MICRO UNDULATED CONTACT SURFACES ON THE CONTACT BEHAVIOR OF A MEMS SWITCH

Yong Shi\textsuperscript{1} Sang-Gook Kim\textsuperscript{2}

\textsuperscript{1} Mechanical Engineering Department, Stevens Institute of Technology, Hoboken, NJ, USA
\textsuperscript{2} Department of Mechanical Engineering, Massachusetts Institute of Technology, Cambridge, MA, USA

ABSTRACT
A novel direct contact micro-device has been developed with periodically micro-grooved lateral metal contacts on the sidewall of the MEMS relay. The uniqueness of the design lies in the self-cleaning mechanism of the micro-grooved lateral metal contacts. The concept-proving device is fabricated by integrating a high aspect ratio polymer beam structure with lateral metal contacts. The long lifecycle test shows that the contact resistance has been maintained below 0.1 ohm over 10 billion cycles. The switch design is compatible to the surface micromachining processes and can be readily integrated into a fully functional MEMS relay. Our design opens the possibility of direct contact MEMS switch for both high power and low cost wireless applications.

1. INTRODUCTION
Recently, RF MEMS switches have drawn great deal of research interests from both academic and industry because they can provide extremely advantageous performances such as lower insertion loss and much higher isolation over solid-state switches, for example, p-i-n diodes. Since the first MEMS switch developed by Petersen in 1979 \cite{1}, different kinds of MEMS switch have been developed by a number of research groups. The typical life cycle requirement for a RF switch for radar systems and other instrumentation systems is over 40 to 100 billion cycles \cite{2}. At the present time, there is no direct contact MEMS switch to meet the life cycle requirement. The objective of this paper is to understand the functional requirements and the failure modes of MEMS RF switch, and develop a long life cycle direct contact MEMS switch by introducing a functionally periodic electric contact, which self-cleans contact surface at every switching cycle.

2. SWITCH DESIGN
The axiomatic design approach is used to investigate and determine the functional requirements of an RF switch systematically. There are several parameters, which have been used to define the performance of an RF switch, however, not all of these parameters are independent. Contact resistance is one of the dominant factors. The functional requirements of a new RF MEMS switch can be summarized as how to provide and maintain the low contact resistance and the high isolation over a long cycles of operation.

![Figure 1: Lateral contact switch design](image)

The conceptual switch design is shown in Figure 1. It’s a lateral contact series switch. Each switching member consists of two parallel beams with associated angled contact surfaces at the tips that are all floating. One of the contact surfaces is undulated (with micro-grooves). Gold or other noble metals are to be electroplated on the contact surfaces as well as the transmission line along the beams and pads. When the movable members meet the fixed members under a linear controllable motion, the physical contacts between the two pairs of angled surfaces will create a short circuit in the transmission line.

The uniqueness of this design is the undulated or functionally periodic contact surface. Debris or microweldments generated on the contact area during operation are to be cleaned through micro sliding motion between the two surfaces, and then trapped in the micro grooves fabricated on one of the surfaces. Undulation for low friction surface engineering was first
developed by Suh [3] and this research adapts the concept to micro-scale device design. Low contact resistance is to be maintained throughout long cycles of operation by refreshing the surface at every cycle of contact.

In order to implement the switch concept above, we have conducted three types of modeling. The switch performances modeling, contact resistance modeling and switch-actuator coupled analysis were made to determine the switch geometry and provide the displacement and force requirement to the switch actuator.

3. FABRICATION
The process steps of the MEMS switch including the actuator part and the switch part are shown in Figure 2.

Su-8 is chosen as the mold and structural material. From step a) to step c) shown in Figure 2, PZT actuator is deposited and patterned. In step d), Su8 mold is coated and patterned. In step e), electroplating of the contact metal is conducted. In step f), the electroplating mold is removed and in step g), the switch structural Su8 is coated and patterned. The device is finally released using XeF$_2$ etcher.

The fabricated contacts and switch are shown in Figure 3, which shows the switch structures and the grooved contacts.

4. TEST AND MEASUREMENT
Contact resistance is measured using 4-probe method, which measures the voltage drop at the contact and also the current in the circuit directly. A ceramic piezo stack actuator is used to drive the switch. Figure 4 shows the contact resistance measurement over a number of operation cycles. It has been demonstrated that the switch contact resistance has been maintained at about 0.1 Ω over 10 billion cycles. No structural failure has been observed during the test.

It’s reported that there are two major failure modes for MEMS micro-switches [4], which are damage, pitting and surface hardening and micro welding between switching members. The micro grooved surface design have largely eliminated these causes and increased the life cycles of the switch dramatically. Figure 5 shows the grooved contact areas after the cycling test, which indicates that the grooves have been flattened after the test. The hardness of the metal contact and form factor of the microgrooves need to be optimized in the future research.

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REFERENCES

Figure 2: Fabrication steps for the MEMS switch

Figure 3: The switch structure with the embedded metal contacts

Figure 4: Contact resistance measurement

Figure 5: Contact metals after the cycling tests