DESIGN AND INVESTIGATION OF A THERMAL ACTUATOR

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Recently, there is tremendous interest in Micro Electro Mechanical Systems (MEMS) technology. MEMS refer to a collection of microsensors and actuators that can sense environment and have the ability to react to changes, with the use of a microcircuit control. Microelectromechanics have accomplished phenomenal growth over the past few years, due to rapid advances in theoretical developments, experimental results and high-performance compute design software.

Thermal actuation has been extensively employed in MEMS. It includes a broad spectrum of principles, such as thermal pneumatic, shape memory alloy (SMA) effect, bimetal effect, mechanical thermal expansion, etc. Thermal actuators can generate relatively large force and displacement at low actuating voltage.

Keywords: MEMS, Thermal actuator, Surface micromachining, PolyMUMPs

1. INTRODUCTION

MEMS motion and actuation has traditionally been achieved electrostatically, using comb-drive or parallel-plate actuation techniques. While successful, this actuation method typically provides a small force per unit area and requires a high actuation voltage. Surface micromachined electro-thermo-mechanical actuator designs can overcome these disadvantages, providing a 100X higher output force, 10 X lower actuation voltages and large motion.

Surface-micromachined thermal actuators use constrained thermal expansion to achieve amplified motion. Most commonly, the thermal expansion is caused by Joule heating, passing a current through thin actuator beams. There are two different thermal actuator designs that have been demonstrated and commonly used in the literature, the pseudo-bimorph or “U” shaped actuator (horizontal), and the bent-beam or “V” shaped actuator (vertical).

The two basic techniques used in MEMS are bulk and surface micromachining. In bulk micromachining structures are etched into silicon substrate. In surface micromachining, the micromechanical layers are formed on the surface of the substrate, in the form of layers and films deposited. The technology used in this paper, is called PolyMUMPs (Poly Multi-User MEMS Processes). The PolyMUMPs process is a three-layer polysilicon surface micromachining process [1].

2. DESCRIPTION OF THE THERMAL ACTUATOR

The *U*-shaped actuator converts electrical to mechanical energy through ohmic heating and the thermal expansion of polysilicon. Applying a voltage to the actuator causes more resistive heating in the narrow than in the large arm, due to the higher current density in the hot arm. As the hot-arm temperature increases the arm extends and this extension causes lateral motion of the actuator tip. Thermal actuators have some advantages over other microactuation methods: they provide fairly large forces (on the order of a few micro-Newton, μN) and large displacements at CMOS compatible voltages and currents [3]. A typical thermal actuator is shown in Fig. 1. In the thermal actuator, the hot arm is usually thinner than the cold arm, so the electrical resistance of the hot arm becomes higher than the cold arm. When an electric current passes through the cold and hot arms, the heat generated in the hot arm is much more than that of the cold arm. It causes that the temperature of the hot arm to become much higher than that of the cold arm. Since the cold and hot arms are made of the same material and same thermal expansion coefficient, the temperature difference causes the hot arm to expand more than the cold arm. This results in the rotation of the actuator [2].

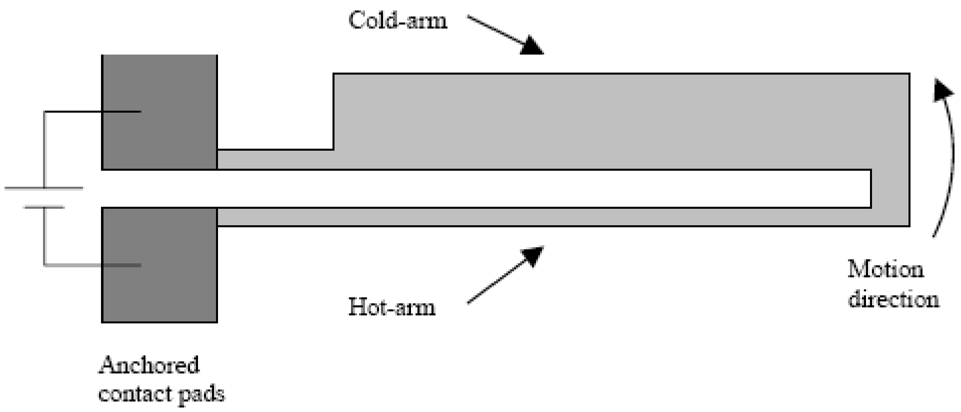


Figure 1 - Structure of the thermal actuator

The technology used in the production of the thermal actuator is called PolyMUMPs. The Multi-User MEMS Processes (MUMPs®) is a commercial program that provides cost-effective, proof-of-concept MEMS fabrication to industry, universities, and government worldwide. Fig. 2 is a cross section of the three-layer polysilicon surface micromachining PolyMUMPs process. This process has the general features of a standard surface micromachining process: (1) polysilicon is used as the structural material, (2) deposited oxide (PSG) is used as the sacrificial layer, and silicon nitride is used as electrical isolation between the polysilicon and the substrate. The process is different from most customized surface micromachining processes in that it has to be capable of supporting many different designs on a single silicon wafer [1].

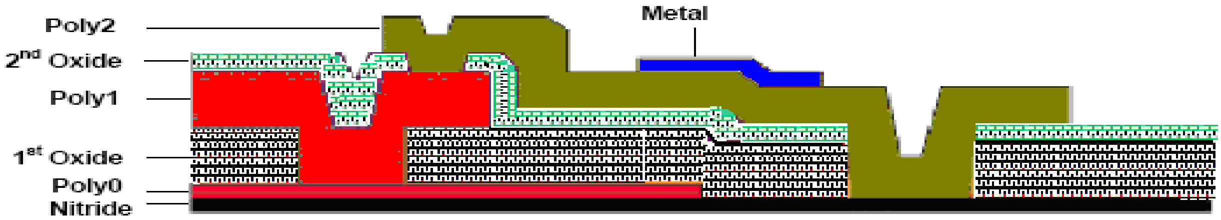


Figure 2 - Cross sectional view, showing all 7 layers of the PolyMUMPs process

After all technological steps of layer deposition, the structure is shown in Fig.3. The final structure, after removing of sacrificial layers, is graphically presented in Fig.4.

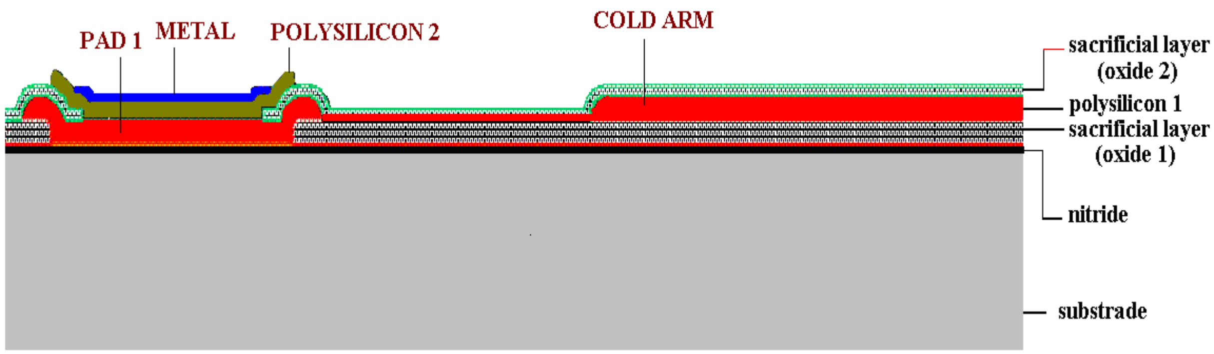


Figure 3 - Cross section of the thermal actuator

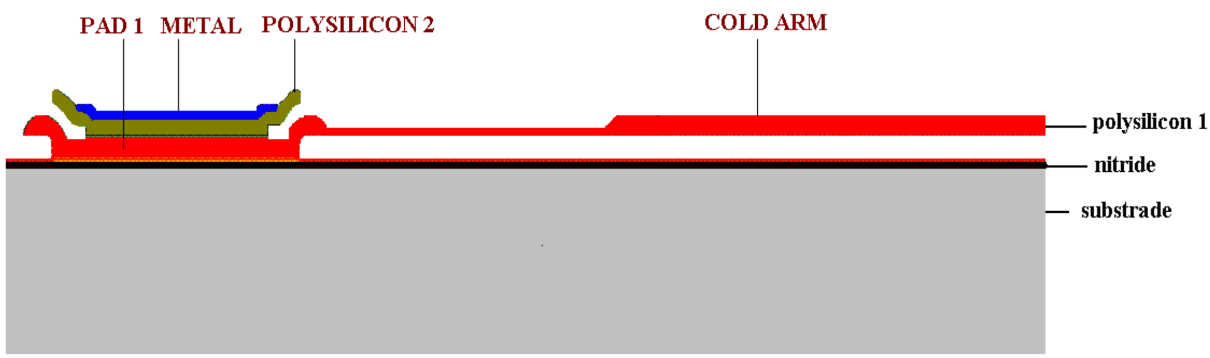


Figure 4 - Topology with removed sacrificial layers

All analyses are made with the help of SoftMEMs and ANSYS CAD systems. The SoftMEMs CAD Design Environment is a customizable set of CAD tools for the development and test of MEMS-based products. SoftMEMs CAD tools are products that support leading electronic design automation environments used for integrated circuit development. The applied tool suites enable designers to develop new MEMS designs and integrate existing designs into systems [4].

ANSYS Multiphysics software is a comprehensive coupled physics tool combining structural, thermal, computational fluid dynamics (CFD), acoustic and electromagnetic simulation capabilities in a single engineering software solution. Multiphysics simulation allows engineers and designers to evaluate their designs operating under real-world conditions. The ANSYS Multiphysics solution allows engineers and designers to simulate the interaction between structural mechanics, heat transfer, fluid flow, acoustics and electromagnetics all within a single software product [5].

3. Design of the Thermal Actuator

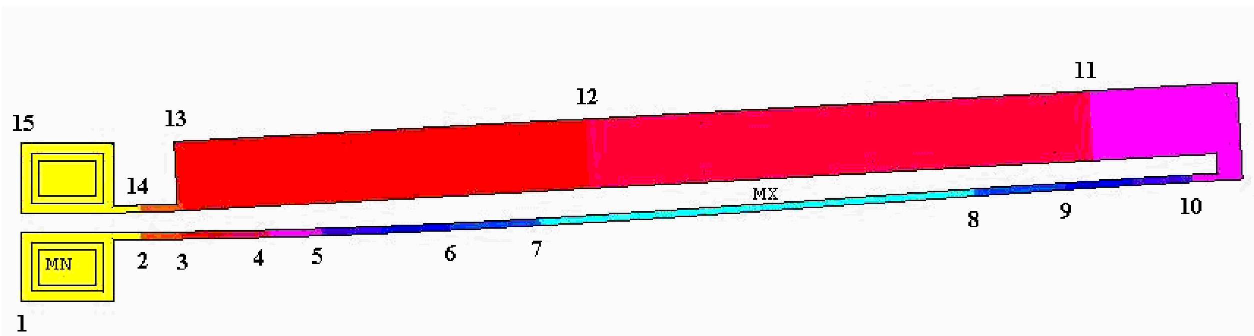
The derived results were received by analyzing of structure of the thermal actuator with dimensions, shown in Table 1. The performance of the designed actuator is investigated with ANSYS tool. First of all the material property values for polysilicon had to be defined. They are shown in Table 2. The next step is to mesh the model. The actuator is meshed on thousand pieces which have tetrahedral shape. This helps easier the analysis of the model. All analyses of the thermal results, made for the actuator, are demonstrated in Fig. 5.

Hot arm length	495 μm
Hot arm width	2 μm
Cold arm length	470 μm
Cold arm width	30 μm
Arms separation	10 μm
Connecting bar width	10 μm
Pad length	40 μm
Pad width	30 μm

Table 1 - Design results of the thermal actuator

Young's modulus	169 GPa
Poisson's ratio	0.22
Thermal Expansion Coefficient	$2.9e^{-6}$/°K
Thermal Conductivity	$150e^{6}$ W/μm°K
Resistivity	$2.3e^{-11}$ Ω-μm

Table 2 - Polysilicon material properties

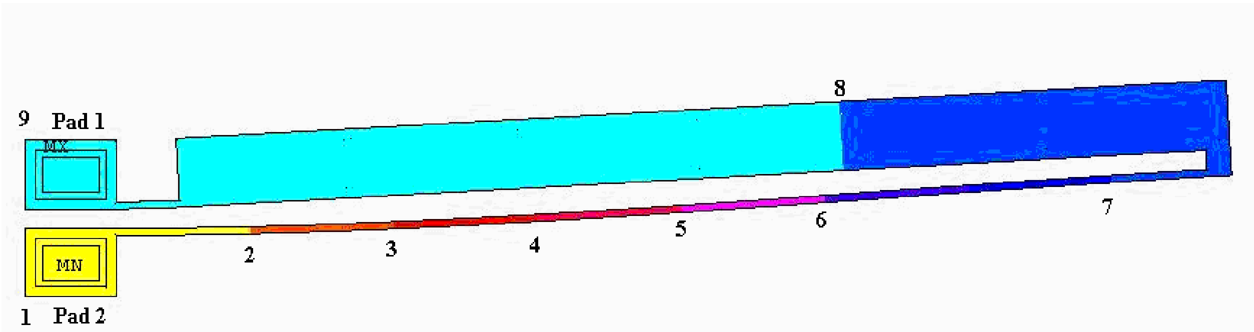


Point	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9
Temperature, °C	30	130	231	432	533	734	835	734
Point	9-10	10-11	11-12	12-13	13-14	14-15		
Temperature, °C	633	432	331	231	130	30		

Figure 5 - Thermal analysis

The electrical connection pads are at the same temperature. It reflects the constant temperature boundary condition. The voltage difference across the pads causes a temperature difference across the blade (cold arm). The thin arm is at higher temperature than the blade.

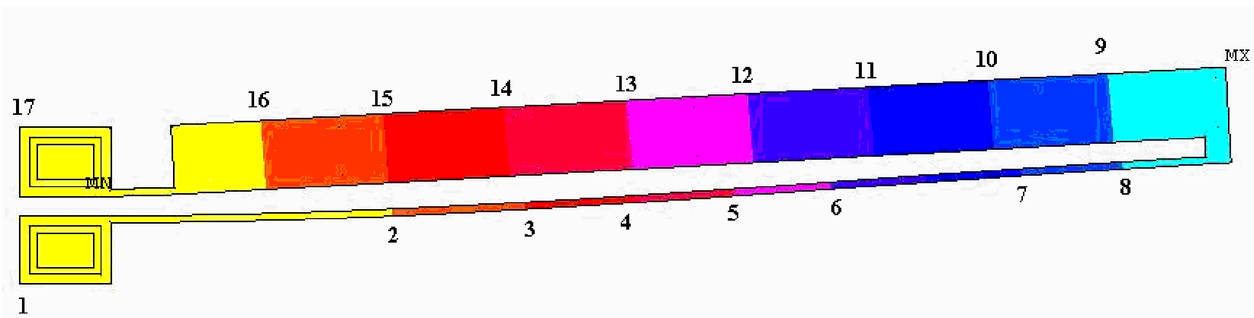
The electrical contact pads in Fig. 6 are connected to two different voltage values. To pad 1 is applied 5V, and 0V to pad 2. The voltage drops from pad 1 to pad 2. It is distributed alongside the electrical conduction path of the actuator.



Points	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9
Voltage, V	0	0.55	1.11	1.67	2.22	3.33	3.89	5

Figure 6 - Voltage distribution

In Fig. 7, the pads are constrained in all directions. The connection pads are firmly fixed to the substrate. The actuator is moving mostly in the area between points 8-9. The displacement is nearly 17 μm.



Points	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9
Displacement, μm	0	1.9	3.9	5.9	7.9	9.9	13.9	18
Points	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17
Displacement, μm	13	12	9.9	7.9	5.9	3.9	1.9	0

Figure 7 - Displacement results

4. CONCLUSION

This work demonstrates a design of a thermal actuator. The simulations are performed using ANSYS and SoftMEMs CAD systems. A parametric coupled physics model has been developed and validated for predicting the performance of a surface micromachined MEMS electro-thermal actuator. This model is useful in the design of customized actuators for specific applications.

5. ACKNOWLEDGEMENT

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6. REFERENCES

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