World Academy of Science, Engineering and Technology
International Journal of Mechanical and Mechatronics Engineering
Vol:12, No:5, 2018

Open Science Index, Mechanical and Mechatronics Engineering Vol:12, No:5, 2018 publications.waset.org/10009034.pdf

Design and Analysis of an Electro-Thermally Symmetrical Actuated Microgripper

Sh. Foroughi, V. Karamzadeh, M. Packirisamy

Abstract**—**This paper presents design and analysis of an electrothermally symmetrical actuated microgripper applicable for performing micro assembly or biological cell manipulation. Integration of micro-optics with microdevice leads to achieve extremely precise control over the operation of the device. Geometry, material, actuation, control, accuracy in measurement and temperature distribution are important factors which have to be taken into account for designing the efficient microgripper device. In this work, analyses of four different geometries are performed by means of COMSOL Multiphysics 5.2 with implementing Finite Element Methods. Then, temperature distribution along the fingertip, displacement of gripper site as well as optical efficiency vs. displacement and electrical potential are illustrated. Results show in addition to the industrial application of this device, the usage of that as a cell manipulator is possible.

Keywords**—**Electro thermal actuator, MEMS, Microgripper, MOEMS.

I. INTRODUCTION

MICROACTUATORS are devices that convert input energy to mechanical movement. Driving micromirrors and micropumps actuation are sample usage of this type of MEMS device in industries [1]. In biological research, microdevices are used to manipulate the cells in order to investigate their behavior. Due to miniature structure and flexibility of micro-electro-mechanical-actuators, these systems are suitable for applying forces on a cell, in a range of piconewton to micronewton without damaging the cell membrane in order to mechanical stimulation of the whole cell or part of its membrane [2].

II. MICROMANIPULATION

Demands in handling of objects in a range of micro scale have led to an improvement of new assembling technologies which empower manipulation of small micro-optical, micro-electrical or micro-mechanical elements in nanometer or micrometer range. Working in nano scale or micro scale causes the limitation in micromanipulators design such as: limit in applying high voltage in piezo actuated grippers, limiting the application of electrostatic or electromagnetic actuated microgrippers [3].

III. DESIGN CONSIDERATIONS

Actuation principle, movements, fingertips shape, having control on applied force and releasing strategy are the factors that have to be taken into account in preliminary design of a microgripper.

Two different methods are being used to actuate micro grippers: internal and external excitations. Designing a part of device with piezoelectric (PZT) material to generate a localized force can be categorized as an internal excitation method. The electrostatic, thermal and magnetic forces are the external actuation methods. Thermal actuators which are based on the thermal expansion of the gripper arms are widely used for handling of micro-objects [4].

Each actuation strategy has its own limits. Thermal actuator may produce high temperature rise in the region close to the cell. In order to overcome this limitation, longer gripper arms are considered to dissipate the heat generated by the actuators.

Translational and rotational motions are two possible movements of the microgripper's fingertip. During the rotational movement, the contact points between the object and the gripping arms are subjected to reaction forces which can cause to push the gripped object out of the gripping arms [3]. This problem can be avoided by considering a trapping space at the tip of the gripper to catch the particle as is applied in the present design.

The fingertip should be designed in a shape that imposes a uniform load on an object. For instance translating fingers compared to rotating fingers are preferred in cell microgrippers. The most common fingertips shapes are flat, angular curved and cylindrical curved.

One of the strategies for watching the force applied on a micro-object is displacement control through optical detection under a microscope. Another strategy is integrating piezoresistive transducers or micro capacitive sensors with microgripper [2]. In implementing displacement control, more accurate result could be achieved by assembling the optic part on a device. No need for optical observing is the significant characteristic of this strategy which is dealt within this research.

Adhesion and capillary forces are leading forces compared to gravity in the releasing process of microgrippers. Therefore, the effect of gravity force which is small cannot lead to micro-object releasing. In cell manipulation and industrial applications hydrophobic coating of the gripper and vibration are the most common strategies of releasing which are

Sh. Foroughi* is with the Optical Bio-Microsystem Laboratory, Mechanical and Industrial Engineering Department, Concordia University Sir George Williams Campus 1455 De Maisonneuve Blvd. W., Montreal, Canada (corresponding author, phone: 514-691-6547; e-mail: s_foroug@encs.concordia.ca).

V. Karamzadeh* and M. Packirisamy are with the Optical Bio-Microsystem Laboratory, Mechanical and Industrial Engineering Department, Concordia University Sir George Williams Campus 1455 De Maisonneuve Blvd. W., Montreal, Canada (e-mail: vahid.karamzadeh@mail.concordia.ca, mpackir@encs.concordia.ca).

* These authors contributed equally to this work

addressed as passive and active methods.

IV. Electro-Thermal Actuator

External forces can be produced using various effects such as the electrochemical, the electrostatic and the magnetic ones. The presented design deals with the electro-thermal actuation of a polysilicon microgripper used to grab a micro-object with a size in a range of 5-12 µm. In this research the polysilicon has been selected as a material of microgripper, due to acceptable mechanical properties and being suitable for fabrication [5]. Mechanical and physical properties of polysilicon are presented in Table I.

TABLE I
Polysilicon Mechanical and Physical Properties [6], [7]

Young's modulus (E_s), GPa	169
Poisson ratio (ν_s)	0.22
Tensile strength (σ_{ms}), GPa	1.2
Density (d_s), Kg/m^3	2200
Coeff. of thermal expansion (α_s), 1/°C	4.7×10^{-6}
Thermal conductivity (k_s), W/(m °C)	148
Specific heat (c_s), J/(kg °K)	100
Electrical resistivity (Ohm)	40

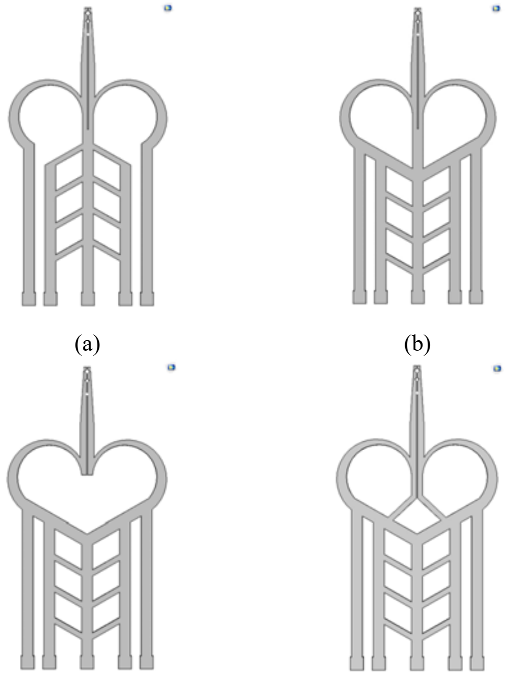
(a) (b) (c) (d)

Fig. 1 Four different microgripper geometries

Multiple geometries of the microgripper have been considered to reach the suitable design. Study of plane displacement in each design leads to select the proper geometry which provides the larger opening at the gripping site. In Fig. 1, four different geometries that have been investigated in this research are illustrated. The operation mechanism of all devices begins by heating up the current-carrying axis, which is located in the middle of the device, because of Joule effect during passing current. Due to temperature gradient along the device and different thermal expansion in arms, the opening at the tip will occur. The temperature raise and opening amplitude are proportional to voltage.

In all designs, overall length of the device is 10 mm, the gripper size is 3000 µm × 100 µm and 8 µm an initial gap has been considered between two arms of fingertips.

V. Microgripper Operation

A. Mechanical Part

In order to provide a space for holding objects with variety of sizes, three trapping places have been located along the fingertip that will be addressed as S1, S2 and S3 in this paper. Fig. 2 illustrates the geometry of fingertip.

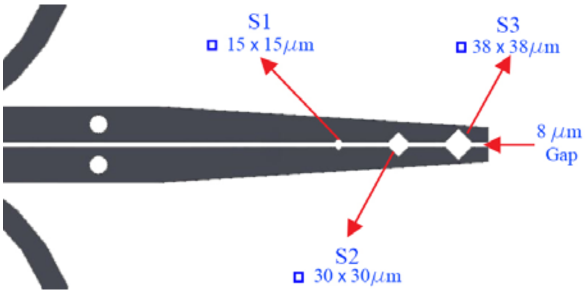

Fig. 2 Fingertip Geometry

All presented design configurations consist of one hot arm thermal actuator. The actuator is activated through thermal expansion. The temperature rise that is required for deforming the hot arm and then displacing the actuator is achieved through resistive heating. Fig. 3 shows configuration of arms and applied voltage poles in design (d) as an example.

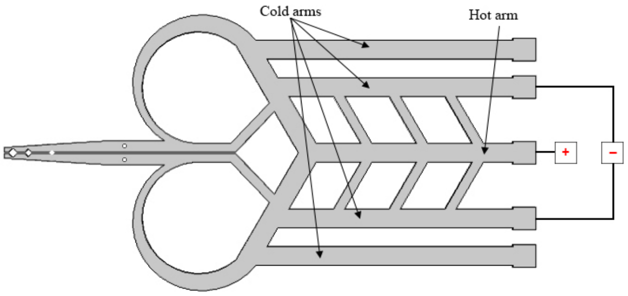

Fig. 3 Configuration of arms and applied voltage poles in microgripper

The electric current through the hot arm increases the temperature in the actuator, which in turn causes thermal expansion and changes the electrical conductivity of the material. Bending of the actuator is caused by the greater expansion of the hot-arm, compared to the cold arms. In this situation, the gripper will be opened and ready to catch the object. The width of gripper opening is proportional to applied voltage.

B. Optical Part

Circular holes with a 30 μm diameter have been embedded in the left and right sides in order to optical control of the gripper opening. The light from the fixed source adjacent to the upper surface of microgripper passes through the holes and is detected by the detector on the opposite side. Fig. 4 shows the location of these holes in the device's fingertip.

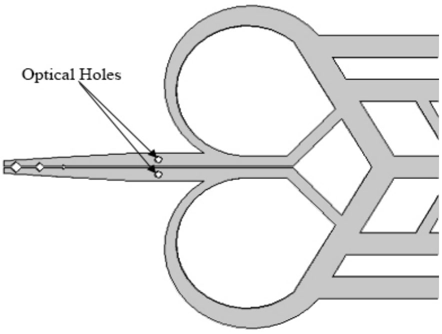

Fig. 4 Location of Optical Holes

As a result of increasing the temperature, the fingertip starts to move angularly. Angular movement of the hole causes decrease in the cross area of the light path. Therefore the intensity of light will decrease. Accordingly, the direct relation between the angular movements of gripper and intensity of light can be derived. This relation will help to enhance the control of microgripper.

VI. FINITE VOLUME SIMULATION AND RESULTS

Polysilicon electrothermal actuators provide low handling force, large displacement, and low operating voltages. These benefits make these type of MEMS devices advantageous for handling and manipulation of microscale objects and biological cells [8].

In order to analyze the design of microgripper numerically, coupled simulations over various physical domains such as thermal, electrical and structural are performed. The coupled simulation was solved using COMSOL Multiphysics 5.2. The gripper works in the normally closed mode. Therefore, heat transfer to the object after catching can be neglected in the simulation in case of disconnecting from the voltage source.

Since the application of the device for manipulation of a variety of micro objects is affected by the geometry of gripper site during operation, the maximum opening sizes for each configuration of microgrippers without considering initial gap, presented in Fig. 1, are indicated in Table II.

TABLE II
MAXIMUM OPENING SIZE OCCURRED IN EACH MICROGRIPPER CONFIGURATIONS PRESENTED IN FIG. 1

Configuration Number	Maximum Opening at S3 (μm)
(a)	12.4
(b)	24.3
(c)	25.2
(d)	28.1

By comparing the results it is known that the configuration (d) has the largest size of the opening. Therefore, from now on the performed studies in this research are focused on this configuration of the microgripper.

Fig. 5 displays maximum opening size at the tip of the device at maximum voltage 4 V. By altering the voltage the size will change.

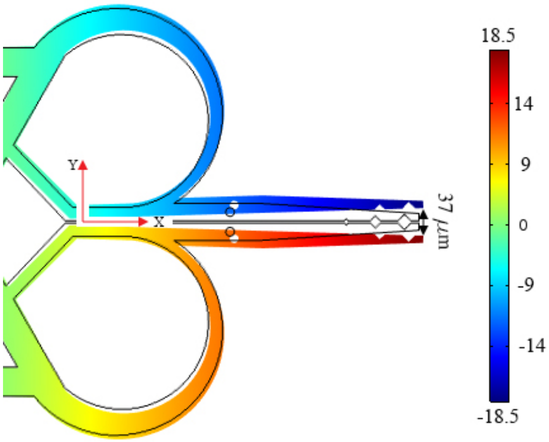

Fig. 5 Maximum opening (μm) at Voltage=4 V

In Fig. 6 the parabolic relationship between the opening size without considering the initial gap and the applied voltage is shown. Varying the applied voltage, objects with different sizes can be caught by the microgripper. For example, applying a voltage equal to 1.5 V an object having a diameter lower than 12 μm (by considering 8 μm initial gap) can be enclosed by the gripper.

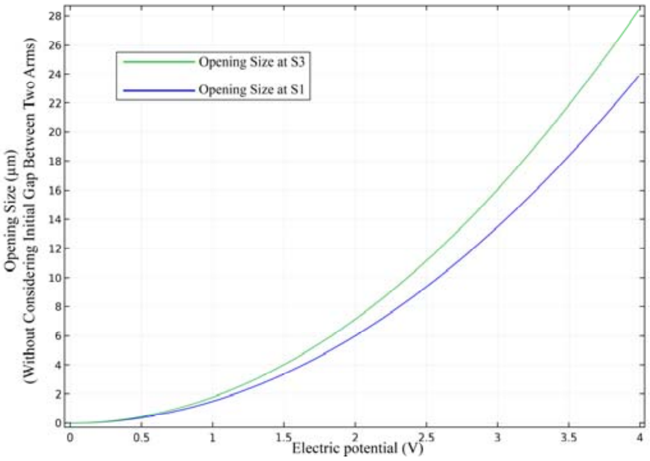

Fig. 6 Parabolic Relationship between Opening Size and Electric Potential

Temperature as a function of the applied voltage along the fingertip is illustrated in Fig. 7.

Having a close look at Fig. 7, the highest value of temperature in the gripping zone is about 23 °c which is a safe result for biological applications.

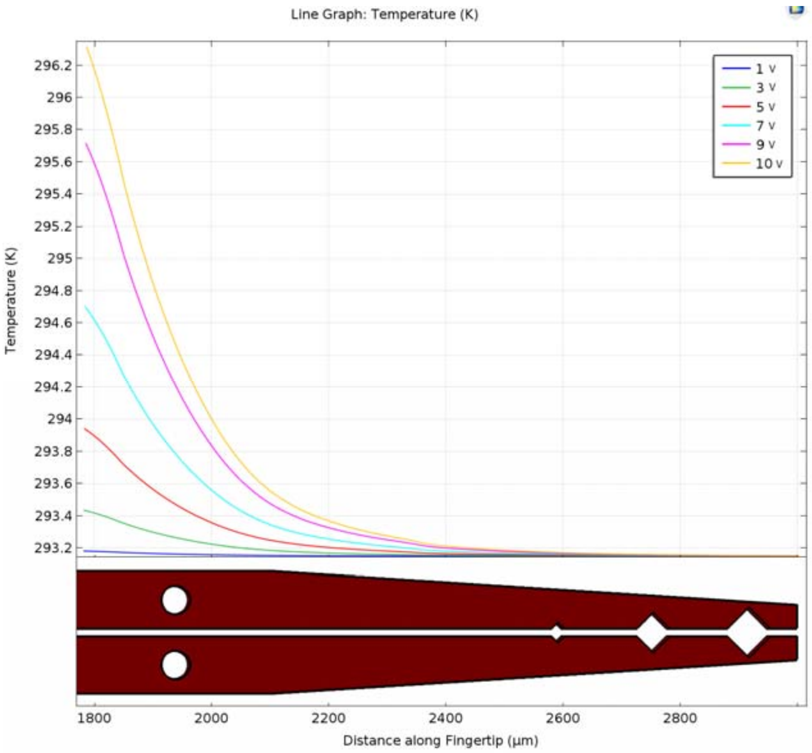

Fig. 7 Temperature as a Function of Applied Voltage along the Fingertip

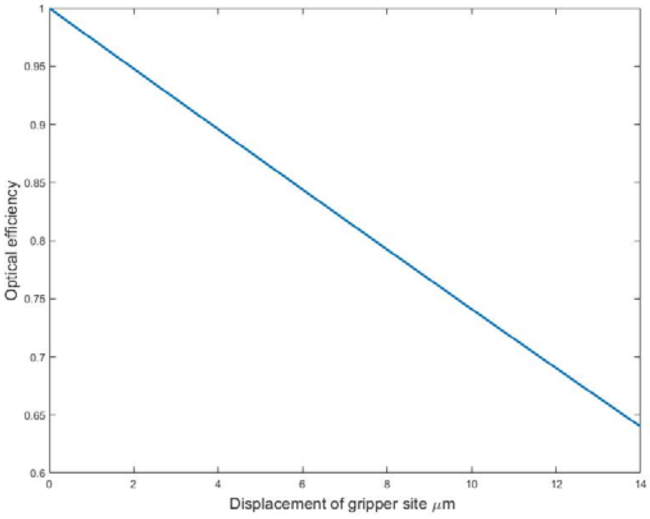

Fig. 8 Optical efficiency vs Displacement of S3 Space

VII. OPTICAL RESULT

By deflecting the gripper site, the circular optical hole will replace which causes changes in detected light intensity. Area reduction in circular section due to angular displacement is calculated by applying:

$$A = 2\pi r^2 \cos^{-1}\left(\frac{d}{2r}\right) - \left(\frac{d}{2r}\right)\sqrt{4r^2 - d^2} \tag{1}$$

where the d is angular displacement and r is the radius of circular optical hole.

Power of light has a direct relation with the area light passes through.

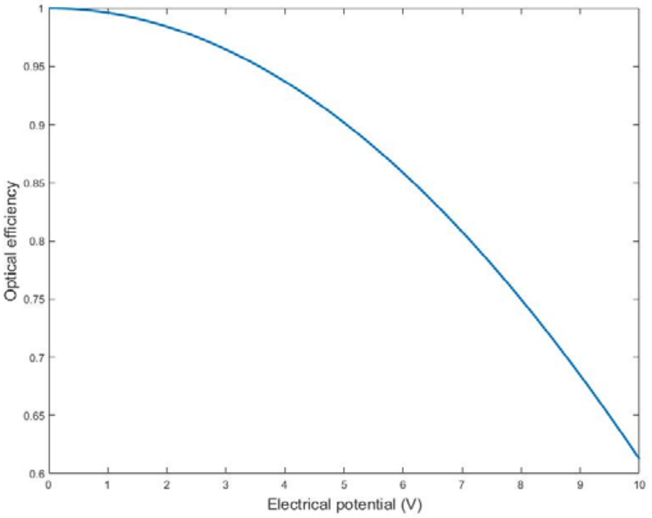

Fig. 9 Optical efficiency vs Electrical Potential

$$P = \int I \, dA \tag{2}$$

The I is the light intensity and is considered as a characterization of the optical source which is constant. In this regard, the Total Power will be a function of area change. Therefore the optical efficiency could be estimated by:

$$Optical\ efficiency\ \eta = \frac{P_{out}}{P_{in}} \tag{3}$$

which P_{out} is the power of the light passing through the optical hole after movement and P_{in} is the total power. Because of small thickness of the microgripper, distance loss has been neglected. On the other hand, experienced optical efficiency by the device is affected by applied voltage indirectly. By increasing the voltage, more gripper site deflection happens so less optical efficiency will achieve. These changes are shown in Figs. 8 and 9.

REFERENCES

[1] A. Baracu *et al.*, "Design and fabrication of a MEMS chevron-type thermal actuator," in *AIP Conference Proceedings*, 2015, vol. 1646, no. 1, pp. 25–30.

[2] J. H. Comtois, M. A. Michalicek, and C. C. Barron, "Characterization of electrothermal actuators and arrays fabricated in a four-level, planarized surface-micromachined polycrystalline silicon process," in *Solid State Sensors and Actuators, 1997. TRANSDUCERS'97 Chicago, 1997 International Conference on*, 1997, vol. 2, pp. 769–772.

[3] I. Giouroudi, H. Hötzendorfer, J. Kosel, D. Andrijasevic, and W. Brenner, "Development of a microgripping system for handling of microcomponents," *Precis. Eng.*, vol. 32, no. 2, pp. 148–152, 2008.

[4] S. Iamoni and A. Som??, "Design of an electro-thermally actuated cell microgripper," in *Microsystem Technologies*, 2014, vol. 20, no. 4–5, pp. 869–877.

[5] F. Beyeler *et al.*, "Monolithically fabricated microgripper with integrated force sensor for manipulating microobjects and biological cells aligned in an ultrasonic field," *J. microelectromechanical Syst.*, vol. 16, no. 1, pp. 7–15, 2007.

[6] W. N. Sharpe, B. Yuan, R. Vaidyanathan, and R. L. Edwards, "Measurements of Young's modulus, Poisson's ratio, and tensile strength of polysilicon," in *Micro Electro Mechanical Systems, 1997. MEMS'97, Proceedings, IEEE., Tenth Annual International Workshop on*, 1997, pp. 424–429.

[7] D. Mihov and B. Katerska, "Some biocompatible materials used in medical practice," *Trakia J. Sci.*, vol. 8, no. 2, pp. 119–125, 2010.

[8] N. Chronis and L. P. Lee, "Electrothermally Activated SU-8 Microgripper for Single Cell Manipulation in Solution," vol. 14, no. 4, pp. 857–863, 2005.