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Design of MEMS Single Pole Double Throw Switch based on PZT

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Abstract — With technological advancement in modern era, sizes of various tools used in various engineering applications has become smaller and smaller. Especially, the field of micro- engineering has gained a tremendous impetus. Working at micro-level has been a challenging job in the field of engineering for quite some time. This paper proposes the design of a 3-dimensional microelectromechanical system (3-D MEMS) model of an inverse piezo- electrically actuated single pole- double throw switch. Inverse Piezoelectric actuation has the advantage of fast response and reasonable power consumption. This paper also focuses on the optimization of the structure which will yield the best possible switching displacement (more displacement) for a particular voltage applied to the piezo – material. We have used Finite Element Method (FEM) of COMSOL Multiphysics version 4.4 to analyze all the structures. Various models have been tried out, each being subjected to numerous dimensional, structural and material variations, and the structure with best possible output has been put forward. All the parametric studies, which included total displacement of the piezo-material, stress developed has been carried out by linearly varying the voltage from 0-10 Volts.

Index Terms— Double Throw Piezo - Switch (SPDTPS), Finite Element Method (FEM), Inverse Piezoelectric effect,Meshing, MEMS, Piezoelectric actuation, Stress.

1 INTRODUCTION

MEMS models, which are being fabricated using complex microfabrication techniques and whose dimensions fall in the micron range, finds a vast application now-a-days [1]. MEMS has been used in fabricating various structures, the most prominent being micro-actuators .Actuators are used for transformation of non-mechanical input energy into mechanical output energy. There are many types of micro-actuation mechanisms, most commonly used are piezoelectric, magnetic, thermal, SMA, electrochemical, electrostatic actuation. In this paper we will be dealing with MEMS switches based on piezo electric actuation scheme. A piezoelectric actuator converts an electrical signal applied to a piezo material, into a precisely controlled physical displacement (stroke) [2]. MEMS technology has made it possible to develop micromechanical switches with high performance [3]. Compared to conventional electromechanical switches, the micro-machined ones have many advantages such as small size, low power dissipation, integration capability and so on. When a DC voltage is applied between the upper and lower surfaces of the piezo, the thin piezo - membrane deflects downward due to the inverse piezoelectric effect. As the applied voltage surpasses a certain voltage (threshold voltage for contact), the membrane deflection range reaches the second substrate (metal layer), thus causing the current to flow through the metal layers.

Switching at micro level is a very difficult job and requires precise dimensioning. This paper focuses on the design of a particular type of a MEMS switch and focuses on the structure which gives maximum displacement for a particular threshold voltage [4]. In micro - circuits where switching between two conducting paths is to be achieved an SPDTPS can be used. Various possible structures of the model have been tried and the structure with the largest displacement for a particular voltage has been selected .Also this paper gives a theoretical structure(that of the middle block) which gives a relatively larger displacement, compared to other structures, for a particular voltage, and for a particular length of piezo, which can find its use in applications where larger mechanical displacement is required for a particular voltage, as in case of a micro gripper. It was also seen that the deflection was independent of the length of extended portion of block.

The paper is organized as follows. Section II presents the structure and principle of the proposed design. Section III validates the proposed model by simulation results. Finally, the concluding remarks are provided in section IV.

2 PROPOSED DESIGN

2.1 Structure of Proposed SPDT Switch

The model consists of 3 blocks each constituting three layers, each of thickness 200 μm [5]. Each block has a unimorph structure i.e. each consists of a single layer of piezoelectric material [6].

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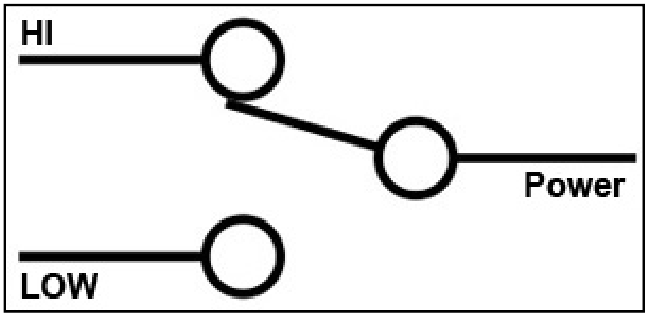

Fig 1. General SPDT Switch.

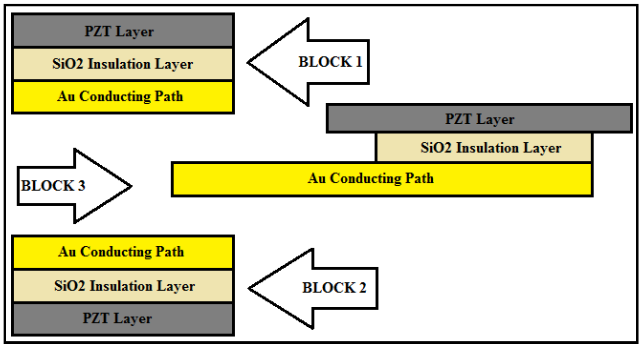

Fig 2. Block Diagram of the proposed MEMS SPDT Switch.

As depicted in Fig 2, Block 3 is placed in between two blocks, each with a certain gap (in µm) from Block 3 depending upon the displacement of each of the blocks due to the applied voltage. Upper layer of the top block (Block 1) is made up of Lead Zirconate Titanate (PZT 5), followed by an insulating middle layer which is made up of silicon-dioxide (SiO_2) and the lowermost layer is made up of a conductor, Gold [7]. The top layer of Block 2 is made up of Gold while the lower layer is made of the PZT 5 with the Silicon-di-oxide (SiO_2), insulating layer, being sandwiched between these two layers. Both Blocks 1 & 2 have similar dimensions (specified in table 1). Block 3 has different dimensions (length) with the top piezo- layer, having length greater than the middle Silicon dioxide (SiO_2) layer and extending in both directions (yields better deflection)[8]. The lower Gold layer of Block 3 has length greater than the middle Silicon dioxide (solid) layer but only extending in the front direction so as to make contact with the gold layers of Blocks 1 & 2 during switching. Instead of PZT we could have used AlN also, as AlN offers the advantage of direct integration with CMOS over PZT [9]. Table I gives a detailed description of the dimensions of the proposed model.

2.2 Principle of Operation

The structure works on the principle of inverse piezoelectric actuation [10]. When we apply positive voltage on the top layer of the piezo material of Block 1 and ground on its bottom layer, the block bends downward. When we apply positive voltage on the lower layer of piezo material of Block 3 and ground on its upper layer, this block bends upward making a metallic contact with the gold layer of the downward bending Block 1. If we apply positive voltage on the top layer of piezo in Block 3 and ground on its bottom layer (intersection between piezo and insulating layer), Block 3 will move downward.

TABLE 1
DEVICE SPECIFICATIONS

Components	Dimensions (in µm)
Arm layer for Blocks 1 & 2	18000 × 1000
Anchor layer for Blocks 1 & 2	2000 × 3000
Arm layer for Block 3 (Piezo layer)	32000 × 3000
Arm layer for Block 3 (Insulator layer)	21000 × 3000
Arm layer for Block 3 (Au layer)	33000 × 3000
Thickness of Blocks 1 & 2 & 3	600

Now if we apply positive voltage on the top layer (junction between the piezo and the insulating layer) of piezo of Block 2, it will move upward making metallic contact with Block 3. By varying the length of the piezo material it was found that the above mentioned structure (extending both ways) will yield the largest deflection (larger stress) for a particular voltage applied for the same length of piezo. It was also seen that the deflection was independent of the length of the extended portion of piezo material (i.e. gave same deflection for different extension length). Gold was preferred over platinum as it yielded better deflection due to its elastic properties and also due to its good conductivity and several other properties which has not been discussed here[11]. The deflection with varying length of the piezo has been shown. All the simulations were done by fixing the length of the piezo material (at 32000 µm). The insulating middle layer was added so that voltage applied to the PZT material does not affect the current passing though Au layer.

3 EQUATIONS

In the presented model the principle of the inverse effect of piezoelectricity is used. The inverse effect of piezoelectricity (i.e. when voltage is applied, the resulting stress developed) can be described by the general equation:

$$s = ST + dE \qquad (1)$$

Where the parameters have the following meanings,
s - Strain Vector
S - Compliance Matrix
T - Stress Vector (N/m2)
d - Piezoelectric Coefficient Matrix
E - Electric Field Vector (V/m)

The inverse effect of piezoelectricity can be simplified to the following expression, if there is no additional mechanical stress present (i.e. T = 0) [12]. Where strain is related the electric field by:

$$s = dE \qquad (2)$$

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$$\begin{bmatrix} s_1 \\ s_2 \\ s_3 \\ s_4 \\ s_5 \\ s_6 \end{bmatrix} = \begin{bmatrix} d_{11} & d_{21} & d_{31} \\ d_{12} & d_{22} & d_{32} \\ d_{13} & d_{23} & d_{33} \\ d_{14} & d_{24} & d_{34} \\ d_{15} & d_{25} & d_{35} \\ d_{16} & d_{26} & d_{36} \end{bmatrix} \begin{bmatrix} E_1 \\ E_2 \\ E_3 \end{bmatrix} \qquad (3)$$

The units of the piezoelectric constant, dij, are the units of electric displacement over the unit of the stress. Therefore:

$$\left[d_{ij}\right] = \frac{[D]}{[T]} = \frac{[\varepsilon][E]}{T} \qquad (3)$$

4 FINITE ELEMENT ANALYSIS AND DISCUSSION

COMSOL Multiphysics is a simulation software based on finite element analysis, suited for various physics and engineering applications. It offers high interfacing capabilities with MATLAB and its toolboxes for various programming, preprocessing and post processing steps.

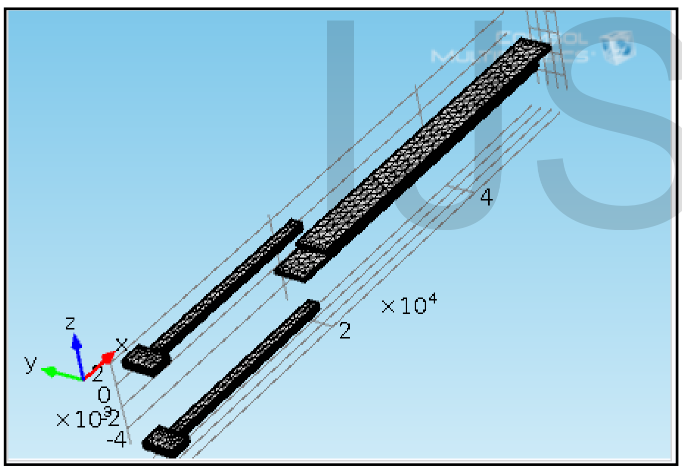

Fig 2. Finite Mesh Analysis of Structure

Fig 2 shows how a user defined mesh is applied to the structure. A user defined mesh gives a perfect flexibility for specifying the number as well as the size of the fundamental elements to be analyzed in a particular region. Fig 3 gives a 3-D view of the entire structure. As established in the previous sections, on application of voltage on the PZT surfaces of the MEMS switch, corresponding deflection can be observed in the Figs 4 & 5.

A succession of 10 input voltages was applied to the PZT layers in all the three blocks. The corresponding values for displacement and von Mises stress (which suggests the yielding of ductile materials) have been recorded in Table II. These values help in estimating the extent and the frequency with which the proposed MEMS switch can perform the switching operation.

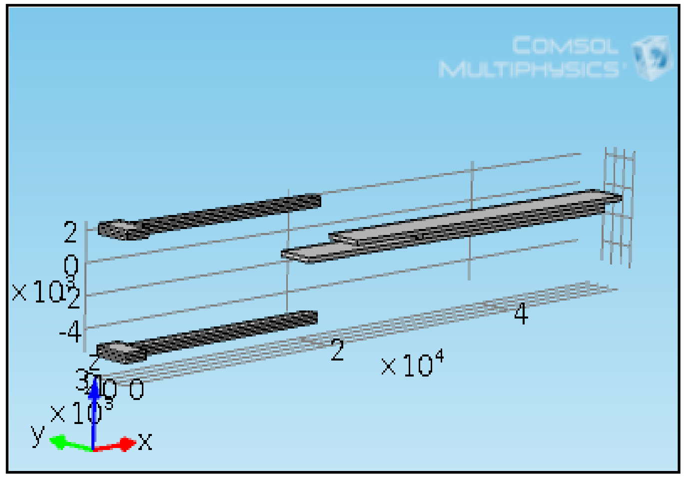

Fig 3. 3-D view of Proposed Structure.

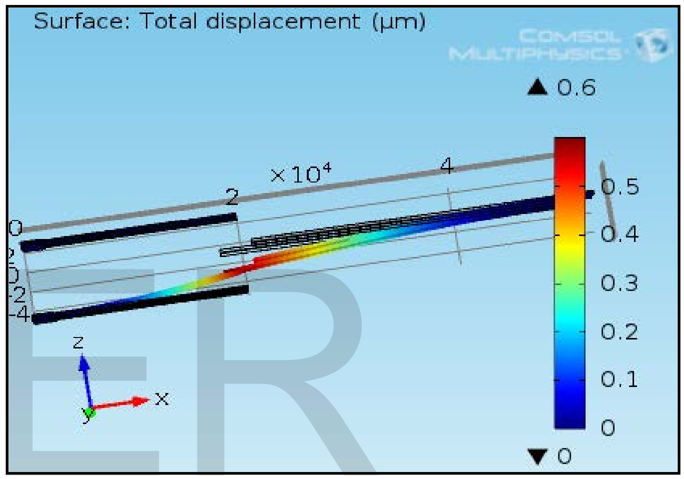

Fig 4. Deflection of Proposed Structure at 1V.

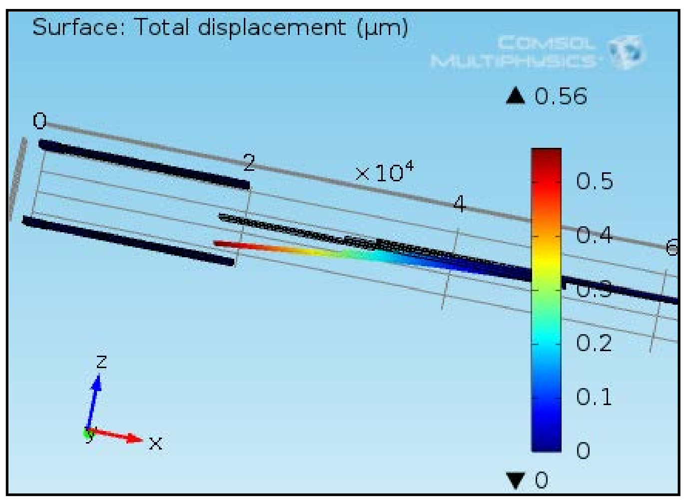

Fig 5. Decrease in deflection due to change of Structure at 1V.

TABLE 2

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SIMULATION RESULTS

Input Voltage (Volt)	Total Displacement (μm)	Stress (N/m²)
1	0.58	2.41×10^{10}
2	1.17	4.82×10^{10}
3	1.75	7.23×10^{10}
4	2.33	9.64×10^{10}
5	2.92	1.21×10^{12}
6	3.5	1.45×10^{12}
7	4.08	1.69×10^{12}
8	4.67	1.93×10^{12}
9	5.25	2.17×10^{12}
10	5.84	2.41×10^{12}

5 CONCLUSION

This paper proposes a Single Pole Double Throw Piezo Switch made up of lead zirconate titanate (PZT 5) for switching at micro levels. The proposed extended structure of Block 3 gives a larger displacement compared to other structures (seen by varying the layer's position) for a fixed length of PZT at a particular voltage. It was also seen that the deflection was independent of the length of extended portion of block 3.This structure can be put into use in areas where larger actuation is required for a particular voltage, e.g. in the case of micrograppers. The designed SPDT switch can be used in micro-electrical circuits working at low voltages, where non-mechanical switching between two current carrying paths in the circuit, is required (as found in several VLSI circuits). At 1V, Block 2 or Block 1 has a deflection of .57μm while the Block 3 has a displacement of .6 μm. Thus the minimum distance between the blocks should be at most 1.17 μm to allow metallic contact between Block 3 and either of the other two blocks.

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