Design & Analysis of Clamped Free MEMS Resonator

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Abstract— This paper presents use of the simple cantilever beam as a Clamped free MEMS resonator, it's design, Eigen frequency and electrostatic analysis. This resonator requires 4V DC voltage and has a quality factor of 1302.5

Keywords- *MEMS, Clamped free resonator, Eigen frequency*

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I. Introduction

MEMS are a micro electro mechanical system. They have been developed since the 1970s. In the last decade Micro-Electromechanical System (MEMS) devices have experienced a tremendous development in various fields of the Information and Communication Technologies (ICT). Especially the recent trends towards the interaction between integrated circuits (IC) components and external environment pushed for the design of innovative devices and technologies able to couple electrical properties with several different physical domains. In particular MEMS devices exploit a miniaturized movable structure whose movement or position can interact with electrostatic, thermal, magnetic, fluidics, electromagnetic signals.[2] MEMS resonator has ability to replace quartz crystal resonator, SAW filter. They provide a promising alternative to traditional electronic components especially for RF devices (e.g. mixers, tunable capacitors, inductors, switches, oscillators) [3]. The device which provides oscillations within a particular frequency band known as resonator.

II. Basic Clamped Free Beam Resonator Structure

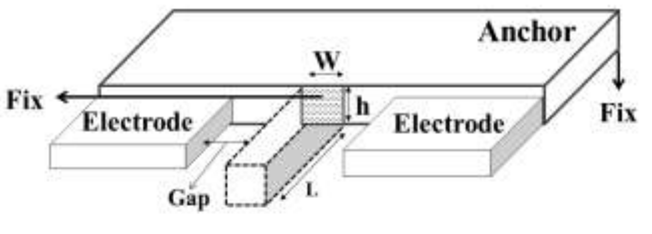

Figure 1. Clamped Free Beam Resonator. [3]

III. Operation of Resonator

Fig. 2 shows the configuration of Clamped free beam resonator, Fig. 3 and Table I shows the design model and design parameters of MEMS poly-silicon resonator. The principle of operation of MEMS resonator based upon a two electrode in which the moving and fixed part forms two electrodes of capacitors. Anchor is used to fixed resonators one end.By applying DC voltage to the anchor and an AC voltage to the excitation electrode, the microstructure being driven into resonance. The DC voltage is used to generate the electrostatic force this will bend the beam but it will vibrate only if this force vibrates and this can be done using AC voltage.

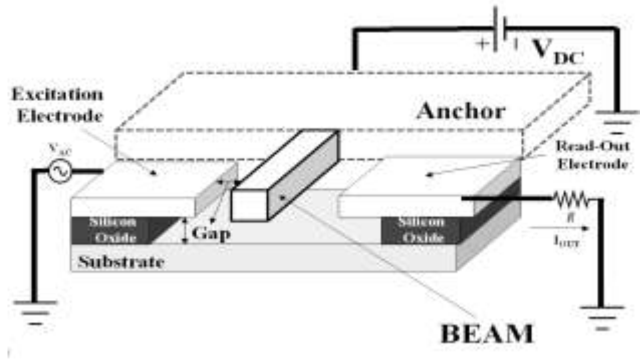

Figure 2. Electrical setup for Clamped-Free beam resonator. [3]

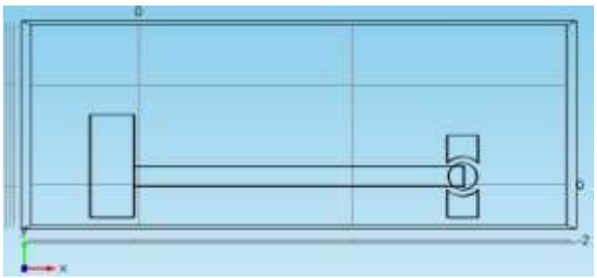

Figure 3. Design Model

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TABLE I. DESIGN PARAMETERS OF MEMS POLYSILICON RESONATOR

Input Parameter	Value	Unit
Beam length, L	15	µm
Beam width, W	1	µm
Beam thickness, t	1	µm
Anchor length	2	µm
Anchor width	5	µm
Anchor thickness	1	µm
Electrode to resonator gap	0.3	µm
Driving, Sensing Electrode length	1.4	µm
Driving, Sensing Electrode width	4	µm
Driving, Sensing Electrode thickness	1	µm

Fig. 3 and Table I shows the design model of clamped free beam resonator and design parameters of MEMS poly-silicon resonator. As the motional resistance has power handling capability, minimum electrode to resonator gap is required to get reduced equivalent motional resistance and reduced anchor losses, but there is a limit on reducing the gap between electrode and resonator as it decides the maximum displacement amplitude. For high resonance frequency the mass of resonator required is less, but In Fig. 3 design model the mass is applied at the end of cantilever beam for efficient transduction, as reduction in resonance frequency is negligible. By using driving (input) and sensing (output) electrode a mask is applied on cantilever beam.

TABLE II. MATERIAL PROPERTIES OF POLY-SILICON

	Property	Name	Value	Unit
✓	Relative permittivity	epsilonr	4.5	1
✓	Density	rho	2320[kg/...	kg/m^3
✓	Young's modulus	E	160e9[Pa]	Pa
✓	Poisson's ratio	nu	0.22	1
	Coefficient of thermal expansion	alpha	2.6e-6[1/K]	1/K
	Heat capacity at constant pressure	Cp	678[J/(kg*...	J/(kg*K)
	Thermal conductivity	k	34[W/(m*...	W/(m*K)

TABLE III. MATERIAL PROPERTIES OF AIR

	Property	Name	Value	Unit
✓	Relative permittivity	epsilonr	1	1
	Relative permeability	mur	1	1

IV. EIGEN FREQUENCY ANALYSIS

Eigen Frequency: The term resonator is most often used for a homogeneous object in which vibrations travel as waves at an approximately constant velocity bouncing back & forth between the sides of the resonator. The resonator can have millions of resonant frequencies, although only a few may be used in practical resonators. The resonant frequencies of resonators called normal modes are equally spaced multiples [harmonics] of a lowest frequency called the fundamental frequency.

$$F = \frac{(\beta nl)^2}{2\prod}\left[\sqrt{\frac{EI}{\rho A L^4}}\right]$$

Where,
F-Frequency
βnl- Arbitrary Constant
E-Young Modulus
I- Inertia
ρ –Density
A-Area of beam
L-Length of beam

TABLE IV. VALUE OF (BNL)²

Beam Configuration	$(\beta nl)^2$ Fundamental	$(\beta nl)^2$ Second mode	$(\beta nl)^2$ Third mode
Cantilever	3.52	22.0	61.7

TABLE V. FREQUENCIES OF DIFFERENT MODE

Frequency	Analytical	Simulation
Fundamental	5.96 MHZ	5.46MHZ
2nd Mode	37MHZ	34MHZ
3rd Mode	101 MHZ	93.48MHZ

V. ELECTROSTATIC (AC ANALYSIS)

A. *Resonance Frequency*

Frequency at which the response amplitude is a relative maximum known as resonant frequency. Resonance occurs when a system is able to store & easily transfer energy between two or more different storage modes. However there are some losses from cycle to cycle called 'damping'. When damping is small the resonant frequency is approximately equal to natural frequency of the system, which is a frequency of unforced Vibration.

$$\lambda = \frac{Lc}{L}$$

Where,
λ- Damping coefficient

Lc- Length of beam overlapped by electrode

L-Length of beam

B. *Pull-in voltage*

Since the beam vibrates either in vertical and lateral displacement, it may touch the electrode or substrate when it reaches the maximum DC voltage. In this work, we are interested in the lateral movement of the beam during vibration. The pull-in voltage is as when the lateral movement of beam reaches beyond the gap distance of 0.3μm. This indicates that the beam is already touching the electrode [3].

$$Vp = \left[\sqrt{\frac{8kd^3}{27\epsilon 0 Aeff}}\right]$$

Where,
Vp- Pull in voltage
k- Stiff constant
d- Electrode to resonator gap
Aeff- Effective electrode area
ε0-Absolute permittivity of air

C. DC Supply Voltage (Vin)

$$Vin = \left[\sqrt{\frac{2Fd^2}{\epsilon\epsilon 0 Aeff}}\right]$$

Where,
Vin- DC voltage
F-Force of actuation
d-Electrode to resonator gap
Є-Relative permittivity
Є0-Absolute permittivity
Aeff- Effective area of beam

Applied VDC Value	Calculated VDC Value
4V	3.82V

As depicted in Fig.4 Clamped free beam shows the first mode resonance frequency at 5.46 MHZ and the displacement at 4.40nm.

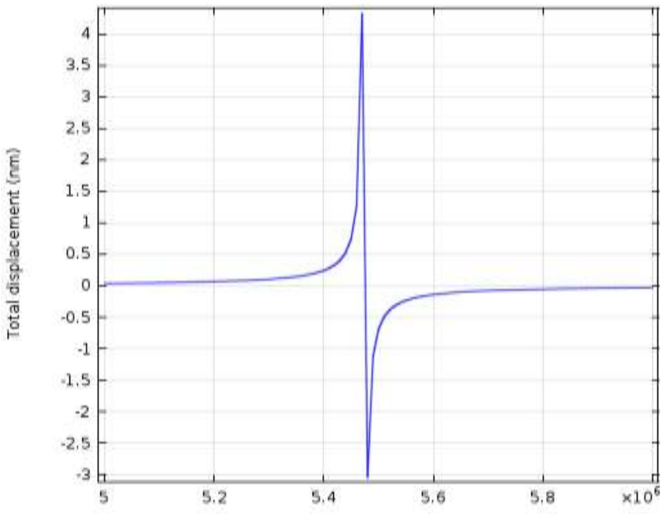

Figure 4. Total displacement and resonance frequency result for Clamped free beam with 4V DC voltage

VI. CONCLUSION

The Clamped free beam was found to have a resonance frequency of 5.46 MHz. This was built using poly-silicon. The required DC voltage is 4V. This resonator can be used as a band-pass filter in RF-transceiver.

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