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Thermal Performance Information by Contact Pressure for a Motion-SPM™ Smart Power Module in Tiny-DIP SPM® package

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Introduction

Semiconductor devices are very sensitive to junction temperature. As the junction temperature increases, the operating characteristics of a device are altered and the failure rate increases exponentially. This makes the thermal design of the package a very important factor in the device development stage and in an application.

Motion-SPM™ smart power module family, the Tiny-DIP SPM® package doesn't have any mounting hole in the package, shown in Figure 1.

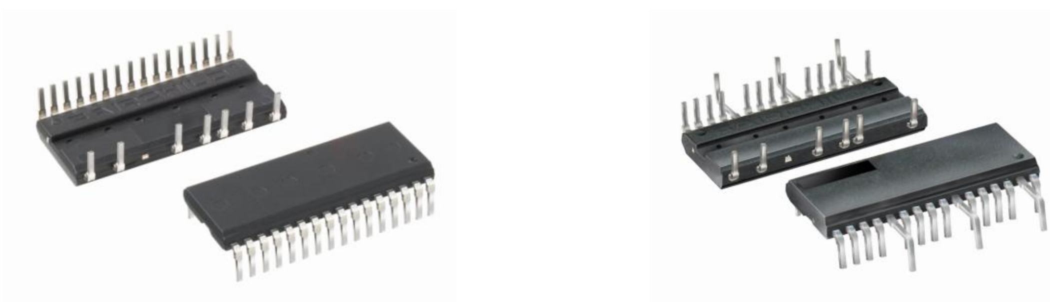

Figure 1. Package outline of Tiny-DIP SPM® series (DIP PKG and Double DIP PKG).

This article will thermal performance information by contact pressure, as well as, it is common to introduce semiconductor device's thermal performance.

What is thermal resistance?

To gain insight into the device's thermal performance, it is common to introduce thermal resistance, which is defined as the difference in temperature between two adjacent isothermal surfaces, divided by the total heat flow between them. For semiconductor devices, the two temperatures are junction temperature, T_J, and reference temperature, T_x. The amount of heat flow is equal to the power dissipation of a device during operation. The selection of a reference point is arbitrary, but the hottest spot on the back of a device on which a heat sink is attached is usually chosen. This is called junction-to-case thermal resistance, $R_{\theta JC}$. When the reference point is an ambient temperature, this is called junction-to-ambient thermal resistance, $R_{\theta JA}$. Both the thermal resistances are used for characterization of a device's thermal performance. $R_{\theta JC}$ is usually used for heat-sink carrying devices, while $R_{\theta JA}$ is used in other cases. **Error! Reference source not found.**2 shows a thermal network of heat flow from junction-to-ambient for the SPM® package, including a heat sink.

The dotted component of $R_{\theta CA}$ can be ignored due to its large value.

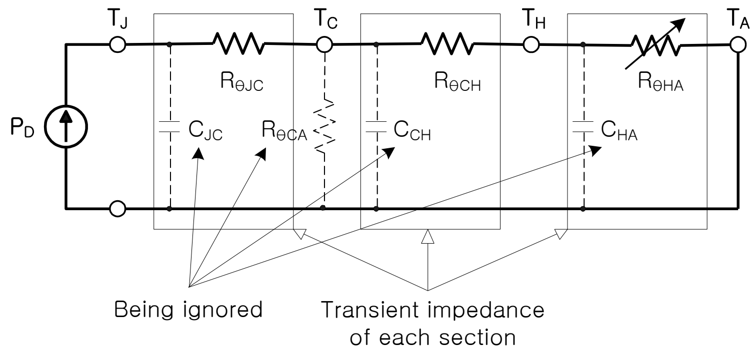

Figure 2. Transient Thermal Equivalent Circuit with a Heat Sink

In this device application, a heat sink is using set case like Figure 3.

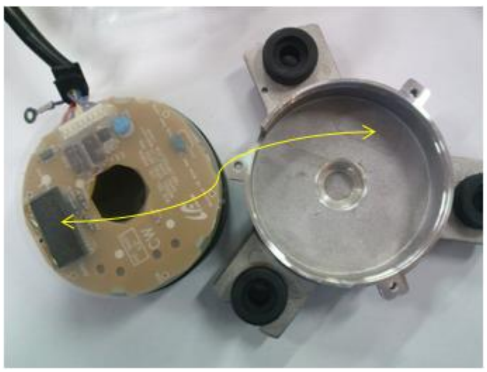

Figure 3. Transient Thermal Equivalent Circuit with a Heat Sink

For a simulation model, Figure 3 can convert to Figure 4. There is a Thermal Interface Material (T.I.M. like a Thermal Pad) between the device surface and the set case.

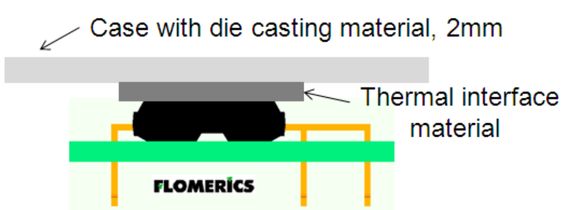

Figure 4. Thermal Simulation model

When the reference point is a set case temperature, this is called junction-to-set case thermal resistance, $R_{\theta JS}$. Figure 5 shows a thermal network of heat flow from junction-to-set case for the SPM® package, including a T.I.M. The T_T is the T.I.M. temperature and T_s is the set case temperature. The dotted component can be ignored due to its large value.

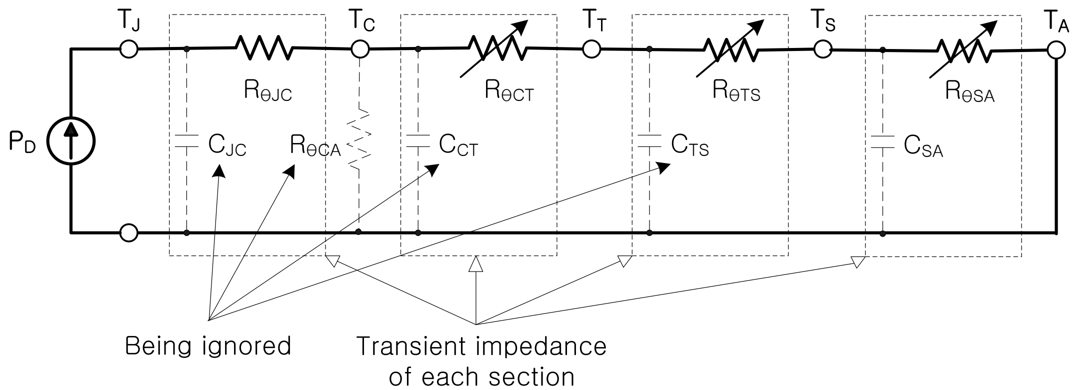

Figure 5. Thermal Simulation model

The thermal resistance of the SPM® package is defined in the following equation:

$$R_{\theta JC} = \frac{T_J - T_C}{P_D} \qquad (1)$$

where $R_{\theta JC}$ (°C/W) is the junction-to-case thermal resistance and P_D (W), T_J (°C), and T_C (°C) are power dissipation per device, junction temperature, and case reference temperature, respectively. By replacing T_C with T_S (set case temperature), the junction-to-set case thermal resistance $R_{\theta JS}$ can be obtained as:

$$R_{\theta JS} = \frac{T_J - T_S}{P_D} \qquad (2)$$

where $R_{\theta JS}$ is important parameter to estimate the thermal performance of the SPM® package, including the T.I.M and the set case. $R_{\theta JS}$ is a serial summation of thermal resistances, $R_{\theta JC}$, $R_{\theta CT}$, and $R_{\theta TS}$:

$$R_{\theta JS} = R_{\theta JC} + R_{\theta CT} + R_{\theta TS} \qquad (3)$$

The thickness and thermal conductivity of thermal pad influences the device thermal performance. An infinite heat sink results if $R_{\theta SA}$ is reduced to zero, so is excluded here.

Mechanical Deformation

Thickness is affected by case joint pressures so it is necessary to consider the hardness of SPM® package. Hardness of Tiny-DIP SPM® package is over 20,000N. This value is large enough to endure some PCB bending or T.I.M deflection. When the case is designed, the designer has to consider PCB hardness and T.I.M. deformation first. Figure 6 shows the compression test method.

Figure 7 shows the deformation test result when thickness of T.I.M is 2mm. It said that the deformation process: T.I.M. → PCB & SPM package lead → SPM package, however, PCB is not deformed because the package surface is in contact with a wide surface of PCB for the SPM package itself test.

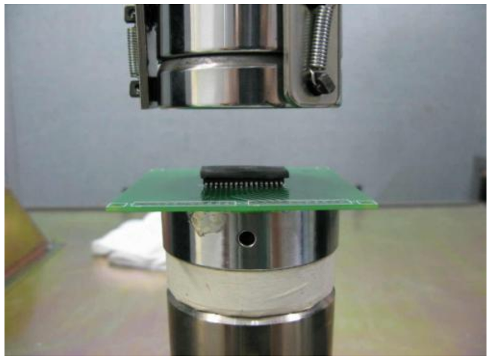

Figure ***６.*** **Compression Test with SPM package, PCB and 2mm T.I.M**

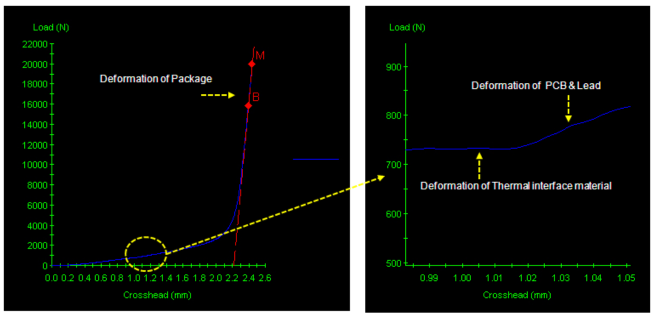

Figure ***７.*** **Compression Test Results : X Axis = Deformation Thickness, Y Axis = Pressure**

Thermal Resistance Simulation

Case thickness and surface diameter are not affected at thermal resistance shown in Figure 8.

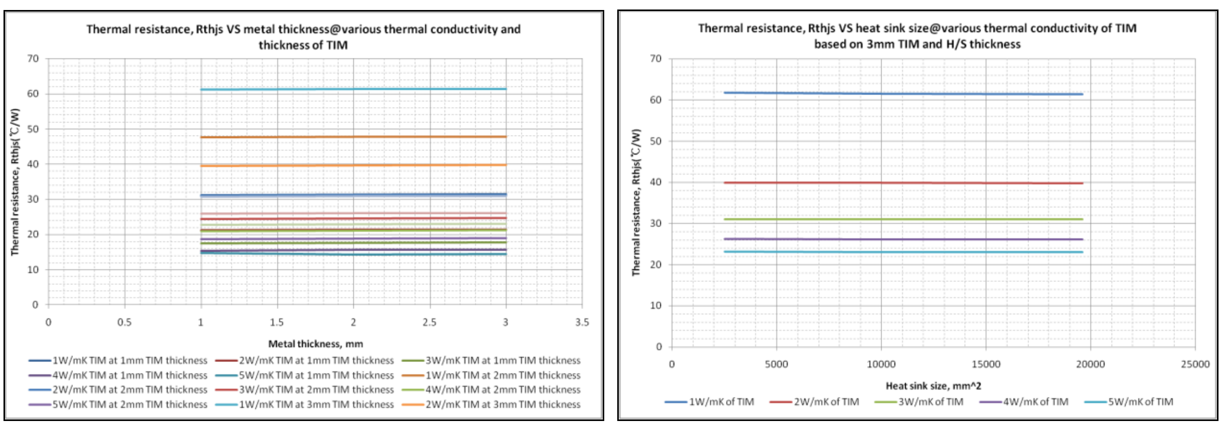

Figure ８. Thermal Resistance by Metal Thickness (Case thickness) and Heat Sink Size(Case surface diameter)

The most affected thermal resistance is the thermal conductivity and thickness of T.I.M, as shown in Figure 9.

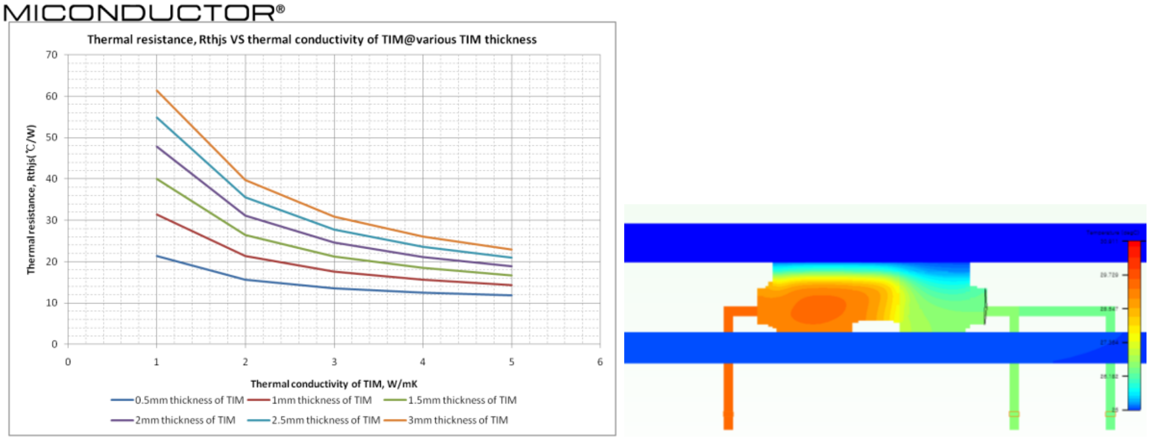

Figure ９. Thermal Resistance by Thermal Conductivity of T.I.M and simulation result(0.5mm, 5W/mK)

Thermal Performance

In case of Fairchild part FSB50550U, thermal performance is calculated as:

$$R_{\theta JS} = R_{\theta JC} + R_{\theta CT} + R_{\theta TS} \quad (4)$$

Thermal resistance $R_{\theta JS}$ is not affected by metal thickness and heat sink size, so $R_{\theta SA}$ is ignored. Figure 10 shows the simulation results when thickness of T.I.M is 0.5&1.0 mm and thermal conductivity is 1&5W/mK.

Simulation condition:

V_{PN}= 400V, V_{CC}= 15V, $V_{CE(SAT)}$= typical, switching loss= typical, T_J= 150°C, T_C=100°C, PF= 0.9, PWM method = 3-phase continuous.

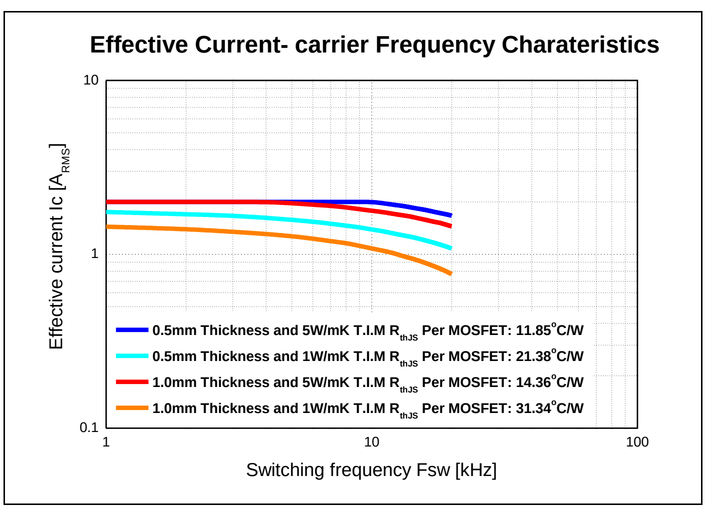

Figure １０. Simulation Results (Effective Current Carrier Frequency Characteristics)

Figure 10 indicates an example of an inverter operated under the condition of T_C=100^{o}C. It indicates the effective current I_C that can be output when the junction temperature T_J rises to the average junction temperature of 150^{o}C (up to which the Tiny-DIP SPM® package operates safely)

Conclusion

According to the simulation results, thermal resistance of junction to case is affected by T.I.M of the material, which is the thickness and thermal conductivity.

For more information about how to reduce thermal resistance as follows: thin thermal pad and thermal conductivity (strong as possible the contact is important)

Base on this article, the Tiny-DIP SPM® package is using more adjusted power level by calculating the power loss according to the simulated results.