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AN-9082

Motion SPM® 5 Series Thermal Performance Information by Contact Pressure

Overview

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.

To gain insight into the device's thermal performance, it is standard 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 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 the 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. Figure 1 shows a thermal network of heat flow from junction-to-ambient for the motion SPM® products including a heat sink. The dotted component of $R_{\theta CA}$ can be ignored due to its large value.

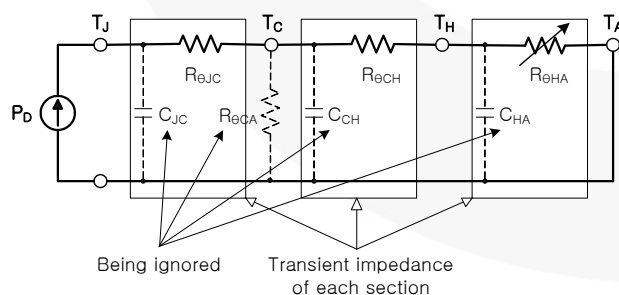


Figure 1. Transient Thermal Equivalent Circuit with Heat Sink

Motion SPM 5 Series doesn't have any screwing hole in the package, as shown in Figure 2.

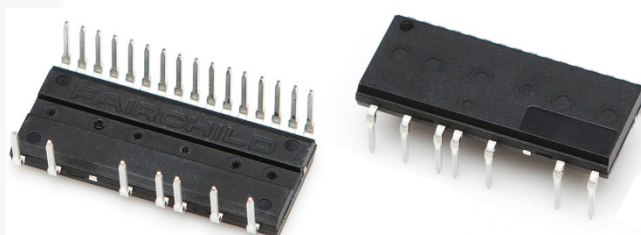


Figure 2. Package Outline of Motion SPM 5 Series

In this device application, a heat sink is used in the set case, like Figure 3.

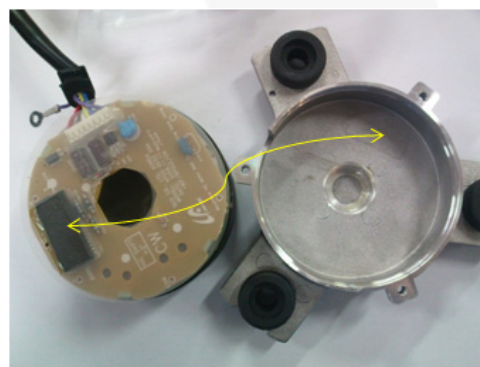


Figure 3. Set Configuration of Motion SPM 5 Series

For simulation models, Figure 3 can convert as shown in Figure 4. There is a Thermal Interface Material (TIM like a thermal pad) between the device surface and the set case.

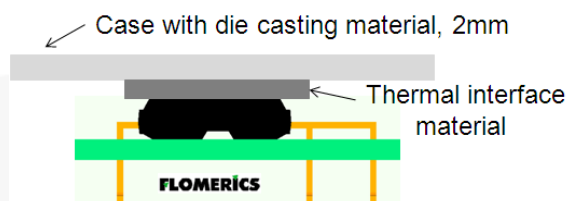


Figure 4. Thermal Simulation Model

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 Motion SPM 5 series, including a TIM. The T_J is the TIM temperature and T_s is the set case temperature. The

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

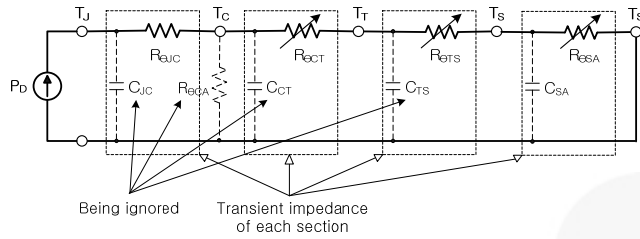


Figure 5. Transient Thermal Equivalent Circuit with TIM

The thermal resistance of Motion SPM 5 series is defined in the following equation:

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

where:

$R_{\theta JC}$ ($^{\circ}\text{C}/\text{W}$) is the junction-to-case thermal resistance;
 P_D (W) is power dissipation per device;
 T_J ($^{\circ}\text{C}$) is junction temperature; and
 T_C ($^{\circ}\text{C}$) is case reference temperature.

By replacing T_C with T_S (set case temperature), the junction-to-set case thermal resistance $R_{\theta JS}$ can be obtained as:

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

where:

$R_{\theta JS}$ indicates the total thermal performance of Motion SPM 5 series, including the TIM and the set case; and
 $R_{\theta JS}$ is a serial summation of various thermal resistances, $R_{\theta JC}$, $R_{\theta CT}$, and $R_{\theta TS}$ defined in:

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

The thickness and thermal conductivity of Thermal pad influenced in the device thermal performance.

Mechanical Deformation

Because thickness is affected by case joint pressure, it is necessary to consider the hardness of the package. Hardness of Motion SPM 5 series is over 20,000 N. This value is large enough to endure PCB bending or TIM deflection. The case designer must consider PCB hardness and TIM deformation.

Figure 7 shows the deformation test results when thickness of TIM is 2 mm. It is said that the deformation process is: TIM \rightarrow PCB and SPM package lead \rightarrow SPM package. However, the PCB is not bent because the test surface contacts a wide surface are in the PCB for Motion SPM 5 series products.

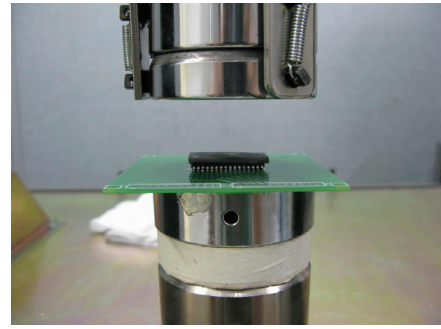


Figure 6. Compression Test with Motion SPM 5 Series, PCB, and 2 mm TIM

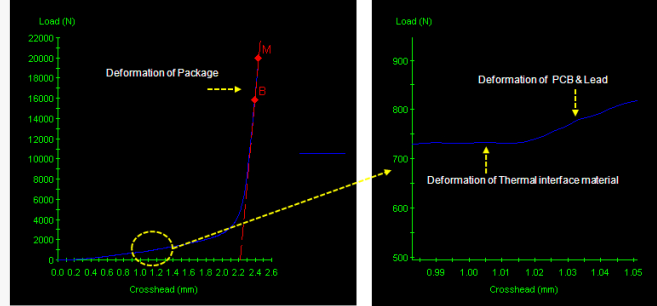


Figure 7. Compression Test Results:
X Axis – Deformation Thickness, Y Axis - Pressure

Thermal Resistance Simulation

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

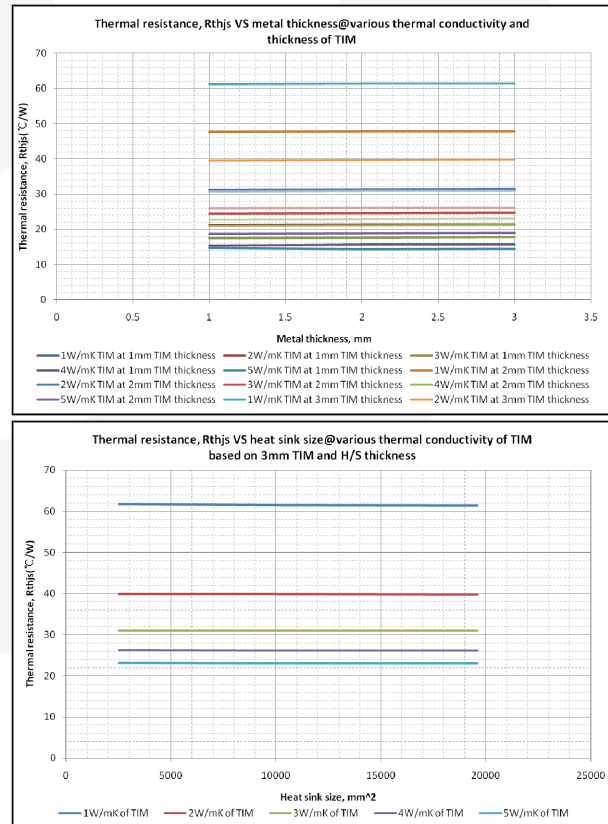


Figure 8. Thermal Resistance by Metal Thickness (Case Thickness) and Heat Sink Size (Case Surface Diameter)

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

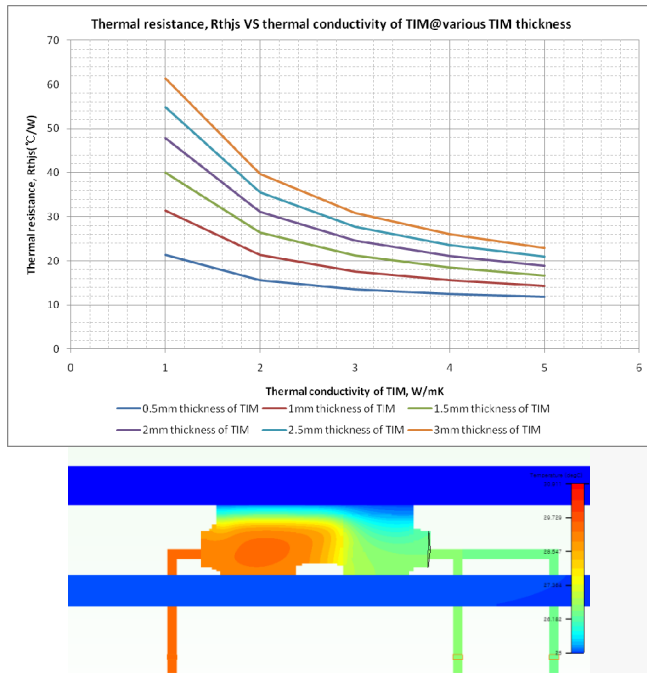


Figure 9. Thermal Resistance by Thermal Conductivity of TIM and Simulation Result (0.5 mm, 5 W/mK)

Thermal Performance

In the case of FSB50550A, which is a Motion SPM 5 series ver.2 product, 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 the thickness of TIM is 0.5 and 1.0 mm and thermal conductivity is 1 and 5 W/mK.

Simulation Condition:

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

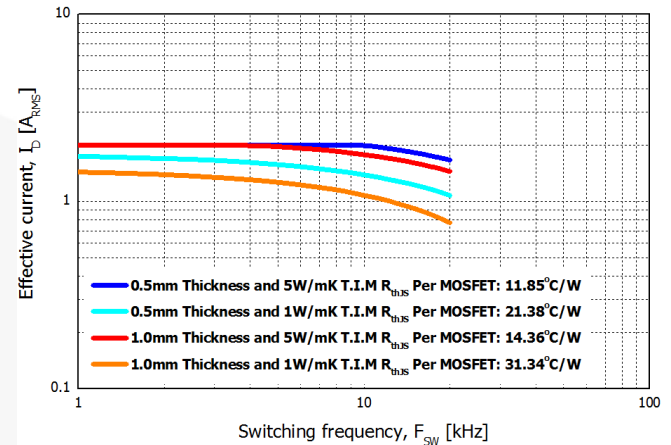


Figure 10. Simulation Results (Effective Current Carrier Frequency Characteristics)

Figure 10 is an example of an inverter operated under the condition of $T_C = 100^\circ\text{C}$. It shows the effective current, I_D , which can be output when the junction temperature, T_J , rises to the average junction temperature of 150°C (up to which the FSB50550A operates safely).

Conclusion

According to the simulation results, thermal resistance of junction to case is affected by the thickness and thermal conductivity of the TIM. Thus, thinner thermal pad and better thermal conductivity are required to reduce thermal resistance. This requirement can be achieved when the contact between Motion SPM and the TIM is strong enough.

Designer can adjust output power level with calculating power loss referring to the simulation result in this application note.

Related Datasheets

[FSB50250 – Smart Power Module \(SPM®\)](#)

[FSB50450 – Motion SPM®](#)

[FSB50450S – Smart Power Module \(SPM®\)](#)

[FSB50550T – Smart Power Module \(SPM®\)](#)

[FSB50325T – Smart Power Module \(SPM®\)](#)

[FSB52006S – Smart Power Module \(SPM®\)](#)

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[FSB50825US – Smart Power Module \(SPM®\)](#)

[FSB50250A – Smart Power Module \(SPM®\)](#)

[FSB50250AS – Smart Power Module \(SPM®\)](#)

[FSB50250AT – Smart Power Module \(SPM®\)](#)

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