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AN-9122

600 V SPM® 2 Series Thermal Performance by Mounting Torque

Overview

Semiconductor devices are very sensitive to junction temperature. As the junction temperature increases, the operating characteristics of a device alter 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.

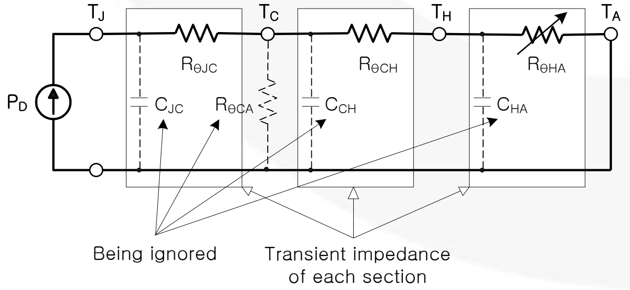

Figure 1. Transient Thermal Equivalent Circuit with Heat Sink

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 2 Series.

Figure 2 through Figure 7 show the thermal impedance curves of 600 V SPM2 series. The thermal resistance goes into saturation in less than one second. Other types of Motion SPM products also show similar characteristics.

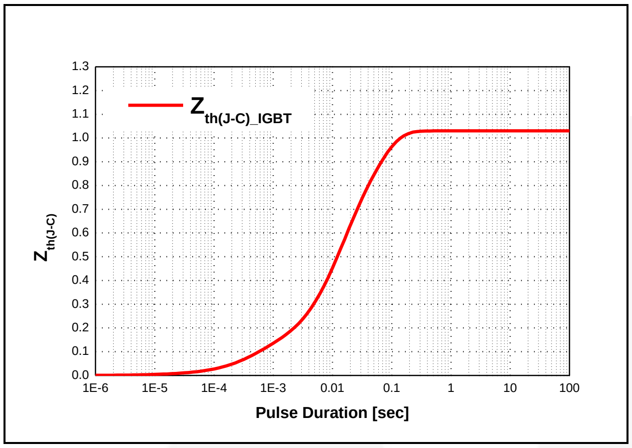

Figure 2. Thermal Impedance Curve IGBT of FN23060

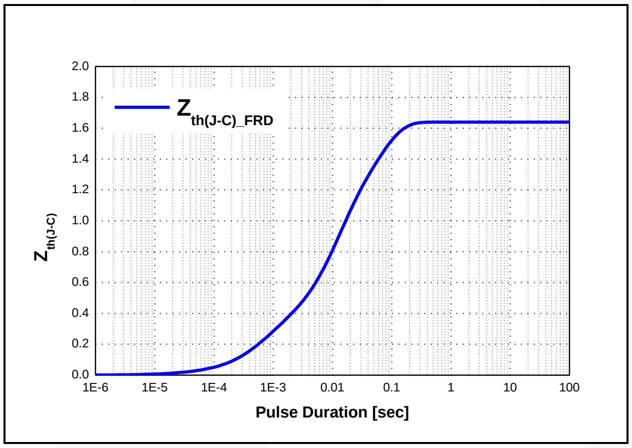

Figure 3. Thermal Impedance Curve FRD of FNA23060

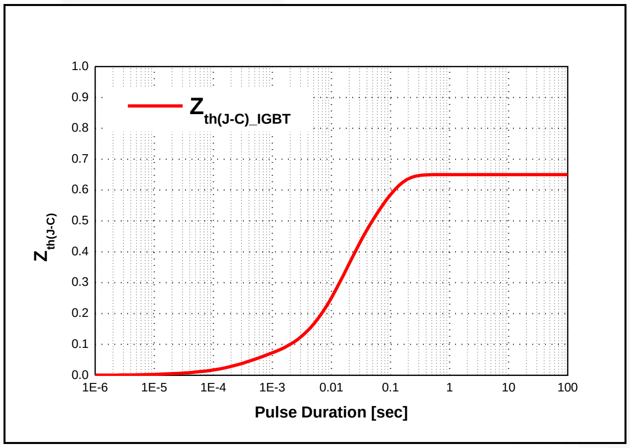

Figure 4. Thermal Impedance Curve IGBT of FNA25060

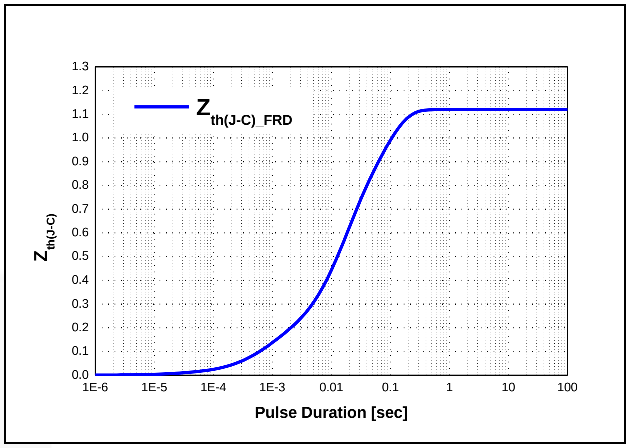

Figure 5. Thermal Impedance Curve FRD of FNA25060

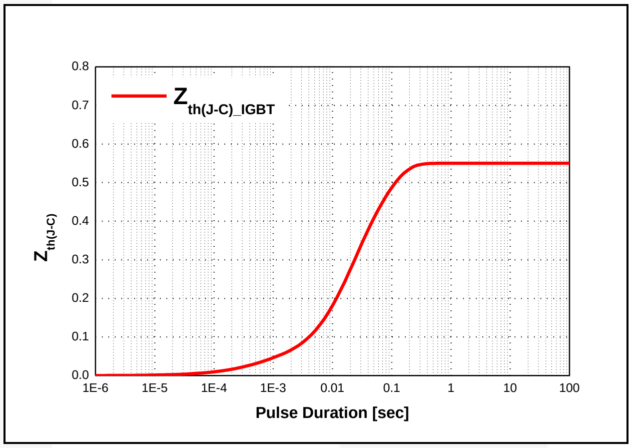

Figure 6. Thermal Impedance Curve IGBT of FNA27560

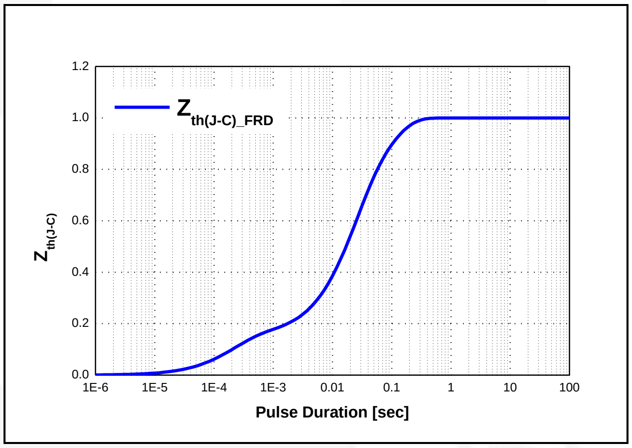

Figure 7. Thermal Impedance Curve FRD of FNA27560

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 8 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.

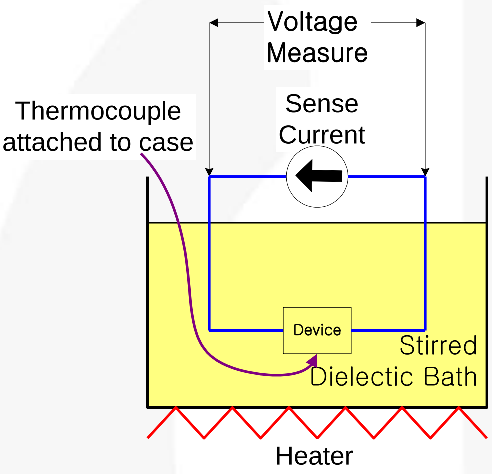

Figure 8. Illustration of the Bath Method for TSP Measurement

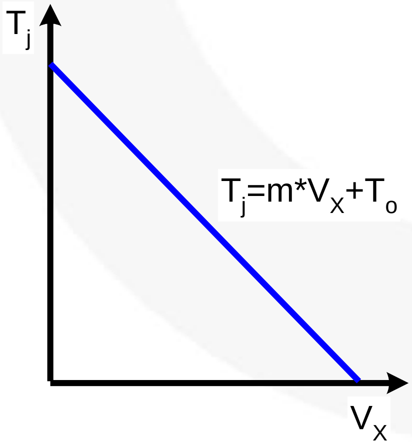

Figure 9. Example of a TSP Plot with Constant Sense Current

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 9 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 Results of T_J

The figures below are measurement results of device junction calibration of **FNA25060**: Figure 10 is for IGBT and Figure 11 for FRD. The slope, *m (°C/V)*, and the temperature coordinate-intercept, T_o *(°C)*, are shown in Table 1.

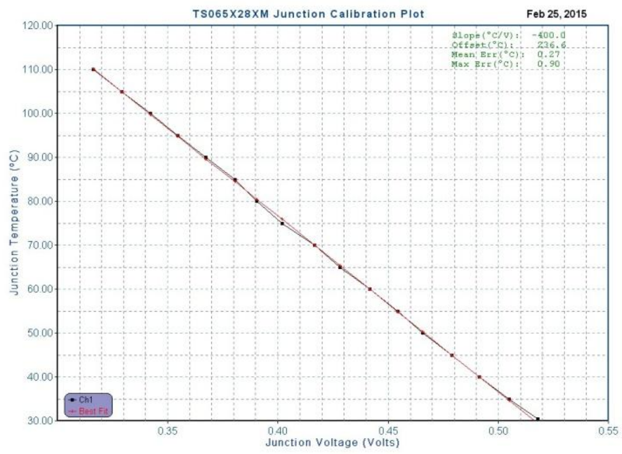

Figure 10. Results of Device Junction Calibration

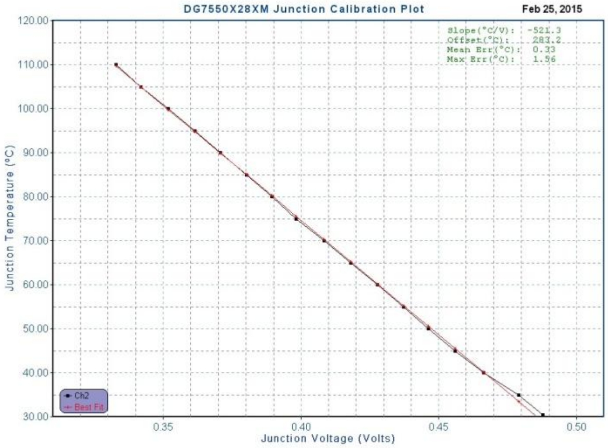

Figure 11. Results of Device Junction Calibration

Table 1. m (°C/V) and Temperature Coordinate-Intercept, T_o (V) for *FNA25060*

Device		m(°C/V)	T_O(°C)	Sensing Current
FNA25060	IGBT	-400.0	236.6	10 mA
	FRD	-521.3	283.2	

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)	T_J	T_C	$R_{\theta JC}$
FNA25060 Chip Center	#1	105.0	122.1	71.0	0.49
	#2	105.2	119.3	69.1	0.48
	#3	106.5	121.4	69.6	0.49

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

Thermal Performance by Mounting Torque

Power devices are very sensitive to junction temperature. As the junction temperature increases, the operating characteristics of a device alter and the failure rate increases exponentially. Contact pressure and mounting torque may affect the thermal performance.

Actual Measure Point

Figure 12 shows real measuring points and Figure 13 shows the detecting point of case temperature (T_C) in a datasheet.

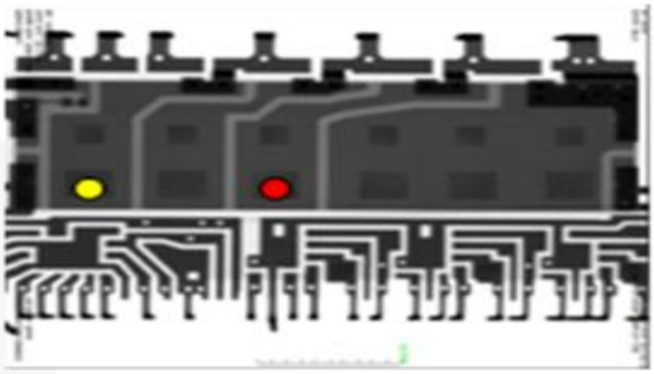

Figure 12. Actual Measurement Points

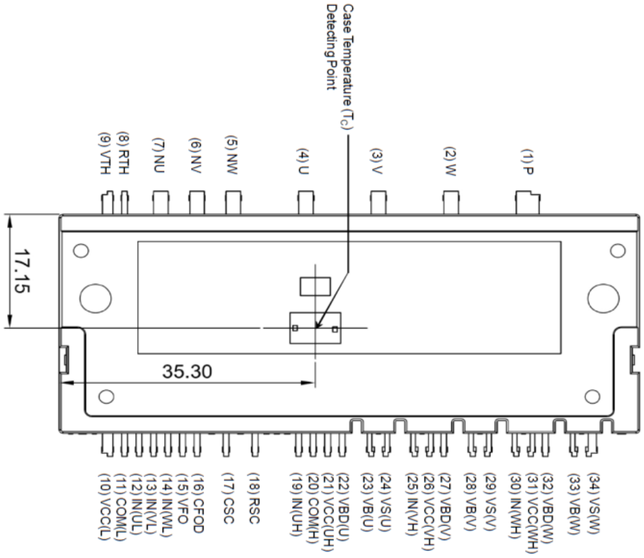

Figure 13. Case Temperature Detecting Point for Datasheet Specification

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.

Test Method

As illustrated in Figure 14, the right side was tightened first, then the other side gets tightened gradually (1, 3, 5, 7, 10, 12, and 15 kg.f-cm), while the thermal resistance is being measured for each torque.

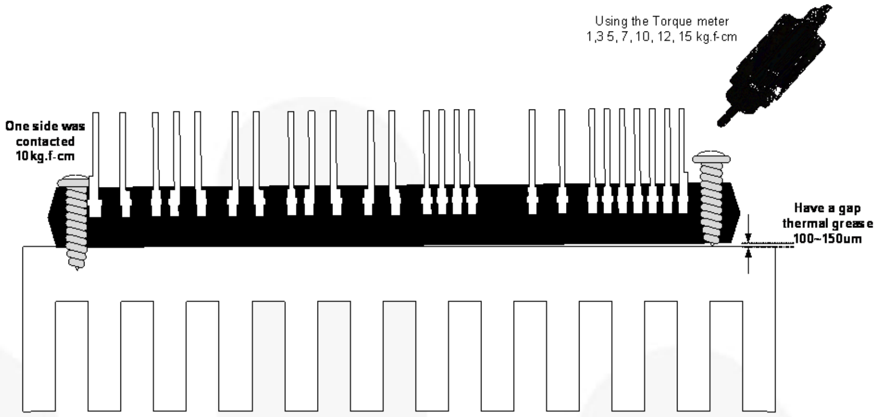

Figure 14. Test Method

Test Results

Figure 15 shows test results for the $R_{\theta JC_}$package center vs. mounting torques and the $R_{\theta JC_}$chip center vs. mounting torques. According to test results, the thermal resistance is saturated when the mounting torque is more than 10 kg.f-cm. Therefore, mounting torque of at least 10 kg.f-cm is recommended for 600 V SPM 2 Series.

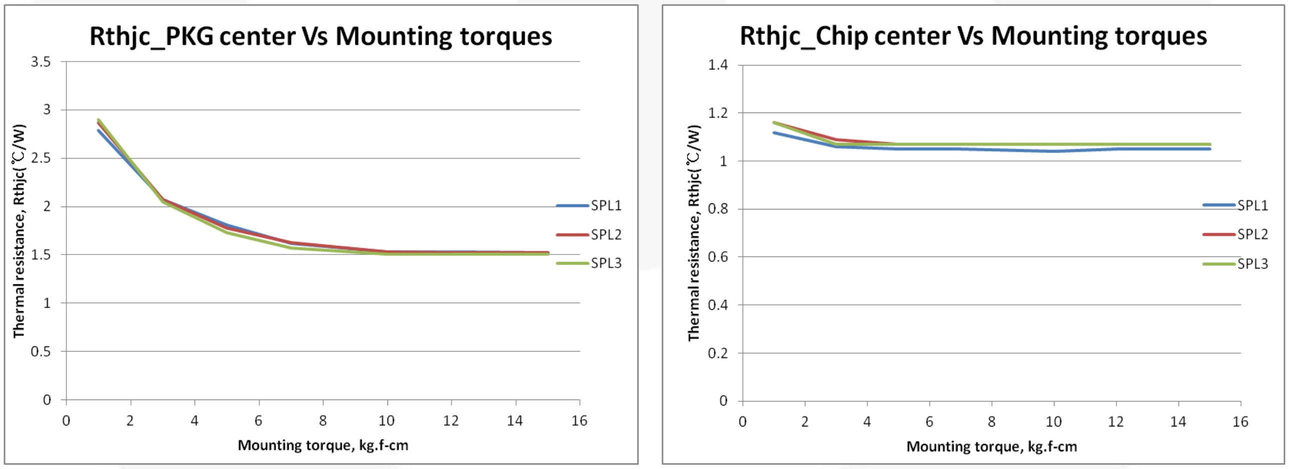

Figure 15. Thermal Resistance by Mounting Torque

Related Resources

FNA23060 – 600V Motion SPM® 2 Series

FNA25060– 600V Motion SPM® 2 Series

FNA27560 – 600V Motion SPM® 2 Series

AN-9121 – 600V Motion SPM® 2 Series, User's Guide

AN-9076 – New SPM® 2 Package, Mounting Guide

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