SEMI G38-0996 (Reapproved 0811)
TEST METHOD FOR STILL- AND FORCED-AIR JUNCTION-TO-AMBIENT THERMAL RESISTANCE MEASUREMENTS OF INTEGRATED CIRCUIT PACKAGES

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NOTICE: This Document was reapproved with minor editorial changes.

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1 Purpose

1.1 The purpose of this test is to determine the thermal resistance of integrated circuit packages using thermal test chips.

2 Scope

2.1 This Test Method deals only with junction-to-ambient measurements of thermal resistance and limits itself to still- and forced-air convection testing environments.

NOTICE: SEMI Standards and Safety Guidelines do not purport to address all safety issues associated with their use. It is the responsibility of the users of the Documents to establish appropriate safety and health practices, and determine the applicability of regulatory or other limitations prior to use.

3 Referenced Standards and Documents

3.1 *SEMI Standards and Safety Guidelines*

SEMI G32 — Guideline for Unencapsulated Thermal Test Chip

SEMI G42 — Specification for Thermal Test Board Standardization for Measuring Junction-to-Ambient Thermal Resistance of Semiconductor Packages

NOTICE: Unless otherwise indicated, all documents cited shall be the latest published versions.

4 Terminology

4.1 *Definitions*

4.1.1 The following definitions and symbols shall apply for the purpose of this test:

4.1.2 *ambient temperature (T_A, in degrees Celsius)* — the ambient temperature is the temperature of the air at a specified location in the vicinity of the microelectronic device under test (DUT).

4.1.3 *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.

4.1.4 *power dissipation (P_H, in watts)* — the heating power applied to the device causing a junction-to-reference point temperature difference.

4.1.5 *temperature-sensitive parameter (TSP)* — 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.

4.1.6 *thermal resistance* — junction to specified reference point, $R_{\theta JR}$ degrees Celsius/watt. The thermal resistance of the microcircuit is the temperature difference from the junction to some reference point in the ambient divided by the power dissipation P_H.

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4.1.7 *velocity (v_A, in linear feet per minute [LFPM])* — the velocity of the air at a specified location upstream of the DUT.

5 Apparatus

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

5.1.1 *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.

5.1.2 *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.

5.1.3 *Controlled Temperature Chamber, Fluid Bath, or Wind Tunnel* — Capable of maintaining the specific reference point temperature to within ±0.5°C of the reset (measured) value. Typical still-air enclosure and wind tunnel assemblies are presented for reference purposes only.

5.1.4 *Still-Air Enclosure Assembly* — The microcircuit shall be mounted in a cubic enclosure of not less than 0.028 m^3 (1.0 ft^3). There shall be no radiation sources other than the microcircuit under test in the enclosure. The interior enclosure wall shall have a high reflectance finish (emissivity <0.1). The ambient temperature should be measured by means of a thermocouple mounted at a distance of approximately 2.54 cm (1.0 in.) beneath the DUT and 1.27 cm (0.5 in.) from the test board or socket.

5.1.4.1 The microcircuit shall be mounted in such a manner that conduction cooling through the leads or the test socket or both shall be small compared to the other cooling mechanisms. No. 36 AWG wire should be connected to the device test socket. The air flow (by natural convection) should be unrestricted above and beneath the device. An alternative approach would be to use a mounting arrangement that approximates an application environment. Such a reference mounting configuration can be found in Specification, Thermal Test Board Standardization for Measuring Junction-to-Ambient Thermal Resistance of Semiconductor Packages. Device mounting and test board positioning inside the measuring chamber are depicted in Figure 1.

5.1.5 *Wind Tunnel Assembly* — A typical wind tunnel design is shown with its dimensions in Figure 2.

5.1.5.1 The fan or blower should be placed downstream of the DUT as depicted in Figure 2. A static pressure differential measurement across a calibrated nozzle is used to calculate the wind tunnel air velocity, while a thermocouple is used to measure the ambient temperature upstream of the DUT. Both of these devices should be placed at a specified location upstream of the DUT, as shown in Figure 2. The thermocouple is located in the center of the wind tunnel, 5.08 cm (2.0 in.) from the test section and 2.54 cm (1.0 in.) above the center plane of the DUT.

5.1.5.2 The microcircuit shall be mounted in such a manner that conduction cooling through the leads or the test socket, or both, shall be small compared to the other cooling mechanisms. To minimize conduction through the leads, No. 36 AWG wire should be connected to the device test socket. The DUT should be aligned so that the air front is parallel to the longer edge of the package (air front hitting the package side). An alternative approach would be to use a mounting arrangement that approximates an application environment. Such a referee mounting configuration can be found in SEMI G42. Device mounting and test board orientation inside the wind tunnel are depicted in Figure 3.

5.1.5.3 Flow straighteners should be placed upstream of the DUT, as shown in Figure 2. The flow straighteners should provide a flat velocity profile across the test section of the wind tunnel. This will ensure that the DUT is exposed to a uniform velocity across its entire cross section. A typical velocity profile for well-developed turbulent flow is depicted in Figure 3.

5.1.5.4 Calibrated hot wire anemometer or nozzle with suitable pressure gauges (p_1 and p_2) for measuring the pressure difference across the nozzle is used to calculate the wind tunnel air velocity. When using the nozzle, the pressure differential across the calibrated nozzle is measured using a liquid monometer, typically in inches of water.

5.1.5.5 Hot wire anemometer capable of verifying the air velocity profile with an accuracy of ±5%. The velocity sensor should disrupt the airflow as little as possible.

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6 Procedure

6.1 *Measurement of Wind Tunnel Air Velocity (v_A)* — The air velocity measurement techniques are direct method and indirect method.

6.1.1 *Direct Measurement of Wind Tunnel Air Velocity* — The direct method is based on a measurement by a hot wire anemometer in wind tunnel.

6.1.2 *Indirect Measurement of Wind Tunnel Air Velocity (vA)* — The air velocity measurement technique is an indirect method based on a pressure differential measurement across a calibrated nozzle. The actual velocity of interest is derived from a calibration curve relating the pressure differential of the nozzle to the volume (or mass) flow rate of the air through the nozzle. The required air velocity (in linear feet per minute) is then calculated by dividing the volume flow rate (in cubic feet per minute) by the cross sectional area at the entrance of the DUT test section (in square feet). The volume flow rate shall be determined to within an accuracy of ±10%.

6.1.2.1 *Air Flow Profile* — Hot wire anemometer should be used to verify that the flow profile of the air front, measured within 5.08 cm (2.0 in.) of the test section, does not vary by more than 10% across the center 90% of the test section. The DUT and mounting board/socket should not be in the test section when the flow profile is determined.

6.2 *Direct Measurement of Reference Point Temperature (T_S)* — For the purpose of measuring the still-air junction-to-ambient microelectronic device thermal resistance in a chamber, the ambient temperature ($T_R = T_A$) should be measured with a thermocouple beneath the DUT. For purposes of measuring forced air junction-to-ambient thermal resistance in a wind tunnel, the ambient temperature should be measured with a thermocouple upstream of the DUT in the section of the tunnel that experiences fully developed flow.

6.3 *Thermal Resistance, Junction to Specified Reference Point ($R_{\theta JR}$)*

6.3.1 *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 ambient 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.

6.3.2 *Indirect Measurement of Junction Temperature for the Determination of $R_{\theta JA}$* — 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.

6.3.3 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.

6.3.4 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.

6.3.4.1 *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 parameters 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}.

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