IJARCCE

ISSN (Online) 2278-1021
ISSN (Print) 2319 5940

International Journal of Advanced Research in Computer and Communication Engineering
Vol. 5, Issue 3, March 2016

A Novel Design of Electrostatic Actuation Based on Comb Drive MEMS Resonator Using Vibrating Energy Storage Application

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Abstract: In this paper, investigates the comb drive based microelectromechanical systems MEMS resonator device has coupled interaction between the electrical and mechanical systems of the transducer. The parametric resonator is the sense and it is electrostatic force driven in lateral direction. However, the mechanical domain was vibrates of modes an along with flexural folded beam. The Polyvinyl Alcohol (PVA) material based on the structures are analyzed for different number of combs with stiffness using Finite Element Methods (FEM) techniques. In addition this dynamic Multiphysics model is developed for the Arbitrary Lagrangian-Eulerian (ALE) formulation. Here, results shown the electrostatic actuation verses number of combs and displacement is related to change in the capacitance due to the comb fingers and calculated the capacitance in overlapping combs. This simulation work done by two dimensional (2D) IDC MEMS resonator structure using COMSOL Multiphysics 4.4 and also theoretical shown on the resonance frequency with the high quality factor.

Keywords: MEMS resonator, interdigitated comb-drive, electrostatic actuators, flexural beam and FEM.

I. INTRODUCTION

Micro-Electro-Mechanical Systems (MEMS) resonators are growingly as parts of sensor and actuator devices have been used in many applications such as communication accelerometer, RF-MEMS filters, microgyroscopes, oscillators, microtweezers etc., [1-7].The first proposed in electrostatic MEMS resonator were designed for polysilicon materials using microfabrication techniques [8]. Nowadays many materials are needed to miniaturization device for the highest quality and system sensitive of electrical and mechanical properties. Therefore the device can be modified by doping and biocompatibility materials are required for the integrated into MEMS designs. In this research work focused on polymer based materials are used for structural materials with great success achieved. Since the polymer like as polyvinyl alcohol (PVA) applied to the structure and it is good results in MEMS device fabrication. Fundamental design on the comb drive model can accomplish large displacement at low actuation voltages. The key research an electrostatic comb drive is believed similar as capacitive device. However, the electrostatic actuation have excited, it is a rise from coupled linear response can be exhibited at a higher amplitude vibration [9].

The paper is organized as follows: First in section 2, the design process of a IDC MEMS resonator is depicted and electrical and mechanical properties are described. Next the characteristics of the theoretical model are studied and the results from the FEM analysis of section 3. Finally the simulations of the movement of the operation as considerable of comb drive and spring suspension are presented.

II. DESIGN OF AN IDC MEMS RESONATOR

The comb drive design is consists of fixed and movable combs, its connected to mass along with suspended by flexural folded beam. This flexural beam is attached to the trusses and beam like as one end fixed and other end is suspended. That structure can be used prototype design of multiphysics model shown in the figure.1 IDC MEMS resonator and also the important dimension shown in table 1.

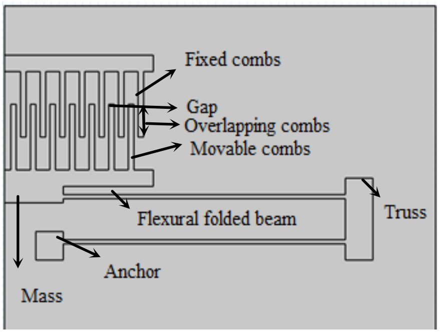


Fig 1. Structure of interdigitated comb drive MEMS resonator

However the device is demonstrated for x-y direction to produce on stable oscillation. The research proposed methods are development of MEMS resonator device, when a actuation voltage is applied to movable combs and

IJARCCE

ISSN (Online) 2278-1021
ISSN (Print) 2319 5940

International Journal of Advanced Research in Computer and Communication Engineering
Vol. 5, Issue 3, March 2016

fixed combs, it can produce an electric field. Therefore the rectangle shape of the overlapping combs move to lateral direction and also 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 [2]. These features mentioned for reduce axial stress, restrict out of plane movement and the device minimize unstable end unwanted vibrations in the other axes.

Table 1. Important dimension of the interdigitated comb drive MEMS Resonators

Part description	Designed Value
Structure thickness T_{th}	5 µm
Different Number of movable combs	5,7,9
Mass width (W_m)	20 µm
Mass length (L_m)	75 µm
Gap (g)	5 µm
Comb finger width (W)	7 µm
Comb finger length (L)	80 µm
Overlapping combs (s)	40 µm
Flexural folded beam spring length	360 µm
Flexural folded beam spring width	5 µm
Anchor Size width × length	35 µm ×35 µm
Truss width	35 µm
Truss length	100 µm

2.1. Electrostatic Forces

The static displacement of capacitance between the overlaps combs of movable and fixed combs are charge of the devices shown in the figure.1. The change in capacitance 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 combs, s is the overlap combs, x is the displacement in y direction, T_{th} is the thickness of the structure, ε_0 is the relativity permittivity 8.852x10^{-12} F/m and g is the gap between the movable comb and fixed comb fingers on the side.

2.2. Mechanical systems of IDC MEMS Resonator

The dynamic modeling is a laterally driven by IDC resonator on single 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 including the combs, c is the damping coefficient. Here it is assumed that as F_e changes direction and due to the change in polarity of V. Therefore the storing force $F_k$and the damping force F_d also change their directions to oppose F_e. The mass is a dimensionless physical quantity, the acceleration applied to the mass and it has been taken the response in mass displaces and this displacement is sensed using the capacitive comb drive attached to the mass. Therefore the mass derived from is

$$M = A\rho T_{th} \qquad (3)$$

Where A the total area is obtained from structure, T_{th} is the structural thickness and ρ is the density of PVA material in 1.19 g/cm³.

The IDC MEMS resonators structure is design of a mass connected to a spring flexural folded beam that itself is anchored to the comb drive resonators. This section focuses on flexural folded beam selection as it should be exhibit a large linear displacement range and have a high lateral stiffness ratio to reduce cross-axis sensitivity. The spring can be modelled as a straight cantilever beam. Since the beam described for using Euler-Bernoulli beam theory and the linear spring constant in the x-direction. The cantilever due to load at the tip of the beam can be defined as

$$K = \frac{12 l_x E}{L_s^3} \qquad (4)$$

$$K = \frac{E T_{th} W_s^3}{L_s^3} \qquad (5)$$

Where l_x is the area moment of inertia in x-direction, $l_x = \frac{T_{th} W_s^3}{L_s^3}$, K is the spring constant, E is the Young's modulus of the PVA material 50GPa and 70GPa, T_{th} is the structure thickness, W_s is the spring beam width, and L_s is the spring beam length.

2.3. Resonance frequency with Quality factors

A simple second order mechanical resonator a mass-spring damper system has a single resonant frequency can be derived from as

$$f_r = 1/2\pi\sqrt{K/M} \qquad (6)$$

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.

III. ANALYSIS OF FINITE ELEMENT METHOD

Traditionally the finite element method (FEM) is numerical analysis from the Multiphysics domain, such as electrostatic, solid mechanics and moving mesh interface can be used to design model for COMSOL multiphysics 4.4. It can be obtained the best results in the fastest manner. Nowadays the structural analysis was demonstrated for multiphysics problem of the frequency response analysis.

In this paper, FEM techniques has obtained the accurate solution and analyzed the potential distributions. Since 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 psychoanalysis for the stiffness on flexural beam and static

ISSN (Online) 2278-1021
ISSN (Print) 2319 5940

International Journal of Advanced Research in Computer and Communication Engineering
Vol. 5, Issue 3, March 2016

and parametric resonators are analyzed [9-11]. That free triangular mash type is done for the 2D view to compute the finite element analysis.

Table 2.Settings of mesh property

Meshing Settings	
Description	**Values**
Maximum element size	55
Minimum element size	1.1
Curvature factor	0.4
Maximum element growth rate	1.4

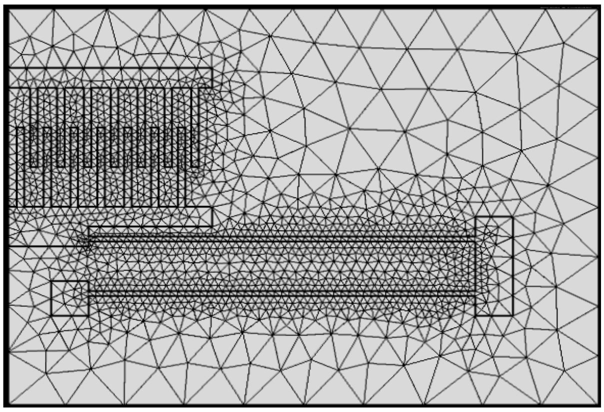
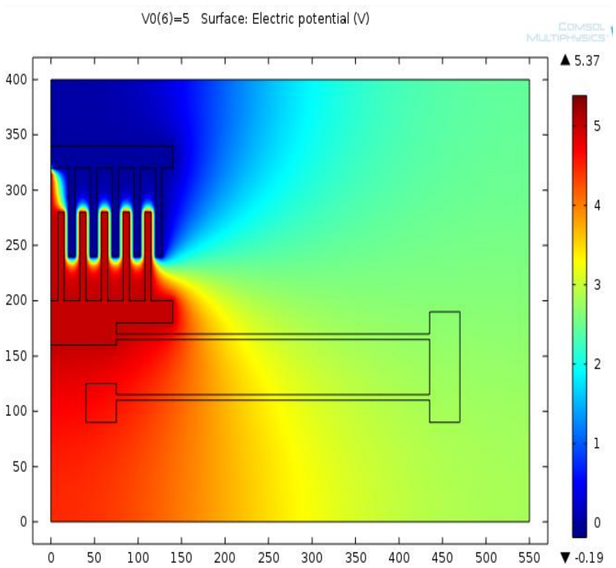


Fig 2. Free Triangular Mesh (coarse)

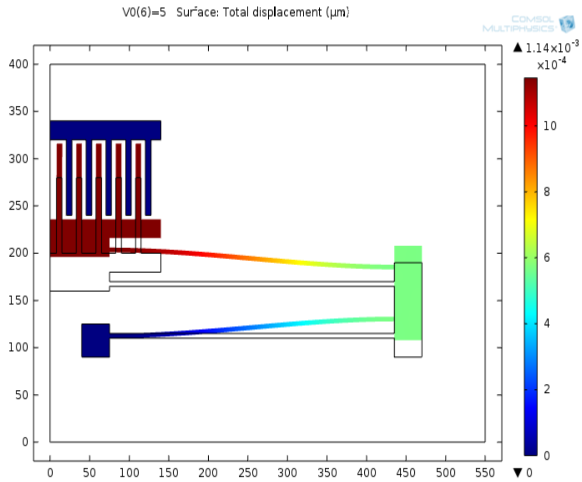
Shown in fig.2 free triangular mesh in seven comb fingers on PVA MEMS resonator and also general physics mesh settings shown in table 2.

IV. RESULTS AND DISCUSSIONS

The PVA material based comb drive MEMS resonator is designed by a two dimensional structure of the structural mechanism. This type of polymer materials are very excellent electrical and mechanical properties used in device. Here, the PVA material is applied as a coating to the comb drive structure and it is surround by air medium. .



(a)



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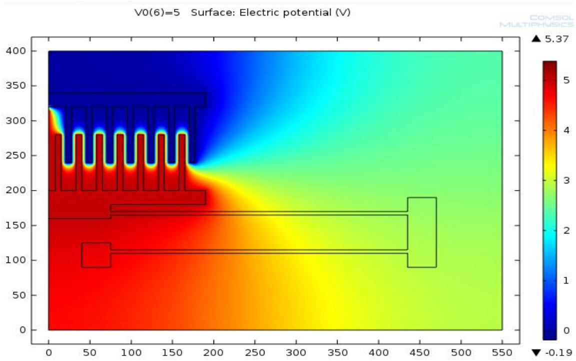
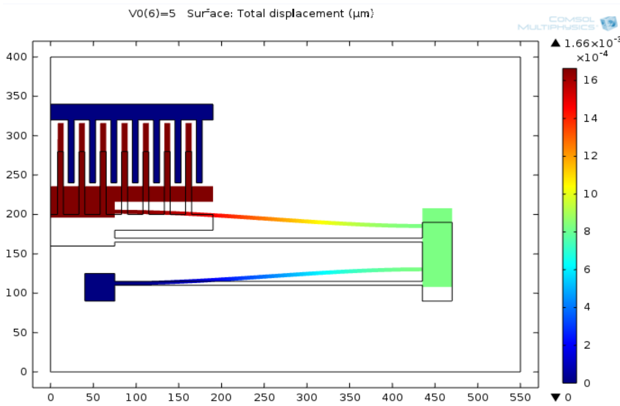


(c)



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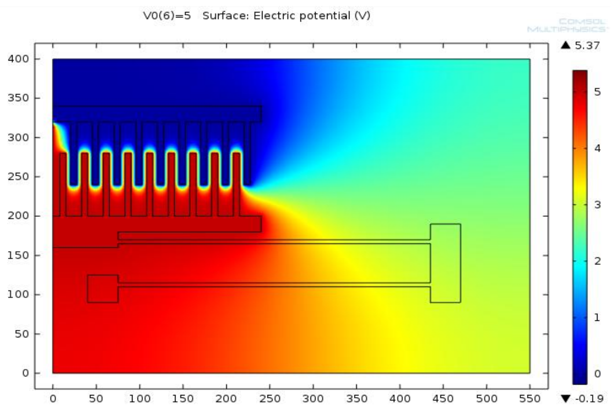

(e)

DOI 10.17148/IJARCCE.2016.53254

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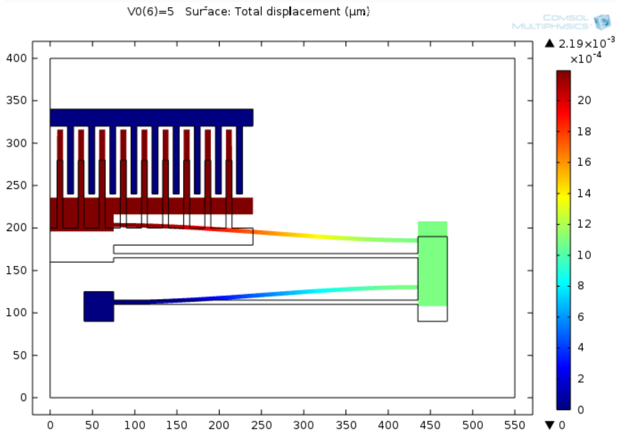

(f)

Fig 3. Illustration of electric potential and total displacement

Here, the results shown fig. 3(a), (c), (e) for electrostatic force in a various number of interdigitated comb fingers as 5,7,9 in voltages 5V. The actuation voltage 1V to 5V is applied to movable comb and fixed combs in ground. This overlapping combs are generates the electric fields in transvers direction.

Therefore that comb fingers has basic principle as parallel plate capacitor, so charging the capacitance. Here, FEM techniques is solving the electric distribution and also fringing field capacitance ignored.

Shows fig. 3 (b), (d), (f) total displacement on the same number of interdigitated combs, it is lateral direction displacement of the flexural folded beam [2,12]. The design a dynamic Multiphysics model is used to solve the electrostatic and deformation problem by Arbitrary Lagrangian-Eulerian (ALE) algorithm.

4.1. Analysis of Capacitance:

The eq.1 calculated the capacitance values, that values are gradually increase in various number of comb fingers shown in fig 4.

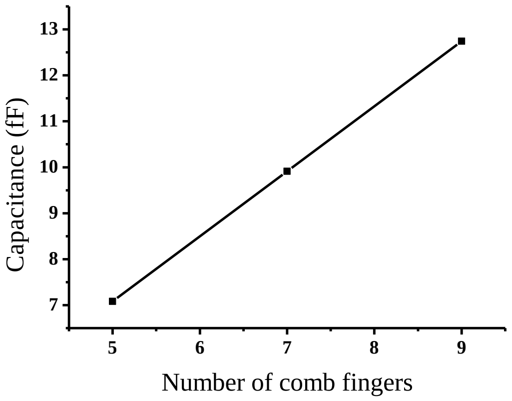

Fig 4. Number of comb fingers vs Capacitance

The actuation voltage is applied to high voltages for the movable combs and electric potential increased in result shows the fig 5.

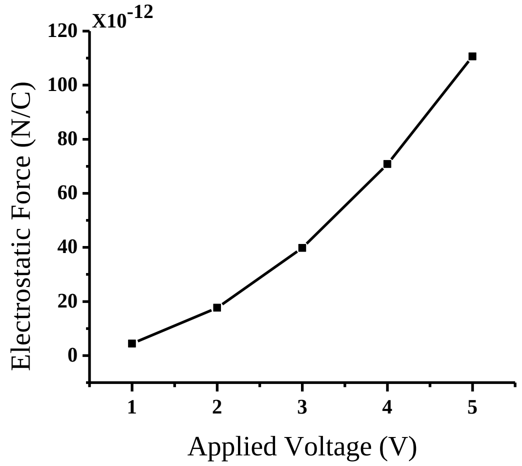

Fig 5. Graphical representation of Electrostatic force vs voltages

Since the number of combs and displacement determined the elastic property of the young's modulus values andpassion ratioin the flexural beam shows the table 4.

Table 4. Material specifications

Specification of Materials	
Polyimide Materials	**Values**
Young's modulus	50GPa & 70GPa
Density (ρ)	1300 kg/m^3
Young's modulus (E)	3.1GPa
Permittivity of free space (ε_0)	8.85×10^{-12} F/m

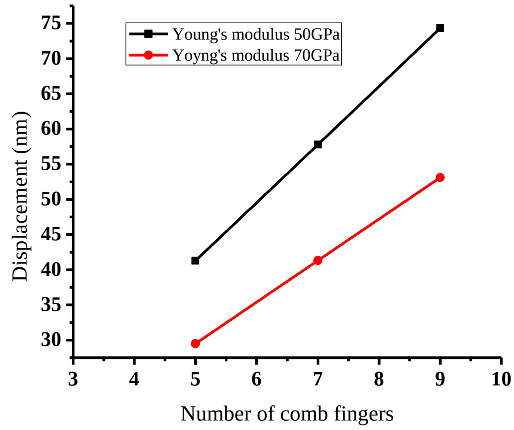

Fig. Number of combs vs displacement

4.2. Resonance Frequency

The most important parameters are mass damper spring constant in resonant frequency. This resonance is a property of many physical system where a device exhibits amplified response at certain frequencies, known as resonant frequencies over a narrow bandwidth.

The eq.3 derived in mass value M= 8925×10^{-12} g/cm^3. Here, results shows the resonance frequency stiffness and quality factor values are determined shown in table 5. The resonance frequencies for large vibration amplitude with highest frequencies.

 DOI 10.17148/IJARCCE.2016.53254

Table 5. Calculate the resonance frequency and quality factor

PVA material Specification	Stiffness (N/m)	Resonance frequency (kHz)	Quality factor
Young's modulus 50GPa	1.34	1.95	508000
Young's modulus 70GPa	1.88	2.3	604700

V. CONCLUSION

We have designed two dimension IDC MEMS resonator that uses electrostatic actuation. This IDC MEMS resonator structure designed using PVA material for the young's modulus of 50GPa and 70GPa, density is 1.19 g/cm³. In this study, Transvers direction an electrostatic force and laterally driven the displacement of the beam. The capacitance calculated from the 5,7,9 comb fingers is designed for energy harvesting system applications. This devices are energy storage mechanism on the comb drive MEMS resonators. This PVA based IDC MEMS resonator has good resonance frequency with high quality factor. The device are determined and simulated by COMSOL Multiphysics 4.4 software. Hence the simulation analysis and analytical calculation are described.

Nomenclature

MEMS	Micro Electro-Mechanical Systems
IDC	Inter-digitated Comb Drive
PVA	Polyvinyl Alcohol
FEM	Finite Element Methods
ALE	Arbitrary Lagrangian-Eulerian
C	Capacitance
K	Spring constant
M	Mass
Q	Quality factor
ρ	Density of materials
C_{total}	Total damping coefficient
f_r	Resonance frequency
T_{th}	Thickness of structure

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