DC—20GHz RF MEMS Switch

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Abstract: The design and fabrication of a RF MEMS switch is reported for the first time in China. The switching element consists of a thin metallic membrane, which has the metal-isolator-metal contact and a capacitive shunt switch as single-pole single-throw. When an electrostatic potential is applied to the membrane and the bottom electrode, the attractive electrostatic force pulls the metal membrane down onto the bottom dielectric. The switch characteristics, such as insertion loss and isolation, depend on the off and on-capacitance. The test results are as follows: the pulldown voltage is about 20V; the insertion loss is less than 0.69dB from DC to 20GHz in the up-state; the isolation is more than 13dB from 14 to 18GHz and 16dB from 18 to 20GHz in the down-state.

Key words: MEMS; RF switch; wideband

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1 Introduction

A capacitive membrane RF MEMS switch has many advantages, compared with FET or PIN diode switch. First, the contacting and spreading resistance associated with ohmic contacts are eliminated, thus low conductivity films are used to fabricate the MEMS switch with the ultra-low loss during the RF transmission. Second, the removal of *I-V* nonlinearity associated with semiconductor junction significantly improves the distortion characteristics. Third, it can work in the wideband frequency. Fourth, the MEMS switch can be easily integrated with traditional MMIC circuits. Its disadvantage is low switching speed (generally, the order of microsecond), which limits its wide application in the high-speed circuits, although GaAs FET switching speed can reach nanosecond.

2 Design

The geometry of the capacitive metal membrane shunt switch described in this paper is shown in Fig. 1. The switch consists of a thin metallic membrane suspended over the dielectric film deposited on the top of a bottom electrode, as shown in Fig. 1(a). When the switch is in the up-state, the RF signal passes the bottom metal with ultra-low loss. When an electrostatic potential is applied between the membrane and the bottom electrode, the attractive electrostatic force pulls the metal membrane down onto the bottom dielectric, as shown in Fig. 1(b). The switch is in the down-state at this time. The RF signal would be rejected. So, the switching is controlled by the electrostatic force. The switch characteristics such as insertion loss and isolation depend on the off and on-capacitance.

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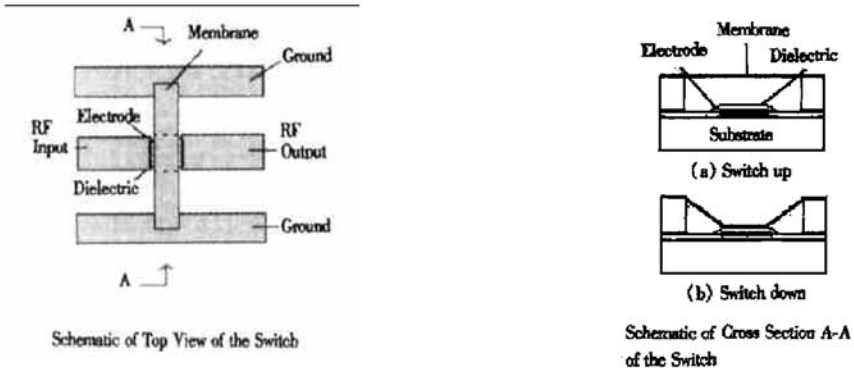

FIG. 1 Schematic of the Switch

When the membrane is unactuated, the air dielectric between the two contacts exhibits a very low capacitance, C_{off}, which is given as

$$C_{off} = \frac{1}{\frac{h_D}{\epsilon_D A} + \frac{g_0}{\epsilon_0 A}} \quad (1)$$

where C_{off} is the capacitance of the switch in the off-state, ϵ_D and ϵ_0 are the respective dielectric constants of air and dielectric material used, h_D is the dielectric layer thickness, g_0 is the air gap between the membrane and the dielectric layer when the switch is in off-state, and A is the overlap area between the bottom electrode and the membrane.

When the switch is actuated, the metal-dielectric-metal possesses a significant capacitance C_{on}, described as

$$C_{on} = \frac{\epsilon_D A}{h_D} \quad (2)$$

The off/on ratio of the switch can be approximately calculated by using the following equation:

$$\frac{C_{on}}{C_{off}} = \frac{\epsilon_D g_0 + \epsilon_0 h_D}{\epsilon_0 h_D} \quad (3)$$

The pulldown voltage is given as

$$V_P = \sqrt{\frac{8k}{27\epsilon_0 W w} g_0^3} \quad (4)$$

where k is the effective spring constant of the membrane, W is the center conductor width of CPW (coplanar waveguide), w is the membrane width. And k approximates to

$$k = \frac{32Et^3w}{L^3} + \frac{8\sigma(1-\nu)tw}{L} \quad (5)$$

where E is Young's modulus of the membrane material, t is the membrane thickness, L is the membrane length, σ is the residual tensile stress in the membrane, and ν is Poisson's ratio for the membrane material.

The CPW transmission line is calculated for an impedance of 50Ω by using Series IV Linecalc. The transmission line is 125μm in width. The spacing between the ground line and the signal line is 80μm.

3 Fabrication

The fabrication process of RF MEMS switch is as follows: A high resistivity (3000Ω·cm) silicon wafer is used as a substrate → One micrometer of the insulating silicon oxide is grown on the substrate → A layer of Wolfram or Ti-Au is sputtered and patterned to define the bottom electrodes → A 180nm LPCVD silicon nitride dielectric layer is deposited and patterned to define the electrodes → A 4μm-thick Au layer (or Al layer) is electroplated for the metal posts and the transmission line → A photoresist sacrificial spacer layer is spinning coated and patterned → The Au membrane (or Al) layer is sputtered → The photoresist sacrificial spacer is removed to release the membrane.

4 Results and Discussion

Figure 2 shows a SEM photograph of the switch sample. The membrane switch is about $480\mu m \times 500\mu m$ in size.

The typical off-capacitance is 18fF and the on-capacitance is 2.85pF. The ratio of available on-impedance to off-impedance of the switch is the ratio of the on-capacitance to off-capacitance, which is more than 150 and sufficient for the switching signal requirement at microwave frequency.

Figure 3 shows the S-parameters of the switch tested by using the WILTRON 369B Network Analyzer.

The results are as follows: the pulldown voltage is about 20V, the insertion loss is less than 0.69dB from DC to 20GHz in the up-state, the isolation is more than 13dB from 14 to 18GHz and 16dB from 18 to 20GHz in the down-state.

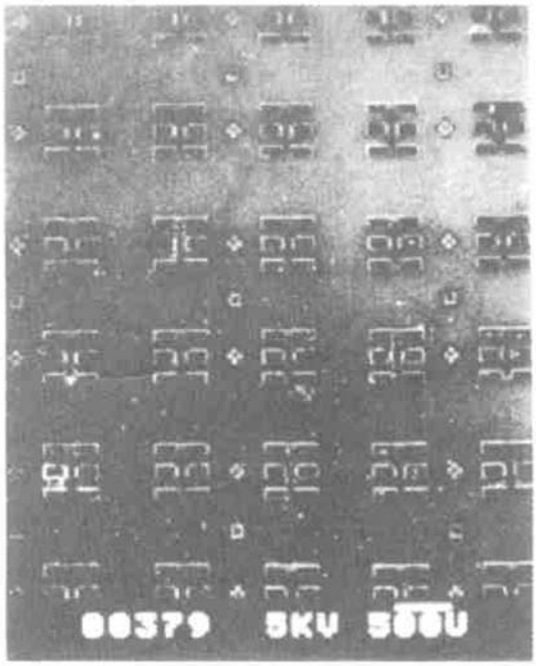

FIG.2 SEM Sample Photograph

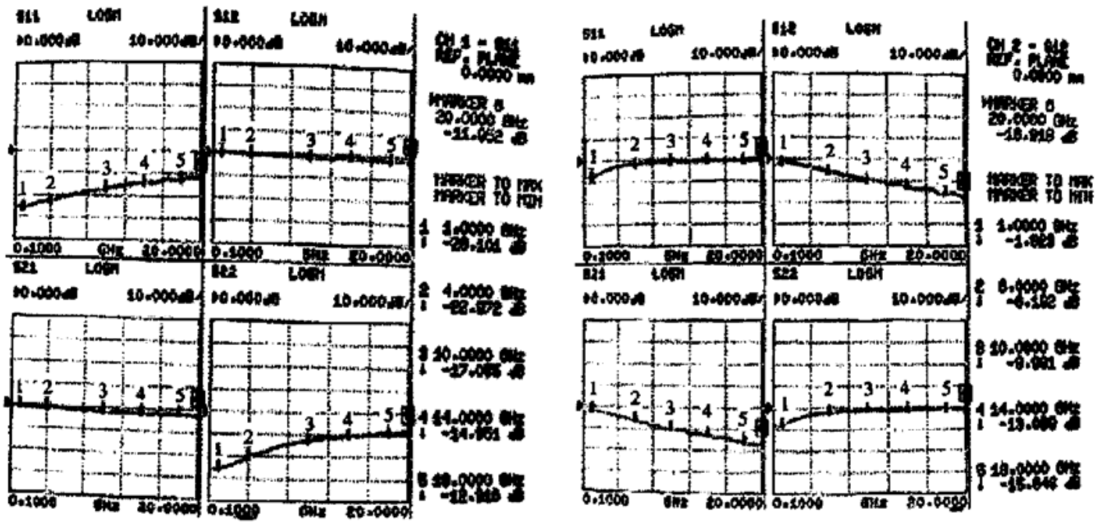

FIG.3 S-parameters of Switch in (a) up-State and (b) down-State

5 Conclusion

RF wideband MEMS switch has been fabricated. The results demonstrate that its switch performances depend on the off and on-capacitance. The tested parameters of MEMS switch from DC to 20GHz are given as follows: the insertion loss is less than 0.69dB, the isolation is more than 13dB from 14 to 18GHz and 16dB from 18 to 20GHz.

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DC—20GHz 射频 MEMS 开关

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摘要: 描述了 DC—20GHz 射频 MEMS 开关的设计和制造工艺. 开关为一薄金属膜桥组成的桥式结构, 形成一个单刀单掷 (SPST) 并联设置的金属-绝缘体-金属接触. 开关通过上下电极之间的静电力进行控制, 其插入损耗及隔离性能取决于开态和关态的电容. 测试结果如下: 射频 MEMS 开关驱动电压约为 20V, 在"开"态下 DC—20GHz 带宽的插入损耗小于 0.69dB; 在"关"态下在 14—18GHz 时隔离大于 13dB, 在 18—20GHz 时隔离大于 16dB. 本器件为国内首只研制成功的宽带射频 MEMS 开关.

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