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Thermal Mode Calculation Tecnique for Thermal Syphone with Two-Component Heat Carrier

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Abstract: One of the ways of power semiconductor devices PSD efficiency increase is the evaporative cooling of PSD using thermal syphons. In this study, we consider the developed technique of thermal resistance calculation on the heat flow path from the evaporator surface to the external environment of a thermal syphon cooling air with a two-component internal heat carrier. The analysis of the obtained formulas makes it possible to reveal the most significant factors affecting the thermal resistance of a thermal syphon.

Key words: Semiconductor device, evaporative cooling, thermal syphon, condenser, thermal resistance, cooler

INTRODUCTION

Now a days, there are many devices to cool power semiconductor devices (Eliseev *et al*., 2010, 2011; Kuznetsov and Razva, 2014; Baliga, 2010; Sivanagaraju, 2009; Jaecklin, 2012; Padmanabhan, 2016; Bergman *et al*., 2011; Kothandaraman, 2006; Thirumaleshwar, 2009). The analysis in the course of structure optimization is hampered by the lack of a technique to calculate the resistance on the path of the heat flow from the evaporator surface to the external environment of cooling air (Eliseev *et al*., 2010, 2011; Isakeev, 1982; Panfilov and Kabanov, 2016ab).

In the patent developed by Eliseev *et al*. (2010, 2011), the device is demonstrated for a tablet structure PSD cooling and also the structural diagram of the thermal syphon is shown on Fig. 1.

A thermal syphon consists of the radiator 1 which is represented by several channels, some of which are ascending 2 and the other downward 3 ones with a finned outer surface, united by the collectors 4 and 5 on both sides. The lower collector is separated by the partition 6. The copper evaporator 7 has a series of longitudinal holes 8 connected on one side by transverse holes 9 forming a single cavity. The evaporator 7 is connected to the collector 5 opposite the ascending channels 2. The tube 10 connects the evaporator 7 to the collector 5 connecting the downward channels 3. The evaporator is sealed by the plug 11.

The principle of the thermal syphon operation is the following one. A thermal syphon is filled with heat carriers in advance. First, the dielectric liquid with a low boiling point (up to 80°C) is poured into 1/5 part of the syphon. The remaining volume is filled with antifreeze at a higher boiling point and is covered with a cork. Semiconductor devices are pressed from one or both sides to an evaporator. A thermal syphon is operated in an upright position. When a semiconductor device is operated, some heat is generated from it which heats the walls of the evaporator and the liquid poured into it. When the boiling point of the dielectric liquid is reached, vapors begin to emerge from it which rush upward into the upgoing channels of the radiator, capturing the antifreeze. The vapor-liquid mixture rises to the upper collector and rushes into the radiator descending channels along it then it is condensed into the liquid and is returned to the evaporator through the tube.

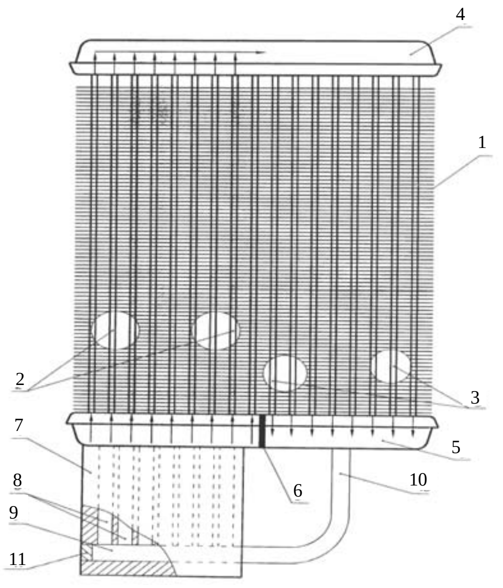

Fig. 1: Thermal syphon general view

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Purpose of the study: The task of this study is to develop the methodology for thermal resistance calculation on the heat flow path from the evaporator surface to the external environment of the cooling air.

MATERIALS AND METHODS

Research data: The main data for the current scientific study was the researches of the Russian and Foreign scientists in the field of a heat transfer in electric energy power converters such researches have been conducted in many organizations until recent. The scientific researches in this direction for the last 10 years as well as scientific researchers and patents in the science field have formed the initial base. When writing this work classical and experimental heating methods were used. All of these allowed making the logical analysis of collected data and we came to the need of developing a calculation method for the thermal mode of a thermo-syphon with the two-component heat transfer agent.

RESULTS AND DISCUSSION

The total thermal resistance of the thermal syphon cooler has the form represented by Eq. 1:

$$R_T = R_\lambda + R_k + R_{\alpha 1} + R_c + R_{\alpha 2} \tag{1}$$

Where:

R_λ = The thermal resistance of the evaporator base
R_κ = The thermal resistance from the rib surface to the heat carrier
$R_{\alpha 1}$ = The thermal resistance from the moving heat carrier to the internal wall of the condenser
R_c = The thermal resistance of the condenser wall
$R_{\alpha 2}$ = The thermal resistance of heat transfer from the outer fin of the condenser to the external air

The thermal resistance R_λ is determined from Eq. 2:

$$R_\lambda = \frac{\delta_\lambda}{\lambda \times S_{cp}}; S_{cp} = \frac{S_k + S_0}{2} \tag{2}$$

Where:

S_k = The unit contact area
S_0 = The finning area of the evaporator base
λ = The thermal conductivity of the base material
δ_λ = The evaporator bottom thickness

The thermal resistance R_k is determined from the following Eq. 3:

$$R_k = \frac{1}{\alpha_k (S_p \times E_u + S_{mp})} \tag{3}$$

Where:

S_p = The evaporator finning surface
E_u = The evaporator fin efficiency factor

The efficiency factor of the evaporator fins is determined by the following Eq. 4:

$$E_u = \frac{th \times h\sqrt{\frac{2_{\alpha k}}{\lambda \times \delta}}}{h\sqrt{\frac{2_{\alpha k}}{\lambda \times \delta}}} \tag{4}$$

Where:

λ = The thermal conductivity of the evaporator fin material
δ = The thickness of the evaporator fins
h = The height of the evaporator fins
a_k = The heat transfer coefficient from the fin surface to the boiling heat carrier

The heat transfer coefficient α_k is determined from the expression proposed by Mikheev and Mikheeva (2010):

$$\alpha_k = 0.075\left[1+10\left(\frac{\rho''}{\rho'-\rho''}\right)^{\frac{2}{3}}\right]\times\left(\frac{\lambda^2}{\nu \times \sigma \times T_s}\right)\times q^{\frac{2}{3}} \tag{5}$$

Where:

ρ', ρ'' = The density of liquid and vapor, respectively (kg/m^3)
λ = The liquid thermal conductivity (Bm/M×°C)
σ = The surface tension (H/M)
q = The heat flux density (Bm/M^2)
T_s = The saturation temperature (K)
v = The kinematic viscosity coefficien (m/sec)

The thermal resistance $R_{\alpha 1}$ is determined from the following Eq. 6:

$$R_{\alpha 1} = \frac{1}{\alpha_2 \times S_k} \tag{6}$$

Where:

S_k = The internal surface of the capacitor
α_2 = The convective heat transfer coefficient which depends on the velocity of a coolant in condenser channels

The velocity of the heat carrier vapor phase is determined according to Isachenko *et al.* (1969) from the following Eq. 7:

$$W = 1.18\sqrt{\frac{\sigma \times q(p'-p'')}{p'}} \tag{7}$$

Taking into account the turbulent mode of a heat carrier motion in condenser channels, we determine the convective nusselt coefficient from the following Eq. 8:

$$N_{u_{ж}} = 0.021 \times R_{eЖ}^{0.8} \times P_{rЖ}^{0.43} \times \left(\frac{P_{rЖ}^{0.43}}{P_{r_c}} \right)^{0.25} \quad (8)$$

where $Re_{ж}$ is the Reynolds number:

$$Re_{Ж} = \frac{W \times \alpha_{ЗКВ}}{v} \quad (9)$$

$$\alpha_{ЗКВ} = \frac{4 \times F_{СЕЧ}}{П} \quad (10)$$

Where:

$F_{СЕЧ}$ = The cross-section of a rectangular pipe (m^2)

П = A pipe perimeter (m)

v = The kinematic viscosity of an antifreeze (M^2/c)

$Pr_{ж}$ = The Prandtl number from the reference book at the temperature of a heat carrier

Pr_c = The Prandtl number from the reference book at the temperature of a condenser wall

The thermal resistance R_c is determined from the following Eq. 11:

$$R_c = \frac{\delta_c}{\lambda \times S_k} \quad (11)$$

Where:

δ_c = The condenser wall thickness

λ = The thermal conductivity of a condenser material

S_k = The internal surface of a condenser

The thermal resistance $R\alpha_2$ is determined according to (Mikheev and Mikheeva, 2010). For the laminar regime, the average convective Nusselt coefficient is determined from the following Eq. 12:

$$\overline{Nu_{ж}} = 1.4 \left(R_{B_{ж}} \frac{\alpha}{1} \right)^{0.4} \times Pr_{ж}^{0.33} \left(\frac{Pr_{ж}}{Pr_c} \right)^{0.25} \quad (12)$$

Where:

α = The coefficient of thermal diffusivity of a heat carrier

I = A cooling channel height.

The nusselt coefficient is determined from Eq. 8 for the turbulent regime. Heat transfer coefficient:

$$\alpha_2 = Nu_{Ж} \frac{\lambda_{Ж}}{\alpha} \quad (13)$$

Thermal resistance:

$$R\alpha_2 = \frac{1}{\alpha_2 \left(S_{2_p} \times E_p + S_{MP} \right)}, \quad (14)$$

Where:

S_{2p} = The surface of the condenser ribs

S_{MP} = The surface between the ribs

The coefficient of the condenser rib efficiency (Mikheev and Mikheeva, 2010; Isachenko *et al.*, 1969):

$$E_p = \frac{th \times h \sqrt{\frac{2_{\alpha_k}}{\lambda \times \delta}}}{h \sqrt{\frac{2_{\alpha_k}}{\lambda \times \delta}}} \quad (15)$$

Where:

h = The height of the condenser ribs (m)

δ = The height of the condenser ribs (m)

λ = The thermal conductivity of condenser ribs

Thus, the research determined the analytical dependencies for the components of the overall thermal resistance of a thermal syphon cooler.

CONCLUSION

The calculation relationships are considered in the article to determine the thermal resistance of a thermal siphon with a two-component heat carrier. The analysis of the formulas makes it possible to identify the most important factors affecting the thermal resistance of a thermal syphon. Using the results of the study, it is also possible to outline the ways for further improvement of a cooling device design and its individual components.

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