2005년도 대한전자공학회 추계종합학술대회 제28권 제2호

Studies on the Pull-up MEMS Switch for the Lower Actuation Voltage and High Speed using Double Electrode

*Seong Dae Lee, Byoung-Chol Jun, Tae-Jong Baek,
Soom-Koo Kim, Sam-Dong Kim, and Jin-Koo Rhee
e-mail : leesd@dgu.edu, jkrhee@dgu.edu

Millimeter-wave INnovatiom Technology Research Center (MINT),
Dongguk University

Abstract

We report a pull-up type RF MEMS switch using double electrode without elastic deformation of the cantilever involved in the actuation. At a voltage of 4.5 V, reliable actuations are achieved such that the movable lower contact pad is pulled up by the electrostatic force to make contact with the upper pad. At a frequency of 50 GHz, an insertion loss of 0.7 dB and an isolation of 50.7 dB are obtained from the switch. The measured transient times for switch-on and switch-off are 120 and 80 ns, respectively.

I. Introduction

Over the last ten years, micro-electro-mechanical-system(MEMS) technology for application to microwave and millimeter-wave has experienced an exponential growth. Especially, RF MEMS switch, which is a representative active device in many MEMS components, has made great strides. Such switches are of sub-millimeter size and are desirable for application with demands on high signal purity in terms of isolation, insertion loss, signal linearity, impedance matching, frequency dependence and power consumption compared to conventional electronic switches based on p-i-n diodes and field effect transistors (FETs) [1]-[4]. However, their mechanical concept implies a slow switching time in the micro-second range [5] and a high actuation voltage to drive the cantilever [6]-[8].

In this article, we present a pull-up type RF MEMS switch fabricated with double pull-up and -down electrodes exhibiting state-of-the-art performances in terms of switching time and actuation voltage.

Ⅱ. Design of the Pull-up MEMS Switch with Double Electrode

Most forms of RF MEMS switches use the elastically deformable cantilever which is fixed to at least one end of the anchor, while the pull-up type RF MEMS switch is adopted a pull-up type structure with no elastic deformation involved in the actuation. And the pull-up type MEMS switch has the lower contact pad moving up-and-down freely. The pull-up electrode of this RF MEMS switch is located right above the center of the lower contact pad. Therefore, the electrostatic force pulling up a movable lower contact pad from a lower to an upper position is provided only by pull-up electrode [9].

The pull-up RF MEMS switch, in this paper, has two electrodes below and above the center of the movable lower contact pad for the purpose of obtaining a lower actuation voltage and faster switching speed, as shown Fig. 1. Therefore, the electrostatic force for pulling up a movable contact pad from a lower to an upper position is provided by upper electrode (called 'pull-up electrode'), and force for pulling down from an upper to a lower position is provided by lower electrode (pull-down electrode). The size of electrodes and the thickness of Si_3N_4 for dielectric films are 100 × 100 ㎛^{2} and 900 Å, respectively. For the driving of lower contact pad, positive DC bias is applied to the pull-up electrode through the DC bias pad and negative DC bias is applied to the pull-down electrode through the signal line and guard pole which is connected by pull-down electrode metal plane. Only one of two guard poles is connected to the signal line because signal lines are shorted if both poles are connected to the pull-down electrode metal plane.

As shown in Fig. 1, the housing glass, which was fixed to the wafer by anodic bonding, completely covers a groove formed on the glass surface containing the movable lower contact pad. The housing glass plays an important role in maintaining a constant distance between two contact pads in switch-off state. Guard poles provide the lower contact pad with the guided motion.

The spacing between the lower contact pad and the pull-up electrode and the thickness of lower contact pad are key design parameters determining the actuation voltage and switching speed. For the design optimization, we characterized the switches fabricated at various lower contact pad thicknesses (2∼20 ㎛) and spacing between the lower contact pad and the pull-up electrode (0.5∼5 ㎛). The spacing was changed by varying the depth of groove at a fixed lower pad thickness. An optimum structure was obtained in a spacing of 1.5 ㎛ and a lower pad thickness of 5 ㎛ each structure. In these design parameters, the lowest actuation voltages and the smallest switching times were achieved from the switches.

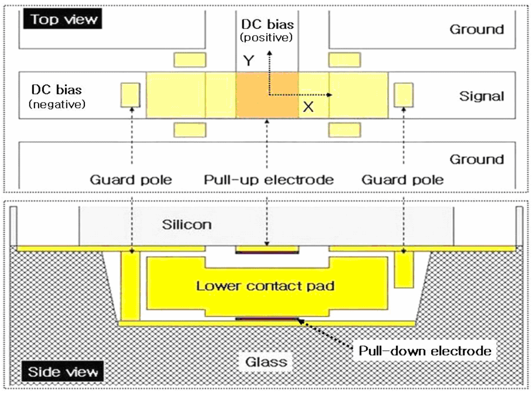

Fig. 1 A schematic of the pull-up switch with double electrode

Ⅲ. Fabrication of the Pull-up MEMS Switch with Double electrode

The fabrication of the switch was performed by the separate processes on the double-polished Si wafer and the glass, and the structures on each substrate were finally combined by the anodic bonding. The same thickness of 200 ㎛ was used for the Si wafer and the glass substrates.

Process on Si wafer proceeded as follows. First, 1500 Å thick Si_3N_4 was deposited on both sides of the substrate using the plasma enhanced chemical vapor deposition. Metal(Ti/Au) evaporations were performed to form signal lines, ground lines, and electrodes. 900 Å thick Si_3N_4 was deposited again for the pull-up electrode structure followed by reactive ion etching. For the formation of lower contact pad, we used double exposure patterning [10] and Au electro-plating. Glass process consists of the followings. On the Cr-deposited glass, we patterned the areas for the grooves followed by wet etching in a diluted Hydrofluoric acid (HF). The DC bias pads and test pads were formed by the metal evaporations. After pattern alignment and anodic bonding for the structures produced on two different substrates, the backside of Si was etched in a wet etchant of tetramethyl ammonium hydroxide (TMAH) to open the bias and test pads.

Fig. 2 shows a fabricated pull-up type MEMS switch. In the micrograph, it is observed that 5 ㎛ thick lower contact pad is formed as a separate body in the glass housing.

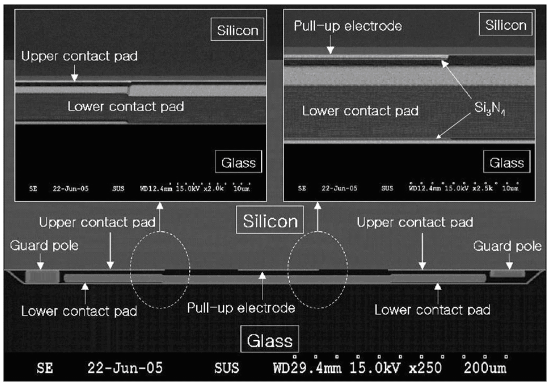

Fig. 2 Fabricated a pull-up type switch with double electrode

Ⅳ.Characteristics of the Fabricated Pull-up MEMS Switch

The fabricated switches were characterized by an Agilent 8510C vector network analyzer in a frequency range of 8 ~ 50 GHz using TRL calibration. DC biases for actuating the switches were supplied by an Agilent 4156A DC parameter analyzer. To measure the actuation voltage, we applied the DC biases of 0 ~ 10 V with a 0.5 V step to pull-up electrode and -10 ~ 0 V with same step to pull-down electrode. Applied positive and negative DC biases are same of magnitude and opposed to the sign. The lower pad showed the reliable switching motions at a DC bias of 4.5 V. The measured contact resistance and contact force were 0.2 Ω and 28 μN, respectively.

Fig. 3 shows the RF characteristics of the switch measured at various frequencies. As shown in the plot, low insertion loss and high isolation of 0.7 dB and 50.7 dB, respectively, were obtained in the double electrode switch at a millimeter-wave frequency of 50 GHz.

Time response of the switch was measured by a Keithley 4200-SCS Semiconductor Characterization System in a time accuracy of 10 ns For the purpose of measuring the time response, we applied the +4.5 V pulse to pull-up electrode and -4.5 V pulse to pull-down electrode. Fig. 4 is time response of pull-up MEMS switch with double electrode. In this figure, the measured transient times for switch-on and switch-off were 120 and 80 ns as shown in Fig. 5 and 6, respectively. Compared to the switching speeds of few micro-seconds reported in MEMS switches thus far [11]-[12], this pull-up switch showed the best performance in terms of speed.

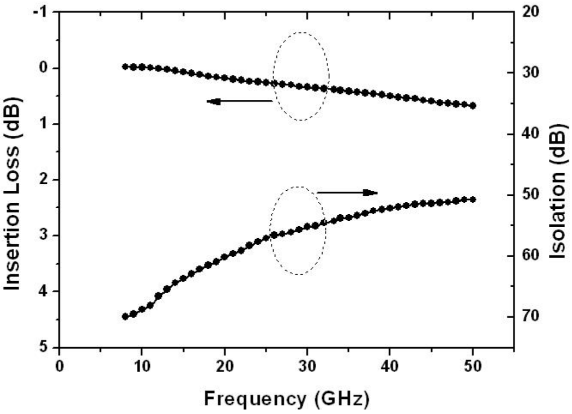

Fig. 3 Insertion loss and isolation versus frequency

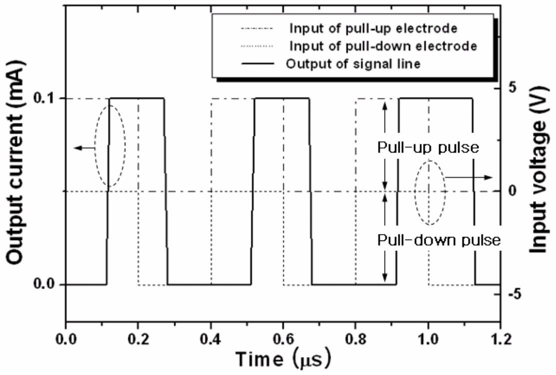

Fig. 4 Time response of the pull-up double electrode MEMS switch

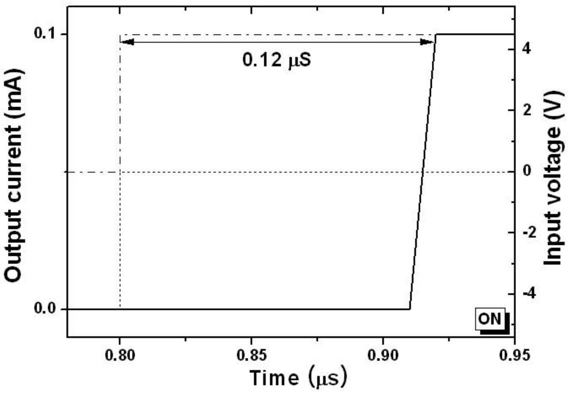

Fig. 5 On transient time

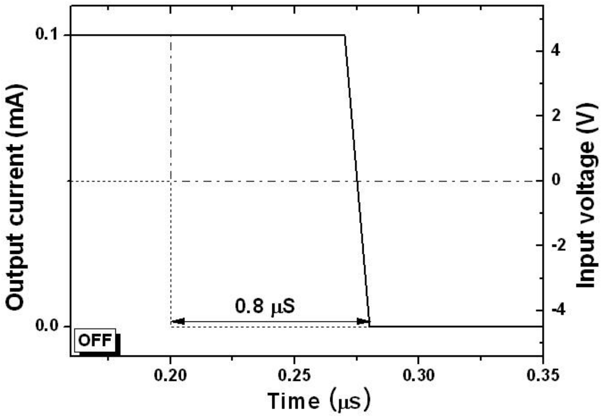

Fig. 6 Off transient time

V. Conclusion

Due to a pull-up structure for the electrostatic actuation and double electrode, the fabricated MEMS switch showed the reliable operation at a voltage lower than 4.5 V. At a V-band frequency of 50 GHz, an insertion loss of 0.7 dB, a return loss of 14.5 dB, and an isolation of 50.7 dB were obtained from the switch. Very fast transient time less than 130ns was also achieved for the switching. To the best of our knowledge, these MEMS switches represent the fastest switching speed with higher isolation of any millimeter-wave MEMS switch reported to date.

ACKNOWLEDGEMENT

This work was supported by the SRC/ERC program of MOST/KOSEF (grant No.: R11-1999-058-02005-0)

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