The Effect of Variable DC Gap and Various Piezo Electric Materials on Resonant Frequency in MEMS EVATunable Filters

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Abstract*—*Micro Electro Mechanical Systems (MEMS) are systems based on a variety of technologies whereby tiny mechanical elements with excellent system properties can be implemented. Evanescent Mode (EVA) tunable cavity filters for RF/microwave frequencies shows potential components in communication system because of its extensive tuning range, elevated unloaded quality factor, reduced size and weight. The application of bring in voltage create electric field within the cavity. The electric field is produced in the gap connecting post and diaphragm. The effect of DC applied gap on electric field distribution for different values of input DC voltage in an EVA tunable MEMS structure is analyzed. The validation of scattering parameter (S21 parameter) is also done which indicates a shift in the resonant frequency with both negative and positive applied voltage. The resonant frequency shifts more in case of negative bias supply voltage. The various materials used for piezoelectric diaphragm varies the resonant frequency. The materials having similar chemical compositions results in identical frequency while having different engineered domain configuration have variable resonant frequency.

Index Terms*— *Micro Electro Mechanical Systems(MEMS), Evanescent Mode Cavity Filter, DC Gap, S_{21} Parameter, Piezoelectric Diaphragm

I. INTRODUCTION

MEMS EVA tunable filters for radio frequencies or microwave frequencies is a promising field of interest to follow a line of investigation [1]. MEMS structure replaces conventional expensive and bulky off-chip discrete components by producing promising incorporated solutions that can be batch processed. In addition to the advantages of MEMS filters the added advantages of EVA filters includes ample tuning range, elevated unloaded quality factor, reduced size or weight [2]-[3]. RF MEMS devices, a new paradigm in the construction of electronic devices produce mechanical structure on micro scale [4]. Evanescent mode cavity filter can be realized by accumulating a structure inside the cavity. The evanescent mode structure resonates with a frequency lower that of the dominant mode of the unfilled cavity. The range of tunable frequency can be adjusted by varying the input bias voltage [5]. This paper focuses on effect of different materials used on the electric field distribution and considers the shift in the resonant frequency with input bias in a MEMS EVA tunable cavity filters.

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II. THEORETICAL EXPLANATION

A. Review of Material Composition Used

MEMS (Micro Electro Mechanical Systems) are the interconnection of involuntary elements, sensors and actuators on a common silicon substrate through micro fabrication technology. The field of MEMS [6] is evolved from the integrated circuit industry and the most intrinsic characteristics are trimness, microelectronics integration and precise bunch production. The various materials used as piezo electric materials includes lithium tantalate ($LiTaO_3$), barium sodium niobate ($Ba_2NaNb_5O_{15}$), barium titanate($BaTiO_3$), barium titanate(poled), lithium niobate ($LiNbO_3$), rochelle salt. Lithium tantalate is a crystalline solid which possesses unique optical, piezoelectric and pyroelectric properties. This possesses good mechanical and chemical stability. High purity, submicron and nano powder forms can be considered. Rochelle salt is potassium sodium tartrate (chemical formula is $KNaC_4H_4O_6.4H_2O$) a crystalline solid having large piezoelectric effect. They decompose at 55ºC and require protection against moisture. Barium titanate is the inorganic compound. This titanate is a ferroelectric ceramic material with piezoelectric properties. The poled barium titanate single crystal with the engineered domain configuration, it was clearly observed that the piezoelectric properties increased with decreasing domain sizes. Lithium niobate is a compound of niobium, lithium and oxygen. Its single crystals are an important material for piezoelectric sensor. It is a trigonal crystal system which lacks inversion symmetry and displays ferroelectricity.

B.EVA Tunable Cavity Filter

Evanescent modes are modes which function below the cutoff frequency and cannot broadcast down the waveguide for any distance, as they dying away exponentially. The importance of evanescent wave fields is that they can store energy. It is possible to design filters that operate internally entirely in evanescent modes. Typically, an evanescent mode filter consists of a length of waveguide slighter than the waveguide feeding the input and output ports. In some designs this may be folded to achieve a more compact filter. In more recent designs the screws are replaced with dielectric inserts. These capacitors resonate with the former length of evanescent mode waveguide which has the equivalent circuit of an inductor, thus producing a filtering action.

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Energy from many different evanescent modes is stored in the field around each of these capacitive discontinuities. However, the design is such that only the dominant mode reaches the output port; the other modes decay quickly between the capacitors. The mode with the lowest cutoff frequency of all the modes is called the dominant mode. Between cutoff and the next higher mode, this is the only mode it is possible to transmit, so it is described as dominant. Any spurious modes generated are rapidly attenuated along the length of the guide and soon disappear. Realistic filter designs are frequently made to operate in the dominant mode.

C.MEMS EVA Tunable Cavity Filter

The MEMS tunable resonator consists of an evanescent mode reverberating cavity, a skeletal diaphragm tuner made of piezoelectric material and a bias electrode positioned over the diaphragm tuner [2]. The resonant frequency and unloaded quality factor of the cavity resonator seem to be dependent on the cavity dimension, post magnitude, and the gap between the post peak and the apex wall of the cavity. The resonant frequency is very susceptible to 'm' where 'm' is the gap between the post top and top wall of the cavity when 'm' is small [5]. The bias voltage when applied to the bias electrode, the slight diaphragm made of gold is pulled away from the post, changing 'm' and, thus the resonant frequency is diversed.

III. COMSOL MODELLING

In section II theoretical explanation on materials used and EVA tunable filter is presented. It is needed to develop a model to analyze all the possible results. Modeling and simulation of tunable filters is done by using COMSOL software. COMSOL MEMS module is the main application area for designing and simulating MEMS components. The MEMS Module addresses design issues that arise in the micro-world

TABLE I
NOMINAL PARAMETERS OF SIMULATED EVA CAVITY FILTER

Parameters	**Description**	
	Parameter Name	***Value***
h post	Post height	49.85mm
W	Diaphragm side	1.52mm
d	Width	0.040mm
g	Initial Actuation Gap	0.05mm
V	Initial Capacitive Gap	Variable
fmin	Bias Voltage	3Ghz
fmax	Minimum Frequency	3.06Ghz
	Maximum Frequency	

For input voltage to change from little values to higher values say (25V-300V) causing the diaphragm to avoid towards the post, used to cause disturbance leading to a change in the electric field allocation and drift in the resonant frequency.
By adding a metallic post and creating reactance inside the cavity, the resonance frequency can be lowered. The cavity is air filled and the altitude of the post is slightly smaller than waveguide aperture dimension which creates a small gap between the top of the post and the cavity where the electric fields are confined. Model all parts - the cavity walls, post, substrate, diaphragm and ground planes etc. The material for diaphragm is piezoelectric material. The substrate is usually developed using silicon (Si) but here it is developed by Silicon On Insulator (SOI) [7],[8] in order to avoid intermodulation distortion [9]-[10]. Intermodulation [11] is the phenomenon by which discarded amplitude modulation of signals occurs owing to machine nonlinearities [12]. Mesh the model using a tetrahedral mesh with approximately five elements per wavelength in each material at the highest simulation frequency. When the diaphragm deforms due to the input bias, the moving mesh interface is used to collapse the mesh for the electromagnetic waves physics.

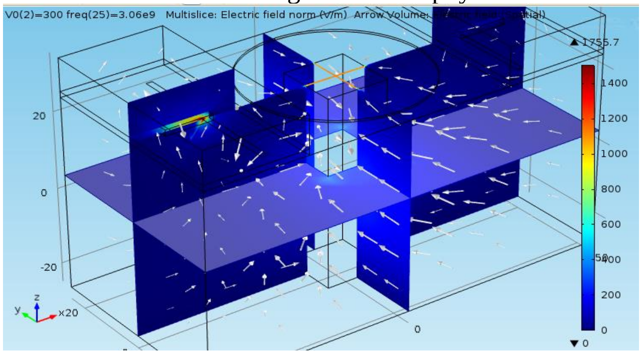

Fig.1. Arrow plot of electric field distribution on EVA tunable filter

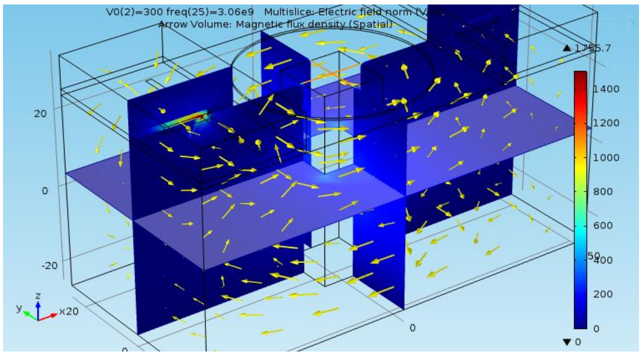

Fig.2. Arrow plot of magnetic field distribution on EVA tunable filter

IV. RESULTS AND DISCUSSION

There exists a tradeoff between tuning range and quality factor in tunable cavity filter [13]. MEMS EVA tunable filter has been designed and measured to validate the relationship between diaphragm displacement and the electric field distribution near the post. When a dc bias is applied to the bias electrode which causes the diaphragm to move downwards i.e. a deflection occurs in the downward direction. This deflection causes a change in the distance between diaphragm and top wall of cavity . As the distance changes the dielectric constant varies and as a result capacitance changes consequently resulting in change in the resonant frequency. Here input bias voltage is varied from very low range of 25V to a higher voltage range of 300V. Both positive bias as well as negative bias voltage are applied simultaneously. The three forces acted on the diaphragm electrostatic attractive dc force (F_{dc}), radio frequency induced attractive force (F_{rf}), diaphragm stiffness (F_k) are changing simultaneously to restore the diaphragm back to its original position.

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The F_{dc} force is dependent on applied dc bias voltage and the dc gap. The dc gap is formed by the application of input bias voltage. As the bias voltage is varied the gap will be changed accordingly. The force F_{dc} is varied directly in accordance with the square of applied dc voltage and varied inversely with square of dc gap. The F_{rf} force is solely depending on the radio frequency induced voltage V_{rf} and gap formed inside the cavity where x is the deflection. During the gradual change in applied voltage F_{rf} is directly related to square of V_{rf} and inversely related to square of V_{rf} induced gap. At low values of applied voltages the force F_{rf} is negligible where only F_{dc} is predominant. Thus as the input is increased potential between diaphragm and post increases pulling the tuner downwards thus resonant frequency reduces.

As power is further increased, this becomes impossible and an uncorrectable distortion in radio frequency filter response becomes noticeable. This is due to the non linear dependence of radio frequency power on applied voltage.

The electrostatic restoring force is dependent on the spring constant of the diaphragm and the deflection.

TABLE II
RELATIONSHIP BETWEEN DISPLACEMENT AND ELECTRIC FIELD

Sl No.	Parameters	
	Displacement(mm)	Electric Field(V/m)
		1805.3
1	0.0030	1806.4
2	0.0076	4397.1
3	0.0153	5170
4	0.023	6175.2
5	0.0306	8923.2
6	0.046	10650
7	0.0613	9090
8	0.0766	7519
9	0.0919	

The relationship between displacement and electric field can be shown in Fig. 3. as:

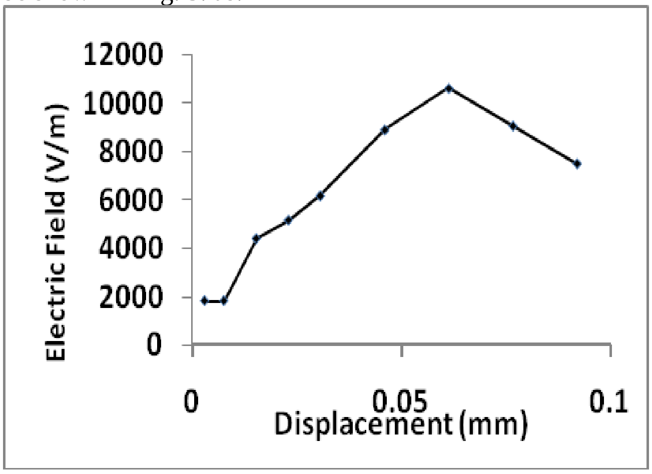

Fig. 3. Relation between displacement and electric field

From fig.3 it is clear that as the dc gap increases the electric field will increase accordingly and after a certain dc gap, electric field starts decreasing. The dc gap can be varied in accordance with the application of input bias voltage.

TABLE III
RELATION BETWEEN BIAS VOLTAGE (+) AND RESONANT FREQUENCY

Sl No.	Parameters	
	Bias Voltage (+V)	Resonant Frequency
1	10	3.03
2	25	3.0275
3	50	3.0275
4	75	3.025
5	100	3.0225
6	150	3.02
7	200	3.0175
8	250	3.0125
9	300	3.01

The relationship between positive bias voltage and the gain parameter $S_{21}$is shown in fig.4.as:

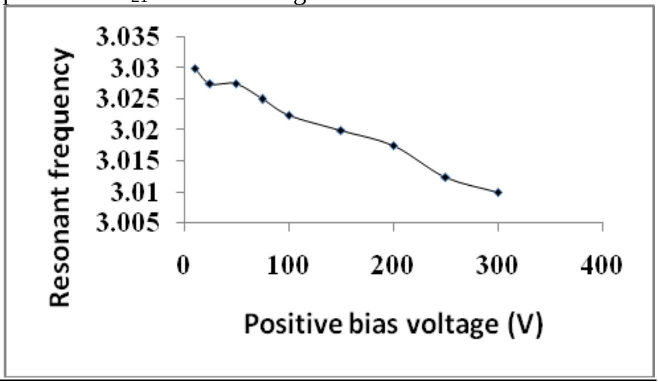

Fig. 4. Relation between positive bias and Resonant Frequency

The resonant frequencyis ploted with increasing positive bias in fig. 4. The resonant frequency and bias voltage is plotted in vertical and horizontal axis respectively. As the voltage increases resonant frequency shifts downwards.

TABLE III
RELATION BETWEEN BIAS VOLTAGE (-) AND RESONANT FREQUENCY

Sl No.	Parameters	
	Bias Voltage (-V)	Resonant Frequency
1	10	3.03
2	25	3.0325
3	50	3.0325
4	75	3.035
5	100	3.035
6	150	3.04
7	200	3.0425
8	250	3.045
9	300	3.0475

The relationship between negative bias voltage and the resonant frequency is shown in fig. 5.as:

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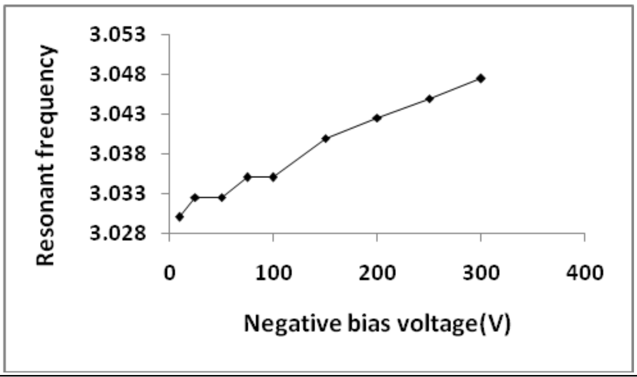

Fig. 5. Relation between negative bias and resonant frequency

The resonant frequency is ploted for both increasing values and decreasing values of bias voltage indicates the shift in resonant frequency. The effect of application of negative bias on the resonant frequency shift is greater when compared to that of positive bias. At low values of both positive bias and negative bias the resonant frequency is almost similar but as the bias voltage increases shift in the resonant frequency is signifiant.

This is due to the fact that as the bias voltage increases the disturbance inside the evanescent mode cavity becomes more stronger and shifts the resonant frequency.

TABLE IV
RELATION BETWEEN MATERIALS USED AND RESONANT FREQUENCY

Sl No.	Parameters			
	Materials used	*Resonant Frequency*		*Electric Field (V/m)*
		Positive Bias	*Negative Bias*	
1	Lithium Tantalate	3.03	3.03	1938
2	Barium Sodium Niobate	3.03	3.03	1976
3	Barium Titanate	3.0275	3.0325	2222.6
4	Barium Titanate(poled)	3.0225	3.035	2826
5	Lithium Niobate	3.03	3.03	1929
6	Rochelle salt	3.03	3.03	1921

The piezoelectric diaphragm when composed of similar chemical structure like lithium tantalate, lithium niobate results in almost similar electric field distribution and cavity resonate at identical frequency. Barium titanate and barium titanate poled has certain dissimilar chemical configuration and resonate with different frequency.

V. CONCLUSION

The effect of dc gap on electric field distribution in an evanescent mode MEMS tunable filter is analyzed. The S parameter is also plotted with varying input dc bias voltage and the shift in the resonant frequency is also validated. The centre frequency can be reduced without increasing the size of the post inside the resonator cavity. The piezoelectric material with different chemical composition results in dissimilar distribution of electric field and resonates with different frequency. In order to meet the criteria of a specific application parameters should be selected carefully.

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