THERMAL MICROACTUATOR

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The greatest promise of microelectromechanical systems (MEMS) lies in the ability to produce mechanical motion on a small scale. Such devices are typically low power and fast, taking advantage of such microscale phenomena as strong electrostatic forces and rapid thermal responses.

A microactuator is the key device for the MEMS to perform physical functions. Thermal actuators can generate relatively large force and displacement at low actuating voltage. The deflection can linearly increase, as the control voltage is increased within a large range. Potential applications are switching of optical components such as mirrors and shutters, micro relays etc.

Keywords: MEMS, Thermal microactuator, Heatuator, Surface micromachining

INTRODUCTION

The actuators have an important role in MicroElectroMechanical Systems (MEMS). They aim to change the parameters of the controlled environment, as a result of the information, obtained from the sensors in the system. The thermal microactuators are only one type of the wide variety actuators, used in MEMS. As a result of heating, they make some displacement, which allows them to be used in different fields like optics, medicine, communications, positioning, computer systems, fluid pumping etc.

Thermal actuation has been extensively employed in MEMS. It includes a broad spectrum of principles, such as thermalpneumatic, shape memory alloy (SMA) effect, bimetal effect, mechanical thermal expansion, etc. According to the principle, used for actuation, the thermal actuators can be classified in some of the following groups: thermal bimetallic, thermal pneumatic, electrothermal and thermal mechanical expansion microactuator.

Bulk and surface micromachining are two basic and major micromachining techniques, which are used in MEMS [1]. These both techniques, together with LIGA process are suitable to produce the thermal microactuator.

One of the most known thermal actuators, elaborated from John Comtois and Victor Bright is the electrothermal horizontal microactuator. In this case, the different thermal extension of two or more mechanical elements is used. As a result, some horizontal or vertical displacement is obtained. For creating this actuator, the surface micromachining technology can be used.

DESIGN OF THE THERMAL MICROACTUATOR

Thermal microactuators are a promising solution to the need for large-displacement, low-power MEMS actuators. Potential applications of these devices are micro-relays, tunable impedance RF networks, extremely precise medical instrumentation etc. The first thermal actuators, developed for such applications were made through thin film deposition of polycrystalline silicon (polysilicon). In the last five years though, the range of materials used for thermal actuators has been expanded to metals and single-crystal silicon. While polysilicon devices have the advantage of easy integration with on-chip electronics and relatively low-power consumption, the polysilicon layers are only a few microns thick, they are brittle, and can result in higher ON-resistance, when are used as a part of a switched circuit. These limitations have been partially minimized by the advent of actuators, made by selectively doped single-crystal silicon. The selective doping of these silicon devices can potentially reduce their ON-resistance, while maintaining the larger temperature difference in the two actuating arms of the actuator.

In comparison to (poly)silicon devices, metallic thermal microactuators have a larger thermal expansion coefficient and can thus undergo larger deformations for a given temperature difference.

The geometry of a typical micro-actuator is shown in Fig. 1 [2]. There are two types of actuators: thermal bimorphs, in which two different thermal expansion coefficient materials are used, and homogeneous actuators, in which a temperature difference is set between the narrower "hot" and the wider "cold" arm (thermal horizontal actuator). In both devices, a bending moment is created in the two beams, and the two-arm structure deflects towards the beam with smaller expansion.

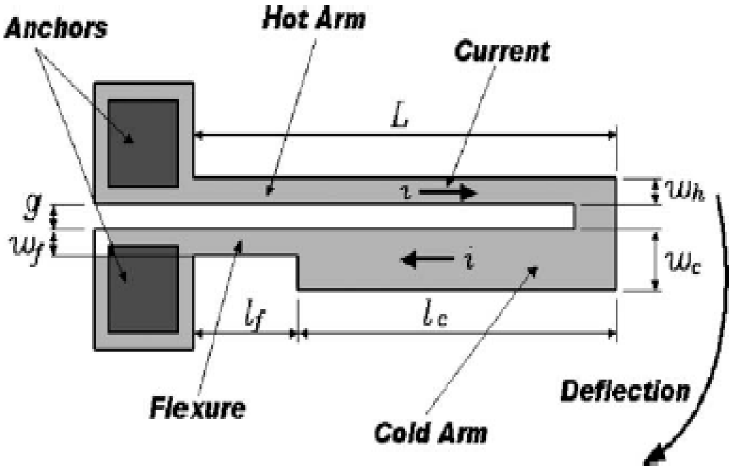

Fig. 1 Thermal microactuator

In this paper, we describe an actuator of the homogeneous type. Both arms of the actuator are made by using of nickel layer. Then, the maximum temperature difference between the hot and cold arms can be estimate as:

$$\Delta T \leq \frac{\pi^2.w^2}{3.L^2.\alpha_T}, \qquad (1)$$

where the thermal expansion coefficient for Ni is - $\alpha_T = 13{,}1.10\text{-}6$ °C-1.

Because of the heating, the length of the hot arm is changing. It is thermally expanded. The expansion is defined as:

$$\Delta L = \alpha_T.\Delta T.L_0 \qquad (2)$$

The deflection of the flexure is:

$$I = \frac{2}{3}.h.\left[\left(w + \frac{g}{2}\right)^3 - \left(\frac{g}{2}\right)^3\right] \qquad (3)$$

where $w = w_h = w_f$.

The free-beam deflection, δ of the actuator can be estimated as [2]:

$$\delta = \frac{\alpha_T.\Delta T.l_c.h.w.(w+g).(2.l_f.l_c + l_f{}^2)}{2.I.(2.l_f + l_c)} \qquad (4)$$

where α_T is the thermal expansion coefficient, $\Delta T = T_{hot} - T_{cold}$, where T_{hot} and T_{cold} are the temperatures of the "hot" and "cold" arms respectively, g is the gap between the hot arm and the flexure;

The values and dimensions of the actuator, which are used in the calculation, are shown in Table 1.

Table 1

Parameter	Value, µm
L	600
l_f	200
l_c	400
w	15
w_c	25
h	16,5
g	15

It is important, that the expansion of the hot arm and the deflection of the actuator are dependent on the thermal difference between the two arms. The values of deflection and expansion are published in Table 2.

Table 2

Temperature difference - ΔT, ˚C	Expansion - ΔL, µm	Deflection - δ, µm
100	0,78	8,1
105	0,82	8,48
110	0,86	8,89
115	0,9	9,29
120	0,94	9,69
125	0,98	10,1
130	1,02	10,5
135	1,06	10,91
140	1,1	11,31
145	1,14	11,72
150	1,18	12,12

In the best case, the flexure is expected to be as narrow as possible [3]. When the flexure becomes narrower, more deflection of the thermal actuator tip can be generated, by the different thermal expansion between hot and cold arms. But, if the flexure is narrower than the hot arm, the temperature of the flexure could be higher than that of the hot arm, which might result in overheating. Also, in order to keep it elastically deflecting, the flexure should be long enough. However, if the flexure is too long, the deflection of the thermal actuator tip will be reduced.

The technology of a horizontal thermal actuator is shown in Fig. 2. A silicon wafer is used as a carrier. There are used layers of copper and nickel, deposited on a silicon surface. The first step of technology is deposition of copper layer on top of silicon wafer, by using of a thermal evaporation process. This layer will be used as a sacrificial layer in the surface micromachining technological sequence, which is chosen. The thickness of this layer is 15µm. It is very important, the silicon surface to be very clean, because only in this case, it can be achieved an optimum adhesion between silicon and copper. One part of the layer could be created by vacuum evaporation and the rest of the layer - by electrochemical deposition. On the next step, a photoresist layer, 16,5 µm thick is deposit. A single photolithography step is used to form a photoresist mold for electroplating of Ni. The layer of nickel is 16,5 µm thick. The actuator release is achieved via timed wet etching of the underlying copper in $(NH_4)_2S_2O_8$ solution. During this step, the wider features are not completely undercut and therefore, they are fixed to the underlying substrate, acting as anchors for the device.

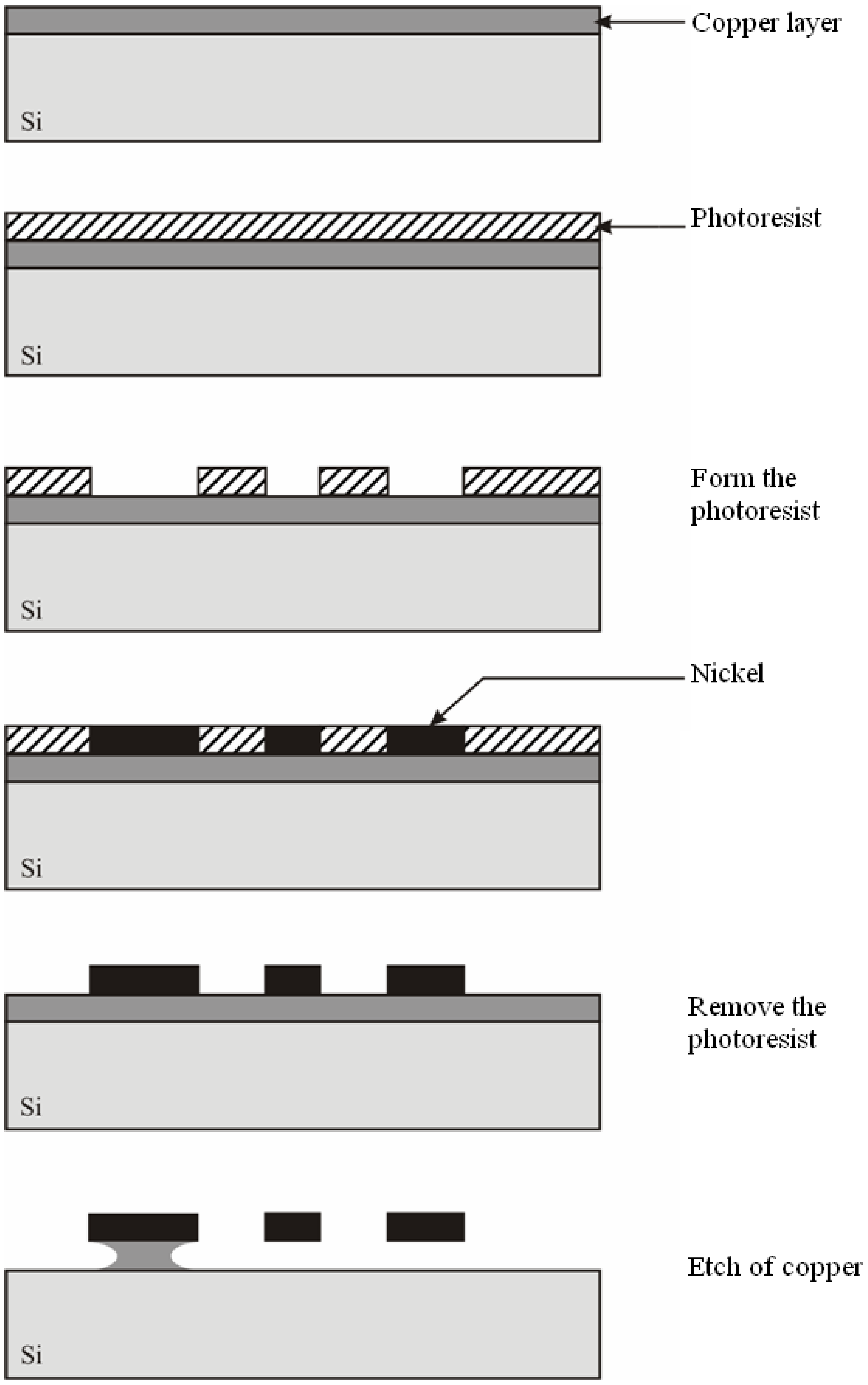

Fig. 2. Technology of horizontal thermal actuator

Most of the thermal microactuators are elaborate on a silicon surface, but similar devices can be made also on PCB substrate.

The integration of the MEMS structures onto the printed circuit board has several advantages:

- Metal-ion contamination of semiconductor devices is avoided.
- The process is compatible with RF and microwave copper circuit fabrication.
- There is no need to modify the existing integrated circuit processes in order to incorporate the MEMS structures in them.
- Reduced power consumption.
- Simpler and inexpensive fabrication process.

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