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Simulation of Nonlinear Coupled Interdigitated Flexible Mems Resonators in Different Vibrating Modes

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Abstract : Nonlinear coupled system of microelectromechanical systems (MEMS) resonator is a laterally driven mechanical resonator, it can be activated by electrostatic force interaction. This study of the electrostatic forces which are generated between the interdigitated combs (IDC) by overlapping movable and fixed comb fingers to produce the force, and it stores the energy.This polymer MEMS resonator begins to exhibit hard and soft spring effect at excitation voltages of 5V and Young's modulus of 8.3GPa (PVDF)and 3.1GPa (polyimide).We discuss the device vibration on the various modes of the folded suspension beams and nonlinear effect arises from the mechanical structure domain. In addition the electrical and mechanical properties of the structure is studied. The key points of the hysteresis characteristics for upsweep and downsweep frequencies are calculated when the nonlinear response appears in device.Here, we calculated the resonance frequency in various modes with the high quality factor, capacitance and displacement. Therefore the nonlinear dynamic multiphysics model has been developed using finite element methods (FEM) technique. The capacitive comb drivede sign speculation is verified by the COMSOL multiphysics 4.4 simulation results.

Keywords: Polymers, MEMS resonator, Electrostatic actuation, Coupled nonlinear system andVibration modes.

Introduction

The interdigitated comb drive resonator is a device in the area of microelectromechanical systems (MEMS) that in the most general form can be defined as microsize mechanical and electro-mechanical devices are silicon made using the microfabrication techniques[1,2]. The main objective of materials are excellent electrical and mechanical properties, which can be modified by doping but further more materials are needed for the incorporation into MEMS devices. Nowadays, polymer materials have mainly used for coupled comb drive MEMS resonator with good achievement. Bio based polymer materials have several merits over the silicon materials, such as transparency, higher coefficient of thermal expansion, superior biocompatibility. This MEMS resonator is essentially growing parts of sensor and actuator systems in many applications such as gyroscopes, frequency reference, microacclerometer, memory elements, and micromechanical filters[3-7]. The advantages of resonator are small size, light weight, good performance, high reliability and lower cost. The polymer materials like as Polyvinylidene difluoride (PVDF) and polyimide has design an interdigitated comb finger structures, it can be effective for electrostatically exciting the resonance of microstructures[8]. The principle of comb drive design have electrostatic force generated by overlapping combs between the movable and fixed comb fingers. Since, the fringe field increases with the potential difference between IDC comb fingers, the nonlinearity response of the flexural folded beam model analysis are reported[2, 9-12]. However, fundamental design of interdigitated comb drive hopes on the possibility of the parallel plate capacitors and array of comb fingers which are normally rectangular shape. In case of a comb drive relationship between a constant electrostatic forces to displacement, which is an operation can change in capacitance with respect to engagement, instead of the total capacitance[13]. The comb drive resonator consists of mass attached suspended beam that response and displacements to an external vibration. Also, the design can operates on flexural folded beam in x- direction and its lateral movement of electrostatic force sensed using a capacitive sensors[14]. The micromechanical resonator usually aimed to achieve a specific range in linear mode of operation and teeth of combs are engagement profiles. In order to MEMS resonators can be nonlinear problems have been extensively studied in the recent years. We have discussed comb drive resonators behavior is nonlinear effects on the parametric resonance in suspended mass sensor. Here nonlinearity study is caused by two or three dimensional stiffness, and it is generating deformation from interdigitated comb drive. However, the devices of coupled nonlinear response can exhibit at higher vibration amplitude and the particular hard spring effect in electrostatically excited comb-drive resonator[15,16]. The nonlinear responses are exhibited of higher and lower frequency in the structure, where a device exhibits amplified response at certain frequencies, known as resonant frequencies[17]. The device has nonlinearities arising from large elastic deformations. That system exhibited classical duffing frequency response, which offered a number of attendant benefits for lower sensitivity to damping, but were deemed to be inferior to their Lorentzian counterparts for most applications. Nonlinear MEMS electrostatically actuated variable gap structures drew slightly more attention from the MEMS system, due to their highly tunable nature[18-22]. In this research actuation mechanism as well as two interdigitated comb fingers in the lateral driven by polymer MEMS resonator, which include for the specifications of resonance frequency with quality factor and young's modulus and moment of inertial are derived[23]. The coupled system has high sensitivity near the bifurcation detail to small perturbations which can be useful for communication and filter applications.

This study also extends an insight into the coupled static and pattern formation that leads to lateral movement and transverse based on interaction between different governing forces[25]. The performance of an electronic/mechanical domain may depend highly on stability and accuracy of the frequency reference device it uses. The research work has higher vibration amplitude of the structure can exhibit hysteresis characteristics during upsweep and downsweep of resonance frequencies[18]. This kind of MEMS resonator involve the large vibration, material an istotropicity in a nonuniform material, circuit elements, and variation in individual structure elements during fabrication process at hysteresis response. In this paper focused on exploiting nonlinear behavior arises from coupled effects of the flexural beam structure on a mechanical system and coupling to improve the performance of MEMS resonators using microelectromechanical filter applications.

Materials and methods

The interdigitated comb drive MEMS resonator structure is two dimensional (2D) view shows in the fig.1, which can be used prototype design of Multiphysics model. This design has laterally driven an electrostatic force and consists of two interdigitated comb fingers on fixed and movable is connected to perforated mass, which is suspended by flexural folded beam. However, the flexural folded beam pairs are attached to the trusses. The device is designed for x-y direction to produce on stable oscillation[26,27]. The proposed method is development of resonator device, when a voltage is applied between the fixed combs and the movable combs and it overlapping combs are generates an electric field E[12]. Therefore the coupled MEMS resonator structure moves on in the x-direction of the actuation forces as the suspended folded beams in that direction. Generally the current motion which is propositional to change in the capacitance between the movable and fixed comb fingers at the excitation voltages is measured and also the resonator generates the maximum total displacement at the resonant frequency[28]. These features mentioned for reduce axial stress, restrict out of plane movement and the device minimize unstable end unwanted vibrations in the other axes[10, 29,30]. Since, the important dimensions and features of the devices are follows as table 1.

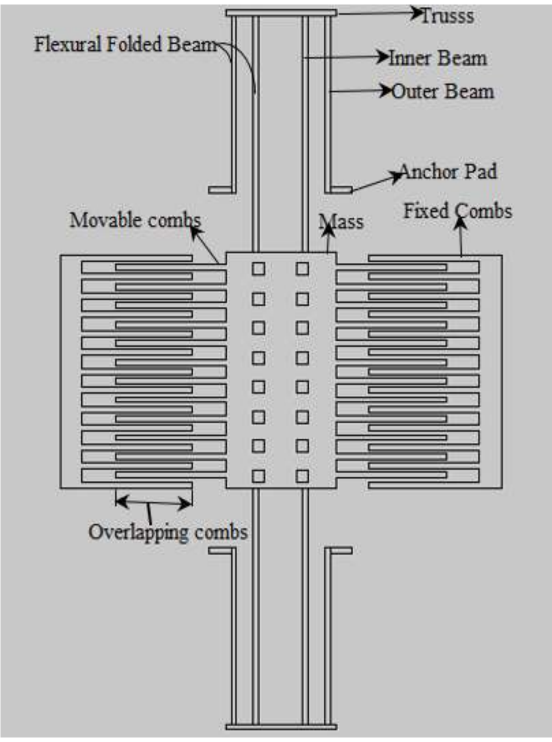


Fig.1: Schematic of coupled interdigitated comb drive MEMS resonator

Model Analysis

Electrostatic forces

We have analysis of electrostatic actuation in the comb drive, where the dynamic capacitance calculated between the movable and fixed combs in either side can be expressed as

$$C(x) = \frac{2N\varepsilon_0(s + x)T_{th}}{g} \qquad (1)$$

Where, N is the total number of movable comb fingers, ε_0 is the permittivity of the free space 8.85×10^{-12} F/m, s is the overlapping between the movable and fixed combs, x is the displacement in x – direction, T_{th} is the thickness of the structure and g the gap between the movable and fixed comb fingers on the single side. Here this conclusion is based on the assumption that, there are no movement in y direction and hence there is no change in gap that can offset the movement in x direction. The results calculated for capacitance between the IDC combs and the boundary of the cavity in very small. Since, the fringe field capacitance can ignore the pertinent distance within x direction >> g. Lateral electrostatic driving is one of the most advantages for perpendicular driving and there is no pull-in effect to be worried about. These electrostatic driving forces are independent of the displacement of combs[31,32,]. Therefore, the structure can be increase comb fingers to the driving force also increase.

Vibration modes analysis

The dynamics of modeling is laterally driven comb-drive on one degree of freedom can be represented as,

$$mx^2 + cx^1 + kx = F_e \qquad (2)$$

Where, x is the displacement along the x-axis, m is the total mass, c is the damping co-efficient. Here it is assumed that as F_e changes direction and due to the change in polarity ofvoltages. A flexural folded beam component is built into the actuator design to provide restraining force and flexibility for the actuator motion in the MEMS resonators[11]. The nonlinear response of MEMS resonator is a large deformation in the flexural folded beam pair with identical lengths can be harden of the beams as known discovered[12, 15, 24]. Here it vibrates the various modes on the stiffness shown in fig.2. These device is the various multiphysics involve an electrostatic, solid mechanics and moving mesh interface can be used for COMSOL multiphysics 4.4. As a result the folded beams harden, when they are driven by large force and this can lead to the nonlinear restoring force. Therefore the stiffness derived as

$$K = 4\frac{ET_{th}W^3}{\left(L_2^3\right)\left(\frac{r}{r+1}\right)} \quad (3)$$

Where, K is the spring constant, E is young's modulus, T_{th} is the thickness, W & L is the width and length of the spring constant, r is the ratio of inner beams and outer beams in range of 2.37.

Results and Discussion

Simulation Results

The polymer IDC MEMS resonator is designed for the dimension shown in table 1. These structure can be micrometer scale size and multiphysics interface include the electrical and mechanical properties. For simulating the design and study the working principle for the coupled comb drive MEMS resonator is carried out by COMSOL Multiphysics 4.4 software. In this paper, polymer material such as PVDF and polyimide has individual material applied to the structure and surrounding by air medium. The material properties are given in below table 2. The voltage applied to 5V in the structure shown in fig.3. This solution focuses an electrostatic force production in laterally driven on overlapping combs. Since, the energy stored in the comb fingers because the movable comb fingers and fixed comb fingers are as well as parallel plate capacitance.

Table 1. The important dimensions used for designing of interdigitated MEMS resonators.

Dimensions	
Geometries	**Designed values**
Number of movable fingers (one side)	12
Mass (L&W)	200µm &100µm
Gap between movable and fixed combs	3µm
Comb finger (L & W)	100µm & 5µm
Overlapping comb area	75µm
Inner folded beam (L & W)	200µm & 5µm
Outer folded beam (L & W)	150µm & 5µm
Air damping	10µm & 10µm
Thickness of resonator	5µm

Table 2. Properties of Polyimide and PVDF materials

Materials specification		
Property	**Polyimide**	**PVDF**
Density	1300[Kg/m^3]	1780[Kg/m^3]
Relative permittivity	3.4	11
Young's modulus	3.1[GPa]	8.3[GPa]
Poisson's ratio	0.34	0.18

Analysis of Finite Element Methods:

The frequency response analysis constitute performed for finite element analysis (FEA) using COMSOL multiphysics simulation. This finite element method (FEM) is used for multiphysics obtaining the best results in the fastest manner[30]. In this paper, FEM techniques has obtained the accurate solution and analyzed the potential distributions. The electric potential energy has a continuous quantity in the electric domain, the basic requirement of the finite element method is derived the system. This kind of simulation has analysis for the stiffness on flexural beam and static and parametric resonators are analyzed. However, the mesh generated is free triangular mesh shown in fig.2 and important mesh setting shown in table 3.

Table 3. Settings of Mesh property

Meshing Settings	
Description	**Values**
Maximum element size	37.1
Minimum element size	0.21
Curvature factor	0.3
Maximum element growth rate	1.3

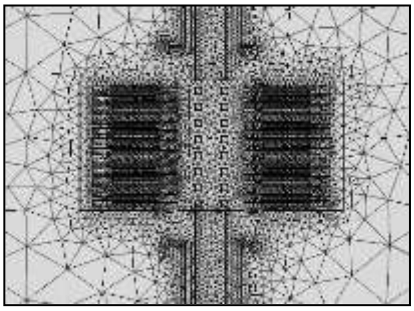


Fig.2:Triangular mesh

Parameters Values:

The spring constant K can be established from 1.805 N/m of PVDF and 0.67425 N/m for polyimide in eq.3, The proof mass is derived from $M=A\rho T_{th}$ = 163.76 $\times 10^{-12}$ kg where, A is the total area is obtained from the structural layout, ρ is the density materials, T_{th} is the structural thickness. The resonance frequency formula is written as $f_r= 1/2\pi\sqrt{\frac{K}{M}}$ where, the K spring constant and M is mass in the comb drive device. However the one crucial point on device quality factors, the Q factors occurred damping effect of system is one of most important steps in analysis for the polymer MEMS resonators. The important parameters a quality factor derived as $Q = \frac{K}{f_r C_{Total}}$ where, C_{Total} the total damping coefficient, and f_r is resonance frequency. Since, the estimated air damping effects are approximated by two mechanism slide film and squeeze film damping. Above the equation can derived the results of resonance frequency in16 KHz for PVDF material with quality factor of 33950 and 10 KHz with quality factor 19894 for polyimide material driven on IDC MEMS resonators.

Discussions

The design and simulation of the IDC MEMS resonator are done by electrostatic, solid mechanics and moving mesh interface modules. The structure is carrier out for the finite element methods (FEM). Also the design a dynamic Multiphysics model is used to solve the electrostatic problem by Arbitrary Lagrangian-Eulerian (ALE) algorithm. The polymers need to have suitable elastic moduli to support the deformation started by MEMS systems. The voltage is applied to movable combs and ground is applied to fixed combs, it can be varied by electrical potential and laterally driven by an electrostatic force as shown in fig.3(a)and fig.3(b) shown in the relation between modes of vibration and displacement[11,12]. The nonlinearity response for flexural folded beam an IDC resonator shown in fig.4 for logarithm response of electrical potential and total displacement. The solution shown an electric potential is increases with total displacement also in decreases.

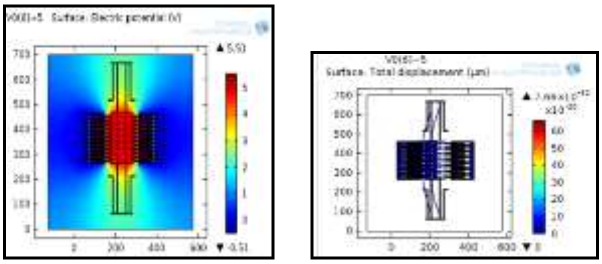


Fig.3: (a) Electric potential distribution (b) Total displacement

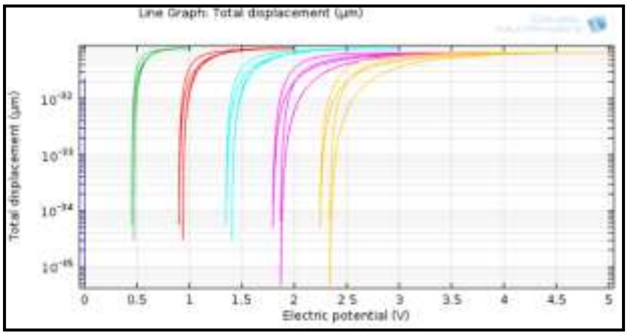
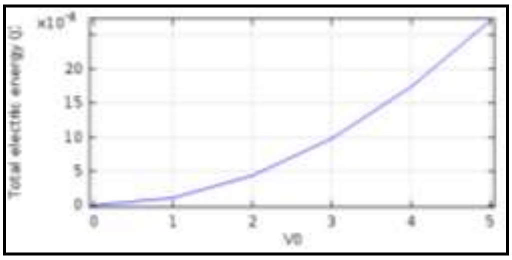


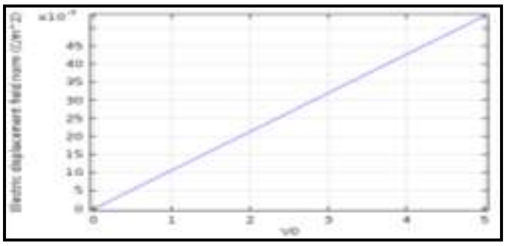
Fig.4: Logarithm response of electrical potential and total displacement

In addition, the devices are analysis of voltages and total electric energy shown in fig.5a. However, the actuation voltages is gradually increase and its produce an electric energy. Also the simulation results of voltage and electric displacement field norm is linearly increases shown in fig.5b for the comb drive resonator.



(a)

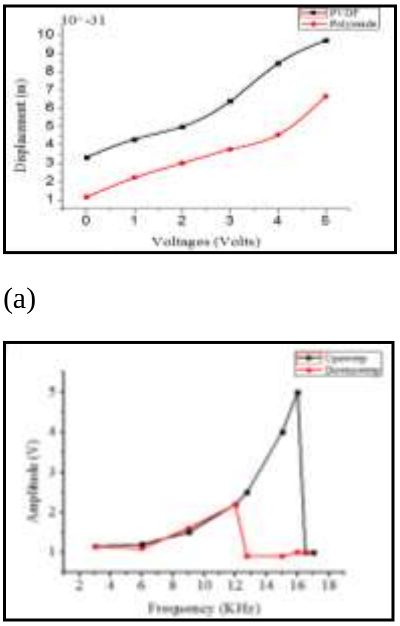
Fig.5a: Voltages vs Total electric energy



(b)

Fig.5b: Voltages vs Electric displacement field norm

Since the high stiffness ratio for the higher amplitude vibration occurred, when the actuation voltages was increased corresponding displacement is also increased shown in fig 6a.



(a)

(b)

Fig.6 (a): Graph of voltages and displacement (b): Nonlinear frequency characteristics

This PVDF material is large displacement than polyimide and the properties of different material. This resonance frequencies are vibrated on large amplitude and during upsweep and downsweep frequency can be excited to stable frequency in hysteresis frequency. This resonance frequency characteristics as shown in fig 6b.

Conclusion

In this paper, the MEMS device have hysteresis characteristics during upsweep and downsweep of resonance frequencies and modes are studied. This PVDF based IDC MEMS resonator has good resonance frequency with high quality factor. We have calculated the capacitance 35fF for PVDF IDC MEMS resonator is suitable for filter devices.

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