단결정 실리콘 RF MEMS 스위치의 제작 및 특성 평가

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Fabrication and Characterization of Single Crystalline Silicon (SCS) RF MEMS Switch

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Abstract - This paper deals with a single crystalline silicon (SCS) RF MEMS switch for telecommunication system applications. The proposed SCS switch was fabricated using a silicon-on-glass (SiOG) process and its performances in terms of RF responses, switching time, lifetime were characterized. The proposed SCS switch consists of movable plates, mechanical spring structures, which are composed of robust SCS, resulting in mechanically good stability. The measured actuation voltage was 30 V, and with this applied voltage, the insertion loss and isolation characteristics were measured to be 0.05 and 44.6 dB at 2 GHz, respectively. The measured switch ON and OFF time were 13 and 9 μs, respectively. The lifetime of the fabricated switch was tested. Even after over 1 billion cycles repeated ON/OFF actuations, the switch maintained its own characteristics.

1. INTRODUCTION

RF MEMS is enabling technology to provide some superior characteristics such as low-loss, negligible power consumption, higher linearity over semiconductor-based electrical passives [1, 2]. It is for this reason that a number of researchers direct their efforts to develop the RF MEMS devices instead of their electrical counterparts. Especially, RF MEMS switch is one of most importance elements for telecommunication systems and the related researches have been widely exploring to meet the increased user's demands.

The RF MEMS switch has mainly employed various thin film metallic structures as moving parts thanks to well-established surface micromachining technology [3, 4]. The metallic switches also show good RF performances up to high frequency region, however, structural deformation according to their residual stress and thermal effect during high temperature fabrication process is still remained as serious obstacle in aspect of a fabrication yield and a device reliability.

The use of the SCS as the switch structure is one clear solution to overcome the drawback of the conventional metallic MEMS switches, and this is due to its superior heat characteristics and near zero residual stress, resulting in higher device reliability. With this reason, recently, several groups focus on development of SCS-based RF MEMS switches [5].

In this paper, the SCS MEMS switch is designed and fabricated using the SiOG process, and its electrical and mechanical performances are characterized.

2. DESIGN

Figure 1 shows the schematic view of the proposed direct-contact type SCS MEMS switch. All the components of the switch were designed and simulated with aids of commercially available electromagnetic simulators, ADS, IE3D and HFSS. The switch structure consists of moving plates, which also act as top electrodes and meander-type mechanical springs. These are composed of robust SCS, resulting in high mechanical stability. Especially, high resistivity silicon was chosen to minimize the silicon effect on RF characteristics of the switch. The CPW transmission line is formed on the bottom glass substrate. The signal line is initially separated between input and output ports, thus, the switch initially stays at OFF state. With the applied actuation voltage, the contact part makes an electrical contact between the separated signal lines, thus, the switch goes to the ON state. Total size of the designed switch is 1.1 mm × 0.7 mm.

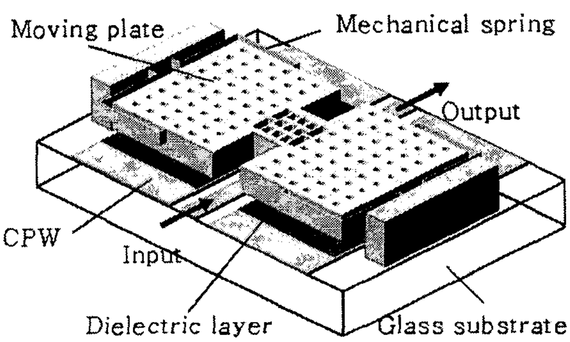
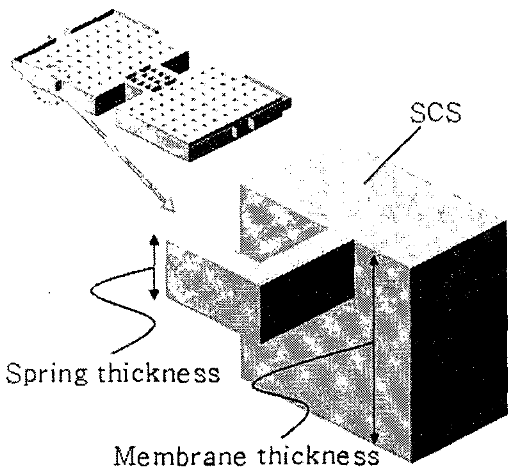
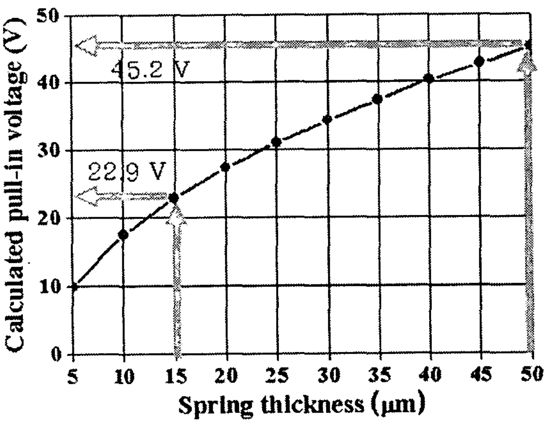


Figure 1. *Schematic view of the proposed SCS MEMS switch.*

Figure 2 shows the schematic view of the mechanical spring and pull-in voltage calculation results as a function of spring thickness. As shown in Figure 2 (a), the spring thickness is partially lowered by 2 step DRIE process to reduce the actuation voltage since the spring thickness is one of important factors influence on the spring constant. However, the switch membrane thickness is maintained for fabrication stability because thin membrane can be easily destroyed during fabrication process. The designed membrane and spring thickness were 50 and 15 μm, respectively. The downsized spring thickness from 50 to 15 μm made it possible to reduce the pull-in voltage from 45.2 to 22.9 V in a MATLAB simulation as shown in Figure 2 (b).



(a)



(b)

Figure 2. *Schematic view of the mechanical spring and pull-in voltage calculation, (a) schematics, and (b) calculated pull-in voltage as a function of the spring thickness.*

3. FABRICATION

The proposed SCS switch was fabricated using the SiOG process with silicon DRIE and anodic bonding techniques. Figure 3 illustrates a fabrication process for the designed SCS switch. At first, the 3 μm-thick CPW line is formed on the glass substrate (Corning #7740) using a gold electroplating process under the current density of 4 mA/cm^2 (Figure 3 (a-1)). Then, the silicon dioxide layer is deposited and patterned on each ground plane to prevent the electrical short between top and bottom electrode at the switch ON state (Figure 3 (a-2)). In the silicon part, first process is to form a cavity to determine the initial gap between top and bottom electrode. The dielectric layer and contact material are patterned in turns on the etched cavity (Figure 3 (b-1)). Then, second DRIE process is performed to partially reduce the spring thickness maintaining the membrane thickness (Figure 3 (b-2)). The pre-fabricated glass and silicon wafers are bonded together by means of the anodic bonding process under the temperature of 380 ℃ and the applied voltage of 800 V. Then, the silicon part of the bonded wafer is lapped and polished to reach the designed membrane and spring thickness (Figure 3 (c)). Final switch structure is released using the DRIE process (Figure 3 (d)).

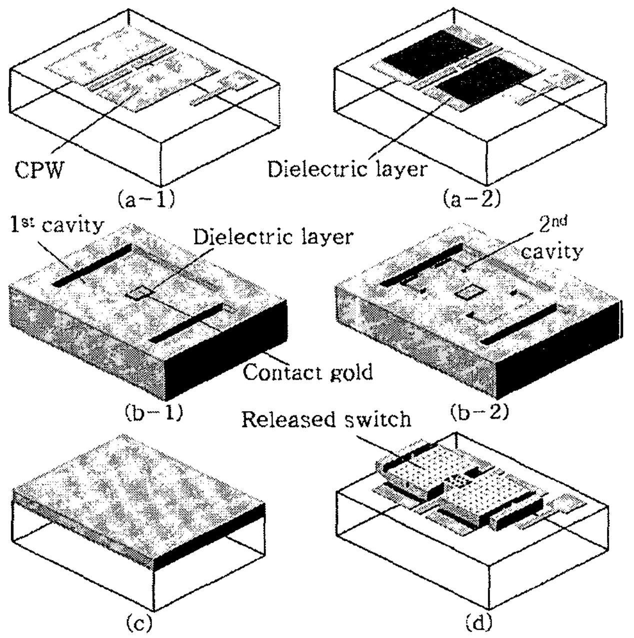
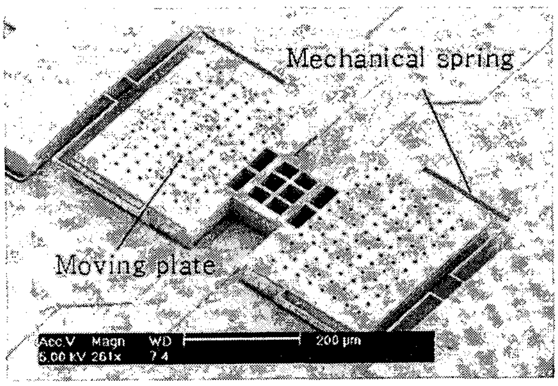
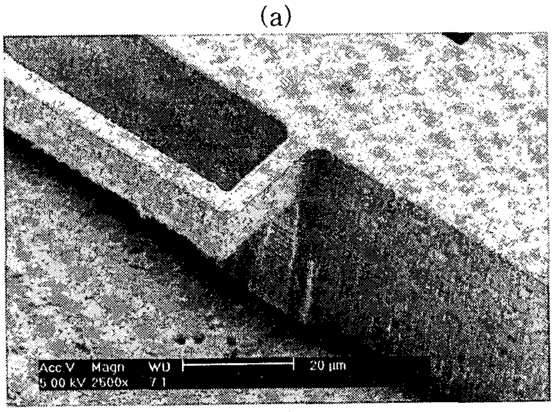


Figure 3. *Fabrication process, (a-1) CPW electroplating, (a-2) dielectric layer patterning, (b-1) first cavity formation, dielectric layer and contact material patterning, (b-2) second cavity formation, (c) anodic bonding, lapping and CMP, and (d) final structure release.*

Figure 4 shows the scanning electron microscope (SEM) images for the fabricated SCS switch. Any structural deformation on the fabricated switch was not observed, and this proved that the SCS-based device is robust against whole fabrication circumstance and mechanically reliable. The enlarged view of the mechanical spring is shown in Figure 4 (b). The fabricated membrane and spring thickness were 53 and 17 μm, respectively.



(a)



(b)

Figure 4. *Fabrication results, (a) whole view of the fabricated SCS switch, and (b) enlarged view of the mechanical spring.*

4. MEASUREMENT

RF performances of the fabricated SCS switch were measured using an HP 8510C network analyzer with frequency ranges from DC to 40 GHz. Figure 5 shows the measured RF responses. The measured results show good agreement with the simulated ones. The insertion loss and isolation characteristics were measured to be 0.05 and 44.6 dB at 2 GHz, respectively. In this case, the pull-in and actuation voltages were 23 and 30 V, respectively.

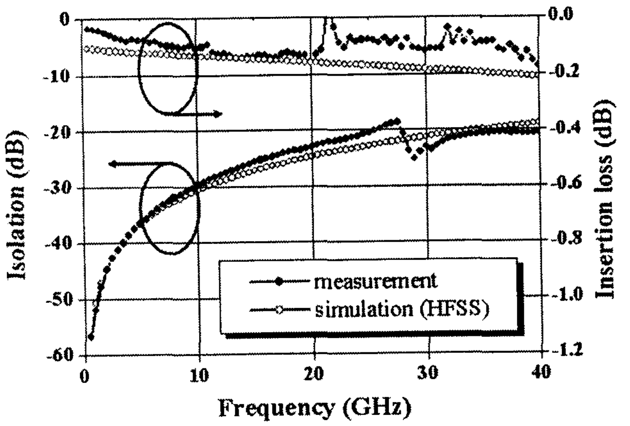
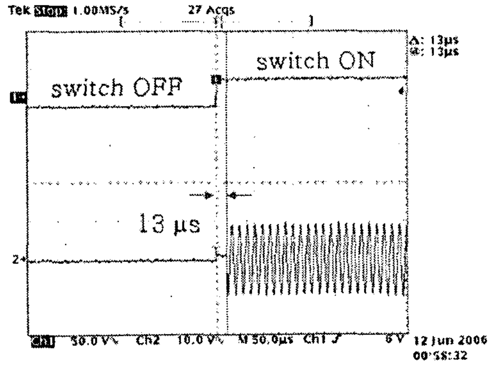
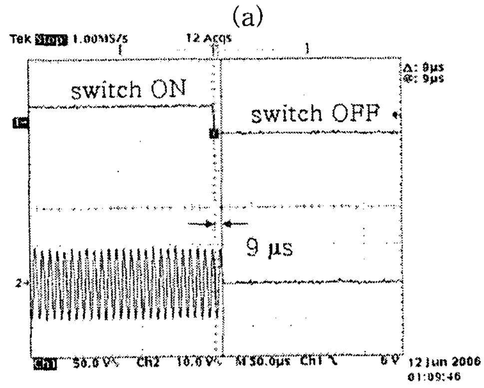


Figure 5. *Measured RF responses of the fabricated SCS switch with HFSS simulation results.*

The switching response time was measured. In this case, the actuation signal was square wave having a frequency of 1 Hz and a magnitude of 35 V, while the input signal was sine wave having a frequency of 100 kHz and a magnitude of 10 V_{p-p}. The measured switch ON and OFF time were 13 and 9 μs, respectively, as shown in Figure 6.



(a)



(b)

Figure 6. *Measurement results of the switching speed, (a) ON, and (b) OFF time.*

The mechanical lifetime test for the fabricated SCS switch was performed. The square wave actuation signal having a frequency of 5 kHz and a magnitude of 35 V was applied using the function generator. Figure 7 shows the actuation signal (upper trace) and the transmitted signal from input to output port (lower trace) for the lifetime test.

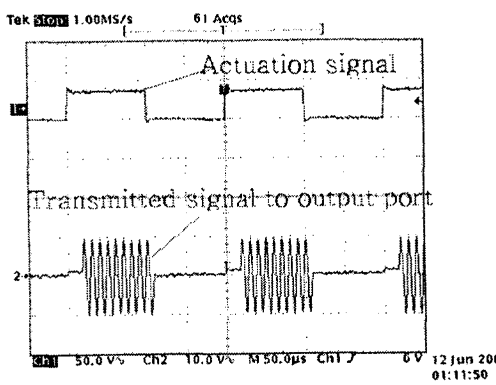


Figure 7. *Actuation signal and transmitted signal from input to output for the lifetime test.*

The mechanical lifetime test was performed up to over 1 billion cycles. In this case, when the test was stopped, the switch was still functional. Figure 8 shows the measured RF responses before and after over 1 billion cycles repeated actuations. As shown in Figure 8, even after over 1 billion cycles repeated actuations, there were no remarkable changes of RF responses. This means that the fabricated switch is mechanically stable.

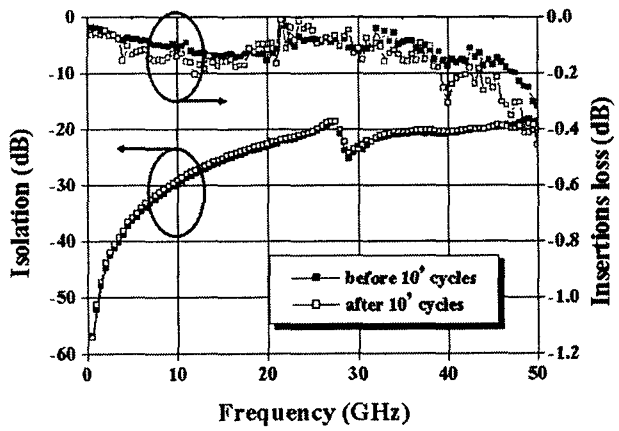


Figure 8. *The measured RF responses for the fabricated switch before and after the mechanical lifetime test.*

5. CONCLUSION

SCS RF MEMS switch was designed and fabricated using the SiOG process. The switch could be fabricated without any structural deformations thanks to robust SCS. The electrical and mechanical performances for the fabricated switch were measured. With the actuation voltage of 30 V, the insertion loss was less than 0.05 dB, and isolation was higher than 44 dB at 2 GHz, respectively. The switching ON and OFF speed were measured to be 13 and 9 µs, respectively. The mechanical lifetime test was performed. Even after over 1 billion cycles repeated actuations, remarkable change was not observed on its RF characteristics. These results clearly show that the proposed SCS switch has a great potential in the telecommunication system applications.

ACKNOWLEDGEMENT

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