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차세대 이동통신시스템에 적용을 위한 저전압구동의 RFMEMS 스위치

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Low Voltage Operated RFMEMS Switch for Advanced Mobile System Applications

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Abstract - A low voltage operated piezoelectric RF MEMS in-line switch has been realized by using silicon bulk micromachining technologies for advanced mobile/Wireless applications. The developed RF MEMS in-line switches were comprised of four piezoelectric cantilever actuators with an Au contact metal electrode and a suspended Au signal transmission line above the silicon substrate. The measured operation dc bias voltages were ranged from 2.5 to 4 volts by varying the thickness and the length of the piezoelectric cantilever actuators, which are well agreed with the simulation results. The measured isolation and insertion loss of the switch with series configuration were -43dB and -0.21dB (including parasitic effects of the silicon substrate) at a frequency of 2 GHz and an actuation voltage of 3 volts.

1. Introduction

Most of studies on RFMEMS switches have focused on the electrostatic actuation mechanism because of being free from restraint of materials, low power consumption, and simplicity of their structures and fabrication. However, electro-statically actuating RF MEMS switches exhibit a very high operation voltage of 20~50V [1]. These high operation voltages cause the electric charging into the dielectric layer formed on top of the transmission line of the RFMEMS switches, which degrades the reliability of RF MEMS switches. Moreover, additional DC-DC converter chips are necessary for the mobile handset applications using a low driving voltage of 3 V. Accordingly, much researches are now being focused to obtain low voltage operation by lowering spring constants of hinges [2-3] or by utilizing electro magnetic actuation [4]. The electromagnetic RF MEMS switches developed for low voltage operation has been consumed much higher power than electrostatic and piezoelectric switches. Piezoelectric actuation is a promising mechanism for realizing the RFMEMS switches with low voltage operation and power consumption keeping the strong advantages of the RFMEMS switches. However, piezoelectrically actuating RFMEMS switches with good performance have not been reported due to the complexity and difficulty of fabrication.

In this paper, fully integrated RFMEMS in-line switches with extremely low operation voltage are investigated by utilizing four cantilever piezoelectric actuators and silicon bulk micromachining technology. Two different switching configurations, resistive and capacitive, are also studied and compared for finding out the better geometry of the piezoelectric RFMEMS switches.

2. Design and Fabrication

The proposed RFMEMS switches were comprised of a piezoelectric cantilever actuator, a contact electrode, and suspended transmission line. If a voltage is applied to the piezoelectric cantilever actuator with a contact electrode, it is deflected upward to contact the isolated transmission lines. If the voltage is withdrawn, deflection is recovered because of the elasticity of a cantilever resulting in the opening of the switch. A schematic diagram of the proposed RFMEMS switch with piezoelectric capacitor actuator is shown in Fig.1 in which geometric parameters are also denoted. As shown in Fig.1, the proposed RF MEMS switch is comprised of a piezoelectric cantilever, a silicon substrate, a contact part, and RF signal lines.

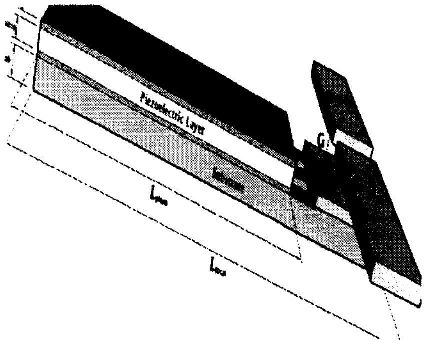


Fig.1. A schematic drawing of proposed piezoelectrical cantilever actuator of RFMEMS switch.

If a voltage is applied to piezoelectric cantilever, the piezoelectric film attempts to expand or contract in its plane by piezoelectricity. As a result, the deflection of a cantilever occurs by the constraint of substrate. When the gap G between the contact of a cantilever and opened signal line is closed, the switch is closed. If the voltage is withdrawn, deflection is recovered because of the elasticity of a cantilever resulting in the opening of the switch. The width of the cantilever is fixed to 90um. The operating voltage of the switch having certain $L_{piezo}$is corresponding to the voltage at which the curve intersects with gap G.. The length of cantilevers and the gap between contact and signal line is fixed to 120 um and 3um, respectively. The operation voltage of RF MEMS switches will be expected to approximately 4 volts at a length of 120um and a gap of 3um.

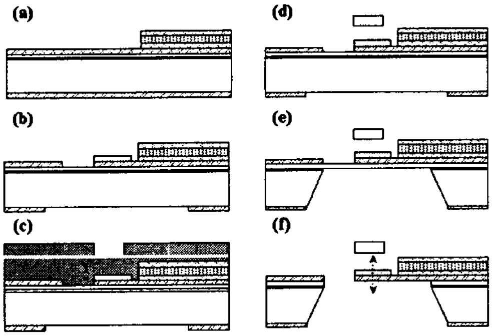
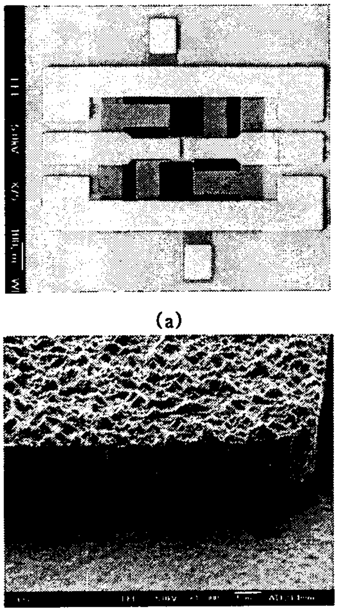


Fig.2. Fabrication sequences of piezoelectrically actuating RF MEMS switches : (a) PZT cantilever deposition and patterning , (b) frontside and backside nitrides patterning & contact part deposition and patterning, (c) sacrificial layer and Au seed deposition and signal line definition , (d) signal lines plating and sacrificial layer removal, (e) Si bulk micromachining, and (f) cantilever releasing.



(a)

(b)

Fig.3. SEM picture of (a) the fabricated RFMEMS in-line switches with series configuration and with suspended CPW ground planes and (b) close up view of a Au contact electrode and suspended signal transmission line.

The detailed fabrication steps of the proposed piezoelectrically actuating RFMEMS switches are described in Fig. 2. A low stress silicon nitride wafer was used as substrate for the deposition of piezoelectric capacitors. Lead zirconate titanate ($Pb(Zr,Ti)O_3$, PZT) is used as a piezoelectric material because of its excellent piezoelectric constants. In the case of the capacitive type switches, Au/AlN/Au capacitor structure was formed as a contact and the capacitor was connected to the bottom electrode for grounding. Fig.3(a) shows the SEM picture of the fabricated piezoelectric RFMEMS in-line switches with serial configurations and suspended CPW ground planes. Fig.3(b) shows the SEM picture of a close up view of the Au contact electrode and the suspended signal transmission line of the fabricated piezoelectric RFMEMS in-line switches with serial configurations and suspended CPW ground planes.

3. Measurements and Discussions

DC characteristics of the fabricated RFMEMS in-line switches were measured by using LCR meter and their RF characteristics were measured by using an HP 8510C Network Analyzer and CASCADE MICROTECH ground-signal-ground high frequency coplanar probes with 150um pitch size. After calibration on open, short, and 50 ohm resistor standards, the RF measurement was performed. In this measurement, the parasitics of the probe pads were not de-embedded. Fig.4 shows the RF performance characteristics of the fabricated RF MEMS in-line switch with serial configuration and with suspended CPW ground planes. As shown in Fig.4, It exhibits very high isolation characteristics of -43dB and low insertion loss of -0.21dB at a frequency of 2GHz as 3 volts are applied. Actuation voltages of the switches with the same geometries were slightly different due to the non-uniformity of thickness and piezoelectric property of their cantilever capacitors.

The switching time of the RFMEMS switch is measured at the rising and falling actuation of the cantilever actuator, as shown in Fig.5. V1 is the applied square wave voltage signal to control the cantilever actuator and V2 is the measured voltage in output signal line when sinusoidal wave voltage is applied to input signal line. Therefore, the difference between V1 and V2 is equal to the switching time when the fabricated switch is on and off. It has a switching on time of 4u seconds at the rising actuation and off time of 20u seconds at the falling actuation. The switching time is similar to that of the previously reported electrostatic RFMEMS switches and is much shorter than that of magnetic or thermal switches. The cycling test of the fabricated RFMEMS in-line dc contact switch is conducted. The measured results are obtained using a function generator at a bipolar pulse frequency of 2Hz and a pulse voltage of 4V. There is little change of the RF performances before conducting 10^5 cycles. However, fatigue-induced degradation in insertion loss was observed over 10^5 cycles. Therefore, the authors are intensively studying on the improvement of reliability by changing contact material configurations.

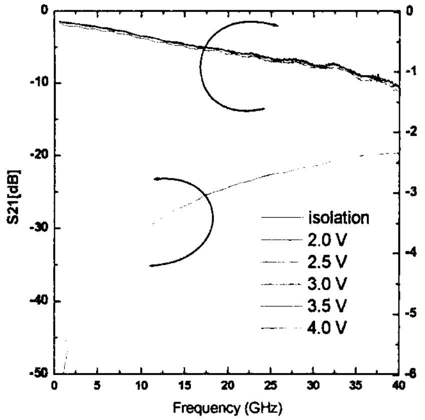


Fig.4. Measured RF performance characteristics of the fabricated RFMEMS in-line switches with series configuration with suspended CPW ground planes as varying the actuation voltages.

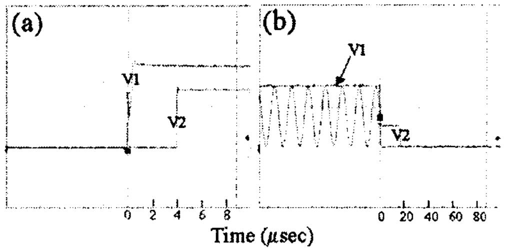


Fig.5. Switching time measurements (a) at rising and (b) falling actuations.

4. Conclusions

Fully integrated RFMEMS in-line dc contact switches on high resistivity silicon substrates have been designed, fabricated, and characterized for advanced mobile/wireless communication systems. Piezoelectric actuators were utilized for obtaining extremely low voltage operation. The measured isolation and insertion loss of the dc contact switch with serial configuration are -43dB and -0.21dB at a frequency of 2GHz, respectively. Also, the fabricated switch has a switching on time of 4u seconds at the rising and off time of 20u seconds at the falling. These integrated RFMEMS switches are promising for developing re-configurable RF systems, smart antenna systems, RF FEM (Front-End Module) operating at multi band/mode, switched filter banks for wireless mobile handset applications due to their low operation voltage and compatible fabrication sequences with silicon CMOS RF circuitry.

[References]

[1] Z. Yao, S. Chen, S. Eshelman, D. Denniston and C. Goldsmith, "Micromachined low loss microwave switches", *J. MEMS*, vol. 8, p129, 1999.

[2] S. Pacheco and Linda P.B. Katehi, "Micromechanical K-Band Switching Circuits", *European Microwave conference*, p45-48, June 1998.

[3] J. Y. Park, G. H. Kim, K. W. Chung, and J. U. Bu, "Electroplated RF MEMS capacitive switches", *IEEE conference on MEMS* , p639-644, January 2000.

[4] URL: http://www.magfusion.com

[5] C. H. J. Fox, X. Chen, H. W. Jiang, P. B. Kirby, S. McWilliam, "Development of micromachined RF switches with piezofilm actuation", *Proceedings of SPIE*, vol. 4700, p40-49, 2000

[6] E. F. Crawley and J. Luis, "Use of piezoelectric actuators as elements of intelligent structures", *AIAA Journal*, vol. 25, p1373-1385, 1987.