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# Microbridge Resonators: Reducing Pull-in Voltage with Preserving Resonant Frequency

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## Summary:

This work introduces a unique microbridge resonator topology that is designed and developed to effectively reduce the device pull-in voltage by 16%. An analytical model incorporating the ratio between microbridge length and bottom electrode is presented, and finite element analysis is conducted using COMSOL Multiphysics. The proposed designs are fabricated utilizing a Multi-User MEMS sacrificial process and electrically characterized to demonstrate the approach.

**Keywords:** bridge sensor, electrode ratio, microelectromechanical systems, pull-in voltage, resonator

## Introduction

Capacitive resonators comprise of a plate suspended over a bottom electrode. The performance of these resonators depends on their required operating DC voltage, which closely align with their pull-in voltage. The pull-in voltage is determined by the physical properties of the resonator, including the plate and bottom electrode overlapped area, plate thickness, gap height between the plate and bottom electrode, and its structural material properties. While there are a few studies presenting the impact of patterned top plate and bottom electrode on the required DC voltage and performance of circular resonators [1, 2], this exploration has yet to extend to other structures, such as microbridge resonators. This work develops an analytical model with experimentally demonstrated functionality that considers the ratio between the length of the microbridge and the bottom electrode as a key design parameter to influence the operating voltage. The developed model is employed to design microbridge resonators using a commercially available sacrificial technique with strategically designed ratios to enhance the device performance.

## Microbridge Operating Mechanism and the Developed Analytical Model

Microbridge resonators consist of a deflectable plate anchored at both ends, which is suspended over a fixed bottom electrode, as shown in Fig. 1. When the DC voltage is applied, the plate deflects towards the electrode, altering the device capacitance. To maintain structural stability while operating at optimum condition, the applied voltage must remain close but below the resonator pull-in voltage [1, 2].

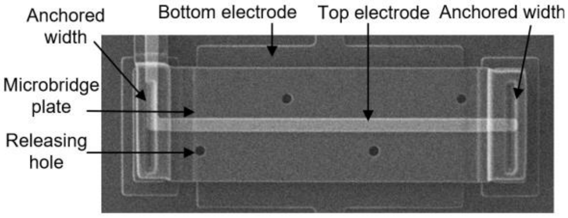

*Fig. 1. Scanning electron microscopy (SEM) image of a designed and fabricated microbridge resonator.*

The developed analytical model in this work considers the overlapping ratio between the bottom electrode's length and a strategically designed suspended microbridge's plate with the aim to reduce pull-in voltage. The model is employed to design the microbridge resonator, and finite element simulations are conducted to further analyze the effect of this ratio on the operating DC voltage of the microbridge. This model includes the structural properties of the microbridge, and the spring softening effect due to the applied DC bias voltage, shown in (1). In this model and similar to conventional resonators, a mass-spring-damper model is used to illustrate the behavior of the microbridge with small deflection under a uniform electrostatic force when parasitic capacitance is neglected. The stiffness can be calculated by (1)

$$k = 32Eb\left(\frac{t}{l}\right)^3 \frac{1}{8\left(\frac{l+w}{2l}\right)^3-20\left(\frac{l+w}{2l}\right)^2+14\left(\frac{l+w}{2l}\right)-1} - \frac{\varepsilon_0 A V_{DC}^2}{g_0^3} \quad (1)$$

where microbridge's thickness, width and length are represented by t, b and l, respectively. w is the length of the bottom electrode, A shows the area of the microbridge, $V_{DC}$ is the applied DC voltage and $g_0$ is the gap height between the microbridge and the bottom electrode, and E is Young's modulus. The stiffness shown in (1) can be used to calculate the resonant frequency of the microbridge shown in (2) [3]

$$f_r = \frac{1}{2\pi}\sqrt{\frac{k}{m}} \tag{2}$$

where $f_r$ and m represent the resonant frequency and mass of the microbridge, respectively.

### Microbridge Design and Fabrication

The proposed microbridge resonators are designed using MEMS L-Edit, as depicted in Fig. 1, and fabricated using a commercially available Multi-User MEMS process, PolyMUMPs [4]. The length and width of the polysilicon microbridges are 120 µm and 40 µm, respectively, with a thickness of 1.5 µm and a gap height of 750 nm. To solely investigate the effect of the ratio, all the design parameters are kept the same between the two designs. To demonstrate the proposed design concept, in one design the bottom electrode is extended underneath the bridge to 82 µm with the resonant frequency of 1.1 MHz, while in the other design, the bottom electrode length is 42 µm with the resonant frequency of 980 kHz. This represents ratios of 68% and 35% between the microbridge and the bottom electrode, respectively.

### Results and Conclusion

Keysight E4990A impedance analyzer is used to measure the resonant frequency of the proposed microbridges up to their pull-in voltages when 500 mV AC is applied. The experimental results for both devices when DC voltage is swept are shown in Fig. 2. The measurements results indicate that the pull-in voltage for the microbridge with 68% and 35% ratios are 21V and 25V, respectively. Comparison between the presented analytical model, the conducted finite element analysis using COMSOL Multiphysics, the electrical characterization for the pull-in voltage and the resonant frequency of the proposed microbridges are shown in Fig. 3. The comparison is presented for the devices with the same dimensions and material properties while the bottom electrode topology varies.

It is demonstrated that the developed analytical model, conducted FEA analysis, and the electrical measurement results are in good agreement indicating that designing the bottom electrode topology with respect to the flexible microbridge reduces the pull-in voltage when other design parameters are the same. As illustrated in Fig. 3, the pull-in voltage reduces with the increase of the bottom electrode's length with respect to the microbridge's length.

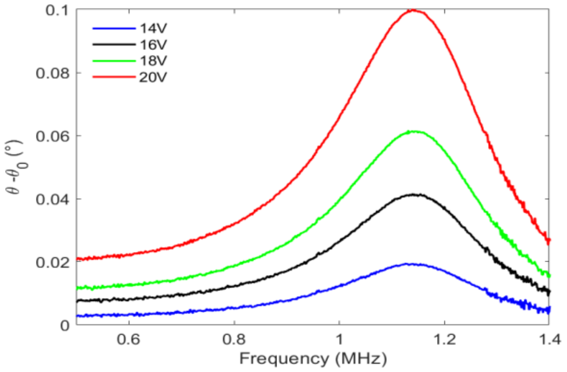

*Fig. 2. Resonant frequency of microbridge with 68% ratio of the bottom electrode to the bridge length.*

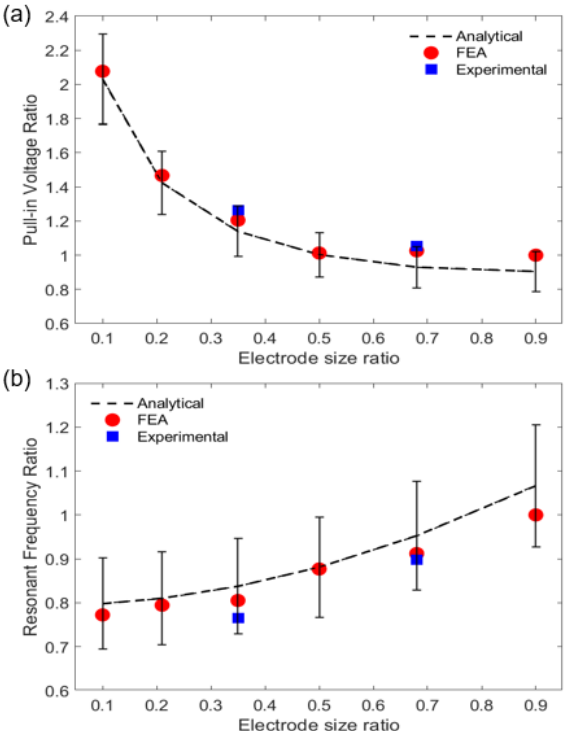

*Fig. 3. Effect of electrode size ratio on (a) pull-in voltage and (b) resonant frequency, normalized by FEA at 90% ratio. The error bar denotes uncertainties in the fabrication process.*

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