Carnegie Mellon University

IMG workshop – COMSOL

Joule heating actuator (V 5.4)

Camilo Velez

April 23th, 2020

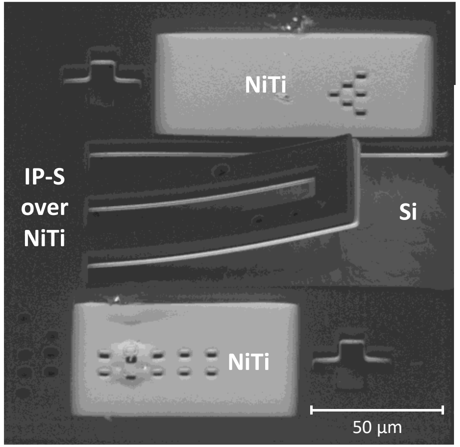
Mechanical Engineering
Carnegie Mellon

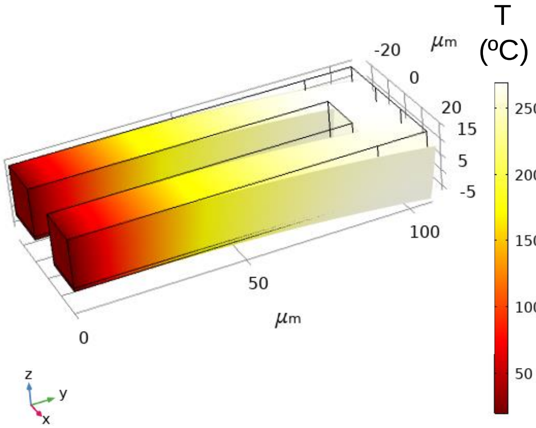
IMG workshop – COMSOL

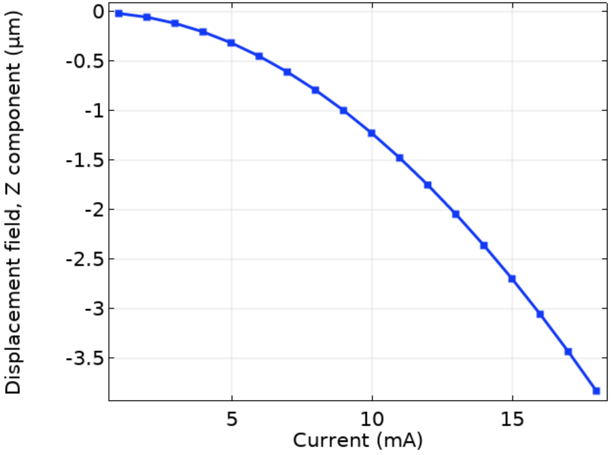
Joule heating actuator

A beginner – intermediate level workshop covering the model of a Joule heating unimorph actuator using COMSOL Multiphysics. It will combine solid mechanics, heat transfer in solids, and electric currents

Presenter: Camilo Velez
Time: Today (April 23th 2020) 4:00 - 5:00 pm
Zoom link: https://ufl.zoom.us/j/92195840607







Goals

Level: Beginner - intermediate

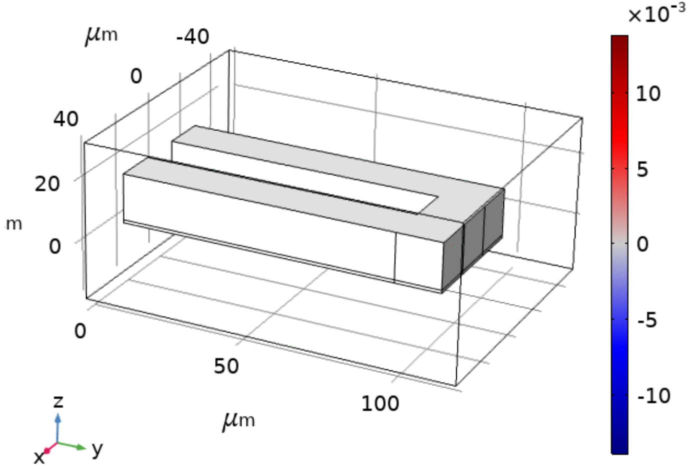
To model a Joule heating unimorph actuator using COMSOL Multiphysics

Content:

- Geometry and materials definition

Physics
- Electric currents
- Heat transfer in solids
- Solid Mechanics
- Multiphysics

Studies
- Mesh definition
- Stationary study
- Parametric sweep study
- Time dependent study



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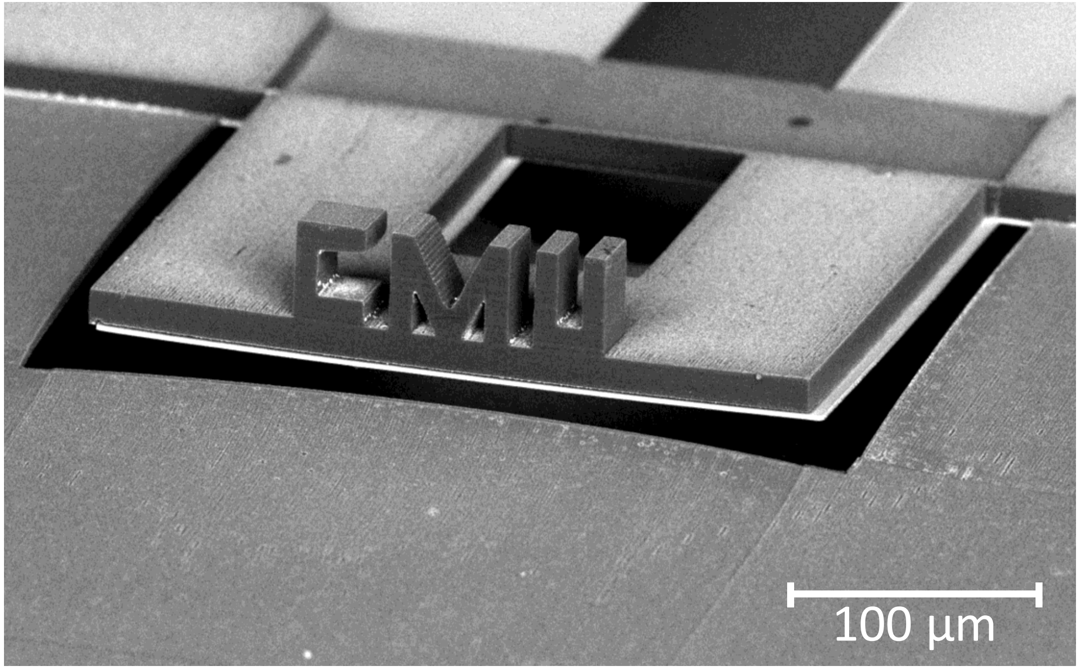
Unimorph actuator

A cantilever that consists of one active layer (metal, piezoelectric, shape memory alloy, etc.) and one passive layer (polymer, oxide)



Thanks to
Dr. Mahnoush Babaei
for the model

C. Velez et al., 2020 IEEE 33rd MEMS Conference. 2020, pp. 893-896,

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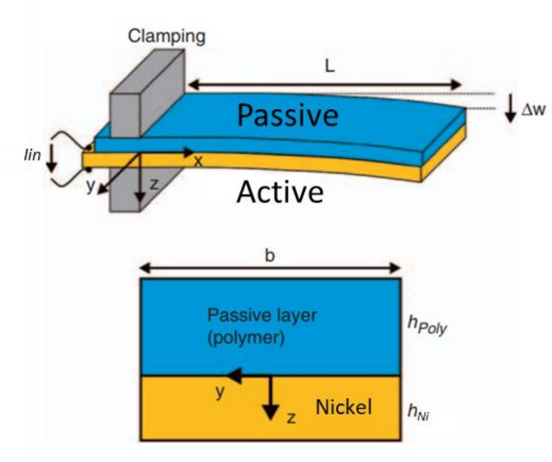
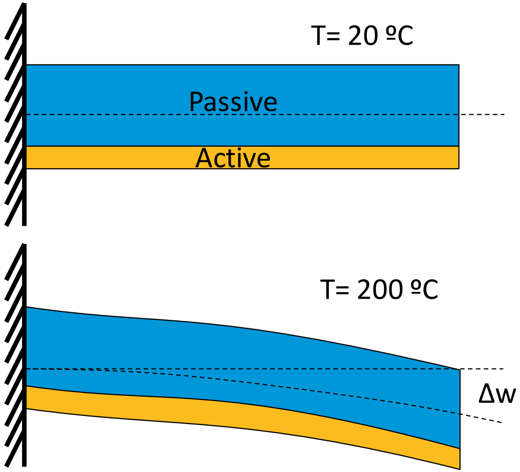
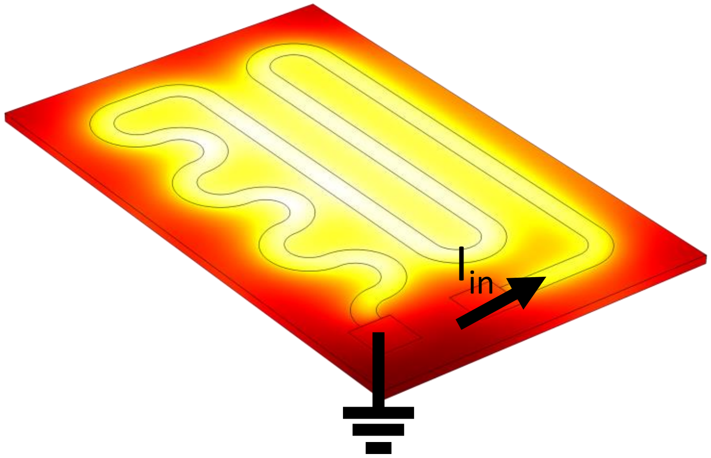


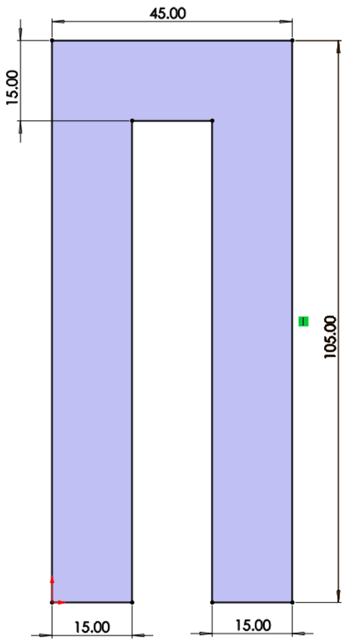


Joule heating mechanism

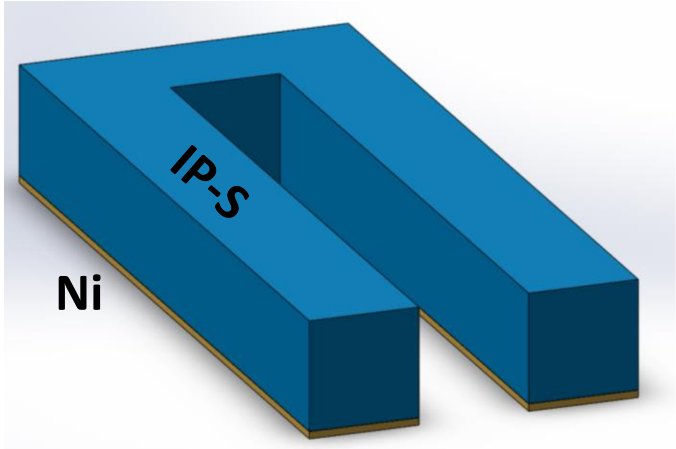


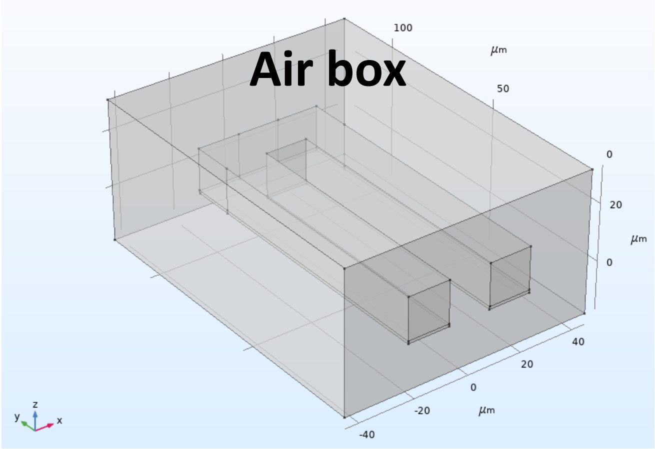
Geometry and materials definition

Top view
(µm)



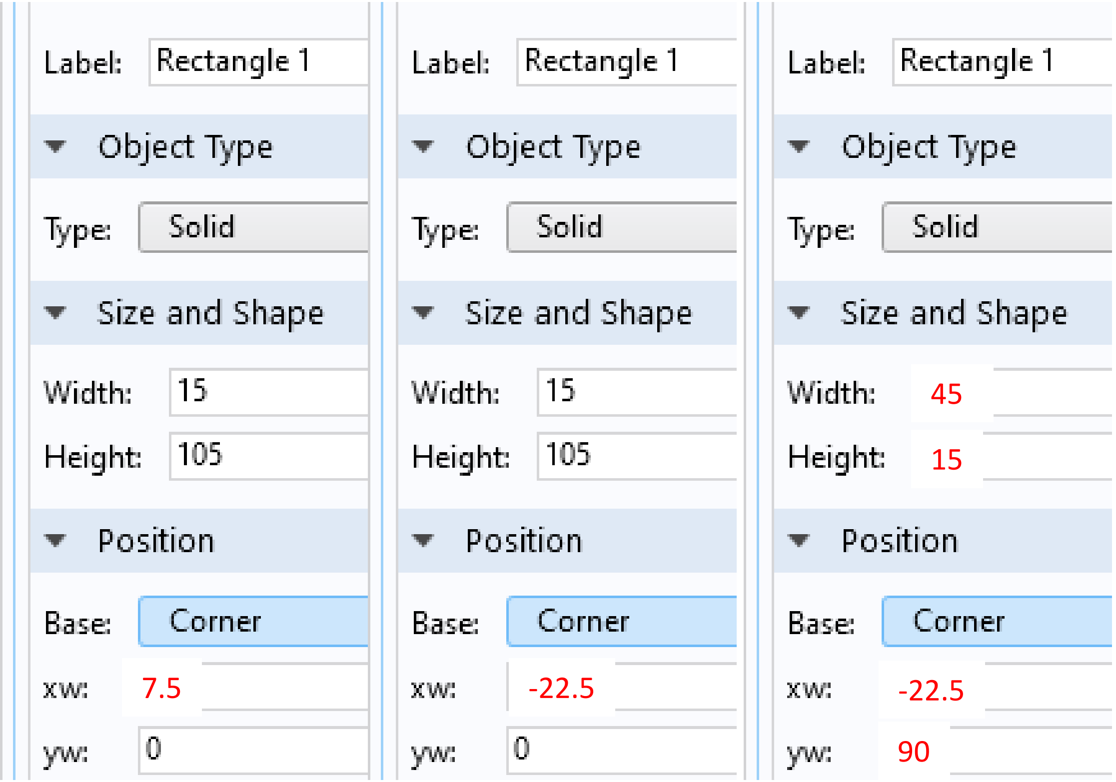
3 D version of the geometry



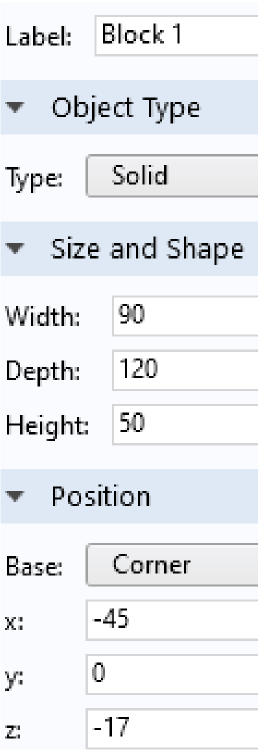


Geometry and materials definition

Active and Passive layer



Air



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Materials

Passive: Polymer / IP-S

Property	Variable	Value	Unit
Thermal conductivity	k_iso ; kii = k_iso, kij = 0	0.3	W/(m·K)
Density	rho	1111	kg/m^3
Heat capacity at constant pressure	Cp	1500	J/(kg·K)
Coefficient of thermal expansion	alpha_iso ; alphaii = alpha_iso, alphaij = 0	52e-6	1/K
Young's modulus	E	4.0e9	Pa
Poisson's ratio	nu	0.3	1

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Materials

Active: Metal / Ni

Property	Variable	Value	Unit
Young's modulus	E	106.01e9[Pa]	Pa
Poisson's ratio	nu	0.33	1
Density	rho	6500[kg/m^3]	kg/m³
Thermal conductivity	k_iso ; kii = k_iso, kij = 0	8.6	W/(m·K)
Heat capacity at constant pressure	Cp	3700	J/(kg·K)
Electrical conductivity	sigma_iso ; sigmaii = sigma_iso, sigmaij...	1.32e6[S/m]	S/m
Relative permittivity	epsilonr_iso ; epsilonrii = epsilonr_iso, ep...	1	1
Coefficient of thermal expansion	alpha_iso ; alphaii = alpha_iso, alphaij = 0	7.6e-6[1/K]	1/K

Materials

Air

Property	Variable	Value	Unit
Coefficient of thermal expansion	alpha_iso ; alphaii = alpha_iso, al...	alpha_p(pA,T)	1/K
Mean molar mass	Mn	0.02897	kg/mol
Bulk viscosity	muB	muB(T)	Pa·s
Dynamic viscosity	mu	eta(T)	Pa·s
Ratio of specific heats	gamma	1.4	1
Electrical conductivity	sigma_iso ; sigmaii = sigma_iso,...	0[S/m]	S/m
Heat capacity at constant pressure	Cp	Cp(T)	J/(kg·K)
Density	rho	rho(pA,T)	kg/m^3
Thermal conductivity	k_iso ; kii = k_iso, kij = 0	k(T)	W/(m·K)
Speed of sound	c	cs(T)	m/s
Parameter of nonlinearity	BA	(def.gamma+1)/2	1

Electric currents – AC/DC

It is used to compute electric field, current, and potential distributions in conducting media. It solves a current conservation equation based on Ohm's law using the scalar electric potential as the dependent variable.

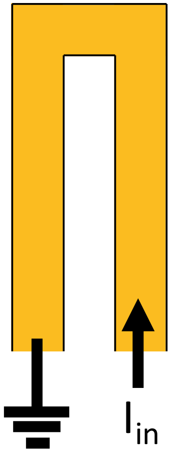
$$\nabla \cdot \mathbf{J} = Q_{j,v}$$

$$\mathbf{J} = \sigma \mathbf{E} + \mathbf{J}_e$$

$$\mathbf{E} = -\nabla V$$

- **J** current density
- **E** electric field
- V electric potential

Unimorph top view (Only conductor)



Boundary Conditions:

- Ground
- Terminal (Current)

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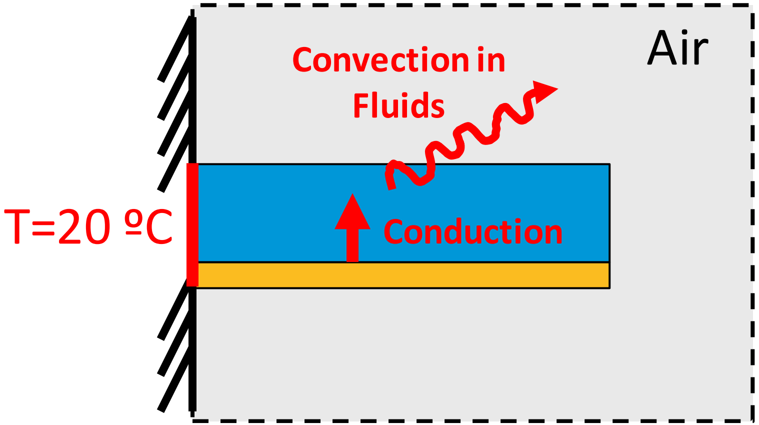
Heat transfer in solids

The temperature equation defined in solid domains corresponds to the differential form of the Fourier's law

Unimorph cross section



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

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

- **q** local heat flux density
- ∇T temperature gradient
- k material's conductivity

Boundary Conditions:

- Room temperature
- Convection in Fluids

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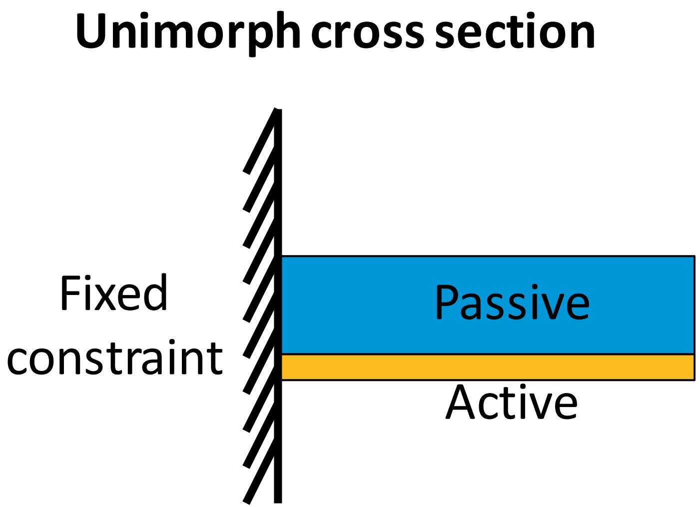
Solid Mechanics – Structural Mechanics

It is intended for general structural analysis of 3D, 2D, or axisymmetric bodies. It is based on solving the equations of motion together with a constitutive model for a solid material. Results such as displacements, stresses, and strains are computed.



Boundary Conditions:

- Fixed constraint

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Let’s move to COMSOL

Model available at:
https://camilovelez.site123.me/comsol-simulations/joule-heating-actuator

cvelezcu@andrew.cmu.edu

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