TECHNICAL UNIVERSITY OF CLUJ-NAPOCA

ACTA TECHNICA NAPOCENSIS

Series: Applied Mathematics and Mechanics
Vol. 55, Issue III, 2012

NEW DESIGN FOR AN ELECTROTHERMALLY ACTUATED MICROGRIPPER AND FINITE ELEMENT SIMULATION RESULTS

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Abstract: *New design for an electrothermally actuated SU-8 polymeric microgrippers is presented, simulated and analyzed. The electrothermally driven microgrippers were studied using computer simulations (the Finite Element Method using CoventorWare software tool). Numerical simulations - coupled electro-thermo-mechanical simulations - were performed. We investigated the influence of the temperatures achieved in the microgripers' arms and the deflections of the tips, as functions of the applied voltages. The electro-thermo-mechanical behaviour of the microgrippers were investigated and an evaluation of the results obtained from simulations (using FEM) was performed. The simulations results show a good mechanical behaviour of the micromanipulator in order to operate in air.* ***Key words:*** *microgripper, electrothermal actuator, FEM*

1. INTRODUCTION

In the last several years many improvements of tools for handling and assembling of microparts (between 10 and 500 µm) have been made [1]. A variety of micro grippers have been developed, for the manipulation of micro-sized objects using various techniques for actuation such as piezoelectric [2-3], magnetic, electrostatic [4-8] or electro-thermal [9-17].

Micro grippers are promising tools needed for handling and manipulating of micro particles and micro objects with application in various fields of science and industry, as medicine, biology or micro assembly.

The electro thermal actuators determine a deflection, as a consequence of the Joule heating effect which generates an expanding of the materials. This is a result of the difference of thermal expansion coefficients of the components which compose the structure.

Electrically driven thermal actuation used in this study is the preferred technique, mainly for biological manipulations, since it is able to produce large deflections at low activation voltages (less than 5 V). Polymers offer a much lower Young's modulus, and thus much lower actuation and handling forces. In particular, SU-8 electro thermally micro grippers demonstrate additional advantages such as good biocompatibility [13, 18].

In this paper we present a new designed electro thermally actuated SU-8 polymeric micro grippers. The lengths of the arms are in the range: 200-400 µm and the thickness is around 20-25 µm. The electro thermally driven micro grippers were studied using computer simulations (Finite Element Method, using Coventor Ware software tool).

The electro-thermo-mechanical behaviour of the microgrippers have been analysed. Numerical simulations - coupled electro-thermo-mechanical simulations were performed in order to characterize their performances. We investigated the temperatures achieved in the micro gripers' arms and the deflections of the tips, as functions of the applied voltages. A comparison between the results obtained from simulations was done.

The choice of biocompatible materials, as SU-8, together with the low actuation voltages required and the large deflection, produced at low temperatures, makes these micromanipulators highly suitable for bio-manipulation experiments in different operation environments.

2. DESIGN CONFIGURATION

The microgripper devices consist of two thermal actuators positioned face-to-face which are composed by hot and cold underarms/parts of 200 μm in length and a pair of extended free arms of 200 μm in length.

The main body of the microgripper is composed by a multilayer structure, first model have two metallic layers and second model has one metallic layer between two polymeric layers. The structures are composed using two ‘hot underarms’ and one ‘cold arm’ in order to increase the capability of the devices (Fig. 1.).

The structural material of the microgrippers is SU-8 which is a biocompatible material and has proper mechanical and chemical complimentary properties [13, 18, 19].

We designed two structures, differing by the multilayers structure and dimensions.

The main dimensions of the first microgripper are 200 μm x 200 μm x 200 μm x 20.6 μm. The length of the free arms is 400 μm, 5 μm is the thickness of the thermal oxide layer (SiO_2), 20 μm the thickness of the polymeric layer (SU-8) which is deposited between two metallic layers, 0.3 μm the thickness of each Chromium/Gold layers (which are deposited on the top of the SU-8 layer and in the bottom of the SU-8 layer) (see Fig. 2., a)).

The main dimensions of the second microgripper are 200 μm x 200 μm x 200 μm x 20.3 μm. The length of the free arms is 400 μm, 5 μm is the thickness of the silicon oxide layer, 10 μm the thickness of each polymeric layer (SU-8) and 0.3 μm the thickness of Chromium/Gold layer deposited between two polymeric layers of SU-8 (see Fig. 2., b)).

The microgrippers were designed to operate through an integrated thermal element which is controlled by applying a voltage to the metallic layers of the structure which produce the expanding of the polymeric material and generate closing of the microgripper. As a result of these deflections, an object can be gripped.

In Fig. 1 is presented the cross section through the hot underarms (the arms that contain the metallic layers) for every microgripper model, namely the Gold layers and the SU-8 layers that compose the structure underarm.

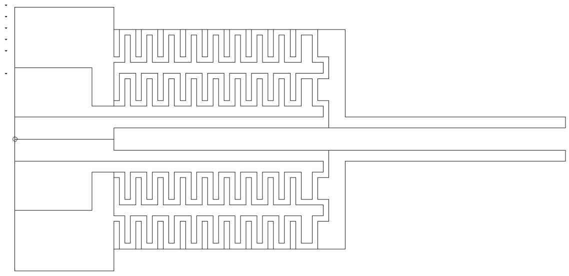

Fig. 1. The new design of the structures with two hot underarms

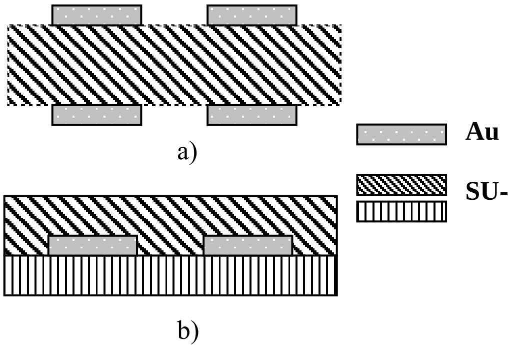

Fig. 2. Cross section through the hot underarms of the microgrippers: a) for the first model; b) the second model [12]

The operation principle of the microgrippers is the U-shaped electrically driven thermal actuator. The in plane deflection is controlled by the difference of the temperatures established between the hot and the cold underarms. The conventional U-shaped actuators use the metallic layer on both arms, reducing considerable the effective temperature difference between them. With the new oblique design of the arms and the new shape of the thermal actuators (metallic layer) no direct Joule effect will be produced in the cold arm [11, 12]. The hot arm will expand more than the cold arm and an in plane deflection will take place.

The microgripper was designed for normally open operating mode. The initial openings of the microgripers were considered around 20-25 μm.

In all cases an actuation is needed for gripping the object, when the tips of the microgrippers are closing and no actuation is needed for the release operation.

3. SIMULATION RESULTS

Coupled electro-thermo-mechanical simulations have been performed using CoventorWare software tool in order to describe the structures behavior in air, as function of the applied voltage.

The module of the software used for finite element simulations computes the thermal field and the electrical potential resulting from an imposed voltage through the resistive material, gold layers. The capability of the Joule heating effect is well suited to the design of the electrothermal actuator and heat sources.

We obtain solutions for the electrical field, thermal field and mechanical deformations.

A voltage is applied across the terminals of the Chromium/Gold layers. The solver converts the potential values to data points that reflect the Joule heating effects resulting from the electrical current [20]. The computed temperature values are applied to determine the deformation due to the temperature. The heat causes mechanical expansion and opening/closing arms of the microgrippers.

The solver software's then uses the material's electrical conductivity, thermal conductivity and the temperature coefficient of expansion in the computing solution. Balance of the thermal energy equation is given by:

$$-\Delta\cdot(k(T)\ \Delta T) = \sigma(T)|\ \Delta V|^2$$

where σ is the electrical conductivity, T is the temperature, V is the potential (voltage) and k is the thermal conductivity [20].

The boundary conditions used are the initial temperature of the whole structure and the temperature of the environment which were considered to be 27 ^{o}C and the air convection coefficient was set to 20 W/m^{2}K. We assumed the thermal conductivity of SU-8 to be 2 X 10^5 pW/µmK.

For the electro-thermal/structural coupled simulation, the model assumes a Young's modulus of 4.95 +/-0.42 GPa [19], a Poisson's ratio of 0.22 and a thermal expansion coefficient of 5.2×10^{-5} K^{-1} for the SU-8 polymer.

The model was meshed using hexahedral elements and the number of volume elements was optimised choosing the proper size of the mesh elements.

In figure 3. is presented the 3D model of the first microgripper realized with Coventorware software tool and in Fig. 4-5 the results of the temperatures and in plan deflections obtained for a 0.2 V applied.

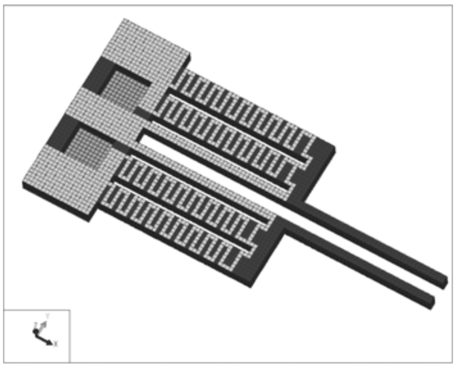

Fig. 3. 3D microgripper model for the first case (Coventoware software)

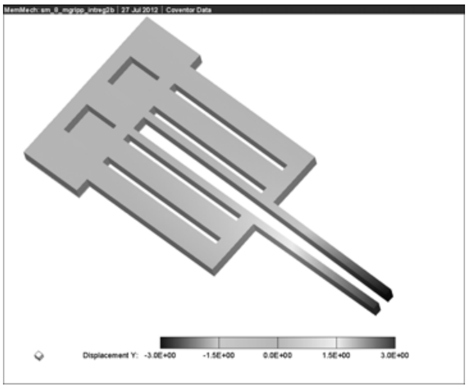

Fig. 4. Displacement obtained for the first microgripper when 0.2 V are applied (Coventoware software)

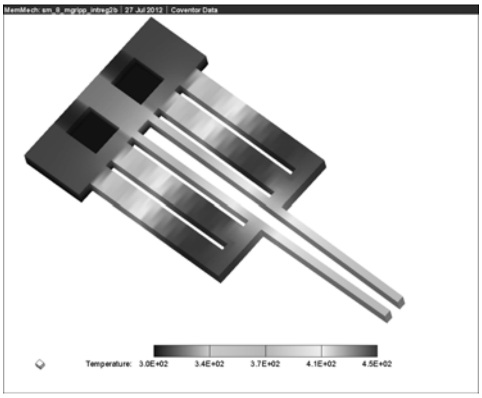

Fig. 5. Temperature distribution for the first microgripper when 0.2 V are applied (Coventoware software)

The results indicate that the polymeric microgripper can work at a relatively low voltage and at low operation temperatures, since the simulations show reasonably low temperature at the microgrippers tips (Fig. 6-7).

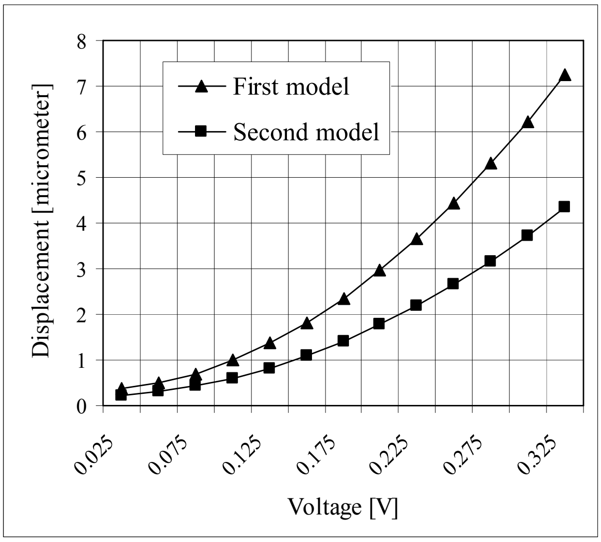

Fig. 6. The in plan deflections of one arm/tip of the microgripper as function of applied voltage

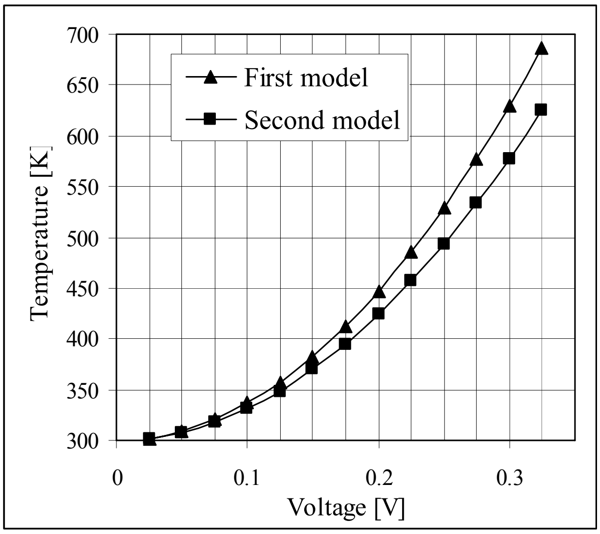

Fig. 7. The maximum values of the temperature reached on the microgripper's arm as function of applied voltage

The second microgripper operate at lower maximal temperatures than the first structure, but the deflections are much lower. Since the maximal values of the temperatures of the both devices don't show major difference, we can conclude that the first microgripper is indicated to be choose for fabrication and testing.

The first configuration shows the best performance for the normally open mode and for operating in air.

A low activation voltage (0.05-0.25 V for the first microgripper model, and 0.05-0.3 V for the second microgripper) and a large displacement (up to 5-8 μm the remaining distance between tips) were obtained.

4. CONCLUSION

Finite-element analyses, using Coventorware software tool, were performed in order to describe the microgrippers behaviours in air as function of the applied voltage on the heaters.

The behavior of the first microgripper seems to be more properly because the temperatures obtained are close to the second and the *in plane* displacements are higher. In consequence low voltage values are needed to actuate this structure to be able to grippe a micro-object.

The first model has the advantage of controlling the two voltage inputs, for both metallic layers, when applying different voltage values. This way we can control the displacements of the microgripper, in different planes. Also, the out of plane displacements can be controlled using this trick.

The new designs proposed and analyzed by means of numerical simulations show that low voltages is possible to be applied on the metallic layers, in order to actuate the microgrippers and to obtain a proper opening of the free arms.

The results obtained in this paper show that the proposed microgripper structures are promising models to be used for manipulation of micro particles and even cells, in different environments due to the biocompatibility of the SU-8 polymer.

5. ACKNOWLEDGMENTS

This work was supported by National Romanian Program Nucleu.

6. REFERENCES

[1] Büttgenbach S. et al. (eds.), Design and Manufacturing of Active Microsystems, Springer-Verlag Berlin Heidelberg 2011, Microtechnology and MEMS, 2011

[2] Carrozza M., Eisinberg A., Menciassi A., Towards a force-controlled microgripper for assembling biomedical microdevices J. Micromech. Microeng. 10, 271–276 (2000).

[3] Rakotondrabe M., Clevy C., Lutz P., Modelling and Robust Position/Force Control of a Piezoelectric Microgripper, Laboratoire d'Automatique de Besancon LAB CNRS UMR6596

[4] Kim C., Pisano A., Muller R. and Lim M.G., Polysilicon Microgripper, Sensors and Actuators, A. (33), (June 1992) 221-227.

[5] Fantoni G., Biganzoli F Design of a novel electrostatic gripper. Int Journal of Manufacturing Science & Production 6(4):163–179 (2004)

[6] Lang D., Tichem M., Design and experimental evaluation of an electrostatic micro-gripping system. In: Proceedings of 3rd Int. Precision Assembly Seminar, pp 33–42, (2006)

[7] Varona J., E. Saenz, S. Fiscal-Woodhouse, A. A. Hamoui, "Design and fabrication of a novel microgripper based on electrostatic actuation," mwscas, 2009 52nd IEEE International Midwest Symposium on Circuits and Systems, pp.827-832, 2009

[8] Millet, O., Bernardoni, P., Régnier, S., Bidaud, P., Tsitsiris, E., Collard, D. and Buchaillot, L., "Electrostatic actuated micro gripper using an amplification mechanism," journal of Sensors and Actuators A 114, 371–378 (2004).

[9] Benecke W. and Riethmuller W., Applications of silicon-microactuators based on bimorph structures Proc. IEEE Micro Electro Mechanical System Workshop, pp 116–20 (1989),

[10] Chronis N., Lee L. P., Electrothermally activated SU-8 microgripper for single cell manipulation in solution, Journal of Microelectromechanical Systems, pp 857–863 (2005),

[11] Voicu R., Esinenco D., Müller R., Eftime L., Tibeica C., Method for overcoming the unwanted displacements of an electro-thermally actuated microgripper, 4M Conference 2007, Borovets, Bulgaria, oct.2007, pp.39-42.

[12] Voicu R., Tibeica C., Muller R., Design and simulation study for an electro-thermally actuated micromanipulator, Proceedings of EuroSimE2009, pp. 429-433, 2009

[13] Voskerician G., Shive M. S, Shawgo R. S., H. von Recum, Anderson J. M., Cima M. J. and Langer R., Biocompatibility and biofouling of MEMS drug delivery devices. Biomaterials, vol. 24, pp. 1959–1967, 2003

[14] Hoxhold B, Buttgenbach S Easily Manageable, Electrothermally Actuated Silicon Micro Gripper. Microsystem Technologies published online:1–9 (2010)

[15] Geisberger A; Sarkar N, Techniques in MEMS Microthermal Actuators and their Applications, MEMS/NEMS, 1191-1251, 2006, DOI: 10.1007/0-387-25786-1_32

[16] Kim K. et all, Elastic and viscoelastic characterization of microcapsules for drug delivery using a force-feedback MEMS microgripper, Biomedical Microdevices 11: 421-427, 2009

[17] Zheng X. et all, Analysis on microfinger with grooved patterns and its application in electric–thermal microgripper, Int J Adv Manuf Technol 56:505–513 (2011)

[18] Choi Y., Powers R., Vernekar V., Frazier B., LaPlaca M., High aspect ratio SU-8 structures for 3-D culturing of neurons. Proc. ASME Int. Mechan. Eng. Congress and Exposition, 2003

[19] Dellmann L., Roth S., Beuret C., Racine G., Lorenz H., Despont M., Renaud P., Vettiger P., N. de Rooij, Fabrication process of high aspect ratio elastic structures for piezoelectric motor applications in Proc. Transducers 1997, Chicago, 641-644, (1997)

[20] Coventoware Analayzer Reference, MEMS and Microsystems Design, Version 2008

UN NOU MODEL DE MICROMANIPULATOR ACTUAT ELECTROTERMIC SI REZULTATE ALE SIMULARILOR CU ELEMENT FINIT

Abstract: In acesta lucrare prezentam un nou model de micromanipulator polimeric fabricat din SU-8 actuat electrotermic. Micromanipulatorul actuat electrotermic este studiat folosind simularile cu element finit si softul Coventorware. Au fost realizate simulari numerice-analize cuplate electro-termo-mecanice. Am investigat influenta temperaturilor obtinute in bratele micromanipulatorului si deplasarile varfurilor bratelor, ca functie de un potential aplicat pe straturile metalice. A fost analizat comportamentul electro-termo-mecanic al structurilor si au fost evaluate rezultatele obtinute. Rezultatele simularilor arata un comportament mecanic potrivit pentru operarea in aer cu scopul de a manipula si apuca diverse micro-obiecte.

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