Novel RF MEMS Switch Process for Ohmic-Contact Reliability Improvements by Narrow Electrode Gaps

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Abstract

MEMS switches will be important building blocks for various communication systems. This work describes simple process method and advantages of sub-100nm DC actuation electrode gaps for Radio Frequency MEMS switch. A novel simple process method is proposed to achieve non-contact DC gaps. Which would address DC contact stiction resulting in stuck closed failures. Fabricated of switch and measurement result are reported.

Index Terms — RFMEMS, Switch, differential step, Coplanar Waveguides.

1 INRODUCTION

Micro Electro Mechanical Systems (MEMS) devices for radiofrequency (RF) and microwave (MW) applications, already acclaimed in the past decade as one of the most promising emerging technologies, have recently received further attention for their ability to implement reconfigurable passive networks for future generation multiple standards and multiple frequency wireless terminals *[1]*. These devices have potential performances that can surpass the limits of their current equivalent implementations using more traditional solid state technologies. In fact, all Radio Frequency Micro Electro Mechanical Systems (RFMEMS) devices maintain good miniaturization and they can be integrated with solid state circuits, either above IC or in the same package. These kinds of devices exhibit almost zero power consumption, extremely good linearity and very low losses (high Q), making them very suitable for tuning. Concerning RF-MEMS switches peculiarities; they achieve very low insertion loss while maintaining high isolation.

From the technology standpoint, they tend to require low-cost fabrication processes. In particular, RF-MEMS can be made using standard foundry silicon processes. Actually, silicon based RFMEMS are very easy to be micro-machined, can be integrated with mature semiconductor technology processes, and have the potential for wide proliferation across the various communication systems. Additionally, Si RF-MEMS technology is compatible with the integrated circuits for digital, analog and RF mixed signal environments, making it possible to realize high frequency RF modules featuring a high level of integration (e.g. network-on-chip (NOC), and system-on-chip (SOC)).

Despite these positive aspects, all the above and further benefits go along with a series of shortcomings, mostly related to the poor maturity of still evolving design methodologies, fabrication processes, limited reliability and poor knowledge of ageing mechanisms.

The presence of mechanical contact introduces a whole new class of reliability issues related to both mechanical and electrical phenomena [2]. Mechanical relaxation of residual material stress, plastic deformations under large signal regime, creep formations and fatigue can all impair the stability of electro-mechanical device behavior and eventually cause device failure. Finally, probably the most important effects impairing device functionality is the 'stiction' of the mechanical parts that reached contact, which is the inability to restore the device to its resting position after the actuation stimulus has been removed. Several factors have been known to cause stiction: Capillary effects due to changed environment conditions, electrostatic charge accumulation or redistribution within dielectric layers, and micro-welding of metals due to DC or RF power. To overcome this mechanical contact, a novel *two step oxidation* process method to create step formation is proposed. By above method sub-100nm gap are realized which does not have much significance on the switch actuation voltage at DC actuation pad.

2 TWO STEP THERMAL OXIDATION

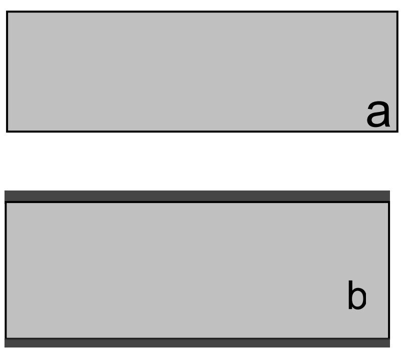
Thermal silicon dioxide growth kinetics explained by the Deal-Grove model, 1-D can be summarized by the following equation:

$$x_o^2 + Ax_o = B(t + \tau) \qquad \textbf{(1)}$$

Where $\boldsymbol{x_o}$ is the thickness of the silicon dioxide grown after time $\boldsymbol{t}$ at a given temperature and ambient, $\boldsymbol{A}$ and $\boldsymbol{B}$ are constants, $\boldsymbol{\tau}$ is a constant which is used to account for initial oxide. Thermal oxidation process consumes silicon from silicon substrate surface. Consumed silicon thickness is 44% of total thickness of oxide.

3. FABRICATION

In this section fabrication process flow sequence illustrated with cross-section view. In the proposed two step-oxidation process first thermal oxide is grown on fresh silicon (Fig.1a) surface, this oxide thickness uniform everywhere (Fig.1b). The oxide is selectively etched with photo-lithography process by pattern transfer (Fig.1c). In the next step once again thermal oxide is grown, this oxidation process consumes more silicon or faster growth rate at silicon exposed area and less silicon or slower oxide growth rate at previously oxide retained area (Fig.1d), which can be explained by equation (1). After second oxidation we will get small step (around 70nm) is created on the surface. Now first metal (metal 1) is deposited and patterned for formation CPW lines and DC actuation pads (Fig.1e). Sacrificial layer is deposited and anchor patterned for bridge formation (Fig.1f). Second metal (metal 2) deposited and patterned to make bridges (Fig.1g).Finally sacrificial release is done, (Fig. 1h).



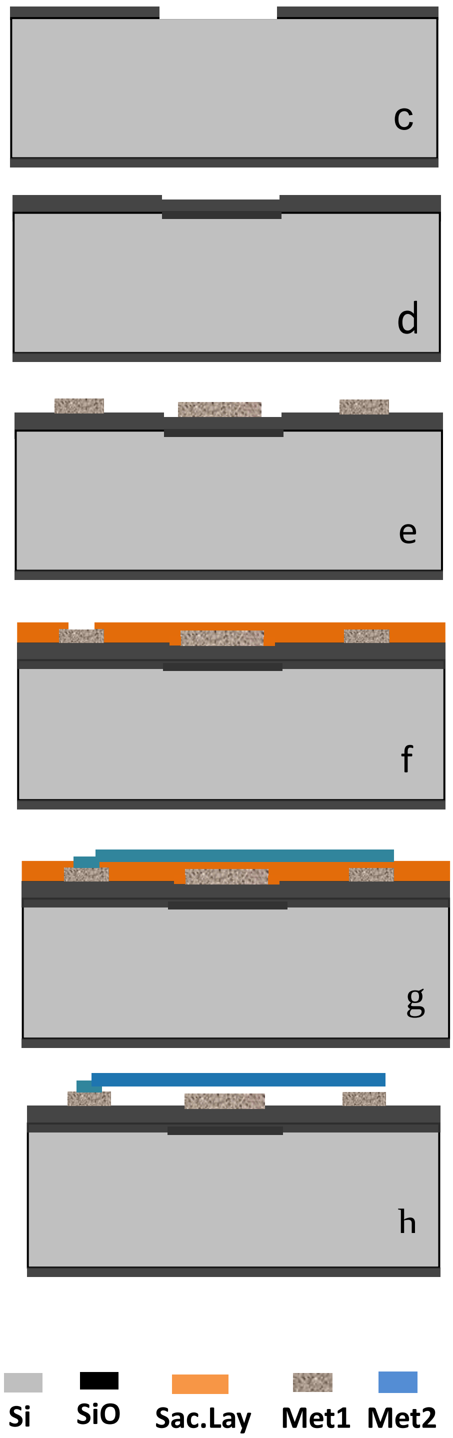
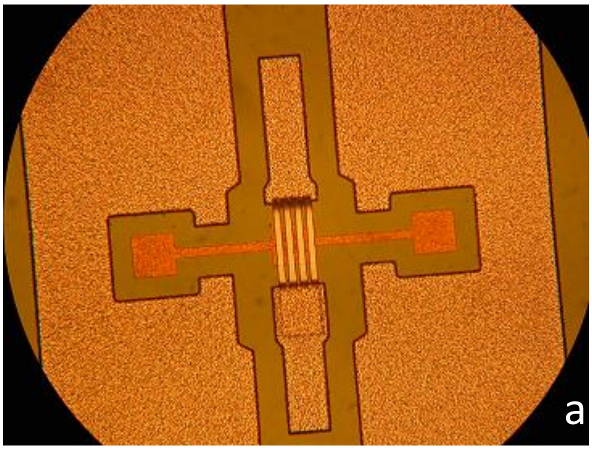


Fig. 1 Fabrication process cross-section Schematic diagram of SCS resonators on SOI wafer (critical process steps a to h)

Chromium is evaporated onto the oxidized wafer by Electron beam evaporation technique to a nominal thickness of 20-30 nm and without breaking the vacuum; a further 1.2um Gold is deposited. This is acts as metal1. Similarly Aluminum is sputter deposited on the sacrificial layer patterned wafer as metal 2 and released the structure. Fabricated switch micrographs is presented. The whole switch micrograph and non-contact DC electrode switch bridge area micrographs are shown respectively in Fig 2(a) and (b).



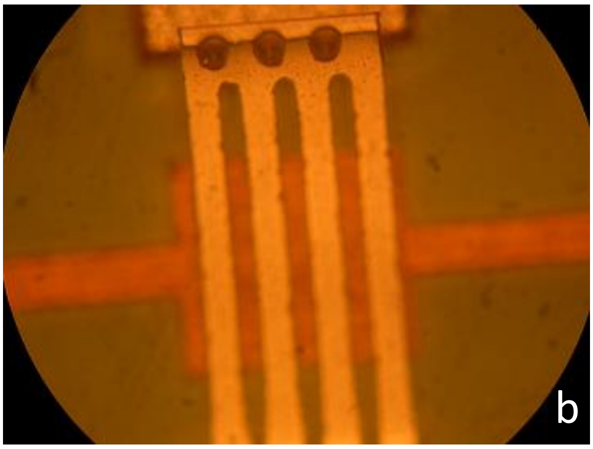


Fig 2: Surface micro-machined Ohmic contact series switch (a & b)

4 MEASUREMENT RESULTS

The wafer level measurement is carried out using Cascade Microtech RF1 probe station and PNA 8362B Network Analyzer from Agilent [4]. Wafer level calibration is carried out prior to the measurement using Short, Open, Load and Thru test structures on standard impedance substrate supplied by Cascade Microtech [5].

Key RF performance characteristics for a single element, ohmic-contact nano-DC electrode gap RFMEMS series switch are shown in Fig 3. The insertion loss of 0.67 dB and isolation of 53 dB at 1.1 GHz and with 1mW power. RF MEMS Switch actuation voltage is 28V for this design.

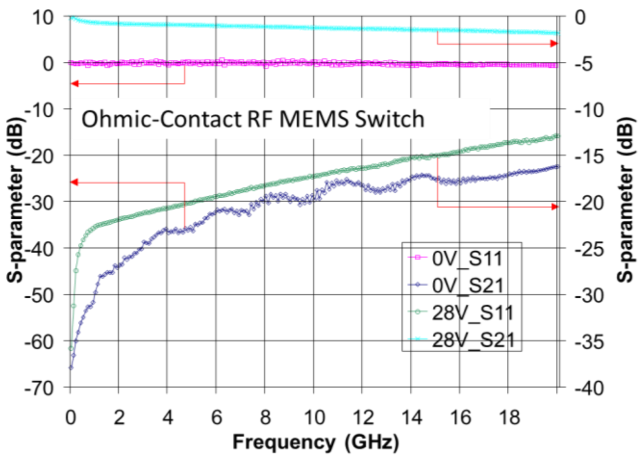


Fig3: Measured scattering parameter of Ohmic-contact RF MEMS switch

5 CONCLUSION

A surface micromachined ohmic series RFMEMS switch has been developed with 70nm final DC electrode actuation gap. This can be used in applications from DC through the microwave region for a variety of commercial and military applications. Applications include T/R and band select switches in a variety of products such as cellular handsets and base stations, phase shifters for Electronically Steerable Antennas, tunable filters, reconfigurable antennas, and pin electronics for Automated Test Equipment. Critical to this development has been the establishment of a low-cost hermetic wafer-scale package that maintains the proper environment for the micro-contacts and yields long and stable lifetimes with minimal RF impact. The uncapped RF MEMS switch measurement performed and reported. Billion cycle test and Optimization of the wafer capping process development is underway.

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