Simulation of Cascaded Thermoelectric Devices for Cryogenic Medical Treatment

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1. Introduction

❖ Thermoelectric device (TED) namely Peltier has the potential to generate the low temperatures required for cryosurgical applications.

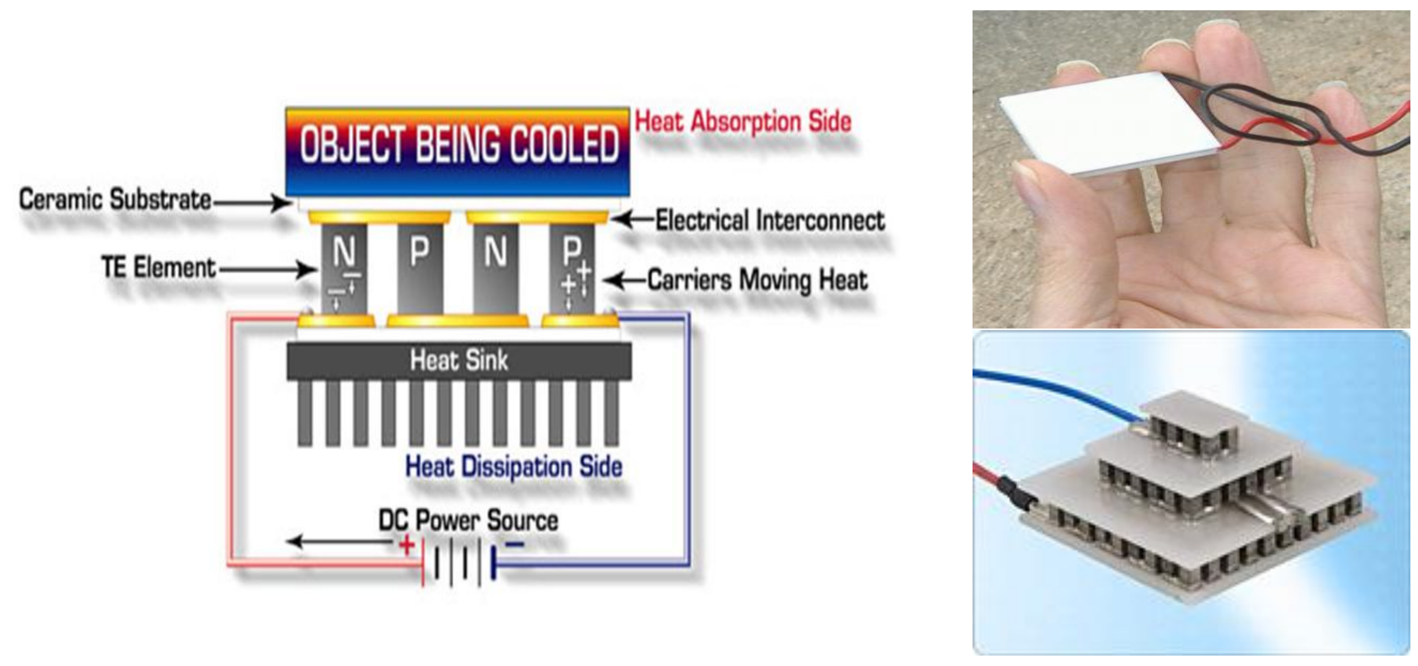

Figure 1. Peltier schematic

❖ Thermoelectric devices are small, lightweight compact devices with no moving mechanical parts, therefore can easily replace the bulky liquid nitrogen cryogenic systems.

❖ Multistage Peltier can be used for generating extremely low temperature.

❖ This work involves the modelling of a single stage and multi-stage Peltier system using COMSOL Multiphysics® software.

Governing Equations

$Q_H = \alpha . I . T_H - \overline{K} . \Delta T + \frac{1}{2} . \overline{R} . I^2$	Heat emitted on the hot side
$Q_C = \alpha . I . T_C - \overline{K} . \Delta T - \frac{1}{2} . \overline{R} . I^2$	Heat absorbed at the cold side
$\overline{R} = \frac{L}{\overline{\sigma} . A}$	Peltier thermal resistance
$\overline{K} = \frac{\overline{k} . A}{L}$	Peltier thermal conductance
$P = Q_H - Q_C$	Power
$COP = \frac{Q_C}{P}$	Coefficient of Performance

$$TM_{n\,n+1} = \frac{(0.5 \times I^2) \times (R_n + R_{n+1}) + (K_n \times T_h) + (K_{n+1} \times T_C)}{I \times (\alpha_{n+1} - \alpha_n) + K_n + K_{n+1}}$$

Inter-stage temperature (for multistage Peltier)

2. Model Development

❖ The Thermoelectric Effect Interface within COMSOL Multiphysics® Heat Transfer Module was used to solve the coupled heat transfer in solids equations and 'electric currents' equations simultaneously, to predict the temperature distribution along the Peltier device.

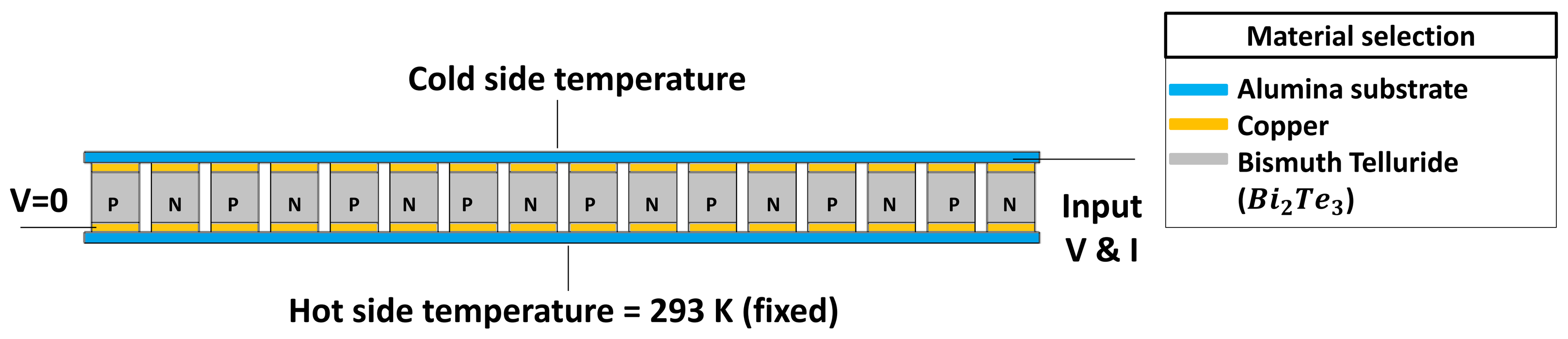

Figure 2. Peltier model set up and material selection within COMSOL

❖ Parallel connection configuration was used in this work.

❖ In parallel configuration power input for all of the stages is similar.

❖ Multistage Peltier model has been simplified by assuming pure conduction from lower Peltier stage to Peltier upper stage.

3. Results

a) Single stage Peltier:

- Figure 3 shows that temperature distribution for a single Peltier device which indicate that a single Peltier is unable to provide the required target low temperature of 200 K, Therefore multistage Peltiers will be considered
- Multistage Peltier is required for generating very low temperature.

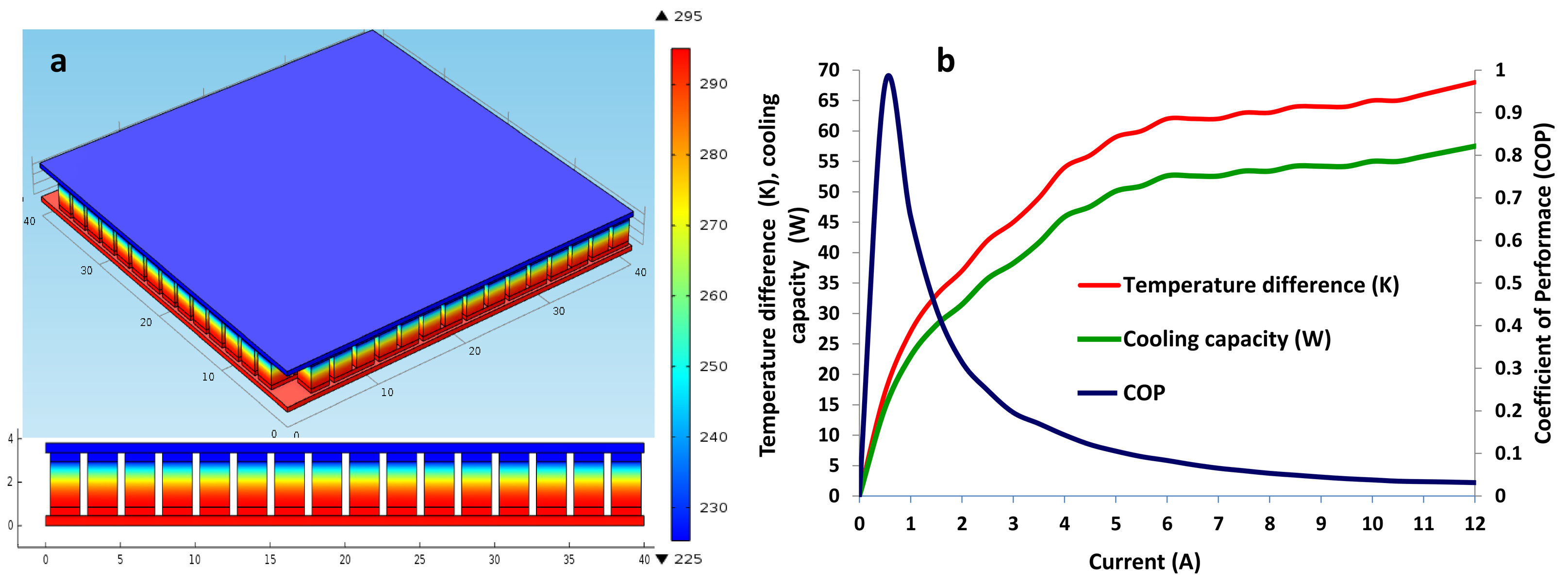

Figure 3. **a)** The resulting temperature distribution of a single stage Peltier (12 A and 15.2 V were applied). **b)** Calculated temperature difference, cooling capacity (Q_C) and coefficient of performance (COP) versus applied current (A) for single stage Peltier.

b) Multi-stage Peltier:

- Results in figure 4 and 5 indicate that 2-stage Peltier is unable to provide target low temperature therefore 3-stage Peltiers will be considered for generating target temperature.
- Increasing number of stage results in decreasing cooling capacity (Q_C) and COP

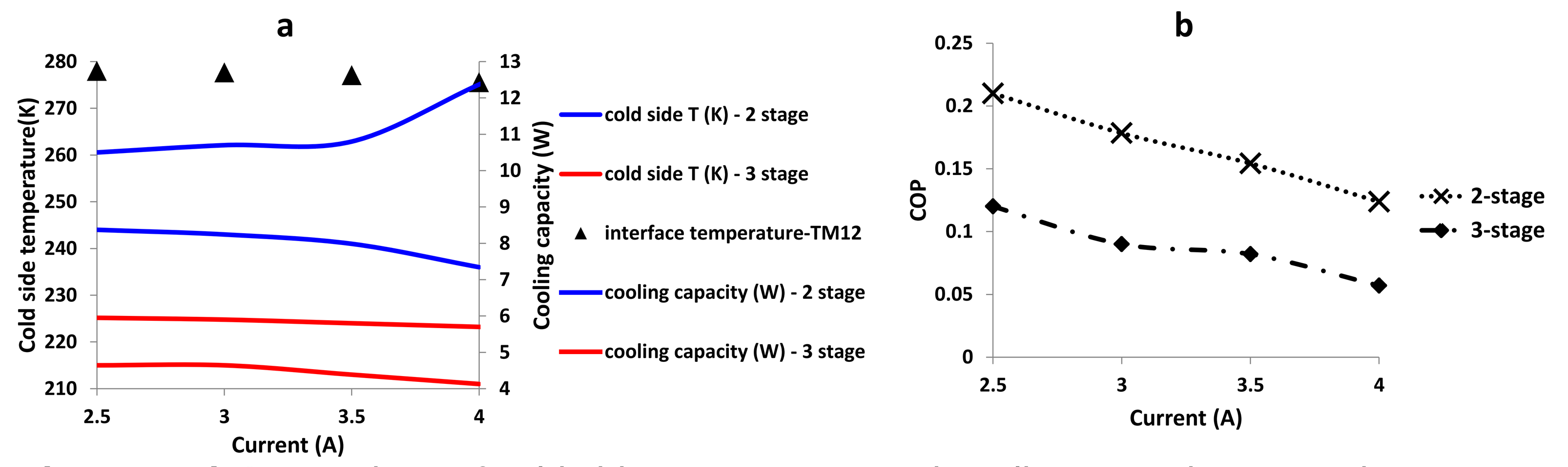

Figure 4. a) Comparison of cold side temperature and cooling capacity versus input current for 2 stage and 3 stage Peltier **b)** Comparison of coefficient of performance versus input current (COP) for 2 stage and 3 stage Peltier

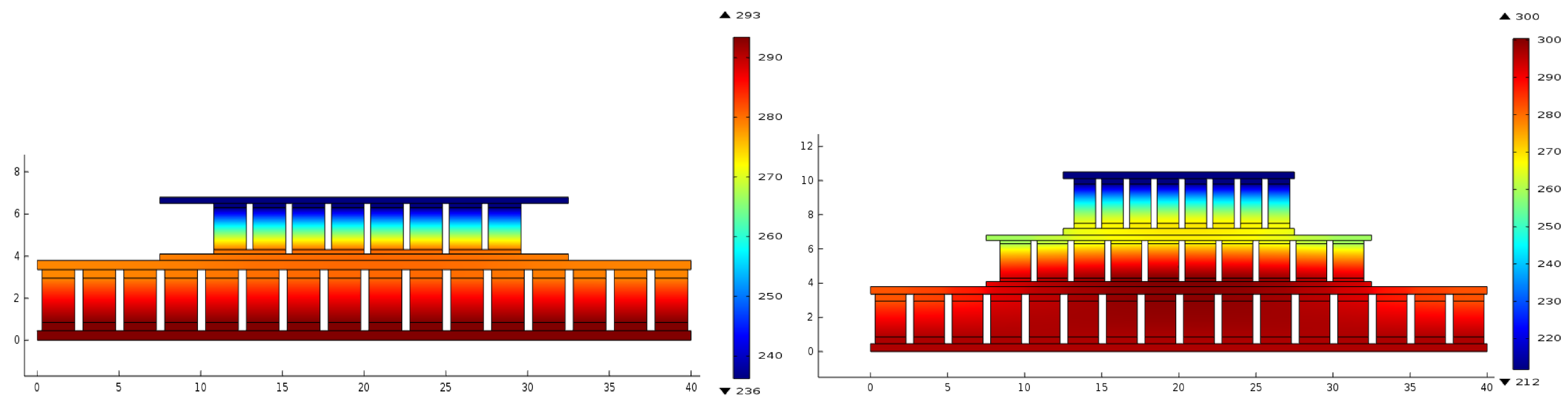

Figure 5. The resulting temperature distribution for 2-stage (left hand side) and 3-stage (right hand side) Peltier with 4 A and 2.5 V input

4. Conclusions

❖ Multistage Peltier are capable to generate freezing temperature for cryogenic medical treatment.

❖ Thermal simulation of thermoelectric device, using COMSOL Multiphysics®, prove to be powerful technique to predict temperature distribution in thermoelectric device.

References

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