Capacitive Microwave MEMS Switch

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Abstract: A novel capacitive microwave MEMS switch with a silicon/metal/dielectric as a membrane is fabricated successfully by bonding and etching-stop process. Its principal, design, and fabricating process are described in detail. A patterned dielectric layer, Ta_2O_5, with dielectric constant of 24 is reached. Experiment results show this novel structure, where the switch's dielectric layer is not prepared on the transmission line, features very low insertion loss. The insertion loss is 0.06dB at 2GHz and lower than 0.5dB in the wider range from DC up to 20GHz, especially when the transmission line metal is only 0.5μm thick.

Key words: capacitive; microwave MEMS switch; Ta_2O_5 thin film

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1 Introduction

Microwave switches are widely applied in wireless communication systems, such as phase shifters, receivers, and transmitters. MEMS technology has made it possible to develop micromechanical switches with high performance for switching microwave signals. Recently, there has been much research work on micromechanical microwave switches[1~4]. Compared to conventional electromechanical switches, the micromachined variety have many advantages including, small size, low power dissipation, high throughput, integration capability, etc. Compared to solid-state switches, they have higher breakdown voltage, lower insertion loss, and much higher off-state resistance.

The capacitive microwave MEMS switches are mainly composed of three parts: the CPW, the dielectric layer, and the membrane. They are mostly actuated electrostatically. In most reports, the dielectric is silicon nitride or dioxide deposited on the transmission line. Available research indicates that the membrane is made of metal deposited by electroplating process. Capacitive microwave MEMS switches have relatively high actuation voltage and low isolation.

In this paper, a novel capacitive microwave MEMS switch with silicon as membrane and glass as substrate material fabricated by bonding and etching-stop is successfully fabricated. The dielectric layer, Ta_2O_5, and its principal performance are described.

2 Principal and design

Figure 1 is a schematic graph of the structure of our capacitive microwave MEMS switch. Commonly microwave MEMS switches consist of substrate, dielectric layer, lower electrode, and upper multi-layer-silicon membrane. When a DC voltage is applied between the upper and lower electrodes, the thin membrane deflects downward due to the electrostatic attraction between the electrodes.

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When the applied voltage is higher than the pull-in voltage of the switch, the membrane reaches the substrate, thus forming a low impedance pass to the ground and the switch is off.

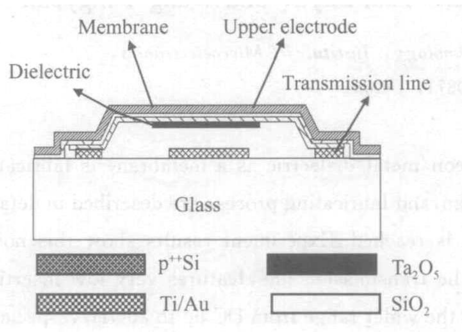

Fig. 1 Structural schematic of the switch

There are several apparent key factors that affect the performances of this RF MEMS switch. The actuation voltage is mainly decided by the mechanical performances of the membrane. The actuation voltage of the micro-mechanical switch is determined by the applied voltage, the membrane geometry, the membrane material properties, and the gap size between the movable plate and the low electrode. The driven voltage can be calculated by

$$V_P = \sqrt{\frac{8k}{27\varepsilon_0 W w} g_0^3} \qquad (1)$$

where k is the effective spring constant of the membrane, W is the width of the low electrode, w is the width of multi-silicon membrane, g_0 is the gap between the two electrodes, ε_0 is the initial dielectric constant. k can be described by

$$k = \frac{32Et^3 w}{L^3} + \frac{8\sigma(1-\nu)tw}{L} \qquad (2)$$

The other important factor is the on/off capacitance ratio of the switch, which can be described by

$$\frac{C_{on}}{C_{off}} = \frac{\varepsilon_D g_0 + \varepsilon_0 h_D}{\varepsilon_0 h_D} \qquad (3)$$

where ε_0, ε_D are the dielectric constants of air and dielectric material respectively, h_D is the thickness of the dielectric layer, g_0 is the gap between the membrane and the low electrode. Since the isolation of the switch is directly proportional to C_{on}/C_{off}, the highest possible dielectric constant is desired.

The membrane of our microwave MEMS switch has a silicon/dielectric/sandwich structure. The metal layer consists of Au/Cr deposited by sputtering. Ta_2O_5 is used as the dielectric layer to realize high dielectric property. The dielectric layer is deposited not directly on the transmission line like most other papers, but on the surface of membrane opposite to the transmission. It is in such a structure that a microwave MEMS switch with extremely low resistive loss or insertion loss can be designed and fabricated. The mechanical properties of the silicon membrane are better than that of metal so it can function with high stability and high reliability. In addition, its switching time could be shorter and lifetime could be longer.

3 Experiment

The fabrication process of our capacitive RF MEMS switch is shown in Fig. 2. The formation of the RF MEMS switch structure started with a 525μm thick 〈100〉 silicon wafer ($\varepsilon_r = 11.9$) and a Pyrex 7740 glass wafer. First, a 2μm shallow trench, which determined the gap size between the membrane and the transmission line, was prepared by KOH etching the silicon wafer. Second, the silicon surface was heavily doped by boron diffusion higher than $5\times10^{19}cm^{-3}$ in order to form an etching-stop layer and determine the thickness of the membrane. Third, a Ti/Au thin film was sputtered and defined via liftoff process. Fourth, a thin Ta_2O_5 film as dielectric layer (about 250nm) was deposited on the Au/Ti layer by sputtering. In order to reduce the residual stress the Ta_2O_5 layer was divided into small squares patterned by liftoff. Fifth, the Au/Ti layer as transmission and ground lines was deposited and patterned on Pyrex 7740. Sixth, the silicon wafer and Pyrex 7740 wafer were anodically bonded together face to face. Seventh, the silicon wafer was wet etched from the back in KOH solution, and the etching was terminated at the heavily doped layer. Finally, the membrane structure was released and patterned by ICP.

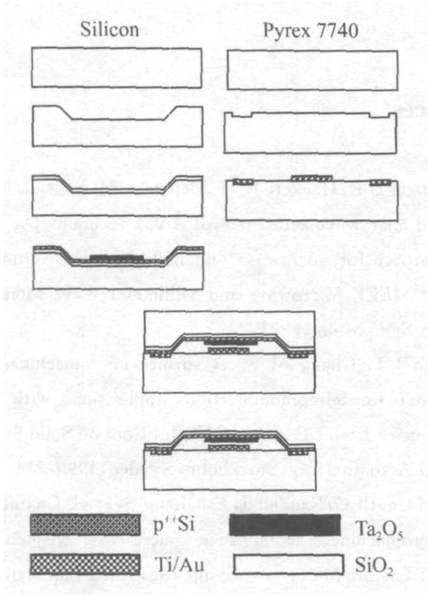

Fig. 2 Process flow

4 Results and discussion

To obtain high C_{on}/C_{off}, the Ta_2O_5 thin film was investigated before fabrication. The dielectric layer was fabricated on Au by magnetron sputtering. An O_2/Ar mixture gas of 50/30 ratio under a working pressure of 0.93Pa was used for the deposition. The Ta_2O_5 thin film is amorphous through XRD measuring. The dielectric constants of Ta_2O_5 materials were measured by preparing MIM (metal/insulator/metal) capacitor. The dielectric constant of the film is relative to the thickness, deposition methods, process, and the substrate. Table 1 shows the dielectric constants of the varying thickness of Ta_2O_5 thin films on Au electrode discussed in this paper.

Table 1 Ta_2O_5 thickness versus ε_r

Thickness/nm	104.3	137	245
ε_r	16	20	24

Figure 3 is a photograph of the capacitive microwave MEMS switch sample. The up structure is made of heavily doped silicon layer with a thickness of 2.4μm. The size of the beam is 90μm ×30μm and the membrane size is 140μm ×140μm. The upper electrode and Ta_2O_5 are under the heavily doped silicon layer and suspend above the substrate. The thickness of Ta_2O_5 is 250nm. The bottom is the transmission line and ground lines which are made of Au/Cr whose thickness is 0.5μm.

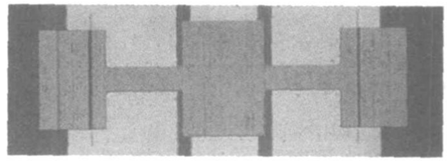

Fig. 3 Photograph of the switch

The pull-down voltage is approximately 38V. The insertion loss and isolation for the switch were measured by WILTRON 369B Network Analyzer and the results are shown in Fig. 4. The insertion loss is 0.06 at 2GHz and less than 0.5dB when the frequency is from DC to 20GHz in the un-actuated state with only a 0.5μm Au/Cr transmission line. This very low insertion loss means that the dielectric layer not prepared directly on the transmission line is useful to reduce the switch insertion loss. The isolation is weak due to the very low on/off impedance ratio. The reason is most likely due to the fact that the Ta_2O_5 layer is divided into many small squares which include more brims, thereby increasing the dielectric layer's roughness and lowering the capacitance.

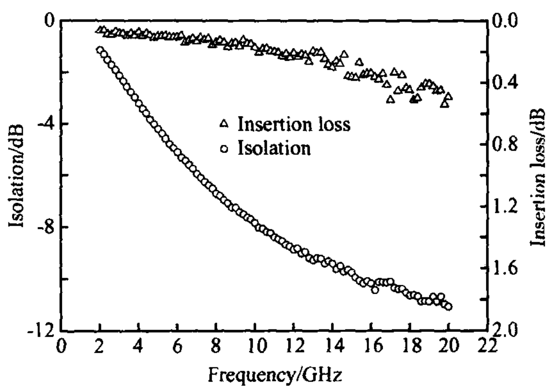

Fig. 4 Insertion loss and isolation versus frequency

5 Conclusion

A novel capacitive microwave MEMS switch with a silicon/metal/dielectric as a membrane is studied. Using bulk micromachining process, this novel microwave switch with the silicon/ metal / dielectric as the movable plate is successfully fabricated. The switch's dielectric layer is not on the transmission line which achieves less than 0.5dB insertion loss from DC to 20GHz when the transmission line metal is only 0.5μm thick. Research is being done to improve isolation.

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电容耦合式微波 MEMS 开关

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摘要: 提出了一种插入损耗较低、介质薄膜生长在桥膜上的新结构微波 MEMS 开关. 该开关桥膜由介质/ 金属/ 硅三种薄膜构成, 并采用键合和自停止腐蚀工艺成功制备. 详细论述该开关的原理、设计和制备过程. 磁控溅射制备出介电常数为 24 的 Ta_2O_5 作为介质薄膜, 利用光刻剥离技术使该介质薄膜图形化. 实验结果显示, 这种介质薄膜在桥膜上的新结构开关的插入损耗较低, 在传输线金属薄膜厚度仅为 0.5μm 的情况下, 频率为 2GHz 时插入损耗仅为 0.06dB, 在直流到 20GHz 的频率范围内插入损耗均低于 0.5dB.

关键词: 电容耦合式; 微波微机械开关; 五氧化二钽薄膜

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