DESIGN AND SIMULATION OF CASCADED KINK BEAM ACTUATOR

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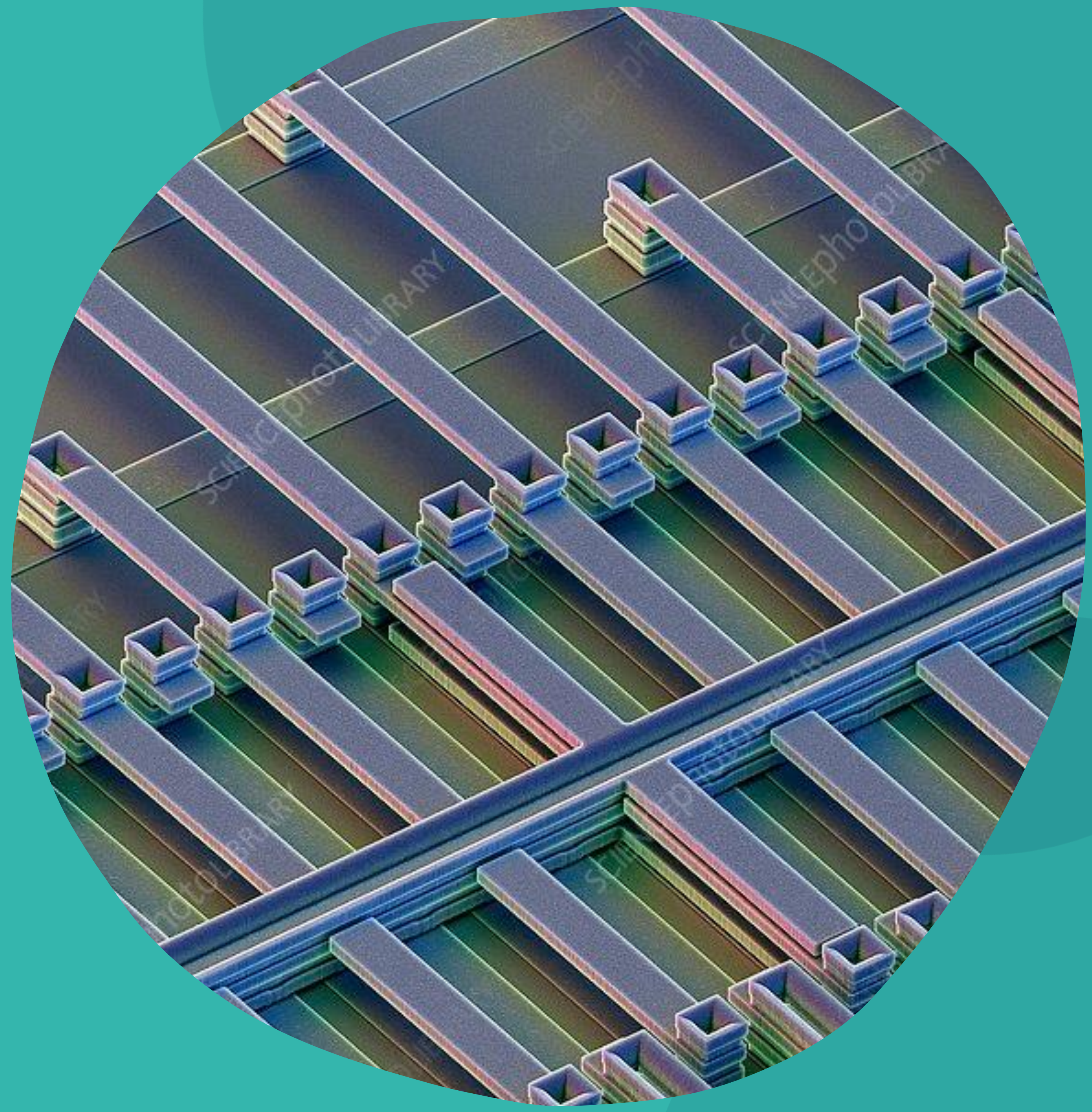
INTRODUCTION

Thermal actuators are mechanical systems that use thermally induced expansion and contraction of materials as a mechanism for the creation of motion. These devices are compliant structures, using elastic deformation and mechanical constraints, that frequently are designed to amplify the motion generated by thermal expansion or contraction. Temperature changes that result in thermal actuation are most commonly provided by environmental changes or by Joule heating from electrical current flow. In context of nanotechnology, thermal actuators refer to microscale and nanoscale devices used to mechanically interact with nanoscale structures, with motion generated by the thermally induced expansion and contraction of materials.



MATERIAL USED

Silicon (single-crystal) isotropic is the material used for fabrication of the MEMS thermal actuator, the material specifications are given below:

Property	Variable	Value	Unit
Coefficient of thermal expansion	alpha_i...	2.6e-6[1/K]	1/K
Heat capacity at constant pressure	Cp	700[J/(kg...	J/(kg·K)
Relative permittivity	epsilon...	11.7	1
Density	rho	2330[kg/...	kg/m³
Thermal conductivity	k_iso ; k...	131[W/(...	W/(m·K)
Young's modulus	E	166e9[Pa]	Pa
Poisson's ratio	nu	0.28	1
Reference resistivity	rho0	0.00005	Ω·m
Resistivity temperature coefficient	alpha	2.6e-6	1/K
Reference temperature	Tref	293.15	K
Electrical conductivity	sigma_i...	20000	S/m

DESIGN OF CASCADED KINK BEAM ACTUATOR

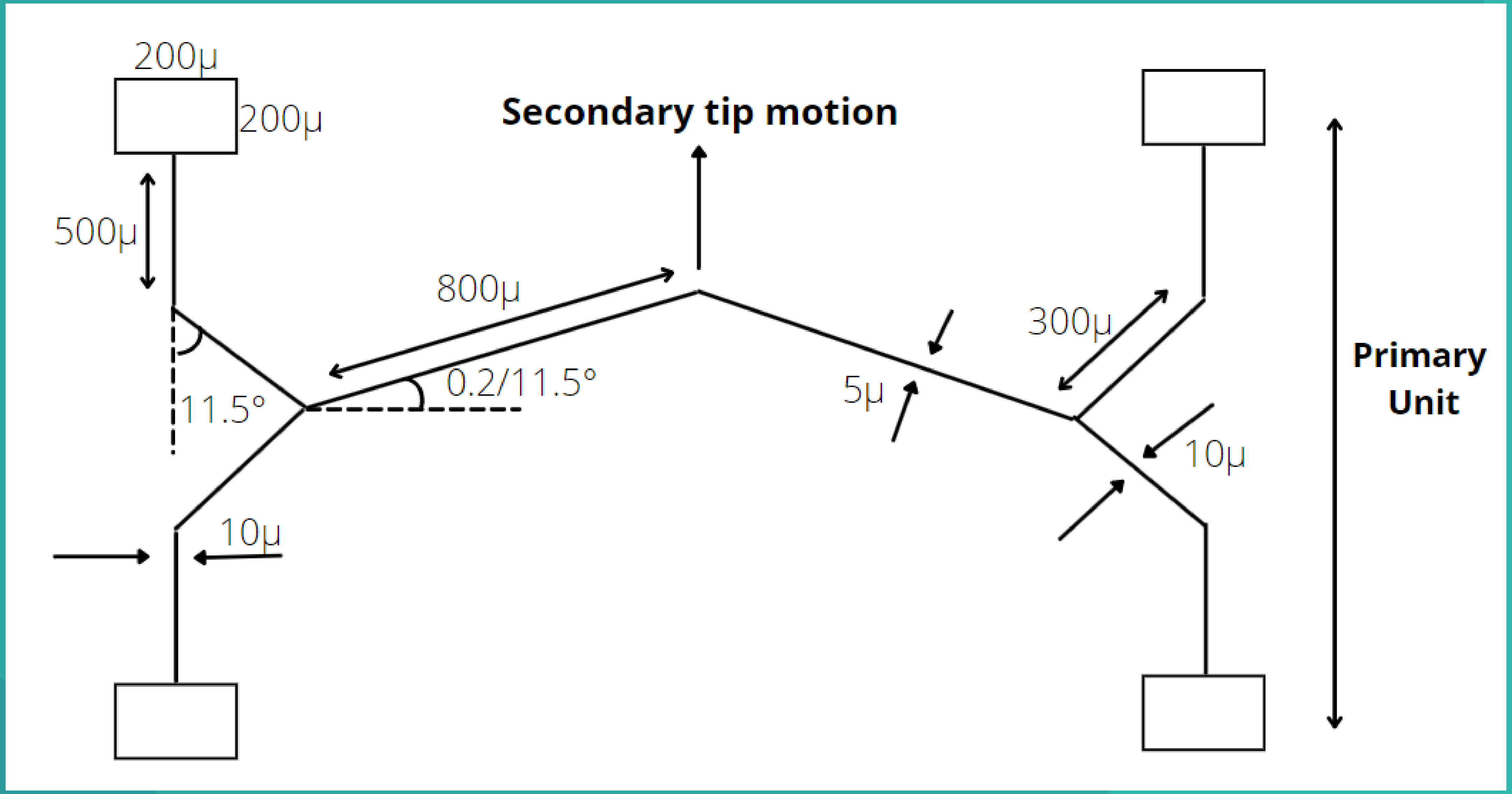


Fig 4: Dimensions of our model

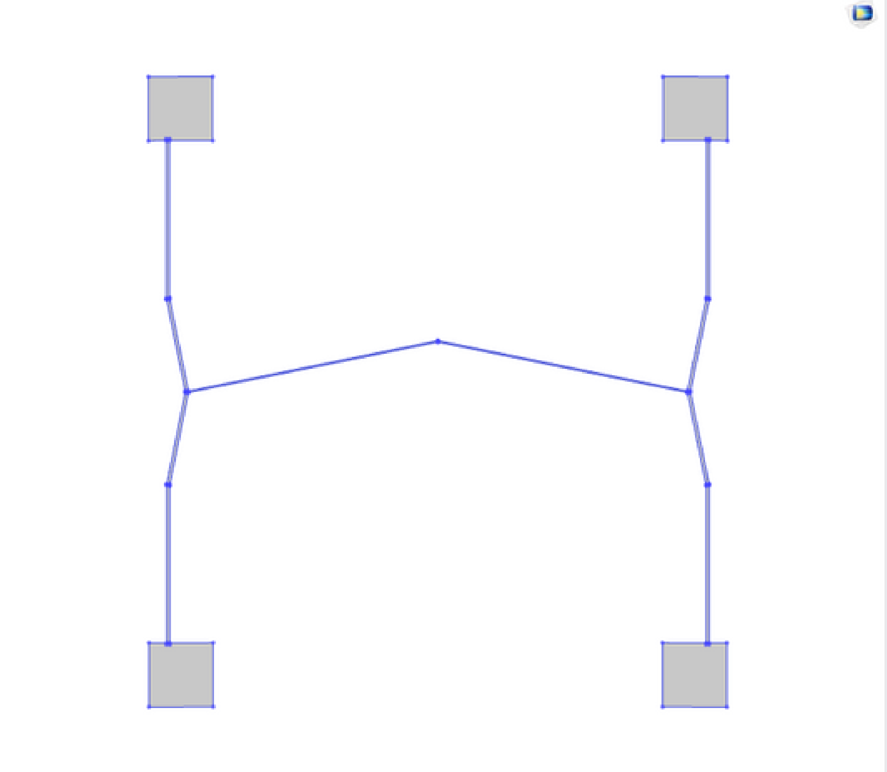


Fig 5: Structure on comsol multiphysics

Design and Innovation

- Traditional chevron shaped bent beam actuators (fig1) are one of the most commonly used actuators, the chevron's displacement increases with decreasing the angle with respect to horizontal.
- The kink actuator (fig2) was selected as it has an **improved amplification factor for a given input electrical potential, compared to an equivalent chevron actuator**.
- A kink is a structure that is formed when the end of the adjoined beams are moved slightly out of their aligned position.

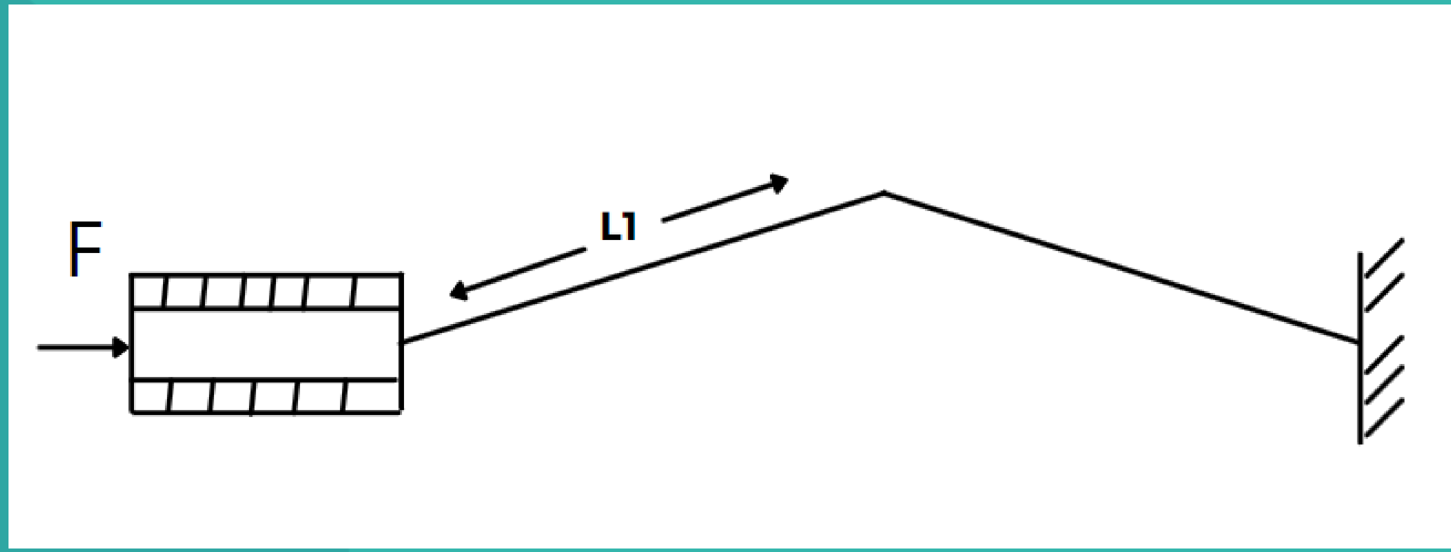


fig 1

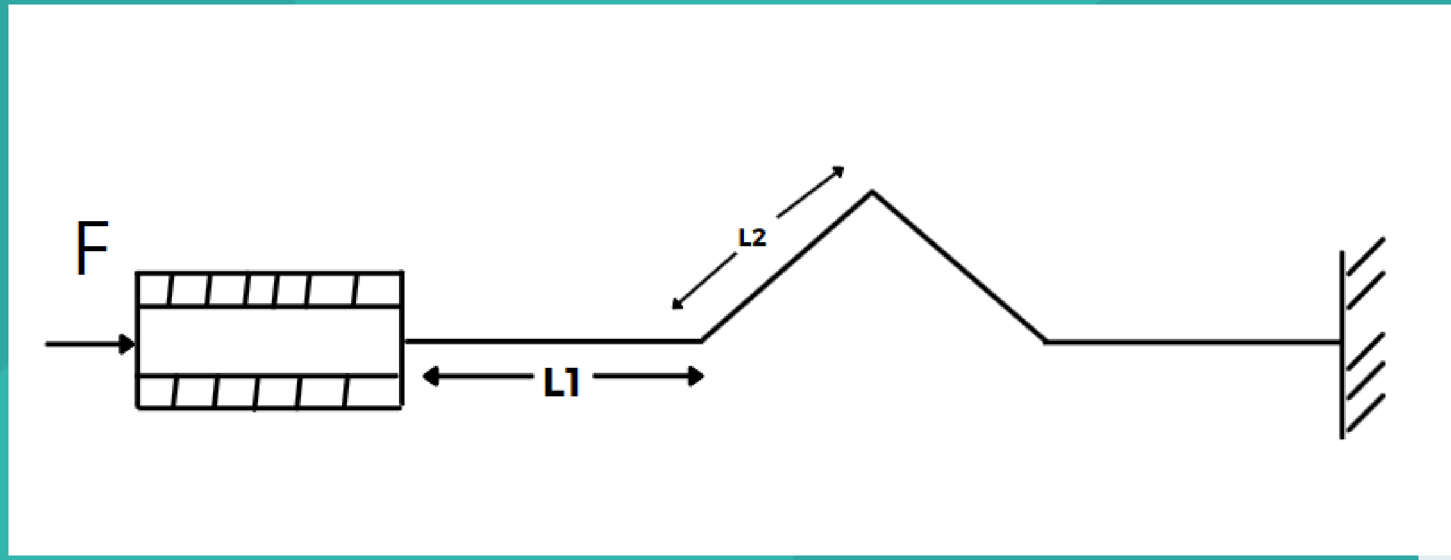
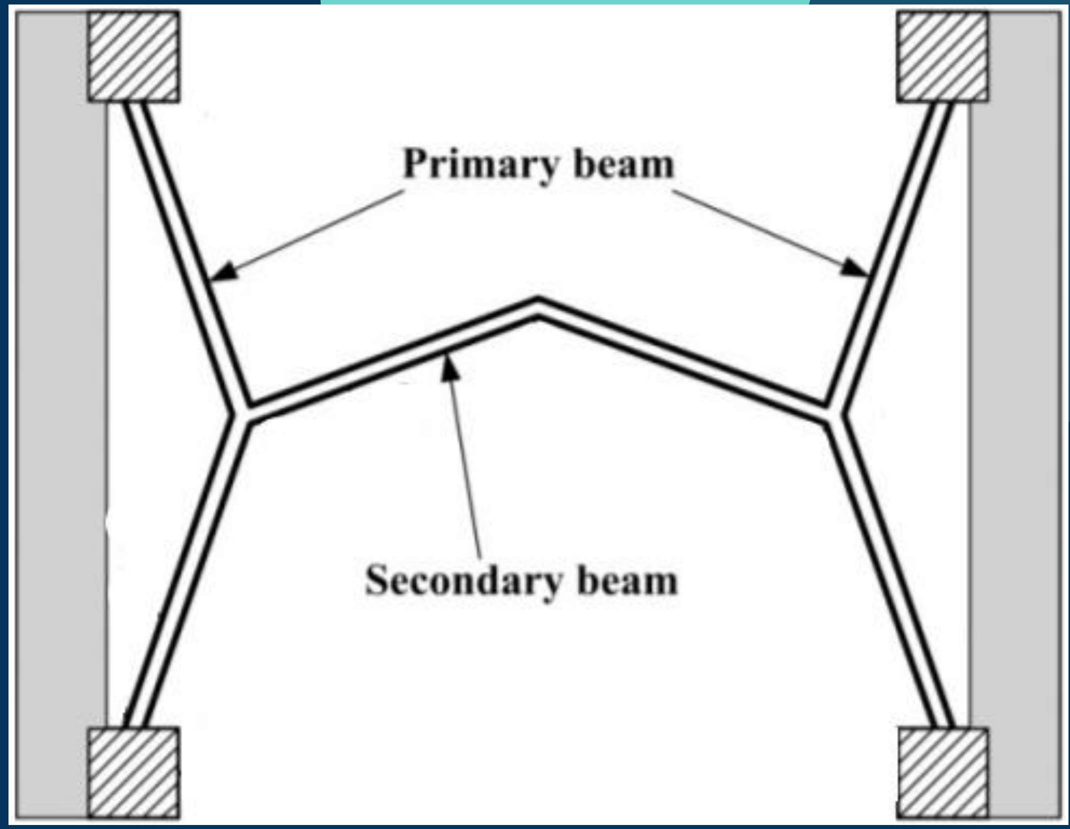
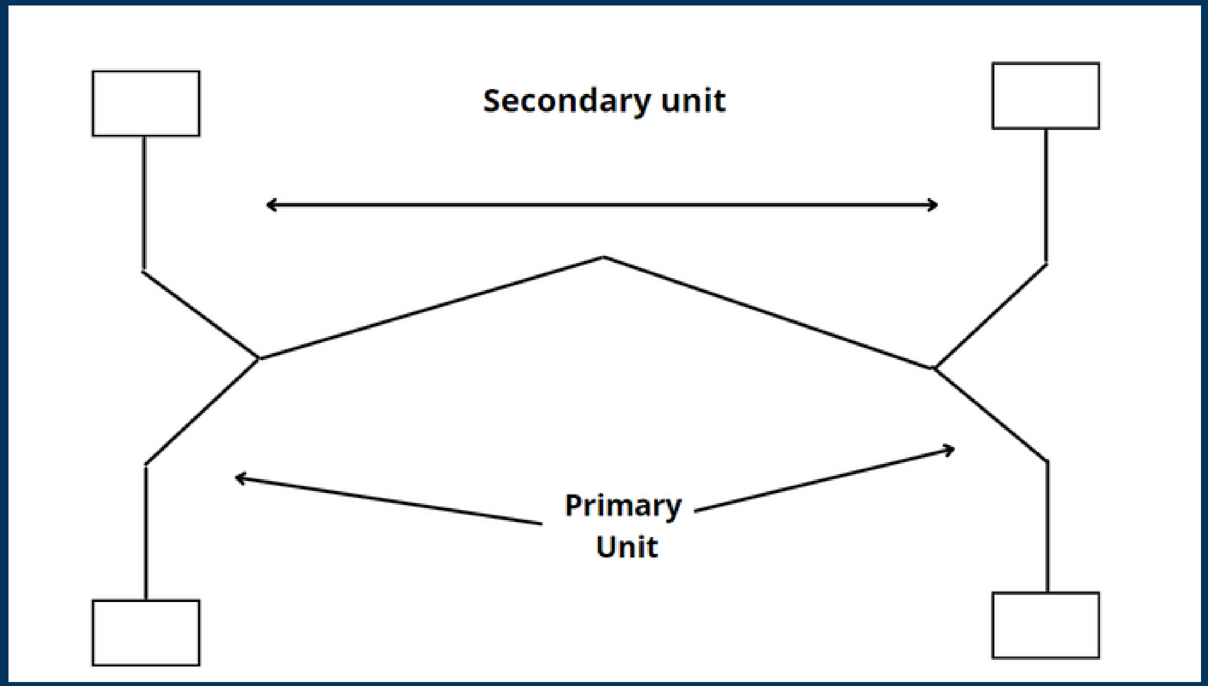


fig 2

Design and Innovation

- Cascaded thermal actuators are **used to further amplify the displacement, when current is confined to two primary units, the secondary unit serves as a motion amplifier**.
- Cascaded devices have a significantly larger displacement than simple beams even when the secondary beam is not heated.
- Also observed is another phenomenon, 'buckling' due to which the amplification factor begins to decrease. The actuators start to buckle out-of-plane instead of in-plane.
- The amplification factor for the kink beam was seen to be higher than the chevron actuators at all offsets.
- Our model prevents the occurrence of buckling-caused by the force applied on the structure, making the overall structure unstable. Kink beams prevent the occurrence of buckling in beams.





THEORETICAL EQUATIONS

- The heat generated per unit volume per unit time due to joule heating is given by:

$$H = i^2Rt$$

- i is current and R is the resistance, which varies due to temperature.
- The maximum displacement of an electrothermal actuator is given by:

$$D_{max} = 2tan\ \theta 1/K * \tan(KL1/4) - L1 \tan(\theta 1)/2$$

- $\theta 1$ is the angle made with respect to horizontal and L1 is the length between the two end points of the beam and K is the unknown eigen value:

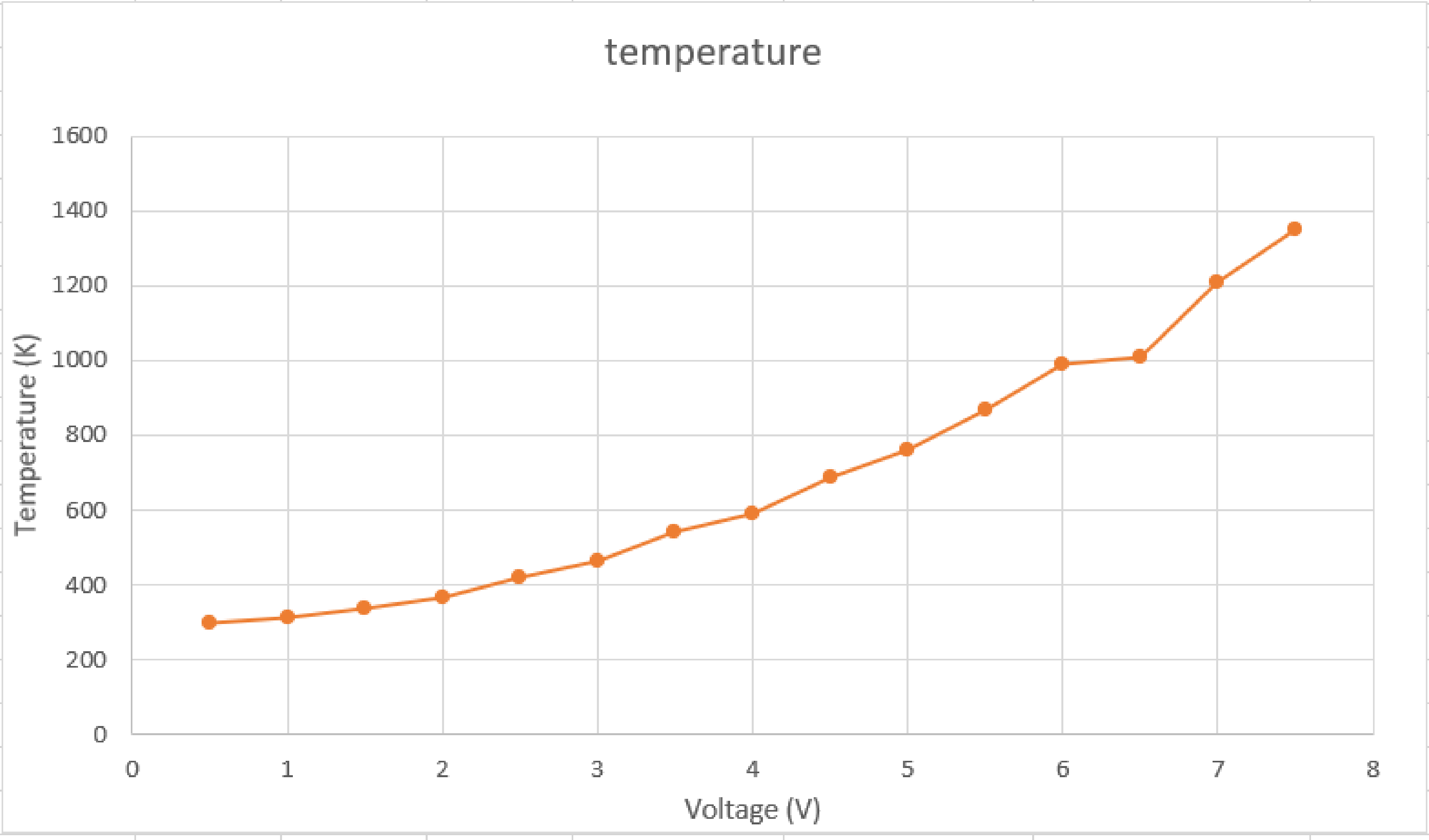
$$K = \sqrt{(F/EI)}$$

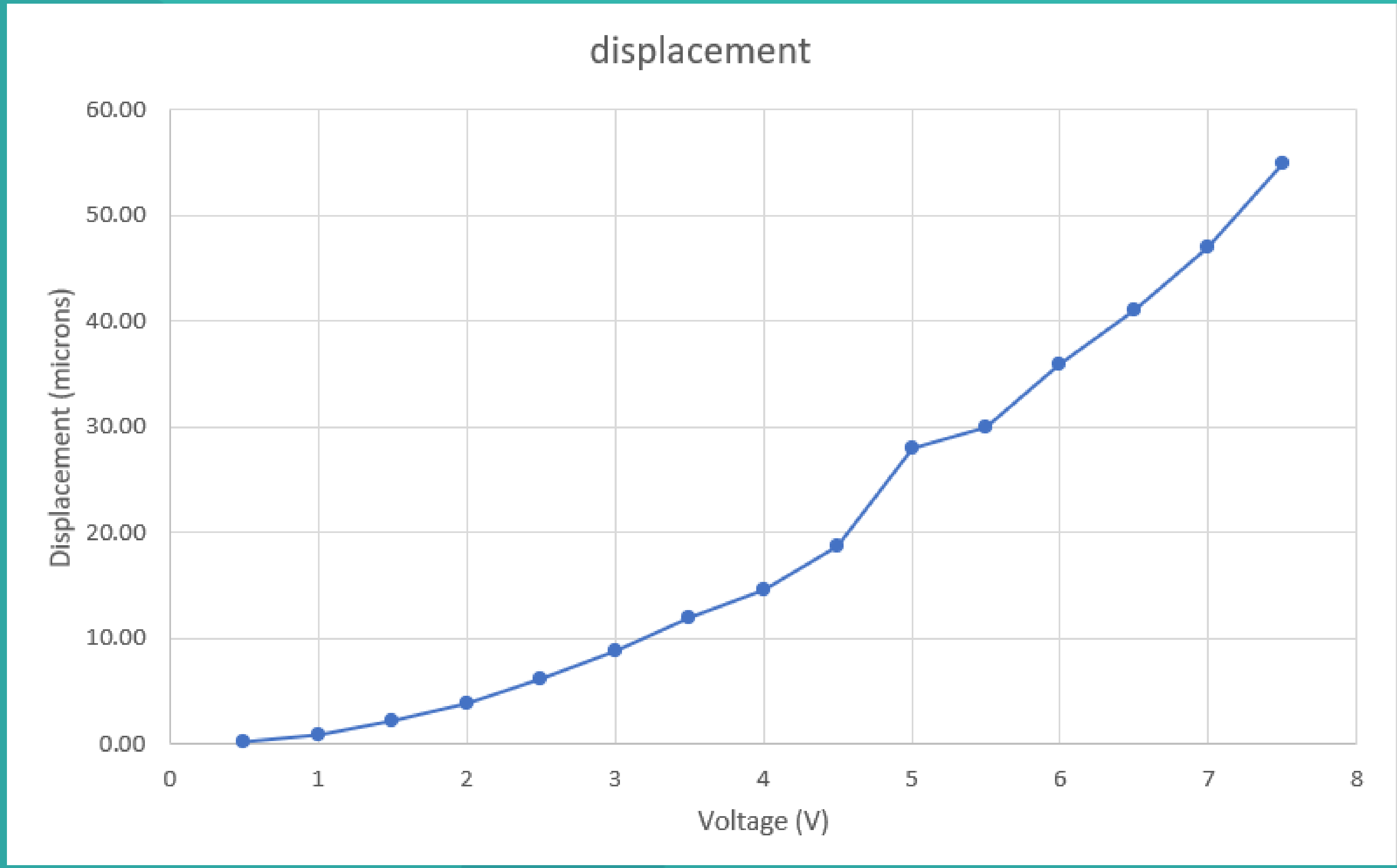
- F is the reaction force, E is young's modulus and I is the moment of inertia of the beams.

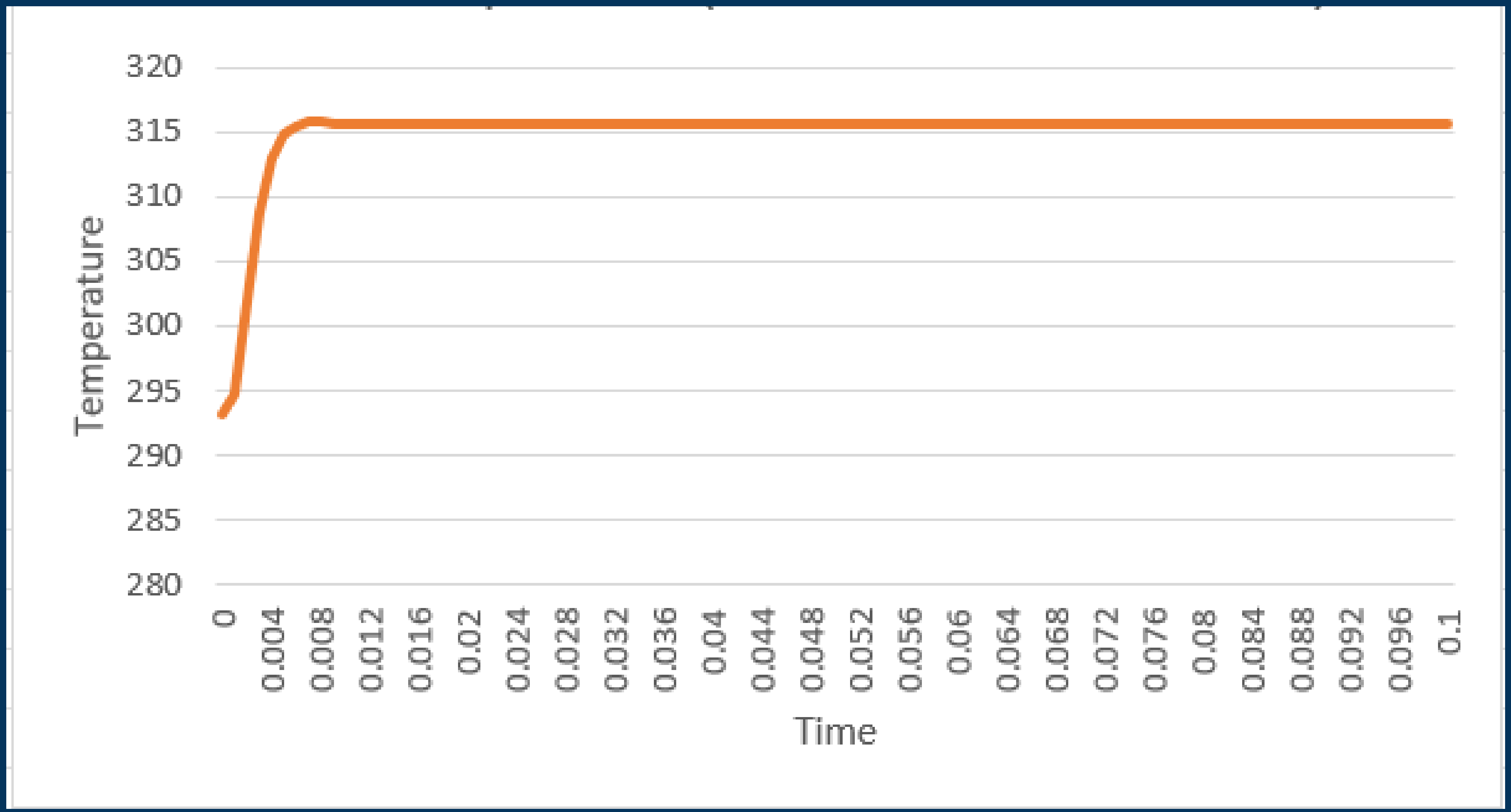
I is defined as:

$$I = (bd^3)/12$$

RESULTS AND ANALYSIS







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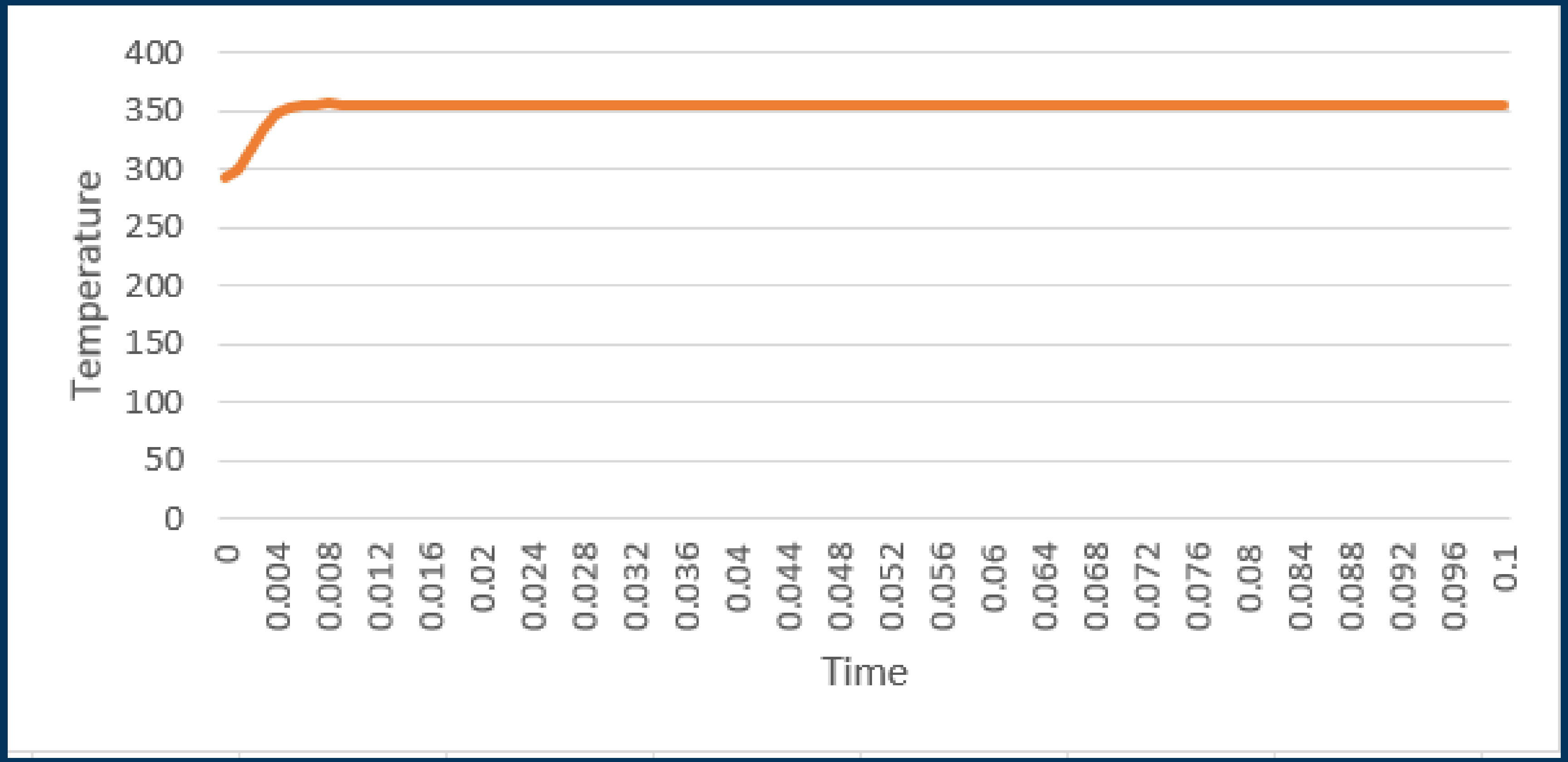

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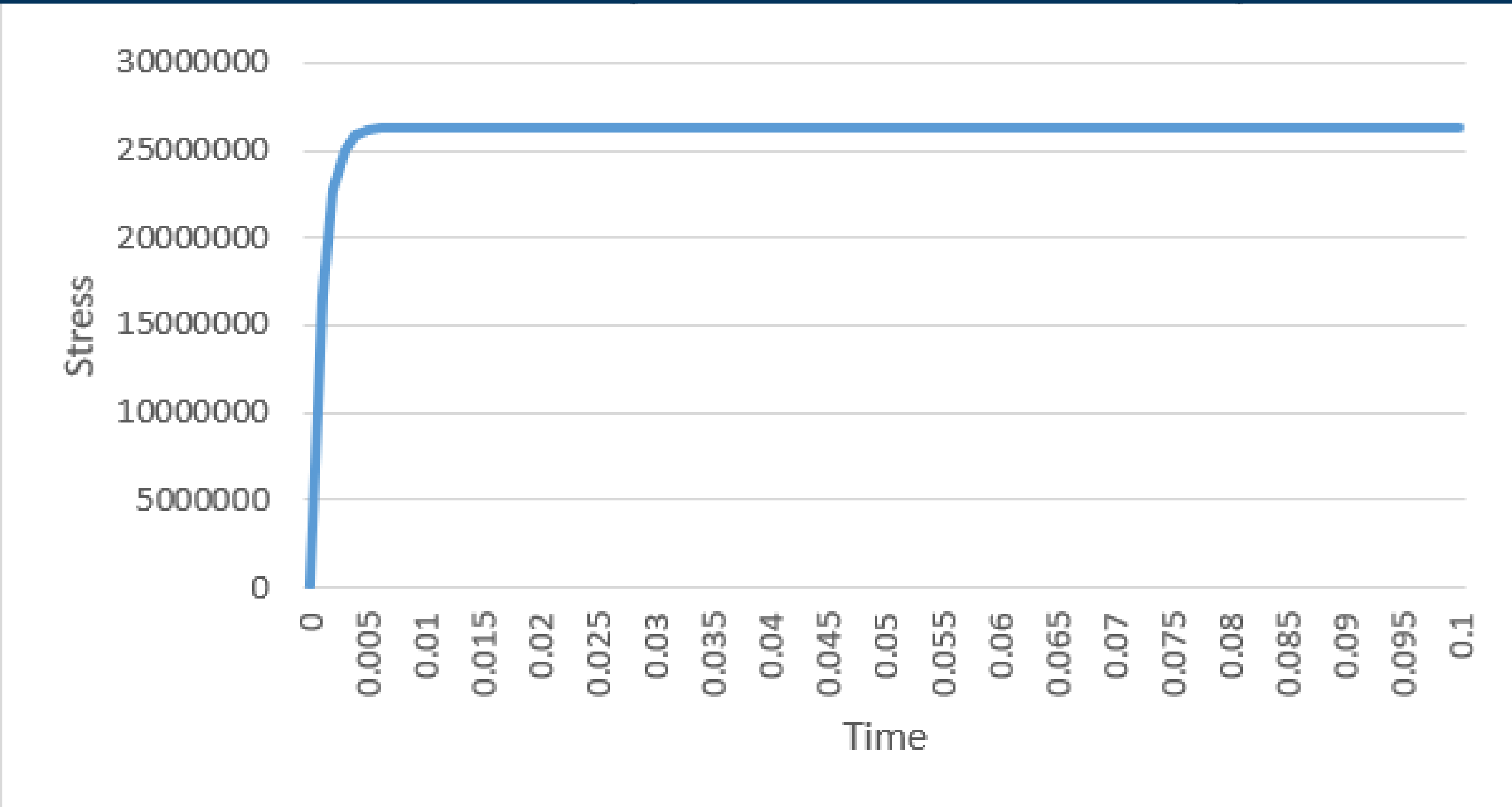
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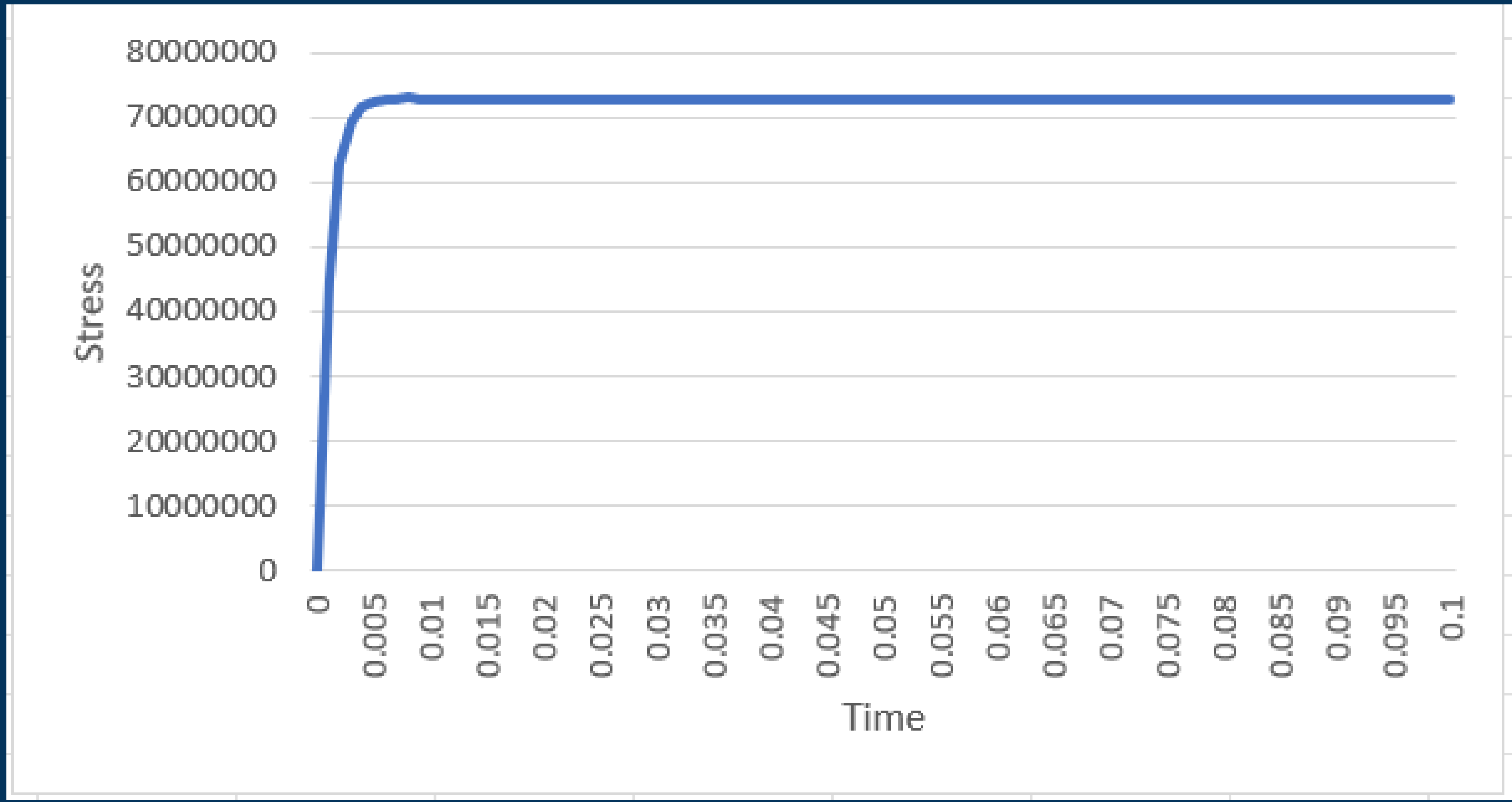
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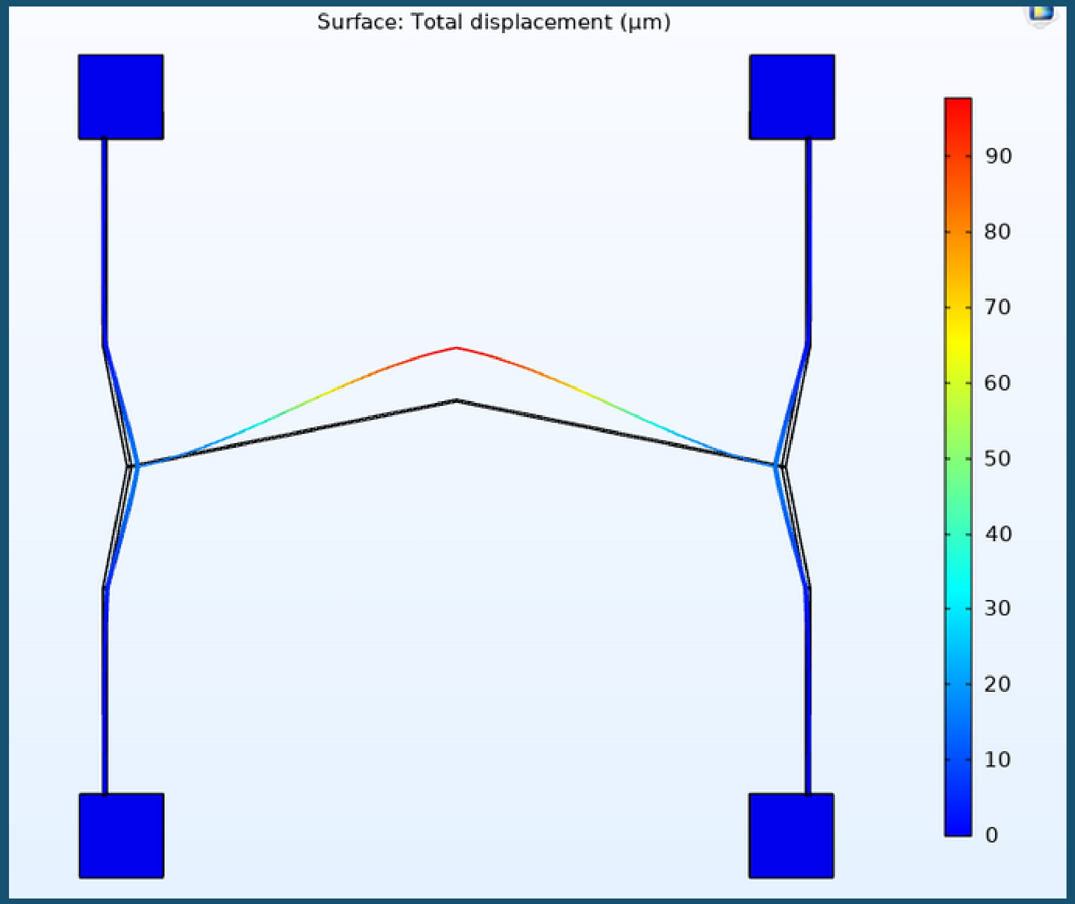
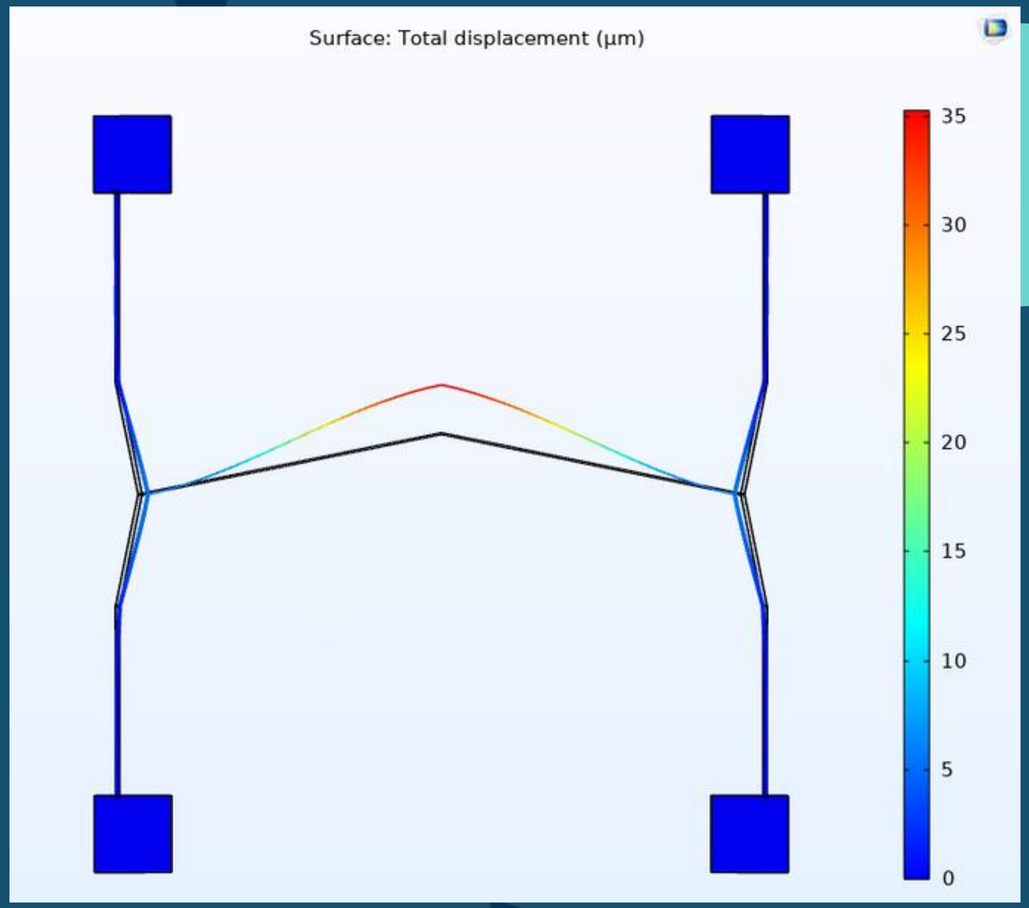
Time

RESULTS AND ANALYSIS

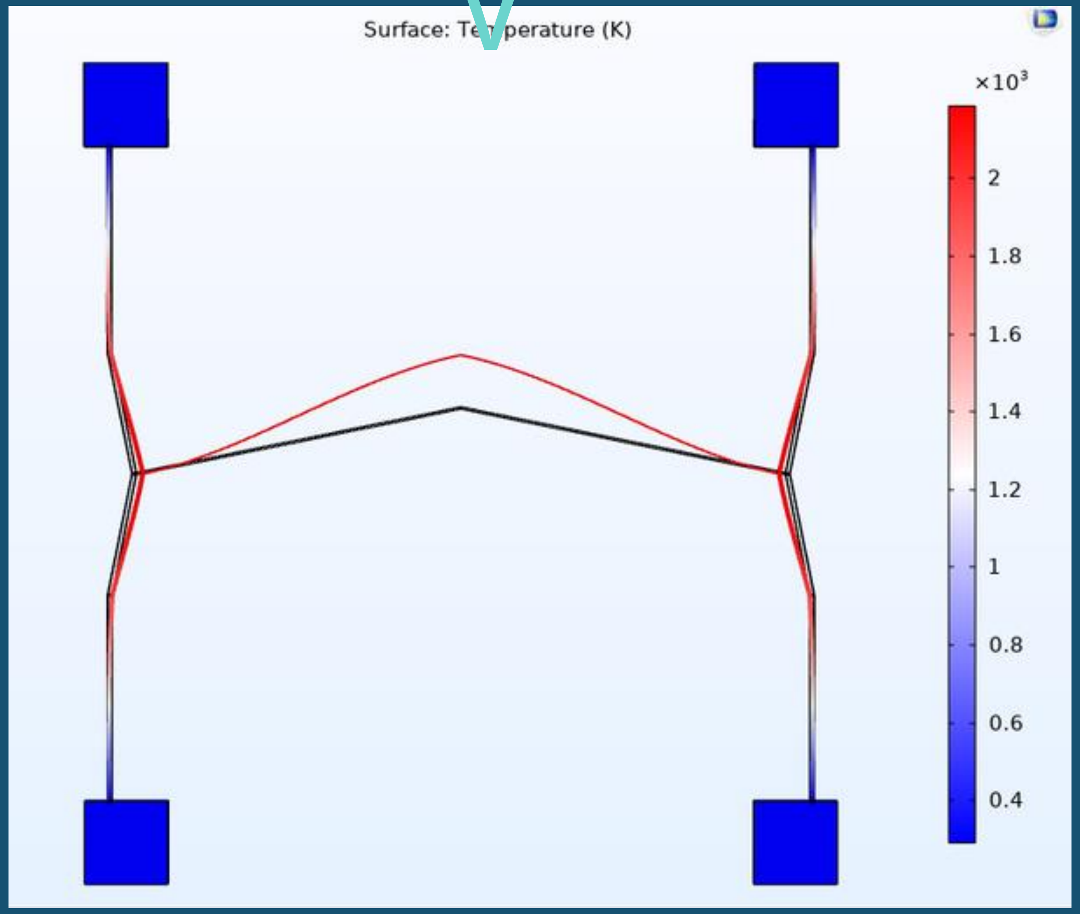
- From our results we were able to achieve a displacement of up to 95µm for a voltage of 10V.
- But since Silicon has a melting point of 1600 K. We had to restrict our electric potential to a voltage of 8.5V.
- The structure has varying cross-section which results in non-uniform pattern of heating, to prevent this unpredictable changes in temperature, the structure must be restricted under 8.5V.
- The model works well between the voltage of 1.5V to 8.5V, achieving a displacement greater than 2µm.

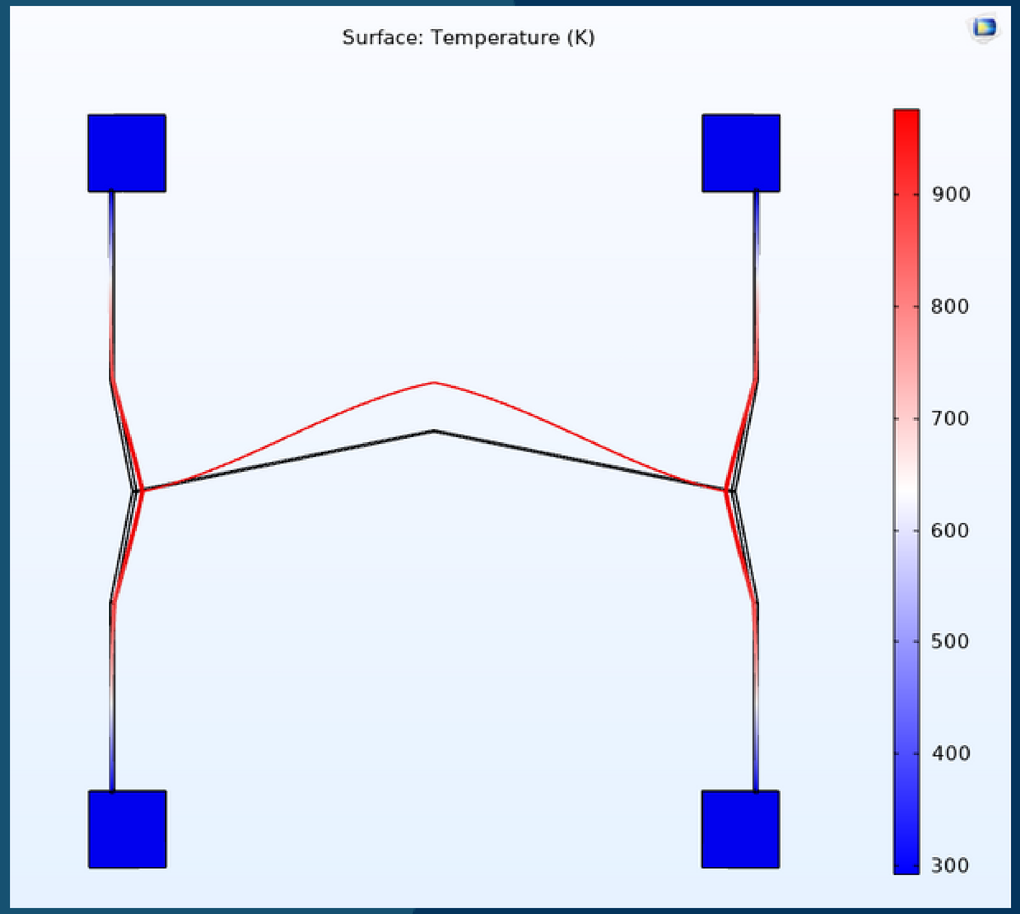




Results for 10 V

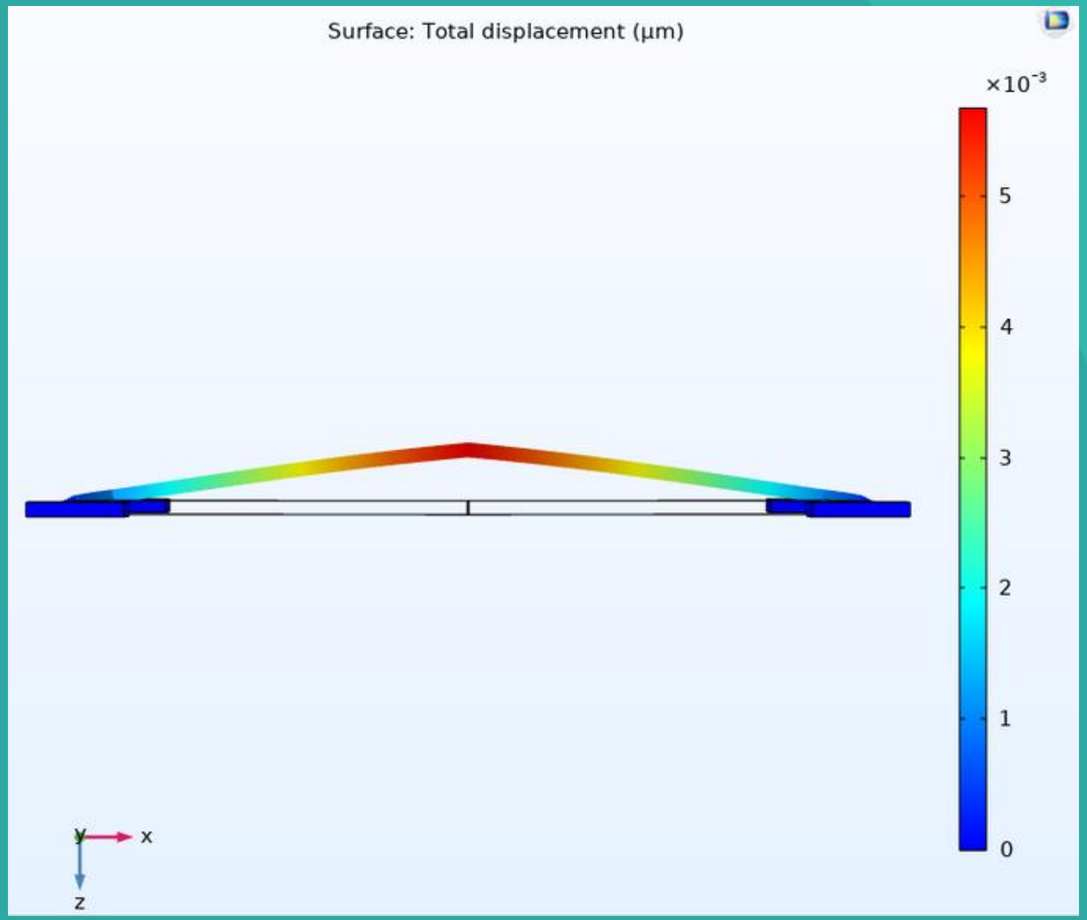
Results for 6V

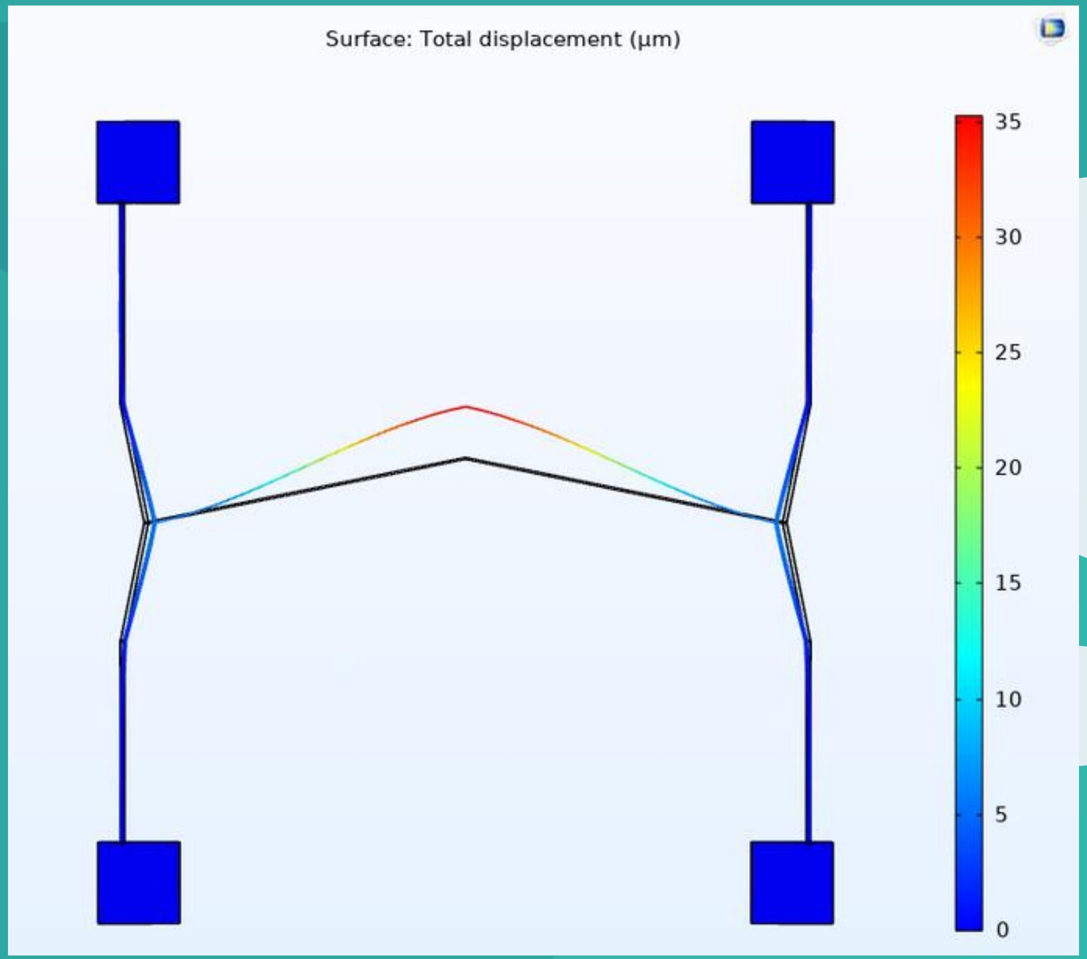




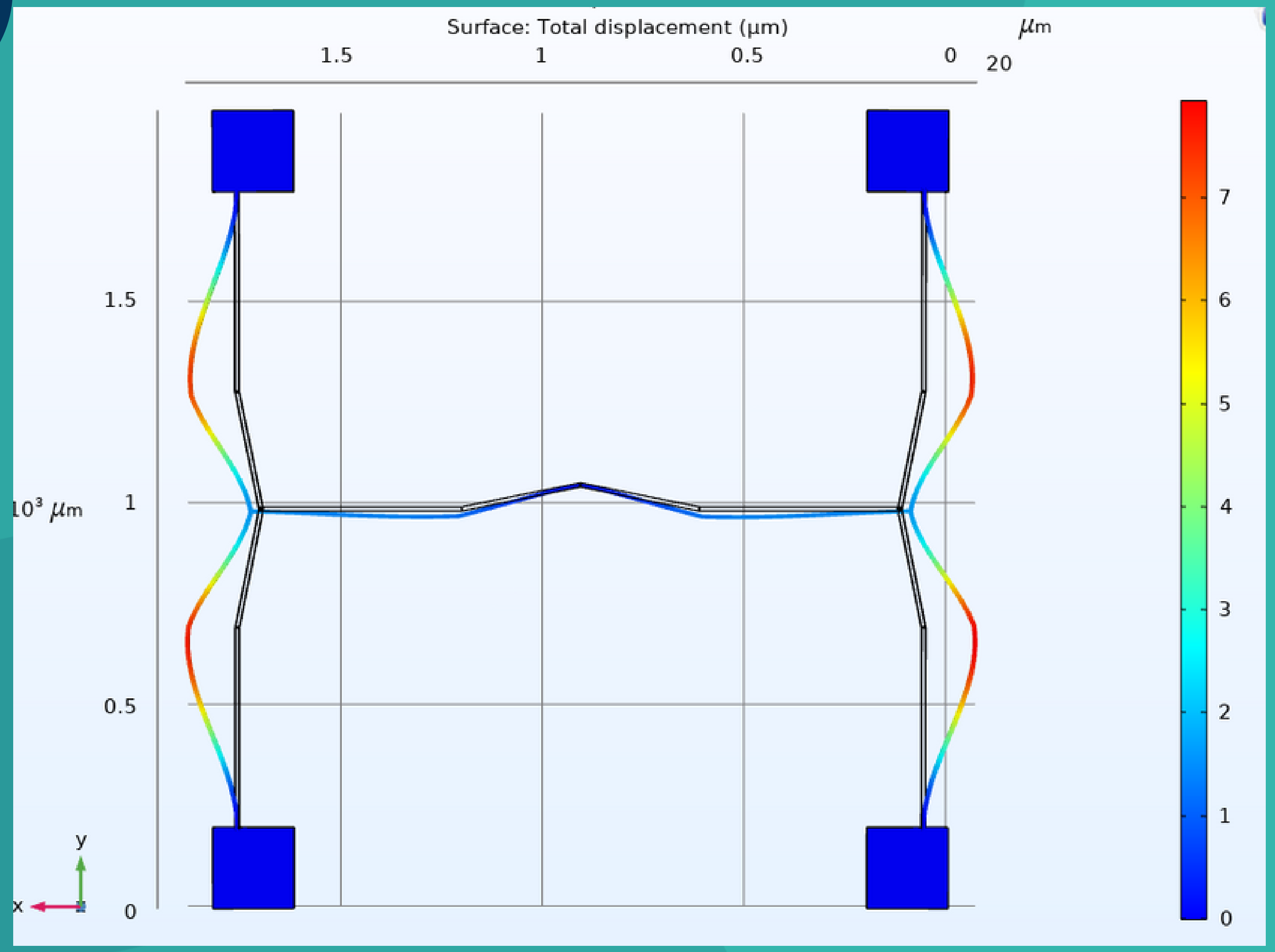
RESULTS AND ANALYSIS

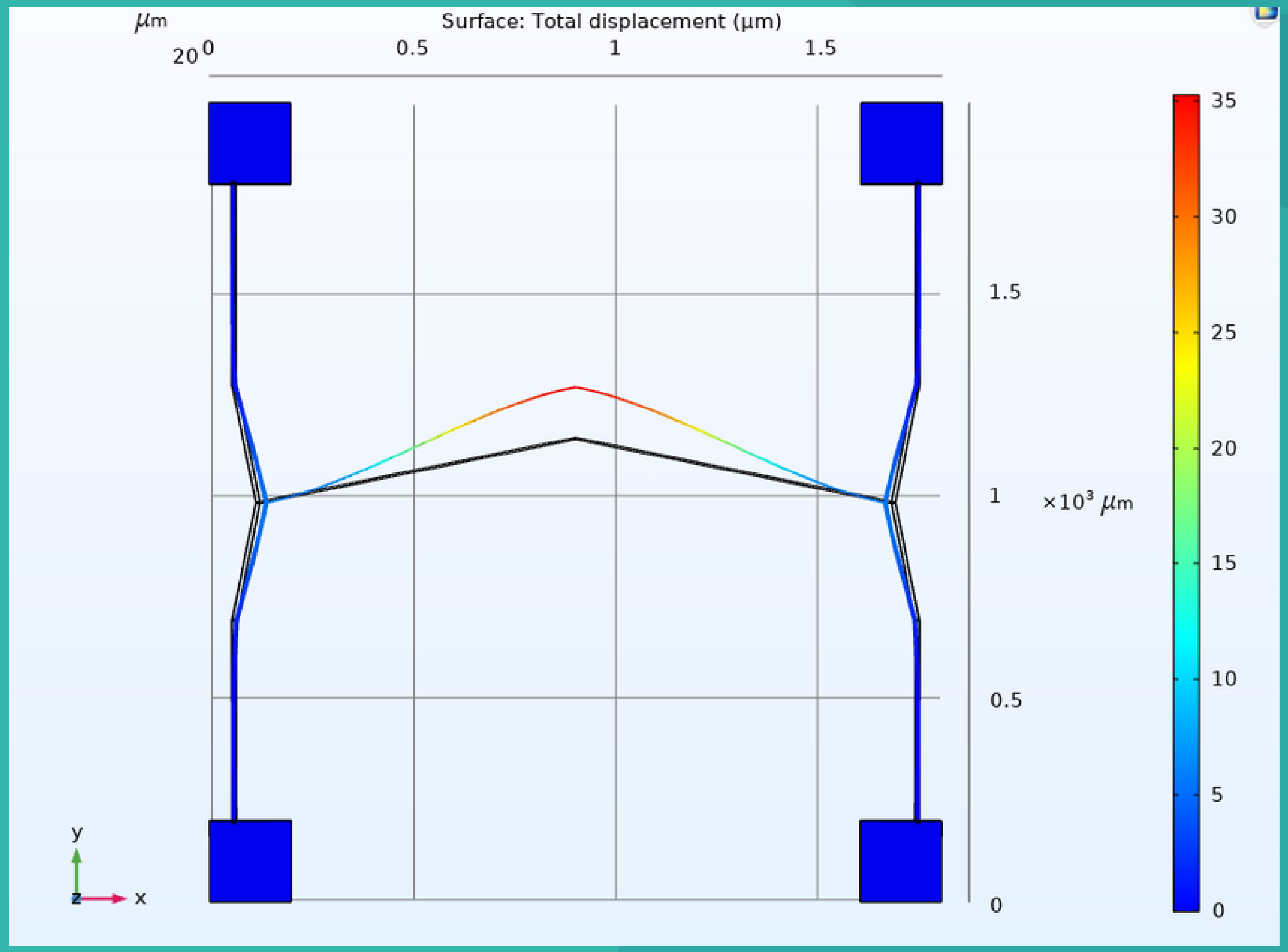
- The results shown are for a voltage of 6V, where we were able to achieve a displacement of up to 35µ keeping the temperature in check.
- The structure consists of beams of different cross-sections, as the secondary beam is very thin, we had to carryout the simulation keeping in mind the effect of gravity on our model, the effect of gravity on the structure has a negligible out-of-plane deflection of about 5.8nm at the secondary beam.
- This out-of-plane deflection has no effects on the performance of the model.





FULLY CASCADED KINK ACTUATOR VS CASCADED KINK ACTUATOR





Simulating the fully cascaded kink beam resulted in the failure of the system due to excessive buckling of the beams. Therefor using a compliant structure for the secondary unit that acts as an amplifier is found to be having better results.

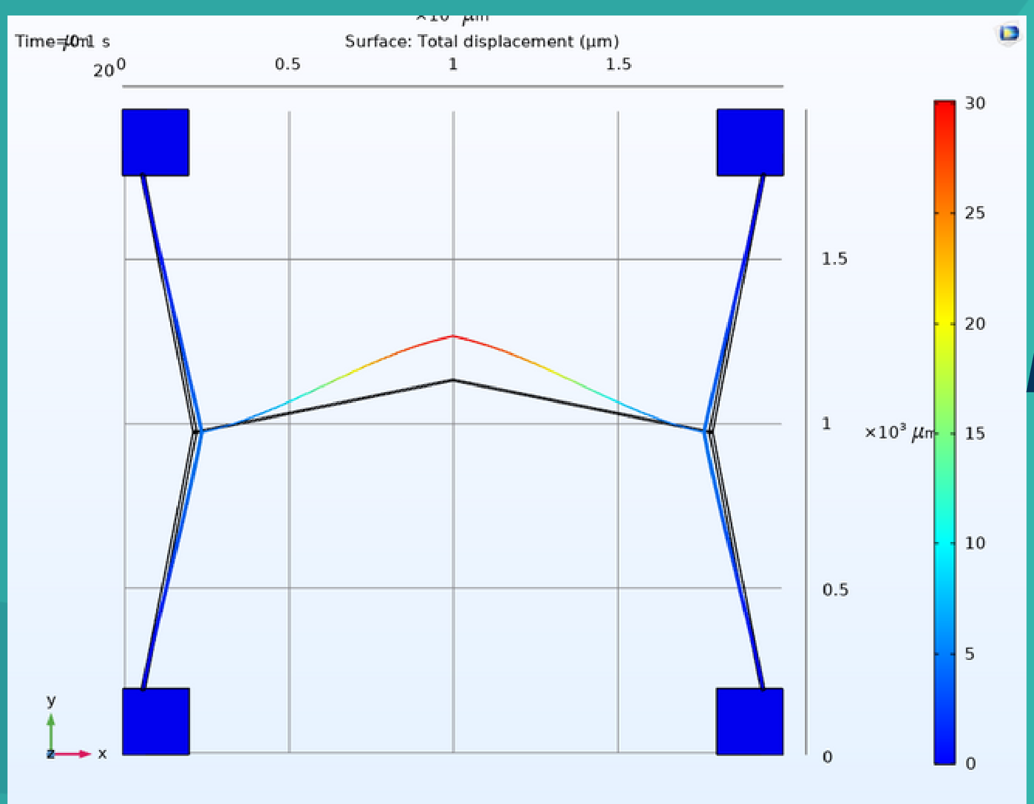
COMPARATIVE STUDY OF THE CASCADED CHEVRON AND THE CASCADED KINK ACTUATOR (HOW OUR STRUCTURE IS BETTER?)

The following results and simulation shows the benefit of using the cascaded kink actuator over the cascaded chevron actuator, this comparative analysis is done mainly considering three factors,

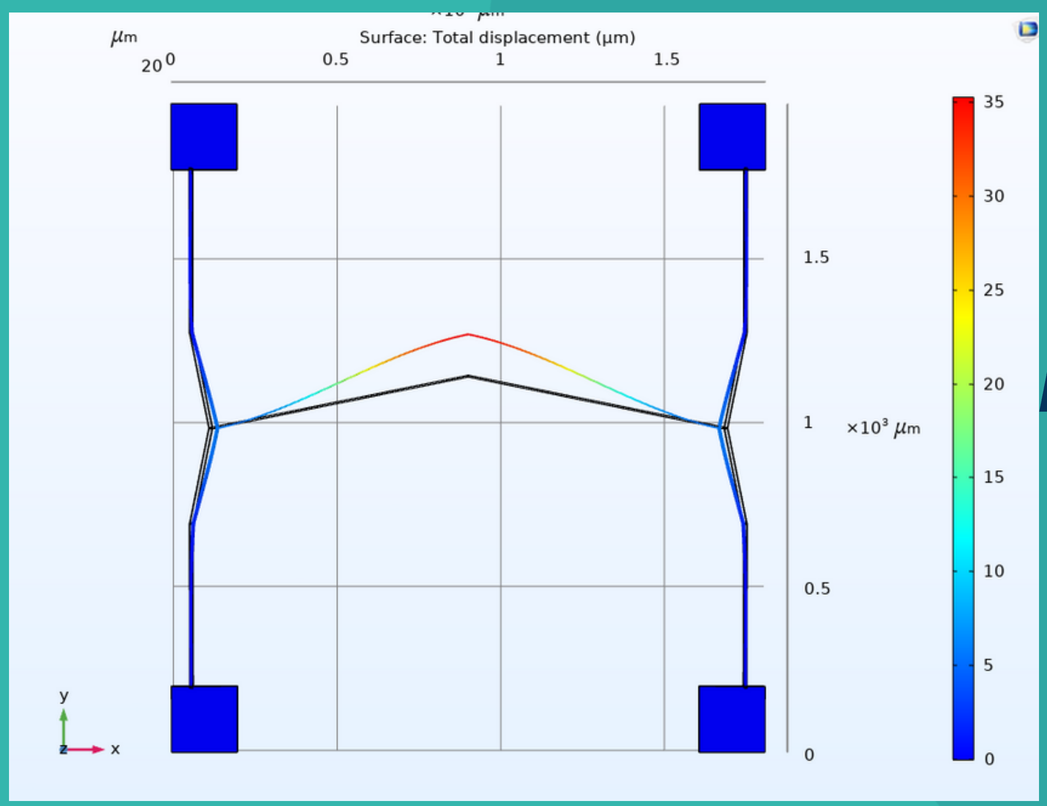
- Displacement
- Temperature
- Stress

COMPARATIVE STUDY OF THE CASCADED CHEVRON AND THE CASCADED KINK ACTUATOR (HOW OUR STRUCTURE IS BETTER?)

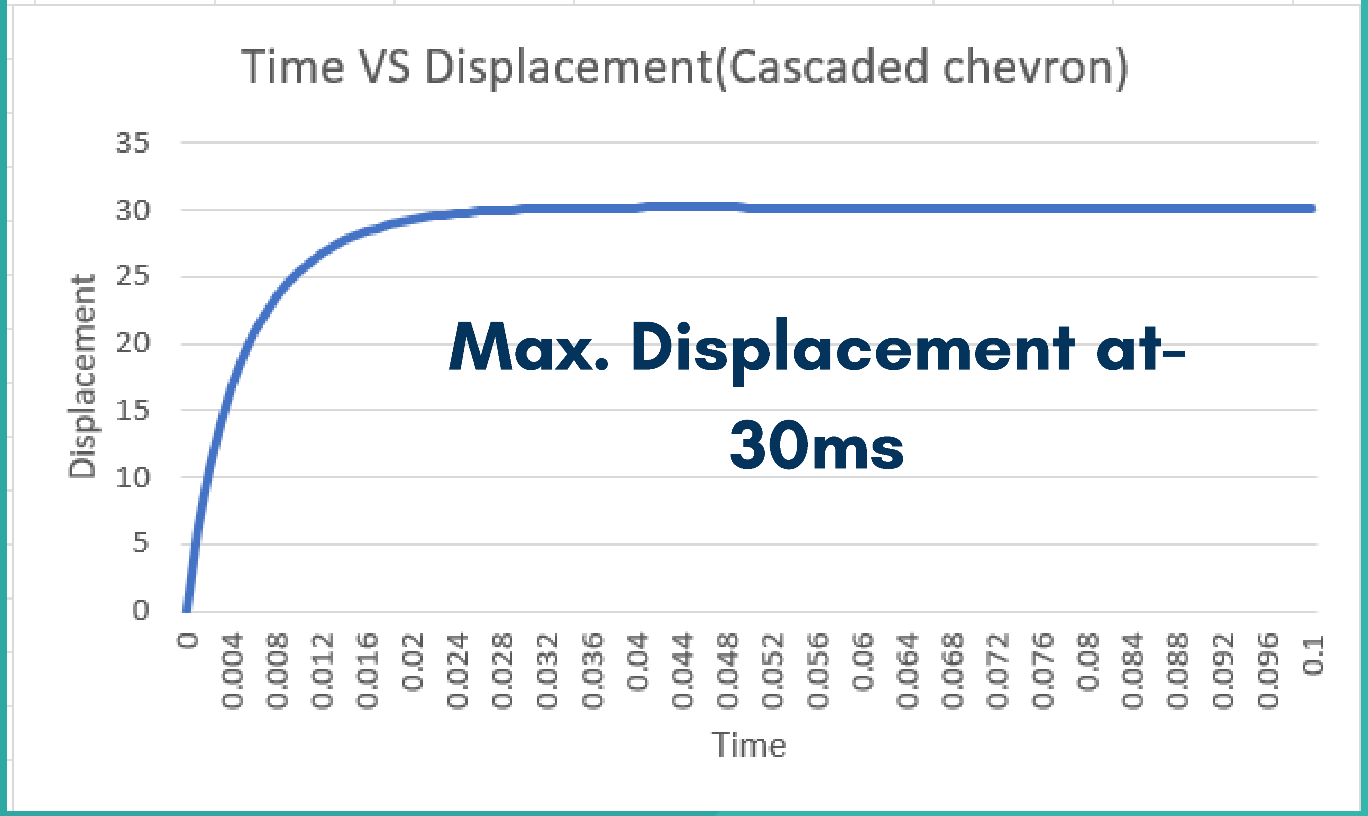
DISPLACEMENT

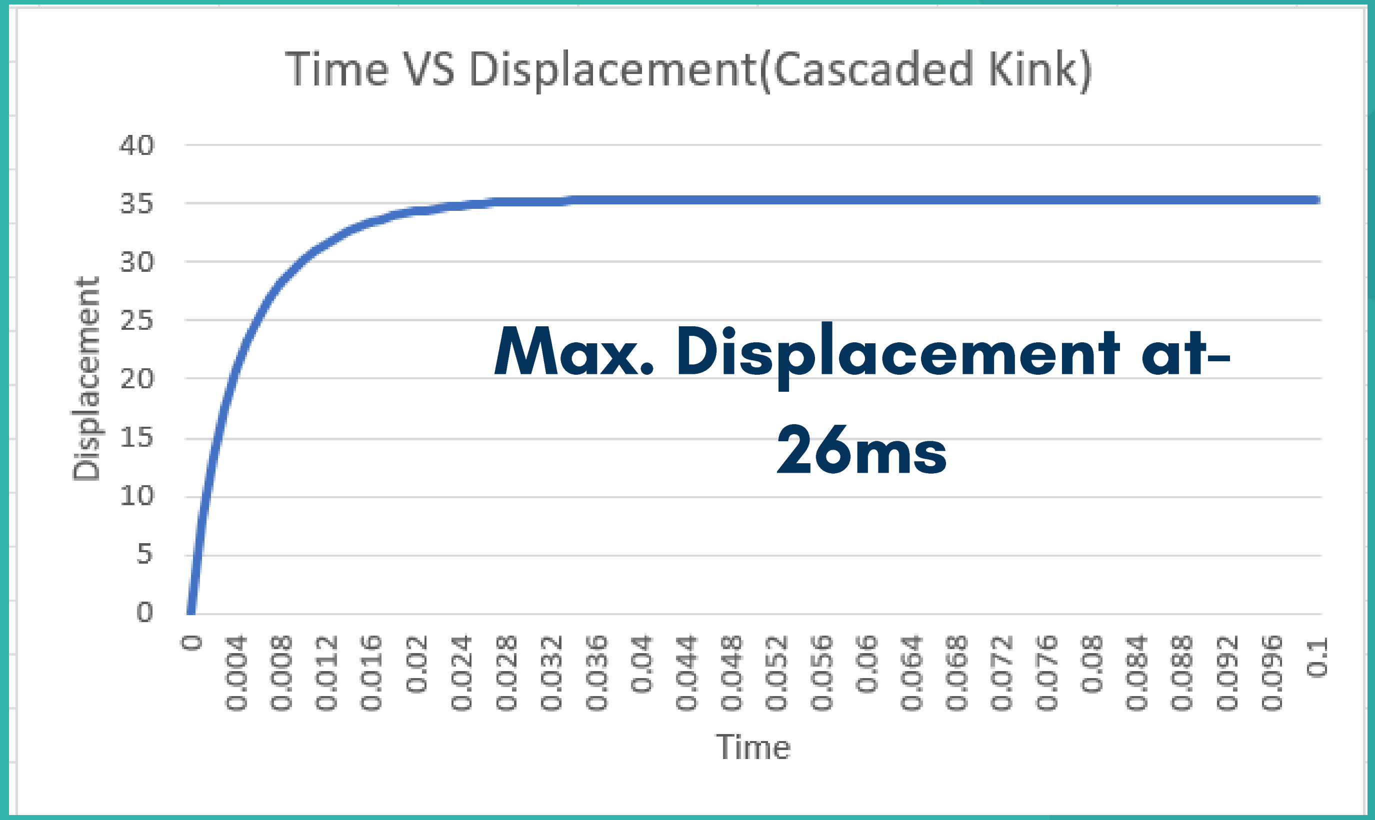


Max. Displacement -30um



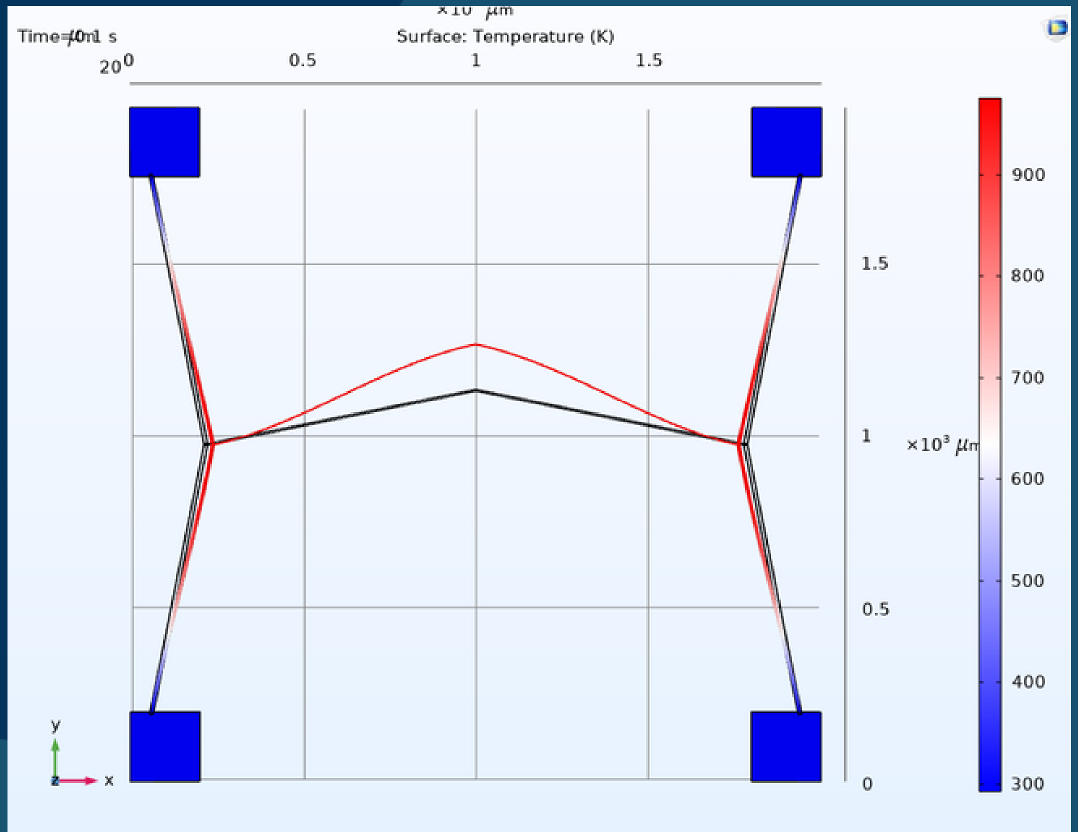
Max. Displacement -35um

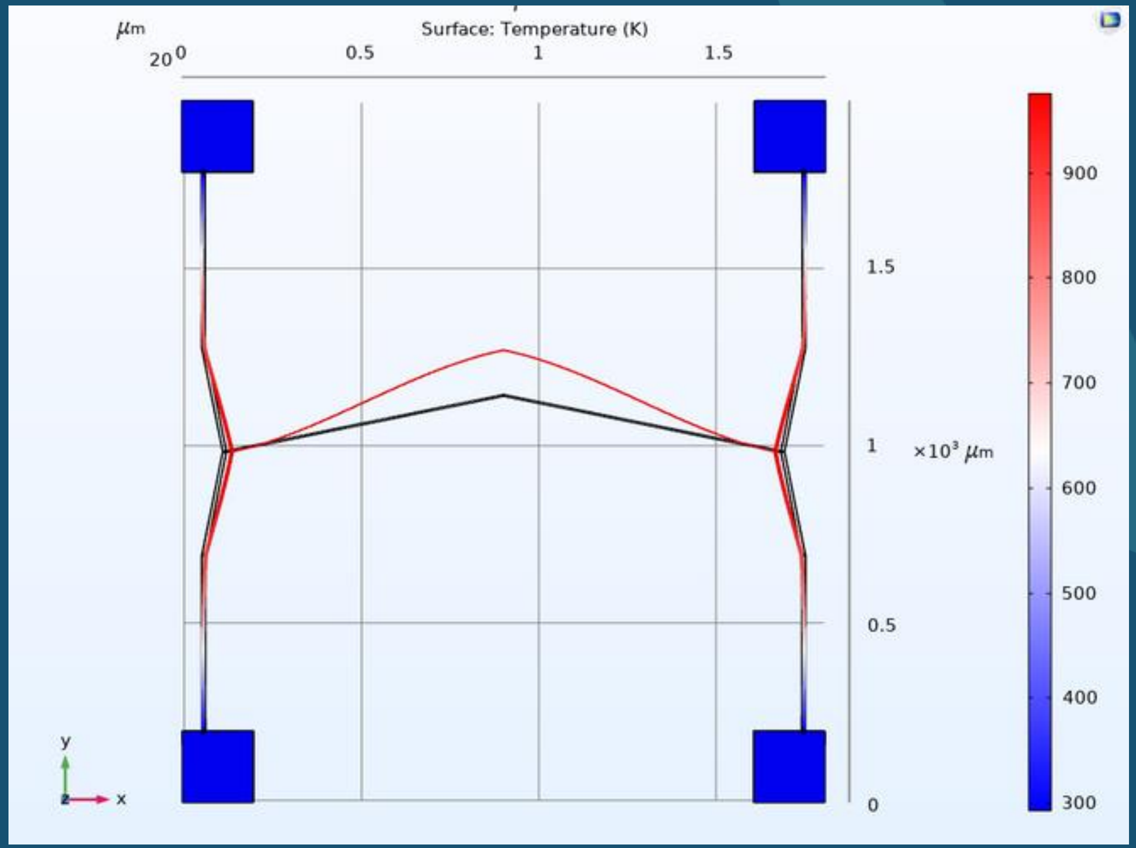


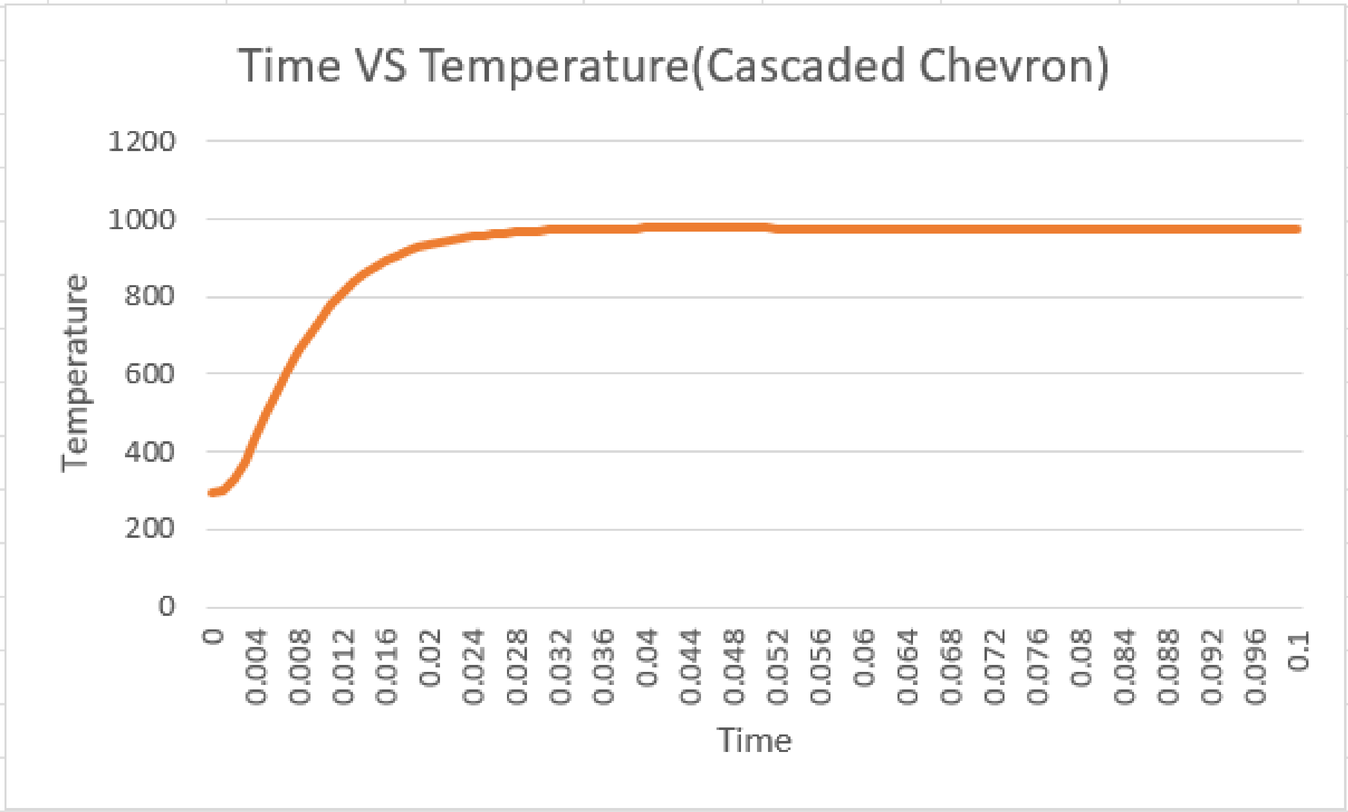


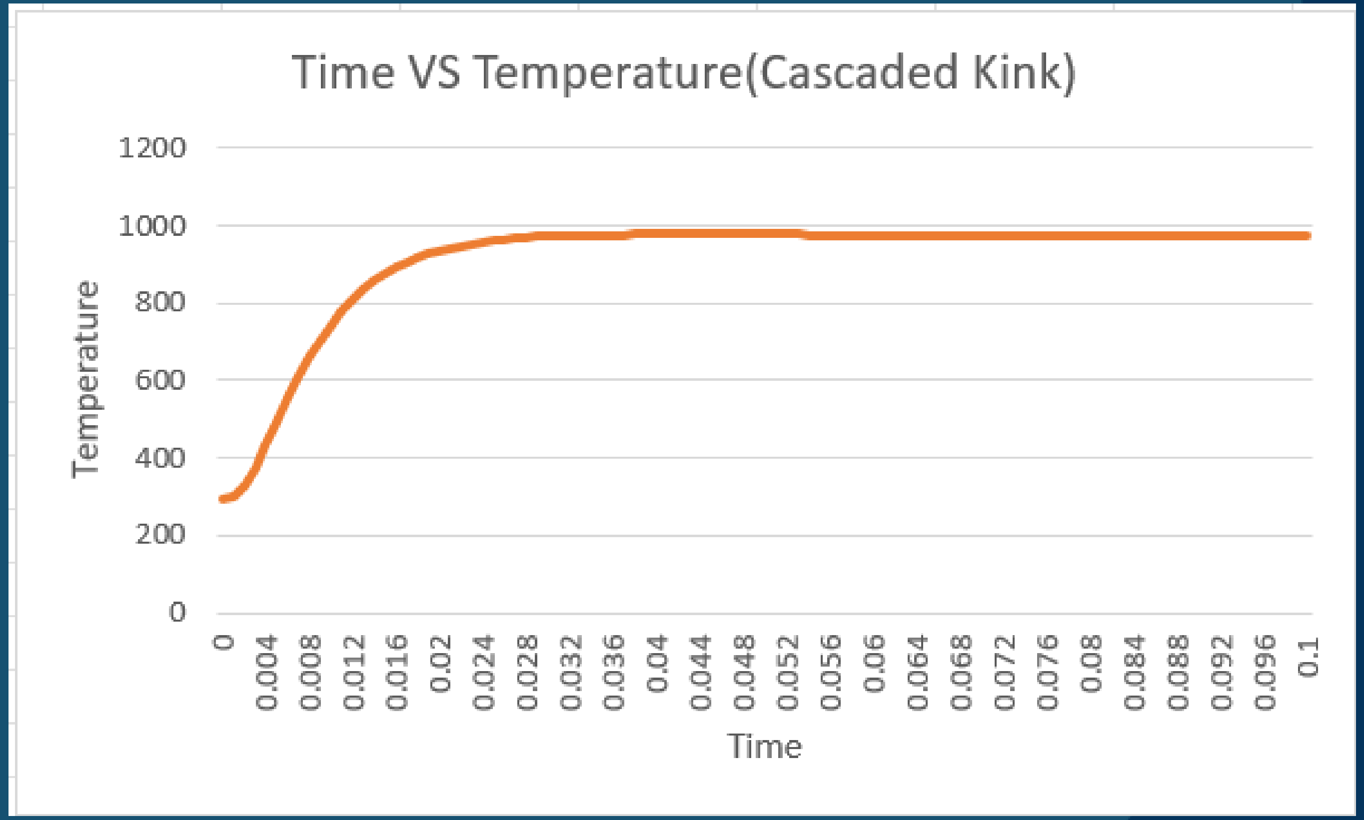
COMPARATIVE STUDY OF THE CASCADED CHEVRON AND THE CASCADED KINK ACTUATOR (HOW OUR STRUCTURE IS BETTER?)

TEMPERATURE



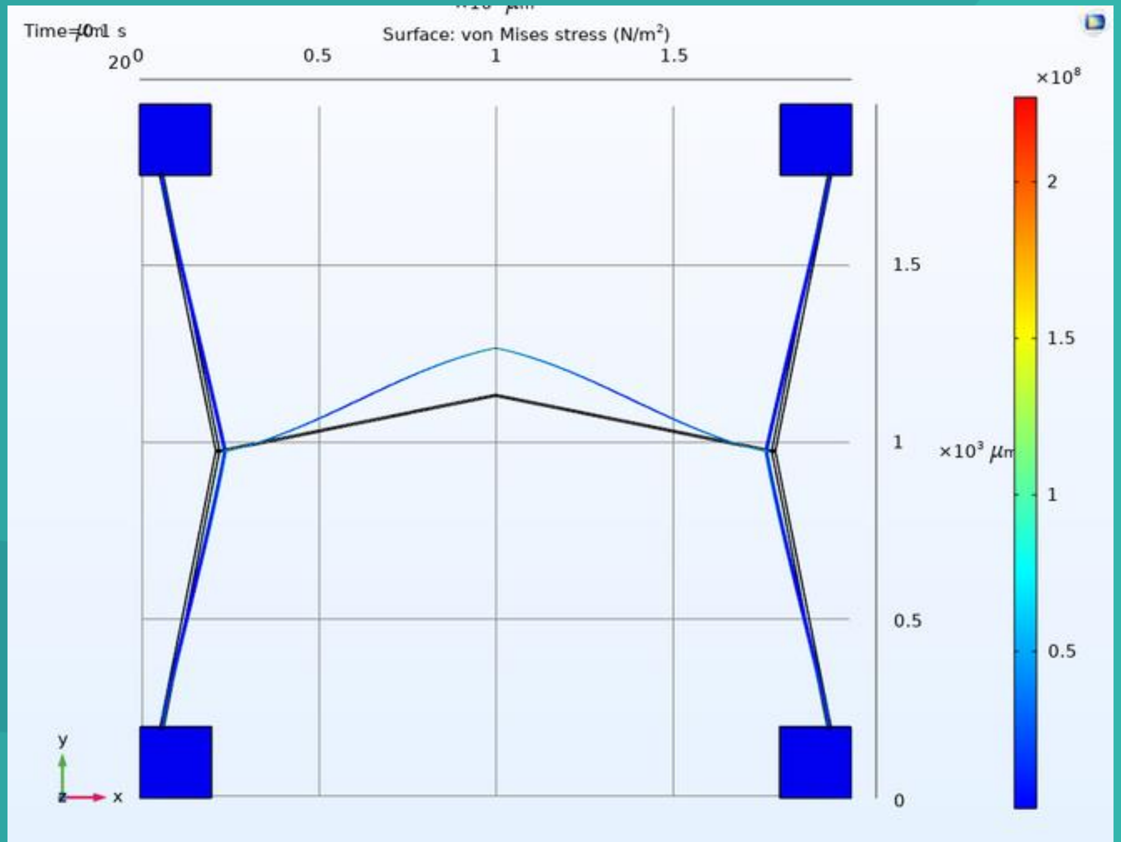


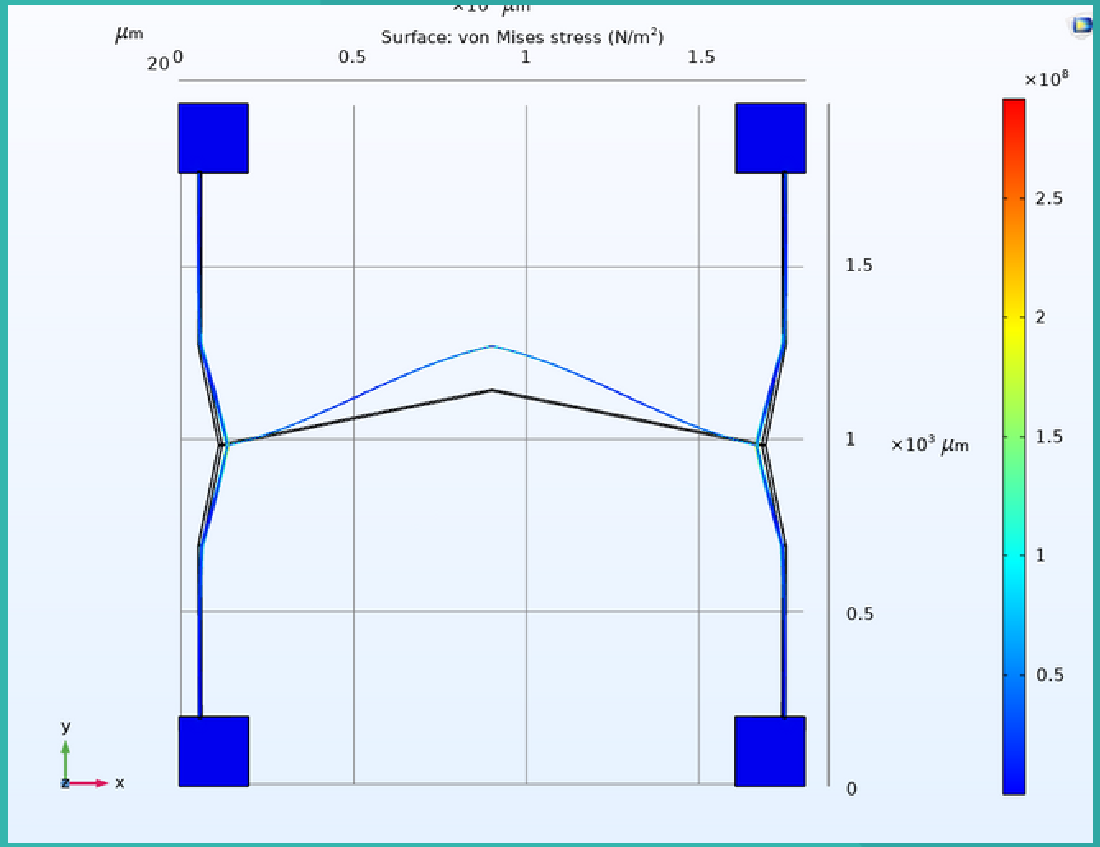


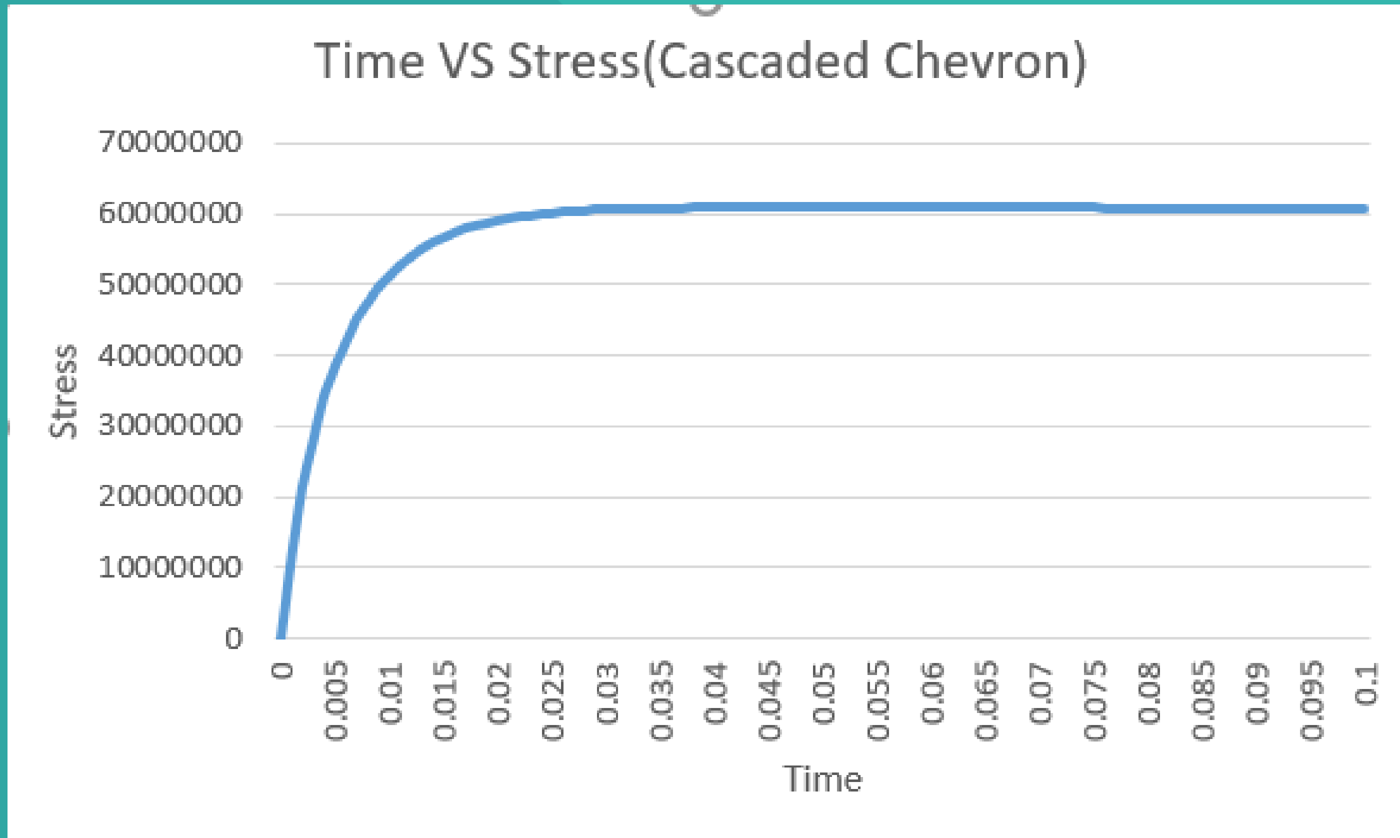


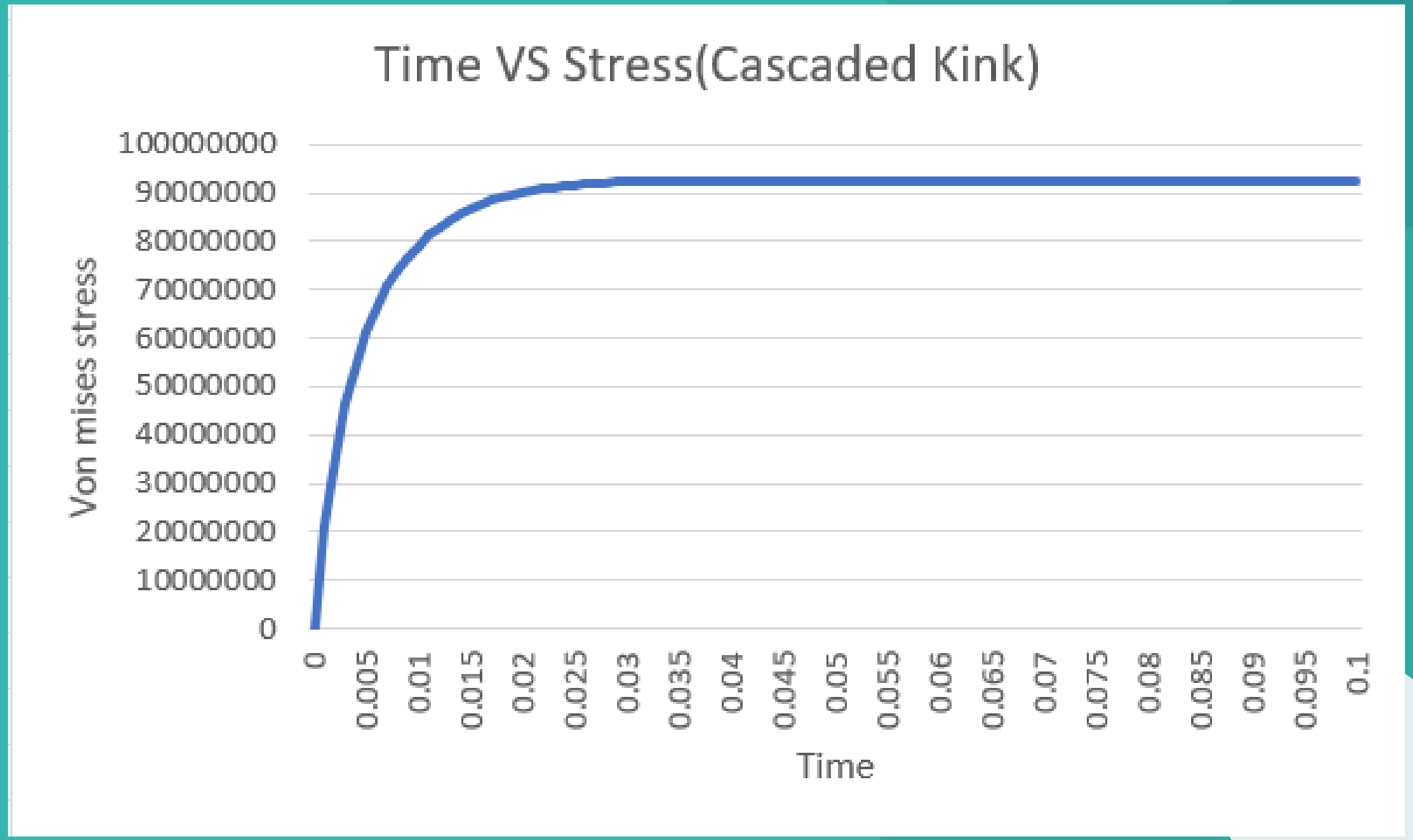
COMPARATIVE STUDY OF THE CASCADED CHEVRON AND THE CASCADED KINK ACTUATOR (HOW OUR STRUCTURE IS BETTER?)

STRESS









ELECTRO THERMAL ANALYSIS

As we fabricate using the SOI wafer configuration, the height of the beam equals the active layer thickness and the gap ‘g’ between the beams and the substrate equals the oxide layer thickness. In the case of very small gap under a suspended silicon beam, convention and radiation can be considered to be negligible and conduction through air to the substrate dominates. But, conduction from sides of the beam to the surrounding air to the substrate cannot be ignored and must be accounted for the shape conduction factor ‘S’. This geometric factor represents the heat loss from the sides and the bottom of the beam to expected heat loss from the bottom of the beam only.[5] An empirical equation has been developed for 2um to 50um. This shape factor is given by,

S=4/w(10^-6+g)+1

Heat loss due to air gap is given by

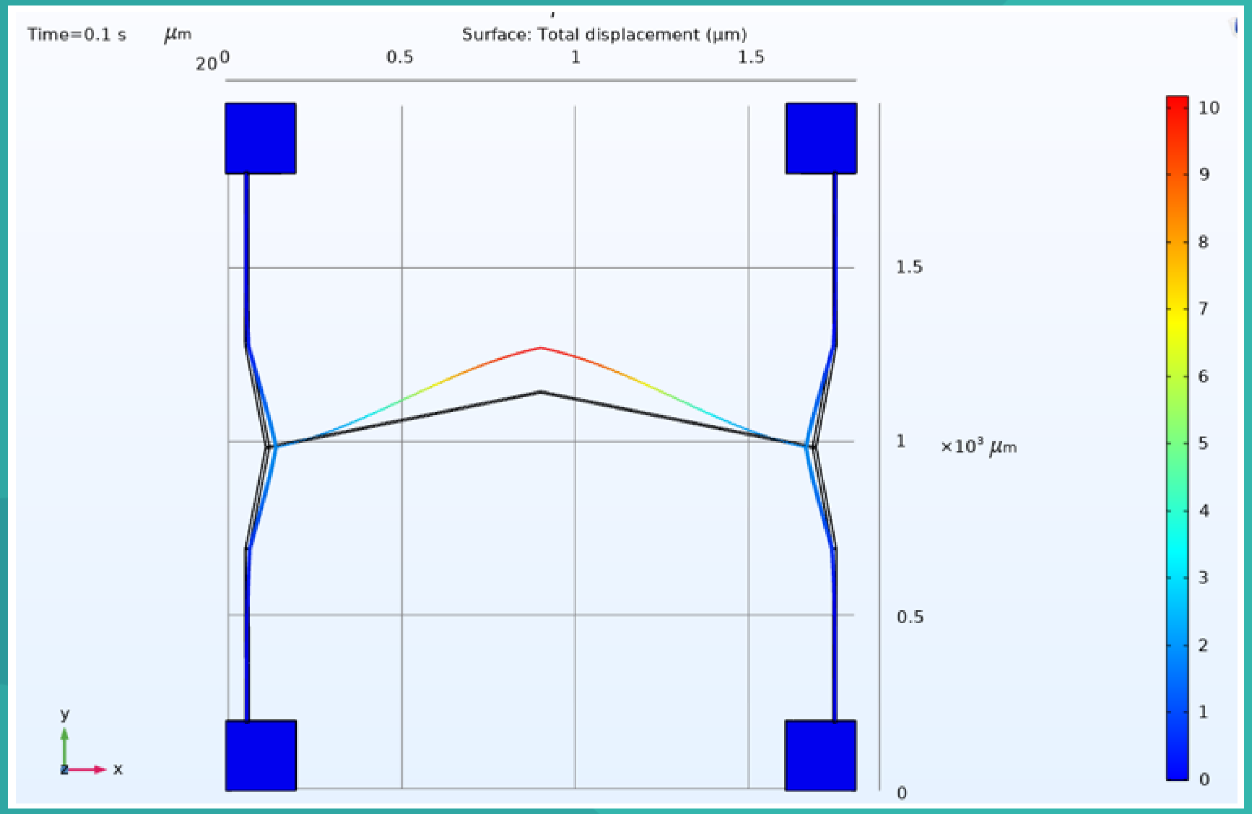
Q=SKaw dx dt/g

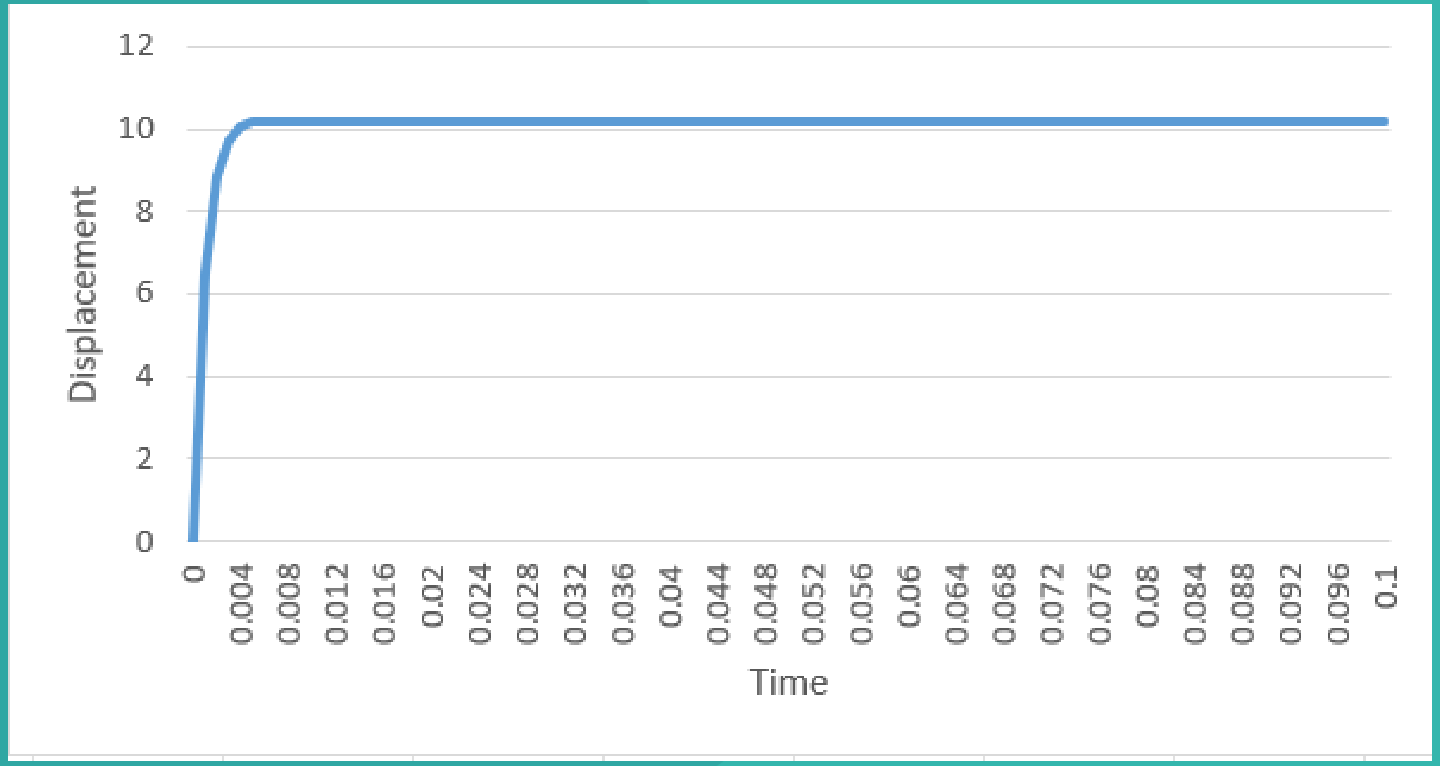
Table2: Material properties

Description	Value
Density	2330 kg/m^3
Coefficient of thermal expansion	2.6e-6/K
Poisson’s Ratio	0.28
Heat capacity at constant pressure	700J/(kg-K)
Thermal conductivity	131 W/(m-K)
Electrical conductivity	2000 S/m
Young’s modulus	166GPa

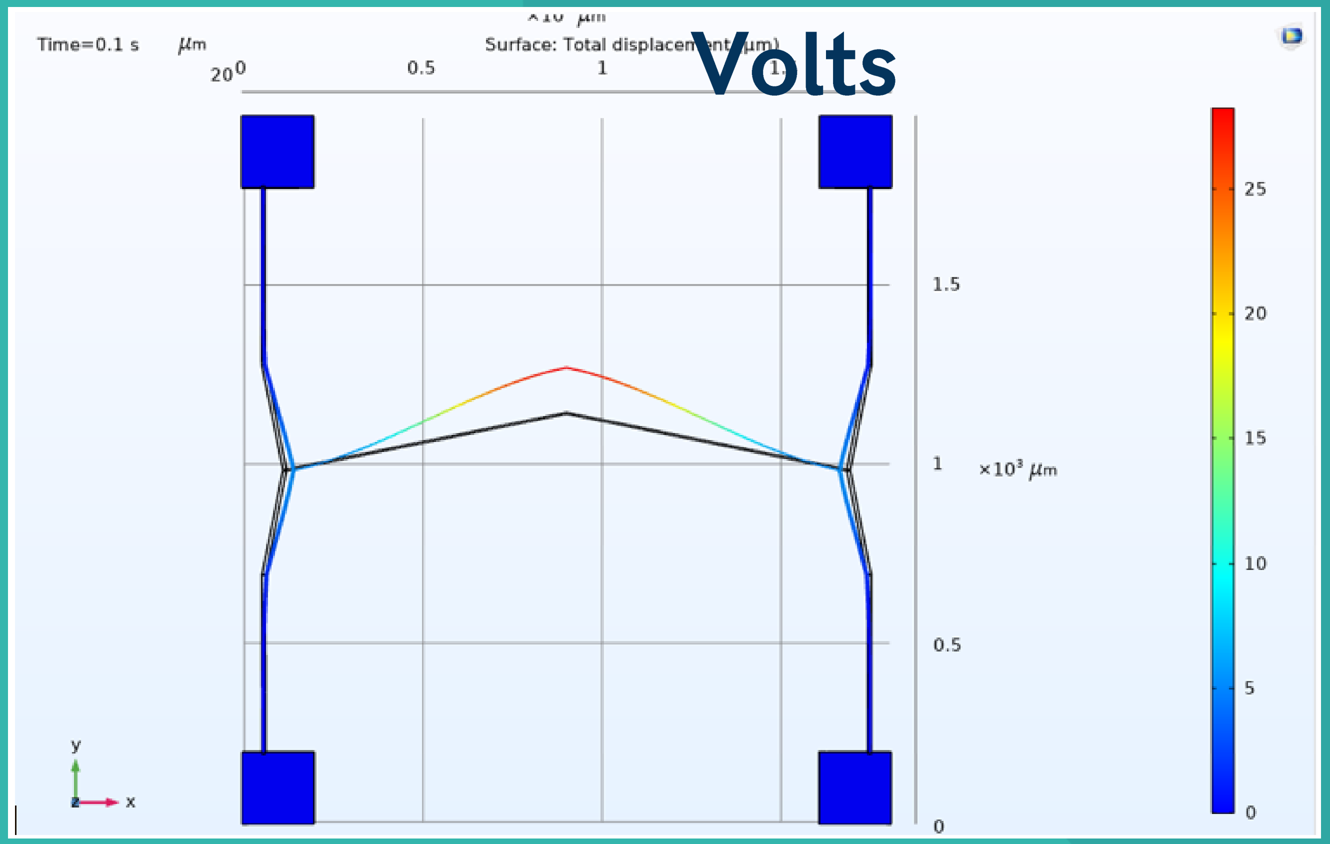
ELECTROTHERMAL ANALYSIS RESULTS

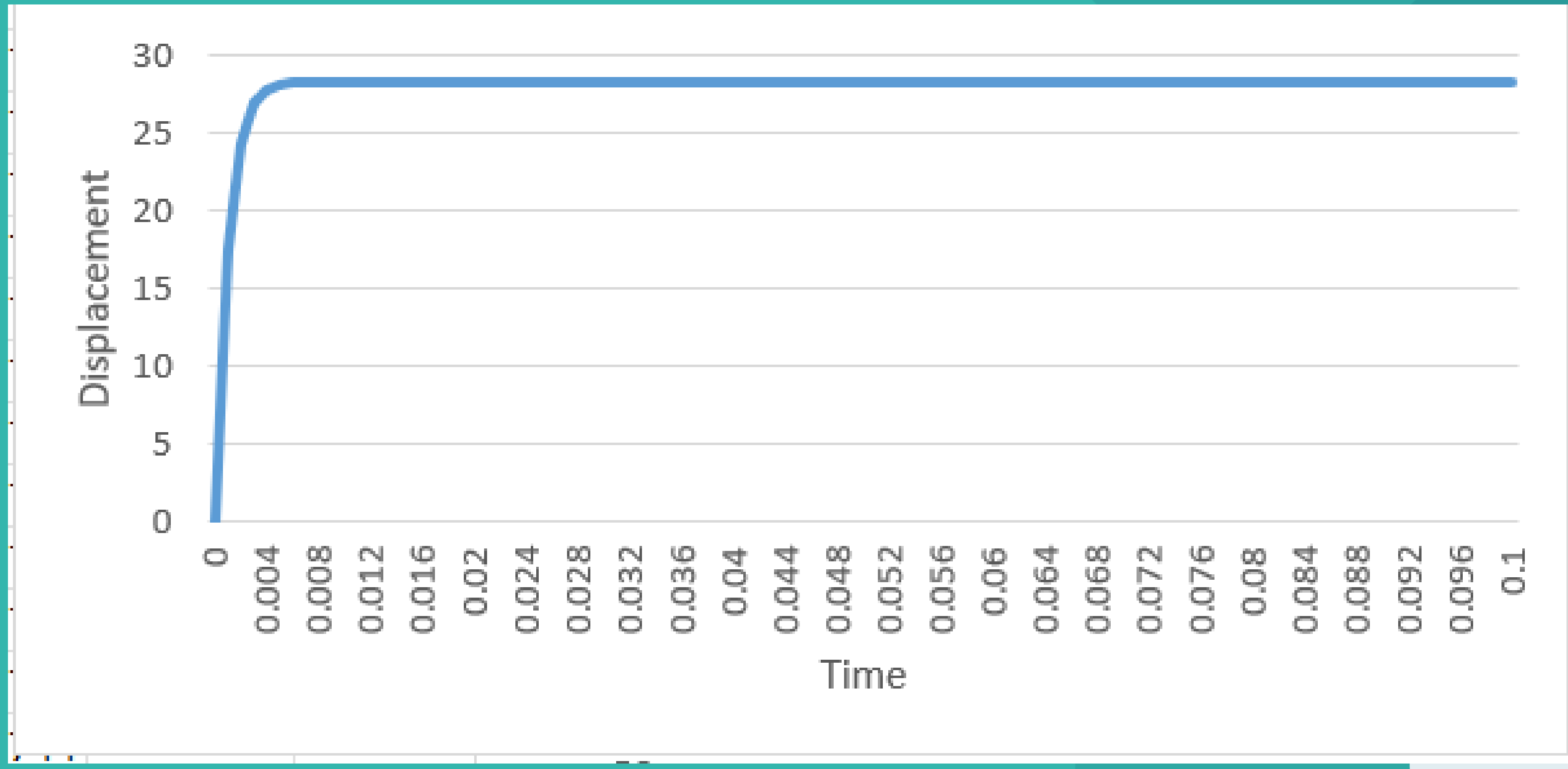
6 Volts





10 Volts





Conclusion

- For a voltage of 6v, we achieve a displacement of 35um and for a voltage of 10v, we observe a displacement of 95um.
- The suitable model works best between a supply voltage of 1.5 v and 8.5 v producing a displacement greater than 2um.
- Fully cascading the kink beam actuator results in failure of the system, which is why **using the primary beams as the kink actuators and the secondary beam to be the bent beam** for amplifications of displacement **has better results**.
- Considering the transient analysis, when we compare the cascaded kink beam actuator and the cascaded chevron beam actuator, the **cascaded kink beam actuator transcends the cascaded chevron beam actuator** in two factors. One is the **displacement** and the other is the **time taken to reach maximum displacement**.

THANK YOU