Fabrication and Testing of a Microstrip Phase Shifter Using Micromachined Reconfigurable Ground Plane

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ABSTRACT: A micromachined phase shifter is implemented along a microstrip transmission line using thin film membranes in the ground plane. Actuation of the membranes controls the transmission line to ground plane spacing, varying line impedance, enabling signal phase shift. Thin film copper membranes on silicon substrates were constructed using micromachining techniques. An array of five 4.3 mm diameter membranes phase shifted a signal by 30.0° at 12.08 GHz. A single 10.4 mm membrane demonstrated a phase shift of 37.1° at 11.01 GHz and 55.5° at 14.25 GHz. Continuous positioning of the ground plane membranes is possible, enabling continuous phase shift control.

I. INTRODUCTION

In recent years, much research has been done in the area of micro-electro-mechanical-systems (MEMS) switch based phase shifters [1-3]. MEM switches can offer very low series resistance and high isolation, and low DC power operation can be achieved using electrostatic actuation. MEM switch based phase shifters achieve discrete phase shifting by routing RF signal to transmission lines of different path lengths, or connecting/disconnecting other microwave or circuit elements [4]. Barker and Rebeiz [5] showed a distributed MEMS transmission line (DMTL) phase shifter for U-band and W-band frequencies. Implementation involved the fabrication of MEM bridges above a coplanar transmission line.

This paper illustrates a micromachined phase shifter formed from a reconfigurable microstrip ground plane, using micromachined copper membranes distributed in the ground plane (see Figure 1). The microstrip transmission line is fabricated on Corning™ 1737 dielectric glass. The copper membranes are fabricated on a silicon wafer. Corrugations 10 μm deep were micromachined into the membranes to increase their flexibility [6]. A pull down electrode below the membranes enables electrostatic actuation. Control of the air gap spacing between the transmission line and the ground plane varies substrate dielectric constant. Thus, transmission line capacitance can be controlled, enabling phase shift of the transmission line signal. Continuous positioning of ground plane membranes is possible, enabling continuous phase shift control and antenna beam steering if the membranes are implemented in the feed network of an antenna

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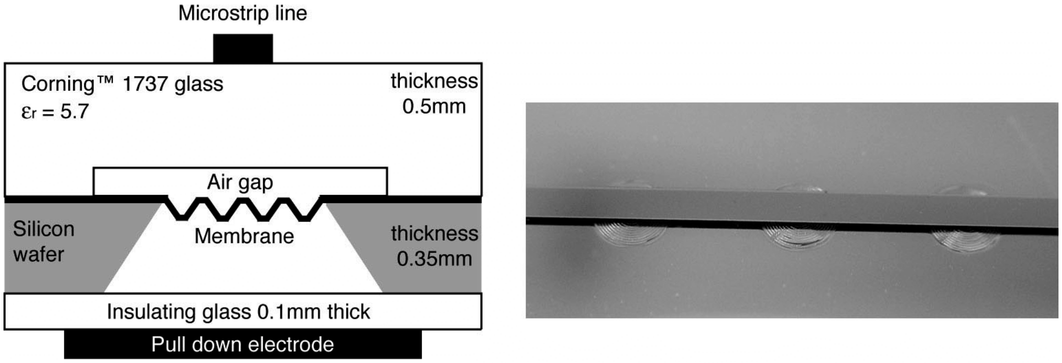
array. An advantage of this structure is that the RF signal is completely isolated from the actuating electrode, which is on the other side of the ground plane. Also, this reconfigurable ground plane is not limited to low RF power applications, which can be a limit with MEM switch based phase shifters. A companion paper in this symposium will discuss phase shift performance simulations.



(a) (b)

Figure 1: (a) Cross-section geometry of the microstrip transmission line over ground plane membrane. (b) Three 4.3 mm corrugated membranes in the ground plane below the transmission line.

II. MEMBRANE FABRICATION

Copper membranes with 4.3 mm and 10.4 mm diameters were fabricated and tested. A description of the membrane fabrication is illustrated in Figure 2.

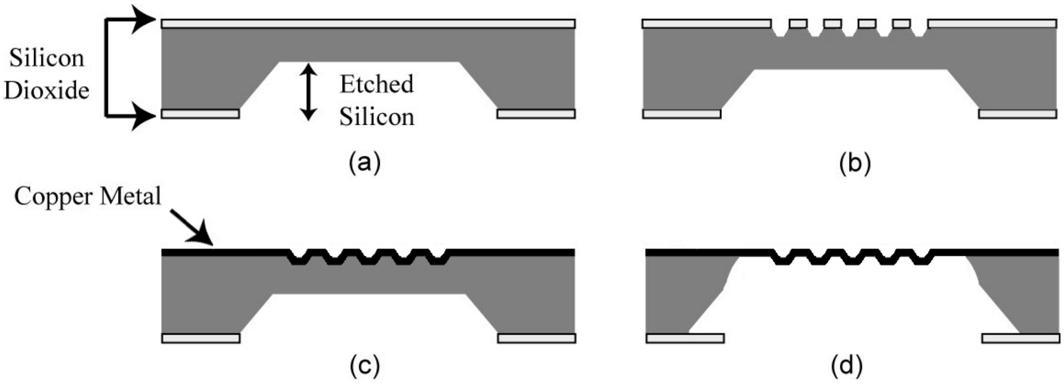


Figure 2: Fabrication of copper membranes. (a) Wafer backside initial KOH etch. (b) Frontside KOH etch to form the corrugations. (c) Copper metallization. (d) Completion of the backside etch to free the membranes.

Silicon dioxide is thermally grown on a silicon wafer using wet thermal oxidation. The backside oxide is patterned, and the wafer is partially etched through using KOH at 80 °C to define the future membrane locations (Figure 2a) until approximately 50 µm of silicon remains. The frontside oxide is patterned, and the wafer surface is corrugated (10 µm deep) using KOH (Figure 2b). The frontside oxide is removed and copper metal is deposited using thermal evaporation (Figure 2c). The remaining silicon beneath the membrane location is etched using XeF_2 gas (Figure 2d) to free the membrane. XeF_2 is selected since it does not attack the copper metal.

III. MICROSTRIP PHASE SHIFTER IMPLEMENTATION

A transmission line 1.7 mm wide and 5 cm long was fabricated on Corning™ 1737 glass using thermal evaporation of copper through a shadow mask. We can see from Figure 1a that a 50 µm high air gap is etched in the glass above the membrane. This air gap was fabricated to minimize mis-match during membrane deflection, but it also had the effect of reducing the phase shift. This air gap was not present in all the membrane tests.

An array of five 4.3 mm membranes was investigated. The membranes possessed a copper thickness of 1.25 µm, with a corrugation pitch of 120 µm. Measured phase shift results are shown in Table 1. For one set of measurements the 50 µm air gap shown in Figure 1a was present. We observe that with the 50 µm air gap, the 4.3 mm membrane array achieved a phase shift of 21.6° at 11.0 GHz with 73 µm membrane deflection, and an S_{21} difference of 0.32 dB. At the higher frequency of 14.9 GHz phase shift was greater, due to the larger effective deflection of the membranes as a function of wavelength. A phase shift of 26.9° was measured with an S_{21} difference of 0.25 dB. We can also see that without the 50 µm air gap, the phase shift is greater. With the air gap and 25 µm membrane deflection, 12.6° phase shift was measured at 11.0 GHz. Without the air gap, 30.0° phase shift was measured at 12.08 GHz. This is more than twice the phase shift, suggesting that removal of the air gap may be desired.

Table 2: Measured phase shift as a function of deflection distance for an array of five 4.3mm membranes.

Membrane Deflection	**Phase Shift**	**S_{21}**
with 50 µm air gap at 11.0 GHz:		
0 µm	0°	-0.76 dB
25 µm	12.6°	-0.68 dB
73 µm	21.6°	-1.08 dB
with 50 µm air gap at 14.9 GHz:		
0 µm	0°	-1.37 dB
73 µm	26.9°	-1.62 dB
without air gap at 12.08 GHz:		
0 µm	0°	-2.32 dB
25 µm	30.0°	-2.25 dB

Table 3: Measured phase shift as a function of actuation voltage for a single 10.4 mm membrane.

Pull-Down Voltage	**Phase Shift**	**S_{21}**
at 11.01 GHz:		
0	0°	-4.96 dB
205	19.9°	
303	25.6°	
404 (switched)	37.1°	-4.10 dB
at 14.25 GHz:		
0	0°	-4.66 dB
205	37.2°	
303	43.4°	
404 (switched)	55.5°	-3.80 dB

Phase shift measurements for a single 10.4 mm membrane are shown in Table 2. The 50µm air gap was not present for these tests. This membrane switched completely down at an actuation voltage of 404 V. With the membrane completely pulled down, phase shifts of 37.1° and 55.5° were measured at 11.01 GHz and 14.25 GHz respectively. The S_{21} difference in both these cases was measured to be 0.86 dB.

VI. CONCLUSIONS

A micromachined phase shifter implemented using a reconfigurable ground plane was presented. An array of five 4.3 mm membranes phase shifted a transmitted signal by 30.0° at 12.08 GHz. A single 10.4 mm diameter membrane demonstrated a phase shift of 37.1° at 11.01 GHz and 55.5° at 14.25 GHz. Both implementations illustrate continuous phase shift capability. Benefits of this device are isolation of the transmission line signal from the MEMS actuation electrode, and operation at high RF powers which can be a problem with MEM switch phase shifters.

ACKNOWLEDGEMENTS

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