저전압구동 무선통신용 MEMS 스위치

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Low Pull-in Voltage MEMS Switches for Wireless Applications

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Abstract - This paper presents the design and performance of low pull-in voltage MEMS switches for commercial cellular/PCS applications. The switches have all-metal(3 μm thick Au) movable plates over CPW(Coplanar Waveguide) transmission line. The stress gradient in a movable plate is considered in mechanical design to obtain an accurate pull-in voltage. Series *metal-to-metal* contact switches are fabricated and evaluated. Those switches exhibit the low loss(<0.2 dB @1.9 GHz) with good isolation(55 dB @1.9 GHz).

1. INTRODUCTION

RF MEMS(Micro Electro Mechanical Systems) *is emerging technology for reconfigurable* RF circuits. Recently, various kinds of RF MEMS switches have been developed and exhibit high performances [1]-[5]. The advantages of MEMS switches over conventional PIN diode or FET switches are their low insertion loss, high isolation and negligible intermodulation distortion. There are two major topologies of MEMS switches, the series metal-to-metal contact switches [4] and shunt capacitive switches [1]. The switches are usually driven electrostatically by pull-in voltage of 20-50 V range which is far beyond the operating voltage of commercial wireless hand-held devices. Pacheco presented switch structures with extremely compliant folded suspension springs and large electrostatic actuation area [2]. However the measured pull-in voltages are considerably higher than the calculated design values. One of the factors was the increase of air gap due to the warping in the suspensions. The warping in movable plates should also responsible for the increased pull-in voltage. Although a 3-Voltage actuated RF MEMS switch is reported it has a reproducibility problem [6].

This paper details the design and fabrication of MEMS switches with a low pull-in voltage. The actuation plates have circular shape for the minimization of warping in movable plates. And more precise predictions of pull-in voltages are made in the design process by considering the stress gradient through the thickness of plates. The metal-to-metal contact series switches are fabricated with 3 μm thick Au on a quartz substrate. The pull-in voltages are measured and compared with the designed value. Furthermore the increase in the pull-in voltage is analyzed using the measured warping *profile of a movable plate.*

2. MECHANICAL AND RF DESIGN

In general, most of the suspended plates with a large area in MEMS suffer from the warping due to the residual stresses and stress gradients. In MEMS switches with highly compliant flexures the stress gradients can cause significant deflections of a suspended thin-film structure even when the average stresses through the thickness of the film is zero. These stress-induced deflections make it difficult to predict the exact pull-in voltage of MEMS switches. Sometimes the edges of excessively warped plates touch substrates and impede the pull-down of plates. However, the stress gradients can be predicted and controlled, then devices with predetermined curvatures can be fabricated.

The movable plates of switches are fabricated 3 μm thick sputtered Au films. The plates e the contour shapes that closely approximated sp sections(convex curvatures) due to the negative gradients. In this case the deflections tend to in with the distance from the center of plates. I common rectangular plates with stress gradien maximum deflections occur at corners as show Fig. 1.

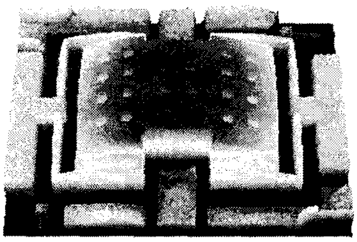


Fig. 1. An interferogram of the rectangular suspended plate with stress gradients through the thickness of a film.

Fig. 2 shows the proposed switch with a circular movable plate to minimize the deflections from stress gradients. Although the shunt capacitive switches are excellent for 10-100 GHz applications, they are not suitable for cellular/PCS applications because bulky quarter-wave($\lambda/4$) transformers are required. So the switch has a series topology with *metal-to-metal contacts.* They are fabricated on 2 μm thick Au CPW t-line with G/W/G = 12/100/12 μm(50Ω) on a 550 μm thick quartz wafer.

The movable plate is fabricated using Ti/Au sputter deposition with total thickness of 3 μm. The plates are anchored to the substrate at the end of the flexures and the anchor is connected to the ground through the bias line of a high impedance. The lines are made of high resistivity material(doped poly-Si with 500 Ω/square sheet resistance). The pull-down electrodes are placed under the movable plates and are connected to supply voltage through the bias lines. They are isolated from the plates using 1500 Å PECVD silicon oxide layers. The size of a fabricated switch is 1.5× 1.4 ㎟ .

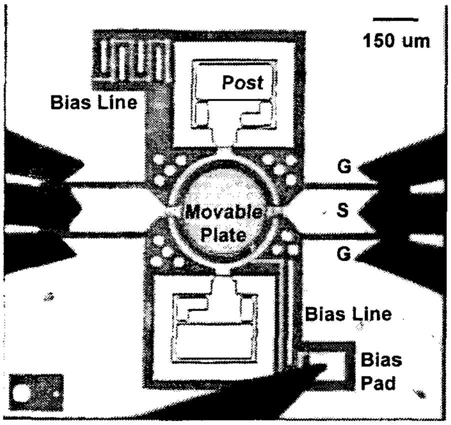


Fig. 2. A top view micrograph of a fabricated RF M switch.

Table. 1 lists design parameters of the MEMS switch shown in Fig. 2. r_a is the radius of movable plate, t is the thickness of the plate, A_c is the contact area, and V_{pi} is the pull-in voltage. E is Young's modulus of the movable plate, and σ_I is the stress gradient of the plate. There are two different parameters, g_o and g_c which are the air gaps under the center and under the contact area of a movable plate respectively. k_z is the vertical spring constant of flexures, w is the width of flexures, and s is the spacing between the plate and the flexures. Fig. 3 shows the simulated profile of a warped movable plate using ANSYS®. The calculated deflections show that the height of the contact area is lower than the reference height of the anchored support by 2.3 μm. And the maximum deflection on the movable plate is 2.7 μm. To satisfy the isolation requirement g_c can be determined as shown in table. 1. Then w and s, the dimensions of flexures, are designed to meet the pull-in voltage, V_{pi}.

Table. 1. Design parameters of MEMS switch show Fig. 2.

r_a [μm]	170	E [GPa]	80
t [μm]	3.0	σ_I [MPa]	-35
A_c [μm²]	30×30	g_o [μm]	3.0
V_{pi} [V]	8.0	k_z [N/m]	6.97
Isolation [dl	> 40	w [μm]	20
g_c [μm]	0.7	s [μm]	20

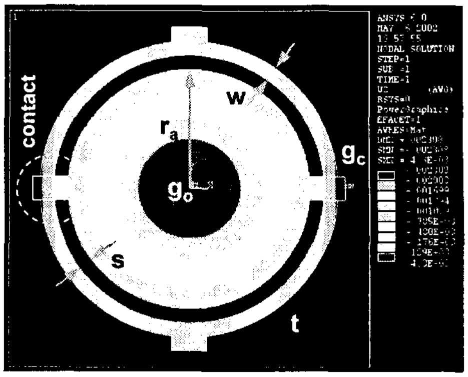
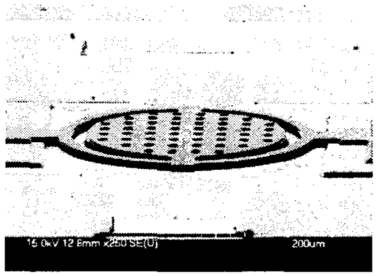


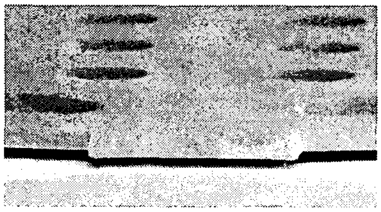
Fig. 3. A simulated movable plate with the vertical stress gradient(σ_I = -35 MPa) using ANSYS.

3. RESULTS AND DISCUSSION

SEM micrograph of a fabricated switch is shown in Fig. 4. Fig. 4(a) shows an entire device and the magnified view of a contact region is shown in (b). The suspended plate above CPW t-line is clearly seen in the figure.



(a)



(b)

Fig. 4. SEM micrograph of A fabricated MEMS swit (a) the entire switch can be seen. A close up view contact region is shown in (b).

The measurement of pull-in voltages are performed using an 8510C vector network analyzer and an external dc power supply. The pull-in voltages are measured for 81 samples and averaged 18.3 V with a standard deviation of 2.8 V as shown in Fig. 5. Although there is the small variation in the voltages the average value is much higher than the calculated designed one(18.3 V and 8.0 V respectively). To trace the increase of the pull-in voltage the warping profile is measured using an interferometric microscope (WYKO NT2000) and shown in Fig. 6. The measured maximum deflection is 2.3 μm, the difference of gap between g_o and g_c., which shows good agreement with the predicted value 2.7 μm. But there are considerable increases in gaps (0.5 μm in g_o and 0.9 μm in g_c) to cause the higher pull-in voltages.

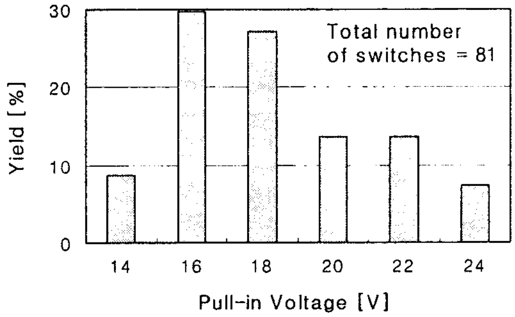
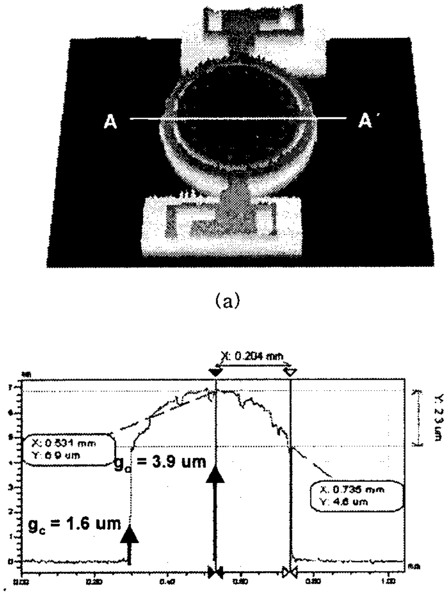


Fig. 5. Measured pull-in voltages of an array of 81 fabricated MEMS switches.



(a)

(b)

Fig. 6. Measurement of a warped movable plate (a) The interferogram of a measured switch (b) A cross-sectional profile of A-A′.

The RF performances are characterized using GGB Picoprobe 150 μm pitch coplanar probes and GGB CS-5 SOLT calibration standard with an 8510C vector network analyzer. Fig. 7 shows the insertion loss and reflection of ON-state and the isolation of OFF-state. The switch possess an insertion loss of better than 0.2 dB up to 4 GHz and an isolation of over 40 dB up to 10 GHz due to a low OFF-state capacitance of 1.5 fF. The switch achieves an insertion loss of 0.17 dB, an isolation of 55.6 dB, and a reflection of 32.6 dB at 1.9 GHz PCS band.

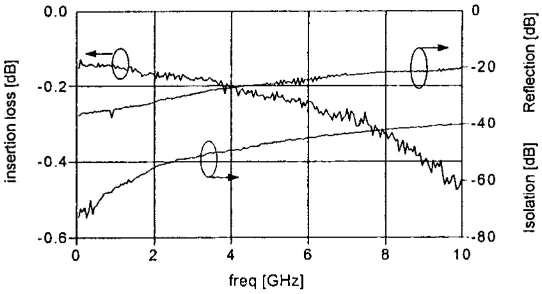


Fig. 7. Measured RF performances of MEMS switch.

4. CONCLUSIONS

RF MEMS switches of series metal-to-m contact for cellular/PCS applications are design fabricated. The switch has a circular movable and the warping of the plate with a stress grad predicted to obtain the precise pull-in voltag fabricated switches. The RF measurement show these switches possess low insertion loss and isolation up to 10 GHz.

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[참 고 문 헌]

[1] C. L. Goldsmith, Z. Yao, S. Eshelman, and D. Denniston, "Performance of low-loss RF MEMS capacitive switches," *IEEE Microwave Guided Wave Lett.*, vol. 8, pp.269-271, Aug. 1998.

[2] S. P. Pacheco, P. B. Katehi, and C. -T. Nguyen, "Design of Low Actuation Voltage RF MEMS Switch," *2000 IEEE MTT-S Digest*, pp.165-168.

[3] J. B. Muldavin and G. M. Rebeiz, "High isolation MEMS shunt swtiches: part 1: Modeling," *IEEE Trans. Microwave Theory Tech.*, vol.48, pp.1045-1052, Jun. 2000.

[4] J. B. Muldavin, and G. M. Rebeiz, "All-Metal High-Isolation Series and Series/Shunt MEMS Switches," *IEEE Microwave and Wireless Components Lett.*, vol. 11, pp.373-375, Sep. 2001.

[5] R. E. Mihailovich, M. Kim, J. B. Hacker, E. A. Sovero, J. Studer, J. A. Higgins, and J. F. DeNatale, "MEM relay for reconfigurable RF curcuits," *IEEE Microwave Wireless Compon. Lett.*, vol. 11, pp.53-55, Feb. 2001.

[6] J.-H. Park, K. T. Kang, N. W. Kang, C. W. Kim, C. M. Song, C.-Y. Cheon, Y. Kwon, and Y.-K. Kim, "A 3-voltage actuated micromachined RF switch for telecommunications applications", *The 11th International Conference on Solid-State Sensors and Actuators Transducers' 01*, pp.1540-1543, 2001.