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A compact MEMS switch based on a cantilever with three elastic elements

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Abstract. MEMS switches are of significant interest for advanced radioelectronic systems. High RF performance combined with small size and low power consumption make them promising for use in phased array antennas, wireless communication devices and navigation systems. This paper presents a resistive switch based on a cantilever with three elastic elements. The pull-in voltage and contact resistance are measured, and the results are compared with the calculated values. The switch provides lower resistance than previous devices.

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

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Компактный МЭМС-переключатель на основе кантилевера с тремя упругими элементами

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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 перспективными для использования в фазированных антенных решетках, устройствах беспроводной связи и навигационных системах. В работе представлен резистивный переключатель на основе кантилевера с тремя упругими элементами. Измерено его напряжение срабатывания и контактное сопротивление, результаты сопоставлены с расчетными значениями. Продемонстрировано снижение контактного сопротивления по сравнению с ранее созданными переключателями.

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

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Introduction

Switches fabricated using microelectromechanical systems (MEMS) technology are actively considered as a new element base for microwave devices [1]. Small size, high isolation, low insertion loss and power consumption make them attractive for wireless communication and radar systems. MEMS switches use various operating principles, among which electrostatic one is the most common [2]. A conventional MEMS switch contains a cantilever suspended above 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 initial position under the elastic force. Electrostatic MEMS switches are fabricated using microelectronic technologies and can be integrated with CMOS circuits, enabling the development of advanced microwave devices [3].

The implementation of MEMS switches in microwave technology is hampered by their poor reliability. Micron-sized switches develop weak contact force, which does not allow achieving low and stable contact resistance. The force is usually increased by using large and complex-shaped electrodes. However, a compact and simple design is more preferable. In this paper, a miniature MEMS switch based on a cantilever with three elastic elements is presented. The shape and dimensions of the electrodes are specially selected to increase the contact and restoring forces, while the moving part remains small [4]. The pull-in voltage and contact resistance of the switch are measured. Experimental data are compared with calculation results. Reduced resistance in comparison to previously created devices is demonstrated.

Materials and Methods

The switch is shown schematically in Fig. 1, *a*. The movable electrode is 50 μm long and 60 μm wide aluminum cantilever (Fig. 1, *b*). It has three elastic elements, each 10 μm wide. The driving electrode surrounds the signal one in order to increase the area of electric field. The cantilever is 3.6 μm thick and has two 0.3 μm high contact bumps. The gap between the cantilever and the electrodes is of 1 μm. The natural frequency of the cantilever is of 750 kHz. It provides

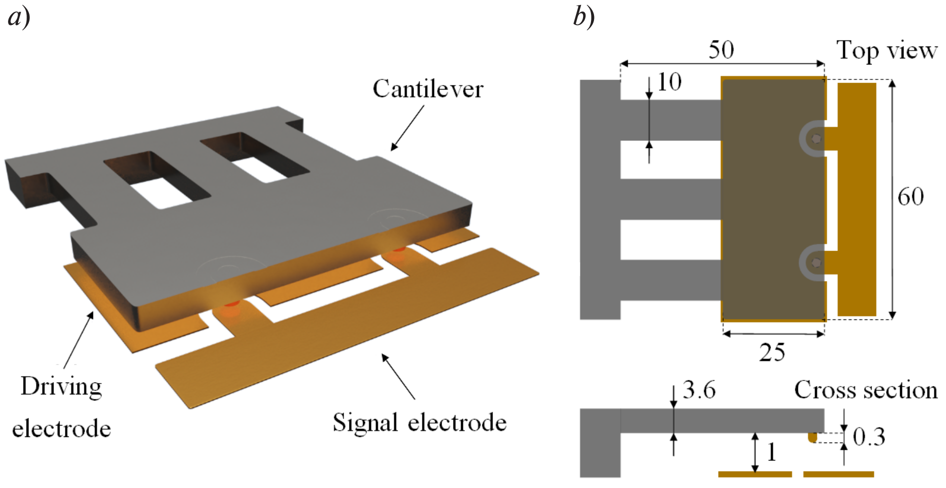

Fig. 1. MEMS switch based on a cantilever with three elastic elements: 3D image (*a*); top view and cross section (*b*), dimensions are given in micrometers

the actuation time of 0.7 μs at a driving voltage of 90 V. The calculated pull-in voltage is of 85 V. The switch is fabricated on a thermally oxidized silicon wafer with a diameter of 100 mm using standard microelectronics techniques. The fabrication procedure is described in detail in the work [5]. The contact material is ruthenium.

The switches are tested under 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 switching signal is a constant voltage of 5 V, while the switching current is about 90 mA and is limited by a load resistance of 50 Ω. The actuation frequency is of 7 Hz. The contact resistance is calculated at each switching cycle using a resistive divider. The calculation is performed automatically by LabView software.

Results and discussion

The average measured pull-in voltage is of 69 V, which is 18% lower than the calculated value. The reason for the discrepancy is the bending of the cantilever under internal mechanical stress. Due to the short cantilever length, this bending results only in a small change in the gap of 0.1 μm, which does not lead to the switch failure.

The dependence of the contact resistance on the number of switching cycles for five samples is shown in Fig. 2, *a*. During the first 5,000 cycles, the switches demonstrate the resistance of 4–5 Ω. Then it varies from 4 to 8 Ω. Probably, the increase in resistance is explained by the formation of friction polymers on the surface of ruthenium contacts [6]. For the same reason, the resistance behaves unstable, increasing and decreasing several times during the test. Most of the samples withstood less than 100 thousand cycles and failed due to a short circuit between the driving electrode and the cantilever. A sharp increase in contact resistance above 10 Ω is observed before failure (samples 1, 3–5). The reason for this phenomenon is being investigated.

Fig. 2, *b* shows the test results for three types of switches: a device based on a cantilever with three elastic elements (green curve), a previously developed switch with two elastic elements (red curve) [7] and a switch with an active opening mechanism (blue curve) [8]. All three devices are fabricated using similar technology. A MEMS switch based on a cantilever with three elastic elements demonstrates the lowest contact resistance due to increased contact force.

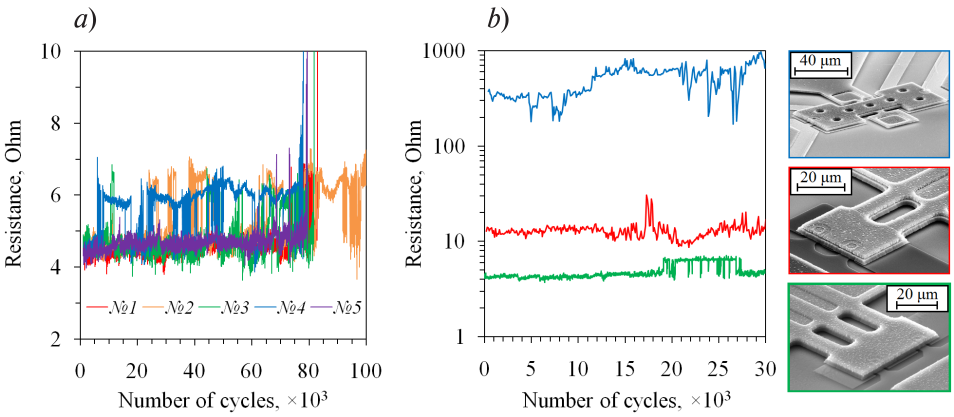

Fig. 2. Dependence of contact resistance on the number of switching cycles: for five switches with three elastic elements (*a*); for switches of three types (*b*)

Conclusion

The paper presents an electrostatic MEMS switch based on a compact aluminum cantilever with a length of 50 μm. The design of the switch provides maximum contact and restoring forces at small dimensions of the moving part. The pull-in voltage is of 69 V on average, which is 18% lower than the calculated value due to the bending of the cantilever under internal mechanical stress. The contact resistance is of 4–5 Ω for 5 thousand switching operations. Then it increases to 7–8 Ω and becomes unstable due to contamination of the contacts. However, the presented switch has significantly less resistance compared to previous developments of the authors.

REFERENCES

1. **Rebeiz G.M., Patel C.D., Han S.K.,** The search for a reliable MEMS switch, IEEE Microw. Mag. 14 (2013) 57–67.
2. **Shao B., Lu C., Xiang Y., et al.,** Comprehensive Review of RF MEMS Switches in Satellite Communications, Sensors. 24 (10) (2024) 3135.
3. **Percy J.J., Kanthamani S.,** Revolutionizing wireless communication: A review perspective on design and optimization of RF MEMS switches, Microelectronics Journal. 139 (2023) 105891.
4. **Uvarov I.V., Belozerov I.A.,** Design Guideline for a Cantilever-Type MEMS Switch with High Contact Force, Micro. 4 (1) (2024) 1–13.
5. **Belozerov I.A., Uvarov I.V.,** MEMS Switch Based on a Cantilever with Increased Contact Force, Russian Microelectronics. 52(6) (2023) 475–482.
6. **Czaplewski D.A., Nordquist C.D., Dyck C.W., et al.,** Lifetime limitations of ohmic, contacting RF MEMS switches with Au, Pt and Ir contact materials due to accumulation of ‘friction polymer’ on the contacts, J. Micromech. Microeng. 22 (10) (2012) 105005.
7. **Belozerov I.A., Uvarov I.V.,** A compact MEMS switch for advanced radar systems, St. Petersburg Polytechnic University Journal: Physics and Mathematics. 75 (3.1) (2024) 178–181.
8. **Uvarov I.V., Marukhin N.V.,** A seesaw-type MEMS switch with enhanced contact force: the first results, Journal of Physics: Conference Series. IOP Publishing. 2086 (1) (2021) 012069.

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