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Sizing electrode and its effect on performance of a microactuator

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ABSTRACT

The vibration amplitude and its frequency are the main factors that affect the performance of resonating microactuators and microsensorson. Electrostatic and piezoelectric actuation/sensing are very common methods used to design Microelectromechanical Systems (MEMS). Both methods requires adding electrode layer for detection or actuation purposes which is normally very small is dimension and therefore have low effect on the performance of MEMS device. In some cases, even a small shift in the vibration resonance frequency of the device or its amplitude of vibration can highly affect the device performance. This work investigates the effect of sizing electrode on the performance of electrostatically actuated MEMS device. Electrode length was varied from fully covering the actuator layer to covering 10% only. ANSYS finite element was used as a simulation tool.

1. INTRODUCTION

MEMS resonators are the key players in most of the MEMS sensors and actuators. Electrostatic actuation is most commonly used method of actuation compared to other alternatives methods (e.g. electrothermal and piezoelectric) and this is mainly due to the low power consumption and ability to very high resonance frequencies [1, and 2]. Electrode layers are used to apply electrostatic voltage to the actuated resonators. For cantilever resonator, a top layer of electrode is deposited to conduct voltage. The electrode characteristics (geometrical dimensions and elastic parameters) will influence the performance of the resonating structure [3]. On the other hand, the deposited electrode material might have undesirable mechanical and electronic properties compared to resonator device. Reducing the electrode length will reduce their effect but at the same time this will affect the active area for electrostatic actuation which may require high voltage to be applied. Effect of reshaping the metal electrode as well as changing the thickness, on the functionality of the resonators, were investigated in the literature [4,5, 6 and 7]. This work aims to investigate the effect of electrode length on the amplitude of electrostatically actuated microcantilever.

2. MODEL OF AN ELECTROSTATIC ACTUATOR

Electrostatic actuator, under investigation, consist of four main parts: silicon base layer (200×2×20 μm^3), isolator layer silicon dioxide (50×3×20 μm^3), silicon actuator layer (200×2×20 μm^3), and copper pad layer (200×2×20μm^3). The device layout, which was modelled in finite element (FE) software (ANSYS v.15), is shown in Figure.1. The properties of material used are presented in Table.1.

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Table 1. Material properties.

Properties material	Elastic Modules (MPa)	Poisson's Ratio (PR)	Density ($Kg/\mu m^3$)	Thermal Expansion Coefficient t(α),1/C	Thermal Conductivity (K),pW/µmºC	Resistivity (R) (ohm-m)
Si	185×10^3	0.28	23×10^{-15}	2.33×10^{-6}	157×10^6	6.4×10^2
SiO_2	73×10^3	0.23	22.7×10^{-15}	0.5×10^{-6}	1.4×10^6	1×10^{13}
Cu	110×10^3	0.34	89×10^{-15}	16.56×10^{-6}	393×10^6	1.72×10^{-8}

To verify the ANSYS model, natural frequency was calculated and compared with the value obtained from FEM model using the following equation [8]:

$$f = 0.16\frac{t}{l^2}\sqrt{\frac{E}{\rho}}$$

Where, f=Natural frequency (Hz),E= Elasticity modulus (Pa),ρ= Density (kg/m³) ,t= thickness (m), li =Electrode length over cantilever for different (i) length, n=2 (the ratio of two areas), since the cantilever is made of actuator and pad layer the equivalent Young's modulus was calculated as follows:

$$E_{eq} = \frac{\sum l}{\sum_{i=1}^{2}\frac{li}{Ei}} = 137.966\times10^9\ \mathrm{N/m^2}$$

And the equivalent density was calculated to be 5600 kg/m^3

$$f = 0.16\times\frac{0.004*10^{-3}}{[0.2\times10^{-3}]^2}\times\sqrt{\frac{137.966\times10^9}{5600}} = 79\ \mathrm{KHz}$$

The calculated value of resonance frequency (79 kHz) is close to the value obtained by ANSYS (79 kHz). Since the aim of this work is to investigate the effect of the length of pad layer (electrode), the resonance frequency was calculated for different

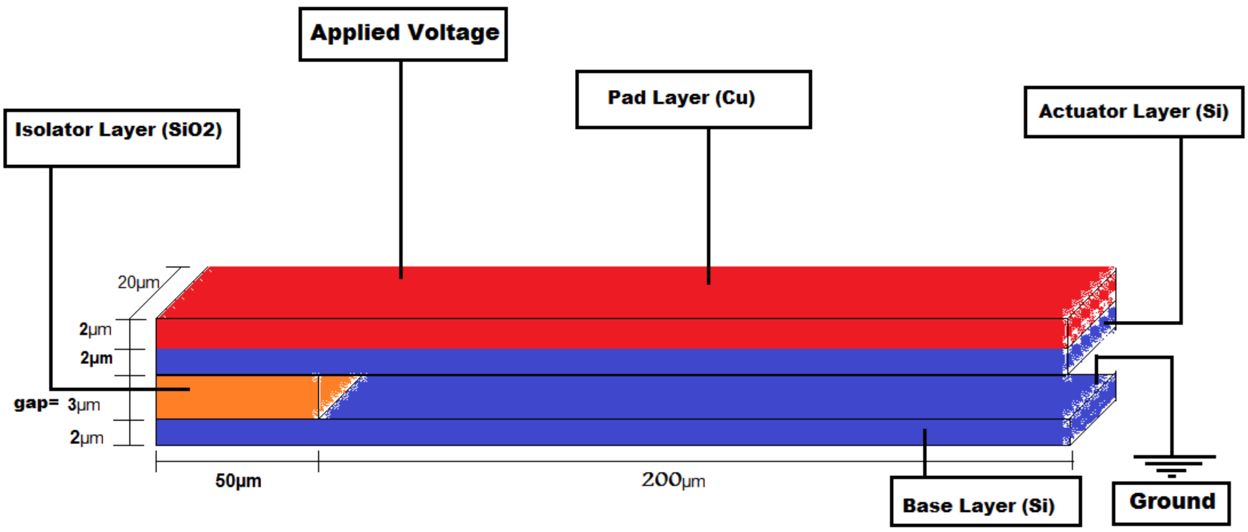

Figure 1. Geometry for electrostatic microcantilever.

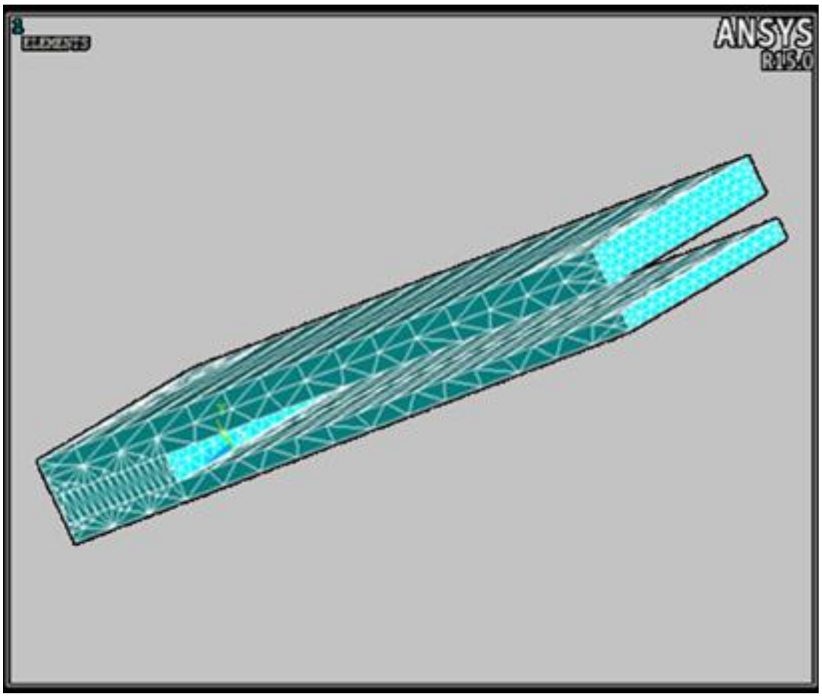

Figure 2. ANSYS meshing of the micro-cantilever device.

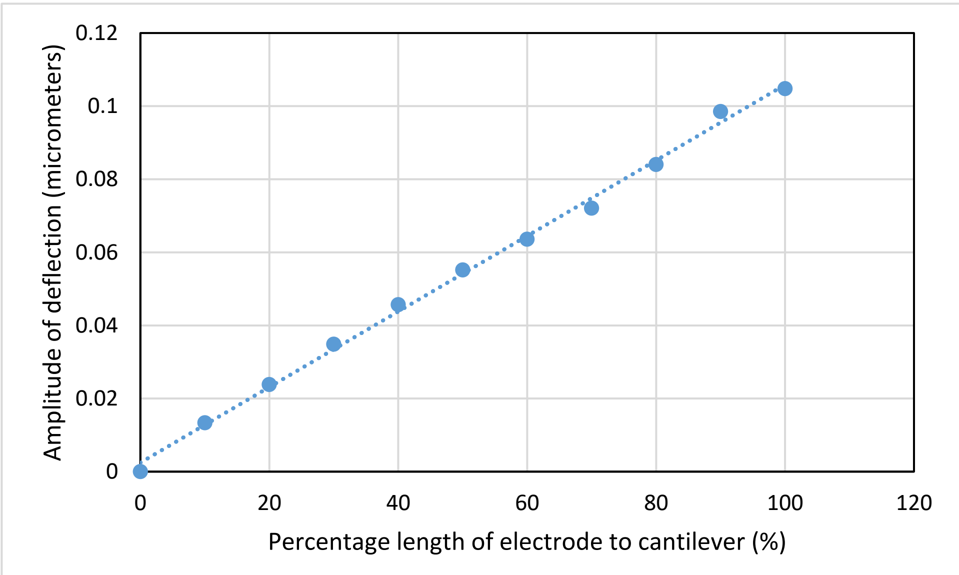

Figure 3. Linear relation between the amplitude of deflection and electrode geometry (for 10mV applied voltage).

lengths of electrodes as shown in Table.2. The large errors in the ANSYS calculated frequencies could be related to the meshing errors.

The model was developed and simulated in ANSYS (R.15). Attributed mesh was carried out, were each layer of actuator was meshed separately shown in Figure.2. Solid227 has been used as element type for all layers. Structural loads were applied to fix the end of the cantilever. Electrical loads were also applied for electrical actuation with electrodes.

2. RESULTS AND DISCUSSION

The applied voltage was then varied from 0 to 200 mV while reducing the size (length) of the electrode layer 100% (when it is fully covers the actuator layer) to 10% of the actuator layer. The results are shown in Figure.2. Although some of the maximum deflection values exceed the electrostatic gap value (which indicates that the actuator will hit the base layer), it is acceptable since it is not meant to mimic a real case. Alternatively, we can consider the values of deflection that are below 3 µm or even below the pull in gap. If the geometry of the model is modified, larger gap can be specified, and we could still obtain same relations about the effect of the electrode length.

The expected linear relation between the amplitude of deflection and electrode geometry (for 10mV applied voltage) can be seen in Figure.3.

Investigating the dynamic behavior of an electrostatically actuated cantilever, based on simple plate theory, shows that the amplitude of deflection is proportional to the square of applied voltage. The electrostatic force (F) generated for

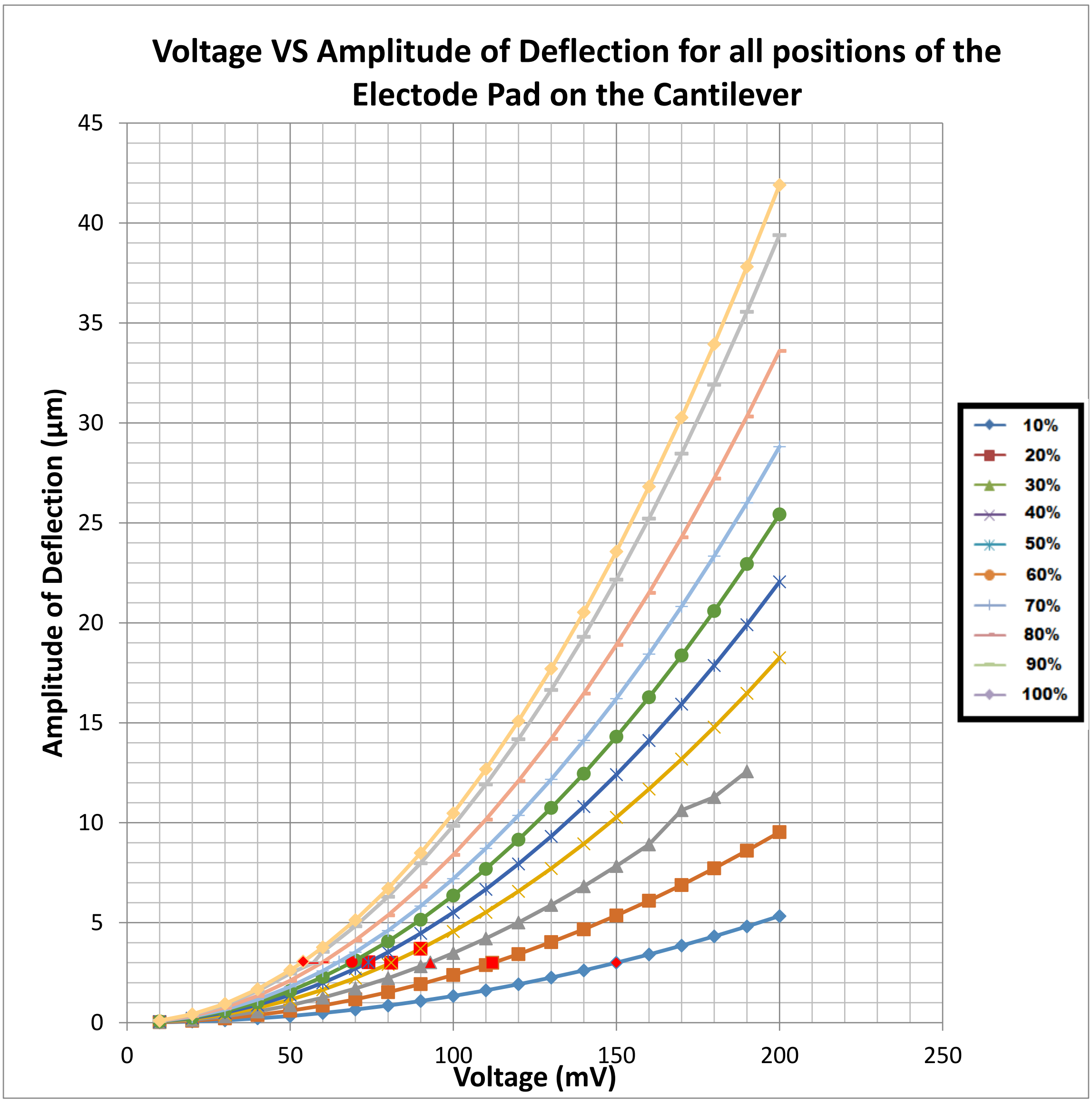

Figure 4. Voltage VS Amplitude of deflection at all positions of electrode Pad on the Cantilever.

Table 2. Natural frequency for different electrode lengths.

% of cantilever covered with Electrode pad	Electrode Length(µm) (li)	Natural Frequency(KHz) By ANSYS	Natural Frequency (KHz) By Calculation	Error for Natural Frequency (%)
100	200	78.1238	79.4167	1.628
90	180	100.799	98.708	2.074
80	160	145.563	125.879	13.52
70	140	149.002	165.837	10.15
60	120	231.653	227.965	1.59
50	100	328.204	332.048	1.16
40	80	556.157	525.827	5.453

simple parallel plates follows this relation generated by applying a voltage V is [9];

$$F = \frac{V^2 \in, A}{2d^2} = kZ$$

where ∈ is the permittivity in vacuum, d is the gap between the two electrodes, A is the area of one capacitor plate, k is the spring constant of the cantilever and Z is the amplitude of deflection due to V.

The results in Figure.4 confirms that the amplitude of deflection is not linearly proportional to the applied voltage.

4. CONCLUSIONS

The effect of electrode geometrical dimensions (length) on the performance of the resonating structure was investigated. Sizing the electrode length doesn't only affect the natural frequency of the structure but it also affect the amplitude of deflection and the voltage necessary to achieve certain deflection level. The results show that the amplitude of deflection may decrease significantly as a result of reducing the size of electrode. For example, at 200 mV, reducing the electrode length to one tenth reduces the amplitude of deflection almost eight times. The authors recommend that the presented finite element analysis can be further developed to address issues like; stress-strain analysis, and nonlinear mechanical behavior inherent in the materials used.

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