Metallization scheme and release methods for fabrication of RF MEMS switches

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1. Introduction: Radio frequency micro electro mechanical systems (RF MEMS) devices are becoming increasingly popular due to their very good RF performance at high frequencies. RF MEMS switches have very low insertion loss in the on state and very high isolation in the off state. Electrostatically actuated MEMS switches consume very little power. They are very linear and have very high third order intercept point compared to any other solid state counterparts. A co-planar waveguide (CPW) MEMS shunt capacitive switch is shown in figure 1. The capacitance is formed between the suspended metal bridge and the bottom electrode, with a dielectric in between. When the bridge is in up state the capacitance is small (fF) and the switch is on. When the bridge is actuated as shown in Fig. 1 (right), the capacitance increases by two orders of magnitude the signal is shorted to ground, and the switch turns off. We are developing a process to fabricate surface micromachined capacitive RF MEMS switches in the SINTEF Micro and Nano Laboratories (MiNa), Oslo, Norway.

2. Design and Fabrication: Successful fabrication of suspended metal bridges requires three process steps: 1) Deposition and patterning of a sacrificial layer, 2) Deposition and patterning of the metal layer, and 3) Removal of the sacrificial layer. We have used a common positive photoresist (HiPR 6517) as a sacrificial layer. The photoresist is baked and the reflow creates a gradually increasing thickness at the edges. This is done in order to achieve a reliable bridge profile, rising with an angle of approximately 45° where it contacts the substrate [1]. We have used DC magnetron sputtering to deposit gold on the sacrificial layer to form the bridge. The reliability and performance of the switch depend on the mechanical properties of the bridge, and especially pull-down voltage and switching time are influenced by residual stress and stress gradients. The stress of the sputtered gold film depends on sputtering parameters such as pressure and power [2]. We have aimed for a low tensile stress, because compressive stress may cause buckling, and too much tensile stress will increase the pull-down voltage. The sputtering power must be low enough to avoid over-heating and burning the sacrificial resist. After patterning the gold bridge, the sacrificial resist needs to be dissolved to release the bridge. A thin layer of skin can be formed on the top surface of resist after the lithographic process and sputtering which makes it difficult to dissolve using a simple acetone soak. Some of the possible reasons for formation of the skin are, baking, and a delay between coating and exposure of resist [3].

3. Experiments and Results: Coating, patterning and baking of the sacrificial photoresist has been described in [1]. For all sputtering experiments described below we used standard lithography.

The sputtering pressure was varied from 10 mTorr to 20 mTorr to tune the film stress. We used a low sputtering power of 500 Watts for all experiments. The sputtering conditions and obtained results are shown in table 1. Example images of structures sputtered at 10 mTorr and 500 watts are shown in Figure 2. In order to measure the residual stress and stress gradient of the sputtered film, we used wafer curvature measurements and micro-machined test structures [4]. For wafer curvature method, we deposited gold directly on wafers and measured the wafers curvature before and after film deposition. In micro-machined test structures methods, cantilevers were used to measure the stress gradient, bridges were used to measure compressive stress, and guckel rings with CoventorWare simulations were used to measure the tensile stress. A lower tensile stress is obtained at higher pressure. A decrease in negative stress gradient was also found with increasing sputtering pressure.

To remove the sacrificial resist, acetone was quite ineffective, and we obtained better results with Shipley Microposit 1165 resist remover. An experiment plan as shown in table 2 was carried out to explore the different options for removal of resist skin. The samples were put in Microposit 1165 for about 90 min at normal temp, followed by 60 min with heating and another 60 min at normal temp, in all cases with magnetic stirring. Afterwards the samples were dried in a critical point dryer. Two released samples RS 2 and RS 8 are shown in figure 3. From the release test, it is found that the plasma ashing and heating has a great effect on the release process as shown in figure 3.

4. Conclusion: We can use 20 mTorr at 500 watts to deposit low stress planar gold. Plasma ashing, followed by Microposit 1165 with heating can be used for successful release of RF MEMS switch.

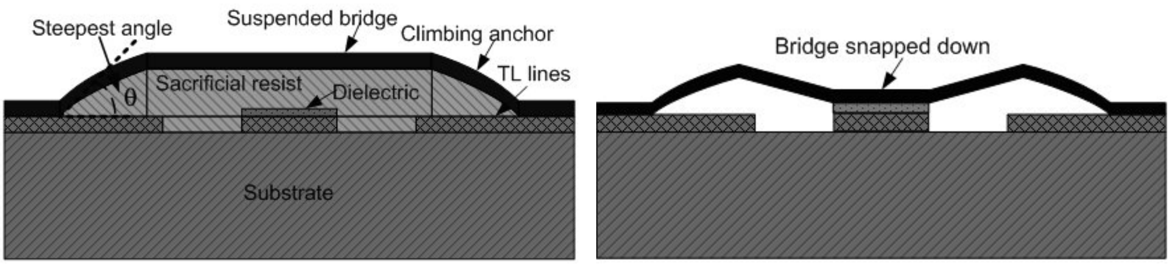

Figure 1: A side view of RE MEMS capacitive shunt bridge with sacrificial resist (left) and an actuated bridge (right).

Table 1: The sputtering parameters and measured residual stress and stress gradients

Wafer curvature methods		Micro-machined test structures method		
Sputtering pressure* (mTorr)	Residual stress tensile (MPa)	Sputtering pressure* (mTorr)	Stress gradient -(MPa/μm)	Residual stress, tensile (MPa)
10	42	10	35	70
16	31	15	5.2	55
24	31	20	4.8	45

*All the wafers are sputtered at 500 watts. The uncertainty of the stress value is 5-15 MPa.

Table 2: The experimental setup to dissolve hard resist with plasma ashing and piranha and obtained results

Plasma strip (150 watt, 45 min)				No plasma strip			
Heating Microposit 1165 (~60° C)		No heating Microposit 1165		Heating Microposit 1165 (~60° C)		No heating Microposit 1165	
Piranha dip, 60 s	No piranha dip	Piranha dip,60 s	No piranha dip	Piranha dip, 30 s	No piranha dip	Piranha dip, 30 s	No piranha dip
RS 1	RS 2	RS 4	RS 3	RS 5	RS 6	RS 7	RS 8
Very clean	Very clean	Very clean	Almost clean	Very clean	Thin skin left	Very clean	Not clean

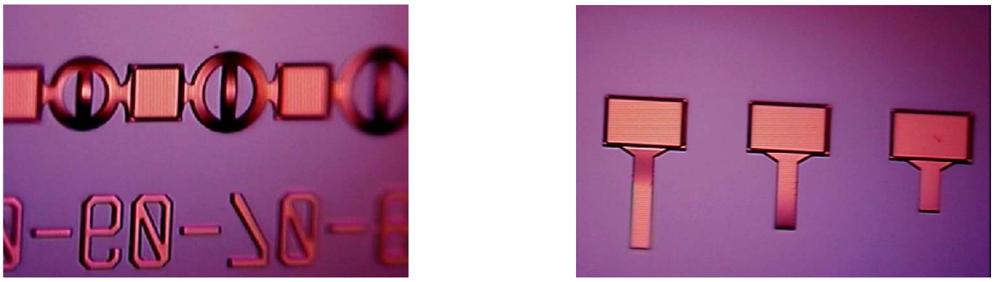

Figure 2: Optical images of buckled guckel ring and cantilever sputtered at 10 mTorr and 500 watt

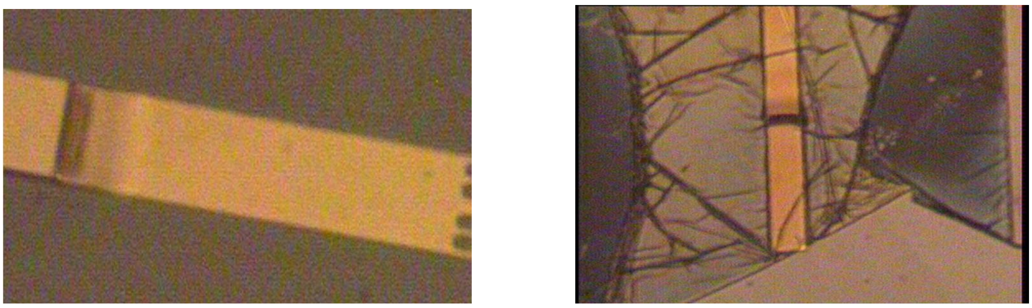

Figure 3: Released sample RS 2 (left) and Released sample RS 8(right)

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