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AN-9087

600V Motion SPM® 3 ver5 Series Thermal Performance Information

Overview

Semiconductor devices are very sensitive to junction temperature. As the junction temperature increases, the operating characteristic of a device is altered and the failure rate increases exponentially. This makes the thermal design of the package very important in the device development stage and in applications. In particular, contact pressure or mounting torque can affect thermal performance. This application note shows a correlation between the mounting torque and the 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 power flow between them. For semiconductor devices, junction temperature, T_J, and reference temperature, T_x, are typically used. The amount of power 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, it is called junction-to-ambient thermal resistance, $R_{\theta JA}$. Both are used for characterization of a device's thermal performance. $R_{\theta JC}$ is usually used for a device mounted on a heat-sink, while $R_{\theta JA}$ is for a device used without a heat sink. Figure 1 shows a thermal network of heat flow from junction-to-ambient for the motion SPM, including a heat sink. The dotted component of $R_{\theta CA}$ can be ignored due to its large value.

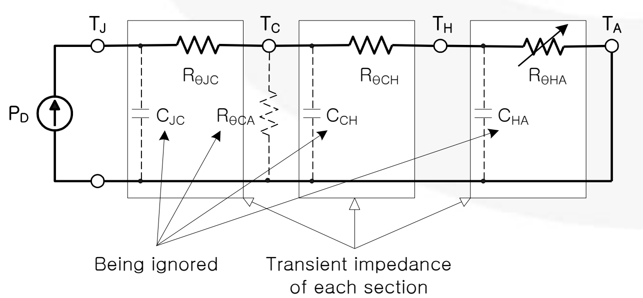

Figure 1. Transient Thermal Equivalent Circuit with Heat Sink

The thermal resistance of motion SPM is defined as:

$$R_{\theta JC} = \frac{T_J - T_C}{P_D} \tag{1}$$

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 ambient temperature (T_A), the junction-to-ambient thermal resistance $R_{\theta JA}$ can be obtained as:

$$R_{\theta JA} = \frac{T_J - T_A}{P_D} \tag{2}$$

where $R_{\theta JA}$ indicates the total thermal performance of the SPM, including the heat sink. $R_{\theta JA}$ is basically a summation of thermal resistances; $R_{\theta JC}$, $R_{\theta CH}$ and $R_{\theta HA}$:

$$R_{\theta JA} = R_{\theta JC} + R_{\theta CH} + R_{\theta HA} \tag{3}$$

where $R_{\theta CH}$ is contact thermal resistance between the package case and the heat sink, where the gap is filled with thermal grease, and $R_{\theta HA}$ is heat sink thermal resistance. From Equation (3), it is clear that minimizing not only $R_{\theta JC}$, but also $R_{\theta CH}$ and $R_{\theta HA}$, is essential to maximize the power capability of the SPM. An infinite heat sink would result if $R_{\theta CH}$ and $R_{\theta HA}$ are assumed to be zero and the case temperature, T_C, would be locked at the fixed ambient temperature, T_A. Usually, the value of $R_{\theta CH}$ is proportional to the thermal grease thickness and governed by the skills at the assembly site, while $R_{\theta HA}$ can be adjusted slihgtly by selecting an appropriate heat sink.

In practical operations, the power loss, P_D, is not a constant DC value, but rather an AC value. Therefore, the transient RC equivalent circuit shown in Figure 1 should be considered. For pulsed power loss, the thermal capacitance delays the rise in junction temperature and thus permits a heavier loading of the 600 V Motion SPM 3 Series.

Figure 2 and Figure 3 show the thermal impedance curves of FSBB30CH60D. The thermal resistance goes into saturation in less than one second. Other types of Motion SPM products also show similar characteristics.

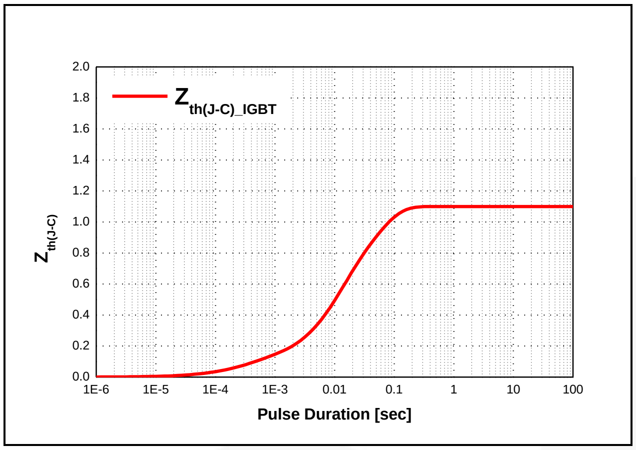

Figure 2. Thermal Impedance Curve IGBT of FSBB30CH60D

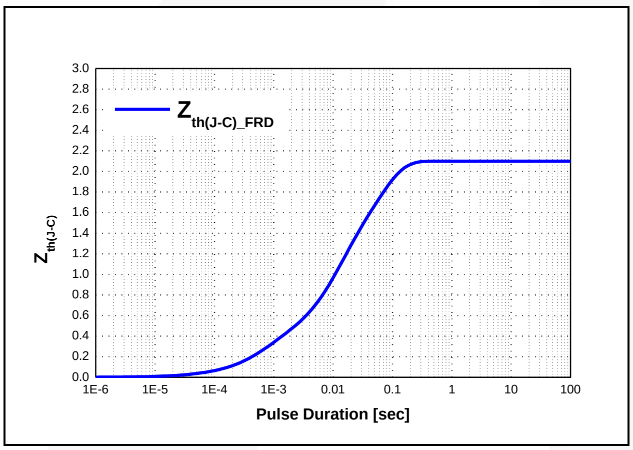

Figure 3. Thermal Impedance Curve FRD of FSBB30CH60D

If more details are required, please refer to *AN-9071*, which shows the thermal performance of the SPM 45 Series associated with various types of heat sinks.

Measurement Method of T_J

At the thermal resistance test, T_J, T_C (or T_A), and P_D should be measured. Since T_C, T_A, and P_D can be measured directly, the only unknown constant is the junction temperature, T_J. The Electrical Test Method (ETM) is widely used to measure the junction temperature. The ETM method is based on the relationship between forward-drop voltage and junction temperature. This relationship is an intrinsic electro-thermal property of semiconductor junctions and is found to be nearly linear when a constant forward-biased current (sense current) is applied. This voltage drop of the junction is called Temperature Sensitive Parameter (TSP). Figure 4 illustrates the concept of measuring the voltage drop vs. junction temperature for a diode. The device under test (DUT) is embedded in hot fluid to be heated to desired testing temperatures.

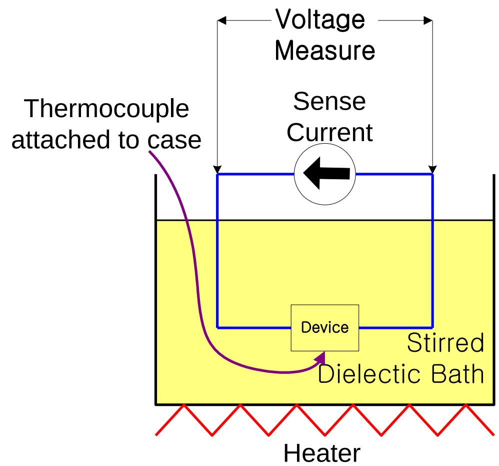

Figure 4. Illustration of the Bath Method for TSP Measurement

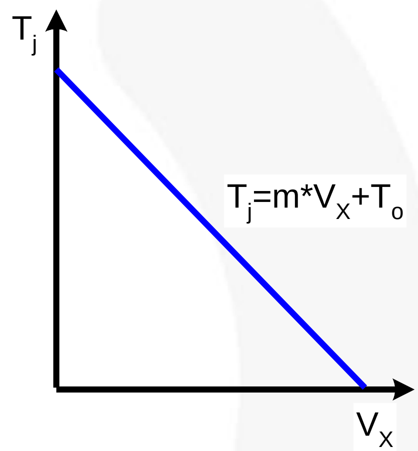

Figure 5. Example of a TSP Plot with Constant Sense Current

When the DUT attains thermal equilibrium with the hot fluid, a sense current is applied to the junction. Then the voltage drop across the junction is measured as a function of the junction temperatures. The amount of sense current should be small enough not to heat the DUT. For instance, 1 – 10 mA can be used, depending on the device type. The measurements are repeated over a specific temperature range with some specified temperature steps. Figure 9 shows a typical result.

The relationship between the junction temperature and voltage drop at a given temperature can be expressed as:

$$T_J = m * V_X + T_O \tag{4}$$

The slope, *m (℃/V)* and the temperature coordinate-intercept, T_O *(℃)*, are used to quantify this straight line relationship. The reciprocal of the slope is often referred to as the "K factor *(V/℃)*." In this case, V_X *(V)* is the TSP.

For semiconductor junctions; the slope, *m*, of the straight line in Figure 5 is always negative, i.e., the forward conduction voltage decreases with increasing junction temperature. This process of obtaining Equation (4) is called the calibration procedure for a given device.

During the thermal resistance measurement test, the junction temperature can be estimated from the measurement of the voltage drop at a given sense current during the calibration procedure and Equation (4). The TSP varies by device. If a specific device does not have the diode voltage TSP, transistor saturation voltage can be used instead. Gate turn-on voltage can be used as TSP for an IGBT or a MOSFET.

Measurement Procedure

The thermal resistance test begins by applying a continuous power of known current and voltage to the DUT. The continuous power heats up the DUT to a thermally equilibrated state. While the device is heating, a continuous train of sampling pulses monitors the TSP, i.e., the voltage drop or the same as the junction temperature. The TSP sampling pulse must provide a sense current equal to that used during the calibration procedure for obtaining equation (4). While monitoring the TSP, adjust the applied power so as to insure a sufficient rise in T_J. Adjusting the applied power to achieve a T_J increase of about 100℃ above the reference temperature will generate enough temperature difference to ensure a good measurement resolution. A typical example is shown in Figure 6.

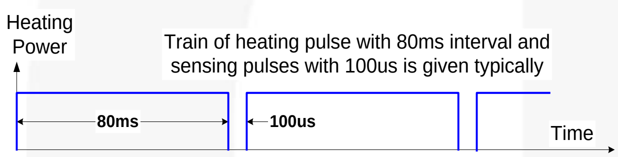

Figure 6. Example of a Power and Sample Pulses Train During the R_{JC} Measurement of a SPM-IGBT

The TSP sampling time must be very short so as not to allow for any appreciable cooling of the junction prior to re-applying power. The power and sensing pulse train shown in Figure 6 has a duty cycle of 99.9%, which for all practical purposes is considered to be continuous power. Obviously, most of the total power is applied to the DUT in Figure 7.

Once T_J reaches thermal equilibrium, its value along with the reference temperature T_C and applied power P is recorded. Using the measured values and equation (1), the junction-to-case thermal resistance $R_{\theta JC}$ can be estimated. $R_{\theta JC}$ here indicates the ability of a device to dissipate power in an ideal environment, that is, mounted with an infinite or temperature-controlled heat sink.

Figure 8 shows the thermal resistance measurement environment for SPMs. The SPM is placed on a heat sink having a large heat carrying capacity. Thermal grease is applied between the SPM and heat sink to prevent an air gap.

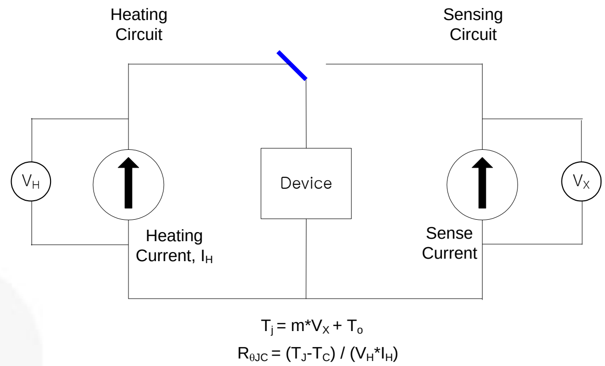

Figure 7. Illustration of the Thermal Resistance Test Method Concept

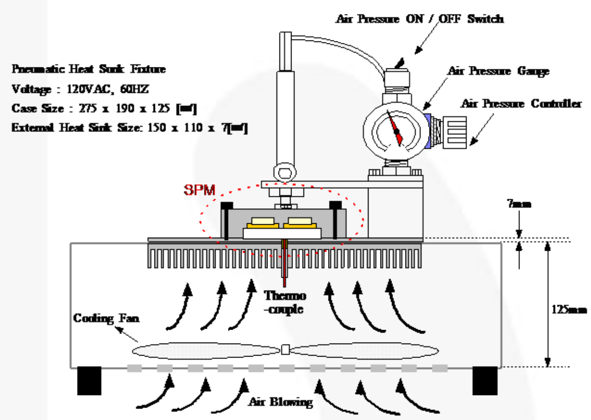

Figure 8. The Thermal Measurement Environment of the SPM

Measurement Results of T_J

The figures below are measurement results of device junction calibration of **FSBB30CH60D**: Figure 9 is for IGBT and Figure 1010 for FRD. The slope, *m (°C/V)*, and the temperature coordinate-intercept, T_o *(°C)*, are shown in Table 1.

Figure 9. Results of Device Junction Calibration for IGBT

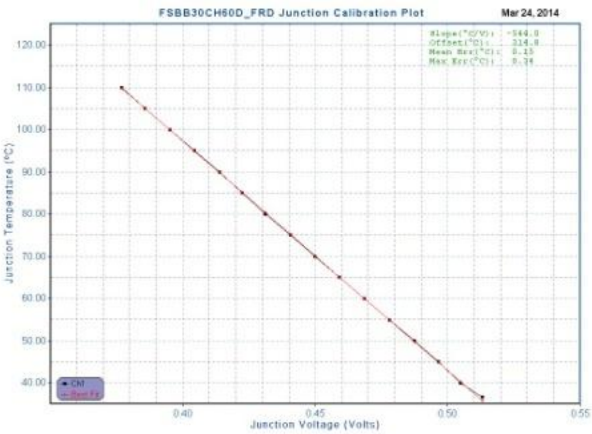

Figure 10. Results of Device Junction Calibration for FRD

Table 1. m (°C/V) and Temperature Coordinate-Intercept, T_o (V) for *FNA21012A*

Device		m(°C/V)	TO(°C)	Sensing Current
FSBB30CH60D	IGBT	-419.9	257.3	10 mA
	FRD	-544	314.8	

Thermal Resistance, $R_{\theta JC}$

The thermal resistance from junction to case, $R_{\theta JC}$, can be calculated from Equation (1). Usaully, the themal resistance is measured at two different points, package center and chip center. Table 2 shows values measured at chip center.

Table 2. $R_{\theta JC}$: Thermal Resistance, °C/W

Classification	SPL	P(W)	TJ	TC	RθJC
FSBB30CH60D Chip Center	#1	28.74	51.0	31.9	0.66
	#2	28.59	51.6	32.7	0.66

The $R_{\theta JC}$ on SPM product datasheets is based on chip center values and has margin to cover manufacturing variations.

Actual Measure Point

Figure 11 shows real measuring points and Figure 12 shows the detecting point of case temperature (T_C) in a datasheet.

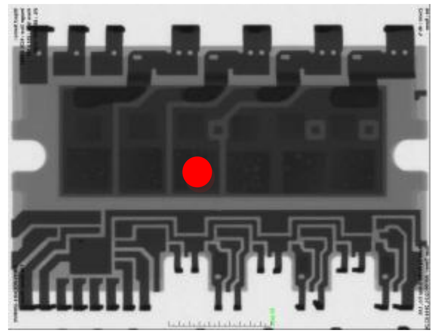

Figure 11. Actual Measurement Points

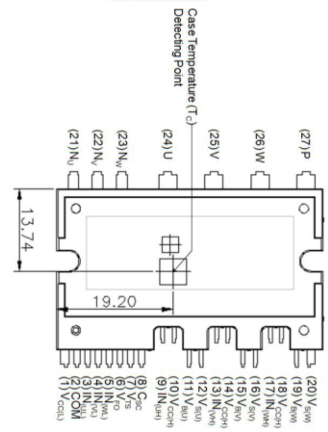

Figure 12. Case Temperature Detecting Point for Datasheet Specification

The $R_{\theta JC_}$chip center is measured at the red point, while the IGBT at the same red point is directly heated. The $R_{\theta JC_}$chip center is not affected by the package warpage and the heat sink warpage because this point is contact ahead of the rest part.

The $R_{\theta JC_}$package center is measured at the red point when the the IGBT in yellow point is heated.

Related Resources

FSBB30CH60D – 600V Motion SPM® 3 ver5 Series- Product Folder

AN-9071 – Smart Power Module-SPM™ in µMini DIP SPM Thermal Performance Information

AN-9085 – 600V Motion SPM® 3 ver5 Series, User's Guide

AN-9086 – 600V Motion SPM® 3 Package Mounting Guide

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