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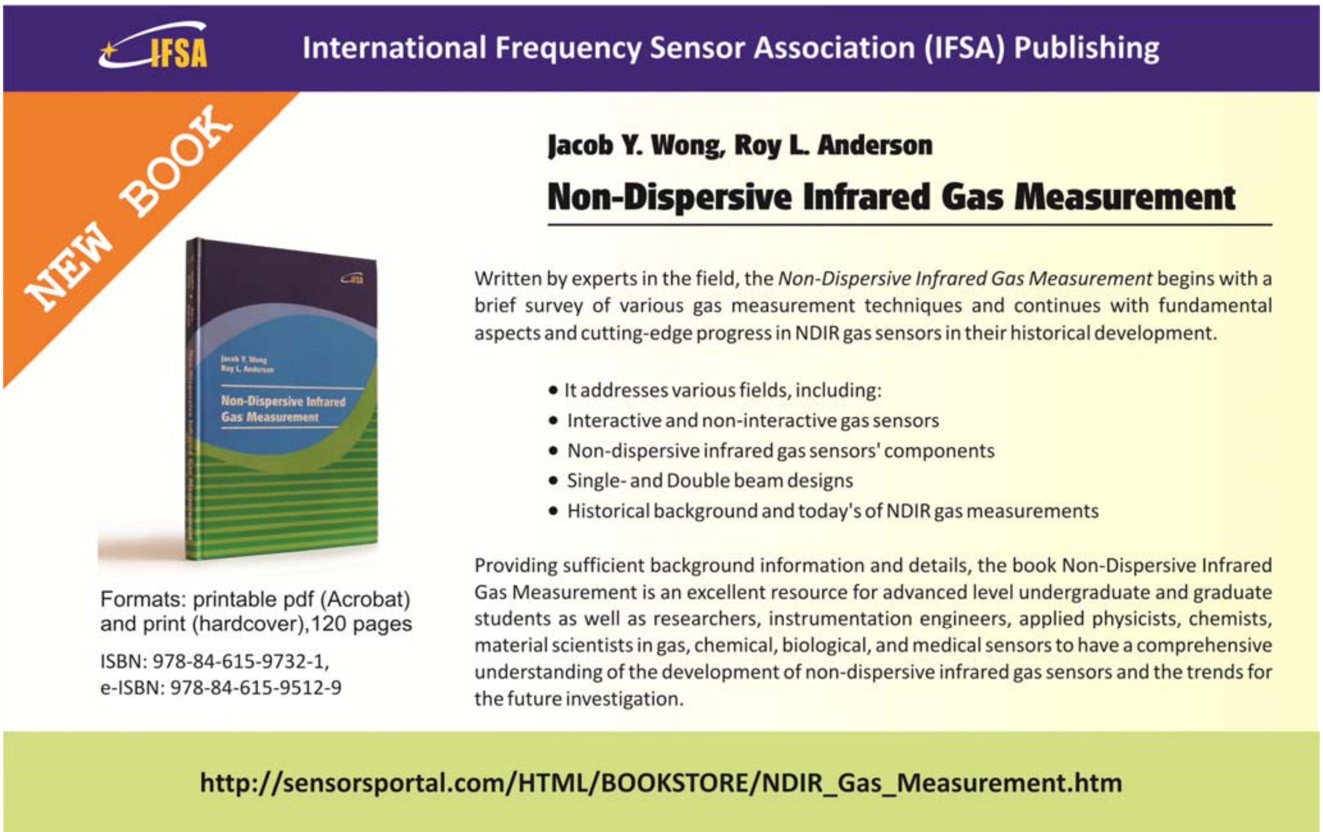
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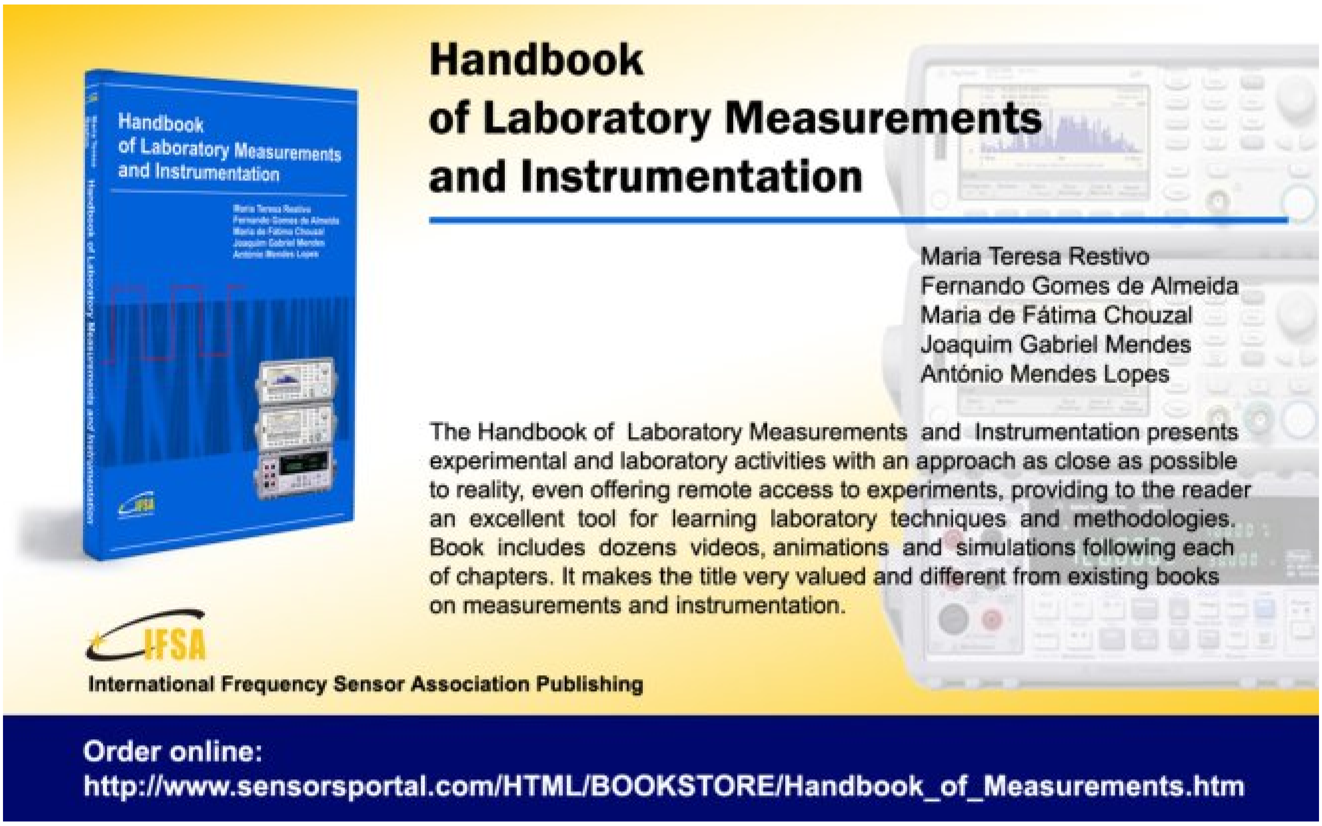
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Design and Simulation of a Novel MEMS Based Linear Actuator for Mirror Shape Correction Applications

Ehsan Atashzaban
Electrical engineering department, Sahand University of Technology,
Tabriz, Sahand new town, 47147, Iran
Tel.: +98-935-810-32-08
E-mail: eatashzabn@yahoo.com

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Abstract: In this paper, we propose MEMS based Electro-thermal actuator that can achieve minimum step size less of 100 nm; Actuator consisted of slider and griper .In the slider structure used of the two electro-thermal chevrons that led to linear forward motion of the slider. The gripper is consisting of clutch and chevrons. The clutch used to connect the slider to the substrate, and the chevrons used to release the clutches. With apply DC voltage of 0.5 Volts; a force is produced by the slider that is 8 mN and a stroke is equal to 2.2 µm. Large stroke is achieved by repeating the step sizes sequentially. Also an important property in this work is the normally latched or zero-power latching scheme.

Keywords: Electro-thermal, Micro-actuator, Chevron, Slider, Gripper.

1. Introduction

Future space missions will require very large aperture telescopes to meet expected light gathering and resolution requirements. These telescopes will consist of extremely large, lightweight optical mirrors, which might require a large number of actuators capable of correcting the mirror shapes. While mirror face sheet technology development has resulted in significant advances in lightweight optical quality face sheet materials, no comparable development has occurred in actuator technology development. The available actuators are still relatively heavy and bulky. To meet future requirements will require the development of large stroke, precision, ultra-lightweight actuators that will match the needs and properties of future lightweight mirrors [1]. The most common modes of actuation are electrostatic, magneto-static, piezoelectric and thermal expansion [2]. The forces produced by electrostatic and magneto-static actuators tend to be small, and to achieve large displacements, it is necessary to either apply a large voltage or operate the devices in a resonant mode. On the other hand, piezoelectric and thermal expansion actuators can be configured to produce large forces and large displacements. Unfortunately, piezoelectric materials are not routinely supported in the fabrication processes offered by commercial MEMS foundries. As a result, these limitations have focused attention on thermally actuated devices for generating large forces and displacements [3]. Micro-electromechanical systems (MEMS) based electro-thermal actuators comprise an important class of MEMS actuators that have tremendous potential in a wide range of prospective micro-actuation applications. Electro-thermal actuators are mechanically compliant structures that rely on the thermal expansion of its heated components to achieve thermal actuation [4]. In this work, we propose a novel actuator for Mirror Shape Correction Applications that actuate with electro-thermal and can creation minimum step size less of 100 nm and stroke equal to *2.2 µm*. A micro linear motor reported [5], but the actuation force and stroke are low and for this application is not appropriate. Large stroke with resolution *59 nm* reported [1], but occupied size is large while our actuator is small size. Another important requirement of the micro actuators for this application is the normally latched or zero-power latching scheme that this technique used in this work. Several issues concerning the actuator behavior are discussed in the following sections: first discusses about the mechanism of this linear actuator (section 2.1); afterward, analyze the gripper system and present theory due to this part of design (section 2.2); also discuss about the slider (Sections 2.3) .Section 3 consisted of conclusion.

2. Design

2.1. Mechanism

Linear micro actuator is composed of three the main parts, contains the substrate, the slider and the gripper as shown in Fig. 1.

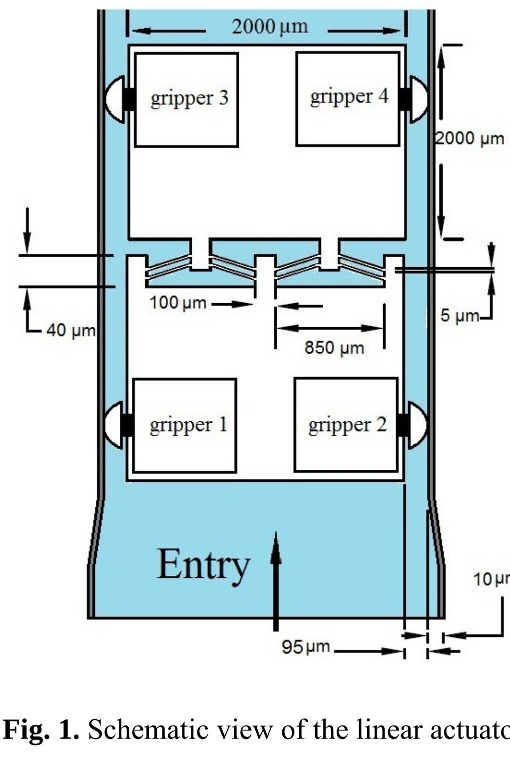

Fig. 1. Schematic view of the linear actuator.

Substrate is the use as the stator; the slider consisted of electro-thermal chevron and electrodes; the slider sits on the substrate and gripper system assembles in four corners of the slider. The gripper is consisting of the clutch and the chevrons; in order to release the slider used of four electro-thermal chevron actuators. In fact, whole linear actuator consisted of the chevron unit six. In normal state, clutches connect to substrate body and prevent of displacement the slider, chevrons *1, 2, 3* and *4* uses to release the clutch. Thickness of the slider and the gripper are *200 µm* and *75 µm,* respectively. At up and low of the slider two the electrodes are located, with apply the *DC* voltage to electrodes of the slider and the active and passive clutches of the grippers; the slider can move Linear. For example, when the voltage *+Vcc* is connected to upper electrode and ground to lower electrode, the slider place in an electrical circuit .Electrical current causes warm the chevron and eventually will displace the slider. In the state (a), the voltage *+Vcc* and the ground respectively is connected to the lower electrode and upper electrode; in this case four clutches are active and can say the slider is stopped and without motion. In the state (b) and (c), the voltage applied to the electrodes remains as same as the state (a), in this case the clutches of *1* and *2* are active, *3* and *4* are inactive. In the state (c), four clutches are active. In the next states three, both electrodes are the ground. In the state (d) whole the clutches are active. In the state (e) alone the clutches *1*, *2* are inactive. In the state (f) again whole the clutches are active. States (a) to (c) are phase of warming, and States (d) to (f) are phase colding of the chevrons. Just when need to release the slider, the chevrons to be activated and at times that do not have the required displacement, chevrons are off and consume power is zero. Fig. 2 shows the electrical signals for stroke 2.2 µm in the y-direction.

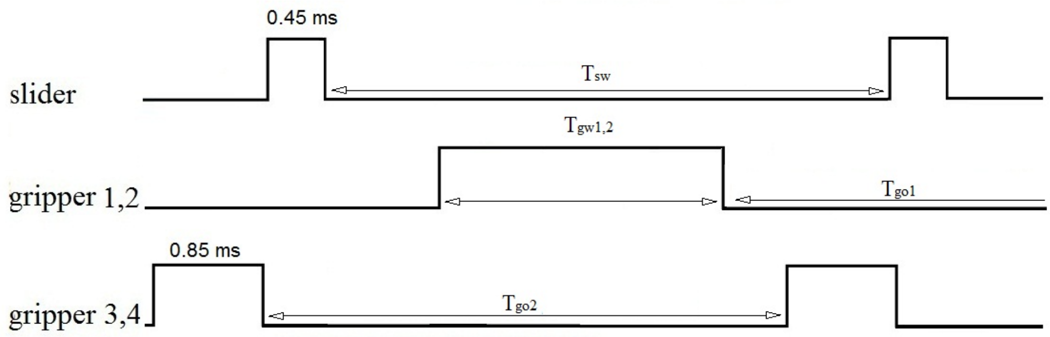

Fig. 2. Electrical signals.

Where T_{sw} is the sum of the slider colding time and waiting time for signal next pulse of the slider. $T_{gw1,2}$ is equal to colding time of the slider .T_{go1} and T_{go2} is off time of grippers1, 2 and grippers 3,4 to next cycle, respectively. In order to motion in backward direction can change phase of the signals. Analysis and simulation related to the slider, and the gripper system was evaluated separately.

Fig. 3 shows the gripper structural that consist of the chevrons, the clutches and the anchors. A chevron type of thermal actuator consists of several long beams, which are held fixed (anchor) by two supports at an angle. As current passes through the beams from one terminal to the other, the beams expand due to the Joule heating, and the thermal expansion leads to a deflection in the y-direction as shown in Fig. 4. The deflection of a chevron actuator strongly depends on the length and the angle of the beams; a larger deflection is produced if a smaller angle is used [6-7] .Contact of the clutch with substrate causes stop of the slider. In some linear actuators, the clutch is inserted in the notch; these structures produce powerful steady-state friction coefficient (*SSFC*), but its disadvantages are the limits of resolution. In this work used the frictional contact method, with this method the linear actuator has the capability that obtained favorable resolution. In order to design this part, the maximum amount of generated force by the slider was considered. Assuming the maximum amount force by slider is *8 mN*, the required steady-state friction force (*SSFF*) to grip by two clutches should be larger than *8 mN*. Once the slider is inserted into drawer, the clutches springs and chevrons displaced by approximately *5μm* and therefore, grip the slider without external power since they are pre-stressed. Hence the clutch contact to substrate and generate *SSFF*. This force should be so enough greater of the force generated by the slider, until the resultant force causes to grip the slider. In order to design the clutch springs, two states are existed. If the spring has low stiffness, friction force generated by the clutch is low, while high stiffness, increase this force, so a trade-off was considered.

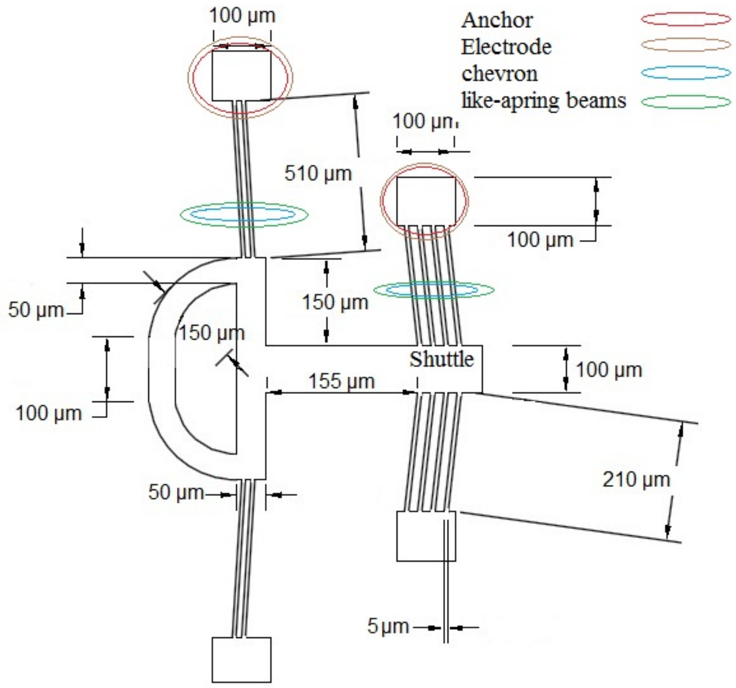

Fig. 3. Schematic view of the gripper.

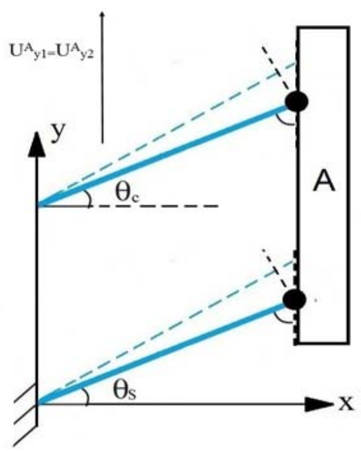

Fig. 4. An inclined beam that joint at the central of shuttle of the chevrons.

2.2. Analysis of the Gripper

The griper is designed in two main steps; in the first step, the slider should be inserted in the drawer of the substrate, therefore an external force will be needed. This external force compresses gripper spring beams and the gripper chevrons. After being inserted into the drawer, we remove external force, thus the clutch contacts to the substrate body (zero-power latching scheme). In the second step, the clutch should be released from the substrate; this step is done by applying a DC voltage to the gripper. The gripper should be designed in such a way that it can generate maximum grip force and maximum forward force. In order to design the gripper system, two inclined beam that joint at the central of shuttle can be analyzed (for example, beam *A*) as shown in Fig. 4; assume that the shuttle is grid. When the slider inserts in the drawer by apply an external force, beams of the chevron and springs of the clutch will compressed. The displacement at shuttle *A* due to this external force *F*, along the *y*-direction is equal to [8]:

$$U^F \equiv U^A_{y_{total}} = U^A_{y1} + U^A_{y2} = F\frac{1}{2(\sin^2\theta_s \frac{EA_s}{l_s} + \cos^2\theta_s \frac{12EI_s}{l_s^{\,3}})} + F\frac{1}{2(\sin^2\theta_c \frac{EA_c}{l_c} + \cos^2\theta_c \frac{12EI_c}{l_c^{\,3}})} \tag{1}$$

First sentence is due to springs of the clutch and second sentence is due to electro-thermal chevrons. Where E is Young's modulus of the material, l_s and l_c are the beams length; A_s and A_c are the beams cross section, I_s and I_c are the moment of inertia of the cross section with respect to the out of plane axis z; F is external force. It is obvious that $U_{y1} = U_{y2}$, because of springs of the clutch and electro-thermal chevrons connected together by the shuttle. Fig. 5 illustrates displacement of the gripper versus applied external force.

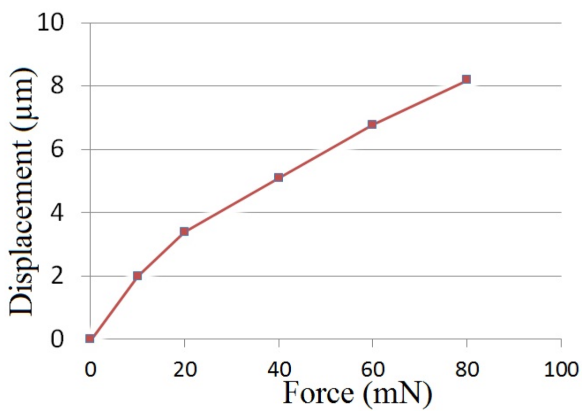

Fig. 5. Displacement of the gripper versus applied external force.

Also can averment that generated *SSFF* by the clutch is equal to:

$$F_{friction} = \mu_{static} F_u \tag{2}$$

In fact, F_u is the elastic potential force of the clutch. In order to calculate *SSFF*, can use of equations (1, 2). The next step is releases the clutch of the substrate body, therefore displacement of beams of the chevron and the clutch springs by electro-thermal actuation calculated. Here sprigs of the clutch act as same as the chevron. If the average temperatures of like-spring beams of the clutch increase to ΔT_s, and ΔT_c for chevrons, the displacement at shuttle *A* in the *y*-direction is equal to [8]:

$$U^{\Delta T} \equiv U_{y\,total}^{A} = \alpha\, \Delta T_s\, l_s \frac{\sin\theta_s}{(\sin^2\theta_s + \cos\theta_s \dfrac{12I}{A_s l s^2})} + \alpha\, \Delta T_c\, lc \frac{\sin\theta_c}{(\sin^2\theta_c + \cos\theta_c \dfrac{12I}{A_c l c^2})}, \tag{3}$$

where α is the coefficient of thermal expansion; the first term and the second term in the right hand side of the equation (3) are equal together.

By attention to equations (1-3) can study the total of the gripper. Fig. 6 illustrates displacement of the clutch versus the DC voltage. Clutch was designed as with the compress to amount of 5µm, make a force equal to 40 mN. With Assuming the SSFC is 0.2 [12] and by attention to equation (4) the total SSFF of two clutches is equal to 80 mN; therefore the slider is allowed to produce a force less of 16 mN. In other words, can be said if a load attached to the slider as the recurrent force equal to 16 mN, grip will make fault ;Because this force is against, and larger than the SSFF. In order to release a clutch from the stator, force more of 40 mN is required. With apply DC voltage to 1.25 Volt; will be produced a force equal to 80 mN. Hence can ensure that release the clutch of the stator body. With this force, the amount of the displacement is 7.9 µm. Fig. 7 shows stress contours in the gripper that is below 0.573 Gpa. maximum temperature in the gripper is equal to 583 C°. Also The slider travels about 2.2 µm within 0.5 ms.

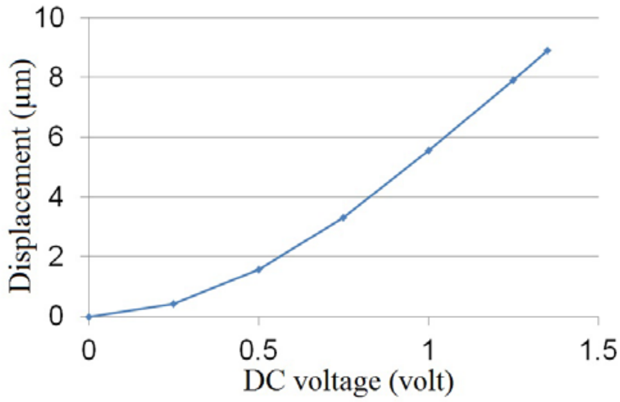

Fig. 6. Displacement of the gripper versus DC actuator voltage.

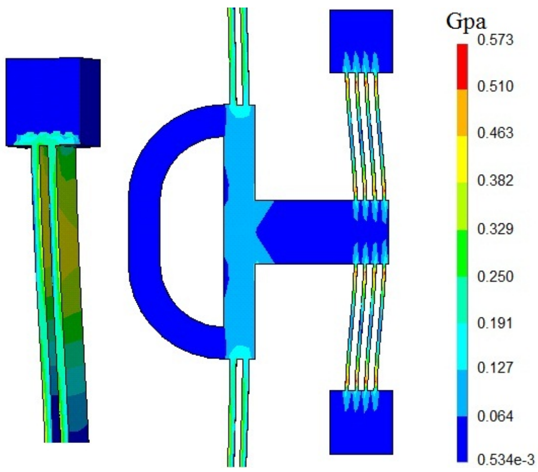

Fig. 7. Contours plot of stress.

2.3. Analysis of the Slider

In order to design of the slider can use of theory of the section 2.2. With applies of couple field element, model meshed and Electro-thermal analysis done. A material property of polysilicon is tabulated in Table 1.With Apply voltage of 0.5 V, the slider will stroke of 2.2 µm. Fig. 8 illustrate the displacement versus the DC voltage. Temperature of whole the electrodes in this work considered 293 K. With selecting appropriate voltage to the electrodes (30 mV), minimum step size less of 100 nm achieve and also if repeat motion cycles, will be increase displacement. Also Fig. 9 (a) and 9 (b) shows contours of stress and temperature distribution in the slider by a 0.5 V applied voltage, respectively. It should be considered that isolate the gripper system from the slider body in terms of electrical. Error is due to interact of the electrical circuits of the gripper system and the slider.

Table 1. Polysilicon properties used in the simulation of the gripper and slider.

Parameter	Unit	Value	Reference
Young's modulus	GPa	170	[13]
Poisson's ratio	-	0.22	[13]
Thermal conductivity	$W\ m^{-1}\ K^{-1}$	34	[14]
Resistivity	Ωm	3.4e-5	[15]
Thermal expansion coefficient	K^{-1}	2.5e-6	[16]

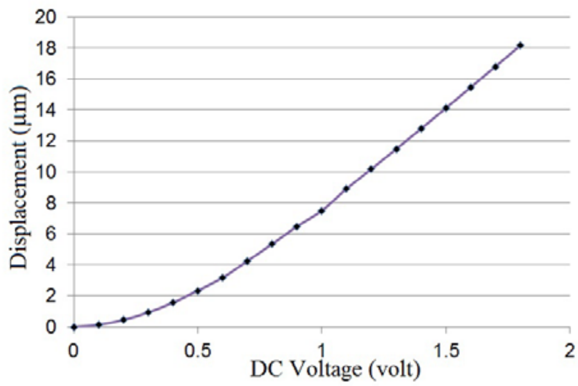

Fig. 8. Displacement of the slider versus time.

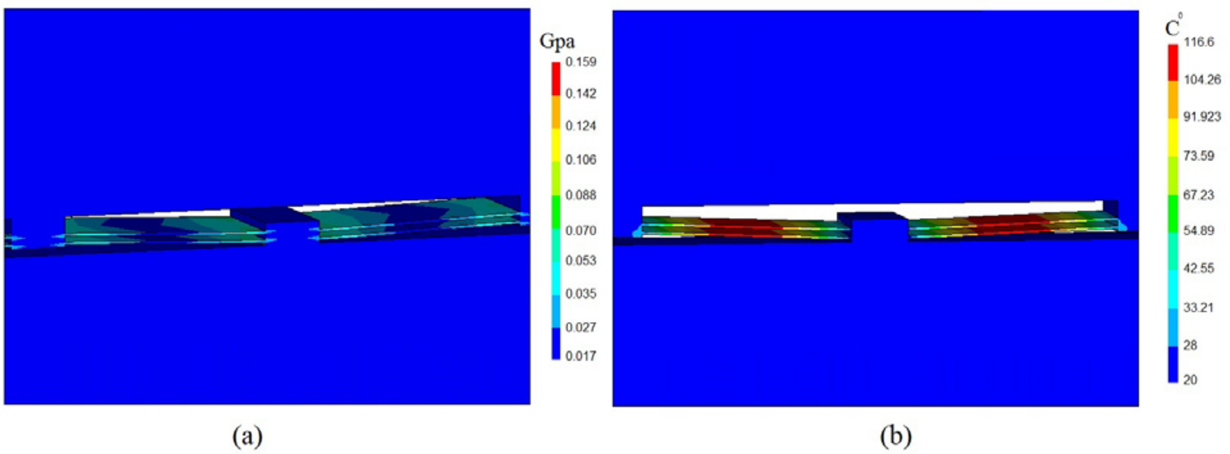

Fig. 9. By a 0.5 V actuation voltage, (a) Contour plots of stress in the slider, and (b) temperature distribution in the slider.

3. Conclusion

Electro-thermal actuator can produce a large force; it also has a minimum step size less of 100 nm and appropriate for Mirror Shape Correction Applications. There are two main ways to increase the friction force; in the First method can increase generated force of the chevrons , in second method use of impact stator head and the sliders with notched edges, that will lead to reduce of the resolution, so it should be considered trade off. Generated force is 8 mN; with apply a DC voltage equal to 0.5 Volt. The simulation results show linear micro-actuator has favorable forward force and is the large stroke. However, if can be control temperature conditions and else parameters of the system, can be achieve a favorable resolution for mentioned application. Large stroke is achieved by repeating the step sizes sequentially. When haven't needed to displacement, consume energy for latching of the slider is zero (power-off latching mode).

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Contributions are invited on all aspects of research, development and application of the science and technology of sensors, transducers and sensor instrumentations. Topics include, but are not restricted to:

- Physical, chemical and biosensors;
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- Theory, principles, effects, design, standardization and modeling;
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