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Spreading Thermal Resistance and Its Applications

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ABSTRACT: Spreading resistance is, in general, a critical parameter on thermal design of electronic equipment. For electronic space equipment, in special, its importance increases considerably due to the absence of the convection heat transfer phenomena in vacuum. With no convection, the conduction through Printed Circuit Boards (PCBs) or through spacecraft/equipment structure becomes the most important mechanism to eliminate hot spots inside electronic equipment or the whole satellite. Whenever heat flows through one or more solids involving a change in cross-sectional area, there is a resistance associated with the spreading or constricting of heat flow. Rarely in electronics packaging applications does a heat transfer analysis exclude estimates of constriction/spreading resistances.

KEYWORDS: Thermal , resistance , LED , Heat sink

I. INTRODUCTION

Thermal spreading resistance theory is widely used in electronics cooling, both at the board and chip levels, as well as in heat sink applications. It also appears in thermal analyses of bolted joints and other mechanical connections with discrete points of contact. In many engineering systems, thermal spreading resistance is caused by discrete heat sources. Typical applications include package and system-level cooling of electronic devices, as well as heat sink-based cooling of power semi-conductors. Heat dissipated by electronic devices is conducted through electronic packages into convectively cooled printed circuit boards or heat sink baseplates in these applications. [1] Convective film resistance is replaced by an effective extended surface film coefficient in heat sink applications.

Thermal spreading resistance has a significant impact on the thermal resistance of LED chips, particularly flip chips, and there is a need for LED package thermal design optimization. In this paper, we investigate the thermal spreading effect in both flip chip and face-up chip, resulting in a thermal design optimization of LED packages. The thermal spreading resistance is calculated first, and then the thermal simulation is performed using the finite element method. These two methods analyse the factors that influence thermal spreading, and the results are quite similar. The optimal heat sink thickness is discovered, and the minimum thermal resistance of the heat sink is achieved in this thickness value. The optimal thickness decreases as the area of the heat source increases. Thermal resistance decreases in flipchip LEDs as the area of Au bumps and thickness of PN junctions increase in current technology. [2] At the same Au usage, decreasing the area of each bump and increasing the number of bumps could effectively reduce PN junction thermal resistance while maintaining good temperature evenness. In LED packaging, the thermal spreading effect must be taken into account.

A common method for increasing thermal contact conductance is to apply highly conductive coatings to contacting surfaces. In many applications, an intermediate coating is required so that the conductive coating can be applied to a non-adhering substrate. In these cases, it is preferable to forecast the effect of intermediate and final coatings on

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spreading resistance. A solution for calculating the thermal spreading resistance of a planar circular contact on a doubly coated substrate is presented. [3] A model for calculating the contact conductance between a bare substrate and a coated substrate is also developed. Comparisons are made with data obtained from the literature that did not have an analytical model. Computer algebra systems were used to solve the governing equations and compute the spreading resistance numerically.

II. REVIEW OF LITERATURE

Lee, S. [4] proposed a compact model to evaluate spreading resistance as a function of heat sink base-plate and heat source thermal/geometrical properties. When he applied his model to the solution of some practical design problems, he discovered some limitations in its application. Lee's spreading resistance equation is presented as a function of heat sink base-plate area. This is useful in situations where the value is already known, such as the example he presented in his paper. However, in many other practical situations, such as the problem of a transistor bonded to a PCB thermally grounded through an Aluminum plate, this area is unknown. In fact, it is critical for the thermal designer to evaluate not only the spreading thermal resistance, but also the effective spreading area in this situation.

Yovanovich [Aung, 1991] and Mikic [Kraus & Bar-Cohen, 1983][5] proposed special case solutions in which the heat spreader base is assumed to be infinitely wide and/or infinitely thick. Because of the idealised boundary condition assumptions, these solutions are rarely applicable to thermal problems in electronics packaging. Kennedy [1960] [6] developed a series solution for a special case where the bottom of the spreader plate is assumed to be at a constant temperature for a plate with finite dimensions, and this solution has been widely used in the packaging industry for approximately thirty-five years. The constant temperature assumption (at the bottom of the plate) produces an optimistic solution that may be an order of magnitude off.

Marotta et al.'s [7] experimental study included two types of interfaces, each with three to four different coating thicknesses. The first type was made up of two aluminium substrates, with the upper specimen bare and the lower specimen coated with silicon nitride and the DLC on top. The silicon nitride coating thickness was set at 3 μm , while the DLC thickness ranged from 0 μm (no coating) to 5 μm . The second type had the same bare aluminium alloy on top, but the coated specimen's substrate was changed to copper.

Objectives

- To study spreading thermal resistance over different powers
- To study surface temperature for a heat sink with four heat sources
- To study thermal conductivity of bulk materials and thin films
- To study heat source on a heat sink base
- To study spreading heat flow

III. RESEARCH METHODOLOGY

Methodology is the systematic, theoretical examination of the methods used in a particular field of study. It consists of a theoretical examination of the body of methods and principles associated with a particular field of knowledge. It usually includes terms like paradigm, theoretical model, phases, and quantitative or qualitative techniques. The current study is descriptive in nature and is based on secondary data gathered from a variety of sources such as books, education, and development, journals, scholarly articles, government publications, and printed and online reference materials.

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IV. RESULT AND DISCUSSION

The heat path shown schematically in Fig.1 was considered to obtain a mathematical expression for the equivalent thermal resistance between the heat source and the environment. A portion of the heat will be lost directly to the environment, while the remainder will be lost via the heat sink base-plate. When the external resistance is much lower than the spreading resistance, all heat flows directly to the environment. [8] As the external resistance increases, a portion of the heat flux flows through the heat sink, increasing the effective heat transfer area and lowering the thermal resistance from the environment to the heat source.

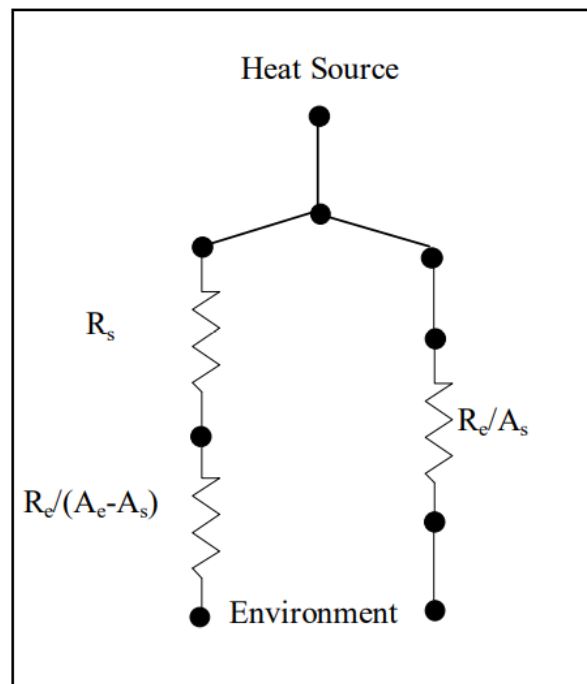


Fig. 1 Equivalent Electrical Circuit

When heat flows by conduction between a source and a sink with different cross-sectional areas, thermal spreading resistance occurs. Figure 2 depicts two scenarios involving spreading heat flow. [9-10]

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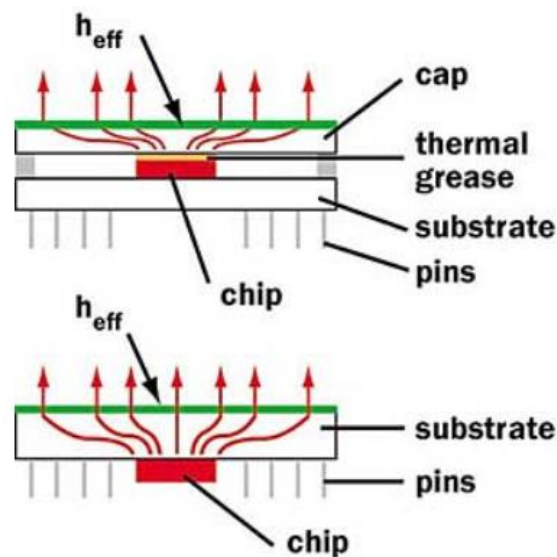


Fig. 2 Example of spreading heat flow in two types electronic packages

Fig 3 shows a cross-section of a circular heat source with radius a on the base with radius b and thickness t . [11-12]

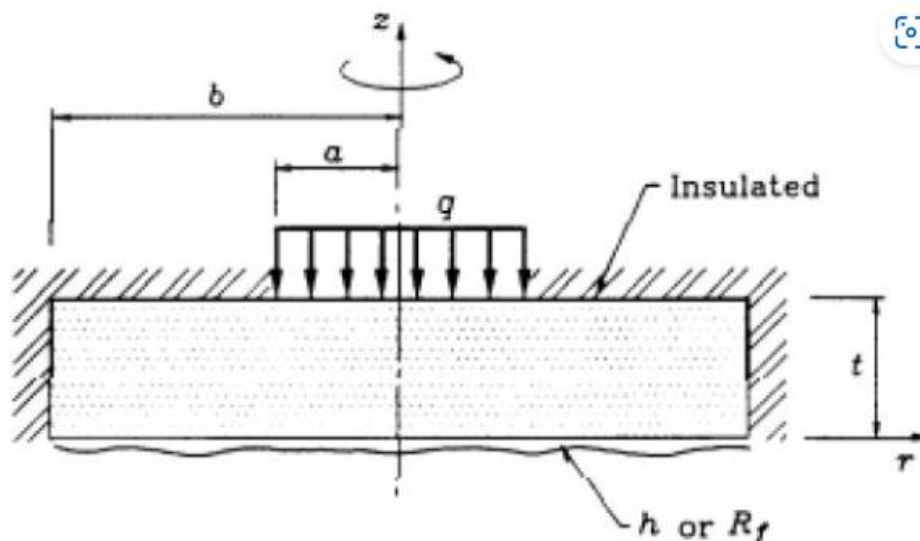


Fig. 3 Heat source on a heat sink base.

The heat, q , is generated at the source, spreads across the base, and dissipates into the fluid on the other side via the heat transfer coefficient, h . As shown in Equation, the effective heat transfer coefficient for heat transfer through finned heat sinks is related to the thermal resistance of the fins, R_f . [13-15]

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$$h = \frac{1}{R_f A_{fins}}$$

Table 1 .Thermal conductivity of bulk materials and thin films

Material	k_{film} , W/mK	k_{bulk} , W/mK
SiO ₂	0.4–1.1	1.2–10.7
TiO ₂	0.5–0.6	7.4–10.4
ZrO ₂	0.04	—
Al ₂ O ₃	0.72	20–46
MgF ₂	0.58	15–30
Air	—	0.025
Oxides/fluorides	—	1.0–10
Diamond I, II	—	1200–2300
Silicon	—	150

Table 1 shows a comparison of bulk and film conductivity. A wide range of thin films of oxides, fluorides, nitrides, amorphous metals, and semiconductors were measured in air. [16-18]

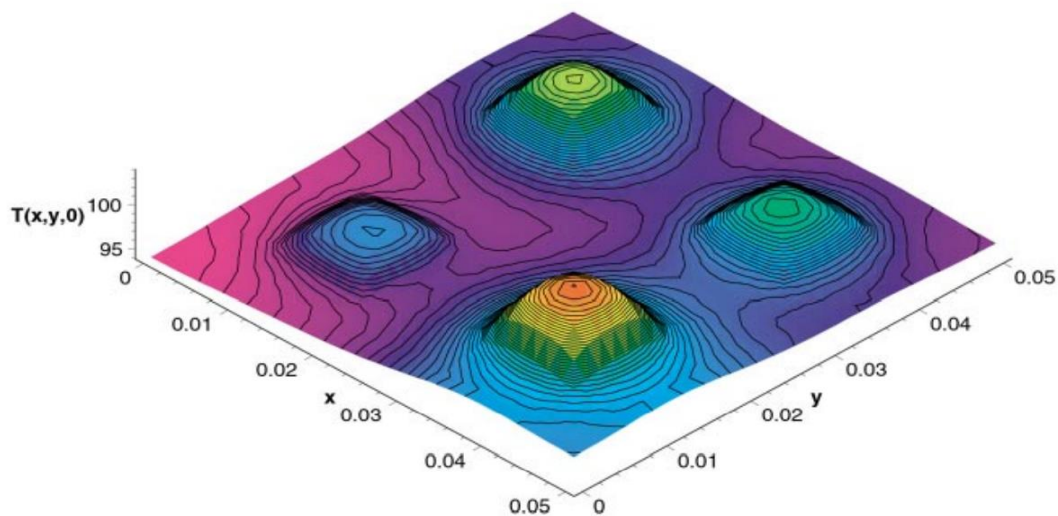


Fig. 4 Surface temperature for a heat sink with four heat sources

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The baseplate has dimensions of a550 mm, b550 mm, k5150 W/mK, t510 mm, and an effective extended surface heat transfer coefficient of h5400 W/m²K. Figure 4 summarises the temperature results.

As shown in Fig. 5, the spreading thermal resistance R includes spreading resistance and one-dimensional conductive material resistance. The spreading thermal resistance over different input powers obtained by simulation with 80 × 80 mm² is shown in Fig. [19-20].

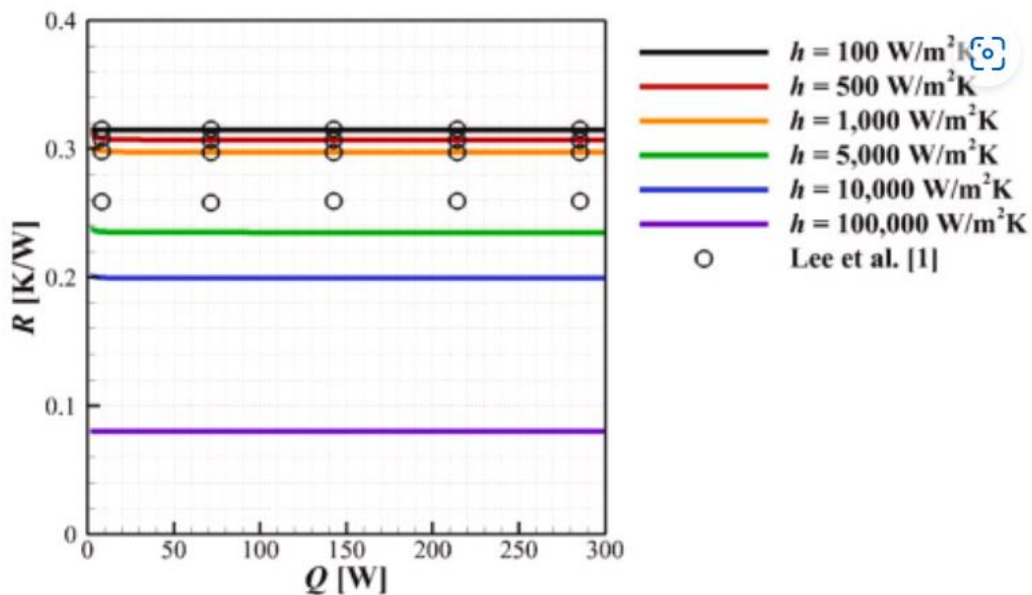


Fig. 5 Spreading thermal resistance over different powers at $k_{eff} = 400$ W/mK and $t = 2$ mm.

V. CONCLUSION

When designing a heat sink for cooling electronics components, heat spreading resistance is an important consideration. If spreading resistance is a major barrier to cooling, techniques such as higher conductivity materials, embedded heat pipes, vapour chambers, and so on are available. The increased weight and cost of such techniques must be balanced against the benefits for each application by thermal engineers. When the spreading thermal resistance decreases or the heat sink area increases while the spreading thermal resistance value remains constant, the effective thermal conductivity increases. Furthermore, when the heat source area is smaller and the heat sink area is larger, the effective thermal conductivity increases. Thermal resistance varies slightly between two heat transfer coefficients ranging from 100 W/m²K to 1,000 W/m²K.

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