Design and Analysis of MEMS Variable Capacitor Driven by Vertical Electro-thermal Actuators

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Abstract – **The electromagnetic force that is most commonly used in microactuators is not the only driving force. A MEMS variable capacitor could be driven by vertical thermal actuators. Thermal actuators can generate relatively large force and displacement at low actuating voltage. The MEMS capacitor is created by using surface micromachining. The power consumption and low switching frequency are concerns for applications with thermal actuators. Although, unlike variable capacitors driven electrostatically, using thermal actuators undesired electrostatic actuation is avoided.**

Keywords – **MEMS Design, Variable capacitors, Thermal actuators, Surface micromachining, PolyMUMPs.**

I. Introduction

Robotics, computers, wireless phones, PDAs, GPS systems and even kid's toys are rapidly evolving. Most of the advances in communications are thanks to the advances in the development of MicroElectro-Mechanical Systems (MEMS). A set of specific devices that are supporting those advances through MEMS technology is composed of capacitors, resonators and filters.

This work presents the design of a variable capacitor using PolyMUMPs MEMS surface micromachining technology. The design could be divided mainly into three parts: design of the capacitor plates; design of the suspension and design of a set of vertical thermal actuators that push the upper plate away from the substrate and the bottom plate.

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II. Description of Vertical Electro-thermal Actuator

The vertical thermal actuator converts electrical to mechanical energy through ohmic heating and the thermal expansion of polysilicon. Applying a voltage to the actuator causes resistive heating 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. When an electric current passes through the hot arms, the heat generated causes a temperature difference between the hot and cold arms. Since the cold and hot arms are made of the same material and same thermal expansion coefficient, this causes the hot arm to expand more and this extension causes lateral motion [3].

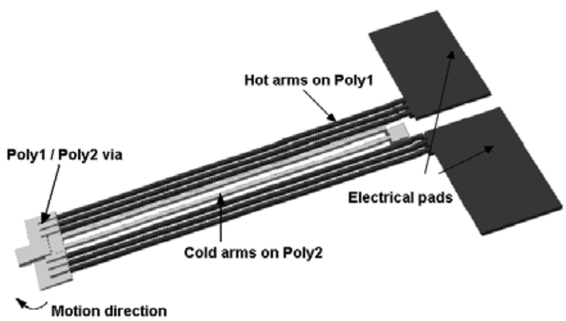

Figure 1. Structure of vertical thermal actuator.

III. Design of MEMS Variable Capacitor

The 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 research groups worldwide. The advantages of using PolyMUMPs process are: low cost; it provides three different surface micromachined polysilicon layers (two of them are mechanically separated from the substrate); and good material properties (well known since PolyMUMPs is widely used), which makes FEM desing analysis available and possible.

The three polysilicon layers are electrically conductive. One of them (Poly0) is hold to the substrate and is used only as electrical and electrostatical layer. The two others (Poly1 and Poly2) are mechanical layers that can be separated from the substrate [2].

The variable capacitor of this work is shown in fig.2.

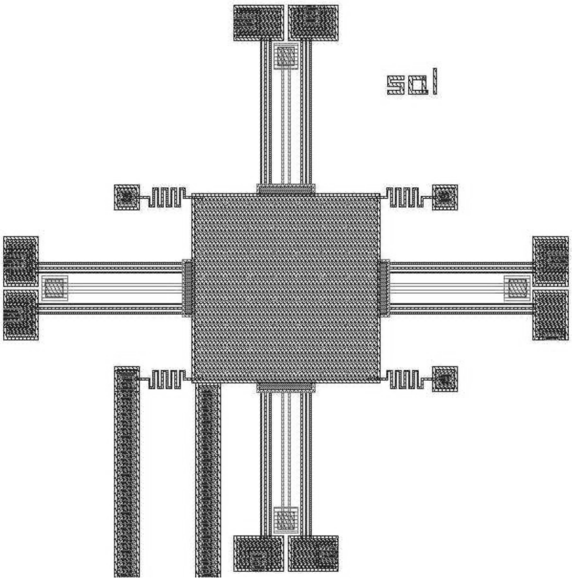

Figure 2. Topology of the variable capacitor.

There are three main components in the design:

A. Plates

A set of two plates on Poly0 and Poly1 layers are composing the capacitor. The upper plate is a square with side length of 250μm. A grid of holes (8x8) is made in it to help the releasing of the structure. The holes are designed according the technology requirements: squares with side length of 3μm.

B. Suspension

A mechanical suspension formed from four springs connected to the edges of the upper (Poly1) plate.

C. Vertical electro-thermal actuators

A set of four vertical thermo actuators that push the upper plate away from the substrate and Poly0 respectively. The cold arms are deposited on Poly2 layer, but the hot arms are on the upper Poly1 layer. Each actuator has two cold arms (length: 200μm, width: 2.250μm) and six hot arms (length: 157μm, width: 3μm).

IV. FEM SIMULATIONS AND ANALYSIS

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][1].

A 3D model of the designed MEMS variable capacitor has been analyzed. Electro, thermal, displacement and material stress factor has been simulated.

All analysis are made reaching maximum temperature of 642°C in the hot arms. This heating is generated when the potential difference between the two pads is 5V.

The major disadvantage of the observed structure comparing to the conventional electrostatic variable capacitor is the power consumption of the four electro-thermal actuators.

The maximum generated displacement is in the center of the upper plate. When the temperature of the hot arms of the actuators reaches 642°C, the displacement generated is 3.976μm.

The minimum generated displacement is at the edges of the upper plate, where it is connected to the suspension and is around 2μm.

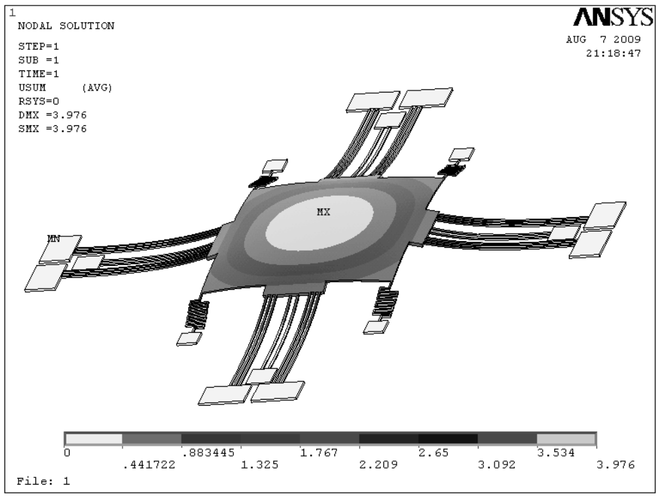

Figure 3. 3D model of the variable capacitor displaced on 3.976μm, due to electro-thermal actuation.

As shown on fig.4, the maximum material stress for the actuators is in the connection of the hot arms to the anchored pads. This stress is 279MPa and is significantly below the maximum specified stress for the polysilicon used.

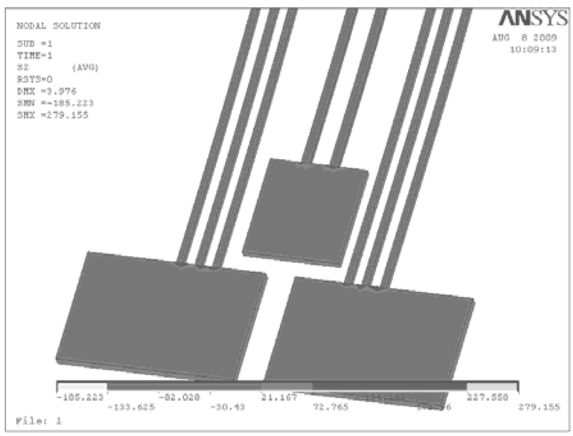

Figure 4. Material stress intensity in the actuators.

The stress intensity simulation results over the actuarors guarantees proper work of this component of the structure. The same conclusion can be made for the suspension component.

Maximum stress intensity in the whole variable capacitor is on very small area at the edge between the actuators and the upper plate (fig.5). At displacement of 3.976μm, this stress is 946MPa witch requires special attention in testing procedures over the prototype.

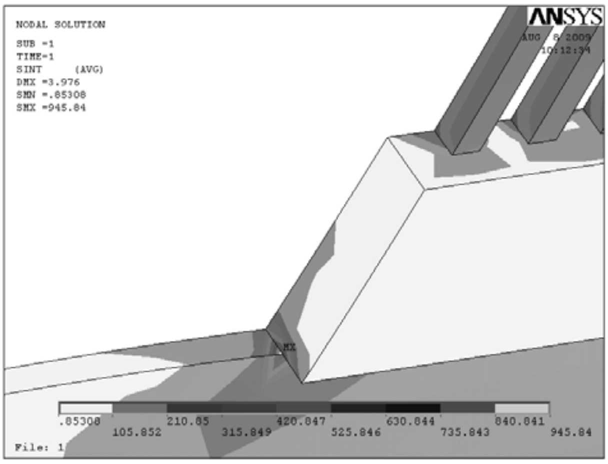

Figure 5. Maximum stress intensity in the variable capacitor structure.

Elecrostatic force between the capacitor plates is generated because of the polarization of the upper plate, while applying voltage to the actuators. This force can be compensated applying an appropriate voltage to the bottom plate so at actuators tip and the bottom plate of the capacitor the potencial is the same.

The design and the simulations are performed using SoftMEMs and ANSYS CAD systems.

IV. Conclusions

This work demonstrates a design of a MEMS variable capacitor driven by four vertical electro-thermal actuators. FEM analysis results of 3D model of the structure shows that it will have a stable behavior and will work properly. Special attention in testing procedures over the prototype is needed near the boundary displacement, because of the stress intensity.

Comparing to variable capacitors based on electrostatical principle, this design has significant power consumption, but undesired electrostatic actuation is avoided.

Elecrostatically generated noise movement of upper plate of the capacitor is around 30 times lower then the conventional electrostatic driven variable capacitor.

V. Acknowledgement

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