Thermal Management

Why do we need Thermal Management?

As power density and complexity increases in electronic devices the amount of heat also increases. If this heat is not managed in an appropriate manner than this can lead to reduced life-times and product failures.

What is Thermal Management?

All electrical energy supplied to electronic devices is dissipated as heat. Thermal management is the controlled dissipation of this heat. This is achieved by providing an effective thermal path from the junction to the ambient environment using all modes of heat transfer:

- **Conduction**
- **Convection**
- **Radiation**

Any engineering surface is rough on a microscopic scale level, due to the presence of microscopic asperities. When two such rough surfaces come in contact, the actual contact occurs only at a few discrete spots, usually at the high points of the two surfaces Heat flowing from one body into the other is constricted to flow through the actual contact spots, because the thermal conductivity of the solid contact spots is much higher than that of the surrounding gap which is filled with air in most engineering applications.

Thermal interface materials (TIMs) are often inserted between the surfaces of a contact pair to reduce the thermal contact resistance. Although they typically have lower thermal conductivity than the substrate, they are highly compliant and hence under the application of relatively small contact pressures, deform to conform to the geometry of the adjacent rough surfaces. A part of the low thermal conductivity air present is thus replaced by a higher conductivity material. This leads to a decrease in the constriction of the heat flow lines, and hence, an increase in the contact conductance.

Heat Transfer Definitions

Thermal Conductivity (k) – is an intrinsic property of a material's ability to conduct heat. This is independent of material size, shape or orientation. Heat transfer across materials of high thermal conductivity occurs at a faster rate than across materials of low thermal conductivity. The thermal conductivity of a material is heavily dependent on the conditions under which it is used:

First, we define heat conduction, "H":
: $H=\frac{\Delta Q}{\Delta t} = k A\frac{\Delta T}{x}$
where $\frac{\Delta Q}{\Delta t}$ is the rate of heat flow, ''k'' is the thermal conductivity, ''A'' is the total cross sectional area of conducting surface, Δ''T'' is temperature difference, and ''x'' is the thickness of conducting surface separating the two temperatures. Dimension of thermal conductivity = M¹L¹T^{−3}K^{−1}

Rearranging the equation gives thermal conductivity:
: $k=\frac{\Delta Q}{\Delta t} \frac{1}{A} \frac{x}{\Delta T}$
(Note: $\Delta T/x$ is the temperature gradient)

I.E. It is defined as the quantity of heat, Δ''Q'', transmitted during time Δ''t'' through a thickness ''x'', in a direction normal to a surface of area ''A'', per unit area of A, due to a temperature difference Δ''T'', under steady state conditions and when the heat transfer is dependent only on the temperature gradient.

Alternatively, it can be thought of as a [[flux]] of heat (energy per unit area per unit time) divided by a temperature gradient (temperature difference per unit length)
:: $k=\frac{\Delta Q}{A \Delta t}\frac{x}{\Delta T}$

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Thermal Resistance (RĐ)

Thermal resistance is a measure of the ability of the material to conduct heat only after heat has entered the material across a specific thickness. From Fournier's law for heat conduction, the following equation can be derived, and is valid as long as all of the parameters (x, A, and k) are constant throughout the sample.

Where:

- RĐ is the thermal resistance (across the length of the material) (K/W)
- x is the length of the material (measured on a path parallel to the heat flow) (m)
- k is the thermal conductivity of the material (W/(K·m))
- A is the total cross sectional area of the material (measured perpendicular to the heat flow) (m2)

This is usually quoted as the thermal resistance from the unction to case of the semiconductor device. The units are °C/W.

For example, a heatsink rated at 10 K/W will get 10K hotter than the surrounding air when it dissipates 1 Watt of heat. Thus, a heatsink with a low K/W value is more efficient than a heatsink with a high K/W value.

Thermal Impedance (ø)

The thermal impedance (ø) of a material is defined as the sum of its thermal resistance and any contact resistance between it and the contacting surfaces, as defined by the equation:
(ø) = R material + R contact

Thermal Interface Materials (TIMs)

The two most desirable properties of a TIM are high thermal conductivity and high compliance. Since relatively few homogeneous materials possess both these properties, TIMs are typically composite materials with metallic or ceramic fillers in a polymeric matrix. Typically used fillers such as alumina (Al O) or boron nitride (BN) are characterized by relatively high thermal conductivity and low compliance. Most matrix materials, e.g., silicone, have low thermal conductivity but high compliance. In view of practical applications, optimal volume fractions and geometric distributions of filler and matrix materials are sought at which the contact conductance assumes a maximum value.

The primary function of a TIM is to:

- **Reduce thermal impedance across gaps**
- **Replace air with more thermally conductive materials**
- **Conform to surface irregularities**

The secondary function of a TIM is:

- **Electrical isolation**
- **Attachment**

Optimization of Heat Transfer

To optimize heat transfer across a joint it is necessary that:

- **The surface is as flat as possible**
- **Surfaces must be in contact**
- **The interface material must fill the voids only**