ON THE DESIGN AND FABRICATION OF ELECTROSTATIC RF MEMS SWITCHES

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ABSTRACT

A surface micromachined capacitive switch has been designed and fabricated on a glass substrate. The switch is constructed of a thin metallic membrane crossing over an electroplated coplanar waveguide transmission line. The electrostatic actuation is utilized as the switching mechanism. The actuation voltage is around 50V. The switch showed low insertion loss of 0.1 dB at 10 GHz and 0.4 dB at 25 dB, and isolation of 15dB at 20 GHz. This device offers a potential application in telecommunication, phase antenna array system, etc.

INTRODUCTION

Compound solid state switches such as GaAs MESFETs and PIN diodes are widely used in microwave and millimeter wave integrated circuits (MMICs) for telecommunications applications including signal routing, impedance matching networks, and adjustable gain amplifiers. [1-3] However, these solid-state switches have a large insertion loss (typically 1 dB) in the on state and poor electrical isolation in the off state. The recent developments of micro-electro-mechanical systems (MEMS) have been continuously providing new and improved paradigms in the field of microwave applications. Different configured micromachined miniature switches have been reported. [4-5] Among these switches, capacitive membrane microwave switching devices present lower insertion loss, higher isolation, better nonlinearity and zero static power consumption. [6] In this presentation, we describe the design, fabrication and performance of a surface micromachined capacitive microwave switch on glass substrate using electroplating techniques.

SWITCH DESIGN AND OPERATION

The geometry of a capacitive MEMS switch is shown in Fig. 1. The switch consists of a lower electrode fabricated on the surface of the glass wafer and a thin aluminum membrane suspended over the electrode. The membrane is connected directly to grounds on either side of the electrode while a thin dielectric layer covers the lower electrode. The air gap between the two conductors determines the switch off-capacitance. With no applied actuation potential, the residual tensile stress of the membrane keeps it suspended above the RF path. Application of a DC electrostatic field to the lower electrode causes the formation of positive and negative charges on the electrode and membrane conductor surfaces. These charges exhibit an attractive force which, when strong enough, causes the suspended metal membrane to snap down onto the lower electrode and dielectric surface, forming a low impedance RF path to ground.

The switch is built on coplanar waveguide (CPW) transmission lines, which have an impedance of 50 Ω that matches the impedance of the system. The width of the transmission line is 160 μm and the gap between the ground line and signal line is 30 μm. The insertion loss is dominated by the resistive loss of the signal line and the coupling between the signal line and the membrane when the membrane is in the up position. To minimize the resistive loss, a thick layer of metal needs be used to build the transmission line. The thicker metal layer results in a bigger gap that reduces the coupling between signal and ground yet also requires higher voltage to actuate the switch. To achieve a reasonable actuation voltage, a 4-μm-thick copper is used as the transmission line. The glass wafer is chosen for the RF switch over a semi-conductive silicon substrate since typical silicon wafer is too lossy for RF signal.

When the membrane is in the down position, the electrical isolation of the switch mainly depends on the capacitive coupling between the signal line and ground lines. The dielectric layer plays a key role for the electrical isolation. The smaller the thickness and the smoother the surface of the dielectric layer, the better isolation of the switch is. But there is another trade-off here. When the membrane is pulled down, the biased voltage is directly applied across the dielectric layer. Since this layer is very thin, the electric field within the dielectric layer is very high. The thickness of the dielectric layer should be chosen such that the electric field will never exceed the breakdown electric field of the dielectric material. The silicon nitride film has breakdown electric field as high as several mega-volts per centimeter and can be utilized as dc block dielectric layer. In this project, the thickness of the silicon nitride layer is chosen as 0.2 μm to accomplish the dc block and RF coupling purpose.

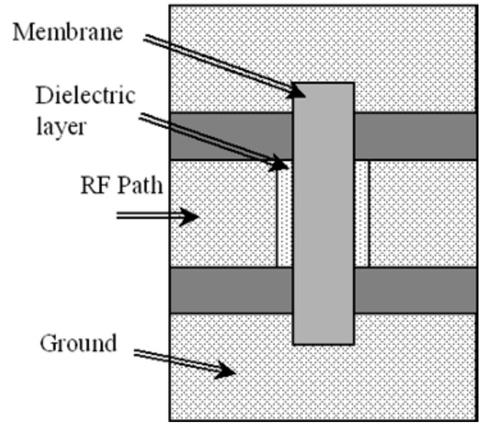

Fig. 1 Schematic of top view of capacitive MEMS switch.

FABRICATION

The switches were fabricated by surface micro-machining techniques with a total of four masking level. No critical overlay alignment was required. Fig. 2 shows the essential process steps:

1. Ti/Cu seed layer deposition: The starting substrate was a 2-inch glass wafer. A layer of titanium (0.05μm) and copper (0.15μm) was sputtered on the substrate as seed layer for electroplating.
2. Silicon nitride deposition: A layer of silicon nitride (0.2μm) was deposited and patterned as DC block by using PECVD and reactive ion etch (RIE).
3. Copper electroplating: A photoresist layer was spin coated and patterned to define the electroplating area. Then, a 4-μm-thick copper layer was electroplated to define the coplanar waveguide and the posts for the membranes.
4. Aluminum deposition: A layer of aluminum (0.4μm) was deposited by using electron beam evaporation and patterned to form the top electrode in the actuation capacitor structure.
5. Release: The photoresist sacrificial layer was removed to finalize the switch structure.

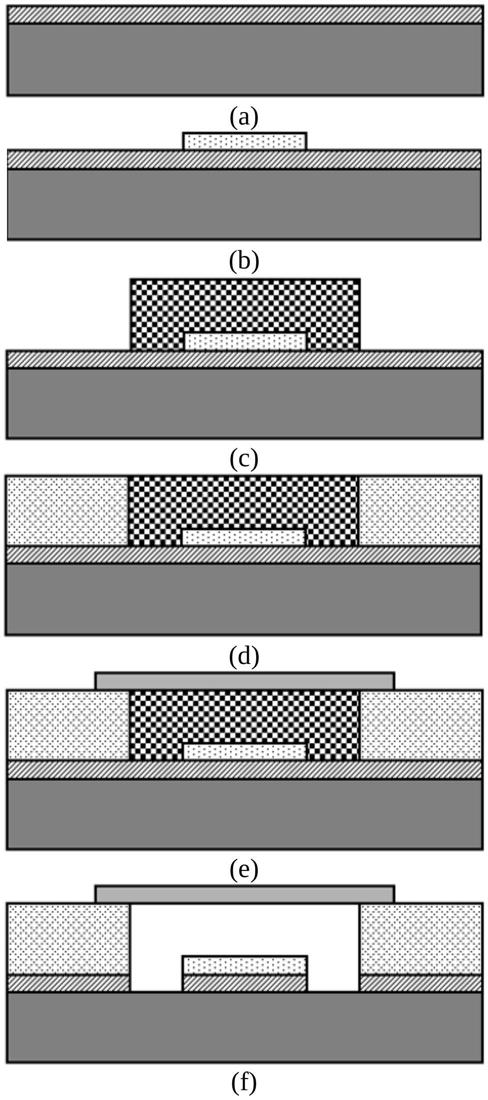

Fig. 2 Process flow: (a) seed layer deposition (b) dielectric layer deposition and patterning (c) spacer coating and patterning (d) transmission line electroplating (e) membrane deposition and patterning (f) membrane releasing.

TEST RESULTS AND DISCUSSIONS

The probe station and network analyzer (HP 8510C) were used to characterize the capacitive MEMS switch. Fig. 3 shows the micrograph of a switch under test. When the switch is unactuated and the membrane is on the up position, the switch is called in *off*-state. When the switch is actuated and the membrane is pulled down, the switch is called in *on*-state. The major characteristics of the switch are the insertion loss when the signals pass through and the isolation when signals are rejected. In the *off*-state the RF signal passes underneath the membrane without much loss. In the *on*-state, between the central signal line and coplanar waveguide grounds exists a low impedance path through the bended membrane. The RF signal will be reflected by the switch.

As shown in Fig. 4, in the *off*-state the switch has insertion loss of approximately 0.1 dB at 10 GHz and 0.4 dB at 25 dB. Compared with typical FET or PIN diode switches, which have about 1 dB insertion loss, the MEMS switches have considerable advantages. For a multi-switch system, the total loss is significantly lower when mechanical switches are utilized. The return loss is better than 20 dB up to 25 GHz, which means the MEMS switch has an excellent impedance match to 50 Ω.

The isolation and return loss of the switch in the *on*-state is shown in Fig. 5. Due to the geometry of the capacitive switch, the signal cannot be coupled to ground perfectly at the low frequency. As the frequency becomes high, the coupling between the signal line and ground lines makes the isolation of the switch approximately 15 dB at 20 GHz, which is sufficient for switching RF signals.

The resonant frequency of 23.4 GHz was observed when the membrane was in the down position. This means that the switch can be equivalently modeled as a capacitor, inductor and resistor connected in series between the signal and ground lines. Since the switch has a better isolation around the resonant frequency, it can be designed such that the desired frequency overlaps with the resonant frequency by adjusting the geometry of the switch, i.e. the width of the membrane and the gap between the membrane and the lower electrode.

The actuation voltage of the MEMS switch is about 50V. The spring constant of the membrane and the distance between the membrane and the bottom electrode determines the actuation voltage of the switch. The spring constant of the membrane is mainly determined by the membrane material properties, the membrane geometry, and the residual stress in the membrane.

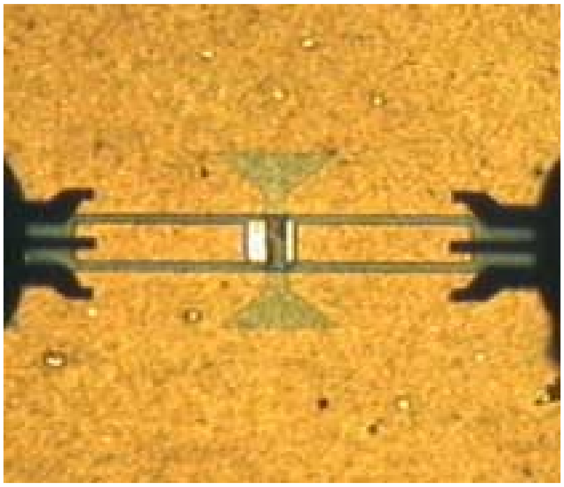

Fig. 3 Micrograph of a switch under test

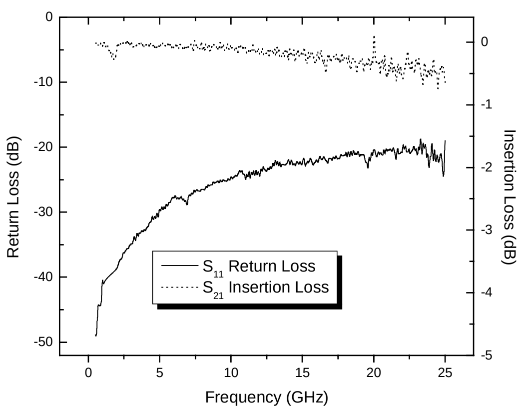

Fig. 4 Switch insertion loss and return loss in *off*-state

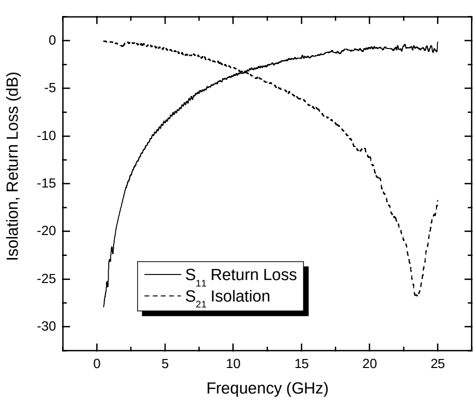

Fig. 5 Switch isolation and return loss as a function of frequency in the switch *on*-state.

CONCLUSION

MEMS capacitive switches for RF applications were designed, fabricated, and tested. The switches show low insertion loss in the *off*-state and high isolation in the *on*-state. The micromachined switches will have applications in phased antenna arrays, in MEMS impedance matching networks, and in communications applications.

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