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RF MEMS Switches With SiC Microbridges for Improved Reliability

Maximilian C. Scardelletti
Glenn Research Center, Cleveland, Ohio

Christian A. Zorman
Case Western Reserve University, Cleveland, Ohio

Daniel R. Oldham
Glenn Research Center, Cleveland, Ohio

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National Aeronautics and
Space Administration

Glenn Research Center
Cleveland, Ohio 44135

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Maximilian C. Scardelletti
National Aeronautics and Space Administration
Glenn Research Center
Cleveland, Ohio 44135

Christian A. Zorman
Case Western Reserve University
Cleveland, Ohio 44106

Daniel R. Oldham
National Aeronautics and Space Administration
Glenn Research Center
Cleveland, Ohio 44135

Introduction

Radio frequency (RF) microelectromechanical (MEMS) switches offer superior performance when compared to the traditional semiconductor devices such as PIN diodes or GaAs transistors (ref. 1). MEMS switches have a return loss (RL) better than –25 dB, negligible insertion loss (IL), isolation better than –30 dB, and near zero power consumption. However, RF MEMS switches have several drawbacks the most serious being long-term reliability. The ability for the switch to operate for millions or even billions of cycles is a major concern and must be addressed. MEMS switches are basically grouped in two categories, capacitive and metal-to-metal contact. The capacitive type switch consists of a movable metal bridge spanning a fixed electrode and separated by a narrow air gap and thin insulating material. The metal-to-metal contact type utilizes the same basic design but without the insulating material. After prolonged operation the metal bridges, in most of these switches, begin to sag and eventually fail to actuate. For the metal-to-metal type, the two metal layers may actually fuse together. Also if the switches are not packaged properly or protected from the environment moisture may build up and cause stiction between the top and bottom electrodes rendering them useless. Many MEMS switch designs have been developed and most illustrate fairly good RF characteristics. Nevertheless very few have demonstrated both great RF performance and ability to perform millions/billions of switching cycles (refs. 2 and 3). Of these, nearly all are of metal-to-metal type so as the frequency increases RF performance decreases.

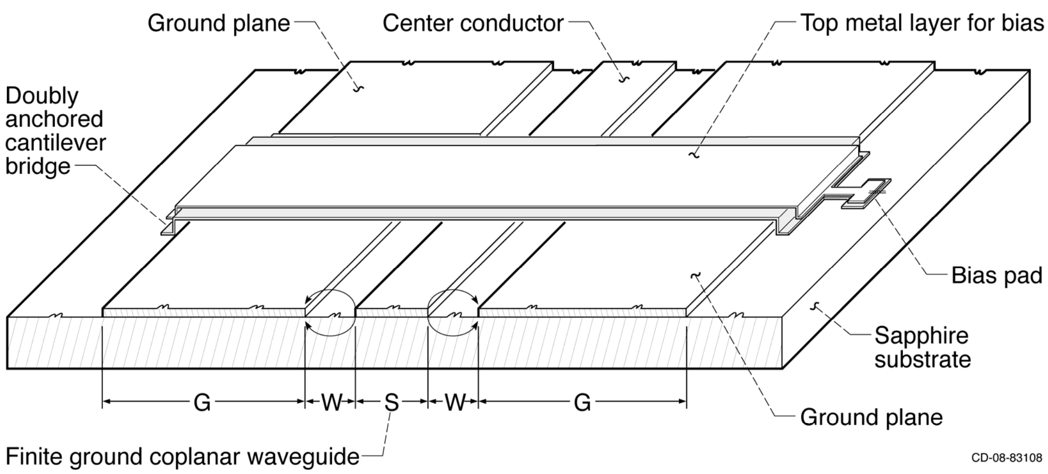
Silicon carbide (SiC) is widely known for its potential as a structural material for MEMS devices designed to operate in harsh environments (i.e., high temperature, radiation, wear, etc.). It has robust mechanical properties that make SiC very attractive for RF MEMS applications. When used as the structural material in micromachined bridges, the inherent stiffness and tensile stresses of SiC results in beams that are extremely resistant to sagging. Moreover, its chemical inertness makes SiC highly resistant to stiction. These properties makes SiC an ideal alternative to metals in surface micromachined bridge-based RF MEMS switches for the reasons described above. Incorporation of insulating, amorphous SiC as the main mechanical structure in bridge-based RF switches eliminates the need to use a stiction-preventing insulating film between the cantilever and transmission because the SiC itself is highly resistant to stiction, due to its chemical inertness coupled with its resistance to oxidation.

In this paper we present RF MEMS switches which utilize 500- and 300-nm-thick amorphous SiC films for structural support in order to improve reliability. The MEMS switch incorporating the 500-nm-thick microbridge actuates readily but suffers from poor RF performance while the switch with the 300-nm-thick SiC microbridge exhibits great RF performance but does not actuate reliably.

MEMS Switch Design and Fabrication

A schematic of the RF MEMS switch with a SiC microbridge is shown in figure 1(a). The MEMS switch is constructed out of coplanar waveguide (CPW) transmission line media. The SiC microbridge spans the width of the CPW completely thus making the effect of the bridge on the CPW negligible while in the up-position (off-state) and renders the MEMS switch in shunt configuration. Furthermore the by making the bridge extend completely over the CPW with no contact the MEMS switch can be biased directly and the CPW left at ground potential to bias other electronic components.

The MEMS switch is fabricated on a sapphire wafer with a dielectric constant of 9.4 and a thickness of 500 µm. The CPW has a center conductor width (S), a slot width (W), and a ground width (G) of 130, 60, and 300 µm, respectively, which equates to a characteristic impedance of 50Ω. Typical integrated circuit (IC) fabrication techniques where used to develop the switches. The CPW transmission lines consist of chrome (Cr) and gold (Au) with a thickness of 25 and 1200 nm, respectively. The SiC microbridge consisted of 300 nm or 500-nm-thick amorphous SiC films deposited by plasma enhanced chemical vapor deposition using a process detailed elsewhere (4). Since the SiC film is insulating, a thin layer of Cr/Au (25/120 nm) was deposited on top of the bridge to ensure a potential would be created between the bridge and the CPW to actuate the switch. An SEM micrograph of a released MEMS switch is shown in figure 1(b).



(a)

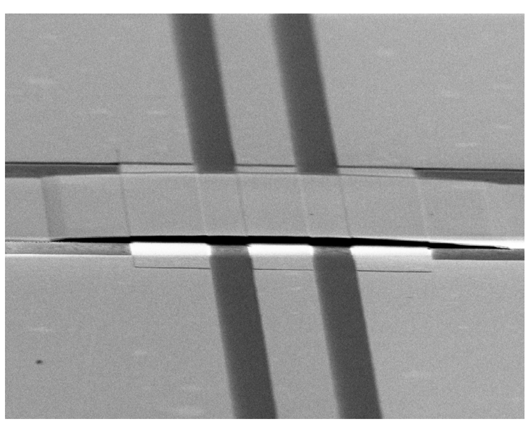

(b)

Figure 1.—(a) Schematic diagram of the SiC-based RF MEMS switch, and (b) SEM micrograph of a SiC micrombridge-based switch.

MEMS Switch Characterization

The SiC RF MEMS shunt switch was characterized with the HP 8510C Vector Network Analyzer (VNA), a RF/Microwave Cascade Microtech probe station and 150 micron pitch ground-signal-ground probes from GGB Industries. MultiCal Software by NIST and a thru-reflect-line (TRL) calibration was performed to calibrate the system with a set of on-wafer TRL calibration standards. The RL and IL for the MEMS switch with the 500-nm-thick SiC microbridge while in the up position (off-state) is shown in figure 2(a). The RF performance of the switch is fairly good but when the switch is turned on when an actuation voltage of 52 V is applied to the DC bias pads and the bridge is set to the down position, as seen in figure 2(b), the RF performance is poor. This is principally due to the thickness of the SiC film which creates a small on-state capacitance. However, figure 3 shows that the switch actuates readily and reliably when repeatedly turned off and on. Furthermore this switch has been subjected to over 500,000 switching cycles to date with no signs of performance degradation. The noisiness illustrated in the figure is strictly from the actuation source. A much more precise and sensitive power source is needed to ensure accurate characterization. The RL and IL of the MEMS switch fabricated using the 300-nm-thick SiC microbridge is shown in figure 4. The RF performance in the down position (on-state) is outstanding. The S11 is less then 0.3 dB from 0 to 45 GHz and the isolation (S21) is better than –20 dB from 10 to 45 GHz. Unfortunately this switch does not actuate as readily as the 500 nm SiC switch. It is believed that this is due to the inherent stresses in the 300-nm-thick microbridge as compared with the 500-nm-thick microbridge and/or the influence of the metal conductor on the mechanical properties of this bridge.

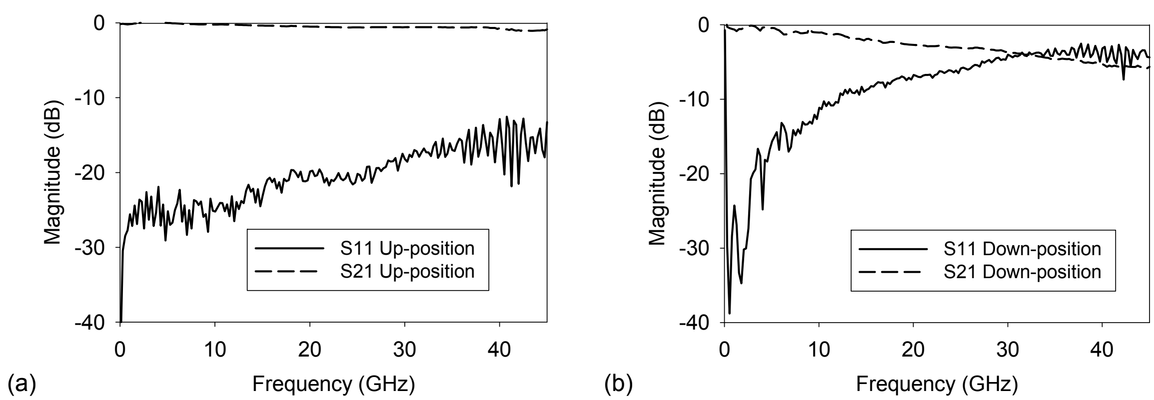


Figure 2.—SiC MEMS switch (a) in the up position (off-state) and (b) in the down position (on-state).

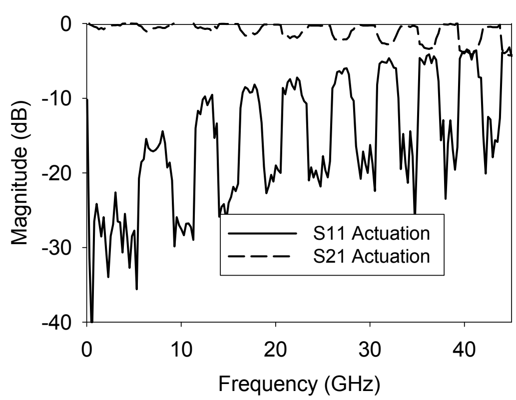


Figure 3.—500 nm SiC MEMS actuation.

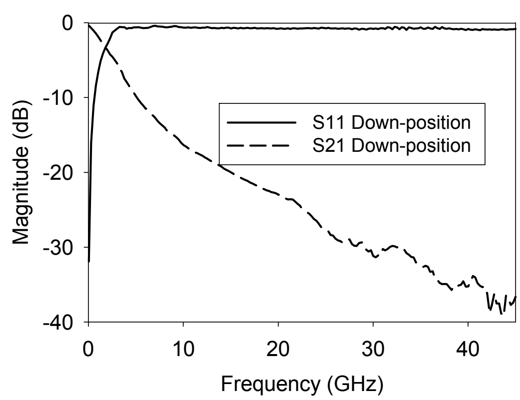


Figure 4.—The 300 nm SiC switch in down position.

Conclusion

RF MEMS switches which utilize an insulating SiC microbridge as a structural layer have been developed. The MEMS switch with the 500 nm SiC microbridge exhibits good off-state performance but poor on-state characteristics due to the small on-state capacitance of the structure. However the mechanical reliability of the switch is exceptional. The MEMS switch with the 300 nm SiC thick microbridge has outstanding down position (on-state) RF characteristics which is do to the film being 40 percent thinner than the 500 nm microbridge thus creating a much larger on-state capacitance. Unfortunately the 300-nm-thick microbridge does not actuate readily. It is believed that this is due to the stresses within the bridge.

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14. ABSTRACT
Radio frequency (RF) microelectromechanical (MEMS) switches offer superior performance when compared to the traditional semiconductor devices such as PIN diodes or GaAs transistors. MEMS switches have a return loss (RL) better than -25 dB, negligible insertion loss (IL), isolation better than -30 dB, and near zero power consumption. However, RF MEMS switches have several drawbacks the most serious being long-term reliability. The ability for the switch to operate for millions or even billions of cycles is a major concern and must be addressed. MEMS switches are basically grouped in two categories, capacitive and metal-to-metal contact. The capacitive type switch consists of a movable metal bridge spanning a fixed electrode and separated by a narrow air gap and thin insulating material. The metal-to-metal contact type utilizes the same basic design but without the insulating material. After prolonged operation the metal bridges, in most of these switches, begin to sag and eventually fail to actuate. For the metal-to-metal type, the two metal layers may actually fuse together. Also if the switches are not packaged properly or protected from the environment moisture may build up and cause stiction between the top and bottom electrodes rendering them useless. Many MEMS switch designs have been developed and most illustrate fairly good RF characteristics. Nevertheless very few have demonstrated both great RF performance and ability to perform millions/billions of switching cycles. Of these, nearly all are of metal-to-metal type so as the frequency increases RF performance decreases.

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