Hybrid Design Electrothermal Polymeric Microgripper with Integrated Force Sensor

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Abstract: Microgrippers are typical MEMS devices used to pick, hold and transport micro-objects.Microgrippers are widely used in the field of micro-assembly, micro-surgery and manipulation of micro-particles. Thermal microgrippers are widely used for large displacement, high accuracy and repeatability. In this paper, a hybrid design electrothermal microgripper (Figure 1), based on Poly Methyl Methacrylate (PMMA) with integrated force sensor is designed and analysed using COMSOL Multiphysics software. The new design is designed by combining asymmetric arm structure and bi-layer structure to minimize the undesired out of plane displacement of the microgripper. The in-plane, out of plane and curl displacements, stress, strain and temperature has been analysed and the results are discussed (Figure 2). A piezoelectric force sensor (Figure 3), based on Poly Vinylidene Fluride (PVDF), which is to be integrated with microgripper to resolve the gripping force exerted by the microgripper on the micro-objects, is also designed and analysed. The force sensor is analysed for charge density for various gripping forces, stress, strain and displacements along X,Y, and Z axis (Figure 4). The hybrid design gives 1.6 µm in-plane displacement and 0.3 µm out of plane displacement at 0.1 V applied voltage. The maximum temperature of the microgripper is 323 K. The fabrication method for the hybrid design electrothermal polymeric microgripper is discussed.

Keywords: MEMS, microgripper, COMSOL, elecrothermal, piezoelectric, force sensor.

1. INTRODUCTION

The field of mechanical micro machining deals with producing miniature 3D components using a variety of engineering materials in the sub-millimeter (1-999µm) range and bridges the gap between nano-scale and macro-scale manufacturing. The demand for micro machined components such as micro shafts, micro nuts, micro spiral inductors, micro motors etc. has been rapidly increasing in nuclear, aerospace, automotive, optical, military and microelectronics packaging. Miniaturization of components leads to material saving, energy saving, increased functionality, quick response etc. [1]

The handling and assembly of the micro components is highly challenging due to their small size. To manipulate the micro-components, microgripper are used. The microgripper is an important component of the system to hold, pick, manipulate and assemble mechanical micro components. The general requirement of a microgripper is that it should be able to pick up and release a component at a specified position. The positional uncertainty during assembly should be well defined and components should not be damaged during assembly. Microgripper applications include assembly of micro components in manufacturing, electronics, information technology, optics, medicine and biology areas like diagnostics, drug delivery, biopsy tissue sampling, tissue engineering and minimally invasive surgery [2]. Thermal microgrippers are widely used for large displacement, high accuracy and repeatability. They work on the principle of the Joule’s Law and thermal expansion. The Joule’s Law states that a material crossed by an electric current will get some thermal energy. This results in collision of the flowing electrons and the atoms making the material. This collision between the electrons and atoms results in vibration which excites the surrounding atoms. The large amplitude of vibration results in increase of dimensions. This phenomenon is known as thermal expansion [3]. The materials with higher co-efficient of thermal expansion result in larger gripping displacements. Polymers have the highest co-efficient of thermal expansion than metals and semi-conductors [4-7].

Due to co-efficient of thermal expansion there is an increase in dimensions in all directions. So, it is necessary to direct and amplify the thermal expansion in dimensions to obtain an efficient thermal actuation suitable for application. The amplification can be done by using asymmetric thermal arm structure, bi-layer structure and bent-beam structure. The microgrippers may require in plane and out of plane actuators based on the application. The in plane actuators move parallel to the substrate surface, whereas the out of plane actuators travel perpendicular to it. Many polymeric in plane and out of plane actuators have been demonstrated using asymmetric arm [8,9], bi-layer [7, 10] and bent beam structures [11, 12]. However asymmetric arm structured micro actuator have undesired out of plane movement. The bi-layer structure of a microgripper gives diverging movement which is undesired. To overcome the above disadvantages, combination of asymmetric and bi-layer structure hybrid design can be used.

Force sensors are used to determine the gripping force of the microgripper. Capacitive, piezoelectric [13, 14] and piezoresistive [15-17] force sensors have been used in microgrippers.

Properties	Aluminium	PMMA
Co-efficient of thermal expansion	23.1×10^{6} per K	70×10^{6} per K
Thermal conductivity	273 W/mK	0.19 W/mK
Heat capacity	904 J/Kg K	1420 J/Kg K
Density	2700 Kg/m3	1190 Kg/m3
Young's modulus	70x109 Pa	3×10^{9} Pa
Electrical conductivity	35.5x106 s/m	1×10^{-19} s/m
Poisson ratio	0.35	0.4
Relative permittivity	---	3

Table 1. Material properties of PMMA and gold.

Piezoelectric force sensors are used for their durability, wide dynamic range and good mechanical material properties. They work on the principle of piezoelectricity which states that charges are accumulated in certain solid materials in response to applied mechanical stress. The advantages of piezoelectric force sensors that they react to compression and the sensing elements show almost zero deflection. They are highly rugged and can be used in harsh and rugged conditions. They have extremely high natural frequency and have excellent linearity over a wide amplitude range. Also they are insensitive to electromagnetic fields and radiations, enabling measurements under harsh conditions.

In this paper, a hybrid design microgripper is designed and analyzed using Comsol Multiphysiscs design and analysis software. The piezoelectric force sensor which is integrated with the microgripper is also designed and analyzed. The analysis results are discussed.

2. DESIGN AND SIMULATION

2.1. Design of microgripper:

The hybrid design microgripper is designed using Comsol Multiphysics software. The hybrid design is a combination of asymmetric arm and bi-layer structure. The major parts of the microgripper are the fixed part (anchor), hot and cold under arms, flexure, gripper arms and heaters. The hot and cold arms vary in cross sectional area in order to obtain different temperature for thermal expansion. The flexure is designed in such a way that it should be as thin as possible but not thinner than the thin arm because the temperature of the flexure could be higher than that of the hot arm which might result in overheating. Also, in order to keep it elastically deflecting, the flexure is designed long enough. However it is taken care that the flexure is not too long that the deflection of the thermal actuator tip is not reduced due to resistivity of additional material. The overall dimension of the microgripper is 400x300x20 µm. The other dimensions of the microgripper is given in table 2. The material of the microgripper is PMMA (Poly Methyl Methacrylate) and the electrode material is alluminium. The properties of PMMA and Alluminium are shown in table 1. The electrodes are sputtered in the pattern as shown in figure 1 by combining the asymmetric arm and bi-layer structure.

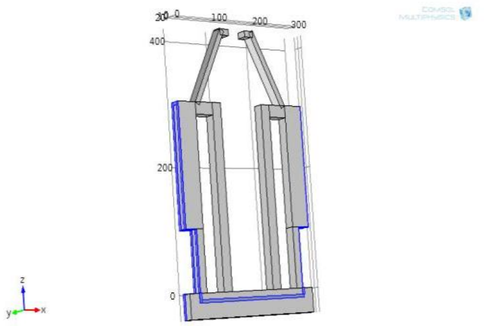

Figure 1. Microgripper

Parameter	values
Overall dimension	400 x 300 x 20 µm
Hot arm dimension	40 x 20 x 300 µm
Cold arm dimension	20 x 20 x 300 µm
Connecting block dimension	40 x 20 x 20 µm
Flexure	15 x 20 100 µm
Gripper arm	10 x 20 140 µm, 30 deg
Gripper extension	20 x 20 x 10 µm
Base dimension	300 x 20 x 40 µm
Initial gap between arms	20 µm
Voltage applied	0.1 V
Atmospheric temperature	293.15 K

Table 2. Dimensions of microgripper

2.1. Design of force sensor:

A piezoelectric force sensor is designed with the dimensions 20x20x28 µm as shown in figure 2. The material of the force sensor is PVDF (Poly Vinyledene Fluoride) which is a piezoelectric polymer.

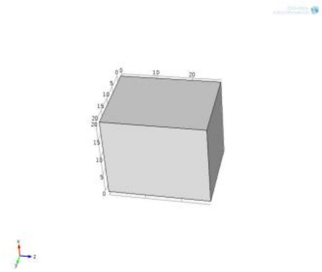

Figure 2. Peizoelectric sensor

3. SIMULATION AND ANALYSIS RESULTS

The designed microgripper is analyzed using Comsol Multiphysis for stress, strain, displacements, and temperature and the results are obtained. At 0.1 V the hybrid design microgripper gives good in-plane displacement of 1.6 µm and very less out of plane displacement of 0.3 µm as shown in figures 3 and 4. The displacement for different voltages is plotted in figure 5. Thus more positional accuracy can be obtained. Desired displacement can be obtained by changing the applied voltage. The maximum stress obtained is $5.4x10^7$ Nm^{-2} and the strain obtained is$4.7x10^{-3}$ as shown in figures 6 and 7. The maximum temperature obtained is 323 K and the temperature at the gripper arm tips is 320 K which is very less and suitable for most of the applications. Temperature analysis is shown in figure 8.

The current density of the piezoelectric force sensor when no force is acting on the gripper arms is 0 V/m. The current density increases as the gripping force increases. So the gripping force can be calculated by equation 1 by knowing the output voltage. The output voltage can be obtained by the charge amplifier which converts the accumulated charges into voltage.

$$V = Fgl/A \quad \text{--------------------- Eq 1}$$

Where ,

V = output Voltage in Volts
F = Force on the object by gripper
g = Gravity
l = length of sensor in mm
A = Cross sectional area in mm^2

The charge density for various forces from 20 mN to 70 mN is shown in figure 9 and is also plotted in a graph in figure 10, which shows that the output voltage is directly proportional to the gripping force exerted by the microgripper on the micro-object.

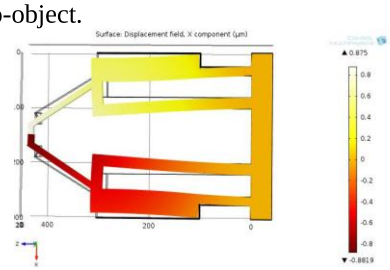

Figure 3. In plane displacement

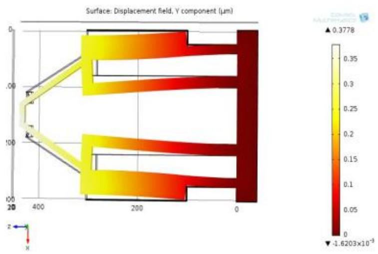

Figure 4. Out of plane displacement

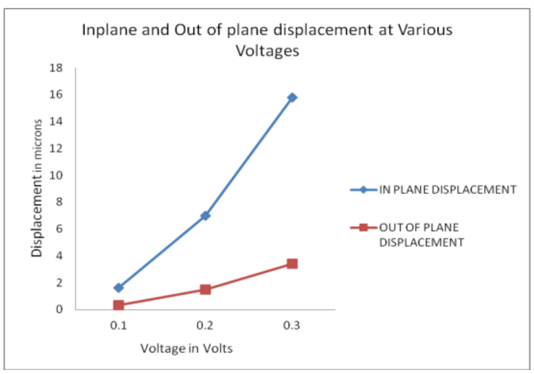

Figure 5. Displacement at various voltages

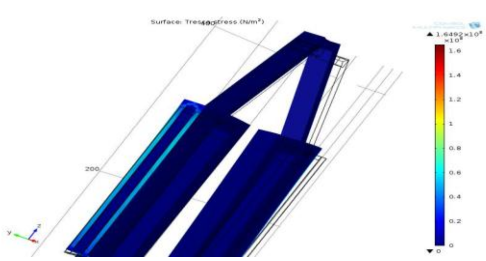

Figure 6. Stress

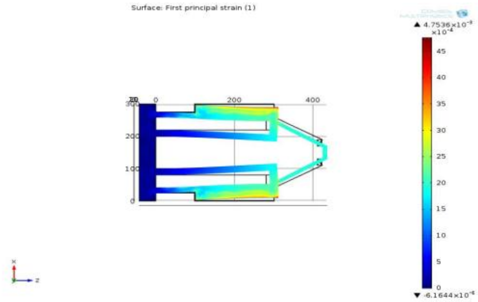

Figure 7. Strain

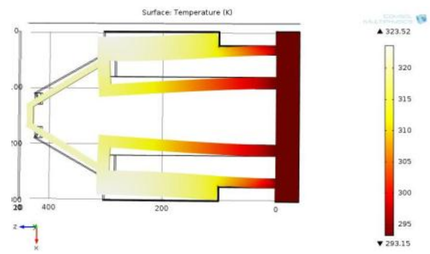

Figure 8. Temperature analysis

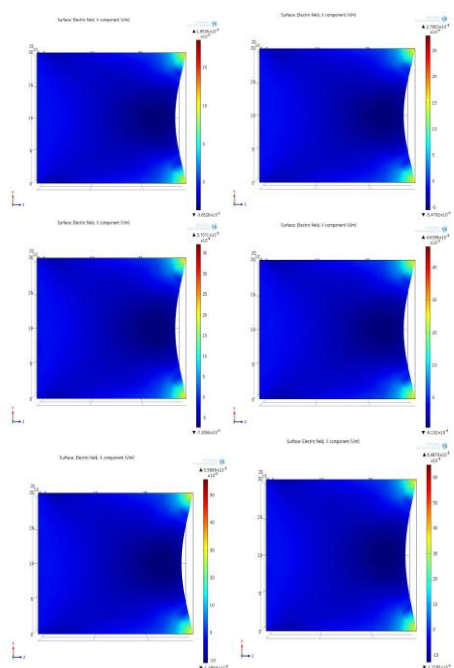

Figure 9. Charge density at 20mN to 70 mN

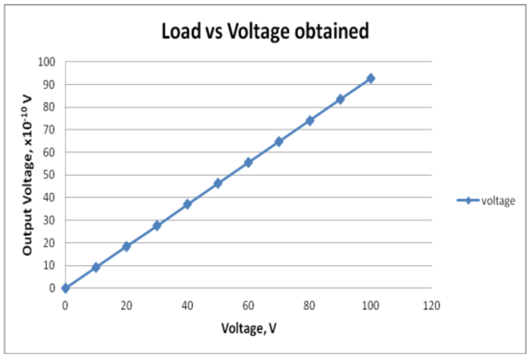

Figure 10. Output voltage for various gripping forces

4. FABRICATION

The microgripper is to be fabricated using microstereolithography which is a rapid prototyping technique. Microstereolithography is a technology at the interface of the micro-engineering and rapid prototyping domains. It is capable of producing 3D complex shapes in small size polymer structures by light induced polymerization of a liquid resin. It permits fabrication of 3D devices on µm to mm scale, including curvilinear and re-entrant micro-structures. The process involves the photo curing of polymer parts in layers by moving a Laser beam on the surface of a liquid monomer formulation. The stl file of the microgripper is given as input to the microstereolithography machine and the basic structure of the microgripper is obtained. Then the electrodes are metalized by sputtering on the fabricated structure. Once the microgripper is fabricated, the piezoelectric force sensor has to be integrated with it, in order to resolve the gripping force exerted by the gripper on the micro-objects. Rectangular piezoelectric PVDF polymer layers are cut using dicing saw. The two flat surfaces of the PVDF film are attached to nickel electrodes that provide electrical connections to a charge amplifier which converts the charges into output voltage. The nickel electrodes on PVDF polymer film layers are bonded with gold wires using silver epoxy (Dotite electroconductive paste) and cured for four hours at room temperature. The PVDF force sensor is then sandwiched between paralyne coated layers that provide sufficient thermal insulation to reduce the pyroelectric effect of PVDF.

5. CONCLUSION

The microgripper is an important component of the system to hold, pick, manipulate and assemble mechanical micro components. Thermal microgrippers are widely used for large displacement, high accuracy and repeatability. They are designed using asymmetric arm and bi-layer structure. These structures have disadvantages such as divergent displacement and more out of plane movement. These disadvantages can be overcome by using a hybrid design structure using a combination of asymmetric arm and bi-layer structure. The hybrid microgripper has been designed and analyzed by Comsol Multiphysics software and the results are discussed. A piezoelectric force sensor is designed and analyzed and the results are discussed. The hybrid microgripper gives very good in plane displacement and very less out of plane displacement which is the most desired feature of a microgripper. The charge density in the piezoelectric force sensor is directly proportional to the gripping force exerted by the gripper on the micro-object. Thus, this microgripper can be used for better accuracy and safe gripping of micro particles.

5. REFERENCES

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