

Abstract

# Pull-In Voltage and Stress in Fixed-Fixed Beams of RF MEMS Switches <sup>†</sup>

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**Abstract:** Electrostatically actuated microelectromechanical system (MEMS) switches with fixed-fixed beams were fabricated. FEM modeling was used to calculate the contributions of stress in the fabricated beams from the measured values of pull-in voltage. The reported study provides useful guidelines to optimize the design of fixed-fixed beams, in order to reduce the stress contributions for the successful development of efficient and reliable electrostatically actuated MEMS devices.

**Keywords:** MEMS; fixed-fixed beam; pull-in voltage; residual stress

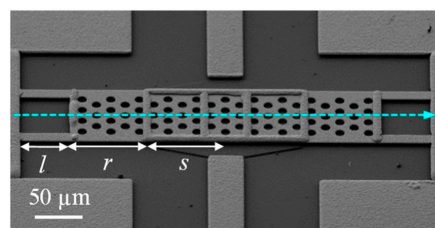
## 1. Introduction

Different geometries of beams and/or actuation pads have been proposed [1] to reduce the pull-in voltage of RF MEMS switches, also taking into account the residual stress of the suspended beam. However, to our knowledge, only in few works [2] have the theoretical values of the residual stress been combined with experimental values of the pull-in voltage and/or spring constant for a variety of beams with different geometric parameters.

Here, electrostatically actuated RF MEMS switches with fixed-fixed beams were fabricated, using a surface micromachining approach. FEM modelling was used to evaluate the residual stress, which is consistent with the measured increase of the pull-in voltage. Moreover, the distribution of the stress, which is induced by the electrostatic actuation force, is calculated.

## 2. Materials and Methods

An eight-mask process was used to fabricate capacitive RF MEMS switches with fixed-fixed beams (Figure 1). Details on the beam fabrication process are reported in Ref. [3].



**Figure 1.** Typical SEM image of a fabricated RF MEMS switch. The labels  $l$ ,  $r$ , and  $s$  are used to indicate the different sections of the beam and are equal to 65  $\mu\text{m}$ , 100  $\mu\text{m}$ , and 95  $\mu\text{m}$ , respectively. The width of the beam is 100  $\mu\text{m}$ .



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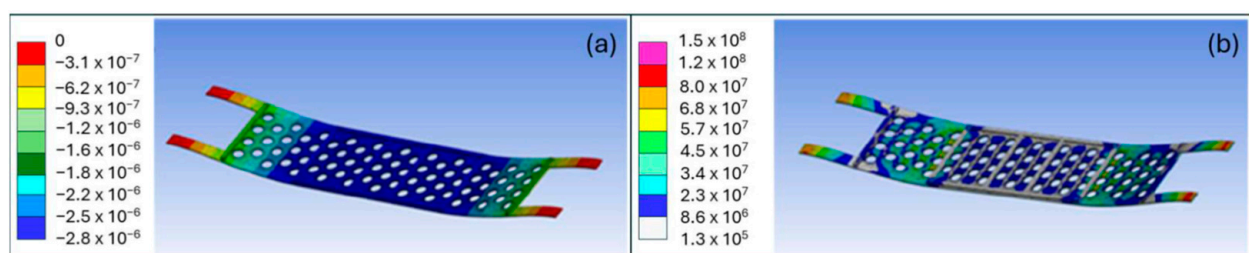


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### 3. Results and Discussion

The pull-in voltage of fabricated switches was measured from the capacitance–voltage curve, finding the value of  $43 \pm 3$  V. The fabricated fixed-fixed beams were modeled in the FEM ANSYS® Multiphysics (<https://www.ansys.com/products/optics/multiphysics>, accessed on 1 April 2024) environment. First, simulations for the calculation of the pull-in voltage were performed not taking into account the residual stress inside beams. A pull-in voltage of 29.5 V was calculated, which is significantly lower than the measured value. A residual stress was applied during simulations, and it was found that the measured pull-in voltage of 43 V is consistent with a residual stress of 48 MPa.

The static deformation of beams was modelled under the application of the measured pull-in voltage [Figure 2a]. When the pull-in voltage is applied, the central region of beams is electrostatically attracted towards the actuation pad. Consistently, the central region shows the maximum deflection, whereas the displacement gradually reduces along the intermediate and the spring sections, until it vanishes in the anchoring points. It is worth noting that the central plate of all beams is flat in the down state, likely due to two reasons: (1) the configuration of the beam-actuation pad allows the application of a central uniform electrostatic force and (2) the presence of the stiffer frame. The collapse of the central plate of the beam on the actuation pad is an important result because it allows us to maximize the ratio of capacitance in the down and up states, which is a figure of merit to measure the performance of capacitive RF MEMS switches. The nonuniform deflection due to the electrostatic actuation stretches the beam and induces an additional stress inside it [Figure 2b]. It is observable that the region of the central frame is characterized by the lowest values of stress, and the stress increases when moving from the central plate to the anchoring points, reaching the maximum values at the anchoring points.



**Figure 2.** Diagram of the deformation (a) and of the stress (b) that are induced by the electrostatic actuation of the beam.

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### References

1. Deng, K.; Yang, F.; Deng, Z.; Wang, X.; Han, K. Analysis and design of a novel high capacitance ratio and low actuation voltage RF MEMS switch. *Microsyst. Technol.* **2021**, *27*, 2803–2813. [CrossRef]

2. Bansal, D.; Bajpai, A.; Kumar, P.; Kaur, M.; Kumar, A. Effect of Stress on Pull-in Voltage of RF MEMS SPDT Switch. *IEEE Trans. Electron Dev.* **2020**, *67*, 2147–2152. [[CrossRef](#)]
3. Persano, A.; Quaranta, F.; Capoccia, G.; Proietti, E.; Lucibello, A.; Marcelli, R.; Bagolini, A.; Iannacci, J.; Taurino, A.; Siciliano, P. Influence of design and fabrication on RF performance of capacitive RF MEMS switches. *Microsyst. Technol.* **2016**, *22*, 1741–1746. [[CrossRef](#)]

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