MEANDER-LINE PIEZOELECTRIC ACTUATOR

Krassimir Hristov Denishev[1], **Vladislav Lyusienov Tabakov**[2]

[1] Department Microelectronics, Technical University - Sofia, Kl. Ohridski Str. No.8, bl. 1,
1797-Sofia, Bulgaria, phone: +359 2 965 31 85, khd@tu-sofia.bg

[2] Department Microelectronics, Technical University - Sofia, Kl. Ohridski Str. No.8, bl. 1,
1797-Sofia, Bulgaria, vl_s@abv.bg

A novel type of microactuator for linear displacements is presented. For the electrical to mechanical energy transformation it uses piezoelectric thin films. To produce linear displacement, this actuator uses a folded (meander-line geometry) path. The surface micromachining procedure is proposed. A particular set of dimensions is chosen and the actuator is designed. For quantitatively estimation of the performance of the actuator, an electromechanical model is developed and used. The results from the evaluation of the structure of meander-line actuator are shown. For producing the microactuator, fabrication procedures have been developed and presented. The technology sequence is in compliance with the standard CMOS technologies and could be performed together with some of them. The status of the fabrication efforts is given.

Keywords: MEMS, Linear actuator, Meander-line actuator, Piezoelectric layer

INTRODUCTION

Microelectromechanical systems (MEMS) are units, containing sensor, signal processing and actuator devices, integrated on the same substrate and produced by using some of semiconductor or/and hybrid technologies. These systems usually use some building elements, prepared on top, or in the volume of specially created micromechanical devices, like microcantilevers, microbridges or micromembranes. That's why these mechanisms can be described, as structures with dimensions smaller than one millimeter, that allow them to be integrated easily together with microelectronic devices on the same chip. The basic mechanisms in the microelectromechanical systems are sensors and actuators. Sensors register and measure some nonelectrical parameters of the controlled media, like pressure, temperature, acceleration, intensity of light, flow etc. After information data-processing, to perform some corrections of the controlled parameters, micromechanisms, called microactuators are used. The change of these parameters could be realized in a different way, depending on the type of nonelectrical quantity, for example the actuator makes displacement, positioning, filtering, pumping etc. Microactuators are widely used in MEMS. That's why, some times, the changes in the controlled parameters are very small and this fact makes them very precise devices [3].

The linear actuators are widely used in MEMS. A linear microactuator, it is an actuator, which moves in a straight line in a defined direction, producing some force. This definition is in opposite to the rotational actuator, which rotates and produces a torque. In microelectormechanical systems, several kinds of actuators for linear displacement are used. For example, such are electrostatic, temperature, magnetic, electromagnetic, piezoelectric actuators etc. Linear microactuators are used in many applications with precise positioning, such as electronic relays, computer disk drives, micromeasurement equipment, micromotors, surgery tools, magnetic heads positioning etc.

In MEMS, for making linear actuators, bulk and surface micromachinings are the most frequently used technologies.

Increasing attention, as an alternative to electrostatic-based and thermal-based actuation concepts, this is the use of piezoelectric materials. Very important advantages of piezoelectrics, these are their big energy densities, lower operating voltages, and greater force generation capabilities. Currently, micron-scale ultrasonic motors for both, rotary and linear motion, are very interesting and attractive.

DESIGN OF MEANDER-LINE ACTUATOR

The meander-line actuator, shown on Fig. 1, is producing linear displacement. It is a kind of piezoelectric actuator, having the advantages, discussed before. Another big advantage of this actuator, this is the fact, that it produces both horizontal and vertical displacement. Its calculations are not very difficult.

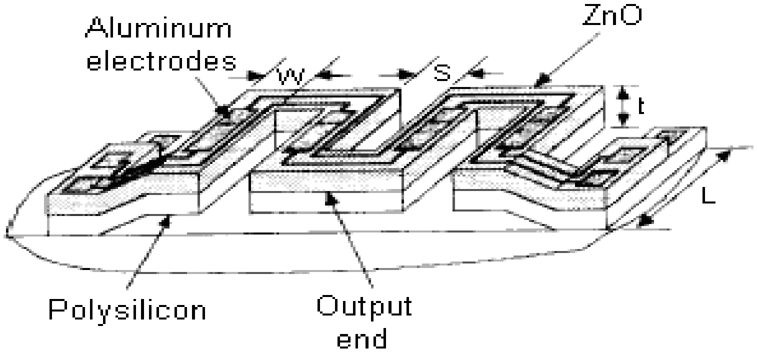

Fig. 1. Meander-line actuator

To produce this actuator, some ordinary materials are necessary. As piezoelectric layer, ZnO is used.

The technological sequence for creation of meander-line actuator is shown in Fig.2. There, three photolithography masks are used [1,2]. One of the most typical structures in the case of surface micromachining, the sacrificial layer should be chosen. As a device carrier, a silicon wafer is used. The first step of the technology sequence, this is the deposition of PSG (phosphorous-silicate glass) layer on top of the silicon wafer. Before its deposition, the silicon surface has to be very clean. After that, the surface is oxidized in phosphorous rich atmosphere. Because of the bonding of the phosphorous atoms to the silicon surface, it is created layer of PSG, 1 μm thick, which will be used as a sacrificial layer. The next stage of the technology is to etch away the PSG-layer, leaving it only on the places, where the meander will be built. Over the layer of phosphorous-silicate glass, a layer of 1 μm polysilicon is

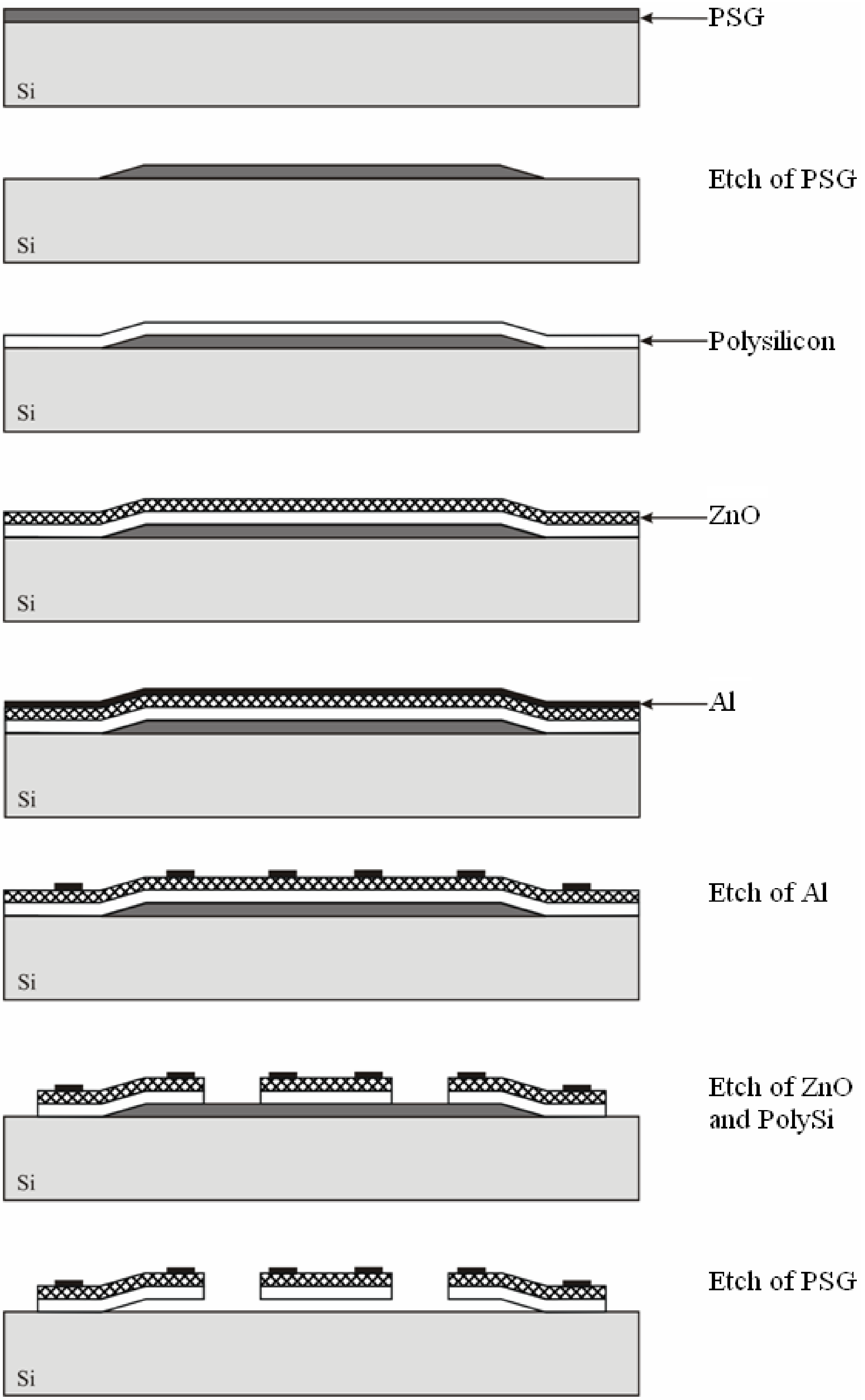

Fig. 2. Technology for a meander-line actuator

deposited. For deposition of this layer, CVD process is used. The next step of the technology, it is the deposition of 1 μm ZnO piezoelectric layer on top of polysilicon. For this deposition a CVD process is used. The next aluminum layer is deposit by using a thermal evaporation. The thickness of aluminum layer is around 0,4 μm. On the next step this layer is etched away and the aluminum electrodes and wires are formed. After that, the polysilicon and ZnO are etched at the same time. The etching is done until the layer of PSG is reached. On this step, the lines of the meander-line actuator are formed. At the end of the sequence, the sacrificial layer of PSG is etched away, by using hydrofluoric acid (HF) containing solution.

The main disadvantage of the meander-line actuator is its very large vertical dimensions. The layers of polysilicon and ZnO forms sandwich structure with thickness 2 micron, and the layer of PSG is 1 micron thick.

The meander-line actuator can be modeled in an approximate manner by two springs, shown in Fig. 3 [1,2]. The large spring, with a spring constant $\mathbf{k_1}$ represents the effect of the piezoelectric bars. The force source $\mathbf{F_{eff}}$, which represents the piezoelectric properties of the piezoelectric layer is the element in the model, which generates the displacements, produced by the actuator. The second spring, with spring constant $\mathbf{k_{bd}}$ represents the combined response of all meander-line elements, both the piezoelectric elements and the connecting bars between them, to the bending moment, produced by the external load. The model applies to both, horizontal and vertical displacement mode.

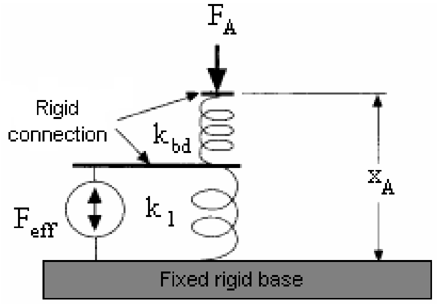

Fig. 3. Electromechanical model of the meander–line actuator.

For the horizontal displacement mode, the model parameters are:

$$k_{bd} = \frac{4.E_{ps}.t.W^3}{3N(N+1)(W+S)^2(L-W)} \qquad (1)$$

$$k_1 = \frac{2.E_{ps}.t.W}{N(L-W)} \qquad (2)$$

The dimensions **L**, **W**, and **t** are defined in Fig. 1. $\mathbf{E_{ps}}$ is Young's modulus of the polysilicon and **N** is the number of bars per actuator half-section. The force source $\mathbf{F_{eff}}$ is given by:

$$F_{eff} = 2.d_{13}.E_{pz}.W.U \,, \tag{3}$$

where $\mathbf{d_{13}}$ is the piezoelectric constant of piezoelectric layer, $\mathbf{E_{pz}}$ is Young's modulus of the layer, and **U** is the applied voltage. The thickness of the structure **t** is given by:

$$t = t_{ps} + t_{pz} \,, \tag{4}$$

where $\mathbf{t_{ps}}$ is the thickness of the polysilicon layer, and $\mathbf{t_{pz}}$ is the thickness of piezoelectric layer.

For the vertical displacement mode, the model parameters are given by:

$$k_{bd} = \frac{2.E_{ps}.W.t^3}{3N(N-1)(L-W)} \tag{5}$$

$$k_1 = \frac{E_{ps}.W.t^3}{2N(L-W)^3} \tag{6}$$

The force source $\mathbf{F_{eff}}$ is given by:

$$F_{eff} = \frac{3.W.t.E_{pz}.d_{13}.U}{2(L-W)} \tag{7}$$

The overall displacement, produced by the actuator, in either mode of operation is given by:

$$x_A = \frac{F_A}{k_{bd}} + \frac{F_{eff}}{k_1} \tag{8}$$

To estimate the displacement in the horizontal mode, the parameters defined in Eqs. (1 ÷ 3) are used. For vertical mode displacement, the parameters defined by Eqs. (5 ÷ 7) are used.

The performance that can be expected from the meander-line actuator is best explained by means of a numerical example. An optimistic set of design parameters is listed below.

The parameters, obtained from the use of electromechanical model, for both modes of operation, are summarized in Table 1, where **L** is the length of the lines, **W** is the width of one meander line and **S** is the gap between two meander lines. The applied voltage is 2 V, and the number of the meander lines is 20.

Table 1

Parameter	Value
L	500 μm
W	15 μm
S	5 μm
t_{ps}	1 μm
t_{pz}	1 μm
N	20
U	2 V
E_{ps}	$1{,}5.10^{11}$ N/m^2
E_{pz}	7.10^{10} N/m^2
d_{13}	3.10^{-10} m/N

When the equations (1 ÷ 8) and the parameters from Table 1 are used, the horizontal displacement of the meander-line actuator is 1,35 micron, and vertical displacement is 975 micron.

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