Contact resistance and lifecycle of an ohmic MEMS switch with single and multiple contact bumps

N V Marukhin and I V Uvarov
Valiev Institute of Physics and Technology of Russian Academy of Sciences, Yaroslavl Branch, Universitetskaya 21, 150007 Yaroslavl, Russia

E-mail: i.v.uvarov@bk.ru

Abstract. Microelectromechanical systems (MEMS) switches potentially have a wide range of applications due to their promising characteristics, but relatively low reliability limits implementation of these devices. Contact region degrades during operation that increases the resistance and lowers the lifecycle. In this paper we demonstrate how these parameters can be enhanced by changing the design of the switch. The devices of four types having different number of contact bumps and beams are fabricated by surface micromachining and tested in a cold switching DC regime. The switch with two bumps has about 25% lower contact resistance and almost two times longer lifecycle than the one-bump device. Using four beams instead of one gives threefold increase of the lifecycle, but does not reduce the resistance significantly.

1. Introduction
Radio-frequency switches fabricated by the microelectromechanical systems (MEMS) technology combine advantages of electromechanical relays and solid state switches. They provide superior radio frequency characteristics, small size, low power consumption and high integration capability [1]. Electrostatically actuated MEMS switches are especially popular, since they are relatively simple in design, fabrication and operation [2]. However, these devices have not achieved commercial success yet due to the lack of reliability [3]. The weak point of the ohmic MEMS switches is the contact of a micromachined beam with the drain electrode. The contact degrades during operation because of melting, material transfer, contamination and other phenomena [4]. As a result, contact resistance and insertion loss increase that leads to the switch failure. The reliability can be improved by proper selection of the contact material or choosing the optimal operation conditions. Another approach is to change the switch design. In this work we investigate the influence of two design solutions on the switch performance. The first one is to equip the beam with several contact bumps, while the second way is to use several beams. The switches of various layouts are fabricated and tested. The contact resistance and lifecycle are measured, analyzed and compared.

2. Materials and methods
The basic switch is shown in figure 1a. The movable electrode is a single beam attached to the anchors by the torsion hinges. It is fabricated of 1 μm thick Al film and is reinforced by the 1 μm thick Al ribs. The length of the beam is 100 μm and the width is 24 μm. Gate and drain electrodes are made of 100 nm thick platinum film and are placed under the each arm of the beam. Thus, the switch has two symmetric output channels. The gap between the beam and the gate electrodes is 1.5 μm. Platinum
contact bumps are located on the bottom side of the beam, so the device provides Pt-Pt contact. The channel is closed by applying a voltage to the corresponding gate electrode. The basic design includes one bump per arm (figure 1b), while the modified switch has two bumps per arm (figure 1c). Figure 1d illustrates the device with four beams connected to each other. The beams and suspensions have the same geometry as in the basic design. They are actuated by a common gate electrode and, therefore, operate simultaneously. Both one- and four-beam switches are fabricated in one- and two-bump versions. The fabrication procedure is described in the work [5].

Figure 1. SEM images of the MEMS switch: (a) the basic design with one beam, the main structural parts are shown by the arrows; (b) the switch with one contact bump; (c) the switch with two bumps; (d) the switch with four beams.

The switches are tested in a standard laboratory environment without packaging. Rectangular voltage pulses are periodically applied to the both gates in such a way that the channels are actuated alternately with the frequency of 3 Hz. The amplitude of pulses is 60 V. The opening of the channels is carried out by the elastic forces of the torsion springs. In order to avoid electric arcing, the switch operates in a cold switching conditions. The source voltage is applied after the beam touches the drain and is turned off before the contact breaks. The testing is performed at the source voltage of 5 V. A load resistance of 4.7 kΩ limits the current flowing through the switch by the value of 1 mA that corresponds to the transmitted power of 5 mW. The resistance of both channels is measured in the closed state at each actuation cycle.

3. Results and discussion

3.1. On-resistance
The resistance of the switch in the on-state $R_{on}$ randomly changes from several tens to several thousand ohms during the test. Typical dependence of $R_{on}$ on the number of switching cycles is presented in figure 2a. All the designs demonstrate similar behavior. It was shown previously that the parasitic resistance of the wires and signal lines is about 10 Ω [5]. Therefore, the main part of the total on-resistance is the contact resistance. The probable reason of the instability of $R_{on}$ is the accumulation of the carbon-containing material on the contacts [6]. After a certain number of cycles $R_{on}$ increases dramatically up to $10^8$ Ω. This increase is usually irreversible and is considered as a failure of the switch.
We tested several tens of samples of each type. The dependence of the on-resistance averaged over the samples on the number of cycles is shown in the figure 2b. It increases during the test, but the most rapid growth occurs in the first two thousand cycles for switches with one bump and in the first four thousand cycles for switches with two bumps. The values of $R_{on}$ averaged over the first five thousand cycles are given in table 1. Using two bumps instead of one reduces the resistance by about 25% for both one- and four-beam designs. This indicates that both bumps touch the drain, thereby expanding the contact area. However, increasing the number of beams does not reduce $R_{on}$ significantly. For the one-bump design the reduction is 5% only, and no decrease is observed for the four-beam switch. To all appearance, the current flows only through one beam at each cycle due to the random behavior of the contact resistance.

3.2. Lifecycle
The lifecycle is measured as the number of switching cycles that the device withstands until failure. The average values of the lifecycle are given in table 2. The basic switch with one bump and one beam has the lowest durability of $2.3 \times 10^4$ cycles. Increasing the number of bumps prolongs the lifecycle more than two times, which can be explained by the distribution of the transmitted power between the bumps. Using four beams instead of one gives an almost triple enhancement of the durability. When the contact at one beam fails, the current is shared by the remaining beams, and the switch continues operation until the failure of the last beam. As a result, the two-bump four-beam switch demonstrates the longest lifetime of $14.5 \times 10^4$ cycles. In general, large scatter of the lifecycle is observed for all types of the switch, see table 2. Contamination of the contacts is considered as the main reason of this phenomenon.

![Figure 2](image)

**Figure 2.** (a) The on-resistance of the channel of the one-beam one-bump switch during the test; (b) Evolution of the average on-resistance during the first five thousand cycles.

| Layout       | One beam | Four beams |
|--------------|----------|------------|
| One bump     | 379 Ω    | 362 Ω      |
| Two bumps    | 283 Ω    | 283 Ω      |

**Table 1.** The on-resistance averaged over the samples and the first five thousand cycles of the test.

| Layout       | One beam | Four beams |
|--------------|----------|------------|
| One bump     | $2.3 \pm 4.1$ | $6.8 \pm 7.2$ |
| Two bumps    | $4.7 \pm 4.9$ | $14.5 \pm 13.7$ |

**Table 2.** The mean value and the scatter of the lifecycle ($\times 10^4$) of the switches with various designs.
4. Conclusions

The contact resistance and lifecycle of the electrostatically actuated MEMS switch with single and multiple contact bumps were investigated. The switch operated in the cold regime at the transmitted power of 5 mW. Multiple contacts are achieved in two ways: by increasing the number of contact bumps of the beam and by increasing the number of beams. Using two bumps instead of one reduces the on-resistance by about 25% and prolongs the lifecycle by more than two times. Using four beams instead of one gives threefold increase of the lifecycle, but does not reduce the on-resistance significantly. Among several designs, the four-beam switch with two contact bumps per arm demonstrates the highest performance. It has the average on-resistance of 238 $\Omega$, which is 25% lower than $R_{on}$ of the basic switch, and the average lifecycle of $14.5 \times 10^4$ cycles, which is 6 times longer than the lifetime of the basic single-beam single-bump device.

Acknowledgments

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