COMSOL CONFERENCE 2015 PUNE

COMSOL Conference 2015

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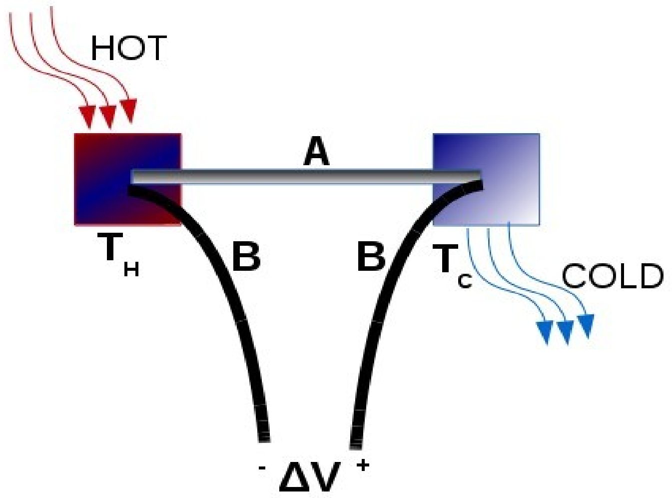
Introduction

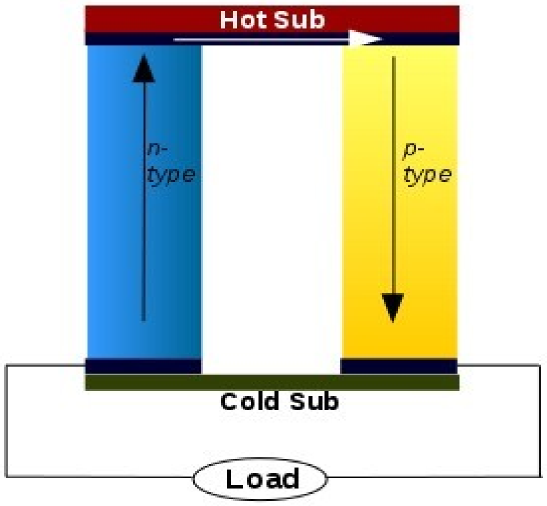
- Energy Harvesting
- Thermoelectricity



Three Effects-

1.) Seebeck Effect

Open circuit voltage (*Averaging Seebeck coefficient*)



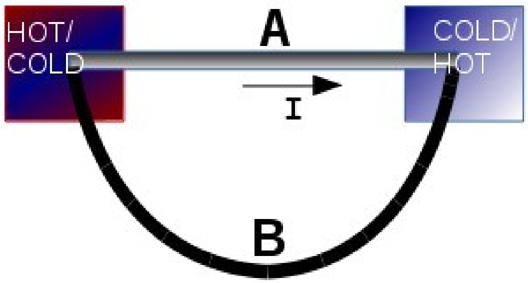
$$V_{OC}=\int_{T_C}^{T_H}\alpha(T)\,dT$$

$$\alpha=\alpha_p-\alpha_n$$

Introduction

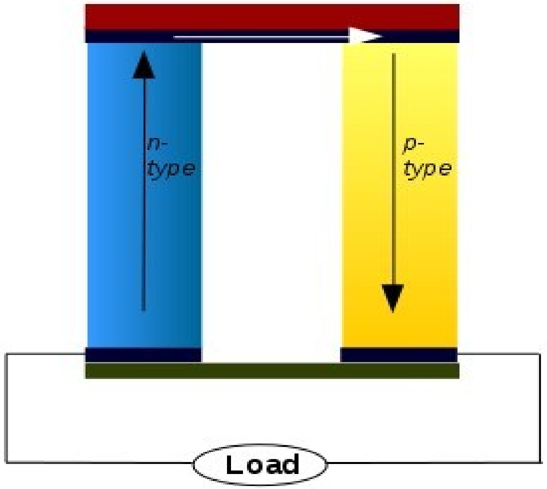
2.) Peltier Effect

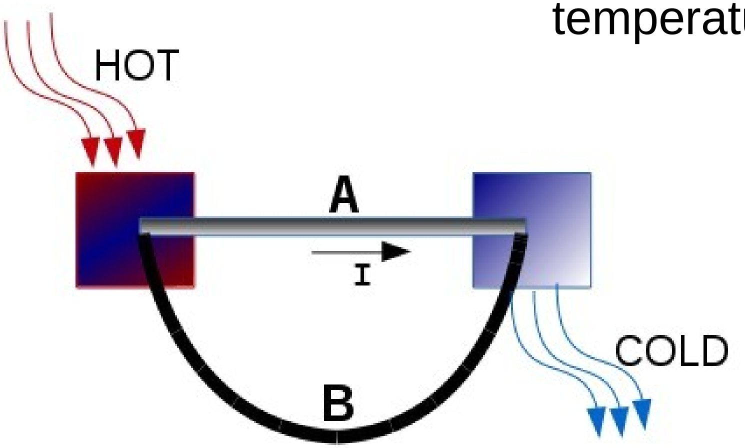
$$Q = \alpha_{total} T_{H/C} I$$



3.) Thomson Effect

Heat is proportional to electric current and temperature difference.

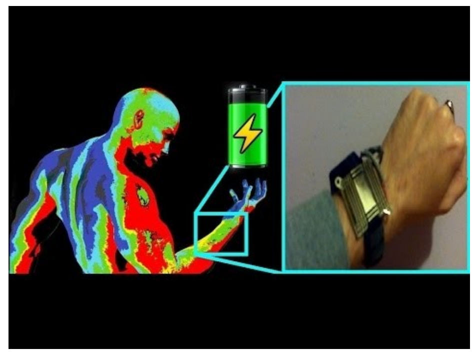


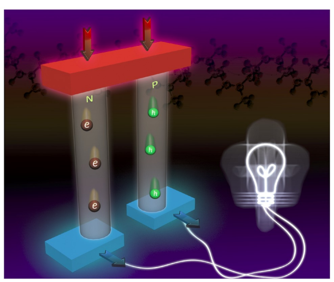


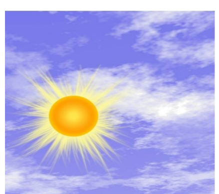
small enough to be neglected

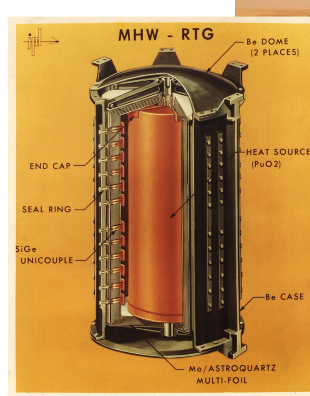
Introduction

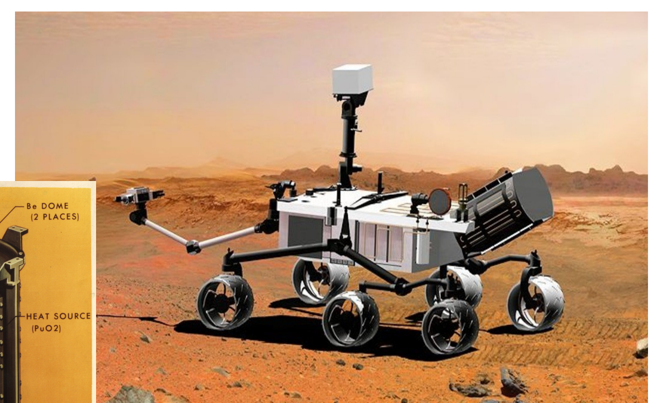
- Applications

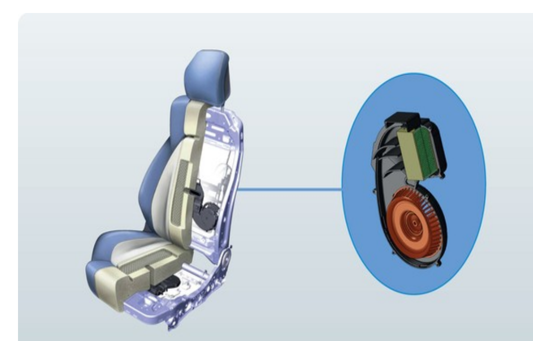












Governing Equation

Used in COMSOL

$$\rho C_P \frac{\partial T}{\partial t} + \nabla \left(-\kappa \nabla T + \alpha T J \right) = Q$$

Steady state (including Joule heating)

$$\frac{T_H - T_C}{R_T} - \frac{I^2 R_E}{2} + \alpha I T_H = Q_H$$

$$\frac{T_H - T_C}{R_T} + \frac{I^2 R_E}{2} + \alpha I T_C = Q_C$$

Conduction heat flow

A *thermoelectric* effect node also adds :

$$J = -\sigma \left(\nabla V + \alpha \nabla T \right)$$

Governing Equation

Terminal Voltage

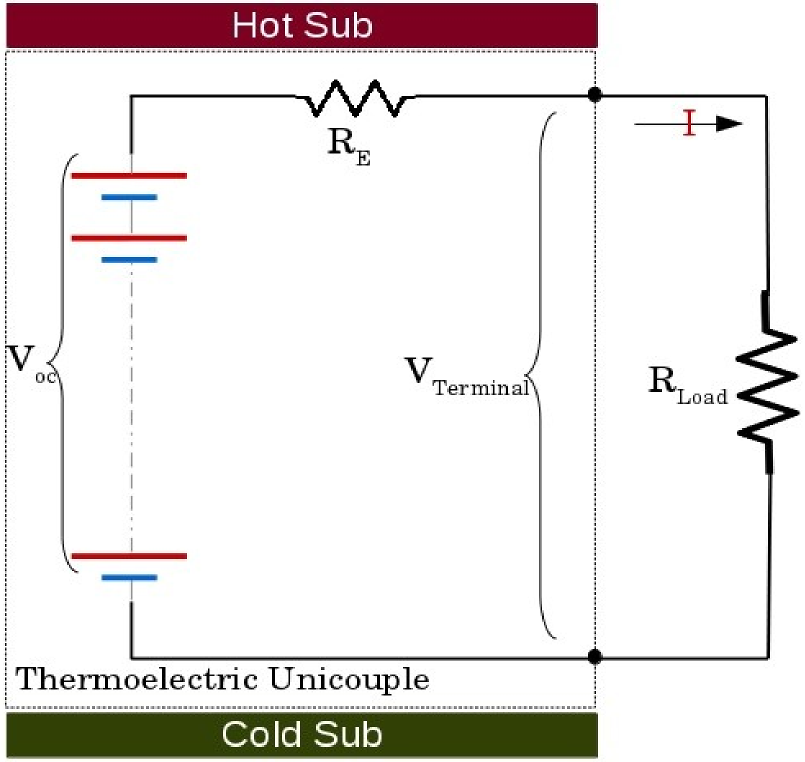
$$P = Q_H - Q_C = IV$$

$$= V_{OC} I - I^2 R_E$$

Emf generated due to Seebeck effect

Loss due to Joule heating

$$\Rightarrow V_{Terminal} = V_{OC} - IR_E$$

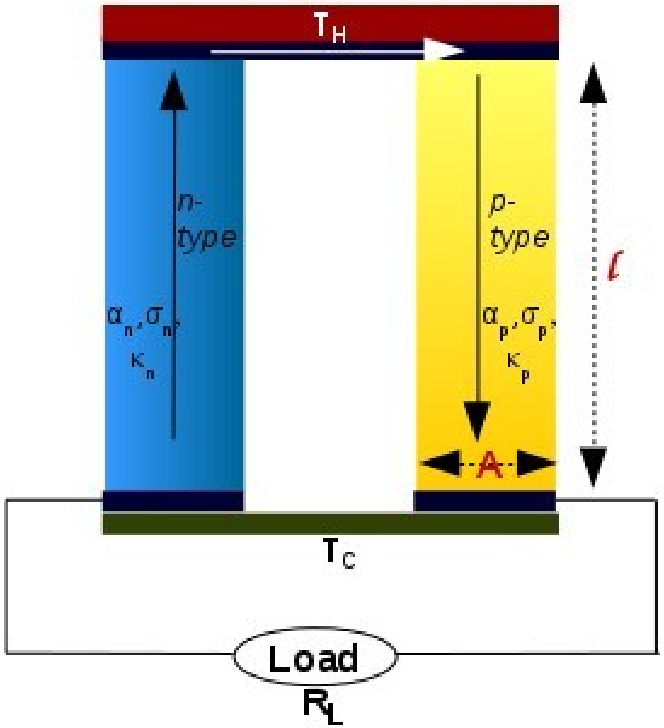


Governing Equation

- Geometry factor

$$R_E = R_{E,p} + R_{E,n} = \frac{l}{\sigma_p A} + \frac{l}{\sigma_n A}$$

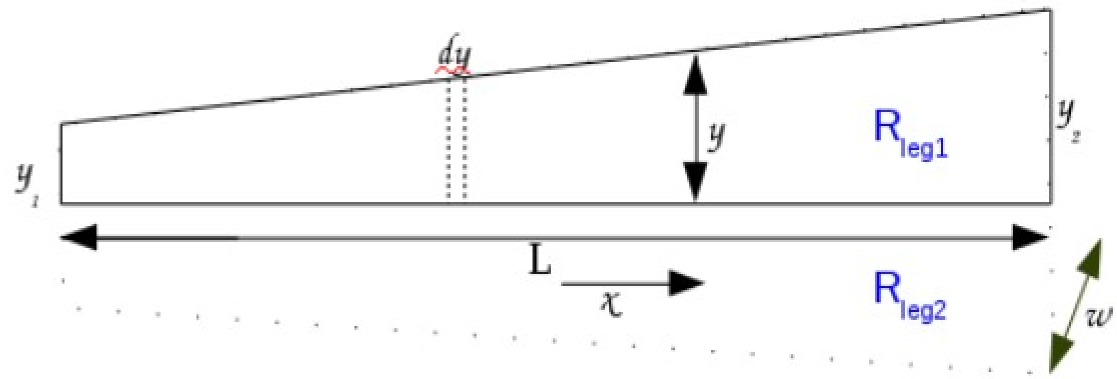
$$R_T = R_{T,p} \| R_{T,n} = \frac{l}{\kappa_p A + \kappa_n A}$$



When structure varying along the length

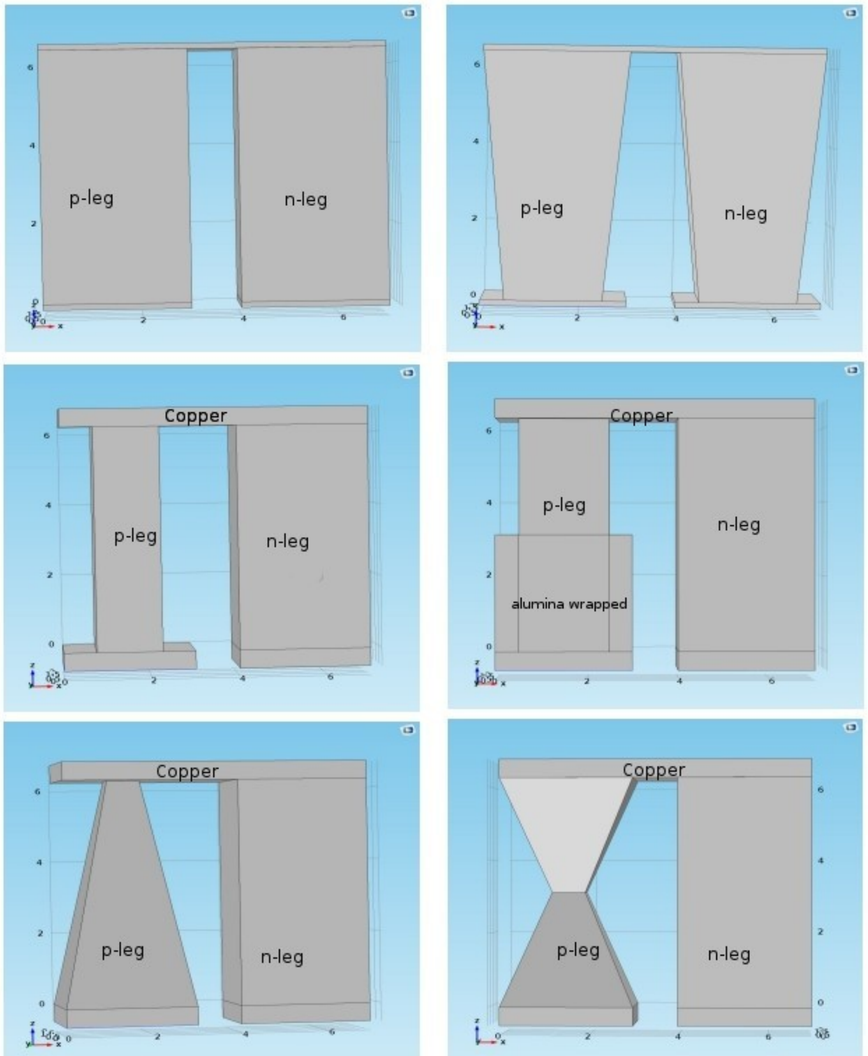
$$R_E = \int dR = \frac{1}{\sigma} \int \frac{dx}{wy}$$

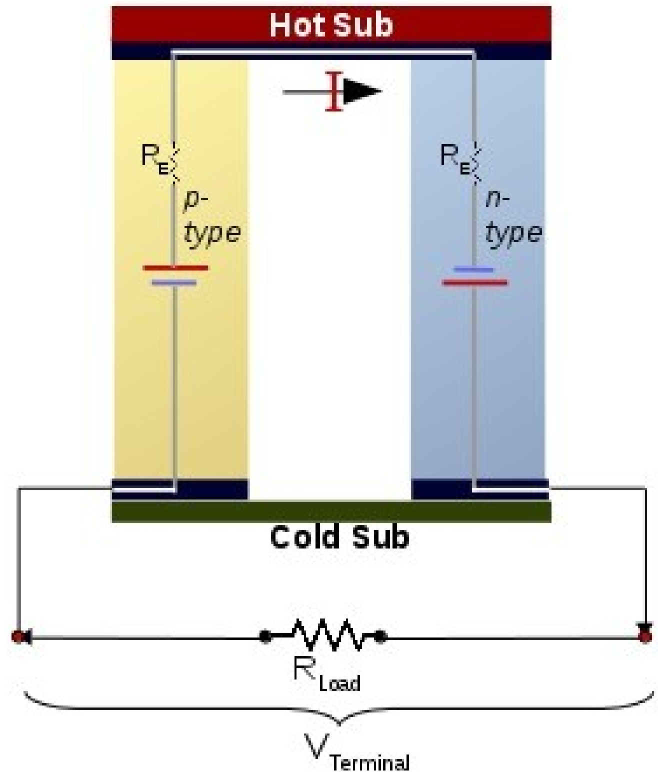
$$K_T = \int dK = \kappa_{avg} \int \frac{wy}{dx}$$



Thermoelectric Unicouple

- Different shape & size of unicouple for simulation



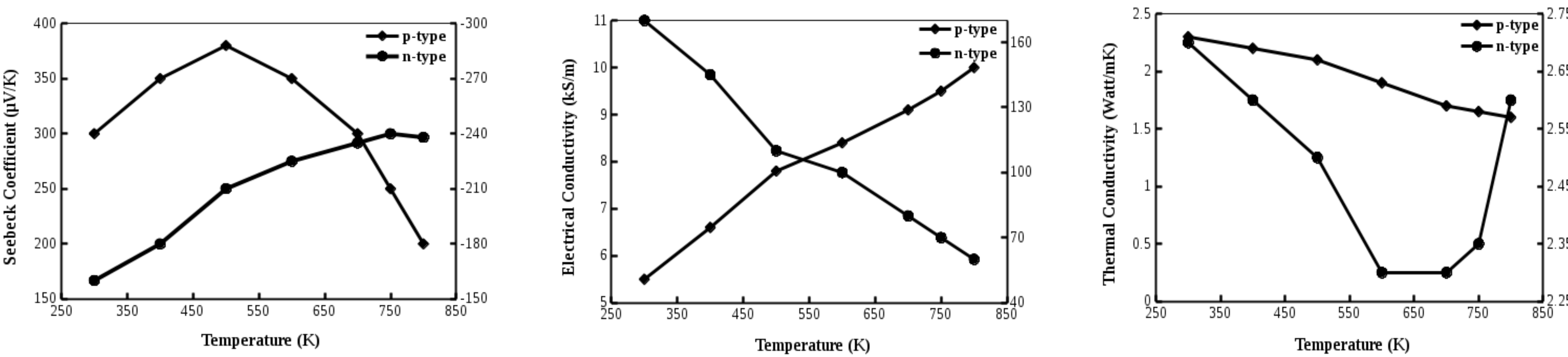


Dimension:- 6.22 x 2.98 x 2.215 mm^3

Tapering factor:- 0.25 & 0.5

Thermoelectric Unicouple

- Temperature dependent material properties for Mg2Si
  - High Seebeck coefficient measured in Ga-doped samples
  - Electrical conductivity slowly increases in the whole temperature range
  - Operate under large temperature ranges (250-850 K)
  - Electronic thermal conductivity is much lower than the lattice



- H. Ihou-Mouko et. al., Thermoelectric Properties and Electronic Structure of p-type Mg2Si and Mg2Si0.6Ge0.4 Compounds Doped with Ga, Journal of Alloys and Compounds, 509 (2011) 6503–6508.
- W. Liu et. al., Convergence of Conduction Bands as a Means of Enhancing Thermoelectric Performance of n-Type Mg2Si1-xSnx Solid Solutions, Physical Review Letters, 108 (2012) 166601.

Simulation in COMSOL

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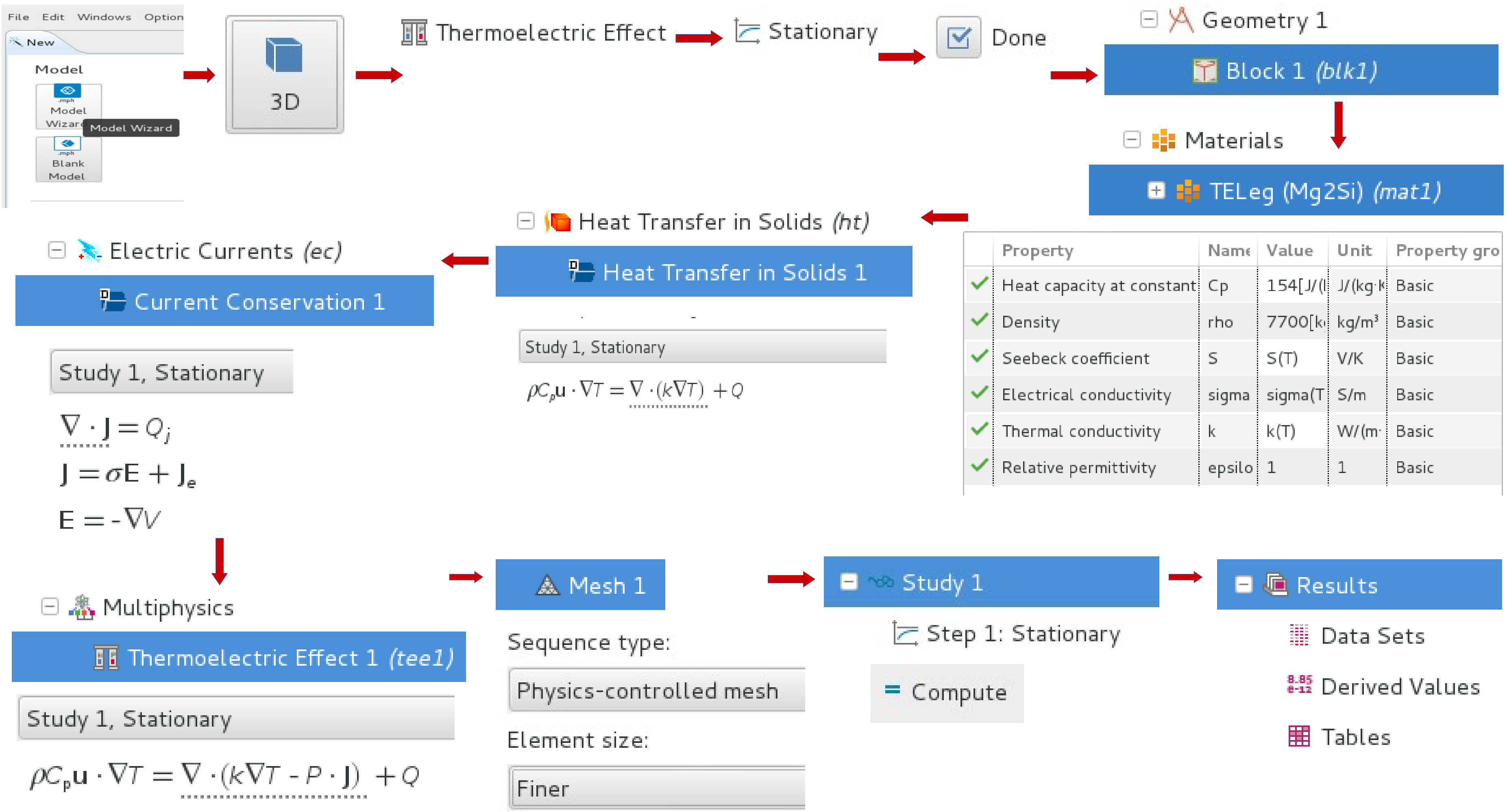
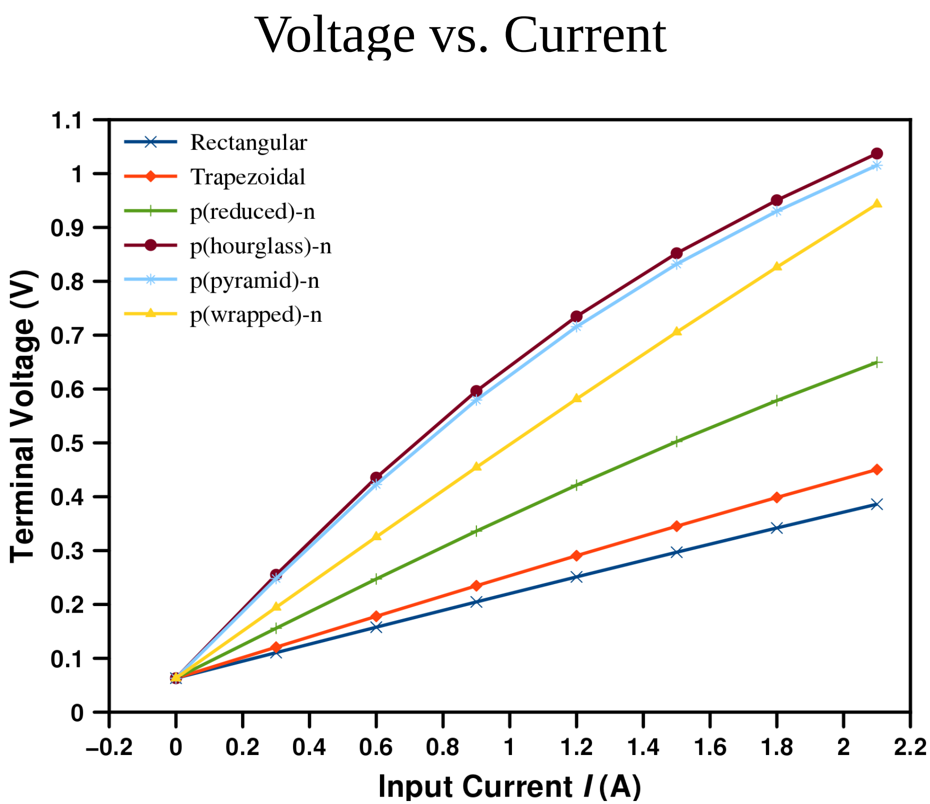
- STEPS

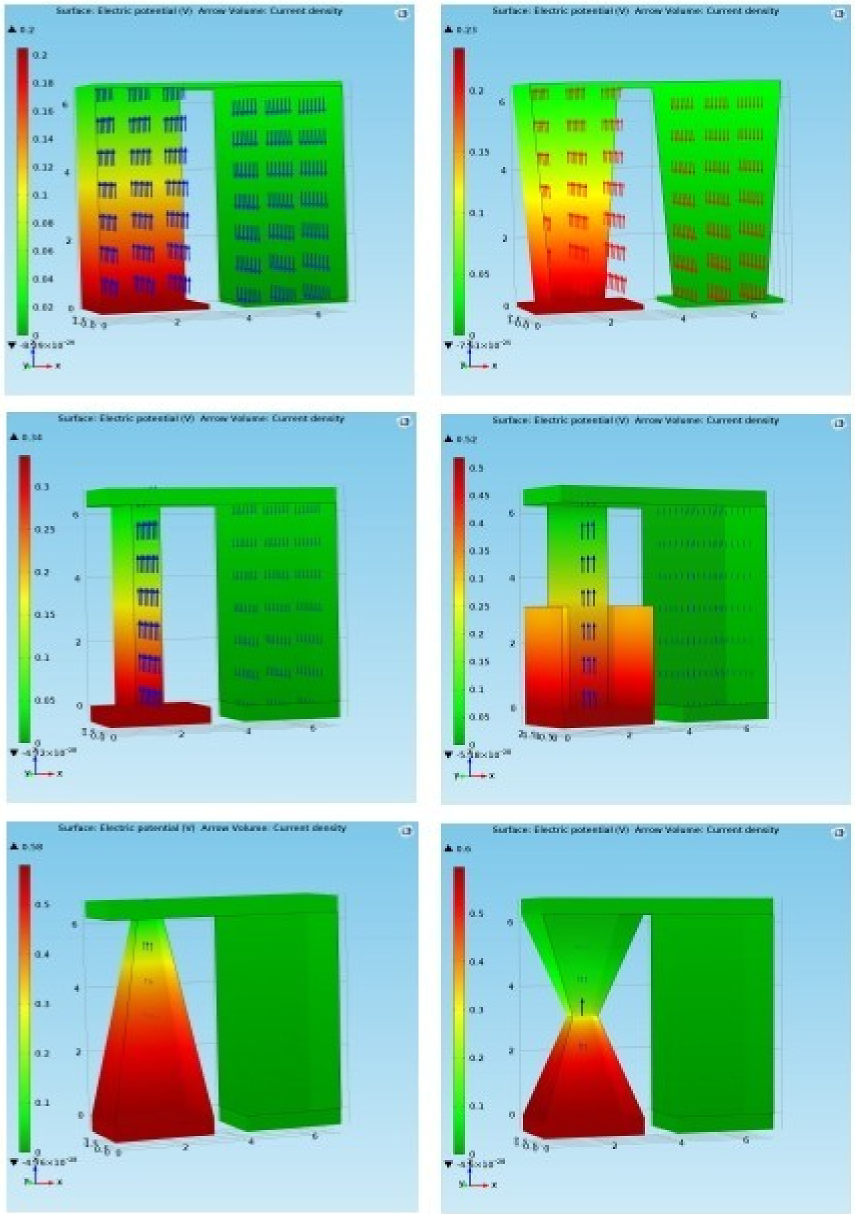


	Property	Name	Value	Unit	Property gro
✓	Heat capacity at constant	Cp	154[J/(l	J/(kg·k	Basic
✓	Density	rho	7700[k	kg/m³	Basic
✓	Seebeck coefficient	S	S(T)	V/K	Basic
✓	Electrical conductivity	sigma	sigma(T	S/m	Basic
✓	Thermal conductivity	k	k(T)	W/(m·	Basic
✓	Relative permittivity	epsilo	1	1	Basic

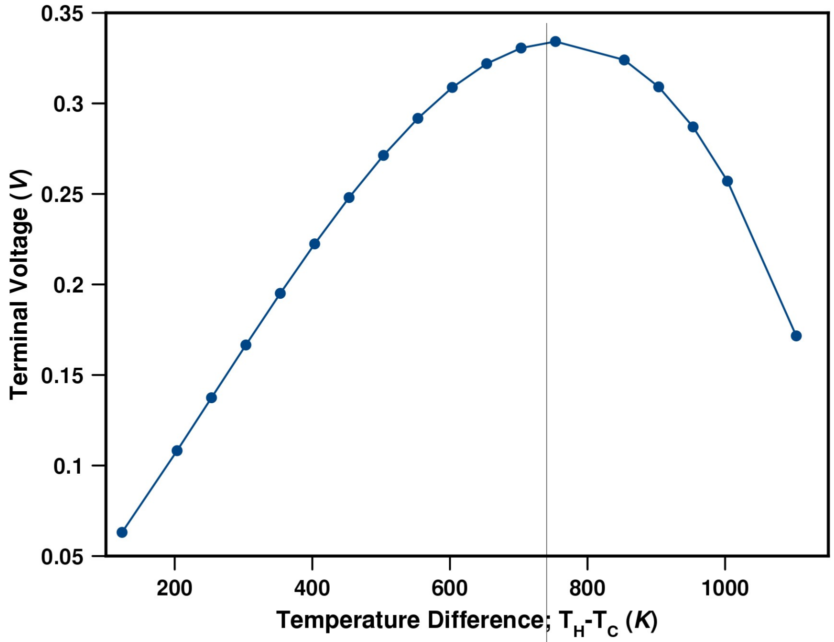
- **COMSOL Multiphysics 5.1**

Results

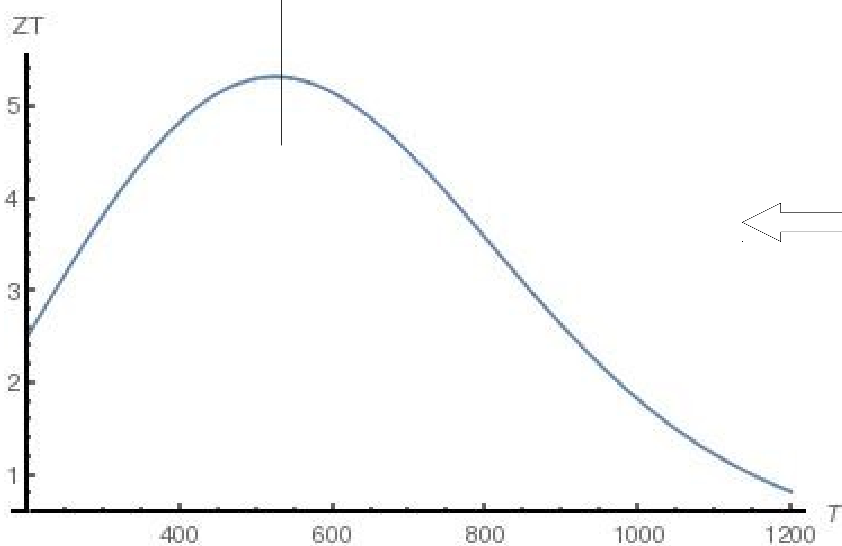

Voltage vs. Current
Rectangular
Trapezoidal
p(reduced)-n
p(hourglass)-n
p(pyramid)-n
p(wrapped)-n
Terminal Voltage (V)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1
Input Current I (A)
−0.2
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
2.2



Results



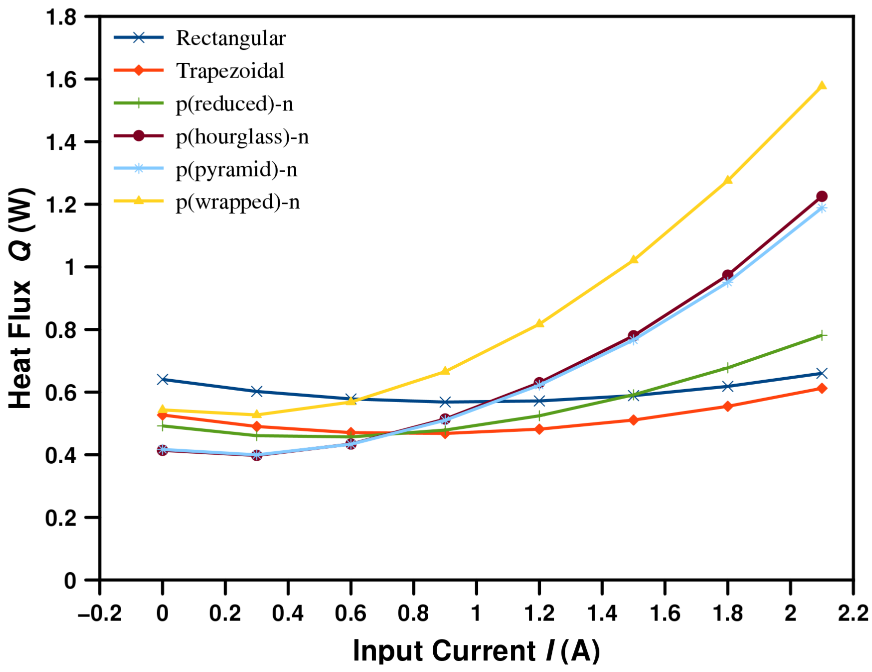
Voltage vs. Temperature

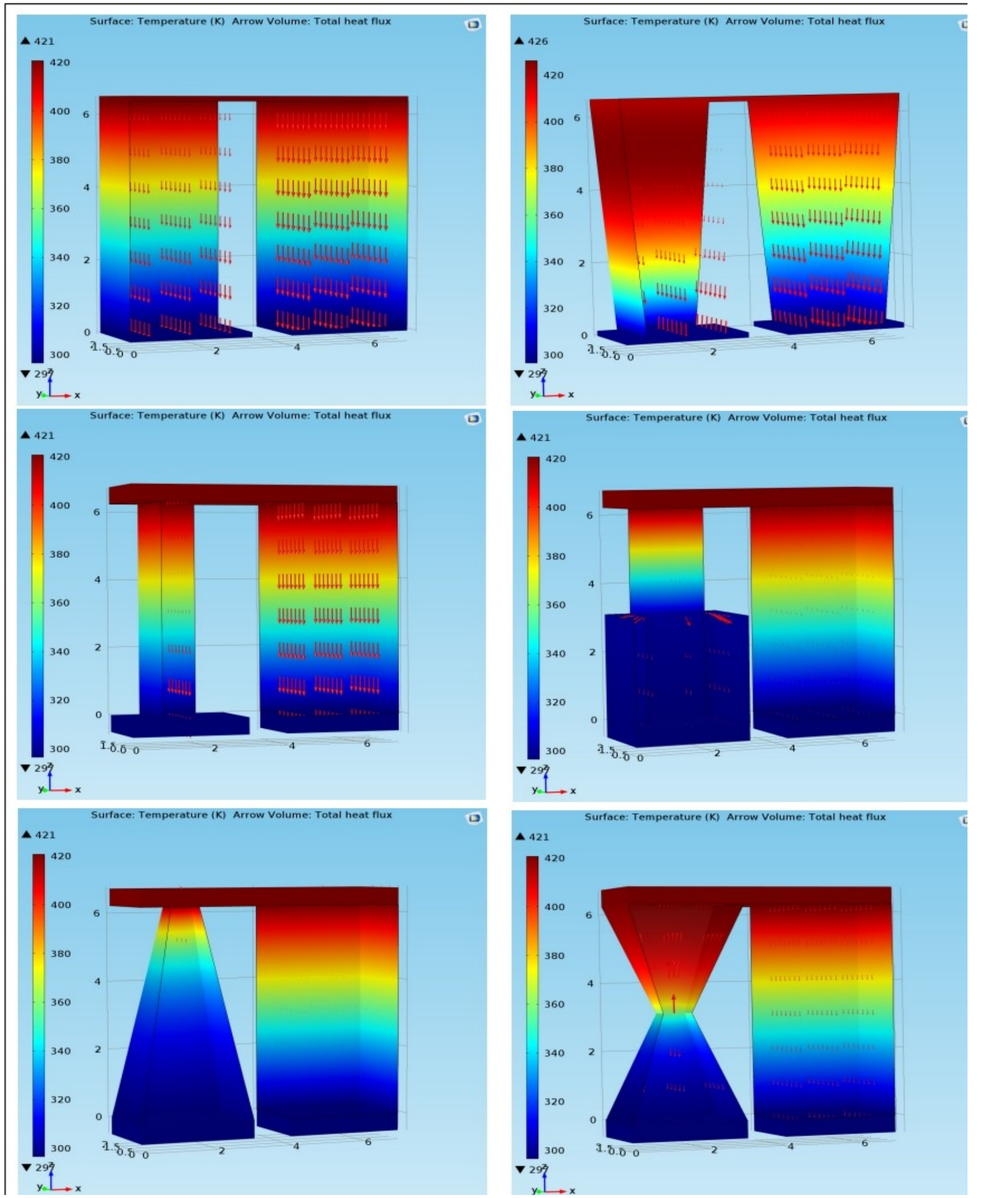


ZT vs. Temperature

Results

- Heat flux vs. Current





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- W. Liu et. al., Convergence of Conduction Bands as a Means of Enhancing Thermoelectric Performance of n-Type Mg2Si1-xSnx Solid Solutions, Physical Review Letters, 108 (2012) 166601.

Thanking You!