Package Thermal Characteristics in a Space Environment

Space Products

Technical Note

1. Introduction

The thermal performance of semiconductor packages is a very important parameter to be taken in consideration when designing an application board. Indeed, the reliability and functional life of the device is directly related to its junction operating temperature. As the temperature of the device increases, the stability of its junctions decline, as does its reliable life. The necessary taking into account of the thermal performances introduces constraints into the design of the boards: limitation of the board density, limited freedom for the location of high power dissipating devices on the board, or requirement of expensive cooling method for the system. As devices have become more complex and boards have become denser, the need of taking into account for the thermal characteristics of packages has shifted from being a minor consideration to being a necessary consideration.

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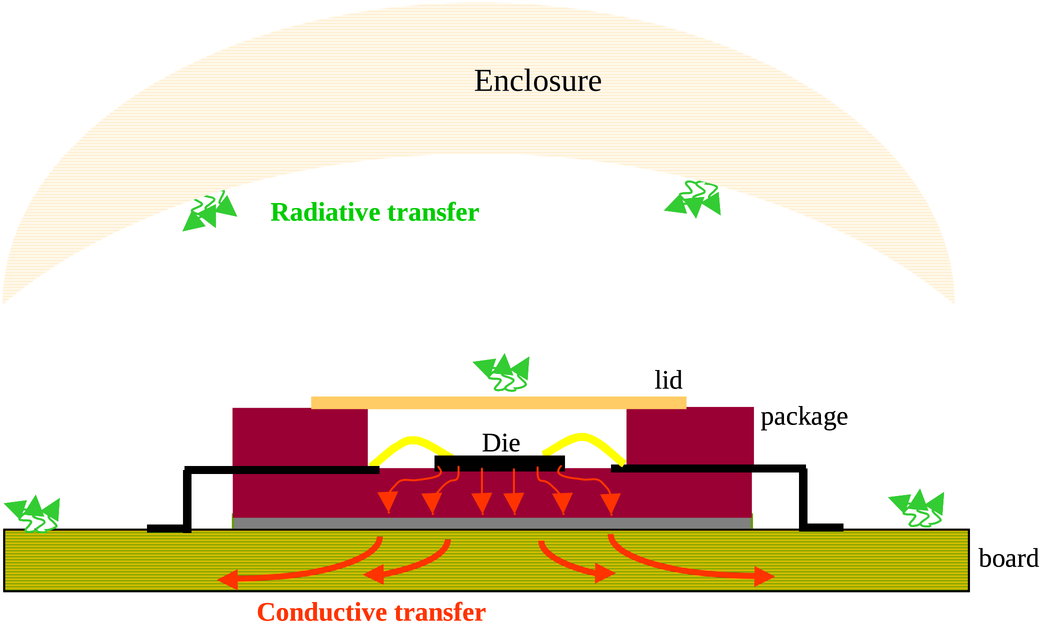
2. Characteristics

The thermal performance of a package is measured by its ability to dissipate the power required by the device into its surroundings. The electrical power drawn by the device generates heat on the top surface of the die. This heat is conducted through the package to the surface and then dissipated by radiative transfer and conductive transfer to the board. In space environment, no convective transfer occurs (Figure 2-1).

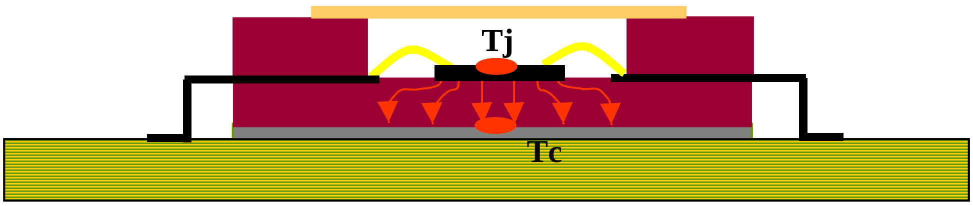
Figure 2-1. Heat Transfer in a device



It may be easily shown that the thermal resistance of the cavity and of the surrounding between the lid and the enclosure is very high compared to the thermal resistance of the package. So, we assume that nearly all the heat flow is dissipated by conduction through the board.

The capability of a package to transfer the heat flow is defined by its resistance junction-to-case Rjc. This parameter represents the resistance between the die’s active surface (junction) and a specified reference point (board, bottom or top of package). In our calculation or measurement, as we assume that all or nearly all the heat flux spreads out to the board through the bottom of the package, the reference point has been defined as the bottom of the case (Figure 2-2).

Figure 2-2. Reference points and heat path



3. Model

In thermal steady-state, the resistance junction-to-case is defined by the following equation:

$$R_{jc} = \frac{T_j - T_c}{P}$$

Where:

- Tj is the junction temperature of the device (K)
- Tc is the case temperature at the bottom of the package (K)
- P is the dissipated power nearly equivalent to the operating power (W)
- Rjc is the resistance junction to case (K/W)

It has to be noticed that Rjc is independent on the dissipated power, but depends on package and die characteristics as:

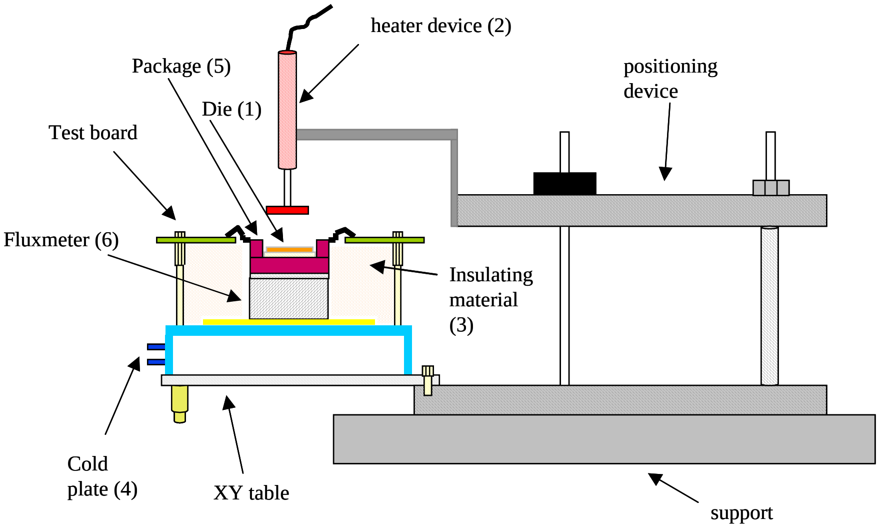
- the thermal conductivities of die attach, package ceramic and thermal join between package and board.
- Die, cavity and package sizes.

4. Experimental Method

The experimental device is shown in Figure 4-1. A heater device (2) impose a constant heat flux P on all the area of the die (1). The system is insulated on each side (3) in order to avoid convective transfer, except on the bottom side where the temperature is imposed by a cold plate (4). So, we assume that nearly all the heat flux P spreads out to the cold plate (heatsink) through the package (5).

According to model equation, Rjc is obtained by the measurement of P, Tc and Tj, in thermal steady-state.

Figure 4-1. Experimental device



4.0.1 Determination of P

A fluxmeter (6) is composed of two conductive plates separated by a PVC plate, of known dimensions (section S, thickness e0) and thermal conductivities ($\lambda 0$) (Figure 4-2). The temperature of each plate of aluminium is measured by thermocouples (T1 and T2).

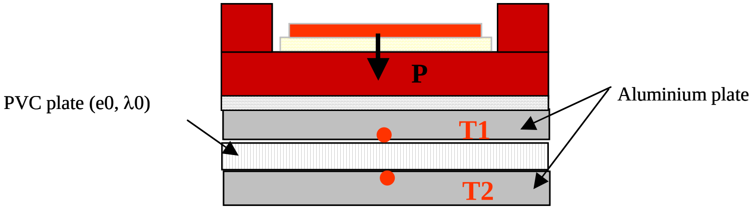
The heat flow is calculated by:

$$\mathbf{P} = \frac{\mathbf{T}_1 - \mathbf{T}_2}{\mathbf{R}_0}$$

with

$$\mathbf{R}_0 = \frac{\mathbf{e}_0}{\mathbf{S} * \lambda_0}$$

Figure 4-2. Fluxmeter Description



4.0.2 Determination of Tc

Tc is measured with a thermocouple in the aluminium plate under the package. The contact between package and aluminium plate is assumed to be perfect, as it is assured with a very conductive glue.

4.0.3 Determination of Tj

ESD protection diodes (4 by die, 1 at each edge) are used as temperature sensors.

A preliminary calibration, in isothermal conditions, is performed in the temperature range [-55°C, +125°C], and leads to obtain the variation law of the junction voltage versus the junction temperature. It may be shown that:

where: $\Delta \mathbf{V}_\mathbf{j} = \alpha(\mathbf{I}_0) * \Delta \mathbf{T}_\mathbf{j}$

$\alpha(I_0)$ is the thermal sensitivity of the junction voltage in V/K. The applied current I_0 has to be sufficiently high to permit Δ_{Vj} measurement and sufficiently low to not induce junction heating.

- $\Delta T_j = T_j - T_{ambiant}$
- $\Delta V_j = V_j(T) - V_j(T_{ambiant})$

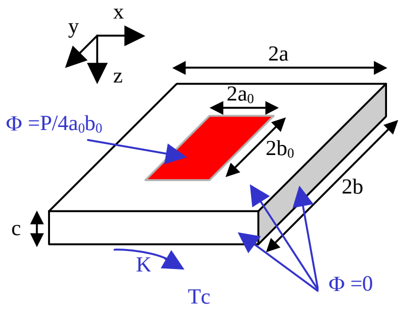
Then, α being known, the measurement of ΔV_j when heater device is switched on, according to Figure 4-1 conditions, gives the overheating of the junction ΔT_j.

5. Analytical Calculation

The thermal resistance of the package is calculated by resolving the heat transfer equation in the simplified following system *(Figure 5-1)*:

Figure 5-1. Simplified geometry of the package

$$
\begin{cases}
\dfrac{\partial^2 T}{\partial x^2}+\dfrac{\partial^2 T}{\partial y^2}+\dfrac{\partial^2 T}{\partial z^2}=0 \\
x=0 \text{ and } 2a \quad \dfrac{\partial T}{\partial x}=0 \\
y=0 \text{ and } 2b \quad \dfrac{\partial T}{\partial y}=0 \\
z=0 \quad -\lambda\dfrac{\partial T}{\partial z}=\begin{cases}\dfrac{P}{4a_0b_0}\text{if } x\in\left[a-a_0,a+a_0\right]\text{and } y\in\left[b-b_0,b+b_0\right] \\ 0 \quad \text{elsewhere}\end{cases} \\
z=c \quad -\lambda\dfrac{\partial T}{\partial z}=K\left(T-T_c\right)
\end{cases}
$$



K represent the thermal interface between package and board.
For instance, in the case of a MCGA, K is the equivalent thermal conductance of the leads (K/m².K)

The thermal resistance Rjc may be expressed by a double Fourier serie as follow:

$$R_{jc}=\frac{1}{\lambda}\sum_{m=0}^{\infty}\sum_{n=0}^{\infty}F_{m,n}\left(n,m,,a,b,a_0,b_0,\frac{Kb}{\lambda},\frac{Ka}{\lambda}\right)$$

$F_{m,n}$ depends on package dimension (a,b) and die dimension (a_0,b_0), thermal property of package (λ) and interface property (K).

6. Thermal Data

Following tables present calculated resistance junction to case.

6.1 ASIC's results

Please note that thermal information is provided as a guideline, the data cover specific cavities and die sizes only. For specific thermal data, contact your local sales representative.

Package type	lead				R_{jc} (K/W)
	count	form	pitch (inch)	material	
Multilayer ceramic quad flat pack - MQFP	100	F	0,025	Alloy42 / Kovar	8
	132	F	0,025	Alloy42 / Kovar	7
	160	F	0,0256	Alloy42 / Kovar	2
	196	F	0,025	Kovar	6
	256	F	0,02	Kovar	4
	352	T	0,02	Kovar	4
Multilayer column grid array - MCGA	349	Columns	0,05	PbSn 90/10	3
	472	Columns	0,05	PbSn 90/10	2

6.1.1 Standard products

Product	Package	lead				Rjc (K/W)
		count	form	pitch (inch)	material	
65608	MFP	32	F	0,05	Alloy 42 / Kovar	2
65609	MFP	32	F	0,05	Alloy 42 / Kovar	4
AT60142	MFP	36	F	0,05	Alloy 42 / Kovar	3
AT17LV010	MFP	28	F	0,05	Alloy 42 / Kovar	8
AT28C010	MFP	32	F	0,05	Alloy 42 / Kovar	3
67025	MQFP	84	F	0,05	Kovar	6
67204	MFP	28	F	0,05	Alloy 42 / Kovar	3
67206(1)	MFP	28	F	0,05	Alloy 42 / Kovar	3
AT40KEL040	MQFP	160	F	0,0256	Alloy42 / Kovar	2
AT40KEL040	MQFP	256	F	0,02	Kovar	2
TSC21020	MQFP	256	F	0,02	Kovar	3
TSC695	MQFP	256	F	0,02	Kovar	3
29C516	MQFP	100r	F	0,0256	Alloy 42	5
TSS901	MQFP	196	L	0,025	Alloy 42	4
T7906	MQFP	100	F	0,025	Alloy42 / Kovar	5

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