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RF MEMS Switch on Poly-Silicon Substrate*

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Abstract: The improvements of the design and the compatibility with silicon IC of RF MEMS switch are presented. The compatibility with silicon IC is realized by dielectric isolation technology, and the decrease of the pull voltage of the switch is done by etching some holes on the metal membrane. The preliminary test results are as follows: C_{off} and C_{on} are 0.32pF, 6pF, respectively; the pull down voltage is about 25V. The package of the RF MEMS switch is done by micro-stripline, and the isolation and the insertion loss are 35dB, 2dB, respectively at 1.5GHz; the switching speed is about 3μs by oscilloscope.

Key words: RF MEMS switch; pull down voltage; electrostatic force; metal membrane
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1 Introduction

Compared with p-i-n switch, RF MEMS switch has low insertion loss and high isolation for eliminating the use of semiconductor p-n and metal semiconductor junctions, significantly reducing the resistive losses in the device, so it will be the fundamental base upon which radar and communication systems are developed, and will replace the p-i-n switch[1~4]. However, there are some drawbacks in compatibility with silicon IC, actuation voltage, and reliability. For example, Yao *et al.*'s switch is made on the high resistivity substrate (high resistivity silicon; sapphire and GaAs wafer), the actuation voltage of the switch is about 50V[3]. Zhu *et al.*'s switch is manufactured by using high-resistivity silicon of 3000Ω·cm as substrate[5]. But the resistivity of substrate of silicon IC is very low (1~10Ω·cm) for speedily transferring heat, so these RF MEMS switches are not compatible with silicon IC. Zhang *et al.*'s polysilicon micromachined switch is made on the dielectric polysilicon substrate, and compatible with silicon IC by dielectric isolation technology[4], but the polysilicon micromachined switch has high insertion loss because it is difficult to reduce the polysilicon film resistivity close to metal resistivity. In this paper, the improvements on the design and compatibility with silicon IC of RF MEMS switch were introduced, the polysilicon film was replaced with Al film to decrease the insertion loss, and a RF MEMS switch was produced. The switch was made on the dielectric polysilicon by dielectric isolation technology, the compatibility with silicon IC was completed[4,6,7], the reliability was improved by bridge capacitance micro mechanical metal membrane switch structure, and the actuation voltage

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was decreased by etching some holes on the metal membrane. It is easy for the RF MEMS switch to be integrated monolithically with silicon IC for radar and communication system applications. The RF performance of the RF MEMS switch was measured, the isolation and the insertion losses were 35dB, 2dB, respectively at 2GHz, and the isolation had the advantage over the pin switch. So the RF MEMS switch could be the basis for developing RF switch systems with IC for radar and reconfigurable antenna applications.

2 Design and fabrication

The RF MEMS switch is an electrostatic actuation switch, and realizes switch function by electrostatic actuation, as showed in Fig. 1. As it is shown, the switch utilizes an air-bridge design, in which a metal membrane hangs over the bottom electrode, separated by an air gap. When the switch is in the up-state, the RF signal passes the bottom metal electrode without blockage, as shown in Fig. 1 (a). When an electrostatic potential is applied to the bottom electrode, the attractive electrostatic force pulls the metal

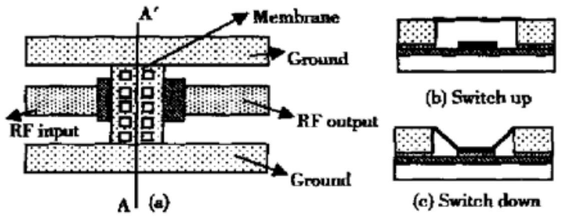

Fig. 1　Schematic of the RF MEMS switch

membrane down onto the bottom dielectric film, the dielectric film serves to prevent the metal membrane from DC shorting, and provides a low impedance AC path between the two contacts, the RF signal would be shorted by the low impedance AC path, and the RF signal is blocked, as shown in Fig. 1(b). When the electrostatic potential is removed, the membrane returns to its original position due to the restoring movement. The electrostatic force applying to the metal membrane is given by[4]

$$f(x) = \frac{V^2}{2(d - v(x))^2} \quad (1)$$

where $v(x)$ is the deflection of the metal membrane, d is the distance between the metal membrane and the bottom electrode, V is the potential of applying to the bottom electrode. When the metal membrane is not actuated, the air dielectric between the two contacts exhibits a very low capacitance, given by

$$C_{\mathrm{off}} = \frac{1}{\frac{h_{\mathrm{D}}}{\varepsilon_{\mathrm{D}} A} + \frac{h_{\mathrm{a}}}{\varepsilon_0 A}} \quad (2)$$

where C_{off} is the capacitance of the switch in the off state, ε_{D} and ε_0 are the dielectric constants of air and dielectric material used, respectively, h_{D} is the dielectric layer thickness, h_{a} is the air gap between the membrane and dielectric layer when the switch is in the up-position, and A is the contact area between the metal membrane and bottom electrode. When the switch is actuated, the metal membrane-dielectric-bottom electrode sandwich possesses significant capacitance (C_{on}), described as

$$C_{\mathrm{on}} = \frac{\varepsilon_{\mathrm{D}} A}{h_{\mathrm{D}}} \quad (3)$$

The goals for the design of the RF MEMS switch are low bottom potential voltage, low insertion loss, and high switch speed. The bottom potential is reduced by etching some holes on the metal membrane because of the reduction of the elastic force of the metal membrane. Reducing the insertion loss is done by replacing silicon substrate by dielectric polysilicon substrate in order to eliminate the parasitical capacitance of silicon substrate, and the compatibility with IC is easily completed. The switch circuitry consists of RF MEMS switch which has an impedance of 50Ω that matches the impedance of the system. The design of the RF MEMS switch is as follows: the metal membrane is 280μm long and 300μm wide, the bottom electrode with width of 180μm is in the middle of two ground lines, and the spacing is 50μm.

The fabrication process of the RF MEMS switch is as follows: the wafers with resistivity of 7～10Ω·cm are used as substrates. A 1μm thick insulating thermal oxide is first grown on the substrate, pattern for the switch substrate is defined, the silicon is etched with KOH, and the depth is 50~ 60μm, followed by 500μm dielectric polysilicon deposited. The silicon area for making IC and the dielectric polysilicon area for making the switch are obtained by grinding/ polishing process, and thus the substrate for fabricating the switch is prepared. The process for making the RF MEMS switch is as follows: one micrometer of insulating thermal oxide is grown on the substrate, pattern for the bottom electrode is etched by RIE, followed by 1μm thick insulating thermal oxide, and the groove is done so that the metal membrane can suspend the bottom electrode at a certain high level. A 1.2μm thick Al-Si layer is sputtered, and patterned to define the bottom electrodes, followed by a 150nm PECVD silicon nitride dielectric layer deposited and patterned to define the electrode via-holes. A polyimide sacrificial layer is spun on and patterned, which followed by a 2μm thick Al layer is sputtered and patterned to form the metal pad as well as the metal membrane. The sacrificial layer is then removed by wet etching. Finally, the switch is released using an ethanol drying technique.

3 Results and discussion

On the basis of above fabrication process, the RF MEMS switch was fabricated. To decrease the pull down voltage, the RF MEMS switch was modified by etching some holes on the metal membrane, and showed in Fig. 2. The RF MEMS switch was measured by TE2819 capacitance instrument. The preliminary results are as follows: C_{off} and C_{on} are 0.32pF, 6pF, respectively; the pull down voltage is about 25V, as showed in Fig. 3. The ratio of the off-state capacitance to on-state capacitance is about 20, less than the designed ratio, which may be affected by the packaging and measuring conditions. The low pull down voltage is suitable for the RF applications, the fabrication process is compatible with silicon IC process, so it is easy for the RF MEMS switch to be integrated monolithically with IC for radar and communication systems.

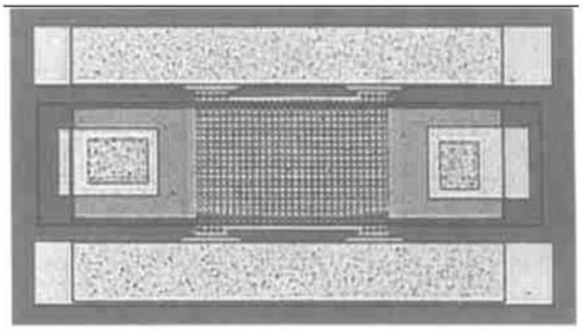

Fig. 2 Photograph of the RF MEMS switch

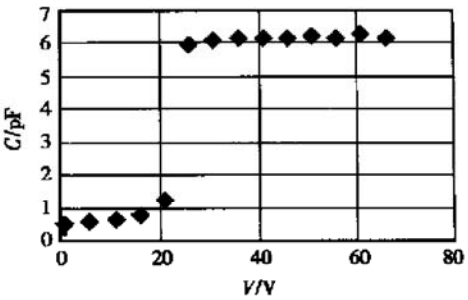

Fig. 3 Capacitance versus actuation voltage of the RF MEMS switch

The package of the RF MEMS switch was done by micro-stripline, and measured by HP8753C network analyzer. The isolation of the RF MEMS switch is 35dB at 1.5GHz, showed in Fig. 4, and is more than that of the pin switch, which is usually less than 20dB. The insertion losses of the RF MEMS switch is 2dB at 1.5GHz, showed in Fig. 5, and is more than that of the designed which is less than 0.2dB. It is only close to that of the pin switch, which is usually 1 ~ 1.5dB. By analyzing the results, it is found that the insertion loss of the isolation capacitance and the micro-stripline affects enormously the insertion loss of the RF MEMS switch, and the isolation capacitance and the micro-stripline will be optimized by selecting the high frequency performance capacitance and optimized structure of the micro-stripline.

The measured switch speed is shown in Fig. 6. The top trace of the oscilloscope shows the corresponding drive signal with 40kHz, 20V. The modulated 200MHz signal is shown at the bottom trace. The modulated signal shows a time delay of 3μs from the

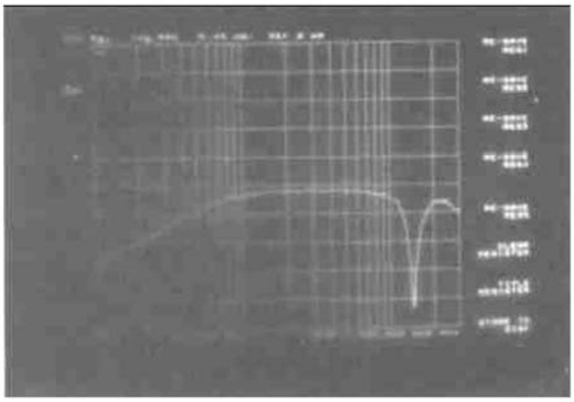

Fig. 4 RF performance of the RF MEMS switch for off state

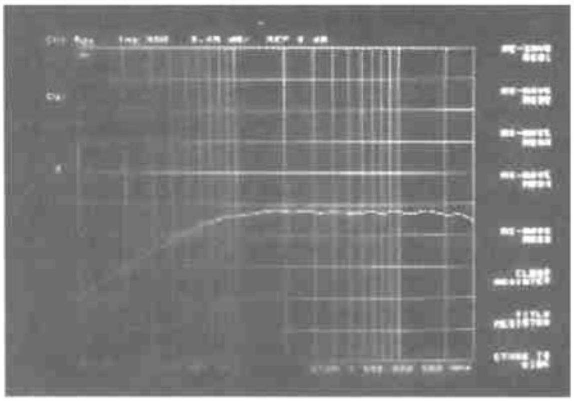

Fig. 5 RF performance of the RF MEMS switch for on state

switching-off state to the switching-on state. This time delay is defined as the switch speed of a switch, so the switch speed is about 3μs.

4 Conclusion

A RF MEMS switch is fabricated, demonstrating that the pull down voltage is decreased to 25V, and the fabrication process is compatible with silicon IC process. The package of the RF MEMS switch is done by micro-stripline, and the RF performance of the RF MEMS switch is measured. As a result, the isolation and the insertion losses are 35dB, 2dB, respectively, the switch speed is 3μs, and the isolation has the advantage over the pin switch. So the RF MEMS switch

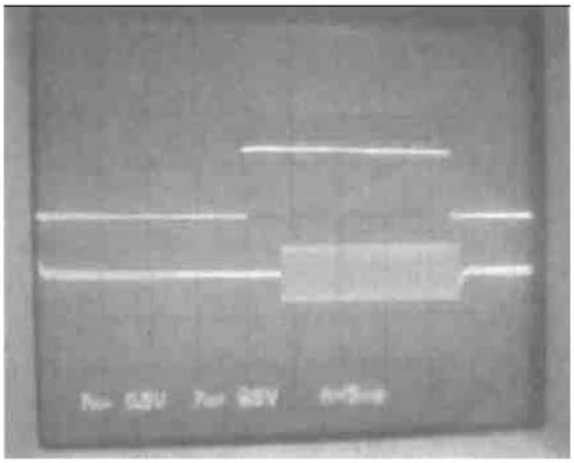

Fig. 6 A switch speed measurement of RF MEMS switch The control signal is shown at the top trace and the modulated signal is shown at the bottom trace.

could be a basis for developing RF switch systems with IC for radar and reconfigurable antenna applications.

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多晶硅衬底上的 RF MEMS 开关*

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摘要: 在微机械开关与硅 IC 工艺设计和兼容方面进行了改进, 获得了一种可与 IC 工艺兼容的 RF MEMS 微机械开关. 采用介质隔离工艺技术把这种 RF MEMS 微机械开关制作在绝缘的多晶硅衬底上, 实现了与 IC 工艺兼容; 采用在金属膜桥的端点附近刻蚀一些孔的优化方法, 降低了 RF MEMS 微机械开关的下拉电压. 用 TE2819 电容测试设备测试开关的电容, 测得开关的开态电容、关态电容和致动电压分别为 0.32pF、6pF 和 25V. 用 HP8753C 网络分析仪对 RF MEMS 微机械开关进行了 RF 特性测试, 得出 RF MEMS 微机械开关在频率 1.5GHz 下关态的隔离度为 35dB, 开态的插入损耗为 2dB, 用示波器测得该开关的开关速度为 3μs.

关键词: 微机械开关; 下拉电压; 静电引力; 金属膜

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