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Analysis for Pull-in Voltage Variations of Fixed–Fixed Beam with Elastic Deformation in Current Input

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ABSTRACT

In this study, the pull-in voltage variations of fixed–fixed beam with elastic deformation are explored. First, electric current is applied to deform the fixed–fixed beam and induced the thermal expansion. Subsequently, the behavior between elastic deformation and pull-in voltage is studied by changing various parameters, such as applied current, geometric length, and material of the fixed–fixed beam. The commercial software COMSOL is used to determine the pull-in voltage when the variables changed. Therefore, in this work we will make the designer understand clearly for the electro-mechanical behavior of a fixed-fixed beam with elastic deformation.

1. INTRODUCTION

Microelectromechanical system components deform when subjected to structural stress such as residual stress released during the manufacturing process (Huang 2007) or thermal stress released during heating processes (Liu 2012). Subsequently, deformation induces changes to the initially ideal flatness, ultimately changing the component properties. In this study, a commercial software package was used to find pre-deformation and simulate the drift in the pull-in voltage of the components to identify the changes in component properties.

2. ANALYTICAL MODEL

About the analytical model, we intend to make bridge beam structure by using SOI wafer, the schematic diagram of the fixed–fixed beam structure is shown in Fig. 1. Fig. 1 (a) indicates that the first layer of the structure comprised silicon-based film, and the second layer of the structure consisted of silicon oxide. Etchant was used to etch the silicon oxide to create a floating structure, where the gap in the middle represented the thickness of the silicon oxide layer. Fig. 1 (b) shows the pre-deformation created when the structure was heated using an electric current, which created a downward bending curve. The gap in the middle was reduced because of beam deformation. The geometric dimension and material property parameters of the fixed–fixed beam are shown in Tab. 1. The parameters are defined as follows: α, coefficient of thermal expansion; Cp, heat capacity under atmospheric pressure; R, electrical resistivity; ρ, density; h, coefficient of thermal conductivity; E, Young's modulus; v, Poisson's ratio; i, current; w, beam width; L, beam length; t, beam thickness; and g_0, initial gap.

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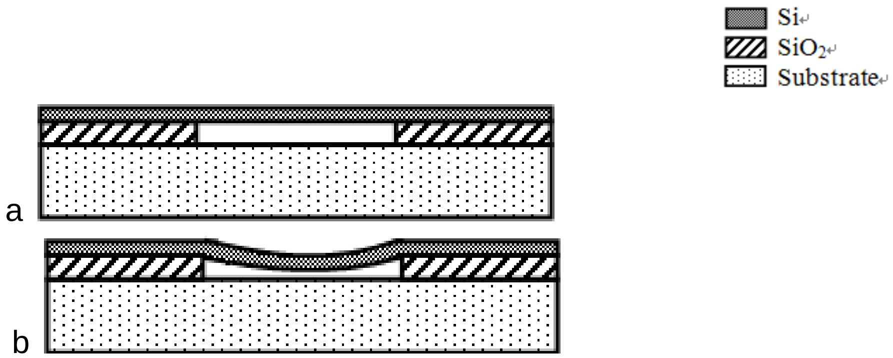

Fig. 1 Schematic diagram of the fixed–fixed beam analysis models: (a) without pre-deformation; (b) with pre-deformation.

Tab. 1 Material properties and geometric dimension parameters

Parameters	**Values**
Beam thickness **t** (μm)	2
Beam width **w** (μm)	10
Initial gap $\mathbf{g_0}$ (μm)	2
Coefficient of thermal expansion α (1/K)	2.46×10^{-6} (Si) 2.31×10^{-5} (Al) 1.7×10^{-5} (Cu)
Young's modulus **E** (GPa)	168 (Si) 70 (Al) 120 (Cu)
Poisson's ratio ν	0.23 (Si) 0.34 (Al) 0.35 (Cu)
Density ρ (kg/m^3)	2330 (Si) 2700 (Al) 8960 (Cu)
Heat capacity under atmospheric pressure $\mathbf{C_p}$ (J/(kg・K))	1.134×10^{6} (Si) 897 (Al) 386 (Cu)
Coefficient of thermal conductivity **h** (W/(m・K))	30 (Si) 237 (Al) 401 (Cu)
Electrical resistivity **R** (Ω・μm)	250 (Si) 2.81×10^{-2}(Al) 1.72×10^{-2} (Cu)
Current **i** (mA)	1 - 10
Beam length **L** (μm) of each group	125, 150, 200 250, 300, 350, 400, 450, 500, 550

3. SIMULATION

In this study, we set the fixed–fixed beam to simulate the characteristics of MEMS device. We use the commercial software COMSOL to simulating the pre-deformation beam when the different levels current input which corresponds to pull-in voltage. Through the result of simulation, we can understand the relationship in current and pre-deformation between pull-in voltages. By knowing the device characteristics and the range in electric signal, it is also beneficial to considerate on measuring device on the subsequent measuring experiment.

3.1 Simulation in current input

In the first part of simulation, we use the modal, "Joule heat and thermal expansion", to simulate how much pre-deformation of the beam when the current input. The beam is heated by applying current between two anchors. One side is input and another one is ground. Thus the structure will be deformed during to the thermal expansion. Especially the part in the middle of the beam is most obvious. Schematic of structure with pre-deformation in current input is shown in Fig. 2.

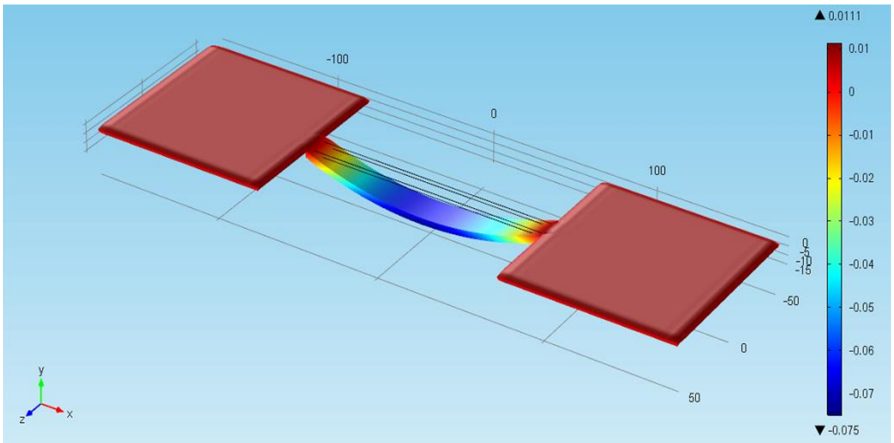

Fig. 2 Simulation diagram of structure with pre-deformation in current input (Si, 150μm long, 10μm wide and 2μm thick)

3.2 Simulation in pull-in voltage

Second, we choose the "Power Institutions" to simulate the pull-in voltage with pre-deformation in the software. Setting the electrode layer under the bottom surface of the fixed–fixed beam and inputting voltage range to scan. When the simulation reaches a voltage value not proceeds at that time, it is reached the grounding state, and this voltage value is the pull-in voltage.

4. RESULTS AND DISCUSSION

4.1 Results of simulation

Simulation results show that, when the geometric dimension of beam is greater, the pull-in voltage will be smaller, because of the stiffness of the beam is decreased that the contact surface of the beam away from the electrode layer is closer. Thus, the pull-in phenomenon is more easily happened. The stiffness of the fixed-fixed beam is K, as shown in Eq. (1). Which L is beam length; E is Young's modulus; I is moment of inertia.

$$K = \frac{192EI}{L^3} \quad (1)$$

Cases in simulation, such as the 150μm long beam, which material is Si, the current input is 1mA at that time which the pull-in voltage in pre-deformation 0.072μm is 171.13V; in the same current input, when the 300μm beam length, and the pull-in voltage in pre-deformation 0.253μm is 38.69V. Hence, with the increase of the geometrical length of the structure, the relative pull-in voltage will be decreased. Owing to the longer length of the beam, the material properties will be softer, and the structure will be more easily collapse. Therefore, the pull-in voltage value is significantly smaller. It reveals that the geometric dimension and pull-in voltage exhibited a nonlinear relationship. The pull-in voltage of simulation in varied parameters in Si material is shown in Fig. 3.

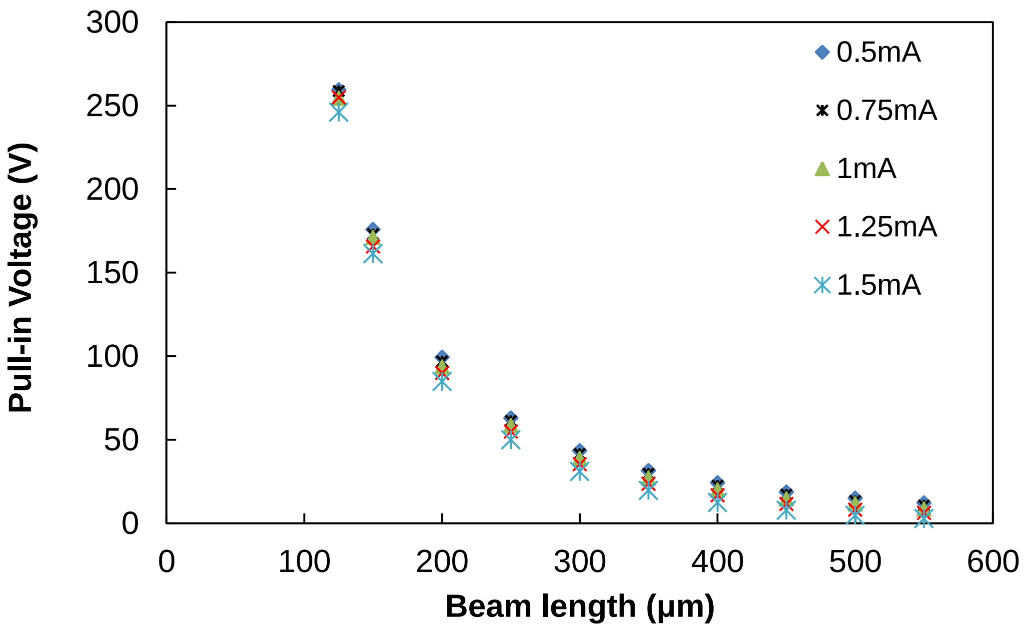

Fig. 3 The data of simulation in material Si

In addition, we also use three different materials, Si, Al and Cu, comparing differences of them in this study. It can be found that the pull-in voltage of Si is greater than the value of Cu and Al. Such as the 150μm long in 1 mA current input, the pull-in voltage of Si is 171.13V, in the same conditions, the pull-in voltage of Cu is 156.75V; the pull-in voltage of Al is 119.95V. The material of Al is softer than Si, more easily bent and deformed downward. Moreover, the Young' modulus of Cu is between Si and Al, so the trend of pull-in voltage can be reasonable. The pull-in voltage of simulation in varied material is shown in Fig. 4.

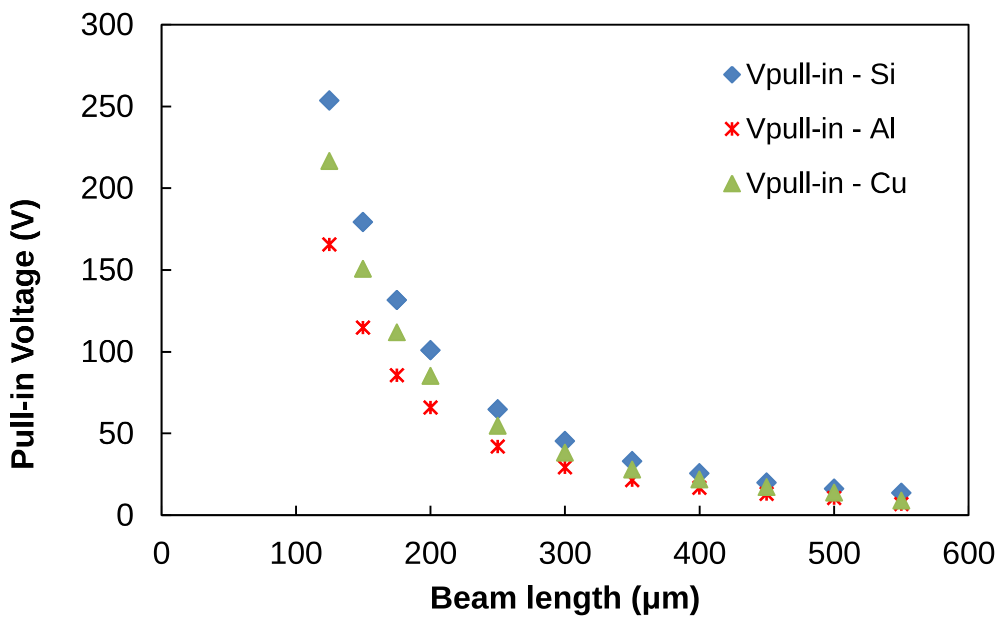

Fig. 4 The trend graph of simulation in material Si, Al and Cu

4.2 Comparing with the reference results

We take the simulation result to comparing with previous experimental data in order to the feasibility check. The comparison is shown in Tab. 2. The pull-in voltage between reference and in this work is very approaching. It can verify the simulation method is useful.

Tab. 2 Comparison with previous experimental data

L (μm)	**i (mA)**	**Elastic deformation (μm)**	**Pull-in voltage in reference[2] (V)**	**This work (V)**	**Error (%)**
180	1	0.105	108	106.82	1.1
200	1	0.127	88	86.92	1.2
250	1.5	0.184	55	54.06	1.7

5. CONCLUSION

In this study, we simulated by using a commercial software package, identify the relations between current, pre-deformation and pull-in voltage. This study can help to knowing the pull-in voltage of different materials or different geometries; it can also be used by knowing the device characteristics and the range in electric signal. On the subsequent measuring experiment, the simulation modal can be widely used to measure considerations in choice.

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