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DESIGN AND SIMULATION ANALYSES OF MEMS GRIPPER WITH ALUMINUM AND NICKEL ALLOYS

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ABSTRACT

A novel MEMS based Electro thermal Gripper is proposed in this paper, the gripper tool proposed in this paper is designed to handle the micro objects of about 100-150 microns. The gripper tool proposed in this article is materialized with Nickel Alloy of UNS NO4400. The material proposed for the Gripper has better heat resistant characteristics and can with stand the high potential applications. The gripper designed is working on the basics of Pull actuation method from the middle hinge part due to the applied potential. The gripper tool is actuated for an applied potential of about less than 2 volts and mode shape response of the gripper was analyzed under Dynamic frequency. Comparative analyses also carried out between the different Gradients of Aluminum and Nickel alloys and applied potential. The yield point criteria analyses have been presented for the gripper with various Gradient of Aluminum and Nickel Alloys. The entire TEM analyses of the gripper tool are carried out with COMSOL multiphysics software.

Keywords: gripper, MEMS, joules heating effect, COMSOL multiphysics, TEM analyses, mode shapes dynamic frequency.

INTRODUCTION

MEMS based gripper tools finds applications in various industrial standards and Bio medical environments. Gripper tool based on the application, the material selection plays a crucial role, since most of biomedical devices are composed with Polymer material as in [1] [5], since the compatibility towards fluidic interactions are considered. Apart from material selection the type of actuation mechanism for Gripper tools grouped into Pull in Mechanism and pulls Actuation methods, where these mechanisms are most probably employed in the Polymer based gripper tools since mechanical parameters like stress, strain plays a critical role in structural stability. The one such tool proposed in this article based on joules heating effect is based on Push mechanism materialized with a Nickel alloy UNS NO4400. Devices undergoing structural mechanics boundary conditions will experience different stress strain phenomenon due to applied load in any form like thermal, Electrical and direct pressure or force over the entire structure. Gripper actuated with applied electrical pulse also experience mechanical stress strain parameters at the point of Joints and middle hinges. The stress experienced by a beam is given by$\sigma = \frac{F}{A}$, where to obtain a true stress factor σ_e, it is given by

$$\sigma_{true} = (1+\varepsilon e)(\sigma_e).$$

Where true stress factor is calculated upon the condition when load is in gripper arm. The true stress factor can be calculated with stress and nominal strainεe.Similar to the true stress factor the true strain can be calculated, since it epics the maximum displacement of gripper until structural failure, which is given by,

$$\varepsilon_{true} = \ln(1+\varepsilon e).$$

Where εebe the strainobserved in the structure. The gripper tool designed is proposed to handle micro assembly tools with dimension ranging in few ~100 microns. To meet such applications gripper tool proposed is compatible, since the impact of temperatures and electric potential will not alter the system parameters. The poly silicon material are usually used in the conventional Electro thermal grippers as in [1], but in our paper the Comparative analyses of Aluminum and Nickel alloys are carried out and nickel alloy of UNS NO4400 grad is particularly used to have a better thermal expansion for a relatively small applied potential.

Mode shape analyses

The gripper when actuated with applied potential, due to thermal expansion, the structure will undergo different mode of vibrations exhibiting a dynamic range of frequency. The Gripper tool simulated in this article exhibits around 6 sets of frequency with varying displacement for each frequency. The set of frequency and Displacement result are shown in Table-1.

Table-1. Dynamic frequency and displacement analyses.

S. No.	Eigen frequency	Displacement
1	2.510356Hz	5.7444 µm
2	3.085406Hz	6.3297 µm
3	6.850456Hz	8.9971 µm
4	7.304762Hz	8.2061 µm
5	1.530516Hz	4.0591 µm
6	1.684439Hz	4.5619 µm

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Material specifications

A comparative analysis has been presented on gripper tool for various gradients of Aluminum alloys and Nickel alloys. And Annealed nickel alloy of UNS NO4400 can exhibit a maximum displacement for the applied potential of 1 Volt where the displacement achieved is about 8.5022microns which is enough to hold a structure of dimension less than 200 microns. A comparative analysis of various material alloys and its corresponding Displacement for an applied potential of about 1V is shown in Table-1.

Table-2. Alloy gradients and displacement for 1V applied potential.

S. No.	Metal	Alloy gradient	Displacement for 1V potential
1			
2	ALUMI NUM	Al	6.8527 µm
3		UNSA91050	8.217 µm
4		UNS A91060	8.259 µm
5	Nickel	Ni	8.2061 µm
6		UNS NO 2201	8.1934 µm
7		UNS NO4400	8.5422 µm
8		UNS NO 8330	8.5422 µm

The Nickel alloys comparatively shows a better response compared with the Aluminum alloys analysis shown in Figure-1, and in Nickel Alloys two gradients UNS NO4400 and UNS NO8330 shows almost an identical displacement response but the Gradient UNS NO8330 will deform quickly because of its lesser Density. Response of various gradients for the applied potential of 1V is shown.

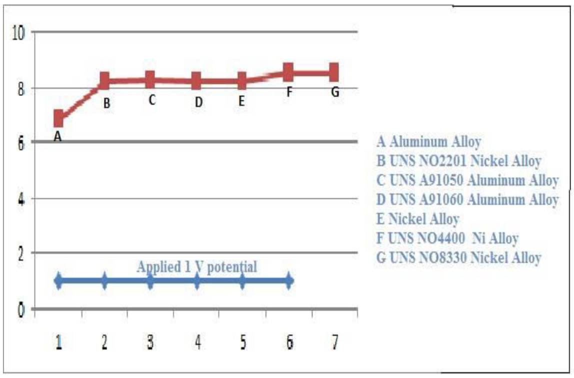

Figure-1. Applied potential vs. material response (Displacement factor).

Design specification

The Gripper structure proposed is materialized with a nickel alloy and entire structure measures for about few millimeters with initial gap of less than 100 microns. The overall structural specifications of the gripper are as follows.

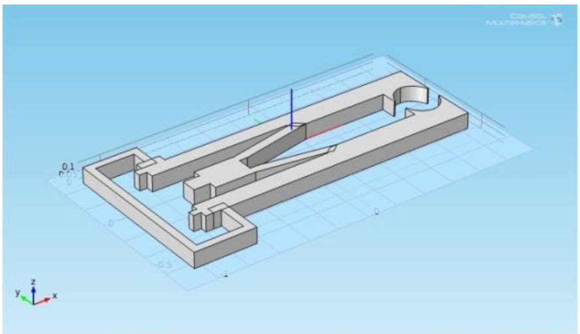

Figure-2. Structural specifications of Gripper.

Table-3. Device specification.

S. No.	Specifications	Measure value
1	Device length	1700 microns
2	Entire base width	1000 microns
3	Inplane displacement (Initial)	75 microns
4	Thickness	500 microns
5	Material	UNS NO 4400

Pull actuation mechanism

Gripper tool proposed in this article is actuated based on the joules heating effect principle. A potential of about ~1 to 2V is applied at the hinges of the middle beam. The applied potential in the hinges will results in the increase of temperature which may end up with hinge expansion leading to opening of the arm closures, since the side arms of the gripper acts as a reference fixed part hold. The thermal impact of the structure due to the applied potential observed at the hinge expansions.

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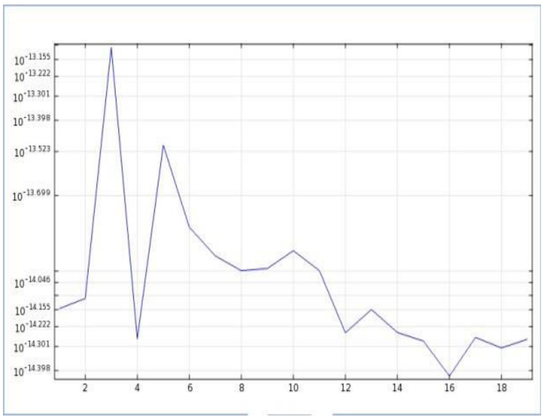

Figure-3. Thermal response of gripper observed from actuation hinge.

Heat transfer modeling

The expansion achieved in the arms of gripper tool is a direct result of the applied potential in the hinge structure. The Material UNS NO 4400 is a high heat resistant alloy series metal which can with stand a relatively better temperature due to applied potential. The Maximum Stress is achieved in the hinge positions of the middle part from where the pressure is distributed for actuation. The stress experienced in the hinge part is given by

$$\rho = \frac{F}{A}, \qquad (1)$$

Where F is the force and A is Unit area where force is applied, In this case the force is applied in form of electrical pulse so, Force analogy is given as

$$F = Q \propto I^2 R\, T, \qquad (2)$$

Since applied force is in the form of Electrical pulse, considerable amount of Resistance will be experienced in the metal, which may result in the heat dissipation factor (Q) and thermal expansion. The Heat generation due to the applied potential is given by

$$Ee = S\nabla T, \qquad (3)$$

Where Ee be the electric potential applied in the hinge part, S be see beck coefficient and ΔT be the change in temperature. The temperature dissipated in the surface of gripper due to applied potential as in [7] is given by,

$$K\frac{\partial 2T}{\partial x2} = \rho c\,\frac{\partial T}{\partial t}. \qquad (4)$$

With initial boundary conditions, x=0,

$$\frac{\partial T}{\partial x} = -P_{in}(t)\,av\delta(T - x = to, L) = T_{in}, \qquad (5)$$

Where K be the initial thermal conductivity, c be specific heat, P_{in} be the power dissipation unit in terms of heat, T_{in} be atmospheric temperature, L_o be the gripper length.

Fabrication process

The gripper structure designed is fabricated with the silicon as substrate material. The nickel alloy material is deposited over the silicon substrate with a thickness of about 500 microns, the then deposited nickel alloy is then exposed to UV radiations for patterning process. The patterned nickel layer is then exposed with wet chemical bath to remove the nickel material. The photoresist material of AZ5214 is used during the patterning process, which is a positive resist photo resist material with having a wall sloping profile of about 70 - 80%. The UV radiation of 52J is exposed for the patterning process.

Simulation analyses

Simulation of Gripper tool carried out in the COMSOL Multiphysics Simulation software, the simulation analyses shows the maximum displacement achieved for applied potential and relatively maximum stress is observed in the hinge of the gripper where the displacement profile is as shown Figure-4.

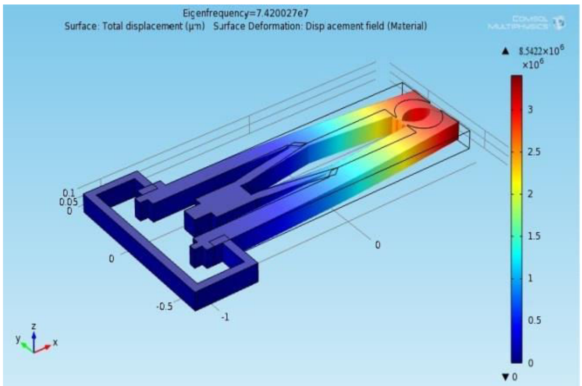

Figure-4. Displacement profile for applied potential in UNS NO 4400.

Stress profile analyses of the gripper tool is also simulated, where the maximum stress of about 7.9806 N\M^2 is observed in the part of hinge. The stress profile analysis of Gripper tool simulation in another frequency condition, where outward movement is observed as a part of deflection, is as shown in Figure-5.

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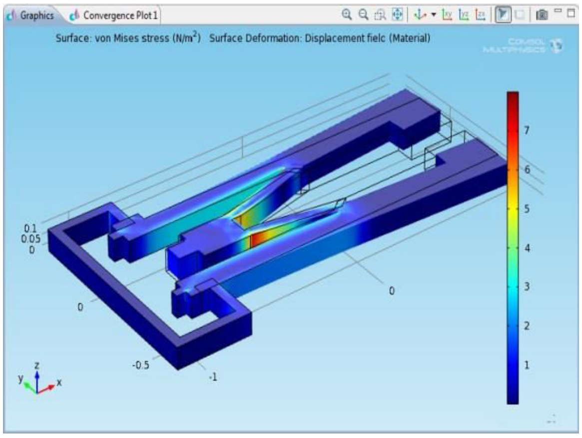

Figure-5. Stress profile analyses in Gripper hinge joints (At another frequency mode).

The current distribution profile on the gripper is analyzed, which is as shown.

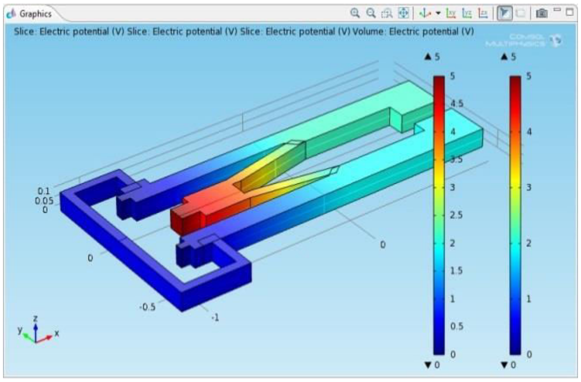

Figure-6. Electric potential distribution in Gripper.

Thermal impact is created due to the applied potential of about ~1-2V. The maximum temperature is observed in the holder of the arms and minimum heat observed in the Middle hinge where potential is applied. Simulation analyses of thermal impact of gripper is as shown.

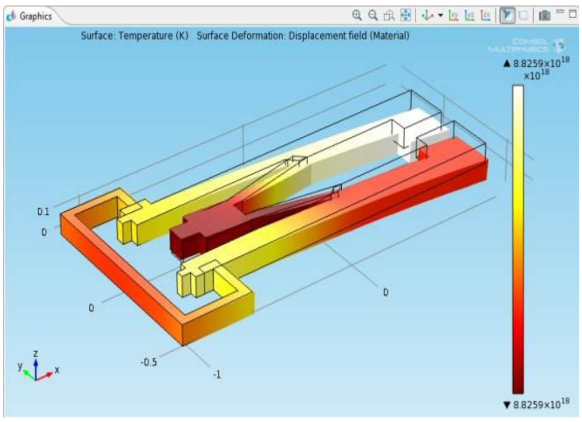

Figure-7. Temperature profile impact in Gripper.

CONCLUSIONS

Electro thermal gripper is actuated with an applied potential of about ~2 volts and the applied potential results in the metal expansion which is based on pull mechanism. The comparative analyses also carried out between various Aluminum and Nickel alloy in this article. Gripper tool designed in this article is suitable for the Micro assembly manipulation with dimension of about 100-150 microns.

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