Design and Fabrication of a Microelectromechanical Switch

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Surface micromachining technique was applied to produce electrostatically actuated microelectromechanical (MEMS) switch. Vibrating cantilever beam of varying length was fabricated using a copper sacrificial layer and nickel electroplating technique. The length and thickness of a cantilever beam as well as a gap space determines actuation voltage and should be optimized to ensure the best performance of a switch. The fabricated microelectromechanical switch can be used as autonomous electrostatically driven microrelay or can be integrated for use in semiconductor chips or hybrid devices.

Keywords: surface micromachining technique, microelectromechanical (MEMS) switch.

1. INTRODUCTION

In the recent years, the field of microelectromechanical systems (MEMS) has quickly developed from pure research into wide spread industrial applications. Especially in the last few years, MEMS has significantly impacted the fast developing fields of information technologies, the biomedical and biological industries, and becomes one of the strong pushing force behind industrial automations [1, 2].

The MEMS technology is based on the semiconductor fabrication process. Basic techniques of MEMS are surface micromachining and bulk micromachining. Surface micromachining technique uses the metal or polysilicon structure above the substrate, which is similar to the conventional semiconductor process. Bulk micromachining uses the characteristics of silicon wet etching. Other technique such as wafer bonding, deep silicon etching are being developed. Conventionally, the MEMS technology is used to fabricate the physical sensors such as pressure sensor, accelerometer, gyroscope, micromotor and other devices. The surface micromachining technique predominatly is based on the LIGA (Lithographie, Galvanoformung, Abformung) process. The LIGA process uses synchrotron radiation to expose the resist. The short X-ray wavelength allows deep (up to 1 mm) resist layers to be exposed without significant diffraction effects, and high aspect ratio structures can be made.

Electrostatic actuation is employed in a wide variety of MEMS for applications ranging from switches to valves and displays. The applications for such devices include electromechanical switches and relays [3], optical switches [4], displays [5], valves [6], flow control actuators [7], microscale mechanical testing instruments and structures [8 – 11], and tunable vertical cavity lasers [12].

Selected material for the electrostatic actuation determines actuation voltage, speed of actuation, actuation force, stroke (or displacement), stored energy, electrical resistivity, mechanical quality factor, and resistance to fracture, fatigue, shock, and stiction. These parameters are determined by the selected materials properties, such us Young's modulus, density, fracture strength, intrinsic residual stress, resistivity, and intrinsic material damping. Materials properties must be estimated during MEMS design stage. Diamond, alumina, silicon carbide, silicon nitride and silicon are good candidates for high-speed, high-force actuators; polymers for large displacement, low actuation voltage devices; and aluminium for low-electrical resistivity, low actuation voltage and high-speed actuators [13].

A kind of MEMS - mechanical switches based on metal-to-metal contact are useful in a variety of power management, information processing and communication systems because their on–resistance is lower than that of semiconductor switches and their off–resistance and transmission frequency are higher. Electromechanical switches can be found in all manner of electrical devices ranging from toys to automobiles, telephone switches to major appliances or RF applications [14].

In this work we present microelectromechanical switch, fabricated using *s*urface micromachining technique and employing UV-exposure of a special thick resist for the nickel electroplating. Different substrates have been tested and technical solutions to increase the cantilever bond strength either durability of the device in action were proposed.

2. DESIGN

A low contact resistance, low threshold voltage, high switching speed and other factors must be estimated in the design stage. The threshold voltage may be reduced by increasing the area of the gate, (thus increasing the electrostatic force acting on the beam), reducing the

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thickness of the cantilever beam or by reducing the gap between the cantilever beam and the gate electrode. Reducing the thickness will limit the maximum switching speed. Reducing of the gap will increase undesirable capacity between the gate and signal line.

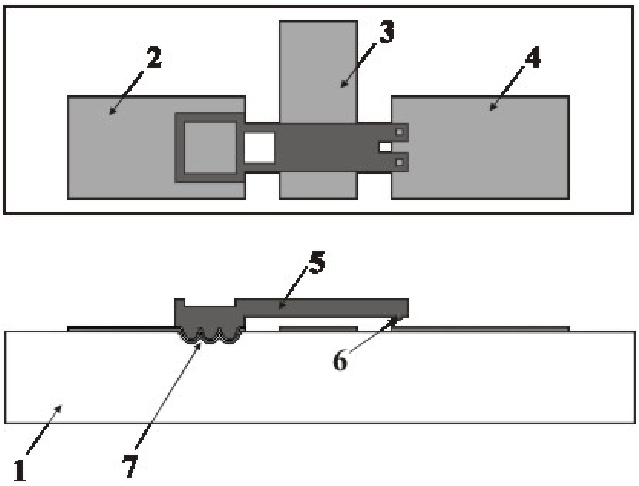

Fig. 1. Schematic illustration of the fabricated microelectromechanical switch: 1 – substrate, 2 – source, 3 – gate, 4 – drain, 5 – cantilever beam, 6 – contact tip, 7 – microstructures (support area)

Schematic illustration of the fabricated microelectromechanical switch is shown in Fig. 1. An array of devices was designed using different lengths of the cantilever beam (67, 87 and 117 µm, measuring from the support area). Cantilever beam (5) was made of electroplated nickel, contact tips (6) and source (2), gate (3) and drain (4) surfaces were coated by the gold film to decrease the contact resistance. The devices were successfully fabricated on different substrates (1), including high resistance silicon, quartz and ceramics. The evident originality of the device is application of the microstructures (7) in the cantilever source (support) area. The width of the cantilever beam was 30 µm, the thickness was about 1.5 µm and the contact tip to gate spacing varied from 0.75 to 1.5 µm, respectively.

3. FABRICATION

The fabrication sequence (Fig. 2) of the microelectromechanical switch begins with the patterning and reactive ion etching of silicon using SF_6/N_2 gas chemistry in the cantilever source (support) area producing microstructures to increase the cantilever beam bond strength either durability of the device. After treatment of the substrate in the O_2/N_2 gases mixture plasma chrome layer of about 30 nm thickness and gold layer of about 200 nm thickness were deposited. Patterning of the source, gate and drain electrodes was performed using lift-off lithography. Electron beam evaporation was performed to deposit a sacrificial copper layer (thickness varied from 1500 to 3000 nm). Copper layer covered the whole area of the substrate. Patterning of the copper layer was performed in two steps. First of all, the copper layer was partially etched (etchant: $H_2SO_4 : CrO_3 : H_2O$) to define the contact tips for the cantilever beam and etching duration directly determined the spacing between contact tip's top and drain electrode. Next, the copper layer was etched away to uncover the source cantilever support area. The next step was photoresist patterning on the top of the sacrificial layer to define the mask for the cantilever beam sector and lift-off lithography of the evaporated gold layer with thickness of about 200 nm was performed. Afterwards, the photoresist was spun and patterned once again in the same sector and nickel layer was electroplated (sulfamate electrolyte: $Ni(NH_2SO_3)_2 : 4H_2O$) fabricating cantilever beam structure. Finally, the sacrificial layer was removed away using the same wet copper etchant to release the free-standing cantilever beam of varying length. SEM photographs illustrate fabricated microelectromechanical switch in Fig. 3 (top view), Fig. 4 (cantilever beam support area) and Fig. 5 (contact tip gap).

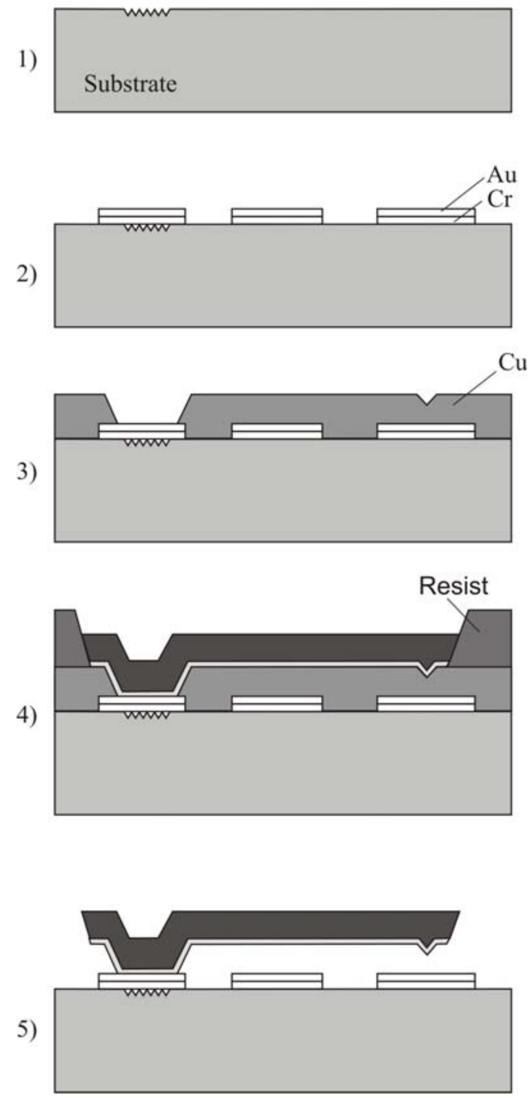

Fig. 2. Fabrication sequence of a microelectromechanical switch: 1 – patterning and etching of the microstructures in the source support area, 2 – "lift-off" photolithography of Cr-Au bilayer, 3 – processing of a sacrificial Cu layer, 4 – evaporation and "lift-off" of Au layer; patterning of the thick resist and Ni electroplating, 5 – removal of a sacrificial layer

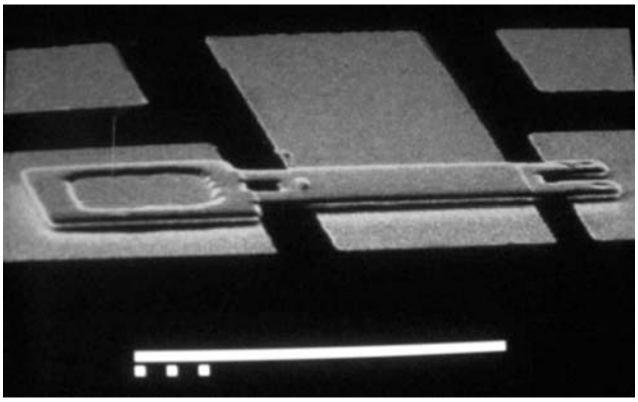

Fig. 3. Top view of a microelectromechanical switch. Mark size 100 μm

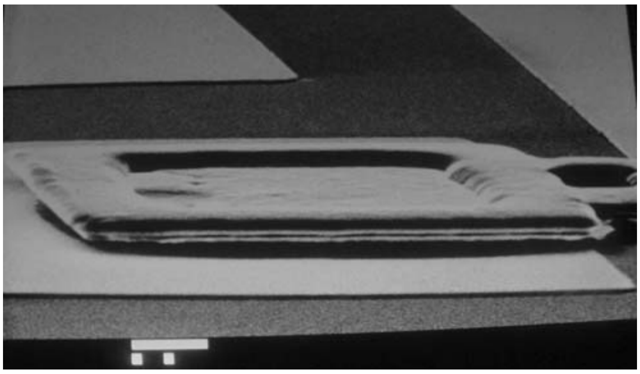

Fig. 4. Cantilever beam support area. Mark size 10 μm

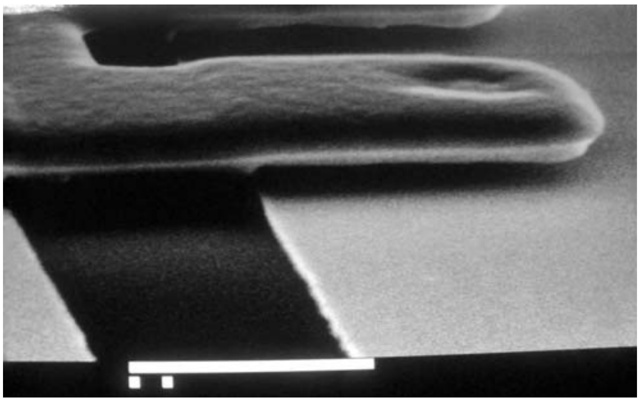

Fig. 5. Contact tip gap. Mark size 10 μm

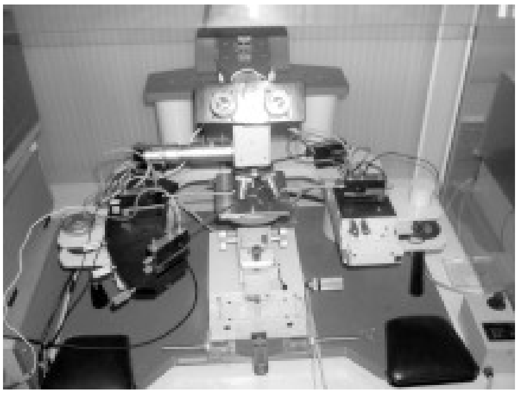

Fig. 6. Testing stand of a microelectromechanical switch

4. TESTING

When voltage is applied to the gate electrode, the cantilever beam is pulled down by electrostatic force until the switch closes. Microelectromechanical switch was tested in the original stand (Fig. 6) using a measurement circuit as shown in Fig. 7. As it can be seen from Fig. 8, actuation voltage is defined by the length of a cantilever beam and a gap space. In the case of the shortest (l = 67 μm) cantilever beam, the actuation voltage reaches up to 140 V. It should be noted, that design parameters predetermines the switch operating frequency, maximum value of current, passing through the switch and quantity of the operation cycles (durability). We are still experimenting on optimization of d/l relation and thickness of a cantilever beam as well as on materials selection to ensure the best fittings of a microelectromechanical switch for RF signal applications.

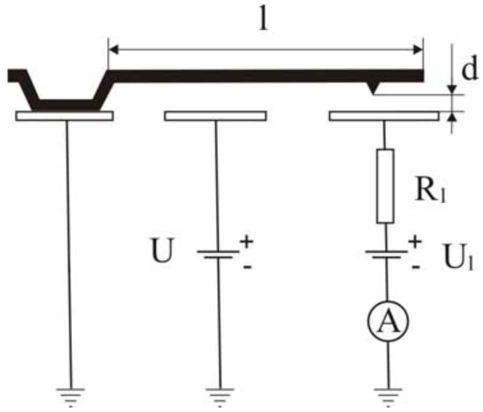

Fig. 7. A measurement circuit of a microelectromechanical switch, l – length of the cantilever, d – contact tip gap

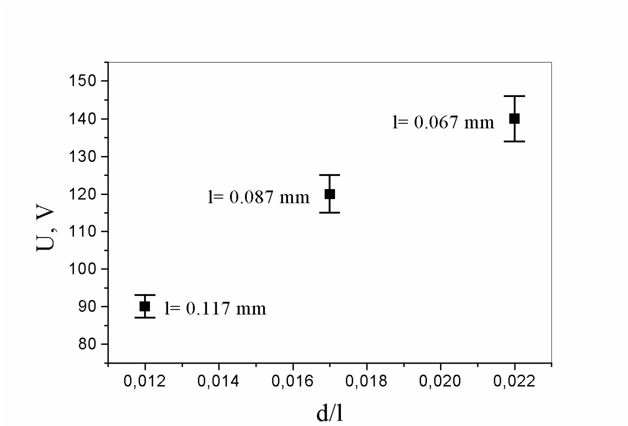

Fig. 8. Actuation voltage versus relation of a gap space (d) and cantilever beam length (l). The thickness of the cantilever beam is about 1.5 μm

5. CONCLUSIONS

Surface micromachining technique was applied to produce electrostatically actuated microelectromechanical (MEMS) switch. Vibrating cantilever beam of varying length was fabricated using a copper sacrificial layer and a nickel electroplating technique. The length and thickness of a cantilever beam as well as a gap space determines actuation voltage and should be optimized to ensure the best performance of a switch.

A fabricated microelectromechanical switch can be used as autonomous electrostatically driven microrelay, which substitute for usual relay or power field transistors in the cars and its testing equipment, telecommunications, measurement technique etc. In the design stage microelectromechanical switch can be adapted to the specific needs, e. g., may be formed on high resistance semiconductor (Si, GaAs, InP) substrate that enables to use it in semiconductor integrated circuits for the commutation of high power signals or on dielectric (quartz, ceramics) substrate that is prerequisite for its using in hybrid microelectronic devices.

Acknowledgments

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