Fabrication and Modeling of an SP3T RF MEMS Switch

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I. INTRODUCTION

Over the past five years, numerous papers have been published on RF MEMS switches [1]-[2]. However, most of the research effort reported in the literature has been directed toward the development of Single-Pole-Single-Throw (SPST) switches. The SPST switch is a two-port device, which acts as a simple RF relay. In today's communication systems, switches are typically used in the form of switch matrices either for redundancy or for signal routing. The use of multiport switches rather than SPST switches, as the basic building blocks, can considerably simplify the integration problem of large size switch matrices. In our knowledge, very limited work has been reported in literature on integrated multiport MEMS switches [2].

In this paper, we present an integrated SP3T MEMS switch. RF simulation along with circuit modeling is used to design the switch. Three beams with narrow-width tips are integrated on top of a co-planar transmission line. The junction where the three beams interact is inherently a wide band junction, which makes it possible to design a wideband SP3T switch with 30dB isolation up to 20 GHz.

II. SP3T SWITCH CONFIGURATION

Fig.1 shows the proposed SP3T MEMS switch structure. It is a compact (500×500 μm^2) coplanar series switch, consisting of three actuating beams. One end of each beam is attached to a 50Ω coplanar transmission line, while the other end is suspended on top of another 50Ω coplanar transmission line to form a series-type contact switch. The pull down electrodes which are parts of the RF ground are placed underneath the beams. The design can be implemented by integrating the beams and the substrate on one chip as in the case of the SP4T switch reported in [2]. Alternatively, the SP3T switch can be implemented in a hybrid-form where the beams are micromachined separately and then integrated on an Alumina substrate using flip-chip technology. In this paper, we report the results of the hybrid version of this switch.

The beams are fabricated using the Multi-User MEMS Processes (MUMPs) surface micro machining. Each beam is made of a Polysilicon layer of a thickness of 1.5µm covered by a gold layer of 0.5 µm. Release holes are accommodated for HF accessibility to the trapped oxide under the beams. The coplanar line circuit is fabricated on an Alumina substrate with thickness of 254µm. The beams are flipped on top of the gold-coated Alumina substrate using flip chip process and gold bumps, as shown in Fig. 2. In order to improve the

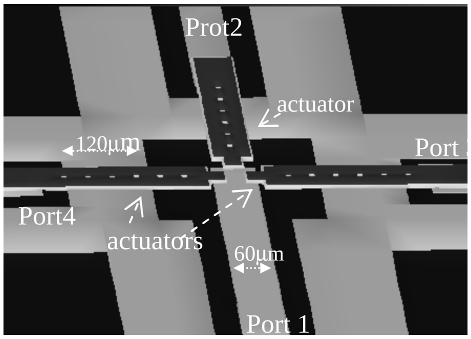
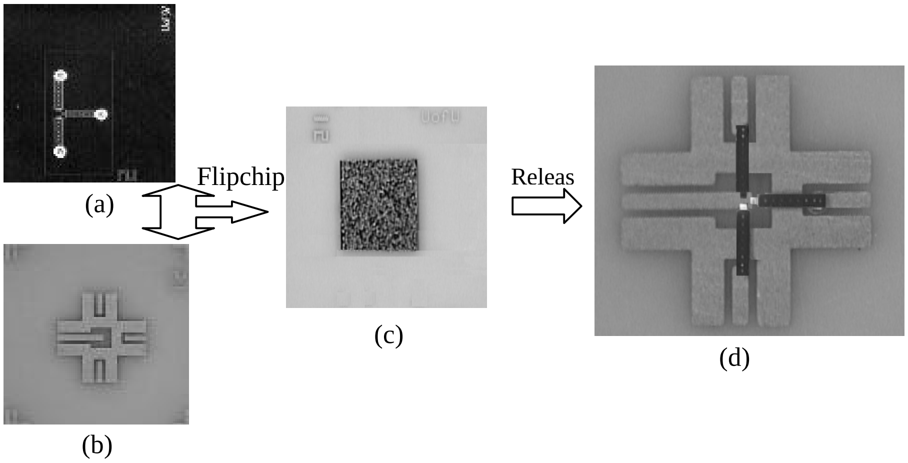


Fig.1: Proposed SP3T MEMS Switch

isolation of the switch, the beams are narrowed at the tip and the contact is performed only by small tips at the end of the beams. With the use of flip-chip technology, a gold-to-gold contact has been realized.



(a) (b) (c) (d)

Fig. 2: The fabrication process of the SP3T switch. a) the PolyMUMPs chip which has the beams, b) The Alumina substrate, c) The PolyMUMPs chip is attached to the substrate, d) the SP3T switch after releasing the beams from the PolyMUMPs chip.

III. SWITCH DESIGN AND CHARACTERISTIC

For testing purposes, the switch is actuated by applying DC voltage to the RF ports, through bias tees. With the application of the actuation DC voltage, the beams deflect, thus closing the gap while providing a continuous path through the transmission line.

The warpage of MEMS cantilever structures consisting of polysilicon and gold on top is one of the design considerations in using the PolyMUMPs process. The warpage exists because of the residual stresses and the thermal mismatches that result from the fabrication process. However, in this design, the top layer gold becomes the bottom layer of the beams, resulting in the inward warpage of the beams, as shown in Fig. 3. It brings the tips closer to the substrate while increasing the distance between the beams and the DC electrodes. The large distance prevents the beams from collapsing to the electrodes and helps in reducing the coupling between the beams and the RF ground. The disadvantage of the warpage is that it increases the actuation voltage. In practice, to keep the distance between the beams and the input RF line constant, the distance between the electrode and the beam is increased leading to a pull in voltage of about 80 volts. It should be noted that depending on the fabrication process and the residual stress of the layers, the flip chip gold bumps height can be controlled to realize the desired performance.

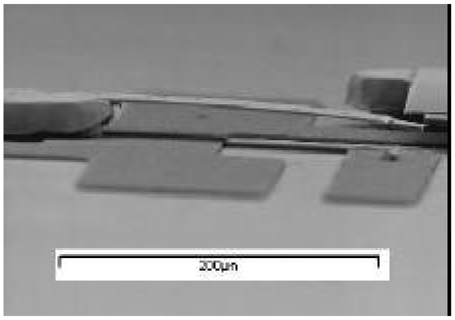


Fig. 3: Cantilever beam warpage, (SEM picture).

The RF performance of the SP3T switch has been characterized over a wide range of frequency from DC to 40GHz, using HFSS software. The results for the case that port 2 is in ON state and ports 3 and 4 are in OFF state are shown in Fig. 5 (a) and (b). For the case that port 3 is ON and the others are OFF is shown in Fig. 5(c). It is worth mentioning that due to the symmetric configuration of the switch, the results for the case of port 4 in ON and port 2 and 3 in OFF states are similar to the case shown in Figure 6. This switch is a four port CPW switch and the effort is done to keep the propagation mode in CPW mode and prevent producing extra Hybrid modes along the signal path from the input line to any of the output ports.

To obtain a better insight on the performance of the switch, its circuit model is studied. The circuit is shown in Fig. 6 and the results are compared with that of HFSS in Fig. 5 (a) and (b). At the input of each port, there is a 50Ω transmission line followed by a gold bump to attach the beam. These bumps generally show capacitive performance at low frequencies and are inductive at high frequencies. We found that the switch performance highly depends on the bumps which play an inductive role in our range of interest. Moreover, due to the multi-port structure of the switch, isolation of the throw ports becomes an important issue. One can notice that because of the narrow tips of the beams in this structure and thus small capacitors, good isolation between the ports is achieved. The inter-coupling capacitors of the output ports are about 0.1 and 0.3fF whereas the isolation capacitors between the input line and the off ports are 5fF. The beam widths are 60μm which are changed to 30μm at the tips. This change is represented by two series inductors and a parallel capacitor.

A two port on wafer 180 degree probe measurement is performed. The results are shown in Fig. 7 (a) and (b) for ON and OFF states. The preliminary results show better than 0.5 dB insertion loss and 20dB return loss up to 20 GHz. Comparing the measured results with that of the simulation, the difference in the return loss and insertion loss is believed to be due to the polysilicon loss and warpage of the beams that are not taken in to account during the simulation. It should be mentioned that the results given in this paper is for an engineering prototype unit which is built to prove the concept. The design is being further optimized to reduce the value of the actuation voltage and to improve the insertion loss as well as the isolation performance beyond 20 GHz.

IV. CONCLUSION

A novel integrated SP3T switch configuration has been presented. The theoretical and measured results demonstrate the validity of the proposed design. The SP3T switch has demonstrated a superior performance up to 20GHz. Even though the concept is demonstrated using flipchip technology, the SP3T switch can be potentially realized by integrating the beams and the substrate on one chip.

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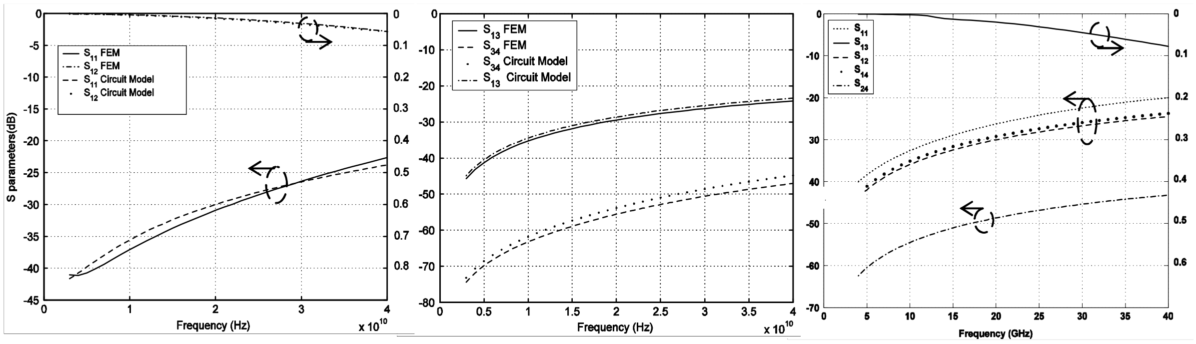
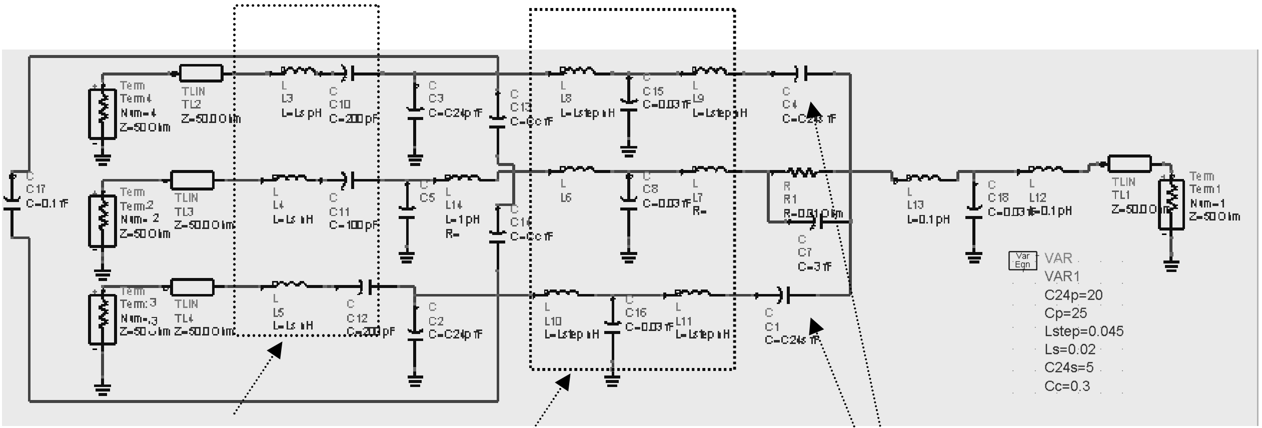


(a) (b) (c)

Fig. 5: RF performance for the switch shown in Fig.1. (a) Insertion loss and return loss when port 2 is ON and ports 3 and 4 are OFF,(b) isolation between the ports when port 2 is ON and ports 3 and 4 are OFF and (c) S parameters when port 3 is ON and ports 2 and 4 are OFF.

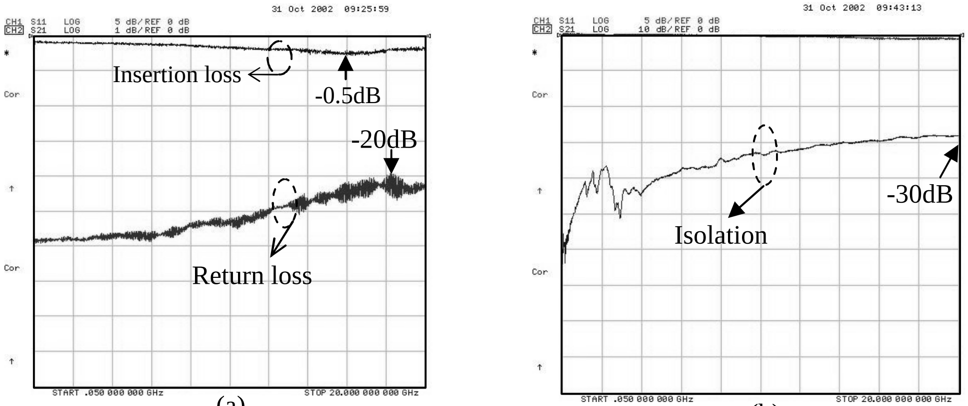


Gold bumps

Transferring from 60 µm beam width to 30 µm tip width

OFF Capacitors

Fig.6: Circuit model for the switch shown in Fig.1 when port 3 is ON and the other ports are OFF



(a) (b)

Fig 7: Measurement results for port 2 of the switch shown in Fig. 1 when port 3 and 4 are OFF, (a) return loss and insertion loss and (b) isolation.