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3D numerical optimization of a heat sink base for electronics cooling ☆

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ABSTRACT

In this paper, the possible optimal thickness of a heat sink base has been explored numerically with different convective heat transfer boundary conditions in a dimensionless three dimensional heat transfer model. From the numerical results, relations among different heat transfer mechanisms (natural or forced, air or liquid), different area ratios of a heat sink to a heating source, and the lowest thermal resistance have been obtained and discussed. Also a simple correlation for these three parameters from data fitting is given for guiding a heat sink design.

1. Introduction

It is well known that the performance reliability and life expectancy of electronic equipment are inversely related to the component's temperature. Conventionally, most optimization works on heat sinks assume that the heat is evenly distributed over the entire base area of the heat sink, and therefore, do not account for the additional temperature rise caused by a smaller heat source (the contact area is smaller than the base area) [1,2]. Several studies have been carried out to determine this spreading resistance (or called constriction resistance) for a system similar to Fig. 1(a) through numerical or analytical solutions [3-5]. However, an optimal result for the base thickness was not obtained in those works for a given boundary condition.

In order to cohere with real situations and to pursue the minimum value of thermal resistance of a heat sink with different heat source contact areas, heat transfer boundary conditions and heating flux, in this investigation, a three-dimensional heat transfer models were developed. Through detailed calculations of dimensionless temperature with variations of base thickness and contact area ratios under different heat transfer boundary conditions, the optimal base thickness can be obtained for a certain heat sink configuration. Furthermore, a rigorous experimental test was carried out to verify the reliability of the numerical predictions.

2. Arguments on base's role in heat sinks' performance

For a problem like in Fig. 1(a), a heating source is mounted on a heat sink. Lee et al. [4] argued that the problem of a thermal resistance analysis in a heat sink base can be simplified to a problem as shown in Fig. 1(b), since the heat enters the bottom surface of the heat sink base and leaves the top surface of the base over which a uniform heat transfer coefficient, or an external resistance, is prescribed. In the following, this argument will be tested.

A numerical simulation result for a natural convection situation by a widely adopted commercial software (FLUENT) is given in Fig. 2. The temperature distribution in the base of the heat sink is compared between the full simulation and the result just for the base with an equivalent uniform heat transfer coefficient which is determined with the following definition,

$$\bar{h}\cdot A_{base} = h\cdot A_{total} \tag{1}$$

Here, $\bar{h}$is the equivalent heat transfer coefficient; A_{base} is the cross section area of the top surface of the base; h is the real convection heat transfer coefficient; A_{total} is the total area of the fins adding the top surface area of the baseA_{base}. From Fig. 2(a) and (b), if a proper heat transfer coefficient is selected (through a detailed integration of $h\cdot dA$ along the fins), the difference between the full simulation for the heat sink and the simulation for the base only is very small. This comparison verifies the previous argument as used historically for the calculation of the spreading resistances [3-5].

3. Heat transfer modeling for a base optimization

From Fourier Law $q = -\lambda\partial T/\partial x$, introducing the following dimensionless temperature

$$\theta(x,y,z) = \frac{\lambda}{q_w b}(T(x,y,z) - T_0) \tag{2}$$

and the following dimensionless length, $X = x/b$, $Y = y/b$ and $Z = z/b$, the dimensionless description of the problem can be obtained as, here if we

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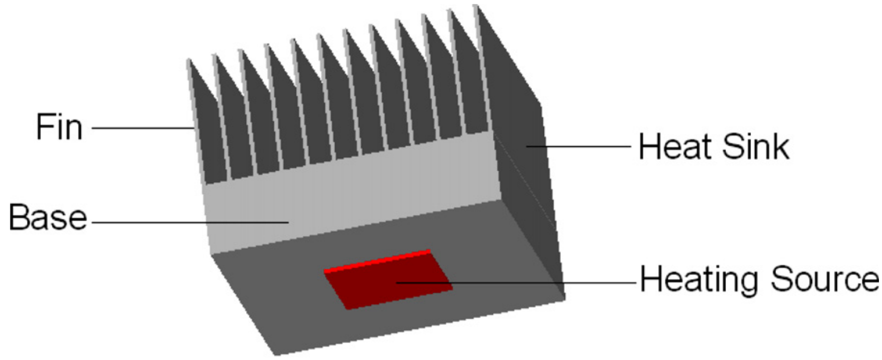
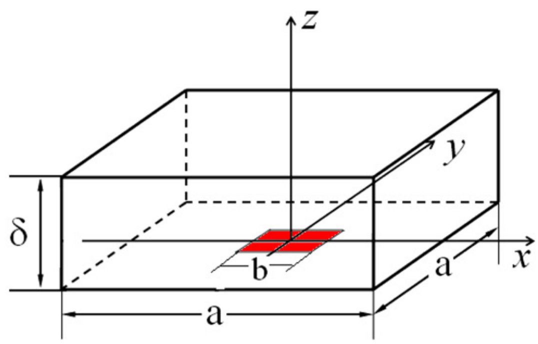
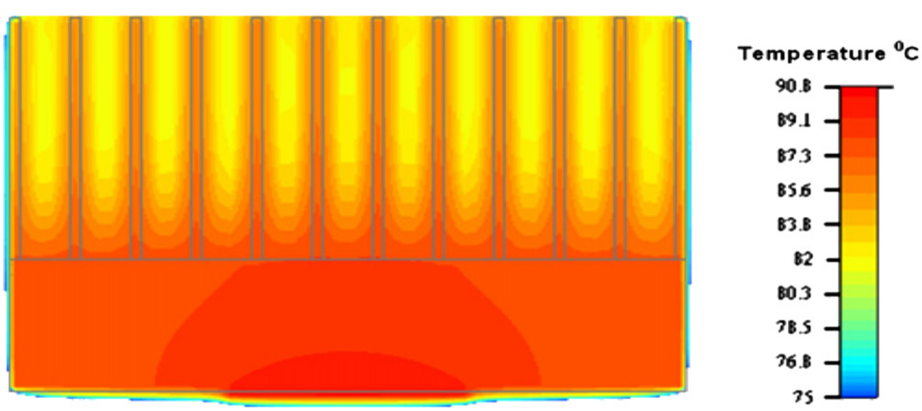


a)

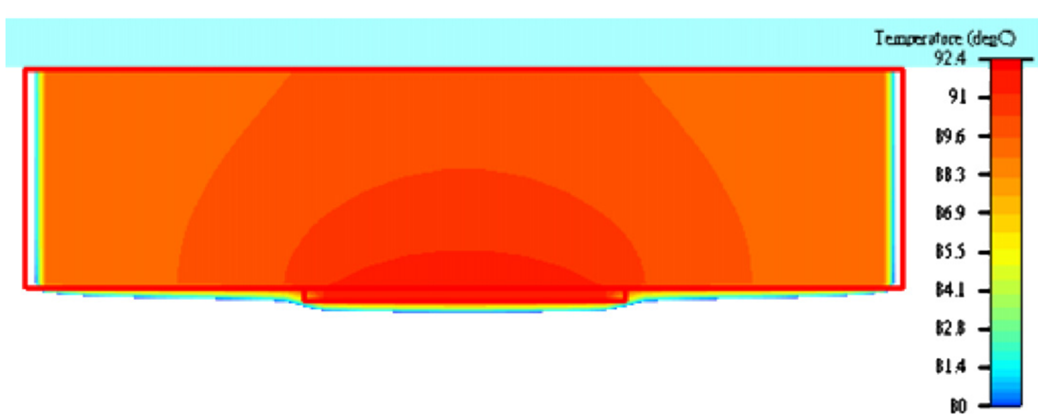


b) Domain of the numerical simulation

Fig. 1. Construction of the object in interest.



a) A full simulation with commercial software



b) A simplified simulation only for base with commercial software

Fig. 2. Temperature distribution comparisons in the base of the heat sink.