Hybrid design electrothermal polymeric microgripper with integrated force sensor

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OUTLINE

- Introduction to MEMS
- Microgrippers
- Types of microgrippers
- Electrothermal Polymeric Microgripper
- Need for new design
- Design and analysis of Hybrid design microgripper
- Design and analysis of force sensor
- Fabrication methods
- Advantages of hybrid design microgripper and applications
- Conclusions

Introduction

- MEMS refers to a collection of micro sensors and actuators that can sense its environment and have the ability to react to changes in that environment with the use of micro circuit.
- MEMS combines mechanical and electrical components in packaging ranging in size from sub-micron to centimeter.

Microgripper

- Micromanipulation of micro parts in assembly, biological cells in micro surgery and micro particles in material science is of great interest to scientists and engineers.
- This resulted in innovation of micro tools such as MEMS based micro gripper which is a typical MEMS device used to grip, hold and transport micro-objects from one place to another.
- There are many types of micro grippers based on actuation systems such as thermal, piezoelectric, electrostatic, electromagnetic, vacuum type and mechanical.
- 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.

Figure 3 Microgripper end-effector interface

Application of Microgrippers

Microgrippers are widely used in

- Manufacturing Industry (assembly)
- Electronics (assembly)
- Medical and biological fields (diagnostics, drug delivery, biopsy tissue sampling etc.)
- Materials research (manipulation of micro particles)

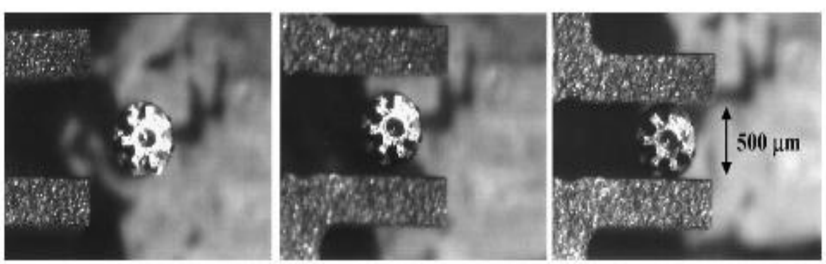
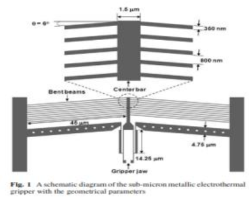


Fig. 12. Grasping action of the microgripper on the miniature gear.

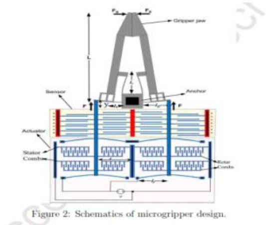

Figure 3 Microgripper end-effector interface

Types of Microgrippers

- Mechanical microgrippers
- Thermal microgrippers
- Electrostatic microgrippers
- Piezoelectric microgrippers
- Vacuum type microgrippers
- Electromagnetic microgrippers



D-S.W. Park et al



Bazaaz et al

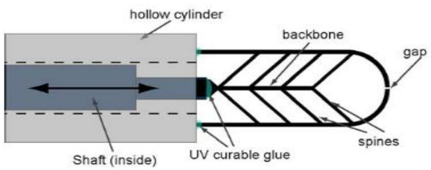


Figure 1. Microgripper diagram showing its different components

J.A. Martinez et al

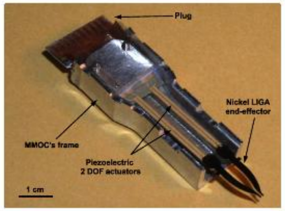


Fig. 1. MMOC microgripper with previous end-effectors in nickel.

Joel Agnus et al

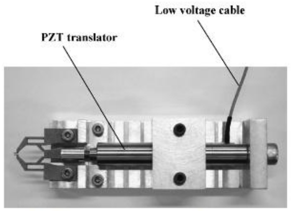
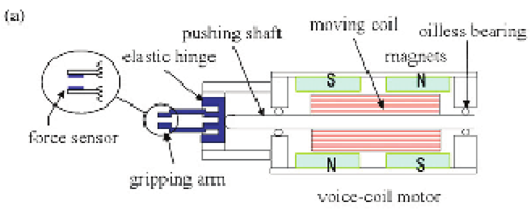


Fig. 5. The prototype of the gripping device with a PZT translator.

S.K . Nag et al



D-H. Kim et al

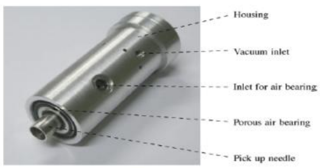


Fig. 4. Assembled gripper photo.

E.J.C. Bos et al

Electrothermal microgrippers

Elecrothermal microgrippers are widely used for

- Large displacement
- High accuracy
- Good Repeatability
- High power to weight ratio
- High work density
- Relatively high gripping force with a compact design

Electrothermal Polymeric microgrippers

- Microgrippers are fabricated using silicon, polysilicon, metals and polymers.

- Polymeric micro grippers recently developed due to their high aspect ratio and displacement.

- Polymeric electrothermal micro actuators work on the following principles.
  - The Joule’s Law
  - Thermal expansion

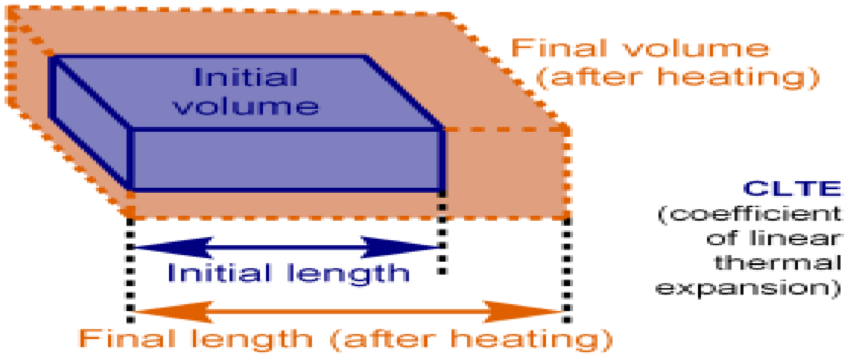
Principle of working of polymeric electrothermal actuator

JOULE'S LAW:

The Joule's law tells that a material crossed by an electrical current will get some thermal energy. This is the result of the collision between the flowing electrons and the atoms making the material.

THERMAL EXPANSION:

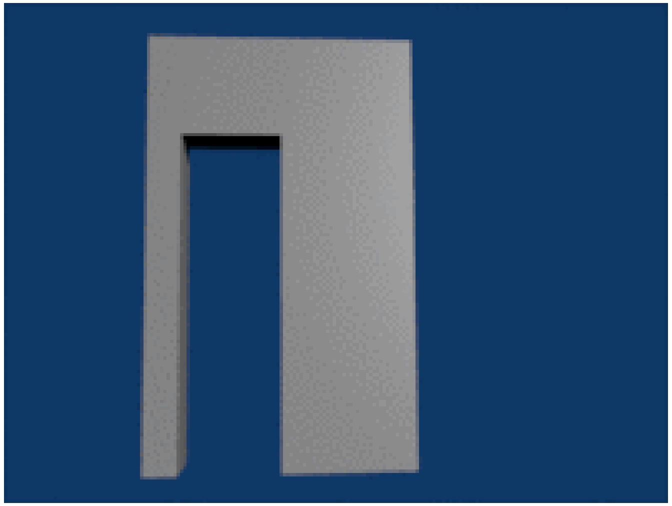
The nature of heat is in the vibration of atoms and electrons making the material. The more an atom is vibrating, the more it is hot and will excite atoms around it. They will have a tendency to push each other away to get enough place as their vibration amplitude is large resulting in increasing the dimensions. This phenomenon is the thermal expansion.

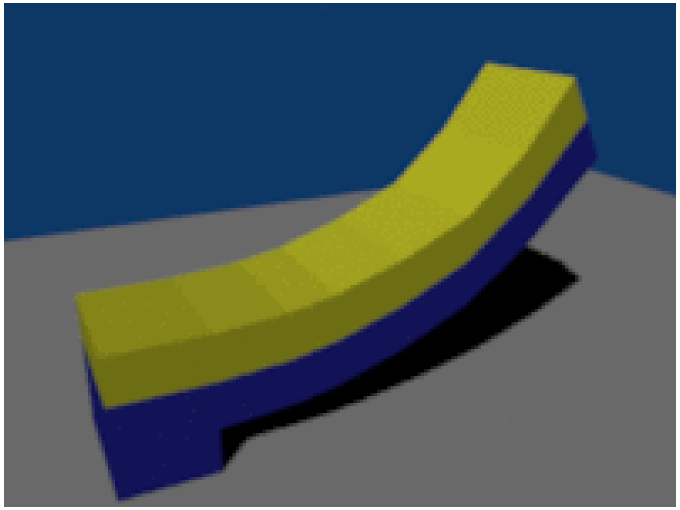


Increasing the actuator efficiency

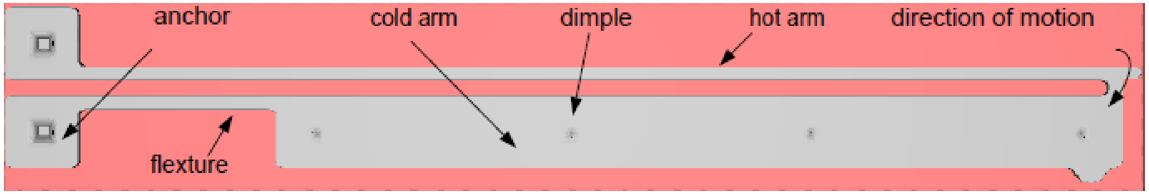
- To increase the actuator efficiency amplification of thermal expansion has to be done. It is done by using
  1. Asymmetric thermal arm

  2. Bi-layer structures



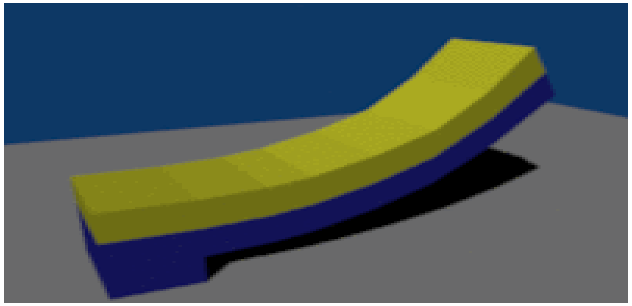


Asymmetric arm



- If a current flowing through a structure meets different resistivity levels, the heating calculated with Joule's law will be higher where the resistance is higher.
- The principle is, if the current flows through three resistive parts being the mobile part, with two long paths and one short linking them, current will flow through them with approximately the same heat distribution.
- If one of the path is thinner than the other, it will become hotter than the two other ones. So its expansion will be higher.
- The thinner part create a mechanical force pushing the structure in the direction thin to large arms.
- This gives in plane actuation.

Bi-layer structure

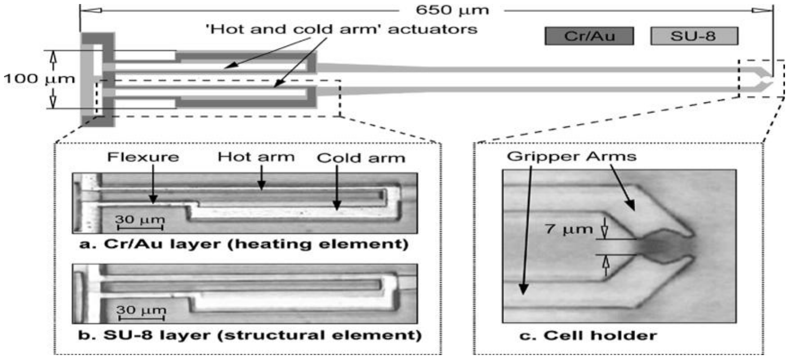


- Thermal expansion is a property particular to each material.
- So two different materials will have two different thermal expansion.
- If a structure made of two different materials is heated the difference in thermal expansion will give a large displacement microactuator.
- This gives out of plane actuation.

Existing polymeric micro gripper designs

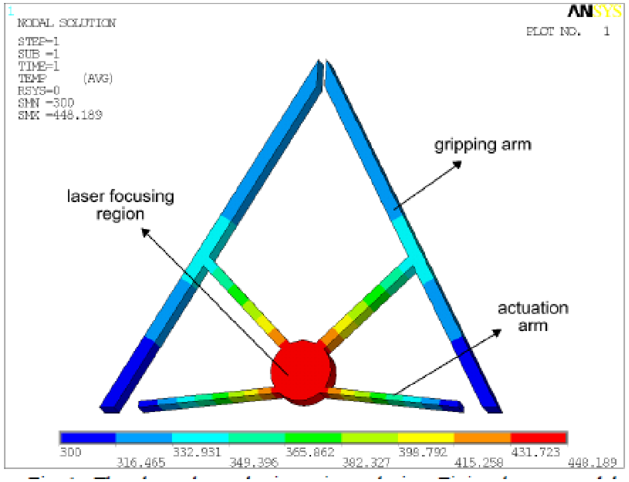
1. Electro-thermally activated SU-8 micro gripper for single cell manipulation in solution – Nikolas Chronis and Luke P. Lee

- ❑ Hot cold arm structure
- ❑ Gold electrodes on both arms
- ❑ In plane and out of plane actuation.
- ❑ 1 μm X displacement at 2 V
- ❑ 1.4 μm Y displacement at 2 V



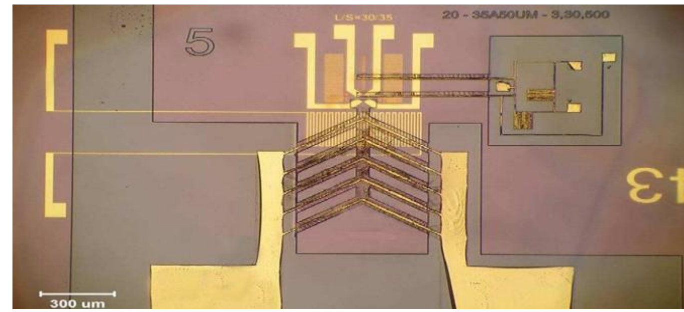
2. A Monolithic Polymeric Microgripper with Photo-thermal Actuation for Biomanipulation - Caglar Elbuken et al

- ❑ Bent beam structure
- ❑ Laser source for heating
- ❑ 2 μm at 3 V



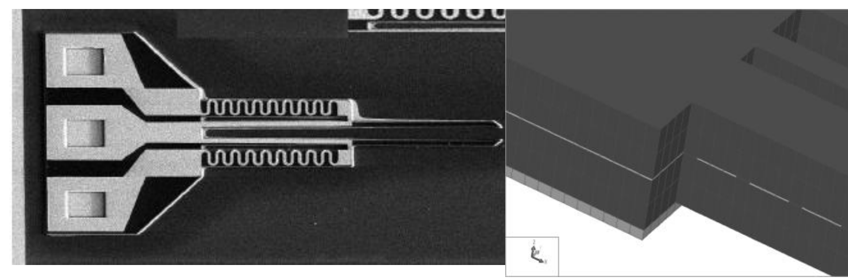
3. A polymer V-shaped electrothermal actuator array for biological applications - Wenyue Zhang et al

- ❑ Bent beam structure
- ❑ 9 µm displacement at 2 V



4. Design Study for An Electro Thermally Actuator for Micromanipulation - Rodica Voicu et al

- ❑ Comparison of two different designs
- ❑ Out of plane and in plane actuation

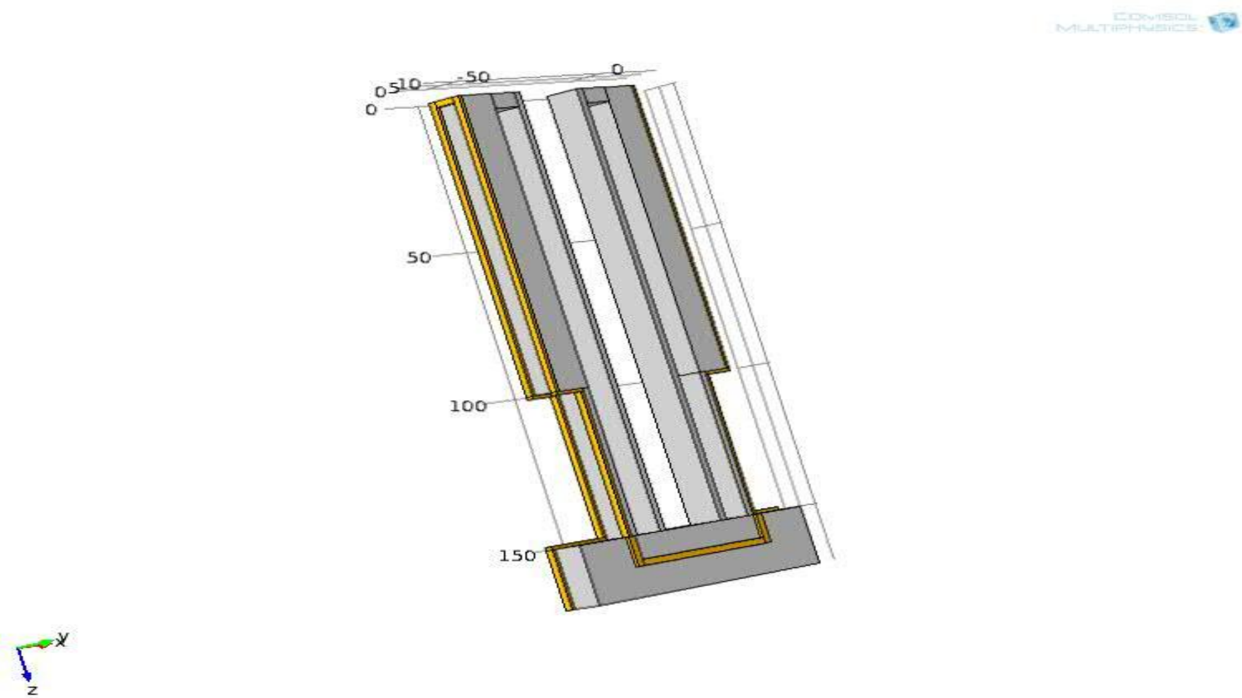


Need for new design

- Only hot cold arm actuation leads to more out of plane movement.
- Only bimorph gives a micro gripper which gives a diverging effect which is not used in most of the application. Converging grippers are more desired.
- So in hybrid design combination of asymmetric arm and bimorph is used to minimize the out of plane movement.

Design of microactuator

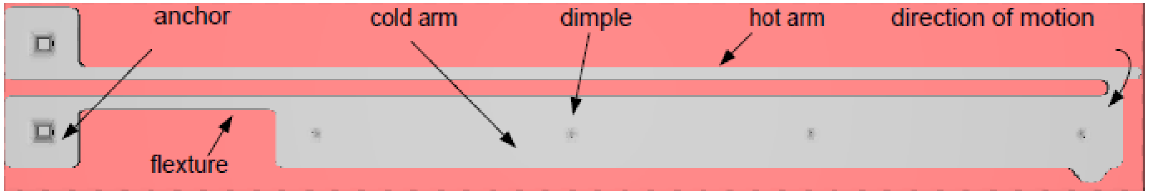
➢ A hybrid design micro actuator has been designed using Comsol Multiphysics design and analysis software.



Design criteria

- The microgripper structure consists of some major parts:
  1. The fixed part (anchor),
  2. Hot and cold underarms,
  3. Flexure,
  4. Gripper arms and
  5. Heaters.

- Flexure should be as thin as possible.
- Flexure should not be thinner than the hot arm, because the temperature of the flexure could be higher than that of the hot arm which might result in over heating.
- Also, in order to keep it elastically deflecting, the flexure should be long enough.



Material properties

Properties	Alluminium	PMMA
Co-efficient of thermal expansion	23.1×10^{6} per K	70×10^{6} per K
Thermal conductivity	237 W/mK	0.19 W/mK
Heat capacity	904 J/kg K	1420 J/kg K
Density	2700 kg/m^3	1190 kg/m^3
Young's modulus	70×10^{9} pa	3×10^{9} pa
Electrical conductivity	35.5×10^{6} s/m	1×10^{-19} s/m
Poisson ratio	0.35	0.4
Relative permittivity	---	3

Comparative study

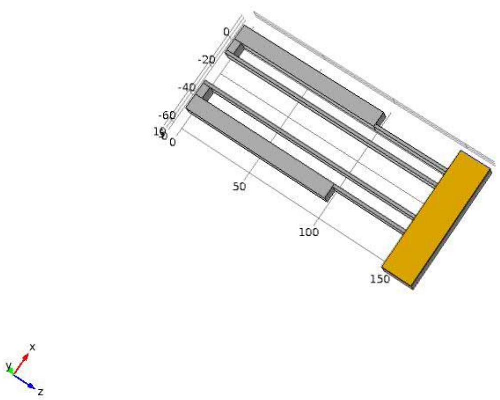
- A comparative study has been made between

  1. Asymmetric arm actuated design
  2. Bi-layer structure actuated design
  3. Hybrid design

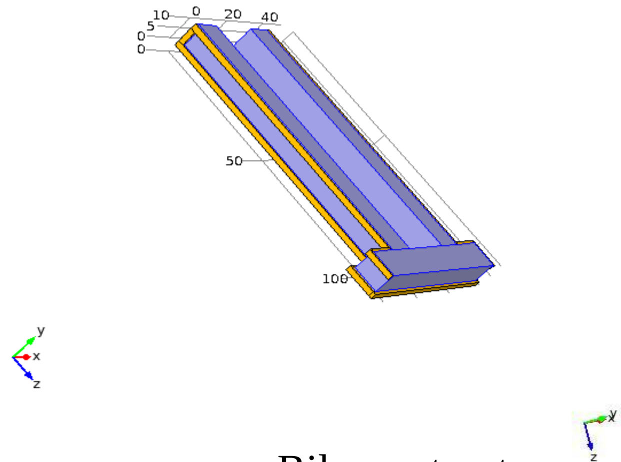
- The design and analysis is done using COMSOL Multiphysics software.

- Thermoelectromechanical analysis is done and the results are obtained.

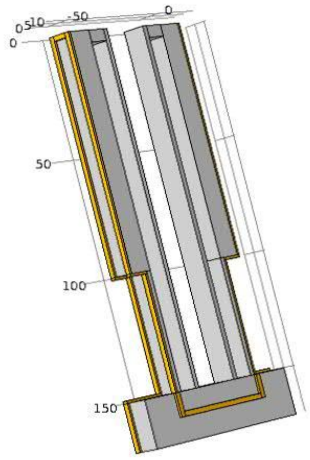
Comparitive study



Asymmetric arm



Bilayer structure



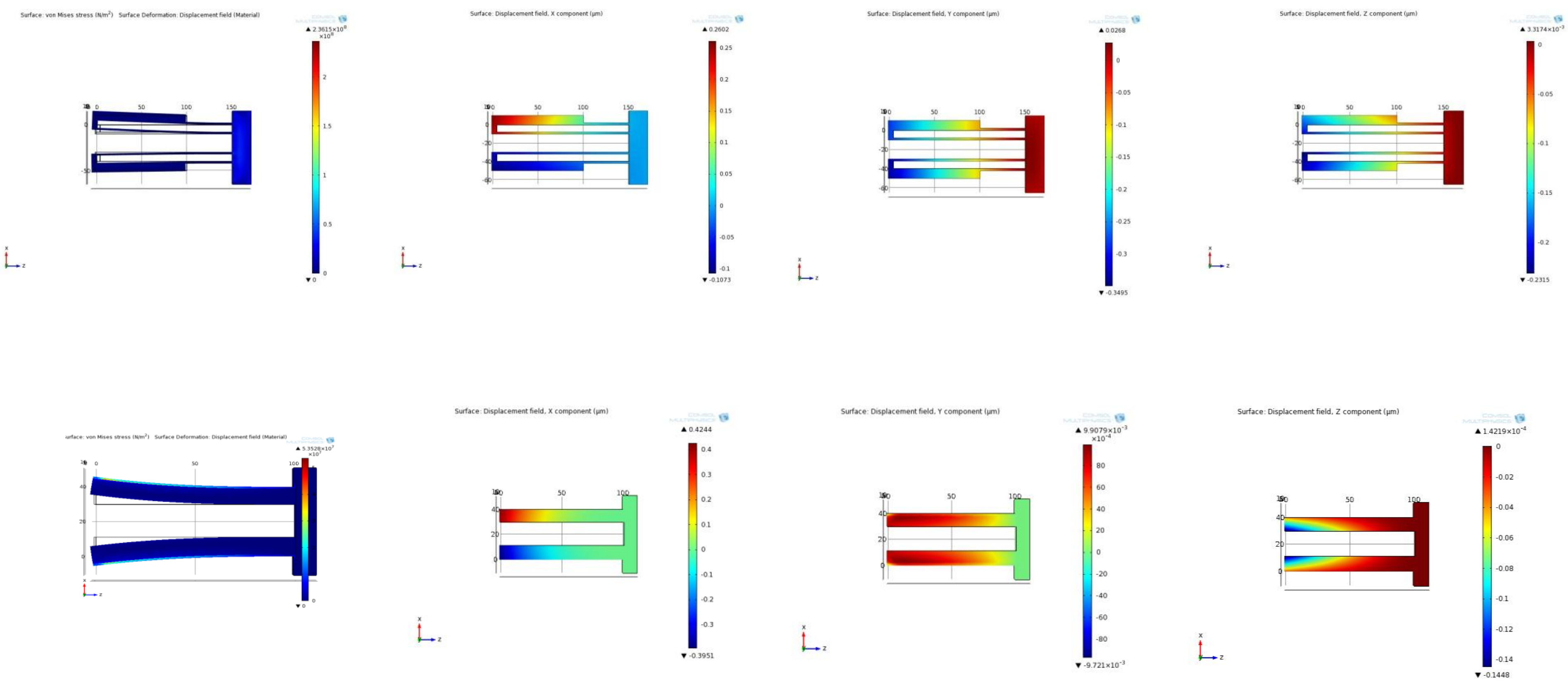
Hybrid design

The design and analysis is done using COMSOL Multiphysics software.

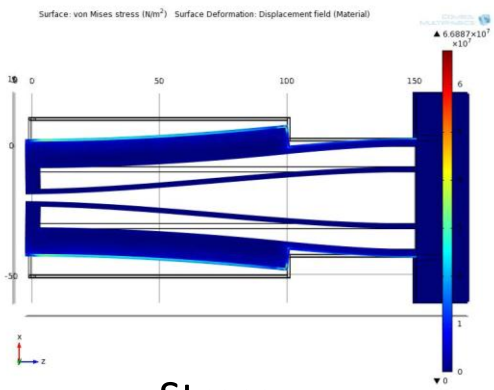
Thermoelectromechanical analysis is done and the results are obtained.

Results of asymmetric arm and bilayer structure

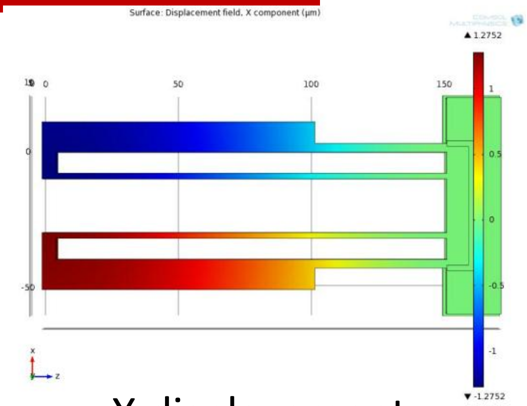
Stress | X displacement | Y displacement | Z displacement



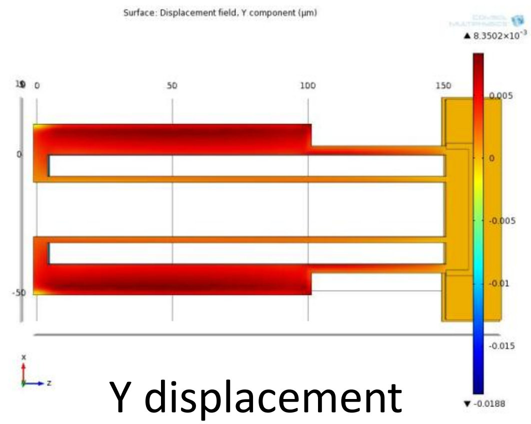
Hybrid design results



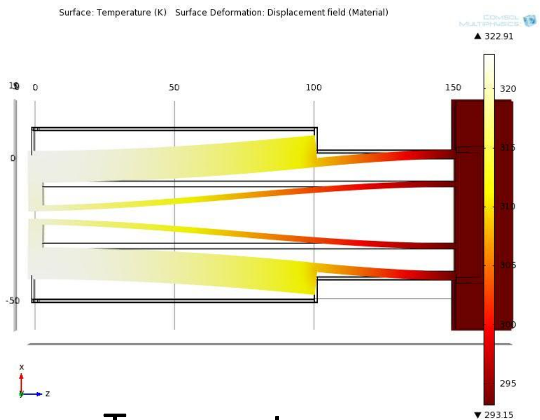
Stress



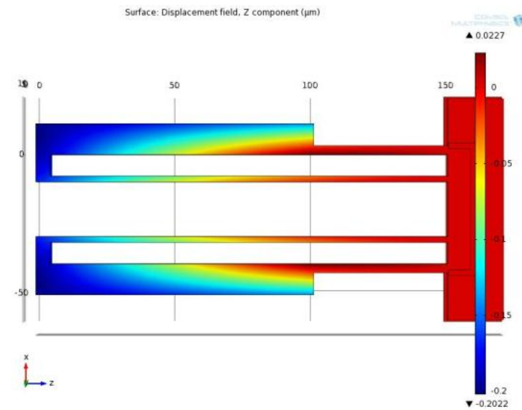
X displacement



Y displacement



Temperature

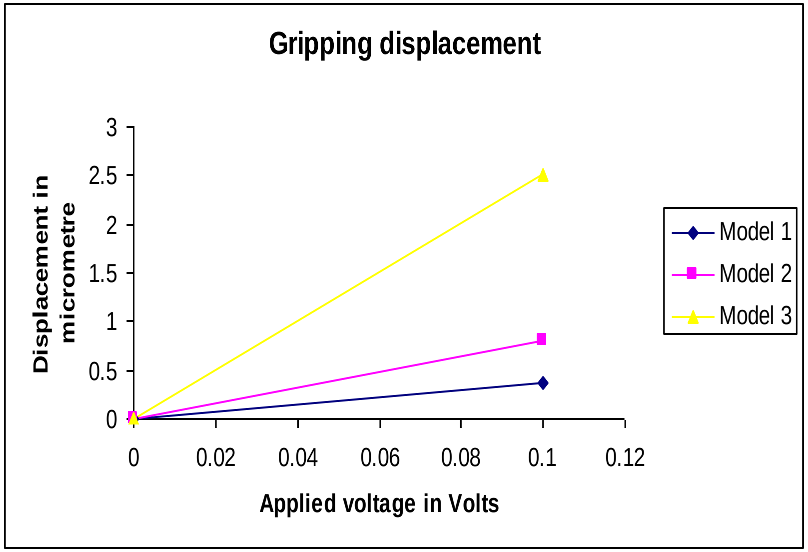


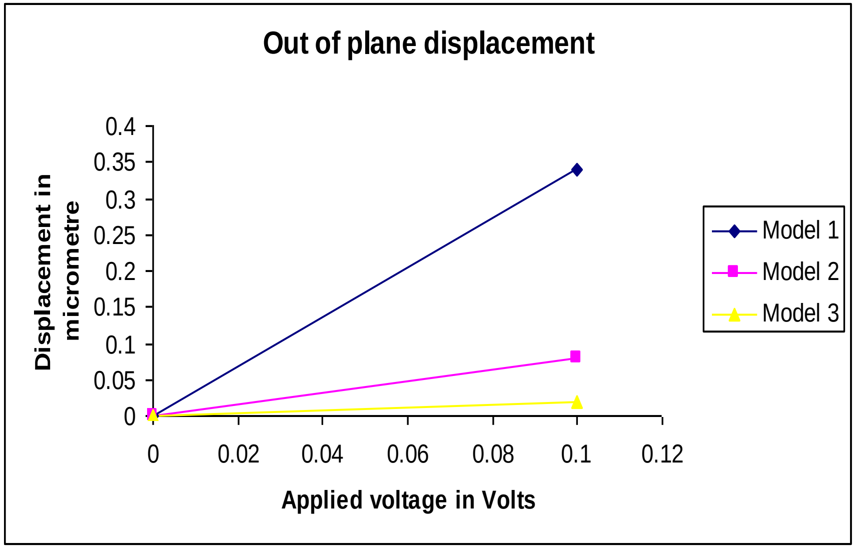
Z displacement

Comparative study results

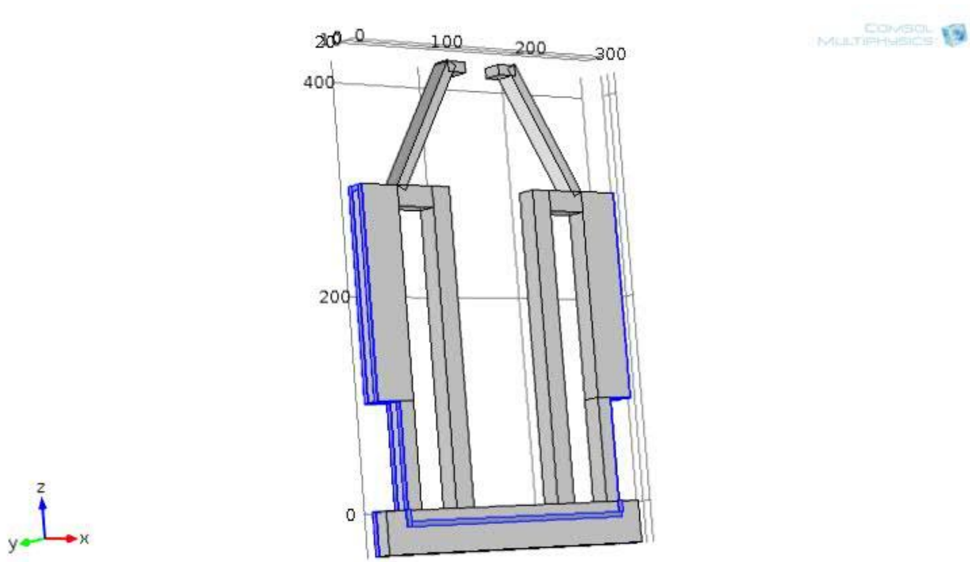
RESULT PARAMETERS	VALUES OF MODEL 1	VALUES OF MODEL 2	VALUES OF MODEL 3
Actuation	More out of plane displacement and less in plane actuation	Divergent displacement actuation	Complete in plane movement. Negligible out of plane movement.
Voltage applied	0.1 V	0.1 V	0.1 V
X displacement	0.36 μm	.8 μm	2.5 μm
Y displacement	0.34 μm	0.08 μm	0.02 μm

Comparison of results





Design of microgripper



➢ Design of microgripper is completed with gripper arms and analyzed using Comsol Multiphysics software.

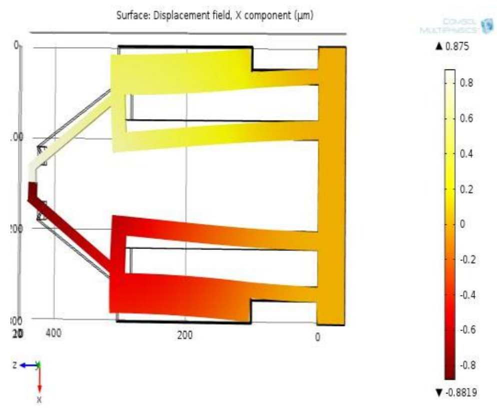
Displacement analysis

- Four displacements are analysed.

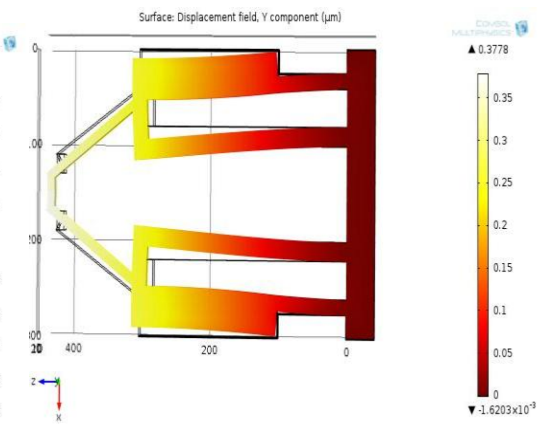
  They are

  - In-plane displacement
  - Out of plane displacement
  - Linear displacement
  - Curl displacement

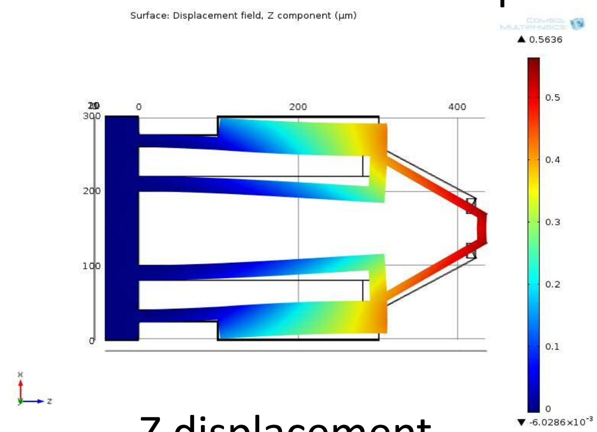
- The in-plane displacement is 1.6 µm and out of plane displacement is 0.3 µm .



X displacement

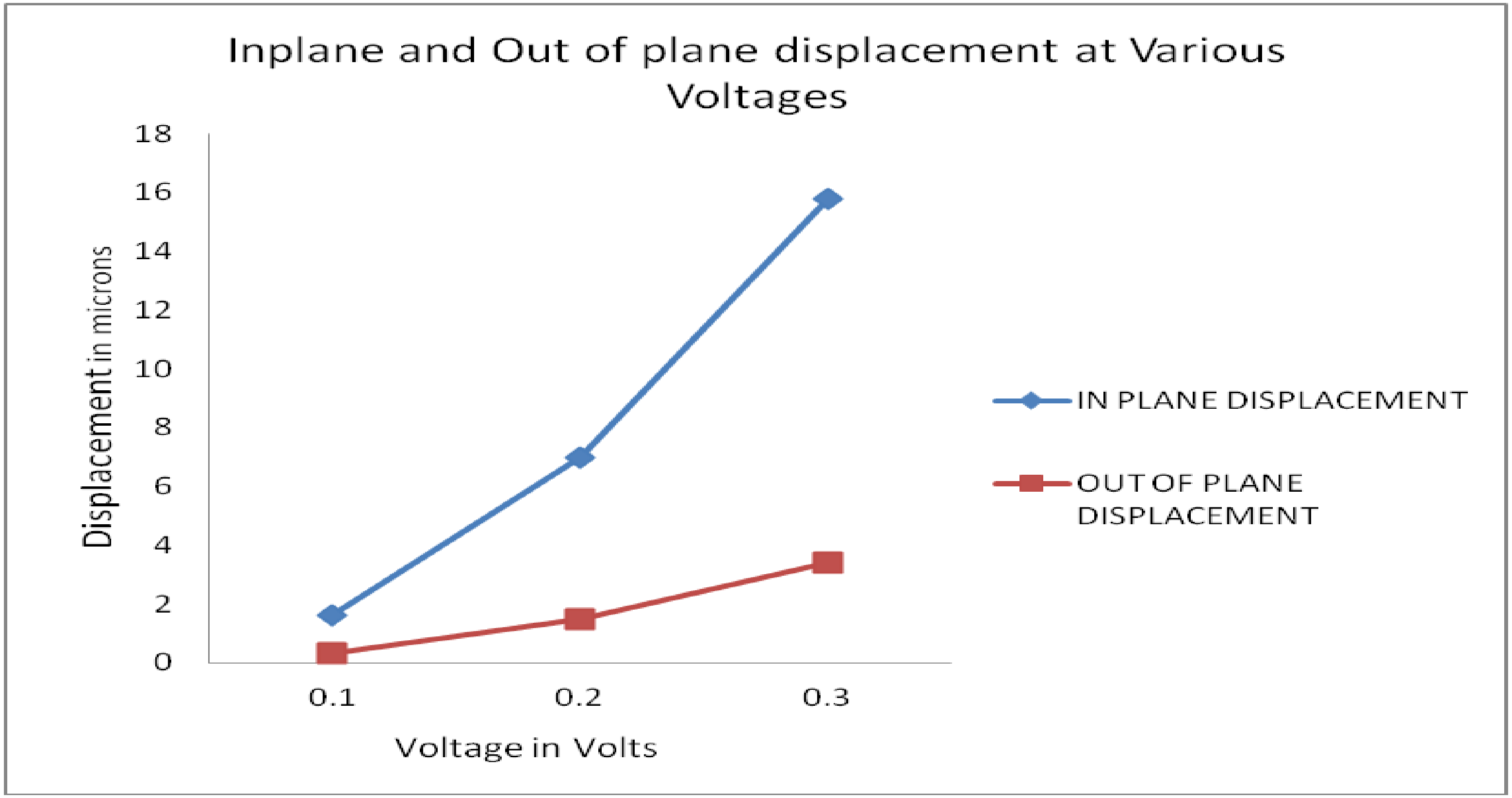


Y displacement



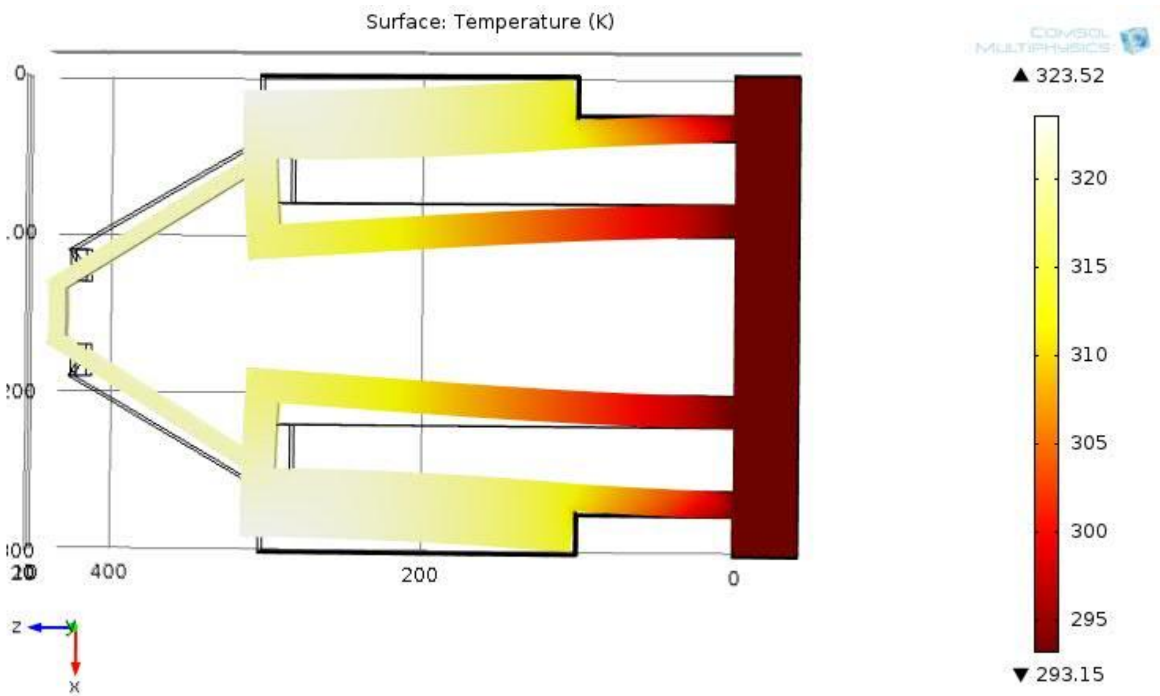
Z displacement

Displacement Analysis



Temperature analysis

- The maximum working temperature obtained is 323 K.
- The temperature at the gripper arm tips is 320 K.



FEM Analysis results

Result parameters	Values
Actuation	More in plane displacement and less out of plane actuation
Voltage applied	0.1 V
X displacement	1.6 µm
Y displacement	0.3 µm
Temperature	323 K
Maximum stress	5.4×10^{7} Nm^{-2}
Maximum strain	4.7×10^{-3}
Curl displacement	-6×10^{-3}
Electric field	3000 V/m

Design of Force Sensor

- Gripping force is obtained by using integrated force sensor.
- Three types of force sensors can be integrated in microgripper. They are
  - Capacitive force sensor
  - Piezoelectric sensor
  - Piezoresistive sensor

S.NO	TYPE	ADVANTAGES	DISADVANTAGES
1	Piezoelectric	Wide dynamic range, durability, good mechanical material properties	Frailty of electrical junctions, inherently dynamic
2	Piezoresistive	Shapable, withstands high temperature	Creep, memory, hysteresis, temperature dependence
3	Capacitive	Good sensitivity, moderate hysteresis, wide dynamic range, linear response, robust	Complex circuitry, susceptible to noise, limited spatial resolution, temperature sensitive

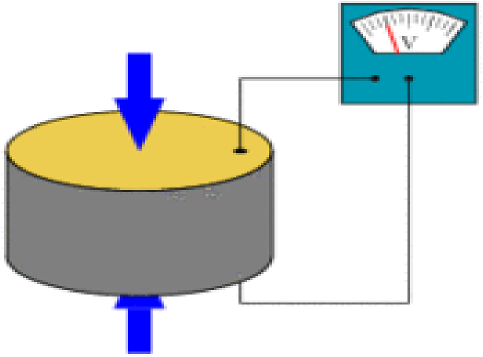
Piezoelectric force sensor

PRINCIPLE:

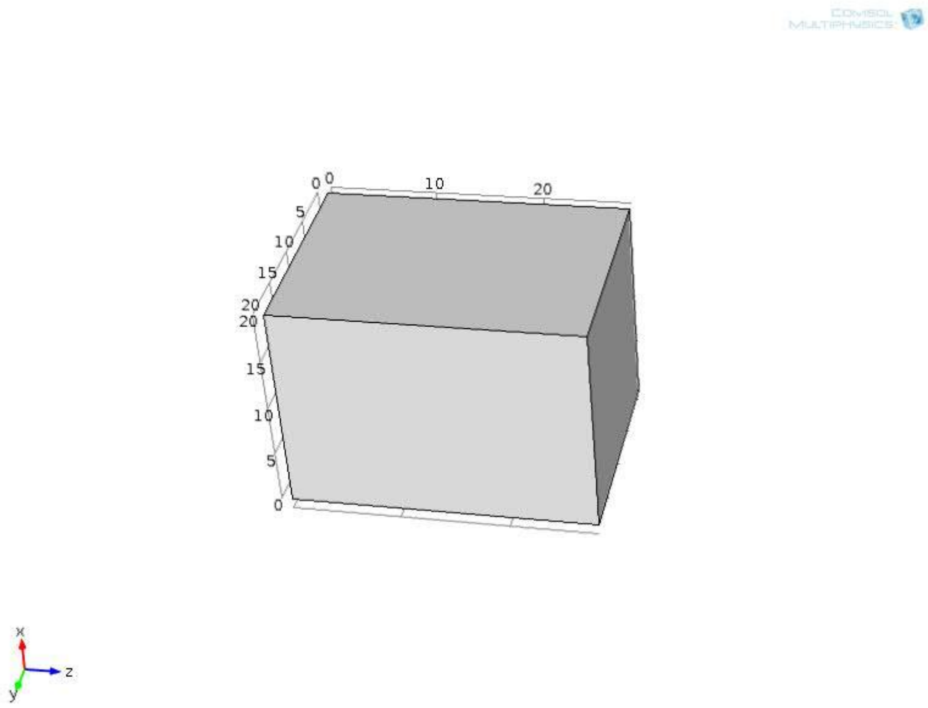
Piezoelectricity is the charge that accumulates in certain solid materials in response to applied mechanical stress.

ADVANTAGES:

- Even though piezoelectric sensors are electromechanical systems that react to compression, the sensing elements show almost zero deflection.
- This is the reason why piezoelectric sensors are so rugged, have an extremely high natural frequency and an excellent linearity over a wide amplitude range.
- Additionally, piezoelectric technology is insensitive to electromagnetic fields and radiation, enabling measurements under harsh conditions.



Design and analysis of force sensor

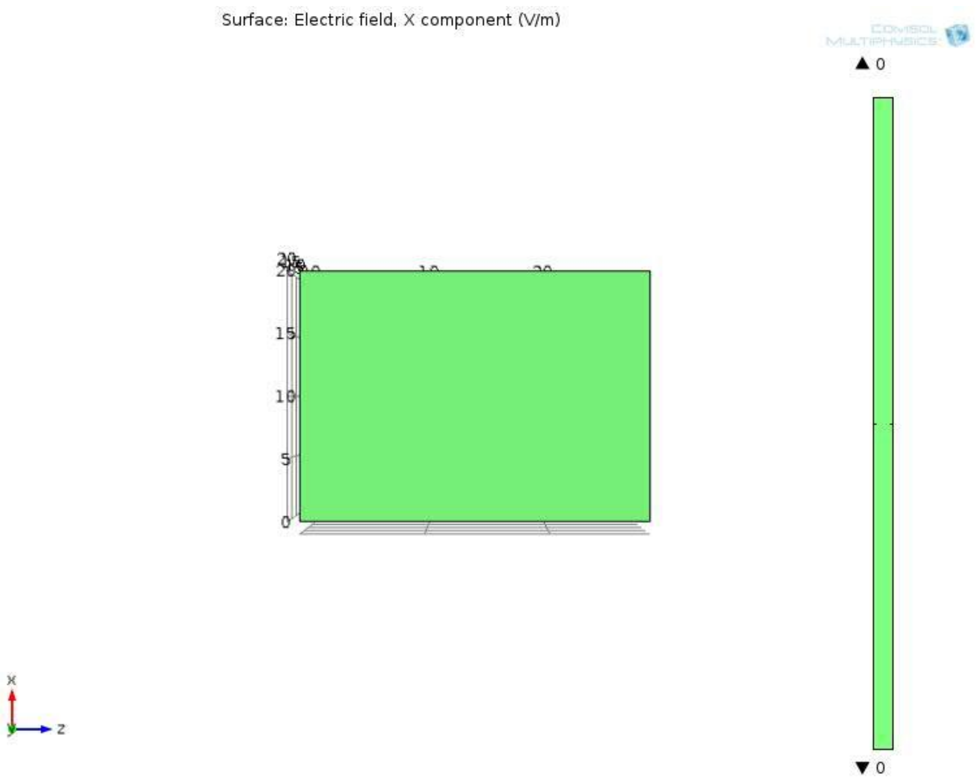


Material : PVDF (Poly vinylidene Fluride)

Dimensions : 20x20x28 µm

Current density for no load condition

- When there is no load or force acting on the gripper arm.



Current density for 10 mN

The voltage obtained can be converted into force using the formula

$$V = Fgl/A$$

Where,

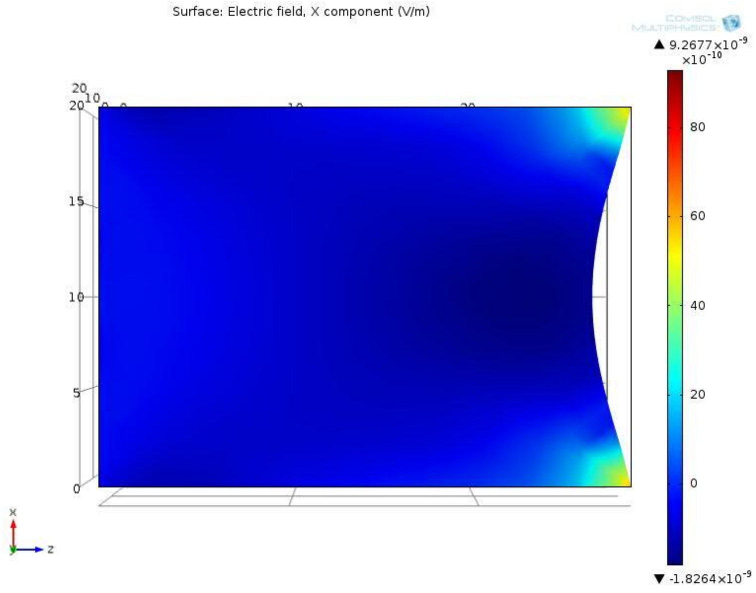
V= Output voltage in Volts

F= Force on object by gripper

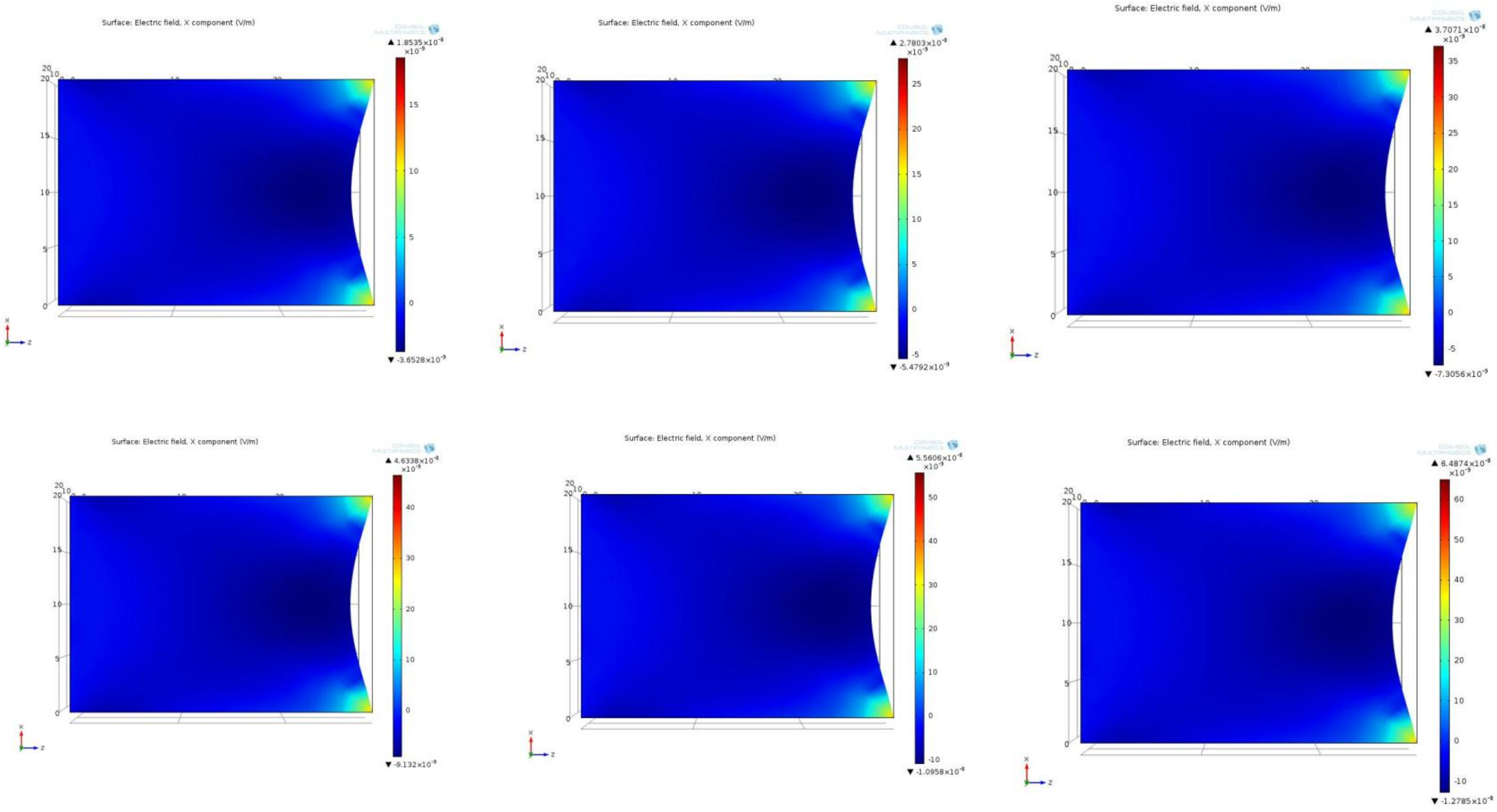
g= Gravity

l= Length in mm

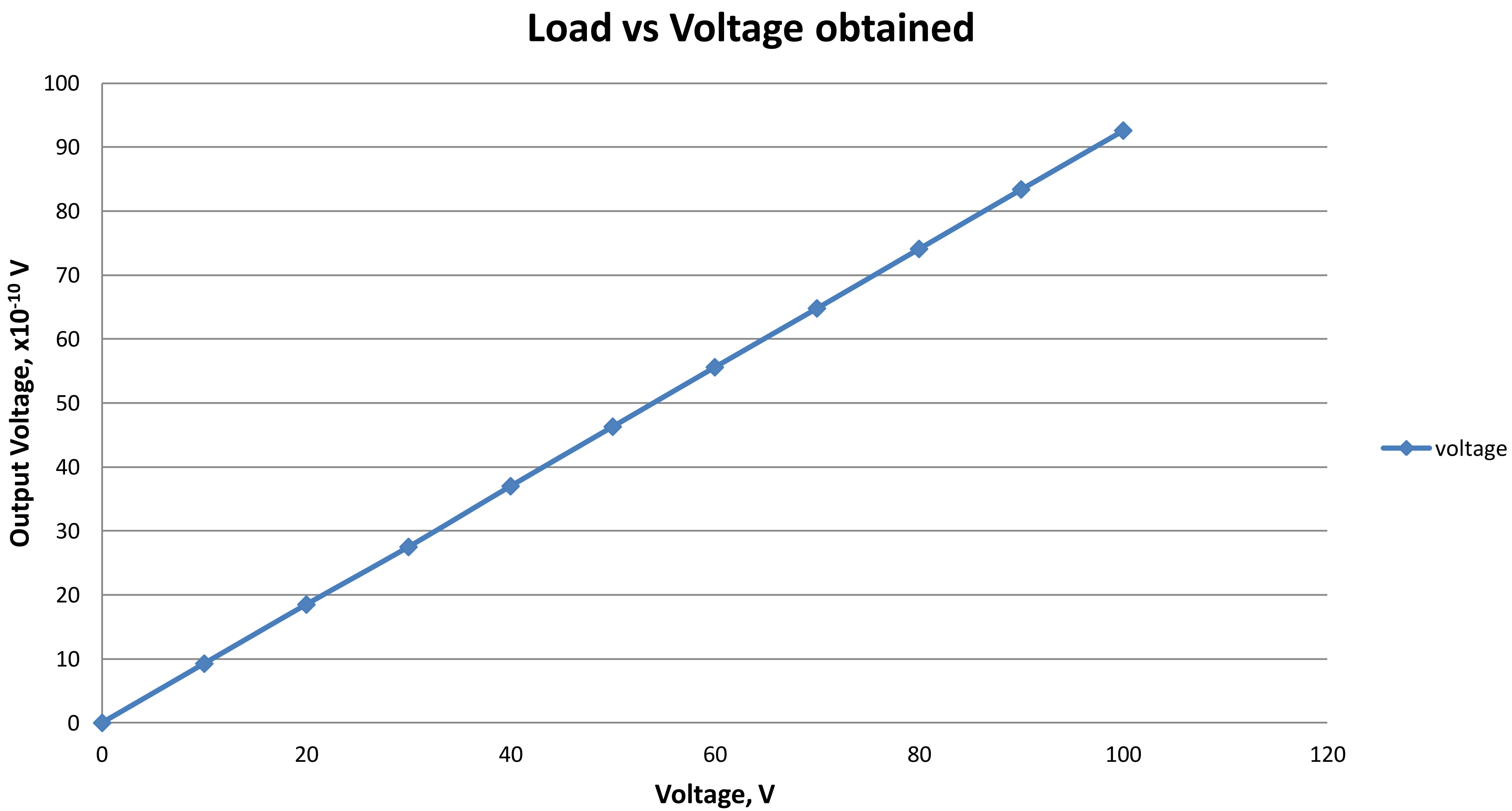
A= Cross-sectional area in mm^2



Electric field for force range of 20mN – 70 mN



Load vs Voltage obtained

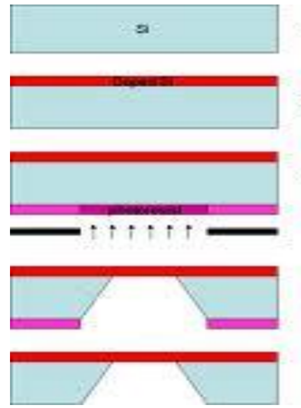


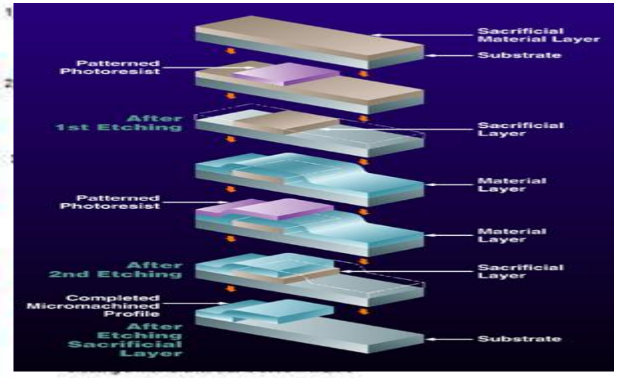
Comparison with existing polymeric microgrippers

Grippers	Voltage applied	Griping displacement (µm)	Out of plane displacement(µm)
1. Electro-thermally activated SU-8 micro gripper for single cell manipulation in solution – Nikolas Chronis and Luke P. Lee	2 V	1	1.4
2. A Monolithic Polymeric Microgripper with Photo-thermal Actuation for Biomanipulation - Caglar Elbuken et al	3 V	2	Not mentioned
3. Hybrid design	0.1 V	1.6	.3

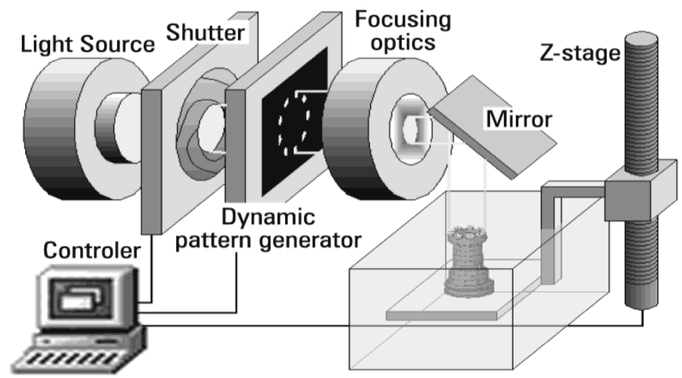
Fabrication methods

- The microgripper can be fabricated using either by micromaching methods such as bulk and surface micromachining or rapid prototyping methods like microstereolithography.
- In microstereolithography, the stl file of the microgripper is obtained and given as input to the machine and the gripper can be obtained.
- Then the electrodes have to be metallized by sputtering on the fabricated structure.





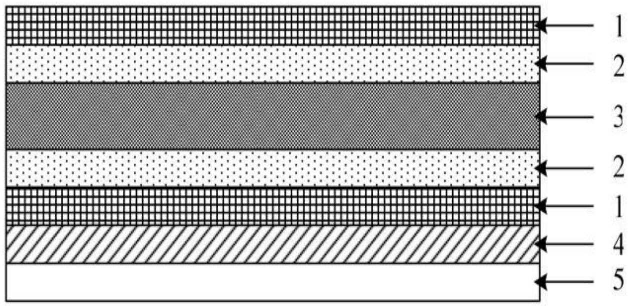
Bulk micromachining surface micromachining



Microstereolithography

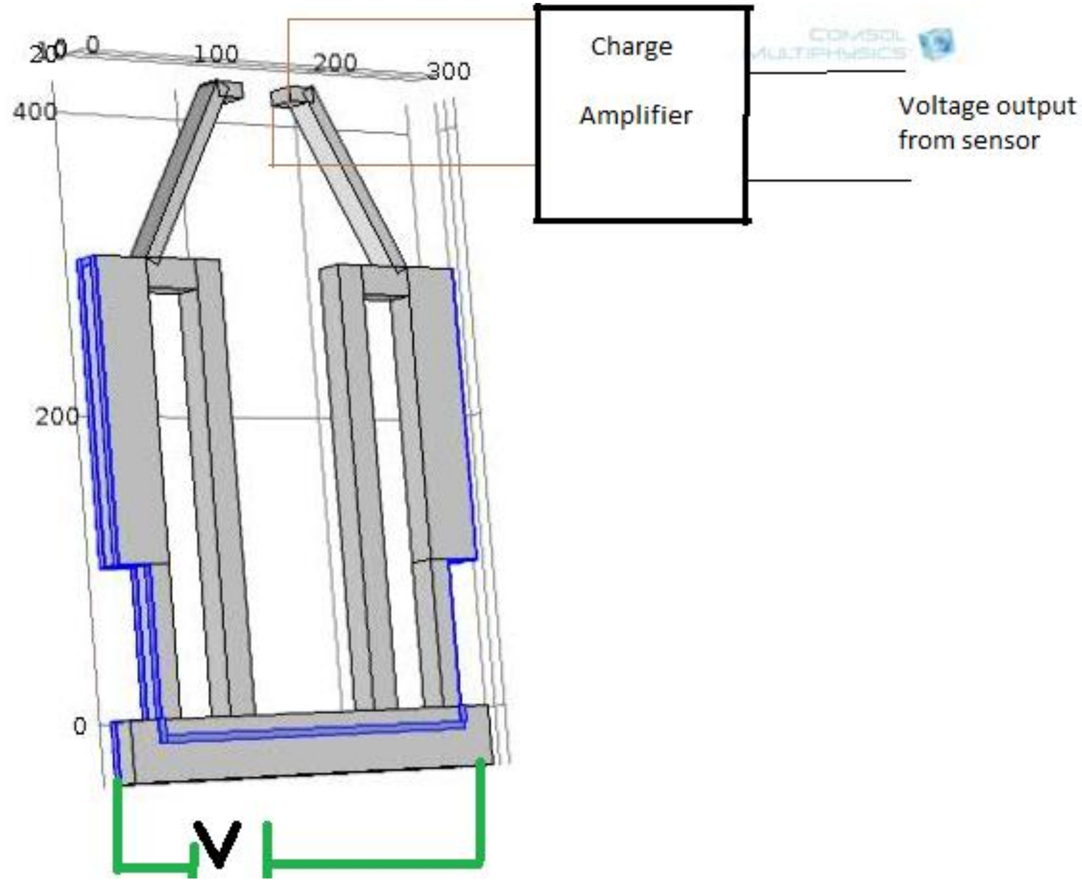
Fabrication methods

- Once the basic structure is fabricated using the above methods, in order to resolve gripping forces, rectangular piezoelectric PVDF polymer layers will be cut using a dicing saw.
- The two flat surfaces of the PVDF film are attached to nickel electrodes that provide electrical connections to an amplifier.
- The nickel electrodes on PVDF polymer film layers will be bonded with gold wires using silver epoxy (Dotite electroconductive silver paste) and cured for four hours at room temperature.
- The PVDF force sensor was then sandwiched between parylene coated layers that provide sufficient thermal insulation to reduce the pyroelectric effect of PVDF.



1. Parelyne layer
2. Nickel wire
3. PVDF
4. Glue layer
5. Microgripper Arm

Working of microgripper



Advantages of hybrid design

- Very Good in plane displacement for very less voltage (0.1V).
- Less out of plane movement.
- Stress of microgripper is very less.
- Required displacement is obtained when sufficient voltage is applied.
- Better displacement than other designs.
- Temperature is very less (323 K or 50^{o}c)

Applications

- This microgripper can be specifically used in micro-surgeries and manipulation of micro bodies such as cells and micro-organisms due to its low voltage and low temperature.

- They can also be used to manipulating micro particles and micro components in micro assembly as the force exerted by polymer microgrippers is very less.

Figure 3 Microgripper end-effector interface

Thank you