SEMI G30-88
TEST METHOD FOR JUNCTION-TO-CASE THERMAL RESISTANCE MEASUREMENTS OF CERAMIC PACKAGES

1 Purpose

The purpose of this test is to determine the thermal resistance of ceramic packages using thermal test chips. This test method deals only with junction-to-case or mounting surface measurements of thermal resistance and limits itself to heat sink and fluid bath testing environments. Following the guidelines outlined in this test method, junction-to-case thermal resistance measurements of ceramic packages using the heat sink and fluid bath methods should give the same results only under certain limited conditions (i.e., under conditions that approximate unidirectional heat flow through the chip and substrate to the preferred heat removal surface). If discrepancies occur, the heat sink mounting technique shall be considered as the referee test method. The heat sink mounting method for measuring junction-to-case thermal resistance will be a conservative measure of the package's ability to transfer heat to the ambient environment because heat sinking is provided only on one side of the package, whereas the fluid bath mounting method has the potential for equally cooling both sides of the package.

1.1 *Definitions* — The following definitions and symbols shall apply for the purpose of this test:

a. *case temperature,* T_C, in degrees Celsius. The case temperature is the temperature at a specified accessible reference point on the package in which the microelectronic chip is mounted.

b. *mounting surface temperature,* T_M, in degrees Celsius. The mounting surface temperature is the temperature of a specified point at the device-heat sink mounting interface (or primary heat removal surface).

c. *junction temperature,* T_J, in degrees Celsius. The term is used to denote the temperature of the semiconductor junction in the microcircuit in which the major part of the heat is generated. For purposes of this test, the measured junction temperature is only indicative of the temperature in the immediate vicinity of the element used to sense the temperature.

d. *power dissipation,* P_H, in watts, is the heating power applied to the device causing a junction-to-reference point temperature difference.

e. *thermal resistance, junction-to-specified reference point,* $R_{\Theta JR}$, in degrees Celsius/watt. The thermal resistance of the microcircuit is the temperature difference from the junction to some reference point on the package divided by the power dissipation P_H.

f. *temperature-sensitive parameter,* TSP, is the temperature-dependent electrical characteristic of the junction under test which can be calibrated with respect to temperature and subsequently used to detect the junction temperature of interest.

2 Apparatus

2.1 The apparatus required for these tests shall include the following as applicable to the specified test procedures.

a. Thermocouple material shall be copper-constantan (type T) or equivalent, for the temperature range -100 to +300°C. The wire size shall be no larger than AWG size 30. The junction of the thermocouple shall be welded to form a bead rather than soldered or twisted. The accuracy of the thermocouple and associated measuring system shall be ± 0.5°C.

b. Suitable electrical equipment as required to provide controlled levels of conditioning power and to make the specified measurements. The instrument used to electrically measure the temperature-sensitive parameter shall be capable of resolving a voltage change of 0.5 mV.

c. Controlled temperature chamber, fluid bath, or heat sink capable of maintaining the specified reference point temperature to within ± 0.5°C of the preset (measured) value. Typical temperature-controlled heat sink and fluid bath assemblies are presented for illustrative purposes only.

2.2 *Heat Sink Assembly* — A typical heat sink assembly for mounting the microelectronic device under test is shown in Figure 1. The primary heat sink is water cooled using a temperature-controlled fluid circulator bath. An adapter socket/heat sink is fastened to the heat removal surface of the primary heat sink, and has a special geometry to handle specific size packages (e.g., flat packs, dual-in-line packages, chip carriers). This adapter provides a repeatable and efficient interface between the package and the primary heat sink. The mounting surface temperature is determined with a thermocouple attached from the side or bottom of the adapter with a thermal conducting adhesive or grease at or near the interface between the adapter and the package. It is at this point that the device-under-test temperature is specified and controlled. The adapter also contains the socket or other electrical interconnection scheme. A thin coating (about 25 - 50 µm thick) of a thermal heat-sinking compound, such as zinc-oxide-loaded silicone thermal grease, is used at the interface to provide a reliable thermal contact.

2.3 *Fluid Bath Assembly* — A typical temperature-controlled fluid bath for thermally characterizing the microelectronic device under test is shown in Figure 2. In this figure, the package is mounted in a fluid bath separate from the fluid circulator, although it can be immersed directly in an integrated fluid circulator/bath unit. The fluid in the bath should be continuously stirred or agitated to ensure the required temperature stability. Since this working fluid is being used as an infinite heat sink, the case-to-fluid (ambient) temperature difference at the case temperature reference point of interest should be minimized, i.e., less than or equal to 20°C. For case-to-fluid temperature differences greater than 20°C, accuracy and repeatability difficulties may occur due to a large variable temperature gradient in the fluid film boundary layer at the package-fluid interface. The case-to-fluid temperature difference can be minimized by increasing the fluid velocity and by decreasing the power density seen by the fl uid. The device under test should be mounted such that heat transfer to the fluid is not impeded. For leaded devices, the leads should be oriented in such a manner so as not to interfere with the heat transfer to the fluid and provide freedom to any thermal currents caused by the power dissipation within the package. The case temperature of the device under test should be measured with a thermocouple that is attached to the package and should not be assumed to be at the fluid temperature. Care should be taken to minimize exposure of the thermocouple bead to the high temperature gradient in the fluid film boundary layer at the package-fluid interface. The working fluid should have a thermal conductivity at 25°C of at least 0.0006 W/cm°C. Working fluids such as inert fluorocarbon liquids and silicone oils are suitable as a cooling media.

3 Procedure

3.1 *Direct Measurement of Reference Point Temperature* — T_C. For the purpose of measuring a microelectronic device thermal resistance, the reference point temperature shall be measured at the package location of highest temperature which is accessible outside the package. This reference point location is determined with the device operating in free air and with no external heat-sinking. In general, this reference point is found to be on the outside surface of the package substrate directly underneath the chip in the major path of heat flow from the chip to the heat sink or ambient. Examples of the reference point location for both cavity-up and cavity-down ceramic packages are depicted in Figure 3. The package surface may be altered to facilitate this measurement, provided that such alteration does not affect the original heat transfer paths and, hence, the thermal resistance, within the package by more than a few percent. For packages with an integral heat dissipater attached to the outside surface of the package substrate, the case temperature reference point shall be on the surface of the heat dissipater at a point opposite the backside of the chip as indicated in Figure 4.

3.1.1 Case temperature, T_C. The microelectronic device under test shall be mounted under specified conditions so that the case temperature can be held at the specified value. A thermocouple shall be attached on the surface of the device package directly under the chip. A conducting epoxy may be used for this purpose. The thermocouple bead should be in direct mechanical contact with the case of the microelectronic device under test. For devices which, in their normal application, are intimately connected (by pressure contact, adhesive, soldering, or other means) to an external heat sink, the mounting surface temperature, as measured directly below the primary heat removal surface of the case, may be used as the equivalent case temperature.

If it is found that attaching the thermocouple directly to the case is impractical, an alternate approach utilizing a thermocouple welded to one side of a thin metal disk should be used. This can be accomplished by parallel gap welding the crossed thermocouple wires to one side of a 0.25 cm (0.094 in) diameter, 0.02 cm

(0.008 in) thick beryllium-copper disk and then, with a thin layer of adhesive, bonding the other side of the disk to the case at the point of interest.

3.1.1.1 Mounting surface temperature, T_M. The mounting surface temperature is measured directly below the primary heat removal surface of the case. It is measured with a thermocouple at or near the mounting surface of the heat sink. A typical mounting arrangement is shown in Figure 5. The surface of the copper mounting base shall be nickel plated and free of oxides.

The thermocouple hole shall be drilled into the mounting base such that the thermocouple lead is directly below the area on the case of interest. It is recommended that the thermocouple be secured into the mounting base with a thermal conducting adhesive (or solder) and that particular attention be paid to minimizing air voids around the ball or the thermocouple. A thermal conducting compound (or adhesive) should be used at the interfaces of the mounting base and the device under test. The mounting surface technique is application oriented in that it takes into account the mounting surface interface.

3.2 *Thermal Resistance, Junction-to-Specified Reference point, $R_{\Theta JR}$*

3.2.1 *General Considerations* — The thermal resistance of a semiconductor device is a measure of the ability of its carrier or package and mounting technique to provide for heat removal from the semiconductor junction. The thermal resistance of a microelectronic device can be calculated when the case/mounting surface temperature and power dissipation in the device and a measurement of the junction temperature are known.

When making the indicated measurements, the package shall be considered to have achieved thermal equilibrium when halving the time between the application of power and the taking of the reading causes no error in the indicated results within the required accuracy of measurement.

3.2.2 *Indirect Measurement of Junction Temperature for the Determination of $R_{\Theta JR}$* — The purpose of the test is to measure the thermal resistance of integrated circuits by using particular semiconductor elements on the chip to indicate the device junction temperature. In order to obtain a realistic estimate of the operating junction temperature, the whole chip in the package should be powered in order to provide the proper internal temperature distribution. During measurement of the junction temperature the chip heating power (constant voltage source) shall remain constant while the junction calibration current remains stable. It is assumed that the calibration current will not be affected by the circuit operation during the application of heating power.

The temperature-sensitive device parameter is used as an indicator of an average (weighted) junction temperature of the semiconductor element for calculations of thermal resistance. The measured junction temperature is indicative of the temperature only in the immediate vicinity of the element used to sense the temperature.

The temperature-sensitive electrical parameters generally used to indirectly measure the junction temperature are the forward voltage of diodes and the emitter-base voltage of bipolar transistors. Other appropriate temperature-sensitive parameters may be used for indirectly measuring junction temperature for fabrication technologies that do not lend themselves to sensing the active junction voltages.

3.2.2.1 Steady-state technique for measuring T_J. The following symbols shall apply for the purpose of these measurements:

I_M	Measuring current in milliamperes.
V_{MH}-	Value of temperature-sensitive parameter in millivolts, measured at I_M, and corresponding to the temperature of the junction heated by P_H.
T_{MC}-	Calibration temperature in degrees Celsius, measured at the reference point.
V_{MC}-	Value of temperature-sensitive parameter in millivolts, measured at I_M, and specific value of T_{MC}.

The measurement of T_J using junction forward voltage as the TSP is made in the following manner:

Step 1 — Measurement of the temperature coefficient of the TSP (calibration).

The coefficient of the temperature-sensitive parameter is generated by measuring the TSP as a function of the reference point temperature, for a specified constant measuring current, I_M, by externally heating the device under test in an oven or in a fluid bath. The reference-point temperature range used during calibration shall encompass the temperature range encountered in the power application test (see Step 2). The measuring current is generally chosen such that the TSP decreases linearly with increasing temperature over the range of interest, and that negligible internal heating occurs in the silicon and metal traces. For determining the optimum TSP calibration or measuring current, V_{MC} vs. log I_M curves for two temperature levels that encompass the calibration temperature range of interest should be plotted. The optimum measuring current, I_M, is then selected such that it resides on the linear portion of the two V_{MC} vs. log I_M curves that were generated. A measuring current ranging from 0.05 to 5 mA is generally used, depending on the specifications and operating conditions of the device under test, for measuring the TSP. The value of the TSP temperature coefficient, V_{MC}/T_{MC}, for the particular measuring current used in the test, is calculated from the calibration curve, V_{MC} vs. T_{MC}. At least three points should be used to generate the voltage vs. temperature curve for the determination of the TSP temperature coefficient.

Step 2 — Power application test.

The power application test is performed in two parts. For both portions of the test, the reference point temperature is held constant at a preset value. The first measurement to be made is that of the temperature-sensitive parameter, i.e., V_{MC}, under operating conditions with the measuring current, I_M, used during the calibration procedure. The microelectronic device under test shall then be operated with heating power (P_H) applied. The temperature-sensitive parameter, V_{MH}, shall be measured with constant measuring current, I_M, that was applied during the calibration procedure (See Step 1).

The heating power, P_H, shall be chosen such that the calculated junction-to-reference point temperature difference as measured at V_{MH} is greater than or equal to 20°C. In accomplishing this, the device under test should not be operated at such a high heating power level that the on-chip temperature-sensing and heating circuitry is no longer electrically isolated. Care should also be taken not to exceed the design ratings of the package-interconnect system, as this may lead to an overestimation of the power being dissipated in the active area of the chip due to excessive power losses in the package leads and wire bonds. The values of V_{MH}, V_{MC}, and P_H are recorded during the power application test.

The following data shall be recorded for these test conditions:

a. Temperature-sensitive electrical parameters (V_F, V_{EB}, or other appropriate TSP).

b. Junction temperature, T_J, is calculated from the equation:

$$T_J = T_R + \left(V_{MH} - V_{MC}\right)\left[\frac{\Delta V_{MC}}{\Delta T_{MC}}\right]^{-1}$$

where $T_R = T_C$ or T_M

c. Case or mounting surface temperature, T_C or T_M.

d. Power dissipation, P_H.

e. Mounting arrangement (including package mounting force).

3.3 *Calculations of $R_{\Theta JR}$*

3.3.1 *Calculations of Package Thermal Resistance* — The thermal resistance of a microelectronic device can be calculated when the junction temperature, T_J, has been measured in accordance with procedures outlined in Sections 3.1 and 3.2.

With the data recorded from each test, the thermal resistance shall be determined from:

$$R_{\Theta JR} = \frac{T_J - T_R}{P_{H(package)}}, \text{ junction -to reference point,}$$

where $R_{QJR} = R_{QJC}$ or R_{QJM} and $T_R = T_C$ or T_M, respectively.

4 Summary Report

The following details shall be specified as appropriate:

a. Description of package, including thermal test chip, location of case or chip carrier temperature measurement(s), and heat sinking arrangement.

b. Test condition(s), as applicable (see Section 3).

c. Test voltage(s), current(s), and power dissipation of test chip.

d. Recorded data for each test condition, as applicable.

e. Symbol(s) with subscript designation(s) of the thermal characteristics determined.

f. Accept or reject criteria.

RELATED REFERENCES

1. Unencapsulated Thermal Test Chip, SEMI G32-86 Guideline, Book of SEMI Standards, Packaging Volume.

2. Accepted Practices for Making Microelectronic Device Thermal Characteristics Test — A User's Guide. JEDEC Engrg. Bull. No. 20, Jan. 1975 (Electronic Industries Assoc., Washington, D.C.).

3. Thermal Characteristics, Method 1012.1, MIL-STD-883C Test Methods and Procedures for Microelectronics, Nov. 4, 1980 (Rev. Aug. 15, 1984).

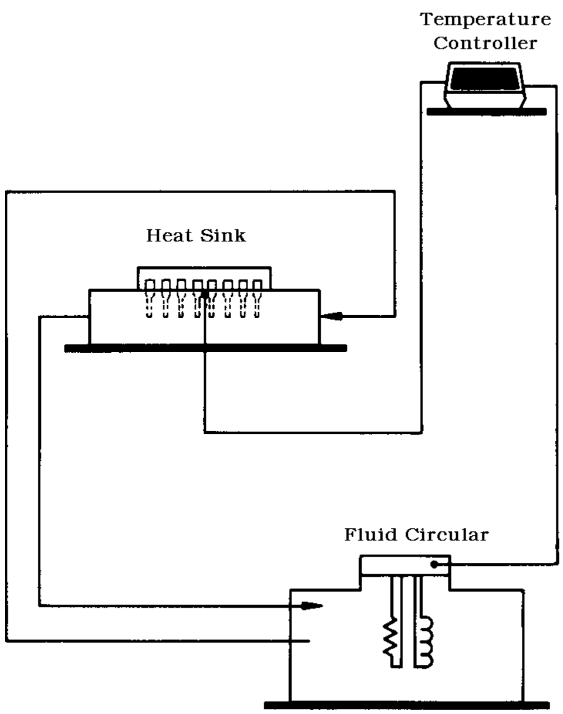

Figure 1
Temperature-Controlled Heat Sink Assembly

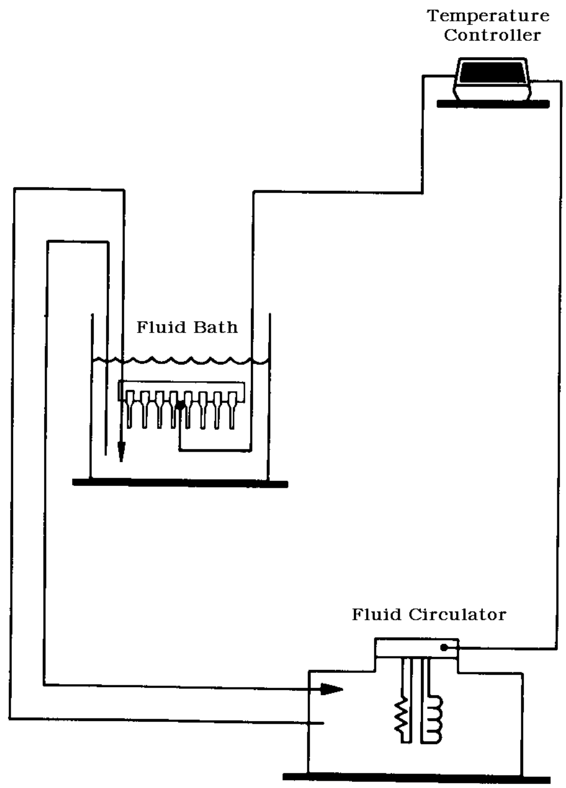

Figure 2
Temperature-Controlled Fluid Bath Assembly

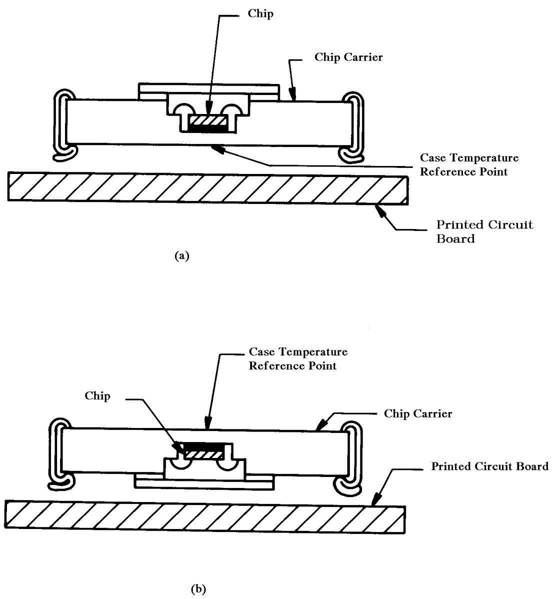

Figure 3

Reference Point Location for Case Temperture Measurement of A) Cavity-Up and B) Cavity—Down Ceramic Packages

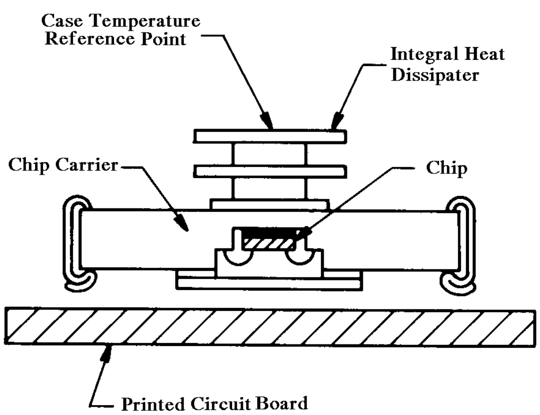

Figure 4

Reference Point Location for Case Temperature Measurement of a Ceramic Package with an Integral Head Dissipater

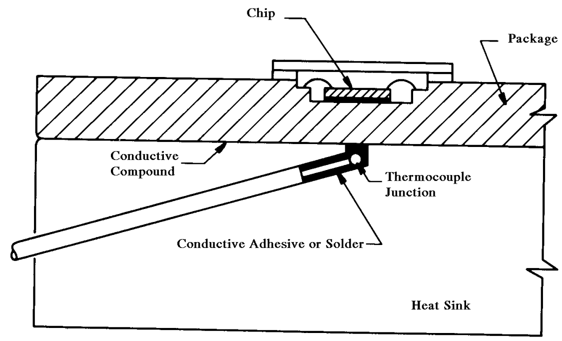

Figure 5

Mounting Surface Temperature Measurements

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