Numerical modeling of imperfect contacts in capacitively coupled RF MEMS switches*

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***Abstract* — A numerical technique is presented for incorporating the imperfections of the contact surfaces into the RF model of capacitively coupled RF MEMS switches. The imperfect contact is caused by the roughness of the surfaces coming into contact in "down" position of the switch. The roughness was quantified by measurement and an equivalent air-gap was used to model the effect. After the inclusion of the roughness, the agreement between the theoretical predictions and the measured data was excellent.**

I. INTRODUCTION

RF MEMS switches are widely employed in communication systems [1]-[2]. Reliability of these switches depends on their design and how they are deployed. RF MEMS technology is a fairly young one compared to other MEMS devices. The speed of progress in this field will depend, partly, on how well the performance of a particular design is predicted before it is manufactured. One impediment is the lack of modeling tools that can handle imperfections in manufacturing [3]-[4]. One such imperfection is the "rough surface" contact formed between the bridge metal and the isolation layer in the "down" position of the capacitively coupled switches. The discrepancy between the measured and predicted data can be as high as %40 [5].

Fig. 1 shows a capacitively coupled MEMS switch operating on a CPW. The switch has been manufactured and measured for various widths at the Air Force Research Laboratory's Sensors Directorate. The switch structure consists of a Coplanar Waveguide (CPW) configuration on a 635μm GaAs substrate. The bridge is anchored on each end to the ground planes by metallic posts and is suspended 3μm above the center conductor. A 0.2μm thick isolation layer (silicon nitride) deposited on the center conductor below the bridge creates a capacitive contact. A pull down DC voltage of 27V is necessary to close the switch. A series of shunt switches with varying bridge widths of 25, 48, 100, 150, and 250μm have been manufactured and measured.

The switch operates in X-band and at this range, its scattering parameters can accurately be characterized by its shunt capacitance. This study is concerned with the accurate prediction of this capacitance in the presence of imperfect contact between the bottom of the bridge metal and the top of the isolation layer.

II. EXTRACTION OF THE SHUNT CAPACITANCE

The extraction of the shunt capacitance is straightforward with static numerical analysis. Finite-element method (FEM) has been employed for its flexibility in modeling small geometrical details and material variations. Prism volume elements have been employed to take advantage of the large aspect ratios involved. The capacitance is computed by integrating the static field over a closed surface enclosing the bridge. On caution here: Integrating over the center conductor of the CPW instead will include the contribution from the "distributed" capacitance of the CPW and requires more processing.

Fig.2 compares the predicted and measured scattering parameters for both the "up" and "down" positions of the 100μm wide bridge. Predicting the switch performance in the "up" position was not challenging and as shown in Fig. 2, the agreement is excellent for both S_{11} and S_{21}. In down position, the discrepancy is significant, especially in S_{21} (~4dB). In fact, as Fig.3 shows, the gap between the

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simulated and the measured S_{21} in "down" position remains significant (2.2-4dB) for all bridge widths (25-250µm).

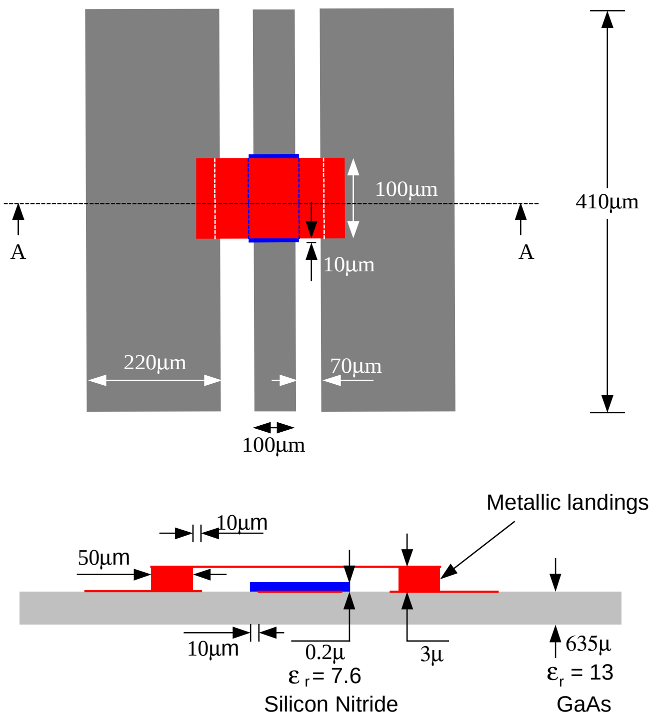

Fig. 1. Capacitively coupled MEMS switch manufactured at the AFRL at Wright-Patterson AFB.

III. Modeling Of Imperfect Contact In "Down" Position

The discrepancy in "down" position is caused by the assumption that the bridge metal and the isolation layer form a "perfect" contact. In reality, both surfaces are "rough" and the imperfect contact can be represented by an effective air gap as shown in Fig.4. In order to quantify

	Bridge is "up"		Bridge is "down"	
	Simulated	Measured	Simulated	Measured
S_{11} [dB]	-15.8	-15.0	-0.2	-1.0
S_{21} [dB]	-0.1	-0.2	-14.2	-10.0

Fig. 2. Simulated vs. measured S-parameters when the bridge is in "up" and "down" positions for 100µ wide bridge.

the thickness of this air gap, measurements of the surface roughness have been carried out. Fig.5 shows the quantitative data on the roughness of the bottom of the bridge metal derived from the measured power spectrum density (PSD). Similar data have been obtained for the top surface of the isolation layer (silicon nitride).

The introduction of the air gap introduces a series capacitance (C_{air}) in addition to that of the SiN layer (C_{SiN}). Then the total capacitance between the bridge metal and the center conductor is given by

$$C_{tot} = C_{SiN}[1+\varepsilon_{SiN}(\Delta/h)]^{-1}$$

where Δ is the thickness of the air gap and *h* is the height of the SiN layer. Based on the measured "range" and "rms roughness" data given in Fig. 6, Δ is estimated to be between 13 and 17*nm*. The S-parameters corrected for the air gap (or the roughness) are shown in Fig. 3 by "o" and "*". The agreement with the measured data is excellent. The fact that both S_{21} and S_{11} improve simultaneously proves that we have identified the main cause of the discrepancy.

IV. Conclusion

The discrepancy between the predicted and the observed scattering parameters has been removed by identifying its cause, i.e., the roughness of the contact surface. What is remarkable is that only one parameter sufficed to bridge the gap. What made it possible to identify the cause is the cooperation between the theoreticians and the practitioners. This is important especially in the field of RF MEMS switches since there are a host of design and manufacturing imperfections that render the theoretical models useless. The field is a young one and in order to expedite the research, theoretical models must address imperfections. The work presented here is one such successful attempt.

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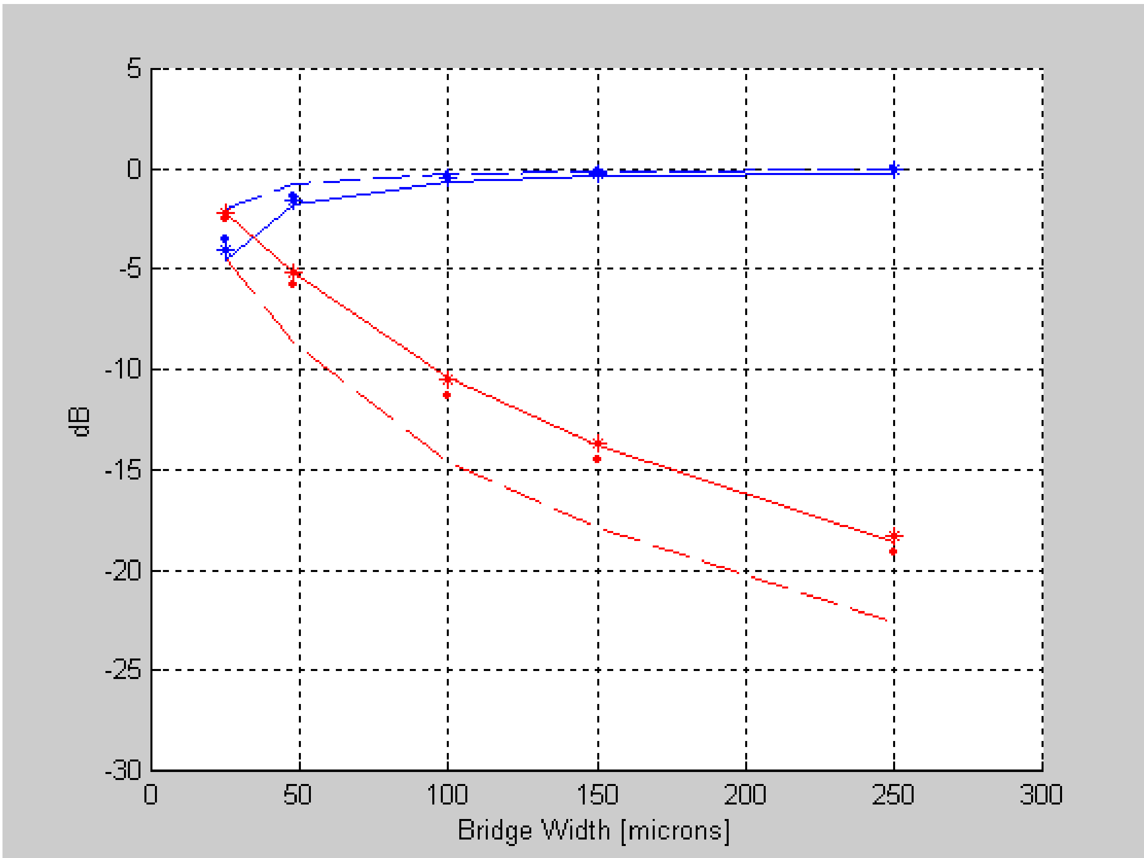


Fig. 3. S-parameters as a function of the bridge width in "down" position, ___: Measurement, -----: Simulation with no air gap, o: Simulation with 13nm air gap, *: Simulation with 17nm air gap.

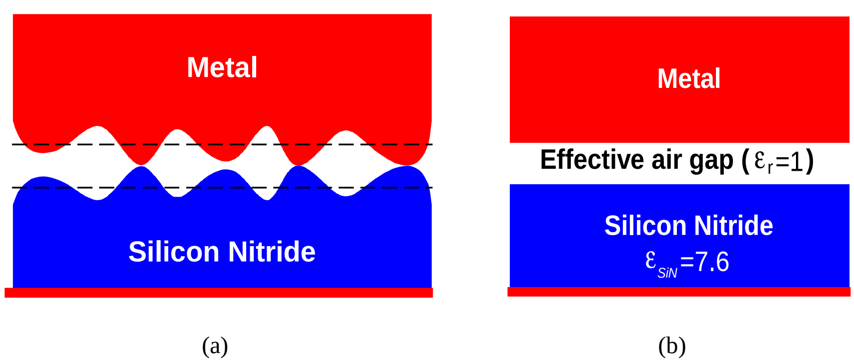
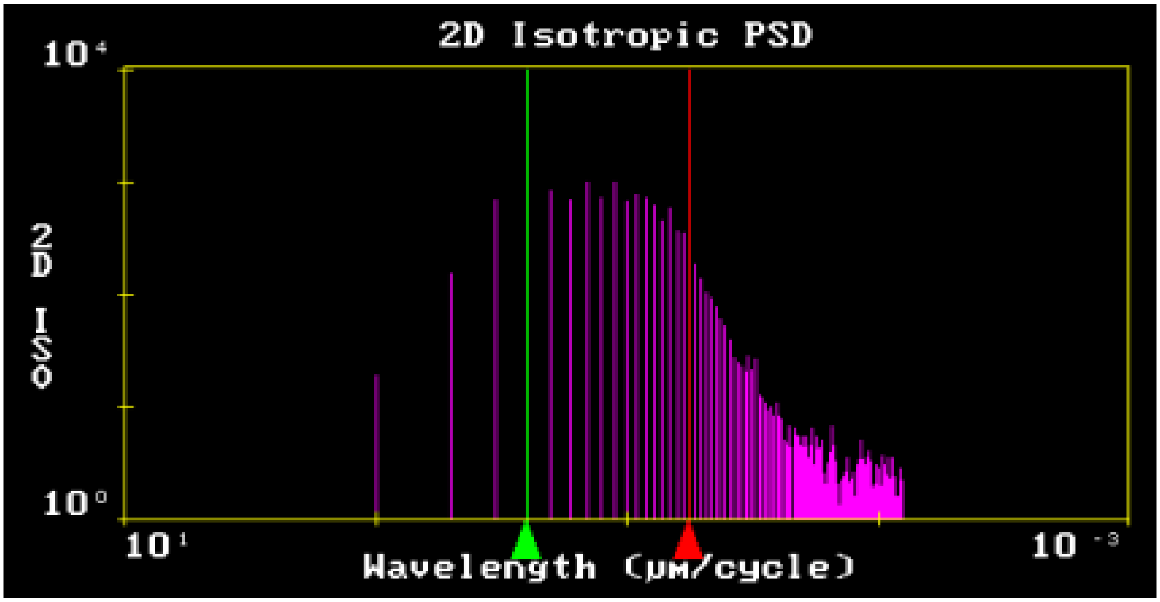
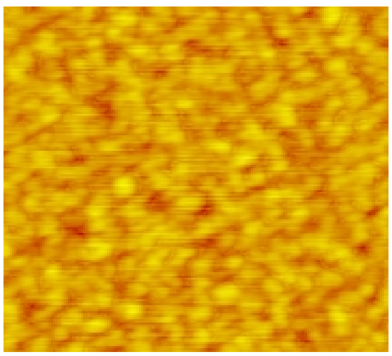
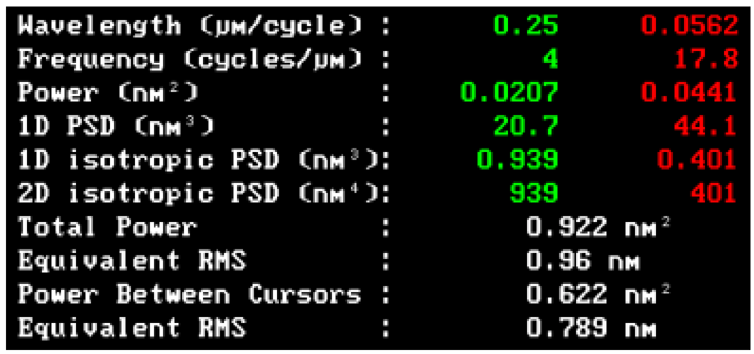


Fig. 4. Effective air gap representation of the rough contact surface, (a) actual case, (b) air gap model.

(a)







(b) (c)

Fig. 5. (a) Measured power spectrum density (PSD) of the roughness of the bottom of the bridge metal, (b) image of the rough surface, (c) quantitative roughness data derived from the measured PSD.

	Bridge Bottom	SiN
Range (nm)	8-12	15-17
RMS Roughness (nm)	0.9-1.1	1.9-2.1

Fig. 6. Measured roughness data.