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Design and Analysis of Piezoelectrically Actuated RF-MEMS Switches using PZT and AlN

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Abstract— This paper proposes the design and analysis of RF MEMS switches using two different PZT materials. The piezoelectrically actuated switches exhibit an actuation voltage of 2-5 Volts which is very low compared to electro statically actuated switches. The switches have been analyzed for variations in beam length. Piezoelectric layer thickness, gap between the beam and transmission line. Electromagnetic performance of the switches has been carried out in HFSS v.13.0. The isolation thus obtained is as high as 42.50 dB and the insertion loss obtained is as low as 0.0002 dB.

Keywords- Piezoelectric actuation, RF MEMS switch, PZT, AIN.

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I. INTRODUCTION

RF(Radio Frequency) MEMS (Micro Electro Mechanical systems) devices are small mechanical structures fabricated by photolithography process, which are used for signal routing functions in RF and Microwave frequency circuits. The phase shifters, switchable filters, tunable antennas, T/R switches are the some RF MEMS components. The most commonly used RF MEMS component is a microwave transmission line switch. RF MEMS switches have many advantages over PIN diode and FET such as high isolation, low insertion loss, no dc power consumption, low RF loss, high linearity [1]. Depending on the method of actuation there are four types of switches namely electrostatic switch, thermal switch, magnetic switch, piezoelectric switch. By circuit configuration switches can be classified as series switch or shunt switch. By way of the contact interface switches can be classified as capacitive or resistive switches [2]. These devices are used in many applications such as aerospace, wireless communication, satellite communication, instrumentation, radar system and defense. In most of the applications the electrostatically actuated switches are preferred because of simple fabrication process and low switching time [3]. But the actuation voltage required by the electrostatically actuated switch is in the range 20-40Volts. The actuation voltage in this case is higher, which makes it unsuitable for mobile applications that require DC supply of 2-5 Volts. In order to reduce the actuation voltage many approaches have been tried out. One of the methods is to use low spring constant structures. However they suffer from reliability problems [5]. An alternate method of actuation is to use piezoelectric actuation since it exhibits low actuation voltage. This paper proposes piezoelectrically actuated RF MEMS series switches designed and simulated to obtain low actuation voltages. Lead Zirconate, Titanate (PZT) as well as Aluminium Nitride (AlN) have been used as the piezoelectric layer. The key parameters of the switch such as width of the piezo layer, actuation beam length, gap between beam and transmission line are characterized

II. BASIC PRINCIPLE

A piezoelectric substance is one that produces electric charge when mechanical stress is applied. Conversely a mechanical deformation is produced when an electric field is applied. This is formed in crystals that have no center of symmetry.

The schematic design of piezoelectric switch is as shown in Fig. 1. The switch consists of a piezo layer that is sandwiched between two metallic layers, and the electrical connection is provided to the top and bottom electrode

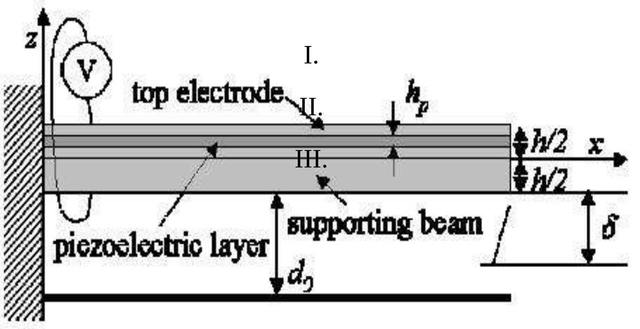

Fig 1: Basic piezoelectric switch

The signal line is interrupted by a gap which is closed by the top beam of the switch. In this case the signal line is represented by two pads of gold which is used as the transmission line. When the no voltage is applied between the two electrodes of the piezo beam the switch is in off state and the signal line has a gap between the transmission line and therefore there is no signal transmission. When voltage is applied between the two metal electrodes the piezo layer exhibits piezoelectric action, and the beam deflects and the top beam touches the signal line resulting in a closed circuit between the two gold pads thus there is signal transmission. When voltage is withdrawn the beam returns to its original position.

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III.DESIGN OF PIEZOELECTRICALLY ACTUATED RF-MEMS SWITCH

The following process flow is used in MEMS+5.0 to create the piezoelectric switch. Here the PZT is chosen as the piezoelectric material, platinum and gold are chosen as metallic layers.

Fig. 2: Process flow for piezoelectrically actuated switch

The process used is shown in Figure 2. The planar fill and stack deposition methods are used. Silicon is chosen as substrate. The pads are created by using gold that can are used as the transmission line. The thermal oxide is used as sacrificial layer. The top beam consists of its top layer which is the top electrode to be made of platinum and the bottom layer is made of gold. PZT material is sandwiched between the two metallic layers. The switch structure is as shown in figure 3.

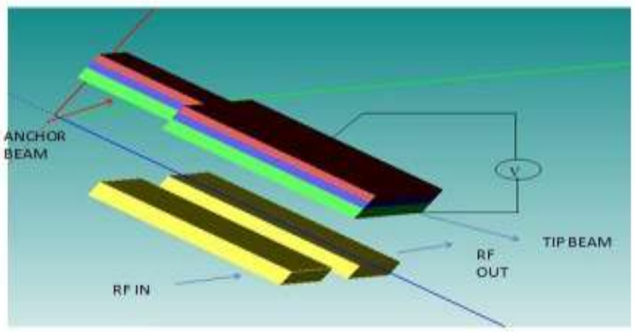

Fig 3: Piezoelectric RF MEMS switch

IV RESULTS AND DISCUSSION

*a) **Variation with width of piezo layer***

Piezoelectrically actuated switches with the structure shown in Figure 3 have been analyzed for variation in gap between the top and bottom beams, variation in width of the piezo layer used, and variation in anchor length. The same structure has been analyzed for two materials such as PZT and AlN.

Table 1: Dimension used for the switch

	Material	Thickness in µm
Substrate	Silicon	50
Transmission line	Gold	-
Top Electrode	Platinum	0.2
Piezo layer	PZT	0.1
Bottom Electrode	Gold	0.8

With this cantilever structure the switch has been analyzed for the piezo layer thickness of 0.1 µm and variation in the gap between top and bottom beam. The pull-in voltage obtained for gap 0.5 µm is as shown in Figure 4.

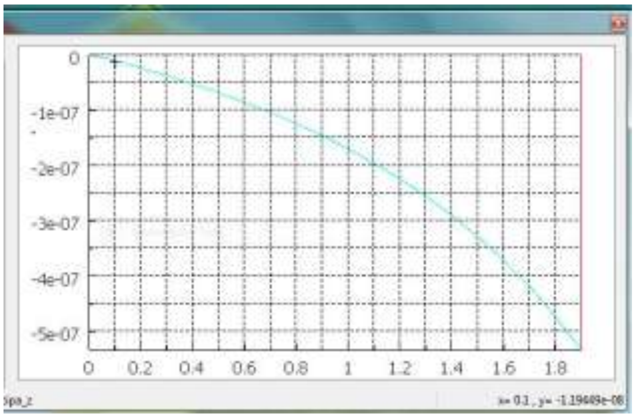

Fig 4: Actuation voltage for gap=0.5µm, piezolayer width=0.1µm

Table 2: Variation of actuation voltage with piezolzyer of width

Thickness of piezolayer in µm	**Gap in µm**	**Pull-in voltage volts**
	0.5	1.82
	1.0	3
0.1	1.5	3.7
	2.0	4.2
	2.5	4.4

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With this cantilever structure the switch has been analyzed for the piezo layer thickness of 0.2 µm and variation in the gap between top and bottom beam. The pull-in voltage obtained for gap 1.0 µm is as shown in Figure 5.

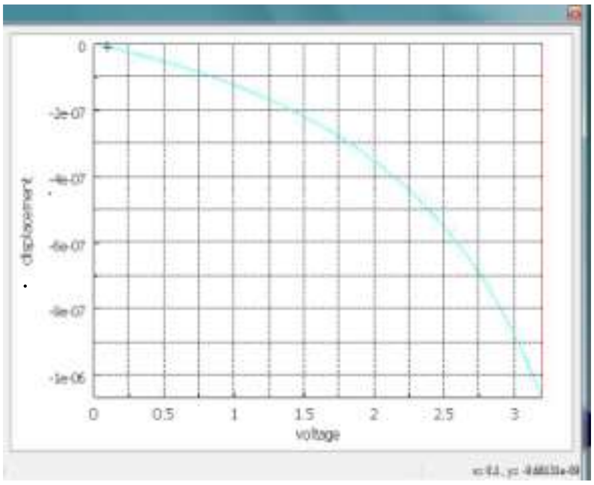

Fig 5: Actuation voltage for gap=1.0µm, piezolayer width=0.2µm

Table 3: Variation of actuation voltage with piezolzyer of width 0.2µm

Thickness of piezolayer in µm	Gap in µm	Pull-in voltage volts
0.2	0.5	2.1
	1.0	3.2
	1.5	4.0
	2.0	4.6
	2.5	5.2

With this cantilever structure the switch has been analyzed for the piezo layer thickness of 0.3 µm and variation in the gap between top and bottom beam. The pull-in voltage obtained for gap 2.0 µm is as shown in Figure 6.

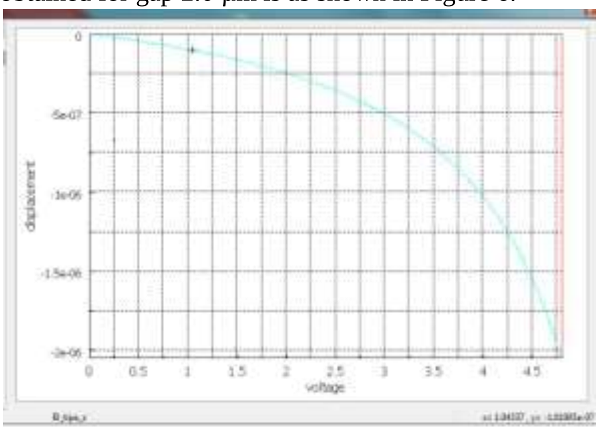

Fig 6: Actuation voltage for gap=2.0µm, piezolayer width=0.3µm

Table 4: Variation of actuation voltage with piezolzyer of width 0.3µm

Thickness of piezolayer in µm	Gap in µm	Pull-in voltage volts
0.3	0.5	2.25
	1.0	3.8
	1.5	4.3
	2.0	4.8
	2.5	5.3

With this cantilever structure the switch has been analyzed for the piezo layer thickness of 0.4 µm and variation in the gap between top and bottom beam. The pull-in voltage obtained for gap 1 µm is as shown in Figure 7

Table 5: Variation of actuation voltage with piezolzyer of width 0.4µm

Thickness of piezolayer in µm	Gap in µm	Pull-in voltage volts
0.4	0.5	2.8
	1.0	3.9
	1.5	4.5
	2.0	4.9
	2.5	5.4

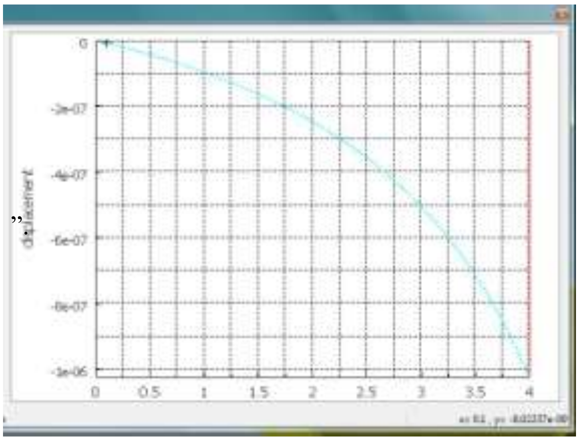

Fig 7: Actuation voltage for gap=1.0µm, piezolayer width=0.4µm

With this cantilever structure the switch has been analyzed for the piezo layer thickness of 0.5 µm and variation in the gap between top and bottom beam. The pull-in voltage obtained for the gap 0.5 µm is as shown in Figure 8.

Table 6: Variation of actuation voltage with piezolzyer of width 0.5µm

Thickness of piezolayer in µm	**Gap in µm**	**Pull-in voltage Volts**
0.5	0.5	3.1
	1.0	4.2
	1.5	4.7
	2.0	5.1
	2.5	5.6

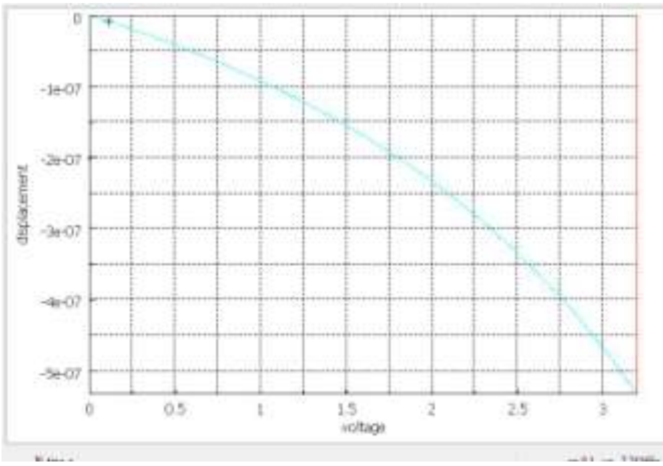

Fig 8: Actuation voltage for gap=2.5µm, piezolayer width=0.5µm

b) Variation with the length of the anchor beam

With this cantilever structure the switch has been analyzed for the different anchor beam length with piezo layer thickness of 0.5 µm and with piezo layer thickness of 1.5 µm. The actuation voltage is shown in the table 7& 8.

The variation of actuation voltage with the length of the anchor length is as shown in the table 9 and 10 for the piezoelectrically actuated switch. So the actuation depends on the length of the anchor beam.

Table 7: Variation of actuation voltage with length of anchor beam

Length of Anchor Beam in µm	**Gap in µm**	**Pull-in Voltage in Volts**
55	0.5	3.1
60		3.25
65		3.4
70		3.5

Table 8: Variation of actuation voltage with length of anchor beam

Length of Anchor Beam in µm	**Gap in µm**	**Pull-in Voltage in Volts**
55	1.5	4.7
60		4.9
65		5
70		5.2

c) Piezoelectrically actuated switch with AIN as the piezoelectric material

Pull-in voltage required by piezoelectrically actuated switch with the PZT is low and hence it can be used for the applications that require low actuation voltage. But PZT contains lead, zirconate, titanium ,presence of lead which is poisonous makes the fabrication process more complex, many things should be taken care in the foundry it may increase the cost of fabrication. So another piezoelectric material is tried as an alternative to the PZT.AIN is taken as an alternative to the PZT. The comparison of the pull-in voltage for the different types of switches is shown in fig 9.

Gap in µm	**Actuation voltage in Volts**		
	Electrostatic actuation	**Piezoelectric actuation**	
		PZT	**AIN**
1	20.06	3.5	10.6
1.5	22.15	4.1	12.4
2	23.88	4.5	13.2
2.5	33.04	4.8	13.6
3	42.81	5.4	14

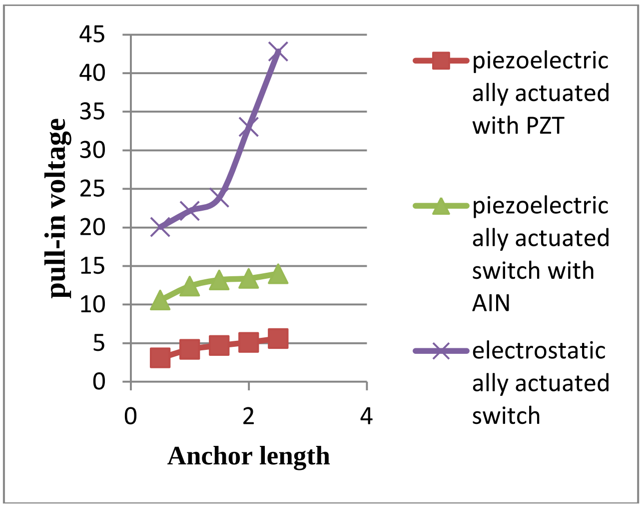

Fig 9: Actuation voltage for different types of switches

V.RF SIMULATION

The RF simulation is carried out using HFSS V13.0, The tool provide electromagnetic characters from static field to high frequency applications. The structure used for the RF simulation is as shown in figure 4.8 .Here the operational frequencies are set between 1 to 10 GHZ. The required excitation and boundary conditions are provided, the box created outside that limits the operational boundary. The required materials are chosen and required sweep is chosen

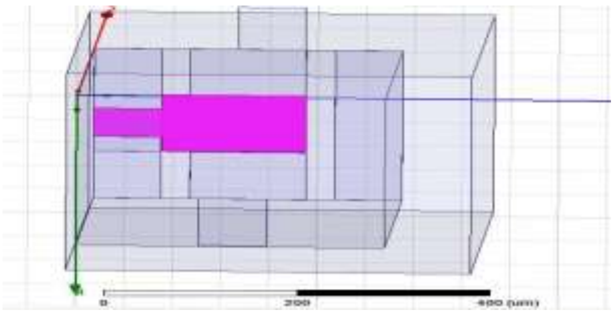

Fig 10: Structure used for the RF simulation

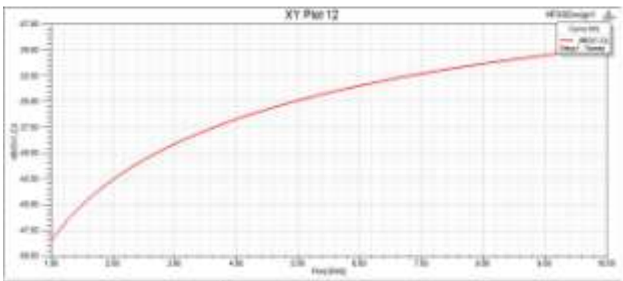

Fig 11: S12 in off state

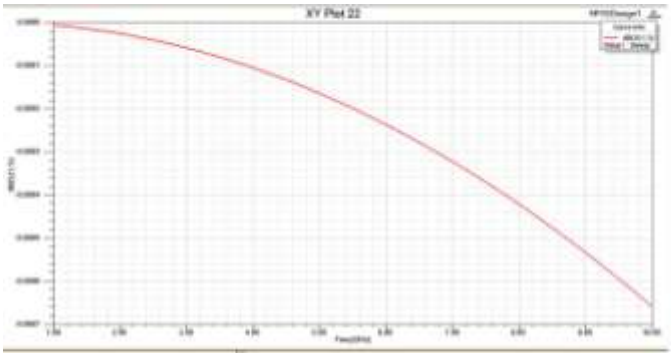

Fig 12: S11 in off state

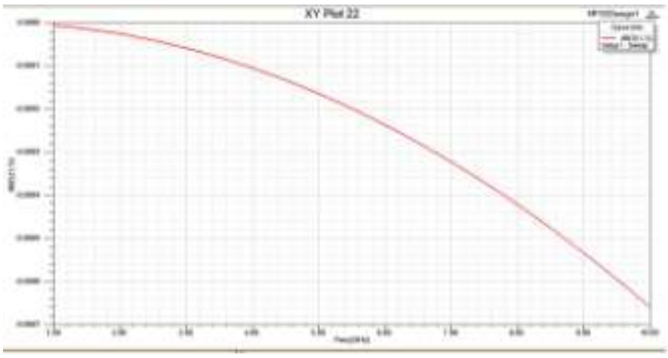

Fig 13: S12 in on state

The isolation measures the signal transmitted from one port to other port when switch is in off state, the isolation is 42.50 dB.insertion is 0.0002db.

VI.CONCLUSION

The main purpose of this project is to design and characterize low actuation RF MEMS switches. Most of the RF MEMS switches have high actuation voltage, but in many wireless applications high performance, low power consumption switches are preferred. So in this present work is focused on designing switch with low actuation voltage. The actuation voltage of 2-5Volts is obtained for the piezoelectric switch using PZT as the piezoelectric material. This project investigates the influence of various RF MEMS switch parameters like beam length, piezoelectric layer thickness and gap between the beam bottom electrode and the transmission line with respect to actuation by using MEMS+ 5.0 software. Presence of lead in PZT which is poisonous makes the fabrication process more complex, so the AIN is tried as an alternative material. RF simulation is carried out and S parameters are obtained

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