

Power Module Target Cooling by Using Micro Thermoelectric Cooler

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Summary

The power module is an important component in the electric vehicle, and inside the module the Mosfet chip significantly generates heat, and therefore requires cooling strategy to remove the extra heat. The present study focuses on the influence of activated number and located position of micro thermoelectric cooler (μ TEC) on chip cooling, demonstrated by simulations. The proposed thermal cooling design is based on 24 μ TEC allocated vertically, plugged into the heat sink under the Mosfet chip, and the ideal Seebeck coefficient is set as 0.1 (V/K). The thermal performance of current power module design can cool the Mosfet chip temperature down to 10°C, while extending the operation time of maximal power output to 39%.

Keywords: EV (electric vehicle), controller, cooling, powertrain, finite element calculation

1 Introduction

Power module is an important component in the electric vehicle (EV), which contains many power electric devices, such as IGBT, Diode, and Mosfet. During vehicle-driving process, the power module generates great amount of heat, especially in the case of high power demand, such as climbing and acceleration. For example, in Figure 1 the EV power module reaches the thermal limit after about 2-minute maximal power output, therefore the power output must be reduced to protect the electric devices, and, the performance of the power module degrades significantly when the device is overheated. Otherwise, some active cooling strategies need to be adopted to remove the extra heat and extend the operating time, and the thermoelectric cooler (TEC) was adopted in the present study to extend the operating time of maximal power output for power module.

Thermoelectric cooler consists of many semiconductor elements. Based on the Peltier effect, powered by direct current, the cold face and hot face on both side of TEC were generated. At this time, the cold face side was attached to the high temperature power electric devices for the thermal cooling purpose. Nowadays, due to the rapid development of the Microelectromechanical Systems (MEMS), micro thermoelectric cooler (μ TEC) has many advantages in thermal cooling, like as without noise, small size, and precise temperature control [1, 2], which becomes a potential cooling device recently.

The previous study of our team was focused on the horizontal located position setting, and the relevant simulation setting and results could be referred to the reference by Lin et al. [3]. In this extension study, the commercial software ANSYS was used to carry out the simulation analysis with Thermal-Electric module on Workbench. For the cooling performance analysis of the power module assembly with μ TEC, as shown

in Figure 2, the effect of the activated number and located position of μ TEC on the power module cooling will be discussed.

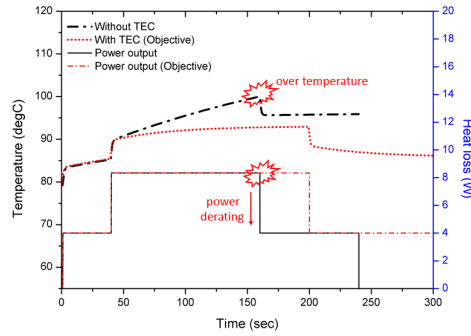


Figure 1: Thermal problem for EV power module

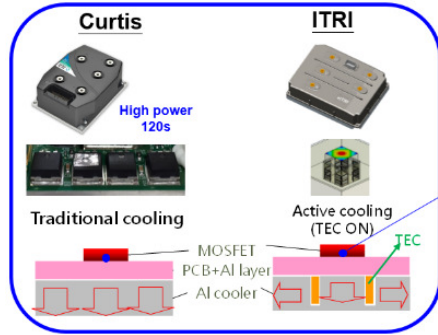


Figure 2: Objective diagram

2 Thermoelectric Cooling Principle

There will be five effects in the thermoelectric cooling process [4], which are: Seebeck effect, Peltier effect, Thomson effect, Joule effect, and Fourier effect. Consider an ideal thermoelectric cooler, when the heat transfers from the cold side to the hot side, the heat at the cold and hot sides can be represented by:

$$Q_h = (\alpha_p - \alpha_n) I T_h - \frac{kA}{L} (T_h - T_c) + \frac{L}{2A} I^2 \rho_e \quad (1)$$

$$Q_c = (\alpha_p - \alpha_n) I T_c - \frac{kA}{L} (T_h - T_c) - \frac{L}{2A} I^2 \rho_e \quad (2)$$

where, Q_h and Q_c are the energy (W) at the hot side and the cold side, respectively, α_n and α_p are the Seebeck coefficient (V/K) of n-type and p-type thermoelectric material, respectively, k is the thermal conductivity (W/[mK]) of thermoelectric material, A is the area (m^2) of thermoelectric material, L is the height (m) of thermoelectric material, T_h and T_c are the temperatures (K) at the hot side and the cold side, respectively, I is the input current (A) of thermoelectric cooler, and ρ_e is the resistivity (Ωm). In (1-2), three items at the right hand side of the equations are caused by the Peltier effect, Fourier effect, and Joule effect, respectively. The coefficient of performance (COP) for TEC is defined in (3), and P_e is the input power (W). In the present case, the power consumption of each μ TEC is about 0.2W when input current is 0.1 A and 0.1 V/K Seebeck coefficient conditions.

$$COP = \frac{Q_c}{P_e} = \frac{Q_c}{Q_h - Q_c} \quad (3)$$

3 Results and Discussions

Figure 3 shows the geometric setup of the investigated μ TEC, and the relevant material property could be found in Table 1. To verify the present simulation model, the simulating COP curve was compared with the product of Laird COP specification [5] at the 5 degree temperature difference. From Figure 4, the black line stands for product specification and the blue triangle is for simulation data. It could be seen that the simulation results are in good agreement with the Laird product specification. As shown in Figure 5, various located positions were conducted to find the optimal thermal cooling layout, and the corresponding simulating chip transient temperatures under four different located positions could be found in Figure 6. As a result, it is noticed that the vertically located position using 24 μ TEC yields a better cooling performance with about 3°C maximum chip temperature reduction. To prevent the heat from returning to the chip and remove the heat more efficient, the convection heat transfer plays an important role. Figure 7 shows that the heat could be removed to the environment more efficiently at higher convection coefficient (h). While the vehicle drives at higher speed, the value of h will increase. At the case $h=100$ (W/[m²K]), after 200 seconds maximal output operation, the chip temperature could decrease with 10°C temperature drop, as compared to the traditional one without using μ TEC, while extending the operation time of the maximal power output to 39%.

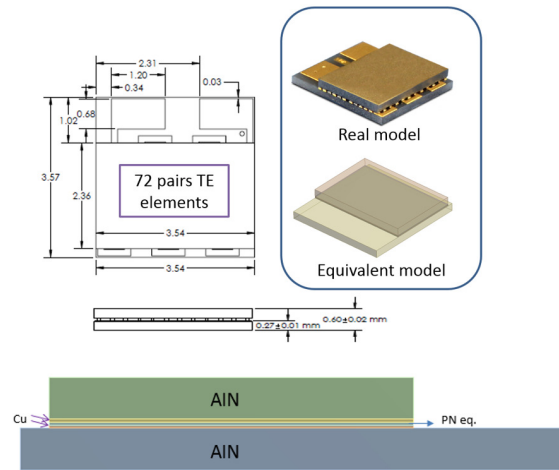


Figure 3: Geometric setup of μ TEC

Table 1: μ TEC material specification

Material	Density (kg/m ³)	Isotropic thermal conductivity (W/mK)	Specific heat (J/kgK)	Isotropic Resistivity (Ω m)	Isotropic Seebeck coefficient (V/K)
AlN	3260	150	740	X	X
Cu.	8920	386	385	1.72E-08	X
PN eq.	7440	0.2394	154.4	2.924	0.0345

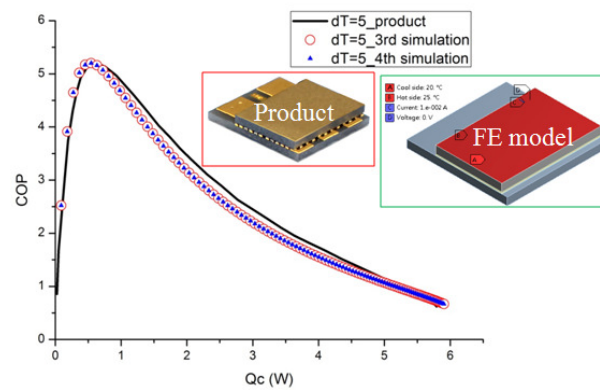


Figure 4: μ TEC simulation model verification

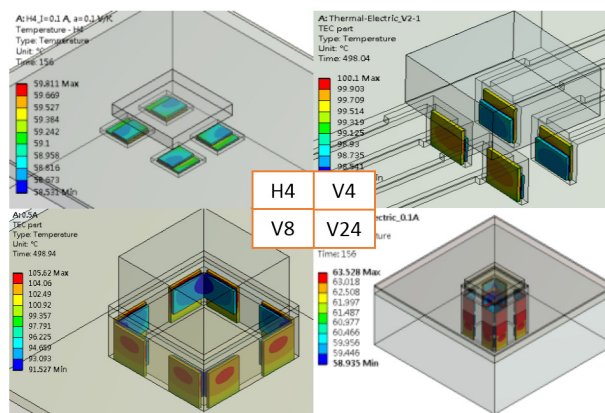


Figure 5: Different μ TEC located positions

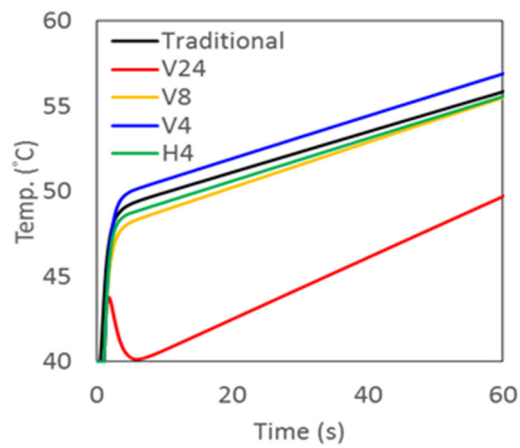


Figure 6: Different located position effect

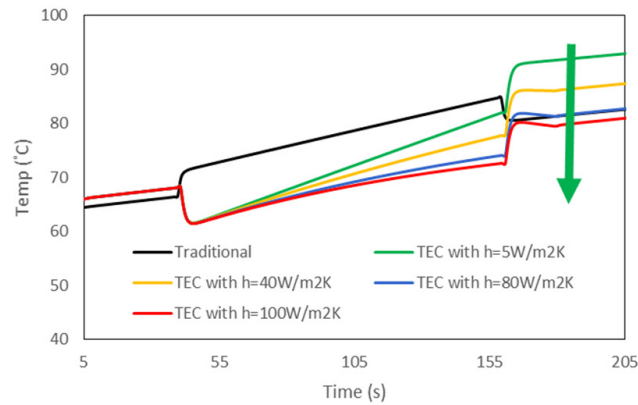


Figure 7: Convection coefficient effect

4 Conclusions

The power module is an important component in the electric vehicle, and the Mosfet chip generates heat, therefore requires cooling as electric vehicle driving. In the present study, the discussion of the influence of the activated number and located position of micro thermoelectric cooler (μ TEC) on chip thermal cooling is proposed. To discuss the located position effect, there are four different cases, including vertical and horizontal setting, in the present study, and the best thermal cooling performance is 24 μ TEC vertical allocation with the ideal Seebeck coefficient as 0.1 (V/K) and the convection coefficient 100 (W/[m²K]). After 200 seconds maximal power output, the proposed cooling design provided with about 10°C maximum chip temperature reduction. And the operation time of the maximal power output could be extended 39% more, as compared to the original design without μ TEC. In the future study, the relevant experiment test will be conducted to verify the present simulation results, and then applied to the real electrical vehicle.

Acknowledgments

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