Available online at www.sciencedirect.com
ScienceDirect
Procedia Engineering 5 (2010) 1462–1465
Procedia Engineering
www.elsevier.com/locate/procedia

Proc. Eurosensors XXIV, September 5-8, 2010, Linz, Austria

A Novel Low Cost Spring-Less RF MEMS Switch Prototype

K. S. Kiang, H. M. H. Chong, and M. Kraft

Nano Research Group, School of Electronics and Computer Science, University of Southampton, SO17 1BJ, UK

Abstract

This work reports on the fabrication process and measurements of a novel radio frequency microelectromechanical system (*RF MEMS*) capacitive shunt switch prototype with a mechanically unconstrained armature. The prototype is fabricated in a low cost process based on a printed circuit board (*PCB*) bonded to a glass slide. The minimum actuation voltage (V_{act}) of the prototype is 93V, with a switching time taken from the down to up state (T_{rise}) and from the up to down state (T_{fall}) of 105ms and 26ms respectively.

Keywords: PCB MEMS; Low Cost; Electrostatic actuation

1. Introduction

Most RF MEMS switches use a mechanically suspended armature. The electrostatic actuation force needs to overcome the spring force leading to typical V_{act} between 20V-80V for with switching heights of 2-5µm [1]. Much work has been conducted to reduce the actuation voltage by relaxing the mechanical spring constant of the switch design or by incorporating hybrid actuation mechanism to generate more actuation force during switching. The main methodology in mechanical spring constant reduction revolves around complex spring design or employing less rigid material for the armature. Some research groups have also demonstrated the possibility of a RF MEMS switch without the mechanical spring in order to reduce the actuation voltage [2]. The fabrication process of these design are often complex and challenging.

This paper presents a RF MEMS switch prototype based on the concept of a spring-less armature [3]. To overcome the complex fabrication process and reduce prototyping cost, a novel fabrication process based on techniques used in PCB MEMS [4] and microfluidic devices [5] was developed. In order to demonstrate the spring-less RF switch concept, a scaled up RF MEMS switch design in the range of millimetres coupled with relatively large electrostatic actuation gaps was realised; its fabrication and test results are described in the following.

2. Fabrication

The process flow is shown in Figure 1. To realise the prototype, a standard microscope glass slide (Agar Scientific, UK) was used as first substrate. It was rinsed in acetone and isopropanol (IPA) to remove any organic

1877-7058 © 2010 Published by Elsevier Ltd.
doi:10.1016/j.proeng.2010.09.392

residues, followed by dehydration bake at 200°C for 30 minutes using a convectional oven. Next, a 10nm layer of chrome and a 200nm layer of gold were deposited using Edwards A306 e-beam evaporator. Acrylic dry film resist, Ordyl AM 130, was used to pattern the actuation electrodes. The resist was laminated onto the chrome-gold (CrAu) layer using a Mega Electronics A4 laminator (Cambridge, UK) heated to 110°C with a laminating speed of 0.15 m min^{-1}. A positive film acetate mask was used for patterning the resist. The resist is exposed for 20 seconds, using a Mega Electronics vacuum ultraviolet (UV) exposure unit that is equipped with 6×15 W bulbs. The resist is then developed for 40 seconds using a 0.8% sodium carbonate solution in an ultrasonic bath. The metal layers were then etched using Rockwood Gold etchant and Rockwood Chrome etchant. The dry photo resist is then removed using acetone and IPA, followed by a 10 minutes fuming nitric acid clean. A 200nm thick layer of sputtered tantalum pentoxide (Ta_2O_5), is then deposited on the metal structure using the Oxford Instrument RF Sputtering machine as a layer of dielectric material. The contacts pads are opened using reactive ion etching (RIE) of Ta_2O_5 as shown in Figure 1(b).

A high frequency application PCB is selected as the material for the second substrate. The design of the 50Ω coplanar waveguide (0.3mm/1.8mm/0.3mm) is fabricated on a 1.52mm Roger's RO4003® board (Printed Wiring Technologies Ltd, UK), cladded with a 35µm copper layer. A 200nm thick layer of Ta_2O_5, is then deposited on the metal structure. A layer of photoresist is used to cover the bond pad of the PCB during the deposition process and later removed using acetone and IPA after the deposition process as depicted in Figure 1(d).

The armature (8mmx4mm) and spacer of the prototype is formed by etching through a 525µm thick low resistivity silicon wafer. First, the wafer is spun with a 10µm layer of AZ9260. It is then patterned with design of the armature and spacer. The patterned wafer is mounted onto a carrier wafer using crystal bond before through etch process, utilising a STS Pegasus DRIE machine. Finally, the spacer and armature is ready to be picked up from the carrier wafer.

A layer of 20µm thick epoxy dry film resist, Ordyl SY320, is laminated on the silicon spacers. This layer of resist will act as the bonding adhesive between the spacer and glass slide. It also forms part of the capacitive gap for the armature to operate within. The laminated spacers are then manually aligned onto the glass slide. The aligned stack is then sandwiched and clamped by two other glass slides and bulldog clips. They are then cured in a 150°C oven for 4 hours with a ramping rate of approximately 5°C/min.

Sub Miniature version A (SMA) are soldered onto the PCB before the silicon armature is manually placed across the CPW of the PCB. A layer of adhesive is applied to the bonding surface of the PCB and spacer. The total capacitive gap of 40µm is determined by the thickness of the SY320 and adhesive layer used. The glass slide is optically aligned to the PCB using the pre-defined alignment marks and bonded together as illustrated in Figure 1(g).

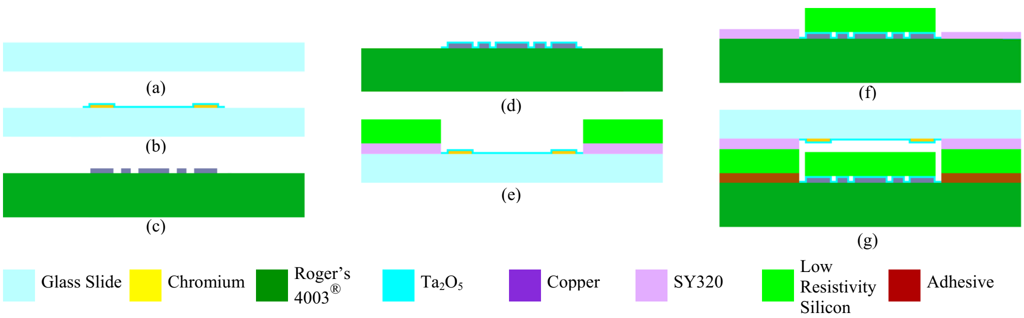
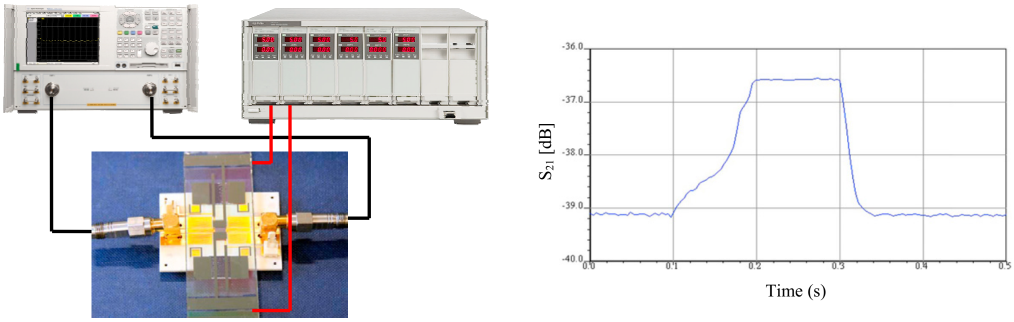


Figure 1 : (a) Microscope glass slide (b) Deposit Chrome-Gold (CrAu) stack and pattern top actuation electrodes followed by deposit Tantalum pentoxide (Ta_2O_5) and pattern dielectric layer (c) Rogers RO4003® PCB with fabricated CPW (d) Deposit Ta_2O_5 and pattern dielectric layer (e) Insert the spacer stack on glass slide (f) Place silicon armature across the transmission line on the PCB (g) Apply a layer of adhesive and bond the glass slide stack to the PCB.

3. Measurements and Discussion

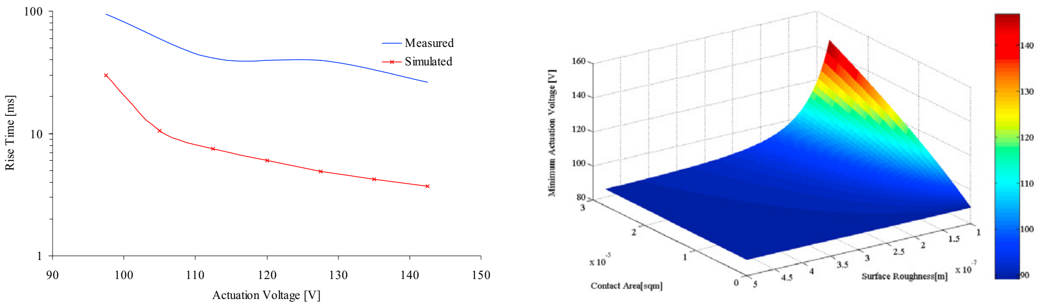
Figure 2(a) shows the measurement setup and the prototype. The setup consists of an Agilent E8631A network analyzer and Agilent 66100 DC power supply. The switch is connected with a *SMA* connector to interface the CPW and the network analyzer. The actuation voltage to move the armature up is generated by switching the DC power supply. When the DC voltage is switched off from the top electrode, the armature is released back due to the earth's gravitation force.



(a) (b)

Figure 2 : Measurement setup for initial testing for rapid prototype device using an Agilent E8361A network analyser and Agilent 66100 DC power supply. (b) Measured S_{21} signal of the rapid prototype switch using an actuation voltage of 97.5V at a RF frequency of 5GHz.

The switching characteristic shown in Figure 2(b) is measured by actuating the armature with a ±97.5V DC pulse at 2Hz. Then a time sweep mode is applied to the network analyzer at a fixed input frequency of 5GHz. The rise and fall of the transmission signal S_{21} of the CPW indicates the switch's on-off characteristic. When the V_{act} is applied, the S_{21} changes from -39.2dB (*Down state*) to -36.6dB (*Up state*). The T_{rise} and T_{fall} is 94ms and 26ms respectively.



(a) (b)

Figure 3 : Measured rise time of the rapid prototype device as a function of the actuation voltage. (b) Calculated minimum actuation voltage considering the effects of surface roughness, contact area for a Tantalum Pentoxide–air–silicon material system as well as the earth's gravitational force acting on the armature.

Figure 4(a) shows measured T_{rise} values of the prototype for different V_{act} (*±97.5V to ±142.5V*), showing faster switching time with higher V_{act}. Although the measured T_{rise} is slower than the simulated value by a factor of 10, the trends for both simulated and measured data show T_{rise} decreases when actuation voltage increases. The minimum actuation voltage for the prototype is 93V. The discrepancy in the two sets of data is attributed to the inability to accurately model the damping dynamic of the actual armature movement, as the works on variable damping coefficient are generally derived from the linearised Reynolds Equation.

A simple assumption on the minimum actuation voltage can be made for such devices, i.e., in order for the armature to be pulled upwards, the actuation force applied must be greater than the gravity acting on the armature as well as the surface adhesion forces present between the armature and dielectric layer. Therefore the minimum actuation voltage can be expressed as:

$$V_{act(\min)} = \sqrt{\frac{2\left(F_{mg} + F_{contact}\right)g_o^2}{\varepsilon_o A_{ap}}} \quad (1)$$

where $F_{contact}$ is the surface adhesion force and F_{mg} is the gravitation force acting on the armature, g_o is the initial air gap, ε_o is the permittivity of free space and A_{ap} is the total area of the actuation pad. The surface adhesion is attributed to Van De Waals forces between the contact surfaces of dielectric layer and armature [6]. It is given as:

$$F_{contact} = \frac{H_{i,j,k} A_{contact}}{6\pi D^3} \quad (2)$$

where $H_{i,j,k}$ is the Hamaker constant, $A_{contact}$ is the total contact area between the armature and dielectric layer and D is considered as the distance between the contact surfaces of the two materials. The subscript i,j,k denotes the type of material system. D can also be considered as surface roughness of the contact surface. The Hamaker constant of Silicon-Air-tantalum pentoxide material system is 4.49×10^{-19}J.

The surface roughness at the contact region of the armature and the transmission line are examined using the white light interferometer on the MSA-400 Micro System Analyser. The surface roughness of the silicon armature is expected to be a few nanometres while the average roughness of the transmission line topography is approximately 280nm. The calculated minimum actuation voltage is 92V for g_o=40µm which agrees within 5% of the measured value found in the experiment.

4. Conclusion

The process flow for rapid prototype device was introduced, requiring two masks and six major fabrication steps. The fabrication of the rapid prototype switch was successful, proving to be a simple and cost effective way of verifying the concept of a RF MEMS switch with a mechanically unconstrained armature.

The measured S_{21} response of the fabricated prototype switch during actuation was presented. The dynamic response of the switch have also been characterise with the minimum actuation voltage being identified at ±93V for a capacitive gap of 40µm. The effects of the surface adhesion forces acting on the armature of the switch were discussed in relation to the overall contact area and the surface roughness of the contacting area. From the experimental data presented, the concept of spring-less RF MEMS switch was proven as viable.

Acknowledgements

The author would like to acknowledge the financial supported rendered by the Commonwealth Scholarship Commission, U.K.

References

[1] G. M. Rebeiz And J. B. Muldavin, RF MEMS Switches and Switch Circuits, IEEE Microwave Magazine, 2(2001), pp 59-71
[2] S. C. Shen et. al., Broadband Low Actuation Voltage RF MEMS Switches, Tech Dig Gaas Ic Symp 2000. Seattle, pp. 161-164
[3] K. S. Kiang et. al, Development Of A Low Actuation Voltage RF MEMS Switch, Proc. Eurosensors Xxii Conference 2008, Dresden, pp. 1462-1465
[4] R. Ramadoss et al., Rf-Mems Capacitive Switches Fabricated Using Printed Circuit Processing Techniques, J. Microelectromech Syst., 15(2006), pp. 1595-1604
[5] M. E. Sandison And H. Morgan, Rapid Fabrication Of Polymer Microfluidic Systems For The Production Of Artificial Lipid Bilayers, J Micromech Microengineering, (7)2005, pp. S139-S144
[6] D. Bachmann And C. Hierold, Determination Of The Pull-Off Forces And Pull-Off Dynamics Of An Electrostatically Actuated Silicon Disk,. J. Microelectromech Syst., 17(2008), pp. 643-652