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# Characterization and optimization to improve uneven surface on MEMS bridge fabrication

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ABSTRACT

This paper presents an optimized fabrication method for developing a freestanding bridge for RF MEMS switches. In this method, the sacrificial layer is patterned and hard baked a 220 °C for 3 min, after filling the gap between the slots of the coplanar waveguide. Measurement results by AFM and SEM demonstrate that this technique significantly improves the planarity of the sacrificial layer, reducing the uneven surface to less than 20 nm, and the homogeneity of the Aluminum thickness across the bridge. Moreover, a mixture of $O_2$, Ar and $CF_4$ was used and optimized for dry releasing of the bridge. A large membrane ($200 \times 100\ \mu m^2$) was released without any surface bending. Therefore, this method not only simplifies the fabrication process, but also improves the surface flatness and edge smoothness of the bridge. This fabrication method is fully compatible with standard silicon IC technology.



## 1. Introduction

Radio frequency (RF) micro and nano electromechanical switches (MEMS/NEMS) are an excellent options for the replacement of conventional semiconductor switches as they offer low power consumption, low noise operation, high electrical isolation, and ultra wide frequency band [1]. Electrostatic MEMS/NEMS switches can be categorized based on their structure (shunt or capacitive) or material (metallic and carbon). The impacts of the structure and the material on the performance of these switches were analyzed and discussed by the authors in [2].

The structure of a typical RF MEMS shunt switch is shown in Fig. 1. The switch consists of a bridge which is suspended over a coplanar wave guide (CPW) transmission line and fixed at both ends to the ground of the CPW. In this switch, the shape and structure of the bridge membrane are critically important as they directly affect both electrical and mechanical resonant frequencies, and pull in and pull out voltage ($V_{\text{pull-in}}$ and $V_{\text{pull-out}}$) [3,4].

When fabricating a membrane for an RF MEMS switch, three issues are encountered as follows (Fig. 1). It is non-flat and also has two sharp edges with 90° sidewall. The non-flat membrane is occurred because of the uneven surface between signal and ground lines after patterning the first layer of the CPW, the type and the characteristic of photoresist (size, thickness), the techniques of coating (spin, spray, or electro deposition), the lithography parameters (temperature, UV exposure, and developing). This uneven surface causes deterioration in performance of the switch as it increases the fringing capacitance, and reduces the contact between the electrodes [5]. A flat membrane was reported in [6,7] by filling the gap after patterning the CPW followed by a chemical-mechanical polishing (CMP). Although this technique greatly improves the flatness and planarization of the membrane, it is very expensive and complicated. In addition, the sharp edge sidewalls increase the risk of bending or cracking during releasing.

The second issue is the thickness homogeneity of the metal along the profile of the bridge after patterning the bridge (Fig. 1). The shadowing effects cause much thinner vertical side walls in comparison to the bridge thickness [8], resulting in the bridge to collapse during the releasing step. Thus, one more step of fabrication process is required for patterning the anchor which consists of: spin coating, soft bake, aligning mask and UV exposure, developing unexposed area, sputtering Aluminum, and lift-off. However, this step not only increases the fabrication time (almost by one day), but is also costly. The steps involved in the fabrication process of RF MEMS switches is shown in Fig. 2. It mainly consists of five steps: (i) patterning electrode, (ii) patterning transmission line,

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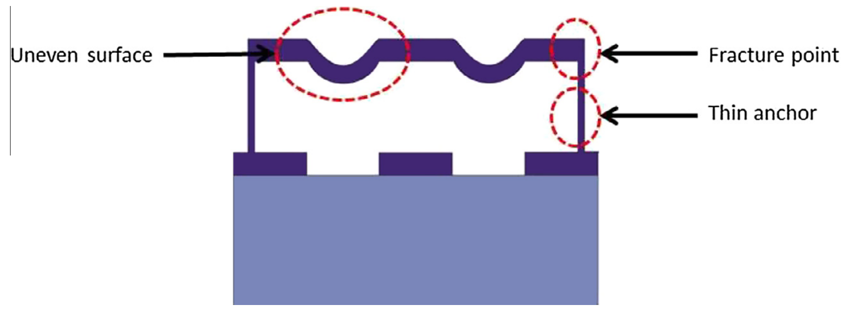


**Fig. 1.** Issues with RF MEMS bridge: uneven surface membrane, sharp edges, and non-uniform metal thickness along the structure.

(iii) patterning anchor, (iv) patterning membrane, and (v) releasing the membrane. The whole process takes about four days to complete.

The third issue is the collapse and buckling of the bridge during the wet or dry releasing process. The risk of collapse in wet release can be reduced if the membrane is rinsed by low surface tension liquids (acetone, methanol and IPA in order) [9] or dried by $CO_2$ supercritical dryer [10]. Dry release is easier than wet release because it eliminates the collapsing of the bridge. Oxygen Plasma ($O_2$) is used to remove the photoresist in dry release. Saha et al. [11] used two experiments to release a membrane. In the first experiment, the sacrificial layer under the bridge is etched and the membrane is released at 400 W. However, using high power $O_2$ plasma for releasing the bridge increases the compressive stress in the membrane, resulting in the buckling of the membrane [12,13]. In the second experiment, etching holes are incorporated in the membrane to avoid the problem of buckling. The membrane is released at 150 W because $O_2$ plasma reaches the sacrificial layer under the bridge through the holes on the surface and the two openings at both sides. However, the main disadvantage of the etching holes is the reduction of the beam's spring constant. Although introducing the etching holes on the beam results in a faster and convenient dry release process, it reduces the resonant frequency of the beam, as well as the isolation of the switch while the switch is in contact [14–16]. The parameters of the releasing process by $O_2$ plasma, power, pressure, and photoresist thickness, were comprehensively investigated by Rahman et al and Yu et al. [17,12]. The releasing became more critical when the photoresist was hard baked as it made a thermal cross link. For example, Saha et al. [11] removed the hard baked photoresist sacrificial layer (baking at 130°) by a combination of dry and wet release. This has two main drawbacks. Firstly, the risk of collapsing is increased as it involves liquid to remove the photoresist. Secondly, acetone cannot remove the hard baked photoresist, and thus other types of etchant liquid such as Microposit 1165, Az 100 or Kwik strip need to be used. It should be noted that if the photoresist is extra hard baked, it may not be removed by liquid etchant.

Accordingly, this paper proposes a new method for fabrication of a bridge particularly for RF MEMS switches in order to address the above-mentioned three issues. The contributions of this paper are as follows:

- The first contribution of the paper is the introduction of a fabrication protocol for developing a membrane for RF MEMS switch applications based on the extra hard baked photoresist. Motivated in part by the work of Soulimane et al. [6], Saha et al. [11], and Nasabi et al. [18], this protocol not only simplifies the fabrication steps, but also improves the flatness of the bridge and softening the edges.
- The second contribution of this paper is the introduction of a low power (250 W) dry release process for a membrane without any etching hole and extra hard baked photoresist at 220 °C. By using this approach, the compressive residual stress is minimized, eliminating the buckling of the membrane.

## 2. Proposed fabrication process

RF MEMS switches were fabricated using the standard photolithography technique. The fabrication process in principal is compatible with the CMOS fabrication process. Fig. 3 gives the details of the proposed fabrication process, and Fig. 4 shows the details of the cross-sectional view of the fabrication steps of the RF MEMS switch. As can be seen in Fig. 3, the proposed fabrication process consists of 4 steps whereas the conventional fabrication process includes 5 steps.

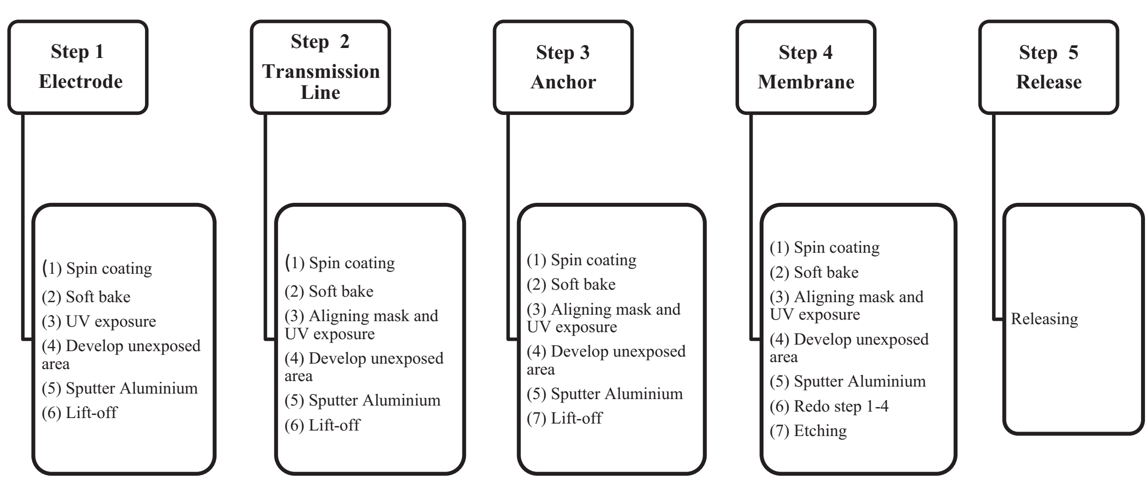


**Fig. 2.** Fabrication process of RF MEMS switch.