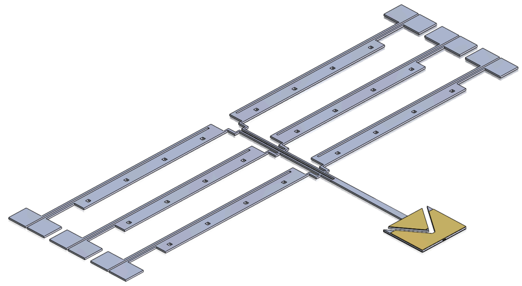


Figure 1: 3D CAD showcasing the six thermal arrays attached to the beam structure

Additionally, on top of the plug and the microfluidic channel will rest a deposited gold metal layer, as seen in Figure 2, which will enable the use of electrostatic forces to further enhance the seal between the triangular tip and the channel, acting as a latching mechanism. The use of the thermal actuators and electrostatic attraction will enable us to control the exhaust for any fluid within the channel and try to mitigate the issue of micro-fluid leakage present in many memes fluidic devices.

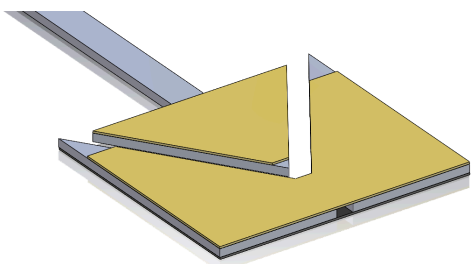
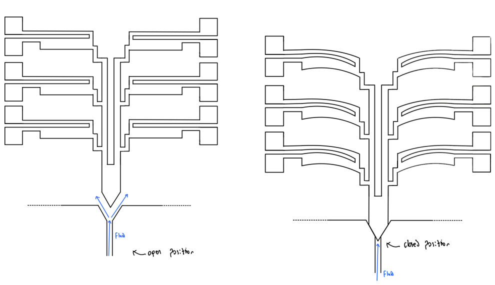


Figure 2: Close up of 3D CAD showing a gold layer which will be used to induce electrostatic force. Rectangular hole seen represents the fluidic channel.



Figures 3 and 4: Sketch of the structure when the channel is open, allowing fluid flow, and when the channel is closed, halting fluid flow.

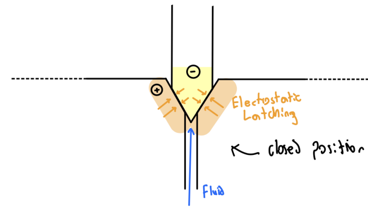


Figure 4: Sketch of the structure during electrostatic latching.

<u>III. Schematic Figure, Design & Fabrication Process</u>

The fabrication of our exhaust valve requires only five masks in the MUMPS process.

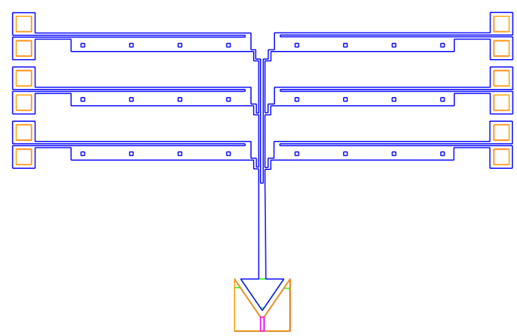


Figure 6: Schematic figure of all masks necessary for MUMPS manufacturing process (Following manufacturing process below for mask order)

We ensured that all components comply with the MUMPS two-micron design rule, which provides ample resolution for our assembly. Additionally, we adhered to the requirement where the gap between the anchor and Poly 0 is 4 µm. The masks, illustrated in Figures 6 and 7, include the Poly 0 bright mask (red), the Poly 0–1 Via dark mask (orange), the Poly 1 bright mask (blue), the Oxide 2 via a bright mask (pink), and the metal bright mask (green).

Manufacturing Process:
Deposit Poly 0
Red - Poly 0 Bright Etch [Mask #1]
Deposit Oxide 1
Orange - Poly0 - Poly 1 Via Dark [Mask #2]
Deposit Poly 1
Blue - Poly 1 Bright Etch [Mask #3]
Deposit Oxide 2
Orange - Oxide 2 Via Bright [Mask #4]
Deposit Metal
Green - Metal Bright Etch [Mask #5]
(gold-chromium alloy)

Mask breakdown:

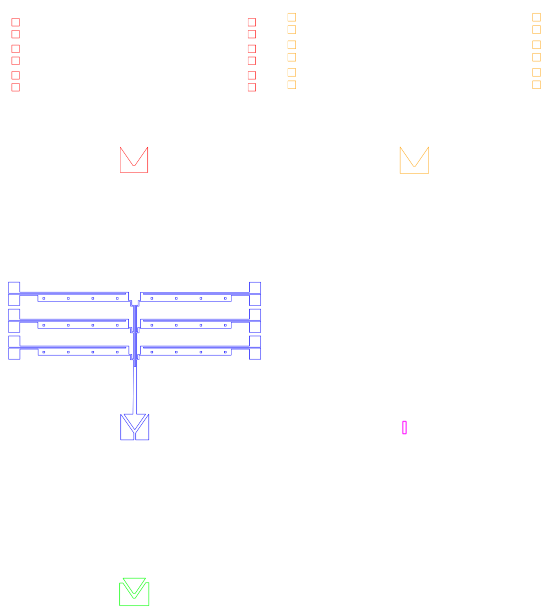


Figure 7: The five masks which will be used during the manufacturing process to create the structure. Colors of masks explained in the manufacturing process prior.

IV. Analysis & Discussions

A lateral thermal actuator with dimensions “'hot' arm 2.5 µm wide, 240 µm long; 'cold' arm 16 µm wide, 200 µm long; flexure 2.5 µm wide, 40 µm long, and gap 2 µm wide can achieve deflections of 16 µm at 3 V and 3.5 mA” was adapted (Comtois and Bright, Fig. 1). The paper states that 4.4 µN force was delivered at 8 µm on deflection, noting that these actuators can deflect up to 16 µm at the tip when unloaded. Since we have a yoke array consisting of six individual thermal actuators connected through a connector beam, at a deflection of 8 µm we can assume a minimum of 26.4 µN total force. Additionally, if we impose back-bending, it can deliver more force; each actuator will be able to produce 15.5 µN at a deflection of 8 µm. The combination of the yoke thermal actuator configuration and the back bending process allows our triangular exhaust tip to exert 93µN at a deflection of 8µm.

To utilize all the force possible, the thermal actuator array travels a distance of 8 µm between its off and on positions, eventually contacting the channel walls to plug the microfluidic channel. At full extension, the yoke thermal actuators generate a force of 93 µN, which will cause the triangular tip to be forced into the 4 µm wide fluidic channel (larger width channels may also be implemented), allowing the force to be evenly distributed to create a secure seal and block the exhaust port.

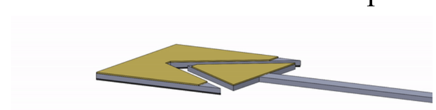


Figure 8: Shows the sealing and blockage of the exhaust port once the thermal actuator array is activated.

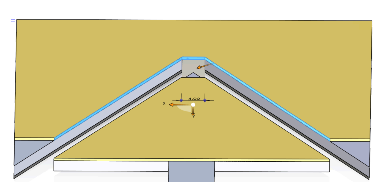


Figure 9: The highlighted region in blue is the area that will make contact with the triangular plug, maintaining a stronger seal.

To ensure a further seal, we will now look into the use of electrostatic forces to attract the faces shown in Figure 9 in blue to the triangular tip using concepts from paper 6. The Scratch Drive Actuator (SDA), as highlighted in paper 6, operates by cyclically applying and removing voltage to generate controlled motion. A voltage pulse creates an electrostatic force that pulls the actuator downward, causing a small forward step. When the voltage is removed, elastic restoring forces lift the actuator slightly, breaking contact. This design avoids issues like stiction and ensures precise, repeatable motion, making the SDA effective for various MEMS applications. The method of creating and maintaining electrostatic attraction is especially useful in our case when trying to plug the channel.

Within the paper, it mentions that it is possible to achieve a wide range of forces, including the millinewton scale which is used within our application. The paper highlights how a setup with 112V can achieve a horizontal force of 63 millinewtons. Since the electrostatic force between the surfaces is proportional to the square of the voltage applied, we can achieve a very precise, controlled level of force needed to create a strong enough seal to prevent leakage.

We have not yet incorporated or considered the necessary circuitry in the masks needed to activate the thermal actuator array, and we anticipate difficulties due to the requirement for vertically protruding channels. In addition, we have not determined an effective channel-based method to apply voltage across the metal layer; if needed, we may resort to using probes. Further computational models are required to simulate fluid flow and ensure a proper seal. Since we will be applying substantial force to block the fluid, there is a concern that we may damage the polysilicon channels over time.

V. Conclusion

This project demonstrates the successful integration of thermal actuator arrays and electrostatic latching mechanisms to address fluid leakage in microfluidic MEMS devices. By employing a yoke thermal actuator array to generate precise forces and leveraging electrostatic attraction to enhance sealing, we developed a robust and efficient microfluidic exhaust valve that can be manufactured using MUMPS. The combination of thermal and electrostatic actuation ensures a secure seal of the fluidic channel and highlights the potential for precise, electronically controlled systems in MEMS applications. Future work will focus on refining the wiring for actuator arrays and electrostatic contacts to further enhance the system's scalability and performance, and fluid simulations will be run to confirm our findings.

VI. References

Comtois, John H., and Victor M. Bright. “Applications for Surface-Micromachined Polysilicon Thermal Actuators and Arrays.” *Sensors and Actuators A: Physical*, vol. 58, no. 1, 1997, pp. 19–25.

Akiyama, Terunobu, Dominique Collard, and Hiroyuki Fujita. “Scratch Drive Actuator with Mechanical Links for Self-Assembly of Three-Dimensional MEMS.” *Journal of Microelectromechanical Systems*, vol. 6, no. 1, 1997, pp. 10–17.