Design of Millimeter-Wave DC-Contact Series MEMS Switch

HOU Zhi-hao[1], ZHU Feng[1], YU Yuan-wei[1,2,3], ZHU Jian[1,2]

(1. Nanjing Electronic Devices Institute, Nanjing 210016, China;
2. National Key Laboratory of Monolithic Integrated Circuits and Modules, Nanjing 210016, China;
3. School of Electronic Science and Engineering, Nanjing University, Nanjing 210032, China)

Abstract: A DC-contact series RF MEMS switch for millimeter-wave application was presented. To obtain high isolation in millimeter wave band, the in- and out-port of the switch was designed as long and thin shape which reduced the coupling capacitance between the in- and out-port. To obtain high contact stability and reduce pull-down voltage, an improved crab-shape structure was used as the bridge structure. The RF MEMS switch was fabricated with gold surface microfabrication process in the Nanjing Electronic Devices Institute. The measurement result showed that the insertion loss was −0.3 dB at 30 GHz, and the isolation was −20 dB at 30 GHz. In the range of 20—40 GHz, the insertion loss was better than −0.5 dB, and the isolation was better than −20 dB.

Keywords: RF MEMS switch; DC-contact; millimeter wave

毫米波串联接触式 MEMS 开关的设计

侯智昊[1]，朱　锋[1]，郁元卫[1,2,3]，朱　健[1,2]

(1. 南京电子器件研究所，南京 210016；
2. 微波毫米波单片集成电路和模块重点实验室，南京 210016；
3. 南京大学电子科学与工程学院，南京　210032)

摘　要:设计并制造了一种应用于毫米波波段的串联接触式 RF MEMS 开关.为了在毫米波波段获得较高的隔离度，在 RF MEMS 开关的输入、输出端口使用细长型的接触端，以降低输入、输出端口的耦合电容.为了获得较高的接触可靠性并降低开关的开启电压，RF MEMS 开关上电极结构使用蟹形梁结构.该 RF MEMS 开关利用南京电子器件研究所微纳米研发部的全表面工艺制备.所获得的 RF MEMS 开关，在 30 GHz 频率下，其插入损耗为−0.3 dB，隔离度为−20 dB.在 20~40 GHz 的频率范围内，其插入损耗均优于−0.5 dB，隔离度均优于−20 dB.

关键词:RF MEMS 开关;串联接触式;毫米波

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Radio-frequency micro-electro-mechanical (RF MEMS) switches are receiving increasing attention in the RF community, especially for millimeter-wave applications. Its excellent RF performance makes RF MEMS switch an attractive alternative to traditional RF switch used in millimeter-wave application[1].

The RF MEMS switch covers the application range from direct current (DC) to 300 GHz. Nowadays, most RF MEMS switches for millimeter-wave applications are in the configuration of capacitive shunt[2-4] and DC-contact shunt[5]. Although DC-contact series RF MEMS switches have better application prospects than capacitive shunt and DC-contact shunt switches, few DC-contact series RF MEMS switches are suitable for the ap-

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作者简介: 侯智昊(1979—　)，男，博士，工程师.

通讯作者: 侯智昊，zh.hou@yahoo.com.

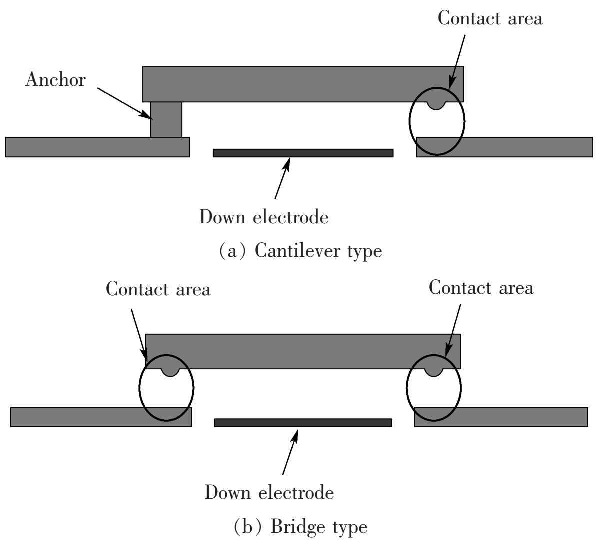
plication of millimeter-wave due to its low isolation at high frequency[6-8].

In order to improve the isolation, an improved crab-shape RF MEMS switch is presented in this paper. To obtain higher isolation in millimeter-wave band, the in- and out-port of the switch was carefully designed to reduce the RF signal coupling through the substrate. In this paper, the major impact on the isolation of DC-contact RF MEMS switch is analyzed. Then, the structure of RF MEMS switch with high isolation is proposed. Finally, the designed RF MEMS switch is fabricated and the measurement result is analyzed.

1 Design

There are mainly two types of DC-contact series RF MEMS switch, i.e., the cantilever and bridge types, with one and two contact areas, respectively. The schemes are shown in Fig. 1 and the equivalent circuit of up- and down-state is shown in Fig. 2.

For the cantilever type MEMS switch, there is one contact area, and the coupling capacitances between the in- and out-ports are C_C and C_{SUB} in parallel. For the bridge type MEMS switch, there are two contact areas, and the coupling capacitances between the in- and out-ports are two C_C in series and paralleled with C_{SUB}.



(a) Cantilever type

(b) Bridge type

Fig. 1 Schemes of cantilever and bridge type DC-contact series switches

If the high-impedance transmission line (t-line) between the contact areas is neglected, the isolation is calculated as[9]

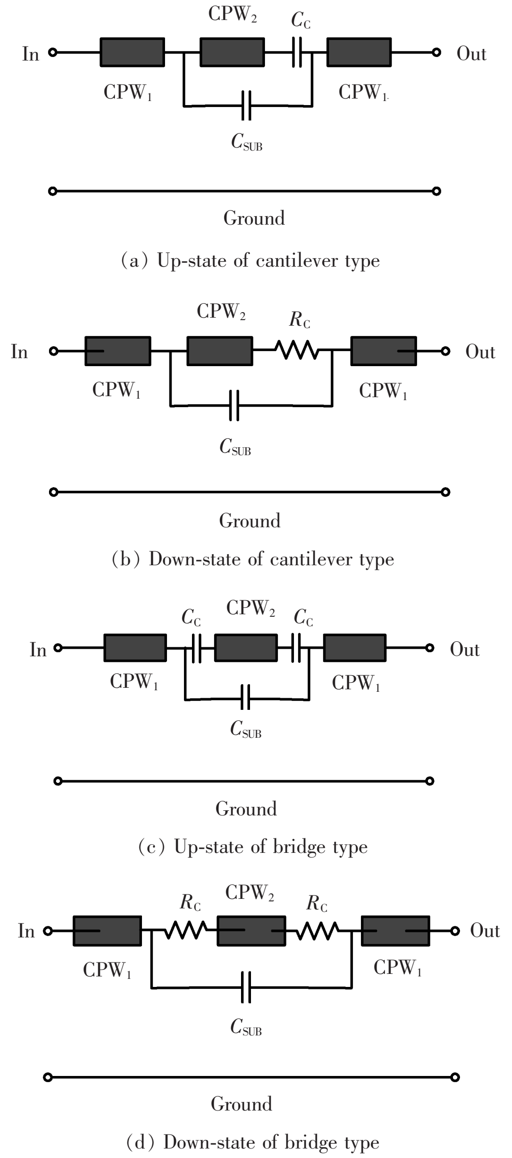
$$S_{21}=\frac{2j\omega C_u Z_0}{1+2j\omega C_u Z_0} \quad (1)$$

where $C_u=C_C+C_{SUB}$ for cantilever type and $C_u=C_C/2+C_{SUB}$ for bridge type switch; C_C is the coupling capacitance between bridge or cantilever and in- or out-port; C_{SUB} is the coupling capacitance between in- and out-port through substrate; Z_0 is the characteristic impedance of CPW_1; and ω is the angular frequency of signal. For S_{21}<<10 dB and $2\omega C_u Z_0$<<1, we have

$$|S_{21}|^2 \approx 4\omega^2 C_u^2 Z_0^2 \quad (2)$$

To increase the isolation, C_u must be minimized.

The simulation was performed with Advanced Design System (ADS) Software Package. The simulation



(a) Up-state of cantilever type

(b) Down-state of cantilever type

(c) Up-state of bridge type

(d) Down-state of bridge type

Fig. 2 Equivalent circuits of cantilever and bridge type DC-contact series switches

result shows that the coupling capacitance (C_S) between in- and out-signal lines has greater impact than that (C_C) between metal bridge and signal line on the isolation. To improve the isolation, the slight signal line with taper is used, which decreases C_S by increasing the equivalent distance between the in- and out-signal line. The coupling capacitance between the signal line and metal bridge can also be decreased by using the slight signal line which further improves the isolation.

The crab-shape bridge is mostly used in bridge type MEMS switch in order to reduce the pull-down voltage[10]. In the design, an improved crab-shape structure was used to obtain high contact stability, as shown in Fig. 3.

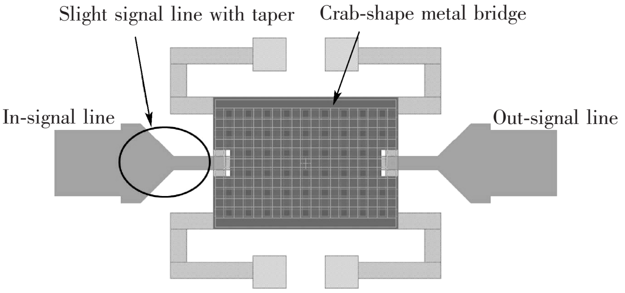


Fig. 3 Illustration of the designed RF MEMS switch

2 Fabrication process

The DC-contact series RF MEMS switch was fabricated on high resistivity silicon, which was used to reduce the loss due to the eddy-current in the substrate. Fig. 4 shows the process flow.

The process is as follows.

(a) A metal layer is deposited by sputter process and the metal is patterned as the down-electrode and the bias line.

(b) A layer of plasma enhanced chemical vapor deposition (PECVD) Si_3N_4 is patterned. Si_3N_4 is used as the dielectric layer upon the down-electrode.

(c) A thick layer of Au is electroplated to define the CPW structure.

(d) A sacrificial layer of polyimide is spun cast, soft baked, and patterned for anchor points.

(e) A thick layer of Au is electroplated to define the up-electrode structure of the MEMS switch, and a low stress electroplating process is used to avoid the warping of metal bridge.

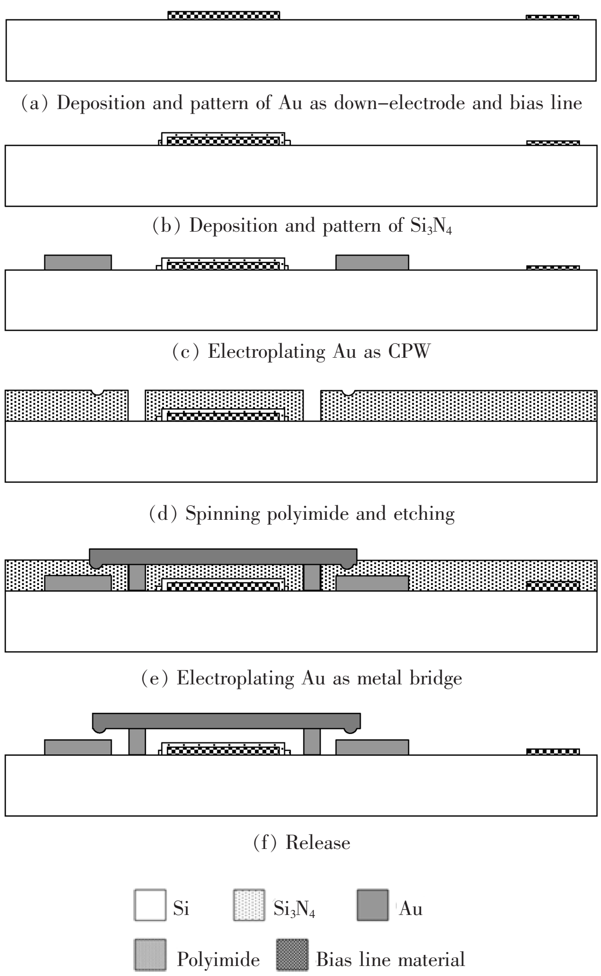


Fig. 4 Fabrication process of the DC-contact shunt RF MEMS

(f) The switch structure is released by a special method to avoid stiction, thus the designed RF MEMS switch is then achieved.

Fig. 5 is the scanning electron microscope (SEM) picture of the fabricated RF MEMS switch. It can be found that the Au metal bridge suspends well over the pull-down electrode without evident deformations because of low stress electroplating process.

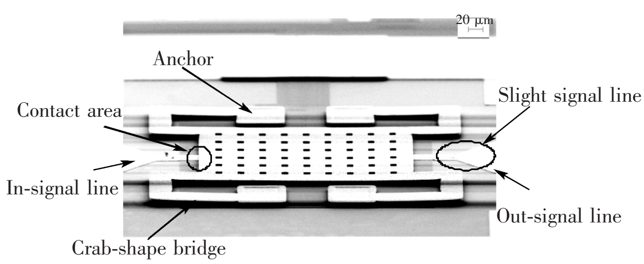


Fig. 5 SEM picture of the fabricated DC-contact series RF MEMS switch

3 Measurement

The pull-down voltage is about 60 V. The cascade micro probe station and HP 8722ES network analyzer were used to measure the *S*-parameter of the fabricated RF MEMS switch, and the result is shown in Figs. 6 and 7. Due to the careful design of in- and out-port of the switch, the insertion loss is low and the isolation is high enough for millimeter-wave applications. The insertion loss is −0.3 dB at 30 GHz, and the isolation is −20 dB at 30 GHz. In the range of 20—40 GHz, the insertion loss is better than −0.5 dB and the isolation is better than −20 dB.

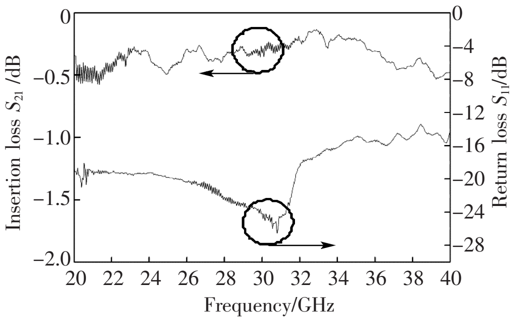


Fig. 6　*S*-parameter of the fabricated switch in ON-state

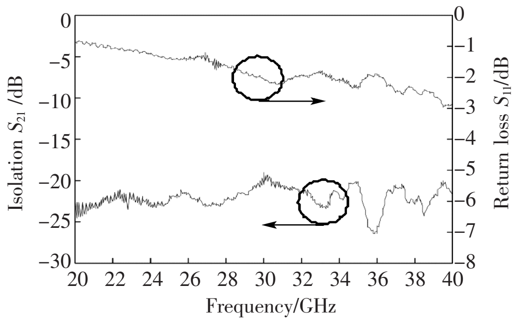


Fig. 7　*S*-parameter of the fabricated switch in OFF-state

4 Conclusion

A DC-contact series RF MEMS switch for millimeter-wave applications was designed and fabricated. The slight signal line at in- and out-port was used to obtain high isolation in millimeter-wave band. To obtain high contact stability, an improved crab-shape structure was used as the bridge structure. The measurement result showed that the insertion loss was −0.3 dB at 30 GHz, and the isolation was −20 dB at 30 GHz. In the range of 20—40 GHz, the insertion loss was better than −0.5 dB and the isolation was better than −20 dB.

References:

[1] Rebeiz G M, Muldavin J B. RF MEMS switches and switch circuits[J]. *Microwave Magazine*, 2001, 2(4): 59-71.

[2] Puyal V, Dragomirescu D, Villeneuve C, et al. Frequency scalable model for MEMS capacitive shunt switches at millimeter-wave frequencies[J]. *IEEE Transactions on Microwave Theory and Techniques*, 2009, 57(11): 2824-2833.

[3] Vietzorreck L. Modeling of the millimeter-wave behavior of MEMS capacitive switches[C]//*Proceedings of IEEE MTT-S International Microwave Symposium Digest*. Anaheim, California, USA, 1999: 1685-1688.

[4] Thakur S K. Performance of low loss RF MEMS fixed-fixed capacitive switch characterization[C]//*Proceedings of Applied Electromagnetics Conference*(*AEMC*). New Delhi, India, 2009: 1-4.

[5] Hou Z H, Liu Z W, Li Z J. Design and fabrication of a DC to 30 GHz DC-contact shunt RF MEMS switch [J]. *Optics and Precision Engineering*, 2009, 17(8): 1922-1927.

[6] Hou Z H, Liu Z W, Li Z J. Al/Au composite membrane bridge DC-contact series RF MEMS switch[C]// *Proceedings of International Conference on Solid-State and Integrated-Circuit Technology*. Beijing, China, 2008: 2488-2491.

[7] Stefanini R, Chatras M, Blondy P, et al. Miniature RF MEMS metal-contact switches for DC-20 GHz applications [C]//*Proceedings of IEEE MTT-S International Microwave Symposium Digest*. Baltimore, MD, USA, 2011: 1-4.

[8] Ghodsian B, Bogdanoff P, Hyman D. Wideband DC-contact MEMS series switch[J]. *Micro and Nano Letters*, 2008, 3(3): 63-69.

[9] Rebeiz G M. *RF MEMS*, *Theory*, *Design and Technology* [M]. New Jersey, USA: John Wiley & Sons Ltd, 2002.

[10] Dyck C W, Plut T A, Nordquist C D, et al. Fabrication and characterization of ohmic contacting RF MEMS switches[C]//*Proceedings of SPIE—The International Society for Optical Engineering*. San Jose, CA, USA, 2004: 79-88.

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