Design of MEMS based 4-Bit Shift Register

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***Abstract*—This paper presents a unique design of MEMS based 4-bit shift register that perform shifting operation same as logic devices that are composed of solid-state transistors. The MEMS shift register design inherits all the advantages from MEMS switches and thus is expected to have more applications. One unique feature of this device is that it can perform all types of shifting mechanisms, but with different electrical and mechanical interconnects. The model consists of multiple switches working on the principle of electrostatic actuation. The shift register has 4 stages with each stage having 4 switches and each switch is one bit implementation of a 4 bit shift register. Since the basic logical switching operation is indicated by a mechanical deflection of a cantilever, the proposed system is accurate and reliable.**

***Keywords*—Shift register, Cantilever, Polysilicon, Lead Zirconate Titanate, SU 8.**

I. INTRODUCTION

In digital circuits, a shift register is a cascade of flip flops, sharing the same clock, in which the output of each flip-flop is connected to the "data" input of the next flip-flop in the chain, resulting in a circuit that shifts by one position the "bit array" stored in it, shifting in the data present at its input and shifting out the last bit in the array, at each transition of the clock input. More generally, a shift register may be multidimensional, such that it's "data in" and stage outputs are themselves bit arrays, this is implemented simply by running several shift registers of the same bit-length in parallel.

Shift registers can have both parallel and serial inputs and outputs. These are often configured as SISO, SIPO, PISO and PIPO. There are also types that have both serial and parallel input and types with serial and parallel output. There are also bi-directional shift registers which allow shifting in both directions: L→R or R→L. The serial input and last output of a shift register can also be connected to create a circular shift register.

MEMS have several distinct advantages as a manufacturing technology. In first place the interdisciplinary nature of MEMS technology and its micromachining techniques, as well as its diversity of applications has resulted in an unprecedented range of devices and synergies across previously unrelated fields (for example biology and microelectronics). Secondly, MEMS with its batch fabrication techniques enables components and devices to be manufactured with increased performance and reliability, combined with the obvious advantages of reduced physical size, volume, weight and cost. Thirdly, MEMS provides the basis for the manufacture of products that cannot be made by other methods. These factors make MEMS as pervasive technology as integrated circuit microchips. However, three points makes it very different: MEMS products tend to be application specific, giving rise to a wide range of very different products. Secondly, the number of MEMS products will be always less than that for semiconductor IC's. Thirdly, contrary to IC manufacturing, there is no such thing as a standard building component like the transistor. This leads to a more diverse technology base with more development and engineering work and therefore to a more expensive and more difficult to maintain technology. The development of a MEMS component has a cost that should not be misevaluated but the technology has the possibility to bring unique benefits. MEMS have applications in various fields such as Automotive, Medical, Communication, Defense and so on.

Rest of the paper is organized as following. In section II literature review over MEMS applications in logical designing is described. In section III the proposed work is explained briefly with required basic figures. In section IV simulation of proposed work using COMSOL Multi-physics is been described. Section V describes about the result. Section VI concludes the paper.

II. LITERATURE REVIEW

In [1], the authors describe Micro-electromechanical systems (MEMS) that provide vast improvements over existing sensing methods in the context of structural health monitoring (SHM) of highway infrastructure systems, including improved system reliability, improved longevity and enhanced system performance, improved safety against natural hazards and vibrations, and a reduction in life cycle cost in both operating and maintaining the infrastructure. Advancements in MEMS technology and wireless sensor networks provide opportunities for long-term, continuous, real-time structural health monitoring of pavements and bridges at low cost within the context of sustainable infrastructure systems.

In [2], the manufacturing techniques, properties, and applications of silicon micromechanical devices are explored.

In [3], a novel model is introduced to simulate the fabrication of MEMS (Micro Electro Mechanical Systems). This approach provides computationally efficient and geometrically accurate simulation results by hybridizing a geometrical and cellular approach.

The dissertation in [4] describes the design, fabrication, testing, reliability and harsh environment performance of single device MEMS-based digital logic gates, such as XOR and AND for applications in ultra low power computation in unforgiving settings such as high ionizing radiation and high temperatures.

The work in [5] the RF MEMS switches is performed and studied. RF MEMS switch which has low actuation voltage due to spiral structure; this work is inspired by the superior performance of electrostatic RF MEMS switches over the conventional state-of-the-art solid state devices and the potential applications in communication field. The customary high actuation voltage limits the reliability and applications especially in wireless communication, and hence focus on the realization of electrostatic low actuation voltage switches is rapidly increasing. The optimization of actuation voltage is achieved by analyzing the flexure design, beam topology, actuation electrodes and gap height using COMSOL models which are validated by simulations. It is observed that with more and more number of spiral ring structure actuation voltages can be reduced.

In [6], the present study is inspired by the superior performance of electrostatic RF MEMS switches over the contemporary state-of-the-art solid-state devices and the potential applications in communications field. The prevalent high voltage actuation mode, limits the reliability and applications especially, in wireless communication, therefore the study focuses on the realization of electrostatic low actuation switches with main emphasis on the pull-in voltage and RF response. The actuation voltage optimization is achieved by analyzing the flexure design, beam topology, actuation electrodes and gap height, using analytical models validated by numerical simulations. The RF performance enhancement is done by incorporating the floating metal design, active beam-area reduction and minimization of the associated parasitic. The fabrication is based on surface-micromachining, metal-electroplating and standard IC processing steps.

The work in [7] describes the future of MEMS which is multifaceted, complex, and subject to change, in response to the prevailing winds. Undaunted by these challenges, the authors present a forecast of the future from the perspectives of technology development, business growth and system integration.

The work in [8] deals with the emerging field of MEMS fabrication and device techno as applied to RF and microwave wireless communication system. The field is in interdisciplinary in that it integrates the areas of integrated circuit fabrication technology.

In [9] thermal functioning circuits with high potential are defined. A practical realization is called Quadratic Transfer Characteristics (QTC) then element of which is driving principle is the Seebeck effect.

The work in [10] introduces substantial improvements to the original comb-drive design. Area-efficient designs are described that have a dramatically increased resistance to side instability. The result is a planar electrostatic actuator which offers more than 150 microns of displacement within 1m sec at an operating voltage of less than 150 V. The analysis of the electrostatic and mechanical side forces provides guidance for designers of comb drive actuators. The actuator redesign is carried out within the context of the recent developments in reactive ion etching that enable aspect ratios of more than 20:1 in single-crystal silicon.

III. PROPOSED WORK

The proposed model is MEMS based 4 bit shift register which works on the principal of electromechanical actuation.

The proposed model consists of an array of cantilevers acting as a basic switch. The model consists of 16 cantilevers, 4 in each stage and each cantilever does a basic bit level logical operation.

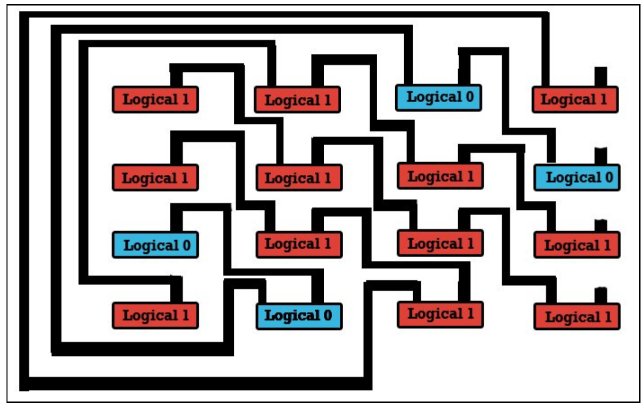

Fig. 1 The block diagram of 4-bit Shift Register

Fig. 1 shows the model of the 4-bit shift register. Each block represents one switch. Consider the example of "1101" being applied to the shift register. In the 1st stage it is '1101'. 1st switch of the stage is connected to 4th switch of the next stage, 2nd switch is connected to 1st switch of the next stage, 3rd switch is connected to 2nd switch of next stage, and 4th switch is connected to 3rd switch of next stage. If the bit is '1' then the switch outputs logic '1' which is connected to the electrode of the bit in next stage hence triggering the next switch to logic '1' as well. When the bit is logic '0', the output of switch is also logic '0' and is transferred to next switch in next stage. By this process at every stage one bit is shifted and after 4 stages the input sequence is shifted by 4 bits. The point to be known to understand the operation of the above shift register is "when the bit is logic '1' the switch [Fig. 2] gives out logic '1' as the output".

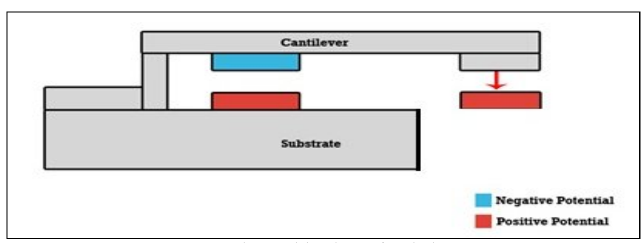

Fig. 2 Side view of switch

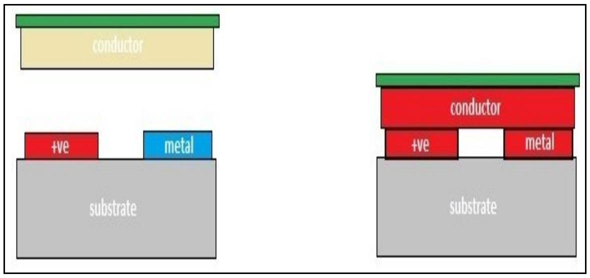

Fig. 3 Front view of switch when off and on

To understand the operation of the proposed model it is necessary to understand how the switch works. Above is the representation of switch. As can be seen from the side view of the switch it consists of substrate and a cantilever attached to the substrate from one end. The above switch uses 5 conductors. The conductors shown as 'positive and negative potential' are the electrodes and the electrostatic actuation takes place between these electrodes and cantilever deflects. On the free end of the cantilever is the 3rd conductor, which after the cantilever deflection touches the two conductors placed below the cantilever as can be seen in the front view of the switch above in fig.3. The conductor beneath cantilever is always at positive potential and when the 3rd conductor touches this, the positive potential is conducted to the 5th conductor. And negative potential is applied to the electrode attached to the cantilever and a positive potential is applied to the 4th conductor beneath the free end of cantilever. Now, the positive potential applied to electrode on the substrate denotes logical '1'. If positive potential is applied to this electrode then the bit is logic '1' or logic '0'.

In the proposed model the dimensions of various blocks are as given below:

A. Cantilever

The dimensions of the cantilever in the switch are as given below:
Height of the cantilever -0.2µm
Width of the cantilever - 20µm
Depth of the cantilever – 5µm

B. Substrate

The substrate is the base of the model for switch. Its dimensions area as below:
Height of the substrate-2µm
Width of the substrate-14µm
Depth of the substrate- 5µm

C. Electrode

Electrode is the metal where potential is applied and results for the actuation of the cantilever.
Height of the electrode-0.25µm
Width of the electrode- 3µm
Depth of the electrode- 5µm

D. Conductor

These are the metals used for conduction of the applied voltage.
Height of the conductor-0.5µm
Width of theconductor-3µm
Depth of the conductor- varies.

Materials used for building the shift register viz. Polysilicon as substrate, Zinc Oxide that acts as insulator, Copper acting as connecting conductor between switches and stages, Lead Zirconate Titanate as the stiff material holding the cantilever made of SU 8 and Air block between the electrodes.

In this proposed model, it is assumed that clock pulse is applied.

IV. SIMULATION

The proposed model is simulated using "COMSOL Multiphysics 4.2a" and the steps are as follows.

- Select 3D in space dimension and click next in the model wizard.
- In this step we choose the physics required for the model.
- Select Electro mechanics from list of physics.
- Right click on Electro mechanics and select ADD PHYSICS and click next.
- Choose micro meters (um) as length unit and click build all icon on top left corner of settings window in next step.
- Right click on geometry and select block.
- Give the dimensions for the block.
- The orientation of the block is also specified with respect to x,y,z axis.
- After entering the dimensions select build all.
- Give the dimension of the substrate block and click build all.
- Give the dimension of insulator layer on substrate and click build all.
- This is clearly pictorized in fig. 4

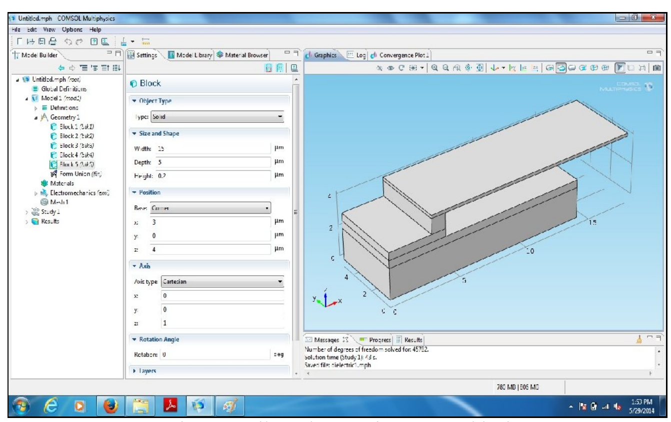
Fig. 4 Cantilever beam using support blocks

- To build electrodes, conductors and air block is shown in fig. 5

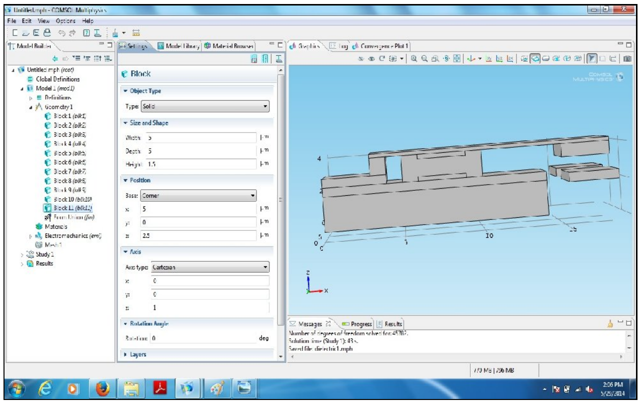

Fig. 5 Cantilever with electrodes and air block

- The material is selected from the material library and blocks are selected in linear elastic material model except the block defined as air. This enables the block to be selected for any structural changes. This is pictorized in fig. 6

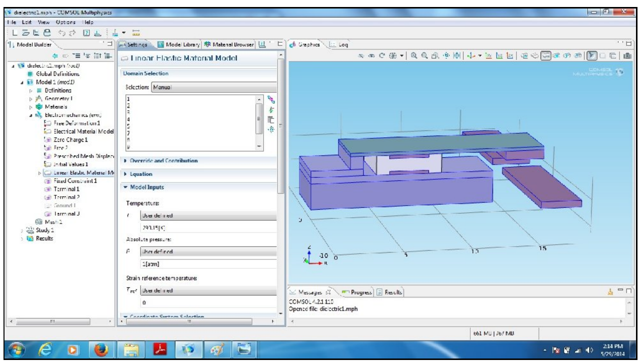

Fig. 6 Model provided material and linear elasticity

- To fix the cantilever and the structure at desired parts select fixed constraints by right clicking electro mechanics and further shown in fig. 7

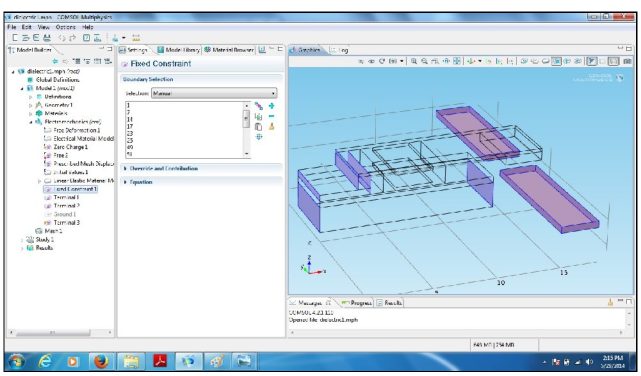

Fig. 7 Fixed boundaries

- Apply voltage by creating terminals 1, 2 and 3. This is shown in fig. 8.

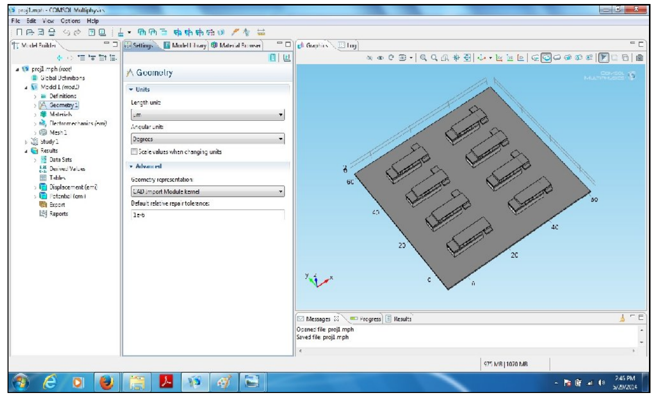

Fig. 8 The switches are designed and placed on a larger substrate

- The connections are made using copper, viewed in fig. 9

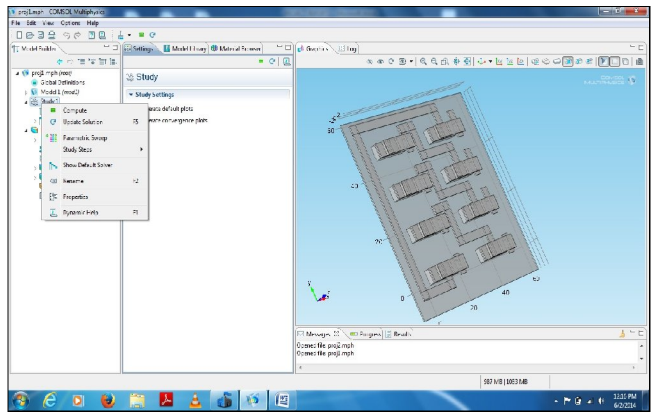

Fig. 9 Copper connections

- Similarly 3rd stage of the shift register is also built.
- The model is computed by right clicking on study and click compute.

V. RESULTS

The first stage which consists of array of 4 cantilevers, where 1st, 2nd and 4th cantilever has been deflected where as the 3rd is unaltered which indicates 1101 as the logical data. This 4 bit logical data has to be shifted and the last bit of 1st stage is connected to the first bit of the 2nd stage.

In the 2nd stage we can observe that 1st, 2nd and 3rd has been deflected where the 4th is unaltered which indicates 1110 as the logical data has to be shifted and the last bit of this 2nd stage is connected to the first bit of the 3rd stage. Similarly for 3rd and 4th stage also. This can be clearly viewed in fig. 10.

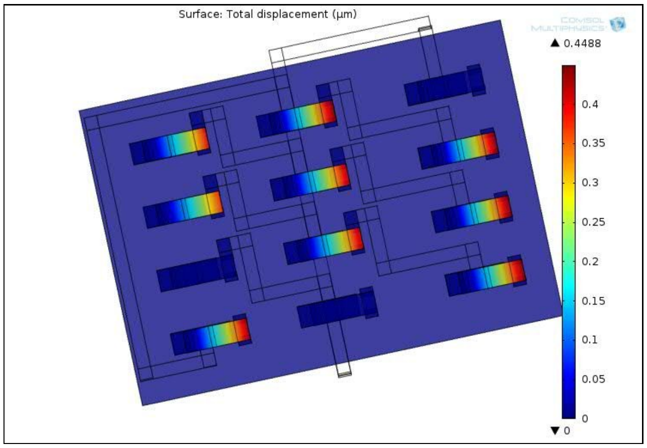

Fig. 10 Deflections of cantilevers and the scale

Red color indicates positive potential and is 20 V and blue color indicates negative potential. When the bit is logical '1' the switch conducts and the output is logical '1' as well, hence the positive voltage can be seen where ever bit is 1. This scale of voltage levels is pictorized in fig. 11.

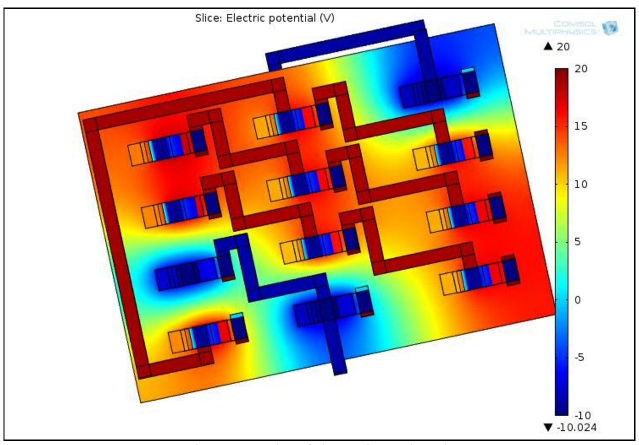

Fig. 11 Scale of the voltage levels

VI. CONCLUSION

In comparison to conventional digital shift register MEMS based shift register has dimensions 100x60 µm which is very small as compared to conventional shift register which has dimensions ranging from 1-4mm. Since the basic logical switching operation is indicated by a mechanical deflection of a cantilever, the proposed system is accurate and reliable.

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