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DESIGN OPTIMIZATION OF DEFLECTION CAUSED AFTER RELEASE OF MULTILAYER STRUCTURAL MEMBRANE OF SYMMETRIC TOGGLE SWITCH

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This paper presents the optimization in deflection caused by the inbuilt stress generated in mechanical or movable membrane of Symmetric Toggle RF MEMS Switch (STS). The movable membrane of STS was initially fabricated with two different materials, i.e. Chrome and Gold. The simulated deflection at 70°C *was* 11.9 *μm, and experimental deflection was* 11-12 *μm. We present a study of inbuilt deflection reduction in multimetal movable layers without change in actuation voltage of the switch. The design study was initially carried out on cantilevers and then on structural membrane of STS. STS with proposed multilayer of Cr-Au-Au-Ti-Au has a simulated deflection of* 0.56 *μm at* 70°C*.*

Keywords: *MULTILAYER, RF MEMS SWITCH, DEFLECTION, FABRICATION, ISOLATION, INSERTION LOSS.*

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1. INTRODUCTION

MICROMACHINING provides a new dimension to the fabrication of RF devices for high performance and low cost. The use of surface micromachining techniques combined with conventional integrated circuit processing enables a new class of high frequency MEMS devices with unique and improved performance. The benefits of the devices include ultra low loss, very high linearity, and negligible power consumption. Actuation mechanisms of these MEMS devices can be piezoelectric, magnetostatic, electrostatic or thermal, but devices are typically operated with electrostatic forces due to its own set of advantages. Basic RF MEMS devices includes switches, capacitors, inductors, filters etc. RF MEMS switches have attracted major attention due to their highly linear characteristics, low loss, high isolation, almost zero power consumption, etc [1, 2]. The geometry and material properties of the switches determine the actuation voltage. The basic two types i.e. capacitive and ohmic type can be further classified as shunt or series switches and can be actuated by four different mechanisms;

electrostatic, piezoelectric, thermal or electromagnetic. Electrostatic mode is preferred, due to its almost zero current drawing capability i.e. almost zero power consumption, small electrode area, relatively short switching time as compared to other actuation modes and low fabrication complexity [3]. The inherent low loss of the switches has been exploited to fabricate high level circuits; such as phase shifters, switch matrices, etc. The loss within the devices is primarily due to transmission line material, capacitive switch configuration and dielectric layer material. Generally for RF MEMS switches, it is desired to have a pull-in voltage as low as possible, a resonant frequency as high as possible, an up-state capacitance as low as possible and a down state capacitance as high as possible [2]. Surely, a trade-off is required here. Lowering the spring stiffness results in a lower pull-in voltage but at a same time the membrane of the switch is more prone to inbuilt deflection. Usually, the mechanical membrane of the switch is fabricated with a multilayer approach, which includes sputter deposition of seed layer (thin Cr-Au) followed by electroplating of Gold. If thickness of the electroplated Au is increased, to improve the stiffness of membrane, the actuation voltage increases.

In this paper we have proposed the design optimization of deflection reduction of structural membrane by additional sputter depositing thin titanium and gold layers over the electroplated Au layer. Fabrication complexity was well taken in care as only increase in single sputtering level is proposed without any additional masking step.

STS is a capacitive type of RF MEMS switch based on 50 Ω CPW configuration, with torsion springs of movable membrane anchored to the ground plane. As shown in Fig. 1 (a), the bridge consists of two micro torsion actuators, connected to each other through levers and an overlap area. The membrane is at a gap of 3 μm from the central conductor. Fig. 1 (b) shows the working principle of STS. The pair of inner and outer actuation electrodes of two micro torsion actuators are electrically shorted together by polysilicon lines and are called "pull-in" and "pull-out" electrodes. With no voltage between bridge and the actuation pads, there is a gap of 3 microns between bridge and the transmission line. A bias of 5 – 10 volts between the inner electrodes and bridge results in an overlap between the bridge and the transmission line increasing the down state capacitance and providing isolation (off-state of the switch). When bias voltage is applied at the outer electrodes, bridge clamps to a height which is double the zero bias height of the bridge, improving the on-state insertion loss [4, 5, 6].

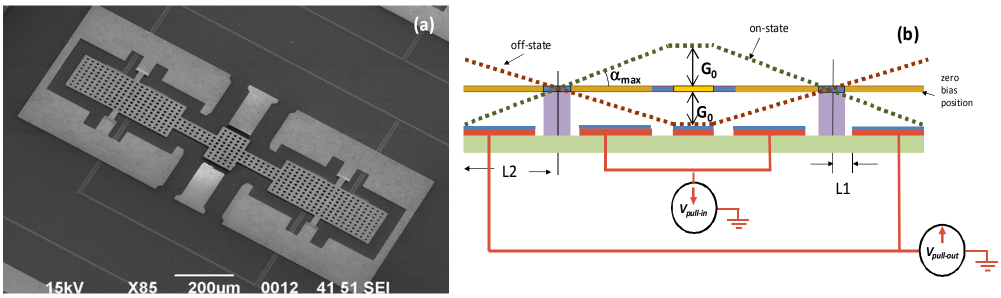

***Fig. 1** – (a) SEM view of fabricated STS, (b) Working Principle of STS*

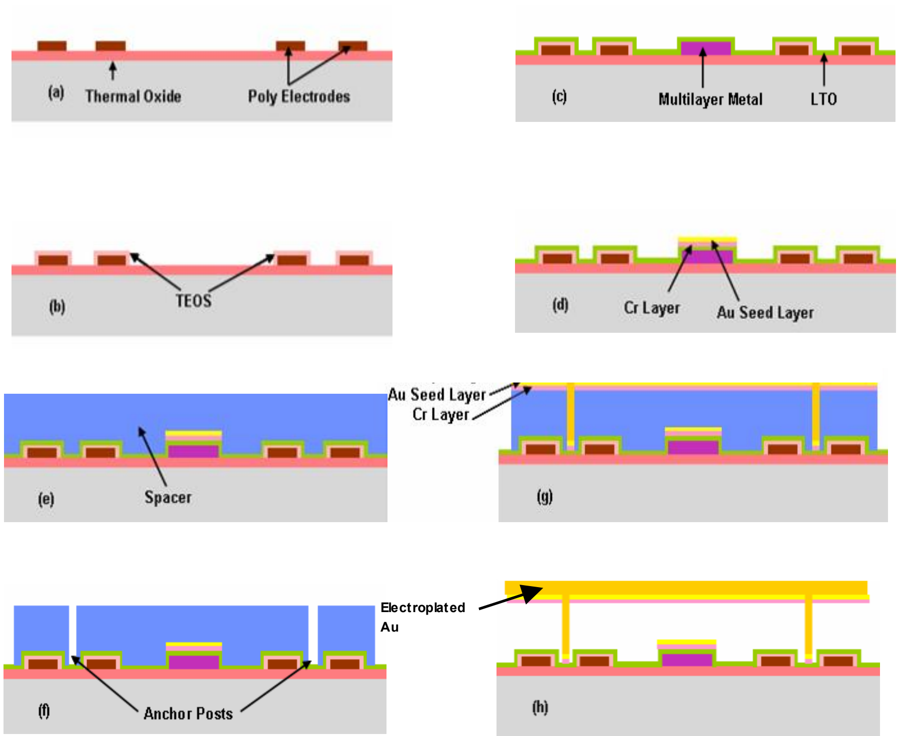

***Fig. 2** – (a)-(h) Schematic of Process flow for STS fabrication*

2. FABRICATION PROCESS FLOW FOR RF STS

Fig. 2 (a) – (h) shows the schematic view of fabrication flow for STS. The surface micro- machined devices are fabricated on high resistivity silicon substrate. Initial thermal oxidation is followed by the LPCVD growth of polysilicon which is further patterned to obtain actuation electrodes. Low temperature TEOS is deposited and patterned to open contact holes. The underpass area for signal transmission is a multilayer stack composed of sputtered Ti/TiN/Al:Si/Ti/TiN thin layers. A LPCVD oxide layer is deposited on the above stack and via holes are patterned. The dielectric layer prevents the short circuit conditions between the underpass area and movable bridge. A floating metal layer can be deposited to obtain optimum capacitance and eliminating the deposition of refractory metals to obtain smooth contact layers. Movable structure is realized through electroplating step over a 3µm thick photoresist, used as a sacrificial layer. A seed layer of Cr/Au for electroplating is deposited by sputtering. This is followed by gold electroplating step providing 1.5 µm thick movable bridge. After the removal of Au and Cr seed layers, switches are released by modified plasma ashing process to avoid stiction problem.

3. COMPARISON OF SIMULATED AND EXPERIMENTAL DEFLECTION IN STS

During the release process, these mechanical membranes get heated to a temperature of nearly 60-70 °C. Due to this they release the stress and gets deflected as shown in Fig. 3.

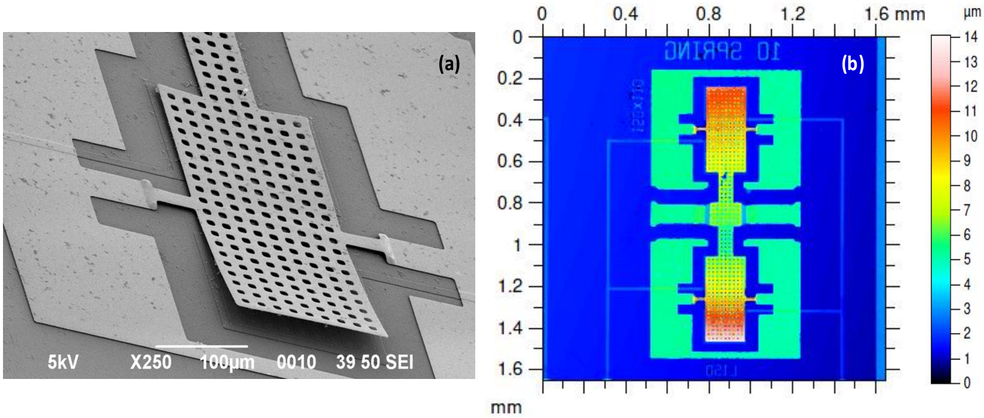

***Fig. 3** – (a) SEM of fabricated deflected membrane, (b) Optical profile of fabricated switch showing maximum deflection of* 11-12 *µm*

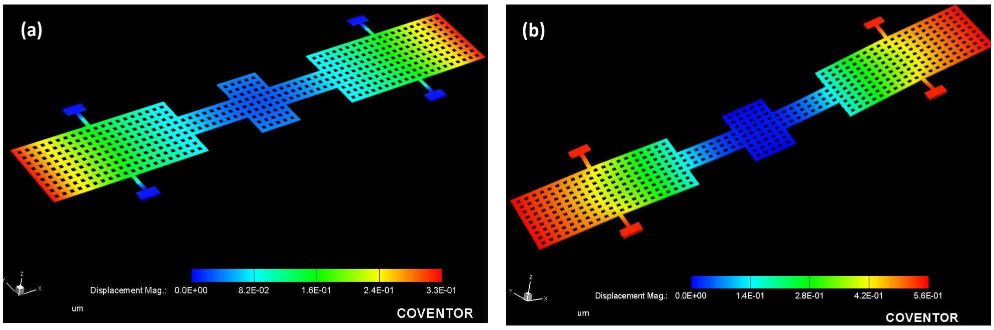

***Fig. 4** – (a) Simulated response of STS with multilayer movable membrane composed of Cr-Au-Au-Ti-Au, at room temperature, showing a maximum deflection of* 0.33 *µm, (b) Simulated response of STS with multilayer movable membrane composed of Cr-Au-Au-Ti-Au, at* 70 *°C, showing a maximum deflection of* 0.56 *µm*

Fig. 3 (a) shows the SEM view of deflected membrane after release. Fig 3 (b) shows the optical profile of fabricated switch showing that the maximum deflection of the fabricated switch membrane is 11 – 12 µm. Simulation for the same was also carried using CoventorWare, giving a deflection of 11.9 µm at 70 °C.

4. SIMULATION RESULTS FOR DEFLECTION REDUCTION IN STS MEMBRANE

As discussed in section 3, fabricated membrane is a multilayer stack of sputtered Cr (30 nm), sputtered Au (150 nm) and electroplated Au (1.5 µm). The coefficient of linear thermal expansion (CTE) of Cr and Au is different, which is the main reason for deflection of thin membranes after heating. CTE of Au is higher than that of Cr and also deposited thickness of Au is higher, suspended beam gets deflected towards Au (ad shown in Fig. 3 (a)). For electroplating, thin Cr-Au layers act as diffusion barrier and seed layer respectively. The proposed idea is to sputter deposit thin Ti (70 nm) and Au (10 nm) on top of the electroplated structural membrane. As, CTE of Ti is lower than that of Au, Final membrane is a sandwich of low CTE layer – high CTE layer – low CTE layer. Here, after simulation, it has been analyzed that the purpose of reduction in deflection after release can be reduced by only incorporating a single titanium layer of 70 nm, but a thin Au layer on top of Ti layer is added, so that the formation of titanium oxide can be eradicated. Though it slightly increases the process complexity by an additional sputtering step, with no extra masking, deflections can be reduced to 0.56 μm at 60-70 °C as compared to the previous Cr-Au membrane. Fig. 4 a) and (b) shows the simulated deflections of STS membrane at room temperature and at 70 °C. The simulated actuation voltage for the multilayer STS changes by only 0.5 Volts. For the switch with Cr-Au-Au membrane it was nearly 11.75 Volts, and for the switch with Cr-Au-Au-Ti-Au membrane, it is 12.25 Volts.

5. CONCLUSION

The design optimization of STS movable membrane has been presented. Deflection caused in movable membranes can be reduced by sputter coating additional layers of titanium and gold of 70 nm and 10 nm each. The simulated deflection of this stacked membrane (Cr-Au-Au-Ti-Au) after release is 0.56 μm at 70 °C, whereas for the previous stack (Cr-Au-Au), simulated deflection was 11.9 μm at 70°C and experimental deflection was 11-12 μm.

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