Temperature Effects on Thermomechanical Properties of Elastomeric Stamps for Micro Transfer Printing Applications

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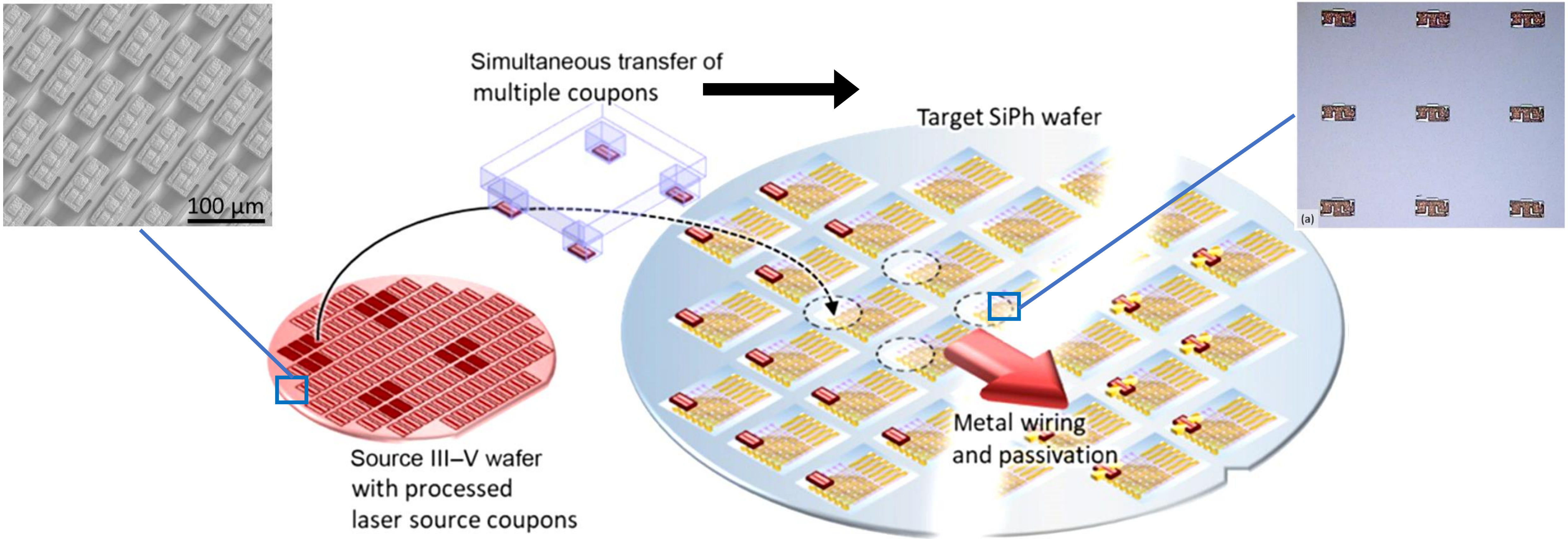
What is Micro Transfer Printing - µTP?

Micro-transfer printing (µTP) enables mass-transfer of wafer-level chips having lateral dimensions ranging from 3 x 7 um to 650 x 650 um to a nonnative target wafer. .

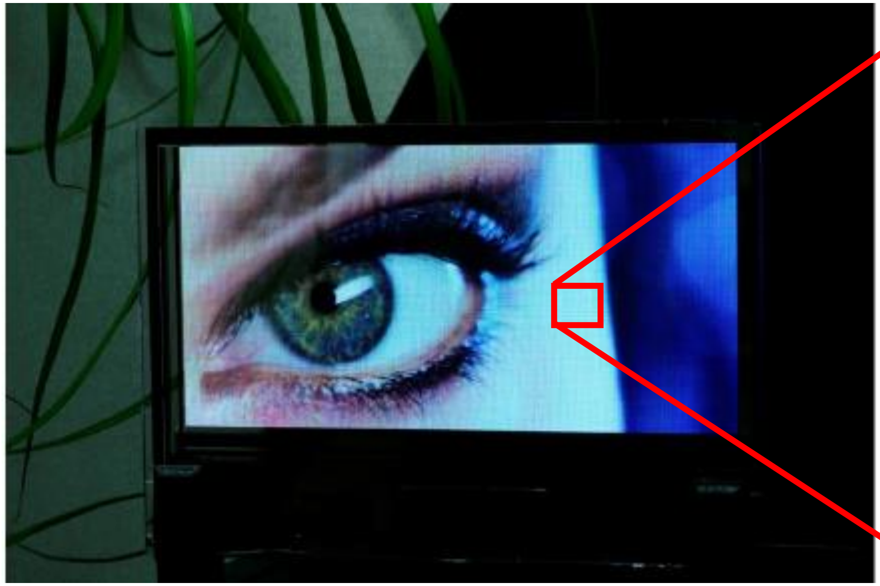


Corbett, Brian, et al. "Transfer printing for silicon photonics." Semiconductors and Semimetals. Vol. 99. Elsevier, 2018. 43-70.

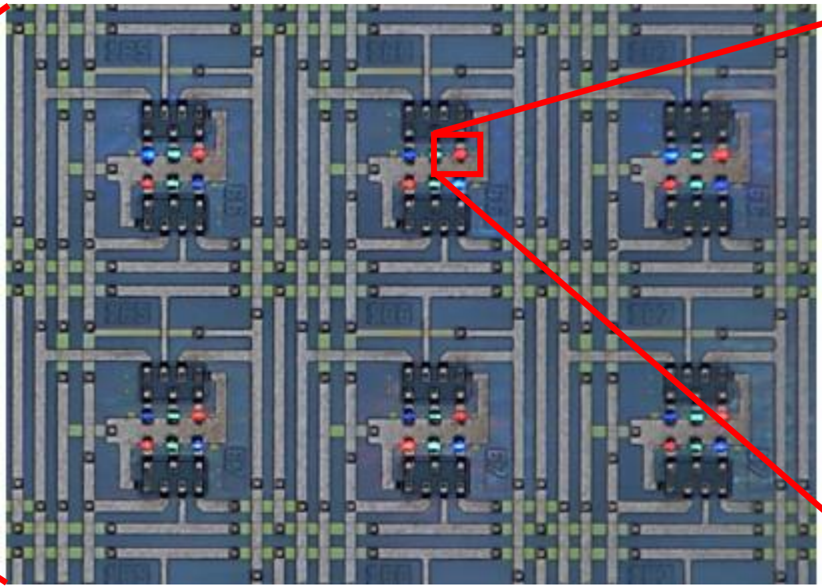
Applications of µTP

Micro-transfer printing (µTP) enables mass-transfer of wafer-level chips having lateral dimensions ranging from 3 x 7 um to 650 x 650 um to a nonnative target wafer. Applications include, solar junctions, lasers, optical devices,LEDs etc.

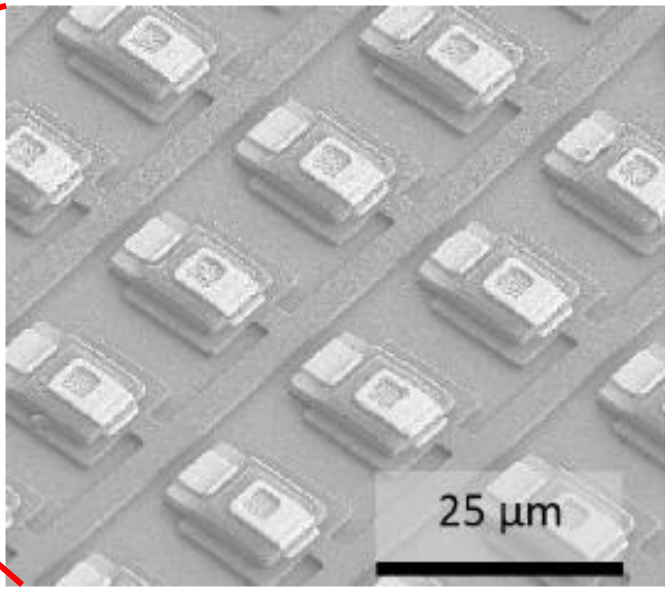
5.1”, 70 PPI MicroLED



Printed MicroLEDs and IC Drivers



MicroLEDs



Bower, C. A., et al. "Emissive displays with transfer-printed microscale LEDs and ICs." *Light-Emitting Devices, Materials, and Applications XXIV*. Vol. 11302. International Society for Optics and Photonics, 2020.

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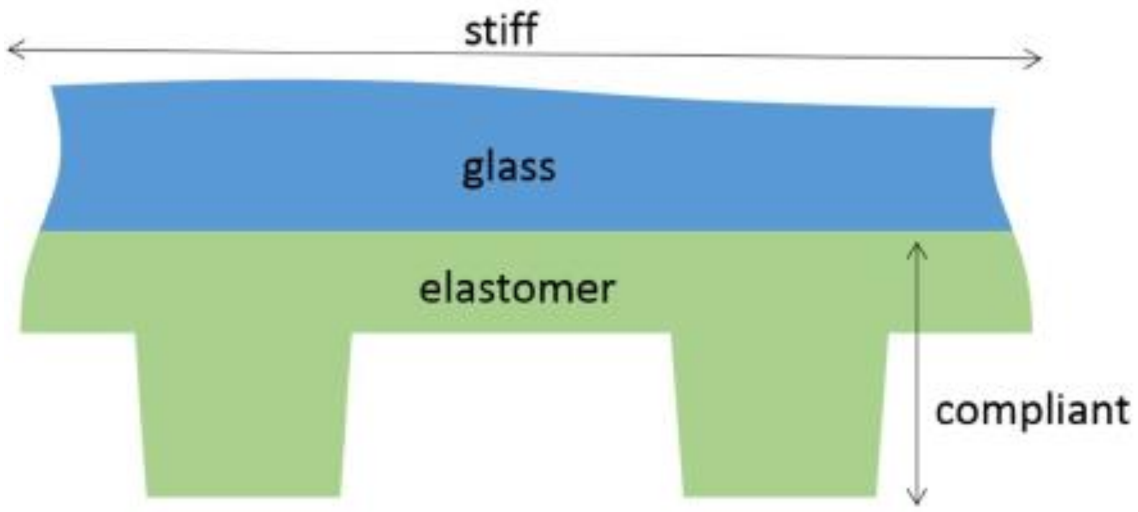
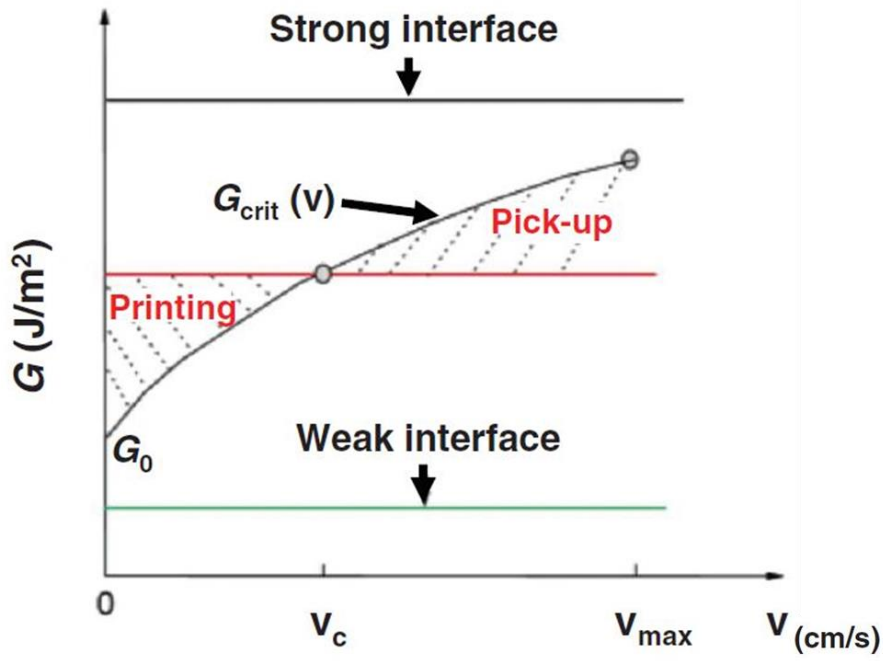
How µTP Works – PDMS Elastomer Stamp

The viscoelastic properties of PDMS allow for kinetic control of adhesion as the stamp/source as the release energy is controlled by the speed of the stamp.

Stamp Cross Section



Release Energy vs Stamp Speed



Carlson, Andrew, et al. "Transfer printing techniques for materials assembly and micro/nanodevice fabrication." Advanced Materials 24.39 (2012): 5284-5318.

Gomez, David, et al. "Scalability and yield in elastomer stamp micro-transfer-printing." *2017 IEEE 67th Electronic Components and Technology Conference (ECTC)*. IEEE, 2017.

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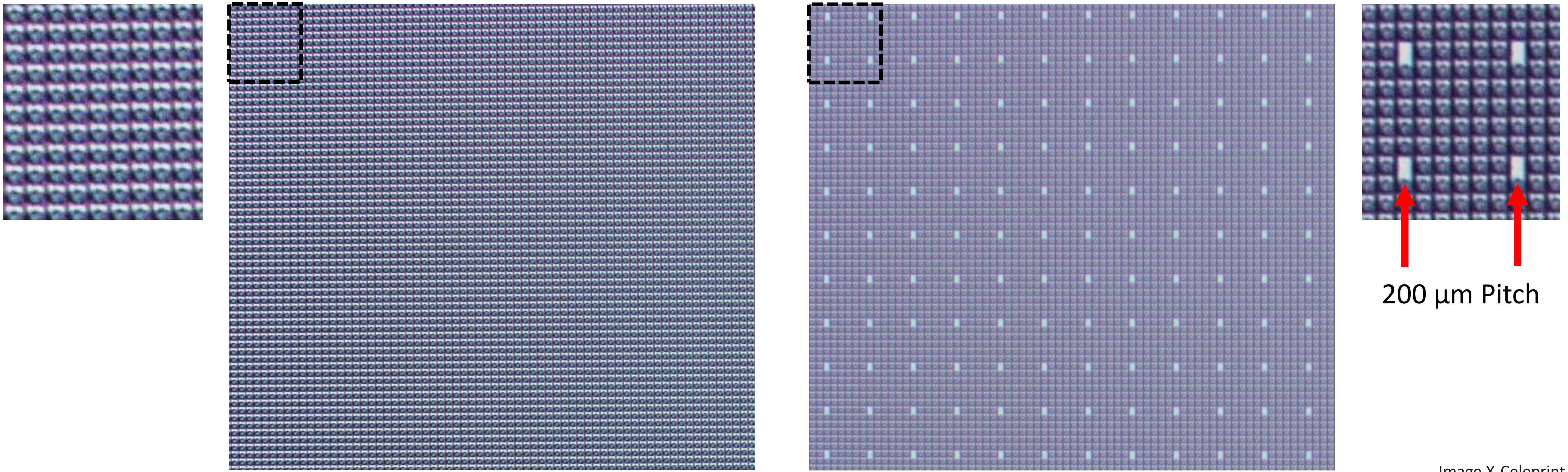
Challenges with µTP – Thermal Expansion

- To enable the printing of high-density small devices, the picking and placement accuracy needs to be within ± 1.5 µm alignment error.
- During extended printing, the temperature inside the µT Printer can increase, leading to thermal expansion of the stamp and decrease placement accuracy.
- *The stamp used for the printing array shown below will be used as the geometric model.*

High Density Array of Devices Before and After µTP



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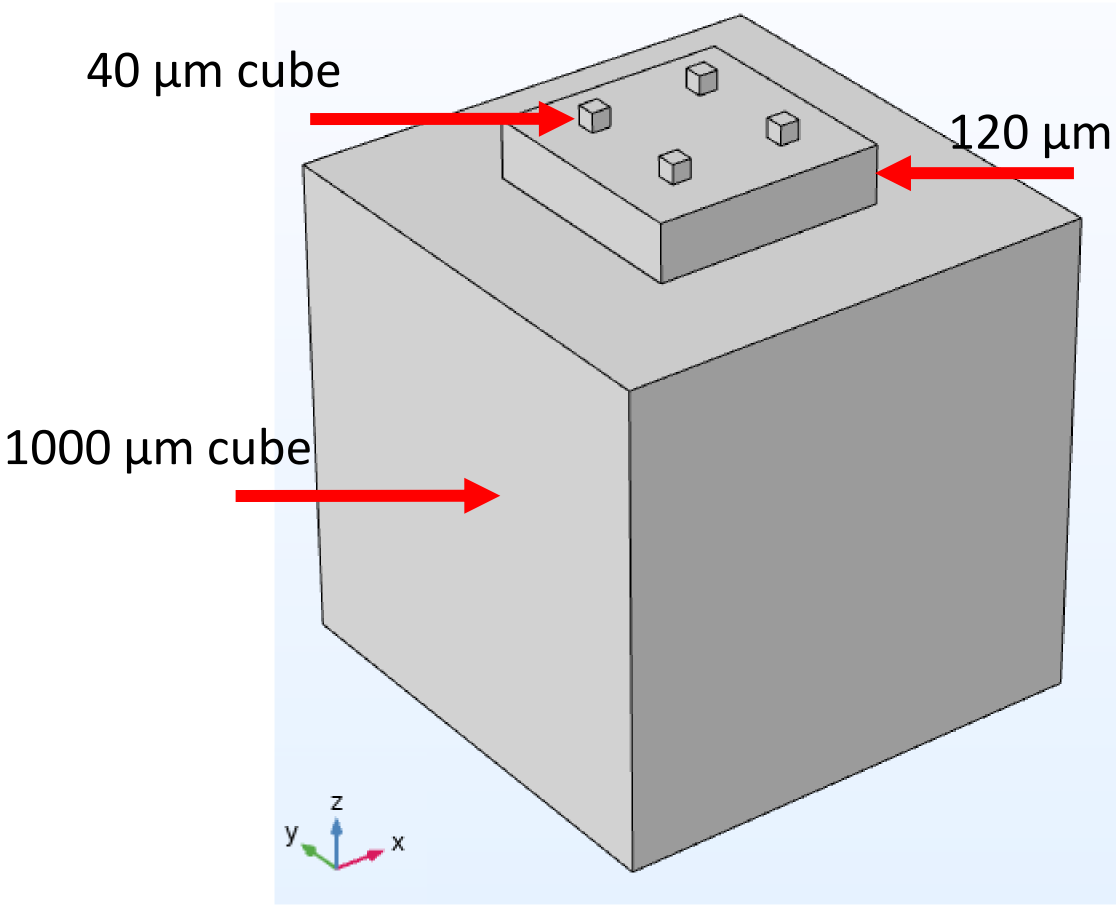
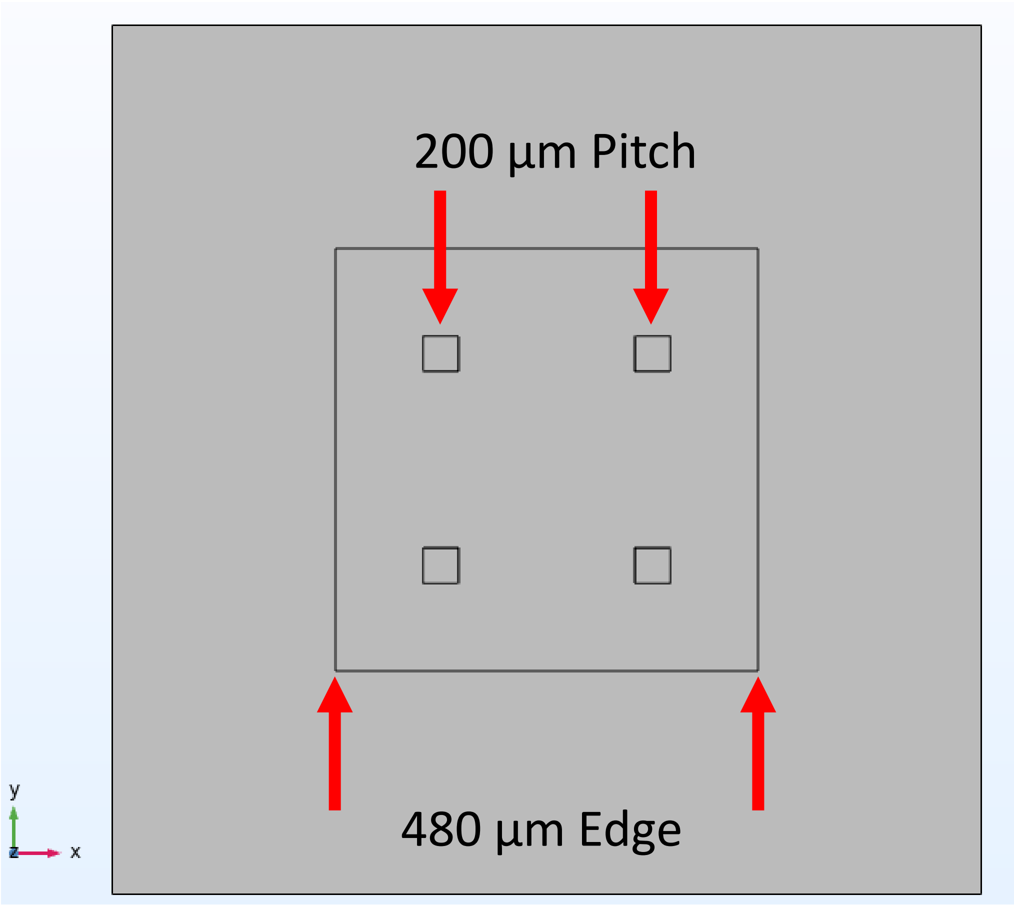
Geometry of the PDMS Stamp

- The model consists of a cubic base, rectangular prism intermediate layer and 4 micro posts.
- The material used is PDMS – Polydimethylsiloxane
- *3D model design based on stamp used in previous slide.*





PDMS Materials Properties

- The following model properties were used in the simulation, see table below.
- Values agree with literature.

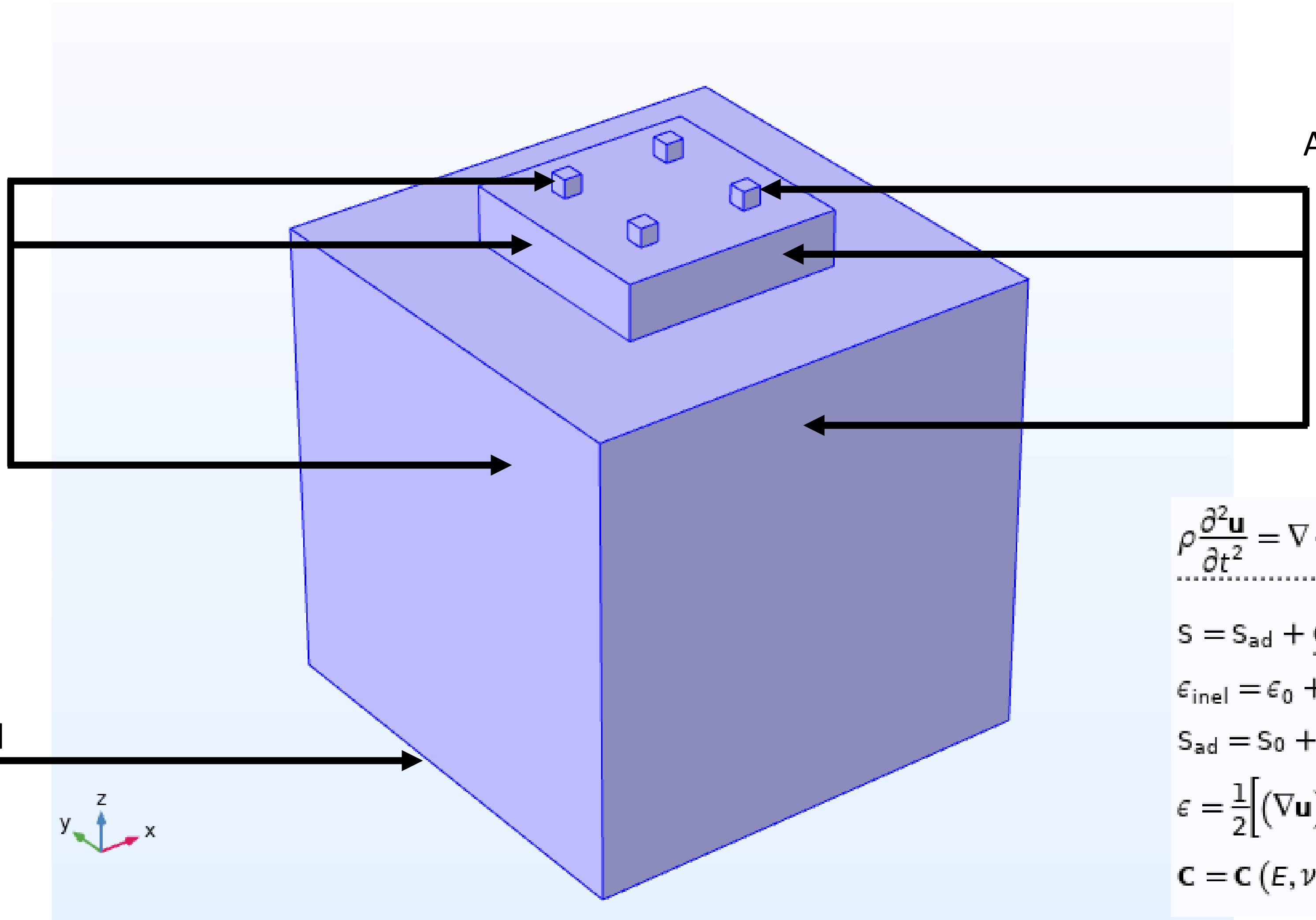
Table 1 – Material Properties

Property	Variable	Value	Unit	Property Group
Coefficient of thermal expansion	alpha_iso ; alphaii = alpha_iso, alphaij = 0	9e-4[1/K]	1/K	Basic
Heat capacity at constant pressure	Cp	1460[J/(kg*K)]	J/(kg·K)	Basic
Density	rho	970[kg/m^3]	kg/m³	Basic
Thermal conductivity	k_iso ; kii = k_iso, kij = 0	0.16[W/(m*K)]	W/(m·K)	Basic
Young's modulus	E	750[kPa]	Pa	Young's modulus and Poisson's ratio
Poisson's ratio	nu	0.49	1	Young's modulus and Poisson's ratio
Relative permittivity	epsilonr_iso ; epsilonrii = epsilonr_iso, epsilonrij = 0	2.75	1	Basic

Solid Mechanics – Boundary Conditions

All boundaries above base are ***Free***

All 3 Domains are ***Linear Elastic***



Base boundary is ***fixed*** to replicate a stamp mounted on glass

Linear Elastic Equations

$$\rho \frac{\partial^2 \mathbf{u}}{\partial t^2} = \nabla \cdot S + F_V$$

$$S = S_{ad} + \mathbf{C} : \epsilon_{el}, \quad \epsilon_{el} = \epsilon - \epsilon_{inel}$$

$$\epsilon_{inel} = \epsilon_0 + \epsilon_{ext} + \epsilon_{th} + \epsilon_{hs} + \epsilon_{pl} + \epsilon_{cr} + \epsilon_{vp}$$

$$S_{ad} = S_0 + S_{ext} + S_q$$

$$\epsilon = \frac{1}{2}\left[(\nabla \mathbf{u})^T + \nabla \mathbf{u}\right]$$

$$\mathbf{C} = \mathbf{C}(E, \nu)$$

*All initial **u** and $\delta^2\mathbf{u}/\delta t^2$ values set to ***Zero.***

Heat Transfer in Solids– Boundary Conditions

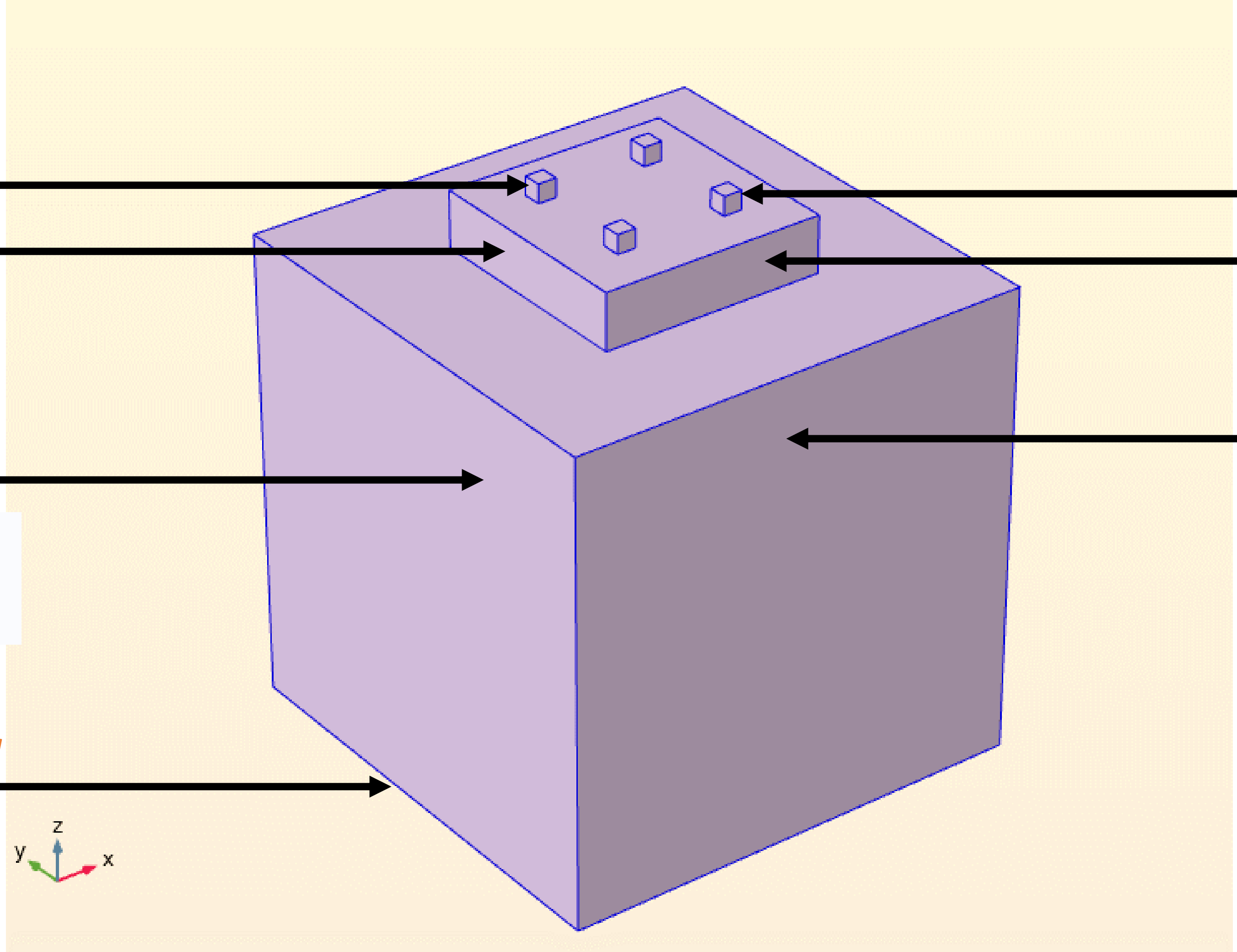
All 3 Domains are ***Solid***

Solid Heat Equations

$$\rho C_p \frac{\partial T}{\partial t} + \rho C_p \mathbf{u} \cdot \nabla T + \nabla \cdot \mathbf{q} = Q + Q_{ted}$$

$$\mathbf{q} = -k \nabla T$$

Base boundary is ***Insulating***



All boundaries above base are set to ***Convective Heat Flux***

Heat Flux Equations

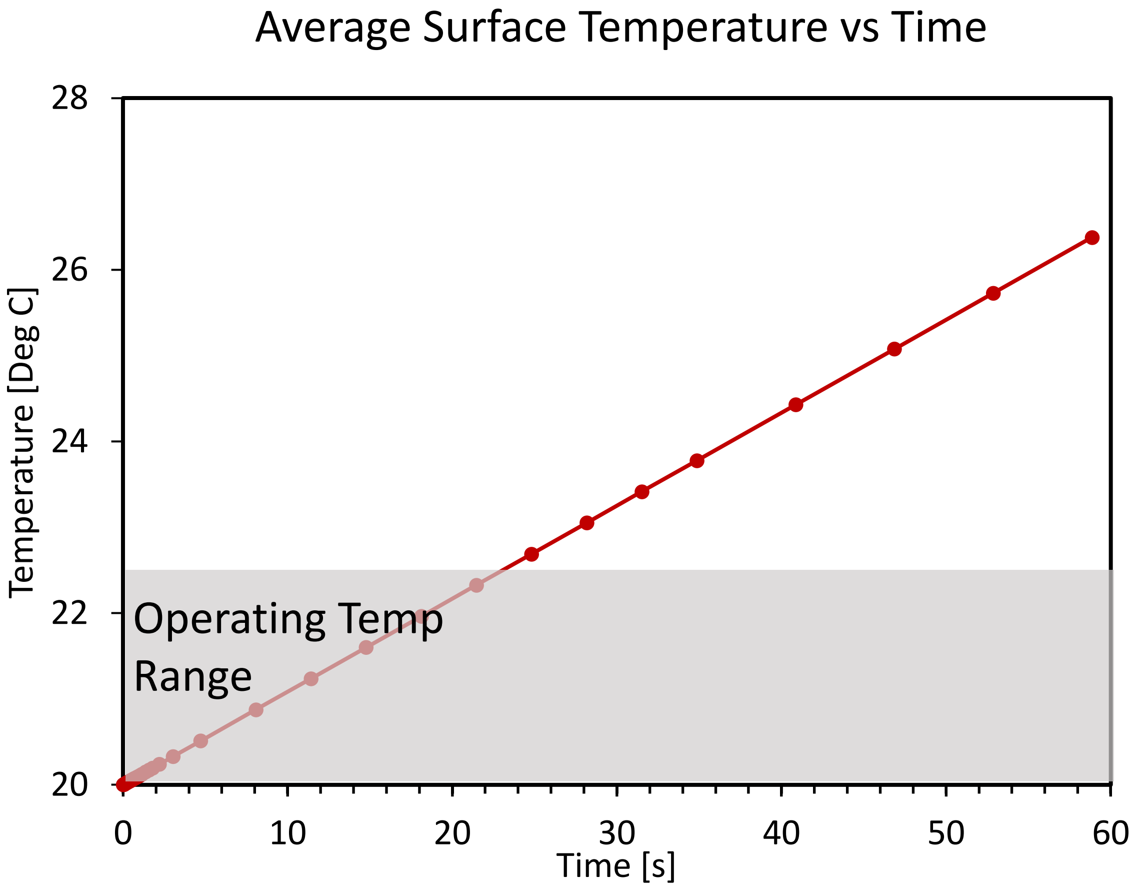
$$-\mathbf{n} \cdot \mathbf{q} = q_0$$

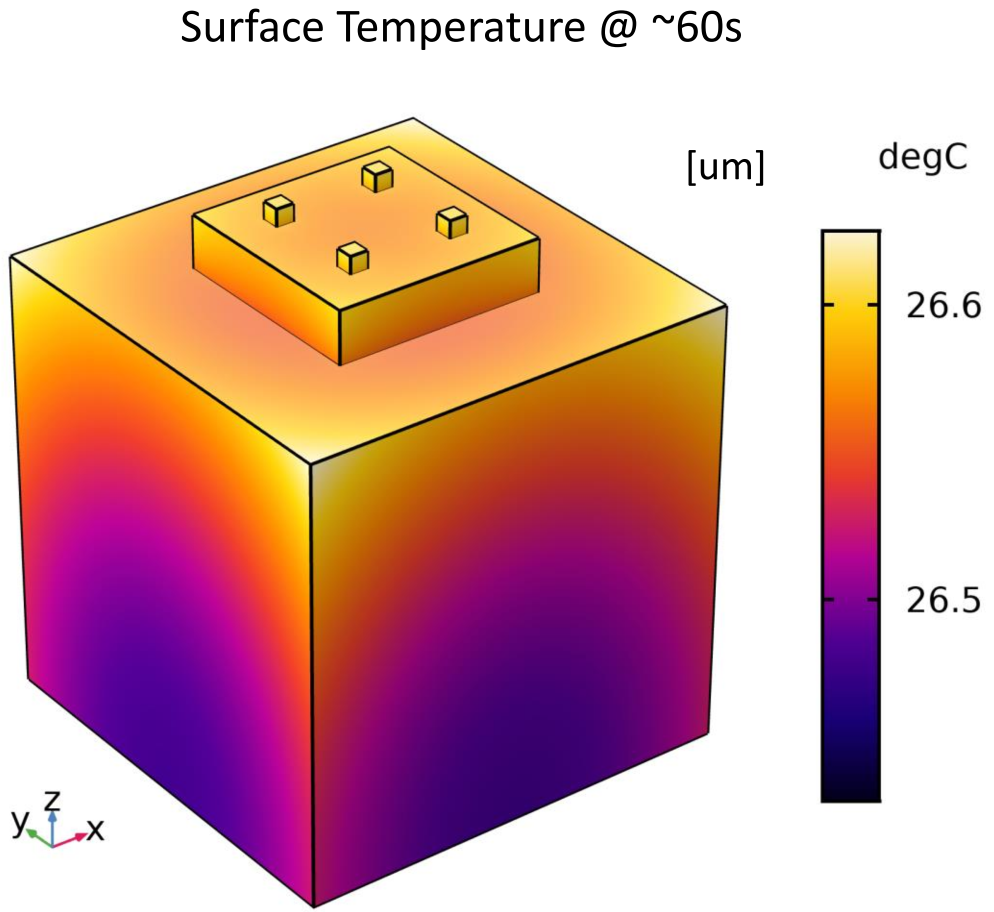
$$q_0 = h(T_{ext} - T)$$

- $T_{initial}$ = 293.15 K
- T_{ext} = 350.15 K
- h, heat transfer coefficient
  - 1 W/m^2

*All initial **u** and δ^2**u**/δt^2 values set to ***Zero.***

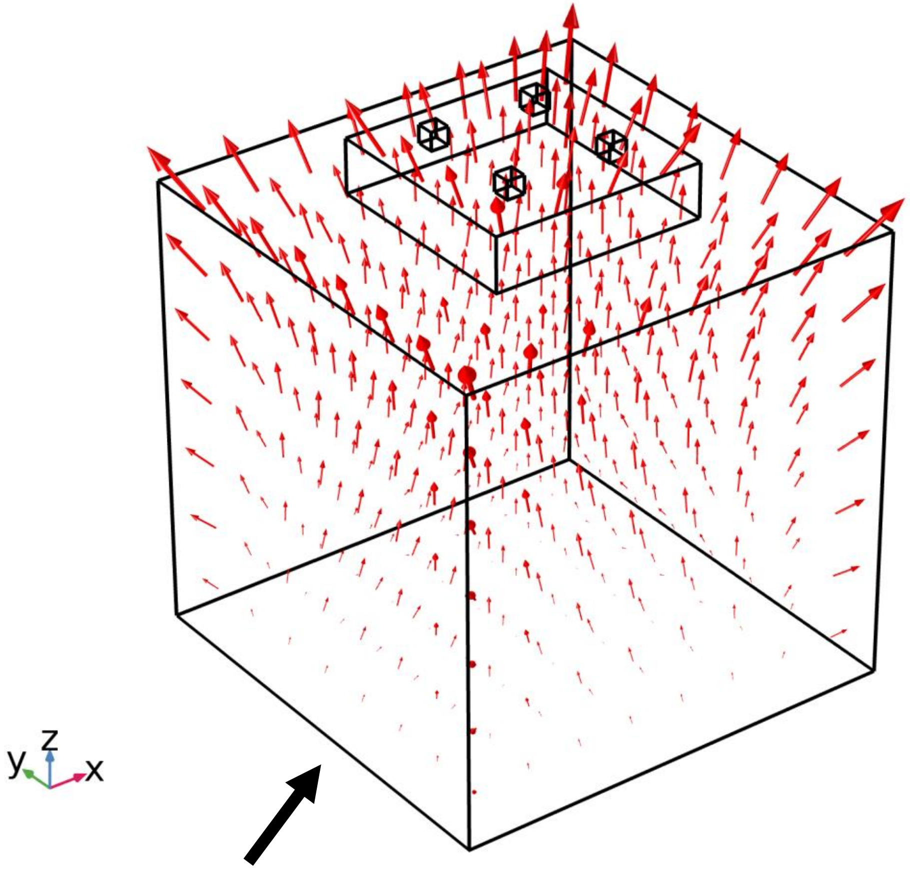
Results – Surface Temperature





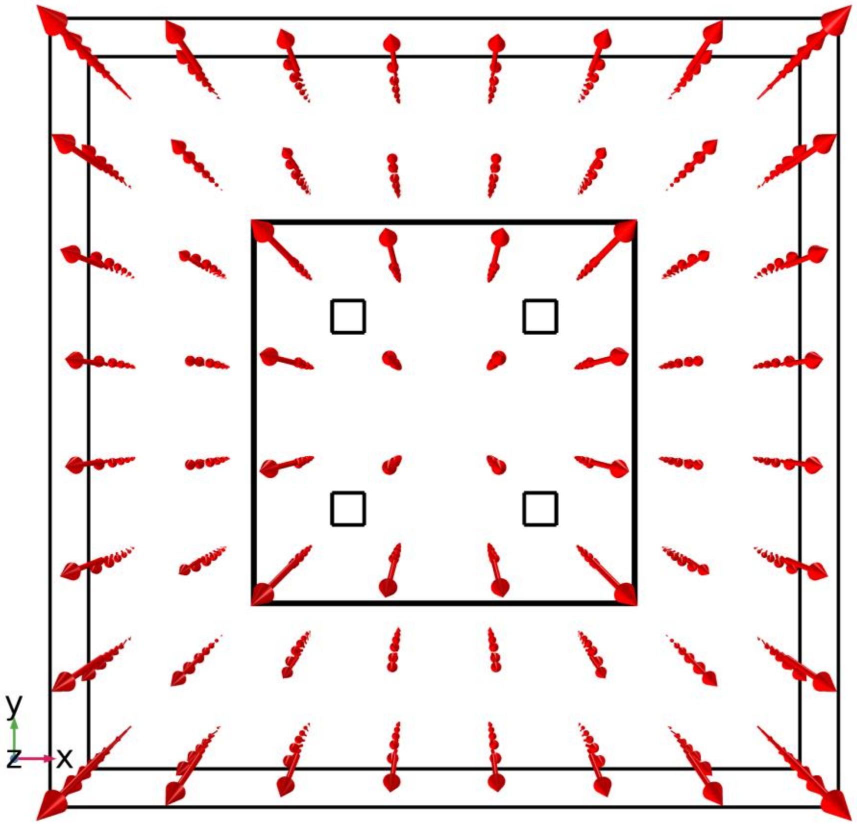
Direction of Volume Displacement

- Volume displacement vector arrows are plotted in an 8 x 8 array and are proportional to the displacement field.
- Displayed arrow is at the end of the simulation ~60 s.



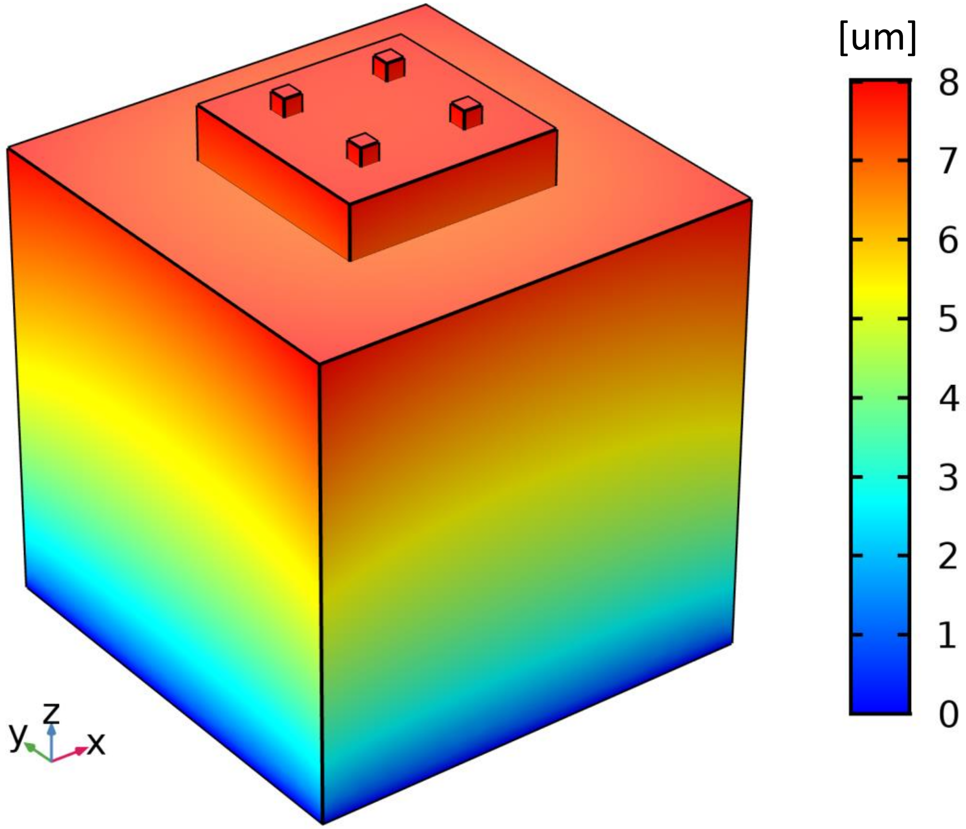
Movement lower at base because of fixed constraint

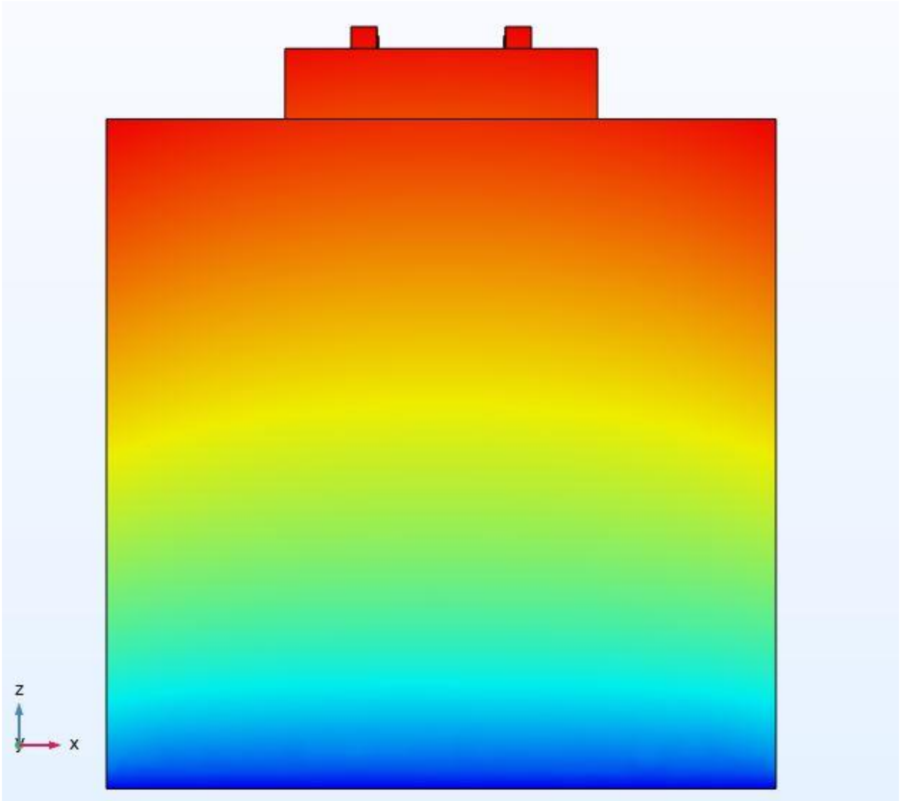
Expansion movement is outward from center and is larger at corners of the base and intermediate layers.



Total Average Displacment

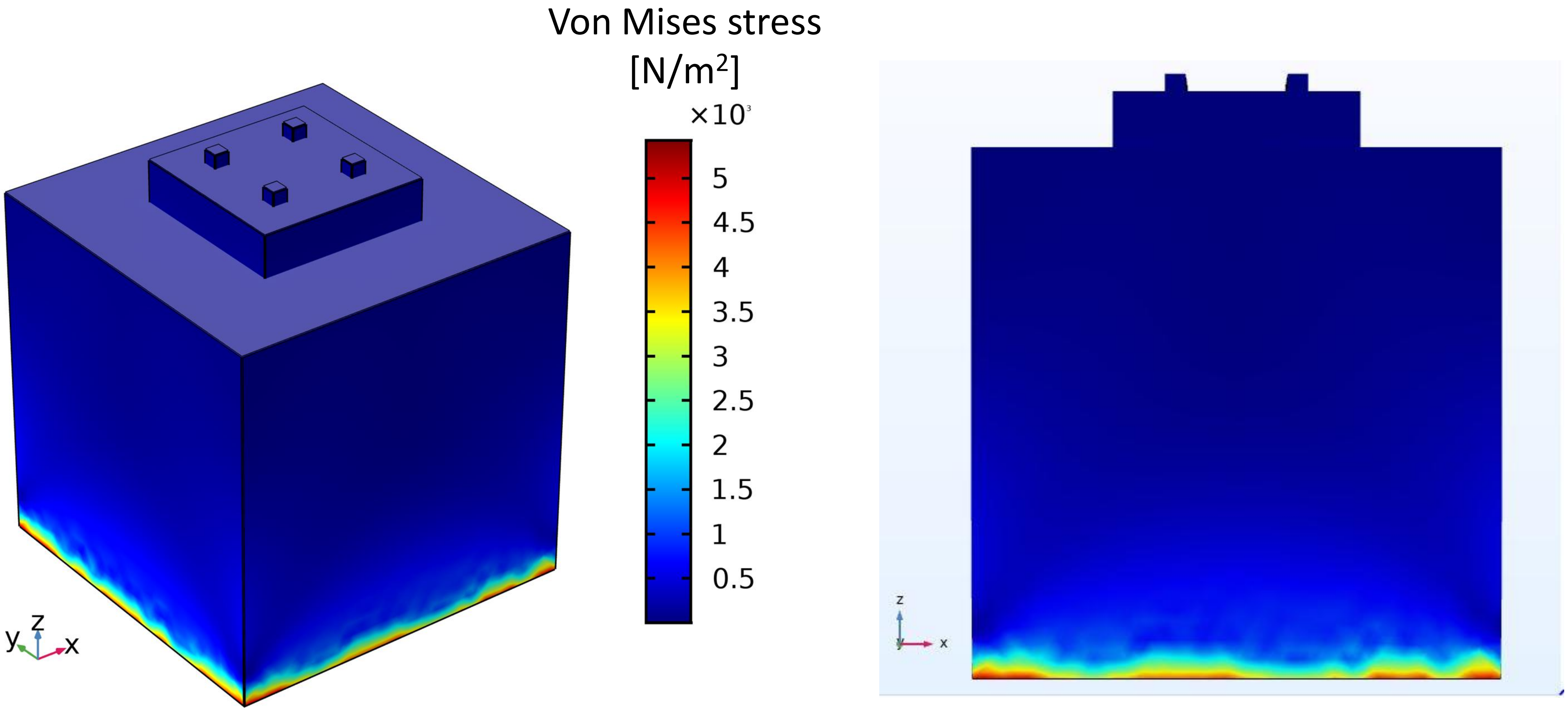
Plotted is the total volume displacement at the end of the simulation. The fixed constraint minimizes the bottom movement, while the upper portion of the stamp moves upwards and outwards as seen in the volume arrow directions.





Von Mises Stress

Plotted are the Von Mises Stresses at the end of the simulation. They are concentrated at the base were the fixed condition is imposed and diminish rapidly towards the top of the elastomer stamp.



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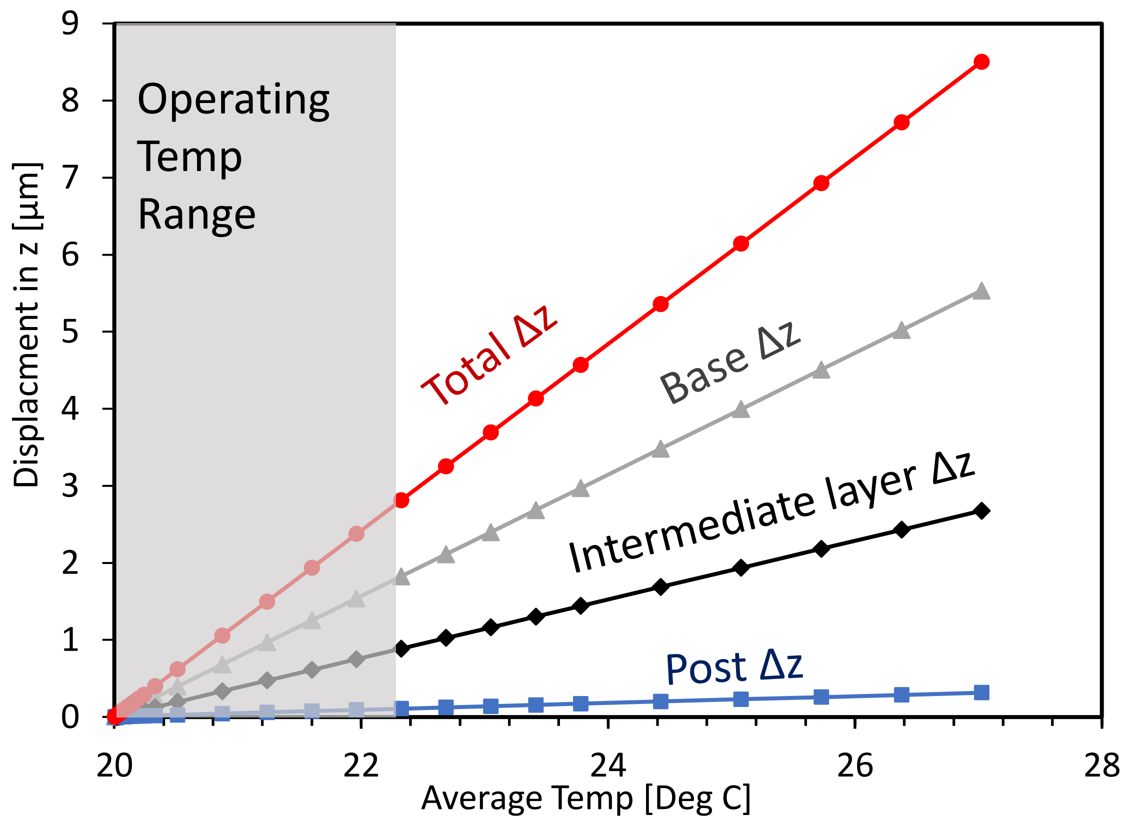
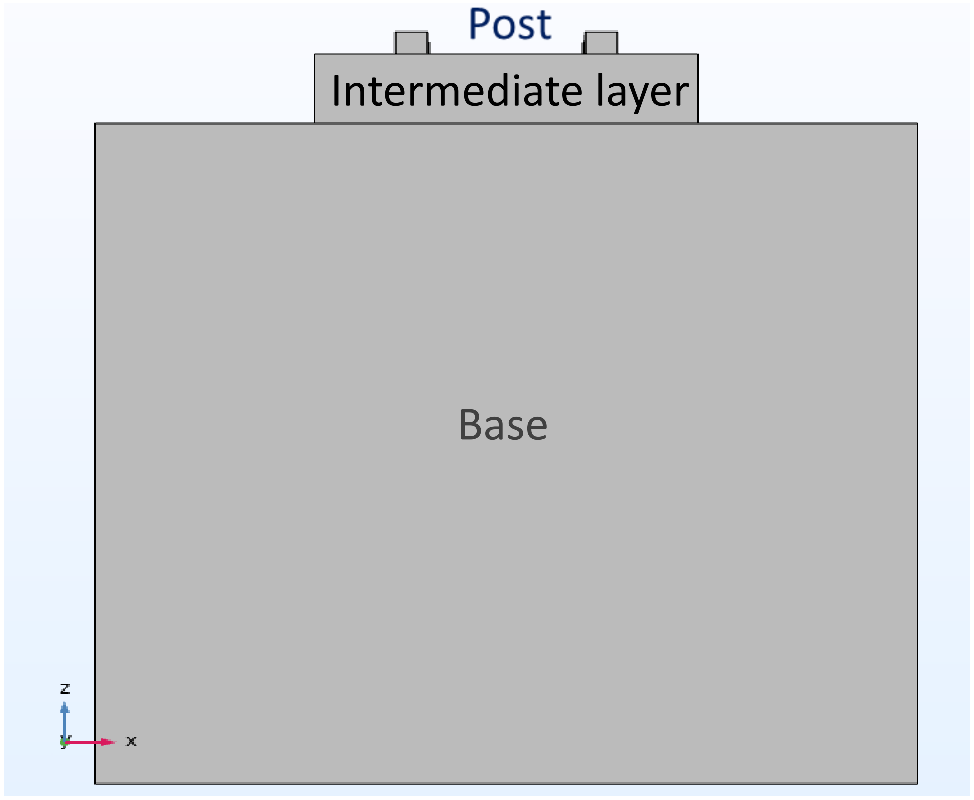
Results – Vertical Displacement

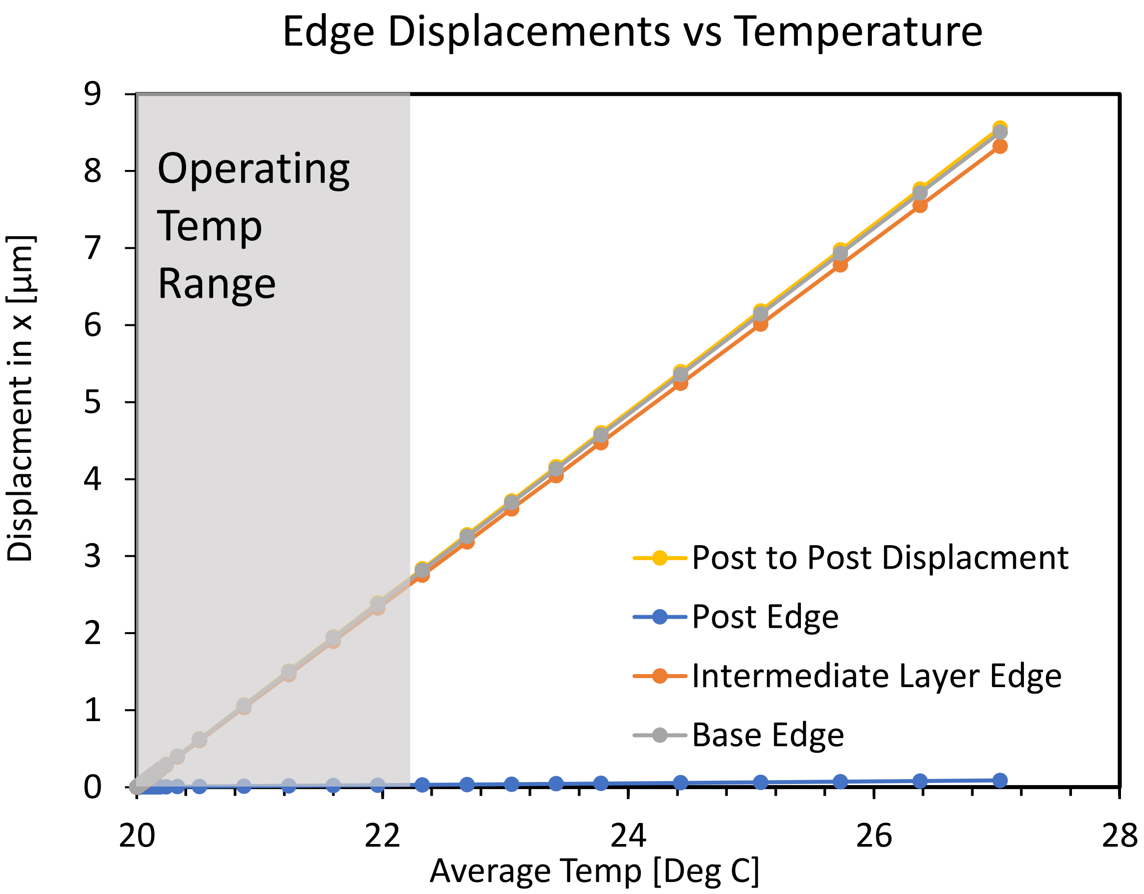
Height Displacements vs Temperature

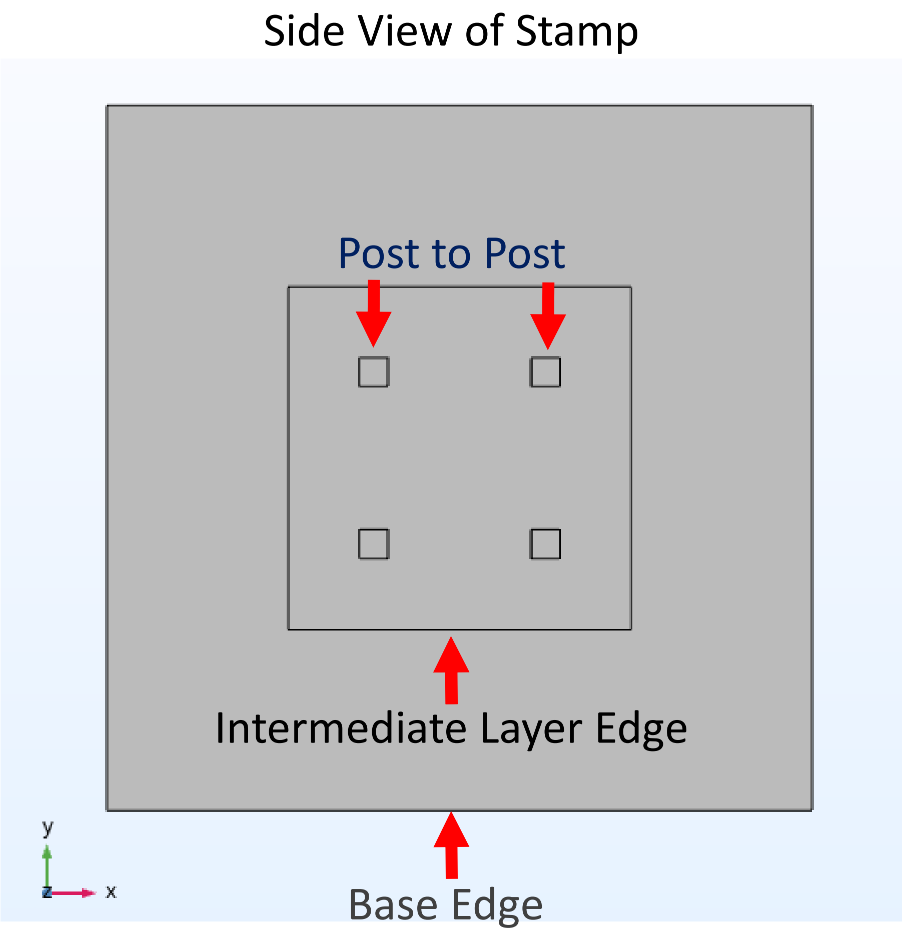


Side View of Stamp



Results – Lateral Displacement





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Conclusions Future Work

- Near room temperature (<20.5C), thermal expansion is below 1.5 µm and is within the current placement alignment error.
- Above 20.5C to 22.2 C, the thermal expansion increases to 2.95 µm, significant enough to cause unwanted variations in chiplet print placement.
- Above 22.2C, the thermal expansion increases significantly and would be detrimental to large array printing.
- Although the variation of the internal temperature of the micro transfer printer is small, accurate temperature measurements and control must be made to ensure consistent printing over extended periods..
- These results need to be validated experimentally to compare the actual thermal expansion at each temperature point used in this study.
- Additives in the stamp and geometric designs may assist in heat dissipation, extending the working window of the PDMS stamp.

Thank You

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