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Research Article

Modelling and Computational Analysis of Piezoelectric Micro-cantilever based Switch

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Abstract

In this paper, study about the Piezoelectric MEMS (Micro-Electro-Mechanical Systems) cantilever as an A.C switch has been carried out. It presents the modeling and designing of the Piezoelectric Micro-cantilever based switch with pull down electrode. The switch structure is composed of silicon as substrate and aluminum as pull down electrode. The Piezoelectric material used is Lithium Niobate. The amplitude of the minimum voltage required to realize the A.C switch is 2 volts. The simulation of the switch has been carried out using COMSOL, a MEMS modeling and simulation software. The simulation results depend upon the time dependent analysis of the A.C switch.

Keywords: *MEMS, Micro-cantilever Switch, Voltage and Displacement.*

1. Introduction

Microelectronics, which is a subfield of electronics, relates to the study and manufacture of very small scale electronic design and components. In the field of Microelectronics, devices such as MEMS (Micro-electro-mechanical systems) are developed. MEMS incorporate miniature electro-mechanical components which are fabricated using processing techniques and equipment developed in the semiconductor industry. MEMS switches are of greater interest because these show wide bandwidth operation with superior characteristics as compared to the FET and diode based switches. The major research effort have been devoted to enhance the performance of AC MEMS switch in the field of required voltage as compared to other microelectronic switches such as, MOSFET and PIN diode switches. The major drawback in these switches is narrow bandwidth operation and poor isolation in the on/off switching states [Sujata N.N *et al* 2011]. So, AC MEMS switches have been developed as they have many advantages like, low power consumption, good isolation and high integration capability. The main concern is to reduce the voltage required for the actuation of the AC MEMS switch. In the recent research work, various techniques have been performed which include varying the geometrical parameters such as length, width and height and the materials used in the fabrication of MEMS switches.

MEMS switches are based on the deflection of the micro-cantilever beam. The proper deflection shows the ON state of the switch and of the OFF state also. The deflection of the micro-cantilever depends upon the voltage applied to the beam. It also depends upon the material assigned to the beam. Different types of piezoelectric materials can be used to improve the sensitivity of the cantilever, so that even small amount of voltage can cause the proper deflection of the cantilever to achieve the best isolation in the switching states of the AC switch. These piezoelectric materials can be Lithium Niobate, Gallium Orthophosphate and Langasite etc.

MEMS switch can be distinguished on the basis of the connection and the applied voltage. On the connection basis, there are two types of switches: series switch and shunt switch. On another basis, there are further two types: AC switch and DC switch. The main focus is to develop the switch with minimum power consumption, high sensitivity and high bandwidth operation, so AC switch need to be developed.

2. Related Work

In this paper, literature investigation is done, which relates to different types of switches, their working and different techniques to reduce the voltage required for the actuation of the AC switch. The earlier work relates to the techniques which focus on the dimensions of the switch i.e. length, width and thickness to reduce the required voltage. Suryansh et al presents the designing and simulations of MEMS based microcantilever which is made up of single crystal silicon using FEM based software [Suryansh Arora *et al* 2012]. The design, fabrication and testing of RF MEMS switches is done for high frequency applications [Dimitrios P. *et al* 2003]. The electroplated RF MEMS capacitive switches are designed and fabricated with various structural geometry of transmission line, hinge, movable plate, which is formed by using electroplating techniques [Jae Y. P *et al* 2000].

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The MEMS capacitive shunt switch is designed and voltage measured is 1.9v [Haslina Jaafar *et al* 2009]. The RF MEMS switch is designed which is built on semi-insulating GaAs substrate and voltage achieved is 10 volts [Shyh-Chiang Shen *et al* 2000]. The capacitive RF switch with torsion spring is designed, presented and analyzed and the actuation voltage obtained is 1.5V by using 4 meanders which are fixed with 4 anchors [Mingsin son *et al* 2008]. The RF-MEMS metal-contact switch with electro-static actuation is designed with actuation voltage of 20V [Noriyo Nishijima *et al* 2004]. RF characterization of micro electromechanical system (MEMS) switches realized on Elevated Coplanar waveguide and actuation voltage achieved is 6V [S. Kanthamani *et al* 2008].RF-MEMS series switch is designed and analysed and the actuation voltage obtained is 6.39V [Hamid U. Rahman *et al* 2008].

3. Main Objective and Computational Model

The main objective is to focus on the dimensional characteristics and shape of the cantilever beam so that the voltage can be reduced, which is to be applied to realize the switch. The proposed structure composed of a silicon substrate, two aluminium made electrodes where one is pull down electrode and one piezoelectric material based cantilever beam.

In the computational model, model of ON/OFF switch has been designed. In this, a piezoelectric microcantilever is designed with two electrodes at the bottom of the microcantilever. A substrate or base has been designed first, which is composed of the silicon material. A base is designed and then two aluminum electrodes are placed above the substrate and after that a piezoelectric layer based microcantilever is has been designed with proper dimensions and placed above the two electrodes. The finite element analysis is done for the modelling of the structure.

The rectangular cantilever beam is designed and the bending of the beam shows the ON/OFF state of the MEMS based switch. Here one end of the beam is fixed and other end is free to move. The mechanical movement of the beam shows the working of the switch. The silicon is the substrate having width, depth and height as 100, 60 and 20 micrometers respectively. The aluminum electrode is placed on the substrate having width, depth and height as 20, 20 and 10 micrometers respectively.

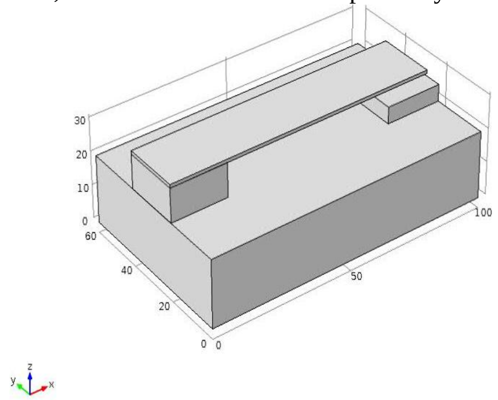

Fig.1: MEMS based cantilever switch

According to the piezoelectric property, when some voltage is applied on the piezoelectric material, some mechanical changes are observed and vice versa. The cantilever is having the piezoelectric layer, so it will exhibits the properties of the piezoelectric material.

Figure (1) shows the whole structure of the switch with cantilever beam having width, depth and height as 95, 20 and 1 micrometers respectively.

In this switch, voltage is applied to the piezoelectric cantilever beam and due to the elasticity of the beam; mechanical stress is observed on the beam which shows the deflection of the cantilever beam and the beam comes in the contact of the pull down electrode and this shows the ON state of the micro-cantilever based switch.

4. Simulation & Analysis

The simulation and analysis work is done on the piezoelectric micro-cantilever switch. Here, firstly the switch is designed and then meshing of the whole switch structure is done.

In the meshing part of the designed structure, the whole structure is divided into the small triangular structures. Using the finite element analysis, the computation of the individual part has been done.
After the meshing, computation is done by the finite element analysis method which is inbuilt in the software. The meshed structure of the switch is shown in fig. (2):

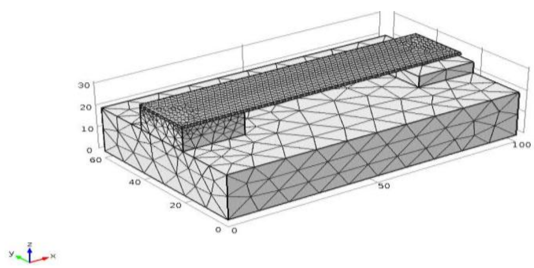

Fig. 2: The Meshed Structure of Switch

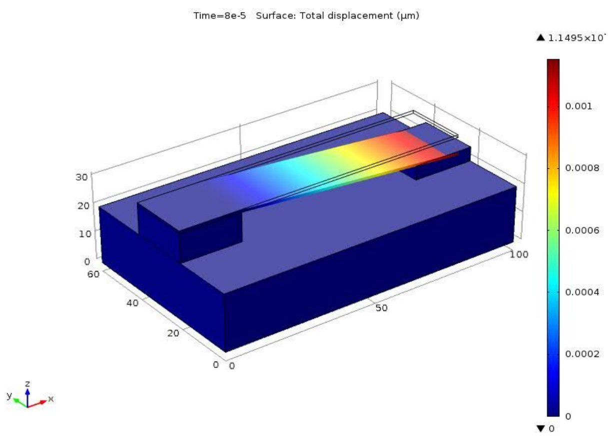

Fig. 3: Simulation Result of the Switch

Then, after the simulation, the deflection of the cantilever beam is obtained. The piezoelectric MEMS based cantilever switch can be viewed as shown in the figure (3). This is the result which is obtained after the computation of the designed model.

This condition is known as ON state of the switch as here the cantilever beam is in proper contact with the pull down electrode of aluminium. Similarly OFF state can be seen after the ON state. Regular sequences of ON/OFF states can be seen after the simulation result.

Here different colours of the cantilever beam are depicting the amount of deflection or stress generated in the cantilever beam. The maximum deflection is shown by red colour. Blue colour depicts the minimum deflection in the cantilever beam. Hence the switch on condition is shown by the tip of the microcantilever, which is of red colour.

5. Results & Discussions

Various graphical results are obtained which are based on the time domain analysis of the micro-cantilever switch. In the time domain analysis, study has been carried out with respect to the particular time interval. With the graphical results, characteristics of the switch are studied and analysis can be done. The graphs are in between the time and displacement; time and electric potential; time and pressure; voltage versus displacement.

5.1. Displacement and time

The graphical results show the relationship between the displacement in the cantilever beam and time. Various rise and fall can be clearly seen. It is seen that the switch istoggling in two states i.e. ON and OFF states in the particular interval of time i.e. from 0 to 0.005 seconds, the microcantilever rise and falls and this process is repeating regularly. This is shown in the figure no. 4 as shown below:

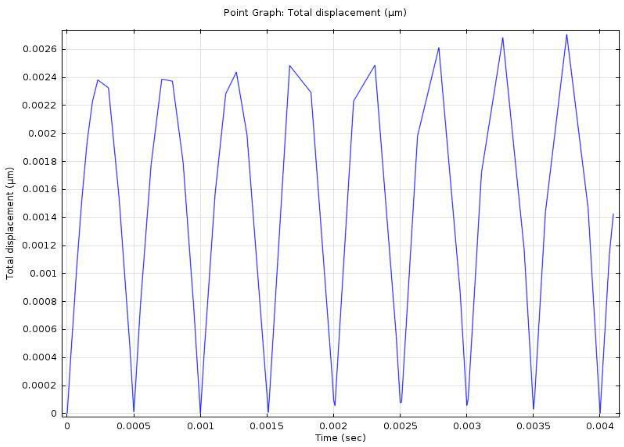

Fig.4: The graph between the displacement and time

5.2. Electric potential and time

The graphical results in fig.5 show the relationship between the electric potential generated in the beam with respect to the time.

In figure no. 5. , it can be clearly seen that the rises and falls are obtained for the electric potential with respect to the time. So, electric potential is also generated in the microcantilever. It is showing the same pattern as the displacement shows. Hence, it indicates that due to rise in the displacement of the cantilever beam, electric potential also rises with respect to the time and decreases when displacement decreases.

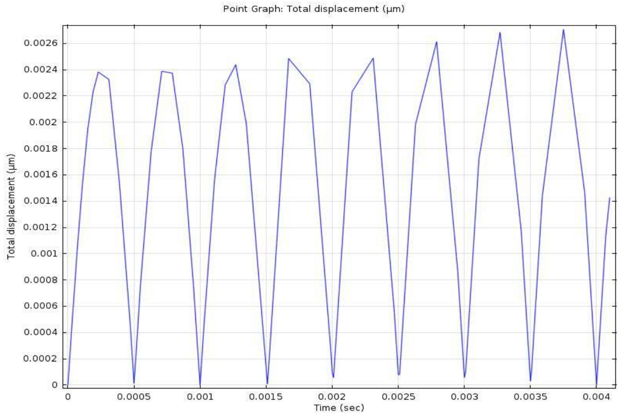

Fig.5: The graph between the electric potential and time

5.3. Pressure and Time

Graphical results are also obtained for the pressure generation in the microcantilever. The pressure generation is obtained at the time of the bending of the microcantilever because in that time interval maximum pressure generation will be there which tends to bend the cantilever in downwards direction and after some time, the microcantilever regain its original position. This is shown in the figure no. 6:

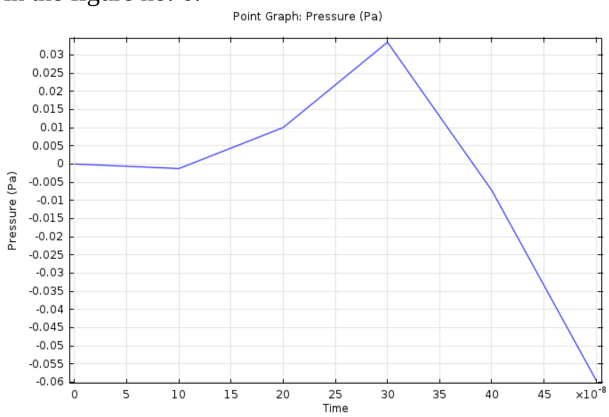

Fig. 6: The graph between Pressure and Time

Here in the above figure, it can be seen that the pressure is increasing with increase in the time and after reaching at some particular interval, it rises at its peak condition and after that it slowly decreases.

5.4. Voltage versus displacement

Here, the optimization in the width of the cantilever beam is done to get the maximum deflection of the cantilever beam due to applied voltage. Different ranges of widths of microcantilever are selected.

And the range of deflection/displacement is to be observed. The displacement is varying due to the variation of applied voltage, which is shown in the table 5.4.1:

Table 5.4.1: Simulated results for applied voltage

S. No	Voltage (V)	Displacement		
		Width=20 (micrometres)	Width=30 (micrometres)	Width=40 (micrometres)
1	0	0	0	0
2	1	0.001	0.0007	0.0005
3	2	0.0025	0.0015	0.001
4	3	0.003	0.002	0.002
5	4	0.0045	0.003	0.0025
6	5	0.006	0.0035	0.0035
7	6	0.007	0.0045	0.004
8	7	0.008	0.005	0.0045
9	8	0.009	0.006	0.005

Hence, from the tabular values graphical plots are obtained. The graph results in fig.7 shows that maximum deflection is obtained with the cantilever beam having minimum width.

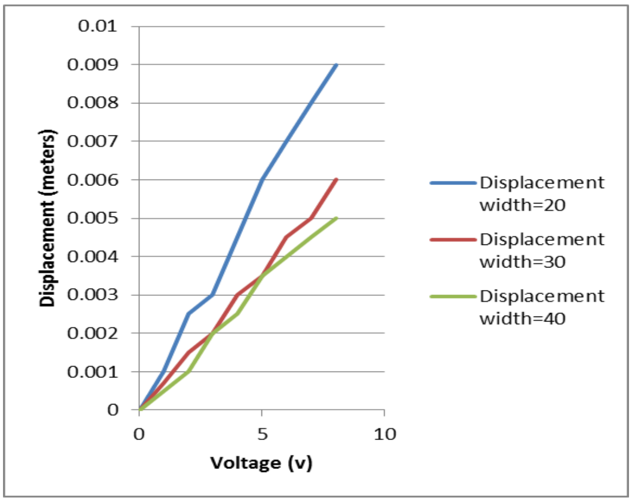

Fig. 7: The graph between voltage and displacement

In the above figure no 7, three different plots are obtained for the voltage and displacement. These plots are shown by blue, red and green colour. Here, it can be seen that blue colour ishaving the maximum deflection and then red colour shows deflection less than that of blue colour and green is showing the least deflection. It indicates that the minimum voltage required to obtain some relevant deflection for the piezoelectric micro-cantilever based switch is 2 volts. Also, the maximum deflection is obtained with the microcantilever having the minimum width.

Conclusion

The piezoelectric micro-cantilever based switch is designed with different dimensions and simulated. Then voltage is applied on the piezoelectric microcantilever and due to the piezoelectric property, displacement in the position of the cantilever is observed. The displacement shows the working of the switch. The ON/OFF condition of the switch is observed. The graphical results shows that the electric potential varies as displacement vary with respect to time. The minimum voltage required to obtain relevant deflection of the cantilever beam is 2 volts. Also, it has been observed that maximum deflection is obtained with minimum width. The width of the microcantilever is inversely proportional to the deflection and the electric potential of the microcantilever. In this work, cantilever beam with width as 20 micro-meters shows maximum deflection.

Future Scope

There are many scope of the future work in this type of the model. An experimental analysis can be done for the comparison of the results obtained by the practical work and by the computational work. Also artificial neural network concept can be implemented in this type of the model.

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