Methods for Real Time Measurement of Y-Displacement of the MEMS Horizontal Thermal Actuator

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Abstract - **MEMS motion and actuation, traditionally has been achieved, using electrostatical 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 100 times higher output force, 10 times lower actuation voltages and large motion.**

In this work, three methods of Y-displacement measurement of a horizontal thermal actuator are designed.

Keywords - **MEMS, Thermal actuator, Surface micromachining, PolyMUMPs, measurement of displacement.**

I. INTRODUCTION

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 computer 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.

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) [1].

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 silicon Multi-User MEMS Processes). The PolyMUMPs process is a three-layer polysilicon surface micromachining process [2] [1].

Three methods of Y-displacement measurement are examined. The first one is an optical method; the second one is a mechanical method and the third one is a capacitive method.

II. 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 (hot), than in the large (cold) arm, due to the higher current density in the hot arm. Thermal actuators have some advantages over other microactuation methods: they provide fairly large forces (few micro-Newton, μN) and large displacements at CMOS compatible voltages and currents [4]. A typical thermal actuator is shown in Fig. 1. In the thermal actuator,

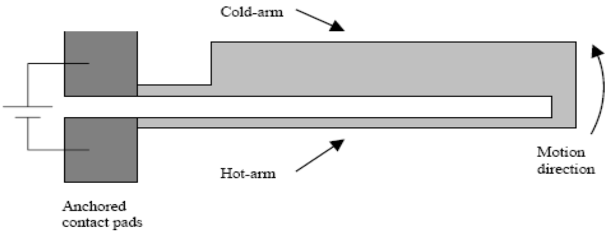

Figure 1. Structure of the thermal actuator.

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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 higher than in the cold arm. It causes a temperature difference between the hot and cold arms. Since the cold and hot arms are made of the same material, with the same thermal expansion coefficient, this causes the hot arm to expand more and this extension causes lateral motion [3] [1].

The MEMS technology used is PolyMUMPs. The Multi-User MEMS Processes (MUMPs®) is a commercial program that provides cost-effective, proof-of-concept MEMS fabrication to industry, universities, and governments worldwide. Fig. 2 shows a cross section of the three-layer polysilicon surface micromachining PolyMUMPs process. This process has the general features of a standard surface micromachining process. Polysilicon with properties, shown in Table 1, is used as the structural material. Deposited phosphor-silicate-glass (PSG) oxide is used as the sacrificial layer, and silicon nitride is used as electrical isolation between the polysilicon and the substrate.

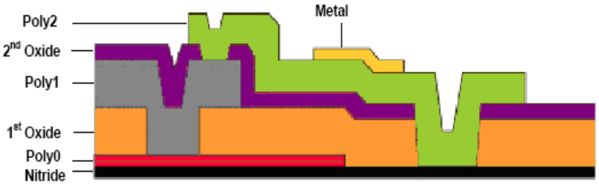

Figure 2. Cross sectional view of all 7 layers in the PolyMUMPs process

TABLE 1. POLYSILICON MATERIAL PROPERTIES

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

III. METHODS FOR MEASUREMENT OF Y-DISPLACEMENT

TABLE 2. DIMENSIONS OF THE EXAMINED THERMAL ACTUATOR

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

The examined methods are applied on a thermal actuator with dimensions, shown in table 2. Few FEM analyses are made, such as displacement on Y (motion direction on Fig.1), electrical, temperature and stress analyses. Table 3 contains some of those results. The power supply is 5 V and the temperature is 30 °C.

TABLE 3. ANALYSES RESULTS OF THE EXAMINED THERMAL ACTUATOR

Maximum displacement on Y-direction	19.9 µm
Maximum temperature created from hot arm	935.8 °C
Maximum intensive stress	206 MPa

A. Optical method

In this method, the movement (displacement) of the actuator is observed with optical microscope. Fig. 3 presents the geometry of the actuator and the ruler. The ruler fingers are 5 µm thick (on Y-direction) with gap of 5 µm between.

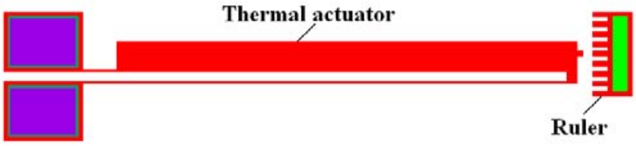

Figure 3. Optical method for thermal actuator displacement measurement, using thermal actuator on Poly1 and ruler on Poly1 layers

B. Mechanical method

One auxiliary structure on distance ΔY from the actuator is created (Fig. 4). ΔY is the maximum displacement of the actuator, which value is 19.9 µm. The resistance between the actuator pads and this auxiliary structure decreases significantly, when a contact is established.

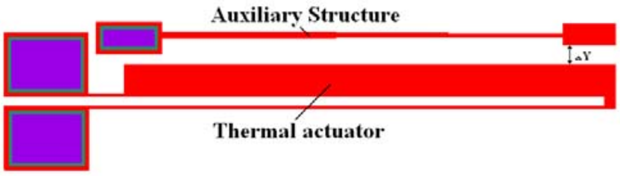

Figure 4. Mechanical method for thermal actuator displacement measurement, using thermal actuator on Poly1 and auxiliary structure on Poly1 layer

This method detects only two states (ON and OFF). For precision displacement detection, an optical or a capacitive method is recommended.

C. Capacitive method

Again, an auxiliary structure is needed and deposited on a polysilicon layer Poly0, covered by the actuator's geometry with 2 µm gap (d on Fig. 6) between them. This layer is used as a static electrode. The actuator arms are the other movable capacitor's electrode (Fig. 5, Fig. 6). When there is no potential difference, applied between the actuator pads, it is in position of maximum overlapping (Poly0 - Poly1), and the capacitor area is $S_0=1.5119\text{x}10^{-8}$ m^2. In this case, the maximum value of the capacity is measured ($C_0=0.06693$ pF). When the actuator is displaced to the maximum value of $\Delta Y=19.9$ µm, the capacitor area becomes $S_1=1.0443\text{x}10^{-8}$ m^2 and the capacity decreases to $C_1=0.04623$ pF. The difference on the capacities are $\Delta C=C_0-C_1=0.0207$ pF. ΔC is proportional to the actuator's displacement.

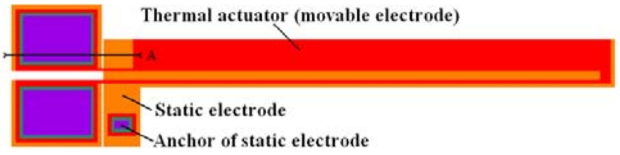

Figure 5. Capacitive method for thermal actuator displacement measurement, using thermal actuator on Poly1 and auxiliary structure (static electrode) on Poly0

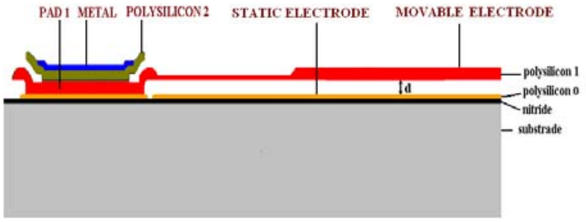

Figure 6. Cross section of the structure for the capacitive method for thermal actuator displacement measurement

All analyses are made with SoftMEMs and ANSYS CAD systems. The SoftMEMs CAD Design Environment is a customizable set of CAD tools for 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 to integrate existing designs into systems [5] [1].

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 [6][1].

IV. CONCLUSION

This work demonstrates the design of additional elements to the thermal actuator, in order to have the possibility to use three different methods of displacement measurement. The design and the simulations are performed using SoftMEMs and ANSYS CAD systems.

V. ACKNOWLEDGEMENT

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