Design of Ohmic Miniature MEMS Components for Fast Reconfiguration

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Abstract. A miniature multilayer beam (alumina / aluminum / alumina) has been recently proposed for capacitive ultra fast RF MEMS switches design and fabrication. This component presents a 40 V pull-in voltage and is able to achieve the switching time as low as 50 ns once biased with 80 V actuation voltage which is the faster RF MEMS capacitor reported up to now. Based on this setup, this paper describes our current work on ohmic contact switch design based miniature and multilayer high stiffness beam geometry. The presented concept is expected to achieve switching time lower than 300 ns considering a 7 V pull-in voltage.

1. Introduction

RF-MEMS switches and switchable capacitor should be promised to a fruitful future. Their impressive linearity capabilities, their superior RF performances and their very small DC consumption requirements make them serious competitors for semiconductor technologies. Huge research efforts are currently done to bring solutions to their reliability limitation and lead this MEMS technology to the maturity required for industrial applications. However, RF MEMS components still suffer from limitation; their switching time, generally of few microseconds is one of them [1-2]. It is usually limited by the time required to move physically the beam mechanical structure. Hence, this time limits the use of MEMS components for fast reconfigurable application.

In order to improve the switching time, some studies were already made. Rebeiz [3], from San Diego University, showed that downsize the beam compare to the actual common sizes, results in high mechanical resonance frequency able to reach high switching speed. Indeed, with a 20 µm long and 9 µm large beam, switching times below 500 ns could be measured. Lacroix [4], from XLIM laboratory, demonstrates by reducing the beam dimensions and adding simple bent sides on conventional beam edges, strongly increases the beam mechanical stiffness. With this setup, he obtained 200 ns switching time. Another study has been made by Berkeley laboratory [5]. It demonstrated the use of micro electromechanical component in logic application. With this setup, 300 ns switching time was achieved.

50 ns are achieved, for capacitive components, made of a multilayer beam alumina/aluminum/alumina [6]. The beam, whose dimensions are 30 µm long by 25 µm large, presents a 40 V pull-in voltage. From this setup, in this paper, an ohmic contact RF MEMS component design is presented based on with nanogap electrostatic actuators. The miniature membrane consists also in a composite structure of three layers alumina/aluminum/alumina supporting a gold based contacting electrode. Thanks to this setup and an appropriated mechanical design, pull-in voltage under 10 V can be achieved for switching time close to 250 ns.

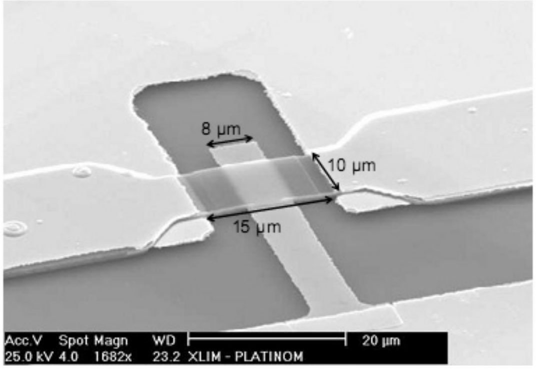

Fig. 1. SEW view of fabricated bridges structure; beam dimension 15 µm long and 10 µm wide.

To increase the beam mechanical resonance frequency, a first approach is to miniaturize the mobile structure [4]. A second approach is to use for the mobile structure, one or combination of materials with enhanced mechanical properties.

In a previous study [6], we designed suspended miniature structures made with several thin film materials stacked to achieved a high mechanical performance membrane that have been implemented on a CPW line to form ultra fast switchable capacitors (Figure 1). Thus, aluminum has been favored since it is a very good conductor and also because it's a very light material (2.7 g/cm^3) that will allow to guaranty high mechanical resonance frequencies for the MEMS structure. To enhance its mechanical capabilities, aluminum layer has been encapsulated between two others material layers. For this stack, alumina was a good candidate because of its very low density (3.9 g/cm^3), but also its high Young's modulus (380 GPa) which allow to achieve a high stiffness thin film. Based on this alumina / aluminum / alumina structural material with respective thickness of 100 nm / 200 nm / 100 nm, some MEMS components have been developed based on fixed-fixed miniature beams geometry. This setup ensures high mechanical resonant frequencies in the range of several MHz, compared to few tens of kHz for conventional RF MEMS components.

In fact, once looking for high MEMS device structural material stiffness that allows reaching fast switching speed, also impacts on the beam pull-in voltage. This voltage is related to the beam stiffness and the gap between the beam and the actuation electrode. This electrode was recovered of a 200 nm aluminum nitride dielectric layer to ensure a RF capacitive contact. Thus, to keep reasonable lower voltages, the air gap was reduced by a factor of 10 compared to conventional values. With a gap of 300 nm, lower voltages than 50 V should be sufficient to actuate the component. From this configuration, in order to reach sub-microseconds switching time range with this device, it’s necessary to tune the beam sizes (length, width, thickness). In Table 1, some geometry which have been designed and fabricated as a proof of concept of ultra fast switched MEMS capacitors are shown.

The beam mechanical resonance frequency and the pull-in voltage were simulated using 3D Finite Element Method Ansys mechanical simulations [7]. Then, the switching time values were calculated from the computed beam mechanical resonance frequency and the equation (1) [8] considering a V_{app}/V_p ratio of 1.5. The computed results for the several designs are summarized in Table 1.

Table 1. Summary of Expected and Measured Values for Several Designs

Beam length (µm)	**Bean witdh (µm)**	**Actuation electrode witdh (µm)**	**Computed beam mechanical resonance frequency (MHz)**	**Measured beam mechanical resonance frequency (MHz)**	**Computed switching time (ns) @1.5×Vp**	**Measured switching time (ns) @1.5×Vp**	**Computed pull-in voltage (V)**	**Measured pull-in voltage (V)**
15	10	8	18.7	18.9	21	40*	120	76
20	15	13	10.6	10.5	37	65	68	54
25	15	18	6.8	6.5	57	75	44	30
30	25	23	4.8	4.7	82	110	31	40
35	25	28	3.5	3.5	111	130	22	42

* @ 1.2×Vp

$$t_s \approx 3{,}67 \frac{V_p}{2\pi V_{app} f_0} \qquad (1)$$

From specific test bench, the beam mechanical resonance frequency and the switching time have been measured and demonstrated good performances (Table 1). Indeed, switching times below 100 ns are achieved and the beam pull-in voltages are close to 50 V.

Moreover, the fabricated switched RF performances have also been measured. To evaluate the off-state and the on-state capacitances, the S_{21} parameters measurements are itting with an equivalent circuit using Agilent Momentum electromagnetic simulator [9]. Table 2 summarizes the RF performance measurements for several designs.

As we can see in Table 1, the smaller components have a low switching time, but also a low contrast corresponds at these components. This is the price of small contacting surface associated to very small air gap distance design.

Table 2. RF Performance Measurements

Beam length (µm)	Actuation electrode witdh (µm)	C_{off} (fF)	C_{on} (fF)	C_{on}/C_{off}
15	8	8	15	1.9
20	13	10	30	3
25	18	13	42	3.2
30	23	18	82	4.6
35	28	19	110	5.8

3. Mechanical Design for Ohmic Contact Relays

From this concept, to improve the contrast and to use low actuation voltage, a design of a miniature ohmic component has been studied. In this case, we keep the miniature multilayer membrane (alumina / aluminum / alumina) geometry and thickness (100 nm / 200 nm / 100 nm). A carbon pull down electrode coated by a dielectric layer has been added since in this case the contact electrode could not be used as electrostatic actuator electrode. An evaporated titanium/gold metallization layer takes place to define the RF contact area at the extremity of the RF line discontinuity. The multilayer membrane is suspended 300 nm above these contact electrodes and is anchored between two metallization layer to mechanically fixe the beam extremities.

To allow the RF transmission signal once the membrane will be pulled down, a gold contact bar including dimples are added below the multilayer membrane. RF signal will be transmitted along.

In order to have a beam pull-in voltage smaller than 10V, several designs are considered. Figure 3 shows the pull-in voltage for a fixed-fixed multilayer beam for several lengths considering a 30 µm large beam. The gold contact dimple dimensions are 28 µm long and 10 µm large. We can see that the pull-in voltage is smaller than 10 V for beam length higher than 42 µm.

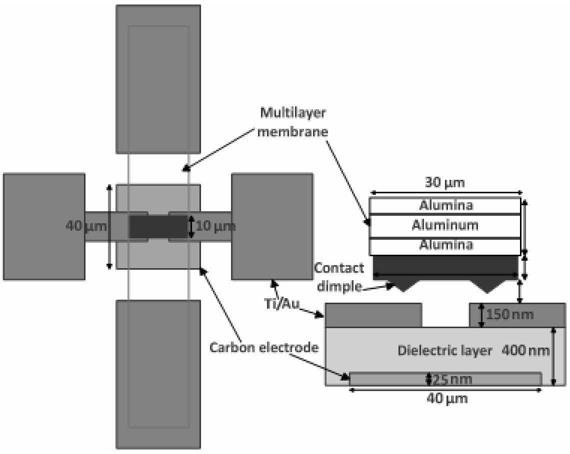

Fig. 2. Design of ohmic contact miniature MEMS relay.

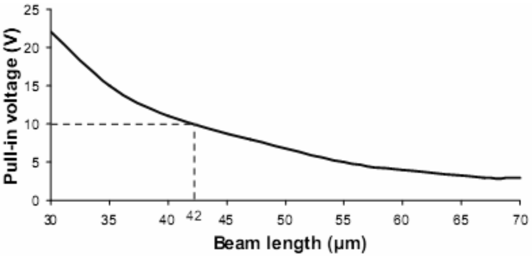

Fig. 3. Effect of the beam length on the pull-in voltage.

The corresponding switching time is shown on Figure 4. For beam length higher than 42 µm, the switching time is higher than 200 ns. We chose to have a small pull-in voltage in despite of a switching time higher than 200 ns. For example, for a 50 µm long beam, the pull-in vol tage is 7 V and the switching time is 285 ns considering 10.5 V actuation voltage.

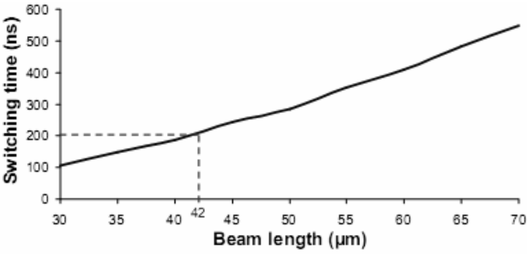

Fig. 4. Effect of the beam length on the switching time.

In order to have switching time below 200 ns and actuation voltage below 10 V the gap should be decreases. But with gap under 300 ns, the technology process becomes complex especially to realize efficient gold dimple contact.

For this design, the contact force per contact area is evaluated to be in the 8 μN range once actuation voltage reaches 10.5 V. When the contact force increases, the insertion losses are reduced.

Beam tests structures are actually in fabrication. The latest experimental results will be presented during the conference.

4. Conclusion

An approach to design miniature ohmic RF MEMS component has been presented. This multilayer beam alumina / aluminum / alumina with gold dimple contact allows reaching pull-in voltage below 10 V with switching time in the 250 ns range. To valid the presented concept, beam tests structures are being fabricated.

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