Low Cost RF MEMS Switches Using LCP Substrate

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ABSTRACT — **In this paper, we present an RF MEMS switch developed on a low cost, flexible liquid crystal polymer (LCP) substrate. LCP's very low water absorption (0.04%), low dielectric loss and multi-layer circuit capability make it very appealing for RF systems-on-package (SOP). Here we present for the first time capacitive MEMS switch fabrication on an LCP substrate and its characterization and properties up to 40 GHZ.**

I. INTRODUCTION

Low-cost MEMS switches are prime candidates to replace the conventional GaAs FET and p-i-n diode switches in RF and microwave communication systems, mainly due to their low insertion loss, good isolation, linear characteristic and low power consumption. In most MEMS switches reported so far, all switches are fabricated on semiconductor substrates like silicon [1-3]. Miniaturization, portability, cost and performance have been the driving force for the evolution of packaging and system-on-package (SOP) approach in RF, microwave and millimeter wave applications. Liquid crystal polymer (LCP) provides the all-in-one solution for such integration approach in terms of high quality dielectric for high performance multi-band passive design, excellent substrate for heterogeneous SOP integration as well as for MEMS structures. Furthermore, low loss and low power MEMS switches fabricated on LCP enable the implementation of multi-band and reconfigurable modules.

This paper presents capacitive RF MEMS switches with silicon nitride as dielectric layer on LCP substrate for the first time. It is well known that organic substrates are typically not as smooth as semiconductor ones, and therefore special consideration must be given when developing MEMS devices. Clamped-clamped (air-bridge-type) and clamped-free (cantilever-type) coplanar waveguide (CPW) switches with a membrane size of 100μmx200μm and various hinge geometries (solid and meander shaped) were fabricated on LCP substrates using a simple four mask low-temperature process [4] that minimizes the surface roughness and assures good switch performance. The measured DC and microwave performance of the air-bridge switches for a given hinge geometry has been reported at this stage.

II. LCP PROCESS & CHARACTERISTICS

Digital and RF analog circuits require increasing operating frequencies and integration density and maintaining low power consumption and low cost.

One material that may offer a solution is liquid crystal polymer (LCP). LCP is a material whose mechanical strength, adhesion to copper, and via drilling/metallization have all recently been optimized to enable its use in microwave circuit construction [5-6]. A unique extrusion process, surface treatments, and experiments with laser, chemical, and reactive ion etch (RIE) gases have been used to overcome its previous process limitations [7-8]. LCP is nearly hermetic, has very good electrical properties (ε_r = 2.9-3.0, tan δ = 0.002-0.003), is recyclable, has a wide range of CTE (0-30 ppm/°C), has excellent chemical resistance, is flexible, and it is capable of multilayer lamination. For multilayer LCP circuits, a 1 mil low melting temperature (290°C) LCP layer can be used to bond high melting temperature (315°C) LCP core layers which typically come in 2 – 8 mil thicknesses. Electrical properties of the two types are the same. Thus, compact, vertically integrated architectures performing as the substrate and package may be realized in LCP material. The cost of LCP (~$5/ft^2) [9], though not yet competitive with FR-4, is already reasonable and should continue to drop as production levels grow.

Several single measurements have been reported showing LCP to have low loss [10-12]. The loss characterization of LCP transmission lines up to W band provides an excellent insight of its potential for mm-wave applications. Conductor backed CPW (CB-CPW) transmission lines have been fabricated on 2 mil LCP substrates with measured insertion loss of 2.35 dB/cm at 110 GHz [12].

III. MEMS SWITCH ON LCP

To fabricate MEMS switch on LCP substrate, a simple four mask process is used as shown in figure 1. A 3 μm PI2610 polyimide is first spun on LCP to planarize the surface and minimize the roughness. The CPW signal lines were then fabricated by evaporating Ti/Au/Ti (300Å/5000Å/300Å). PECVD Si_3N_4 layer was patterned between the membrane and the signal line. A 1.8μm thick photoresist (1813) was spin coated and patterned to create the air-gap. Ti/Au/Ti (300Å/3000 Å/300 Å) seed layer was then evaporated and patterned and electroplated. Finally, after removing the sacrificial photoresist layer with a resist stripper, a critical point drying process was used to release the switches.

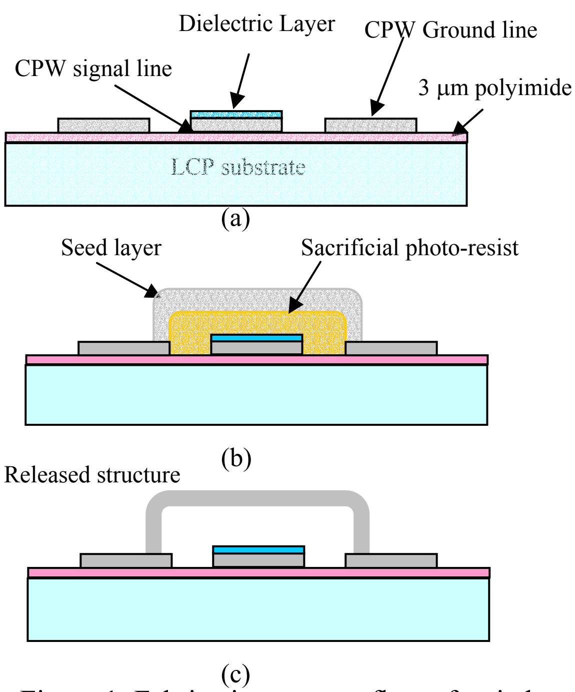

Figure 1: Fabrication process flow of switch.

A Scanning Electron Microscope (SEM) picture of the fabricated air-bridge type CPW switch structure with a 1.2μm thick gold membrane, a 1.8μm air-gap and a membrane size of 100x200 μm^2, is shown in Figure. 2.

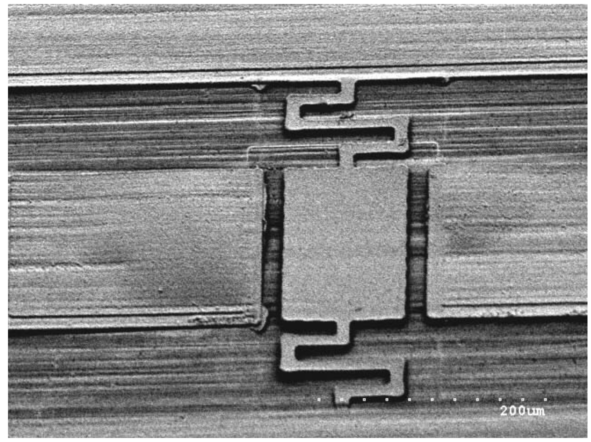

Figure 2: SEM of a fabricated air-bridge type CPW switch on LCP with 1.2μm thick Au membrane and meander-shaped support

IV. MEASURED RESULTS OF MEMS SWITCH ON LCP

Measurements of the air-bridge type switch were taken using an Agilent 8510 network analyzer. A TRL calibration was performed to de-embed the coplanar line and transition losses. Measured results for the nitride switches with silicon substrate and LCP are shown in Figures 3-4. The pull-down voltage was measured to be 25 V. For the LCP switch, when the switch is activated, the isolation is around 20 dB at 20 GHz and C_{ON}=3 pF, while the return loss is around 0.1 dB at 20 GHz. When the switch is in the UP position, the insertion loss is around 0.08 dB at 20 GHz and C_{OFF}=35 fF; the return loss is 18 dB at 20 GHz. For the same switch on silicon substrate, when the switch is activated, the isolation is around 17 dB at 20 GHz and C_{ON}=2 pF, while the return loss is around 0.4 dB at 20 GHz. When the switch is in the UP position, the insertion loss is around 0.8 dB at 20 GHz and C_{OFF}=25 fF; the return loss is 10 dB at 20 GHz. The deteriorated return loss of the switch on silicon is due to the thinner sacrificial layer that increases the capacitance, while the different C_{ON} between the two types of switches with different substrate is because the thickness of silicon nitride is a little different. All air-bridge switches with LCP substrate have better insertion loss than that of the switches with silicon substrate at up state and have better isolation loss at down state, all the LCP switches have smaller insertion loss is mainly due to extreme lower dielectric loss tangent of LCP substrate.

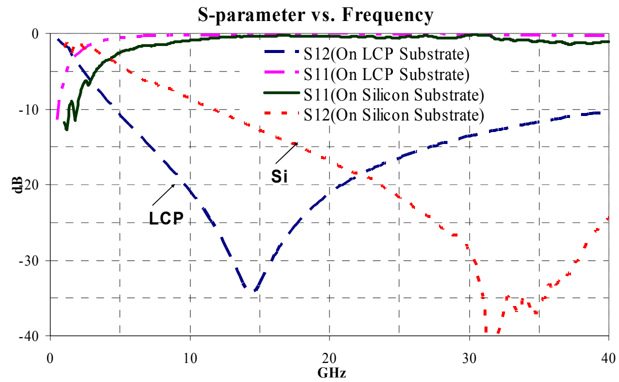

Figure 3: Measured S-parameters for the Air-bridge switch with Silicon and LCP substrate in DOWN state.

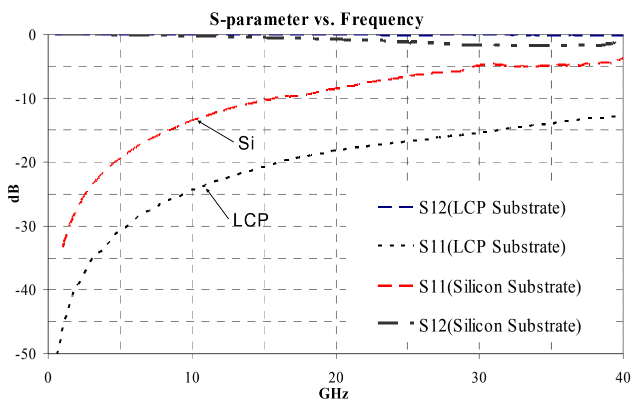

Figure 4: Measured S-parameters for the air-bridge switch with Silicon and LCP substrate in UP state

V. Conclusions

A capacitive RF MEMS switch on an organic "rough" substrate has been presented for the first time. The surface was made smoother by a thin layer of polyimide. The LCP substrate is flexible and can also be used as a package. It enables integration of reconfigurable architecture on LCP for 3D RF front ends. It also shows that the switch on LCP substrate can be a low-cost/enhanced performance alternative to the RF MEMS switches on silicon.

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