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A compact MEMS switch for advanced radar systems

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Abstract. MEMS switches are promising candidates for use in advanced radioelectronic systems. High RF performance combined with small size and low power consumption make them attractive for phased array antennas, aviation and space equipment. This work presents a switch based on a tiny cantilever with a length of 50 μm. Its working characteristics are compared with the calculation results. The advantages of the switch in comparison with previously developed products are demonstrated.

Keywords: MEMS switch, radar, cantilever, contact resistance, pull-in voltage

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Компактный МЭМС-переключатель для перспективных радиолокационных систем

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Аннотация. МЭМС-переключатели представляют значительный интерес для перспективных радиоэлектронных систем. Высокие СВЧ характеристики в сочетании с малым размером и низким энергопотреблением делают их привлекательными для использования в фазированных антенных решетках, авиационных и космических радиосистемах. В этой работе представлен ключ на основе миниатюрного кантилевера длиной 50 мкм. Выполнено сравнение его рабочих характеристик с результатами расчетов. Продемонстрированы достоинства ключа в сравнении с ранее созданными изделиями.

Ключевые слова: МЭМС-переключатель, радиолокация, кантилевер, контактное сопротивление, напряжение срабатывания

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Introduction

Switches fabricated using microelectromechanical systems (MEMS) technology are actively considered as a new element base for microwave devices [1]. They have lower insertion loss, higher isolation and lower power consumption than solid-state switches, which is critical for ultra-high frequency applications. These characteristics make them attractive for use in phased array antennas [2], aviation and space radar systems [3]. A conventional MEMS switch contains a cantilever suspended above the driving and signal electrodes. Applying voltage to the driving electrode creates an electrostatic force that bends the cantilever and brings it in contact with the signal electrode. When the voltage is turned off, the cantilever returns to its original position under the elastic force. MEMS switches are fabricated using microelectronic techniques and can be integrated with CMOS circuits.

MEMS switches have been developed since the 1990s, and the reliability of these devices remains a major unresolved problem [1]. One of the main reasons of poor reliability is high and unstable contact resistance. To solve this problem, the cantilever is replaced by complex structures with extended lateral size, which increases the contact force and thereby reduces the resistance. However, large size makes the switch sensitive to internal mechanical stresses, since even a small stress gradient significantly changes the gap between the electrodes. In addition, switching speed decreases, parasitic capacitance increases, and RF performance deteriorates. The complex shape of the electrodes makes it difficult to integrate the switch into a coplanar transmission line.

A cantilever-based switch has several advantages. The simple design allows both series and shunt configurations to be implemented. The small size of the device ensures resistivity to mechanical stress and short switching time. This paper presents a compact cantilever-based MEMS switch. Its pull-in voltage and contact resistance are measured. Experimental data are compared with the calculation results, and the advantages of the switch in comparison with previously created devices are revealed.

Materials and Methods

The switch is shown schematically in Figure 1, *a*. The movable electrode is an aluminum cantilever with the length of 50 μm, the width of 10 μm at the attachment sites and 40 μm at the free end (Fig. 1, *b*). The driving electrode surrounds the signal one in order to increase the area of electric field. The shape of the cantilever and electrodes was selected earlier to provide the highest contact force for the given footprint of the device [4]. The cantilever is 3.6 μm thick, and the contact bump height is of 0.5 μm. The gap between the cantilever and the electrodes is 1 μm. The natural frequency of the cantilever is 750 kHz, and the actuation time at a driving voltage of 90 V is 0.7 μs. The calculated pull-in voltage is of 85 V. More details on calculating performance characteristics can be found in [5].

The switch is fabricated on a thermally oxidized silicon wafer with a diameter of 100 mm using standard microelectronics techniques, namely photolithography, magnetron sputtering, plasma and wet etching. The fabrication procedure of the switch is described in detail in [4]. The contacts are made of ruthenium.

The switches are tested under standard laboratory conditions without packaging. The testing is carried out in the cold switching mode, in which mechanical contact is first made and then the switching signal is applied. The driving voltage is 90 V, while the switching signal is 1.5 V, and the

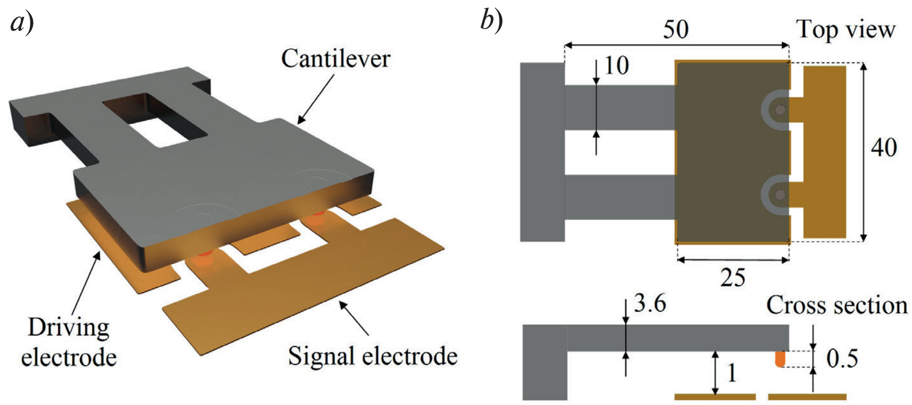

Fig. 1. Cantilever-based MEMS switch: 3D image (*a*); top view and cross section (dimensions are given in micrometers) (*b*)

actuation frequency is 7 Hz. At each switching cycle, the contact resistance is calculated using a resistive divider. The calculation is performed automatically using LabView software.

Results and discussion

The measured pull-in voltage is 64 V in average, which is 25% lower than the calculated value. The reason for the discrepancy is the bending of the cantilever under internal mechanical stresses. Due to the short cantilever length, this bending results only in a small change in the gap of 0.25 μm, which does not lead to the switch failure. The pull-in voltage decreases with the number of switching cycles and after 100 thousand cycles is on average 40 V. The voltage drop explains by plastic deformation of the cantilever, leading to a reduction in the air gap [6].

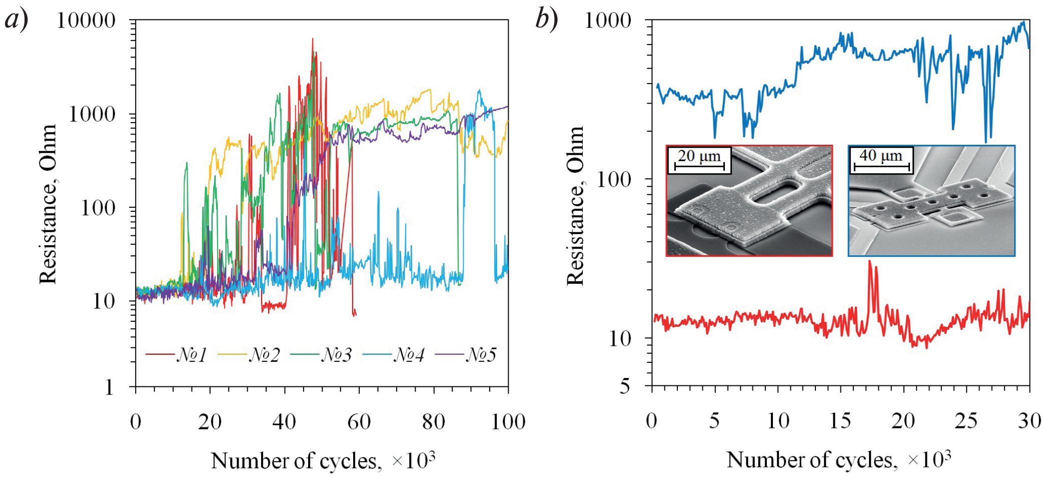

Fig. 2. Dependence of contact resistance on the number of switching cycles: for five cantilever-based samples (*a*); for a cantilever-based switch in comparison with a switch developed by the authors earlier (*b*)

The dependence of the contact resistance on the number of switching cycles for five samples is shown in Figure 2, *a*. During the first 10 thousand cycles, the switches demonstrate the resistance of 10–15 Ohms. Then it increases to several tens and hundreds of Ohms. The growth of resistance is explained by the formation of friction polymers on the surface of ruthenium contacts [7]. For the same reason, the resistance is unstable, increasing and decreasing several times during the test.

Figure 2, *b* shows the comparative test of the proposed switch (red curve) and a switch with an active opening mechanism, developed by the authors earlier [8] (blue curve). Both devices are fabricated using the technology described above, but the cantilever-based switch has 1–2 orders of magnitude lower resistance. The probable reason is the higher impact force of the cantilever that helps to break the contamination film on the contact surfaces.

Conclusion

This paper presents an electrostatic-type MEMS switch based on a compact aluminum cantilever. Its pull-in voltage is 64 V on average and is 25% lower than the calculated value due to cantilever bending under internal mechanical stress. The pull-in voltage decreases with increasing number of switching cycles because of plastic deformation of the cantilever. The contact resistance is of 10–15 Ohms for 10 thousand cold-switching cycles, and then it increases to several tens and hundreds of Ohms and becomes unstable due to contamination of the ruthenium contacts. However, the proposed switch has 1-2 orders of magnitude lower resistance compared to the previously developed device. Reliability testing under sealed conditions is planned for the presented MEMS switch.

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