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Design and Analysis of Microgripper for Various Piezoelectric Materials

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Abstract Micro Electro Mechanical System (MEMS) is a highly miniaturized device or an array of devices combining electrical and mechanical components. The microgripper uses a piezoelectric stack actuator for the parallel movement of gripping arms. Microgripper is a device used to grip and handle various micro or nano objects. In this paper the mathematical model of the micro gripper is proposed and its effects on the displacement are analyzed in MATLAB. The microgripper is designed in COMSOL for different piezoelectric materials such as lead zicronate titanate, Bismuth germinate and barium titanate and obtained results are compared with theoretical results.

Keywords Microgripper, Actuator, Piezoelectric Materials

1. Introduction

Micro Electric Mechanical System or Microsystems is an emerging technology, it has a big potential to reshape life patterns for future microelectronics technology. This technology is used in many application areas, including automotive, biomedical, telecommunication, consumer electronics and also in defense application. It is expected that the MEMS technology will make the potential use of nano technology through it, performance and application area of MEMS product will enhance. During recent years, with the increasing effort to minimize the system and products in industries, the need for micro and nanotechnology has become important issues. The problem of handling the micro optical and micro electrical elements in nano or micrometer range can be solved by using special micro gripper. In the gripping process, the reaction forces operate between the object to be gripped and the microgripper arms. The reaction forces act perpendicular in case of micro objects with curved or circular surfaces. This can be explained on the basis of Newton's third law. During gripping action the normal reaction of the object to be gripped acts on the microgripper jaws and a component of this force acts downwards. Because of this F'COSΘ component, the gripped object will have a tendency to move downwards and this tendency keeps on increasing with the increase in applied force and finally the object would slide from micro gripper arms as shown in figure 1. Therefore it is hard for the gripper to grip the objects efficiently and certainly the issue sets a limit on the force, which can be applied by the gripping jaws, on the object to be gripped. This performance bottleneck can be avoided if the gripping process can be obtained without any rotational like movement of the jaws as shown in Figure 2. This can be realized by using a mechanism with parallel movement of the gripping arms while they grasp or release micro objects as shown in Figure (2). Θ is 90 degree which

Results in (FcosΘ) to be zero. Hence the probability of the object to slide from gripping arms is reduced.

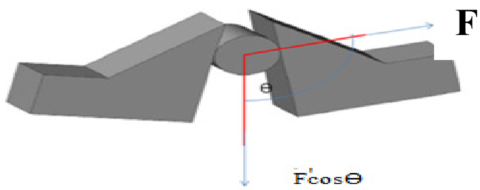

Figure 1. Non parallel arm movement

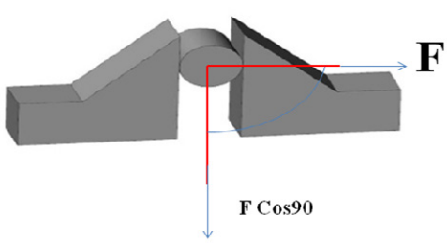

Figure 2. Parallel Arm movement

Applying an input voltage, across piezoelectric material, results in a strain across the same and due to this strain dimension elongation occurs. The value of strain occurred for same input voltage is different for different piezoelectric material and is an inherent property of that material.

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This paper deals with the study of effect of voltage on the micro gripper which uses piezoelectric actuator. Piezoelectric actuator that operates in the longitudinal mode is used in this design. Elongation in the longitudinal direction creates a lifting movement in the structure. Simultaneously contraction in the transversal direction closes the gripper and allows it to move objects. The middle arm represents the piezoelectric actuator. Different piezoelectric materials are used such as lead zicronate titanate (PZT-5A), Bismuth germinate and barium titanate displacement measured for different input supply voltages. The materials used as piezoelectric are compared based on voltages measurements.

2. Related Work

Various researches have been carried out in microgripper. H.Noori[1] deals with the study of effect of frequency on a microgripper which uses piezoelectric actuator. In this different control approaches that are used in piezoelectric microgripper are investigated and compared. In this paper a novel concept is defined to study about deviation of microgripper displacement. Jose A. Martiez[2] Experimental results are presented for both the actuation techniques along with failure analysis.[3] Pradhan, R this paper study with the parallel microgripper was micro fabricated and tested successfully. Xiangjin Zing[4] deals with the improved the efficiency of microgripper. Achkar, H[5] this paper presents a stimulation of mems based three electrode device using comsol multiphysics. The impedance data obtained from comsol simulation was fitted by using the equivalent circuits of PSB. Syaifudin[5] Electromagnetic field analysis of interdigital sensor has been carried out, it was observed simulation results using comsol multiphysics, the novel interdigital sensor with configuration sensor one had better sensitivity measurement compared to other novel interdigital sensor.

3. Structural Analysis

The different material used for microgripper designs, In structural analysis we investigate the effects on stress by applying the potential voltage

(a) In first case the actuator is made lead zicronate titanate of piezoelectric material and the gripper consist of polysilicon. Again both the material is presented in the COMSOL libraries and is arranged by rotating coordinate system. The reading has been observed from COMSOL. However by applying the potential voltage it can effect on the stress (μPa). In which we are observe the different values of stress on different voltage (μV).

(b) In second case the actuator is made **bismuth germanate** of piezoelectric material and the gripper consist of polysilicon. Again both the material is presented in the COMSOL libraries and is arranged by rotating coordinate system. The reading has been observed from COMSOL. However by applying the potential voltage it can effect on stress. In which we are observe the different stress on different voltage.

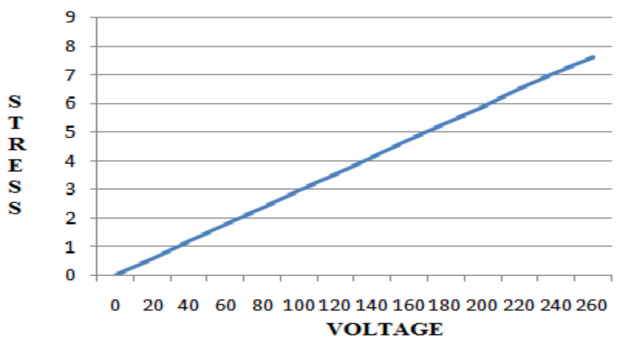

Figure 3. stress (μPa) v/s voltage (μV) for lead zicronate titanate

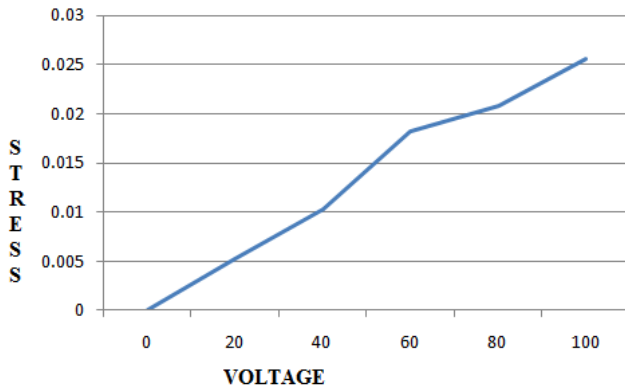

Figure 4. stress (μPa) v/s voltage (μV) for Bismuth germanates

(c) In third case the actuator is made **barium titanate** of piezoelectric material and the gripper consist of polysilicon. Again both the material is presented in the COMSOL libraries and is arranged by rotating coordinate system. The reading has been observed from COMSOL. However by applying the potential voltage it can effect on the stress. In which we are observe the different values of stress on different voltage. The following graph shows the reading between stress (μPa) and voltage (μV).

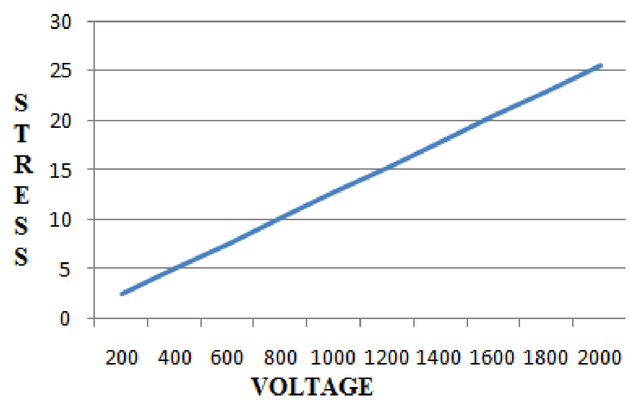

Figure 5. stress (μPa) v/s voltage (μV) for Barium Titanate

4. Mathematical Model of Piezoelectric Microgripper[1]

Piezoelectric microgripper uses the curved type piezoelectric bimorph cantilever as finger, two fingers with symmetrical.

In the figure of 3 we ignore the thickness of the middle layer. As the beam length is greater than of its width and the second stress of cantilever is t1=t2=t3=t4=t5=t6=0, strain s1, s2, s3, s4, s5, s6≠0 so according to the first piezoelectric equation, we obtain the strain of piezoelectric layer .

$$s1 = s11^e T1 + S12^E T2 + - - \mp d31^{e3}$$
$$= s11^e T1 + d31E3 \quad (1)$$

Sij^e = Ci = 1,2,3 ,j = 1,2,3 … … . . elastic compliance.

Where E= Coefficient in the electric field.

D31= Piezoelectric strain coefficient.

E3 = Electric field, T1=stress tensor.

$$T1 = (S11^e)^{-1} s1 \pm (s11^e)^{-1} d31E3 = Eps1 \pm EpD31\ E3 \quad (2)$$

Ep= elastic modulus as shown in Figure 4 We set the origin coordinates of center of cross-section of piezoelectric where y is the distance from the center 1. Where h is the thickness of the piezoelectric actuator.

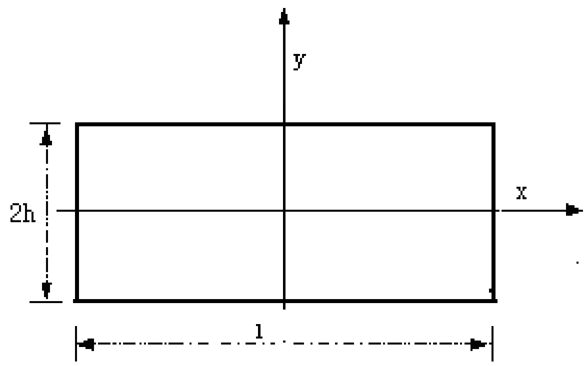

Figure 6.

$$M = \int_{Hup} T1ldy + \int_{Hdown} T1ldy = 0 \quad (3)$$

$$\int_{-h}^{0} (Epy\mu + Ep\ d31\ E3) lydy + \int_{0}^{h} (Epy\mu Epd31E3) lydy \quad (4)$$

μ = plane curvature for deformation

$$E3 = \frac{U}{h} \dots\dots \quad (5)$$

$$\mu = \frac{3Epd31u}{2Eph^2}$$

u=piezoelectric voltage.

Have a look from the disturbing degree equation

Y(x) =μ (this is the relationship between y and the voltage u is)

$$Y = \frac{3Epd31u}{4Eph^2} lpze$$

Lpze= length of piezoelectric actuator.

5. Design and Comparison

5.1. Design Detail of Microgripper

In the microgripper actuator is made up of piezoelectric material. The microgripper contains a piezoelectric actuator that operates in the longitudinal mode. Simultaneously contraction in the transversal direction closes the gripper and allows it to move objects. The actuator is made of different materials, and the gripper itself consists of polycrystalline silicon (poly-Si). Both materials are available in COMSOL Multiphysics material libraries.

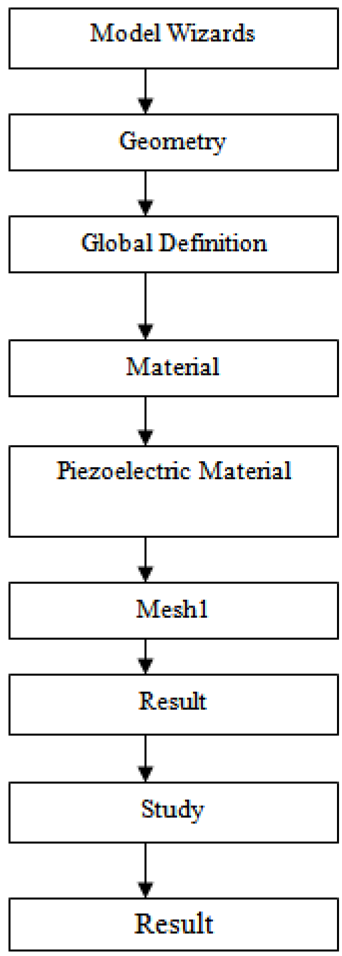

Figure 7. Flow diagram for designing the microgripper

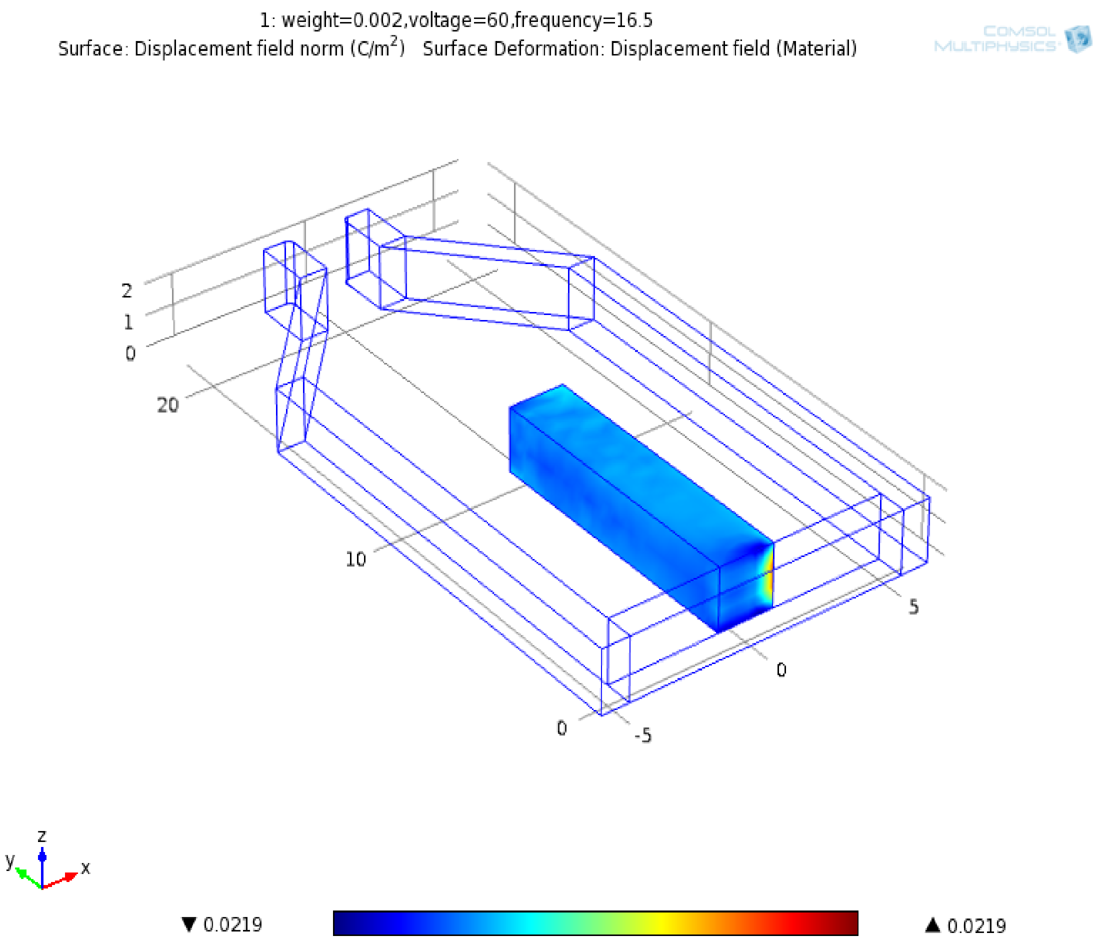

Figure 8. Microgripper Design In COMSOL[7]

This diagram 8 shows the simulation of microgripper which realizes a parallel movement of the gripping arms. The kinematic structure consist of parallegram mechanism (1) with flexure hinges (3) which are arranged parallel to each other and mounted on the base. The piezoactuator (2) serves as a movement generator for the microgripper mechanism. It is mounted on the base (7) and contact point (4). The amplification of the piezoactuator (2) displacement is simultaneously transmission of this movement to the gripping arms (5) and (6). The parallelogram can designed in such a way that the piezoactuator movement will be amplified upto 100 times. The release of the gripped object can be achieved when the voltage applied to the piezoactuator (2) is reset and the gripping arms (5) and (6) are opened due to elasticity of the flexure hinges (3).

5.2. Study of Voltage/Displacement Relationship for Various Materials

(a) Lead Zirconate Titanate

In first case the actuator which is made of **lead zicronate titanate** and the gripper consist of polysilicon. Again both the material is presented in the COMSOL libraries and is arranged by rotating coordinate system. The reading has been observed from COMSOL. After that, readings of the MATLAB are compared with the readings of the comsol.

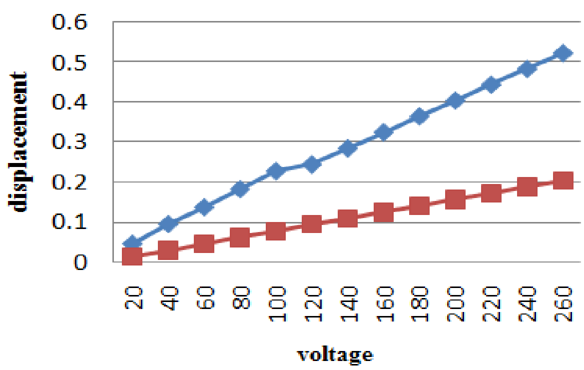

Figure 9. Displacement v/s voltage for lead zicronate titanate

Figure 9 represents displacement v/s voltage for lead zicronate titanate .In this graph blue color shows the experimental values that were obtained from COMSOL and red color shows readings that were obtained from MATLAB.

At **250 Micro volts** the two gripping arms are getting close to each other. In this the actuator is made up of lead zicronate titanate. The gripper consists of polysilicon and requires 250 micro volts to grip the object. The value of displacement of gripping arms is more in comsol as compared to MATLAB as shown in figure 9.

(b) Bismuth Germinate

In second case the actuator is made up of **Bismuth**

germinate and the gripper is made up of polysilicon. Again both are the material which are present in the comsol libraries and are arranged by rotating coordinate system. Then readings of the MATLAB are compared with the readings of the comsol.

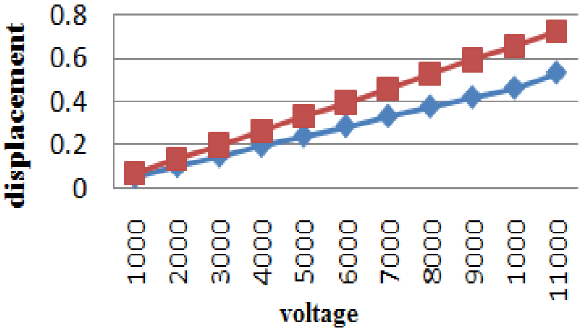

Figure 10. Displacement v/s voltage for bismuth germinate

Figure 10 shows displacement v/s voltage for bismuth germinate. In this graph blue color shows the experimental value that was obtained from COMSOL and red color shows readings that were obtained from MATLAB.

In this the actuator is made of Bismuth germinate. The gripper consists of polysilicon in which 11000 micro volts are required to grip the object. This voltage is very high as compared to lead zicronate titanate. The value of displacement of gripping arms is more in MATLAB as compared to COMSOL as shown in figure 10.

(c) Barium Titanate

In third case the actuator is made up of Barium titanate and the gripper is made up of polysilicon. Again both material are present in the COMSOL libraries and are arranged by rotating coordinate system. After this readings of the MATLAB are compared with the readings of the COMSOL.

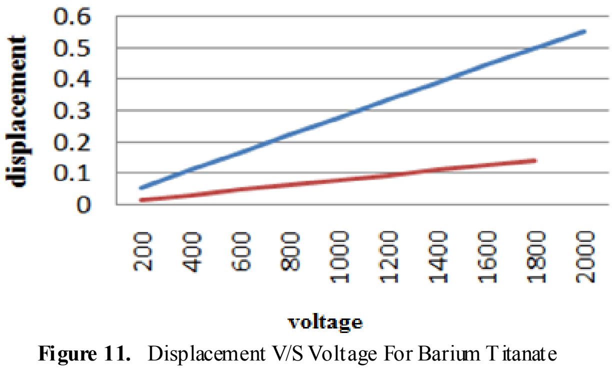

Figure 11. Displacement V/S Voltage For Barium Titanate

Figure 11 shows displacement v/s voltage .In this graph blue colour represents Bismuth germinate and the experimental value that were obtained from COMSOL and red color shows readings that were obtained from MATLAB.

In this case the actuator is made of Bismuth germinate. The gripper consists of polysilicon in which 1800 micro volt is required to grip the object. This voltage is very high as compared to Bismuth germinated.

Comparison and results

In which several input voltage applied to the microgripper with different piezoelectric materials such as lead zicronate titanate, bismuth germinate, barium titanate. As shown in table 1 the bismuth germinate requires very high voltage that is 11000 micro volt which is too high to grip the micro objects. On the other hand it is observed that lead zicronate titanate and barium titanate require 250 and 1800 micro volts respectively. This is very less as compared to bismuth germinate.

Table 1. Shows the different values of voltage

MATERIAL	VOLATGE(microvolts)
Lead Zicronate Titanate	250
Bismuth Germinate	11000
Barium Titanate	1800

6. Conclusions

In this paper several input voltages are applied to the microgripper with different piezoelectric materials such as lead zicronate titanate (PZT-5A), Bismuth germanate and barium titanate. The displacement changes are obtained for different values of applied voltage and are investigated for several closing and openings. The comparisons of the several piezoelectric materials have been done, for example, in first case the actuator is made of lead zicronate titanate (pzt-5a). It required 250 micro volts to grip the object. In second case the actuator is made of bismuth germanate in this 11,000 micro voltage is required to grip the object. In third case actuator is made of barium titanate in which 18,000 micro voltage is required to grip the object and since this much high voltages practically raises the safety concerns. So by comparing these three materials, we preferred the actuator which is made up of lead zicronate because it requires very less voltage as compare to the other two. However strain coefficient of lead zicronate titanate (PZT-5A) is 1.8 *`10^{-4}µm/v.whereas for barium titanate the coefficient of strain is 10^{-6}µm/v becuase lead zicronate titanate has higher value of strain coefficient (almost 200 times more than barium titanate).So that it requires lesser voltage for moving the arms. That's why lead zicronate titanate (PZT-5A) Material is mostly preferred among these. The simulations of the COMSOL are compared with the readings of MATLAB.

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