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Beaded Thermocouple Temperature Measurement of Semiconductor Packages

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GUIDELINE FOR BEADED THERMOCOUPLE TEMPERATURE MEASUREMENT OF SEMICONDUCTOR PACKAGES

Foreword

This guideline provides procedures to accurately and consistently measure the temperature of components during exposure to thermal excursions. The guideline applications can include, but is not limited to, temperature profile measurement in reliability test chambers and solder reflow operations that are associated with component assembly to printed wiring boards (pwb).

GUIDELINE FOR BEADED THERMOCOUPLE TEMPERATURE MEASUREMENT OF SEMICONDUCTOR PACKAGES

(From JEDEC Board Ballot JCB-02-34, formulated under the cognizance of the JC-14.1 Subcommittee on Reliability Test methods for Packaged Devices.)

1 Scope

This method specifies procedures to determine the temperature of a component or its solder joint over time as it is exposed to temperature gradients due to testing or processing. It defines appropriate thermometry sensors, tools, and attachment methods for temperature measurement of semiconductor packages in the applications mentioned in the Foreword..

2 Applicable Documents

ASTM STP 852, *Manual on the Use of Thermocouples*

ASTM Manual 12, *On the Use of Thermocouples*

ASTM E220, *Calibration of Thermocouples by Comparison Techniques*

IPC TM-650 2.6.20.3, *Surface Thermometry of Plastic Parts with Low Thermal Mass*, January 1999

3 Terms and definitions

For the purposes of this procedure, the following terms and definitions apply.

3.1 Thermometry sensors

Devices and/ or materials used in the science of measuring the temperature of a system or the ability of systems to transfer heat.

3.2 Thermocouple

A temperature measurement sensor that consists of two dissimilar metals intimately joined together in a bead at one end (a junction) that produces a small thermoelectric voltage, corresponding to a temperature, when the junction is heated.

3 Terms and definitions (cont'd)

3.3 Temperature profile

A relational dependency of temperature as a function of time.

3.4 Components

Packaged semiconductor devices.

3.5 Emissivity

The ratio of the radiant energy emitted by a surface to that emitted by a blackbody at the same temperature.

4 Apparatus

The temperature profiling apparatus used shall be capable of providing accurate temperature profiles, nominally within 1.5 °C - 2.0 °C of the actual temperature of the components in the working zone(s) in the heated and cooled equipment; such as, reliability test chambers or solder reflow ovens. Periodic calibration of thermometric measurement technique chosen should be incorporated into the process using reference criteria as required to ensure run-to-run repeatability.

5 Procedure

A number of procedures for temperature profiling exist. The method selected depends on the types of results required, the accuracy needed and the physical layout of the equipment/ componentry being profiled. Based on the type of equipment referenced in this guideline, use of beaded thermocouples to measure the temperature profiles is the most effective and useful. Other methods, such as fluoroptic thermometry, IR thermometric probes, phase change materials, ribbon thermocouples, etc., are not well suited to these applications due to either line of sight, continuous monitoring or temperature accuracy requirements.

5 Procedure (cont'd)

5.1 Thermocouple (T/C) used to measure component temperature

The thermocouple is the most common thermometric tool in surface mount reflow and component thermometry. Thermocouples are relatively inexpensive, have fast response times and are well supported by an electronic instrumentation and computing infrastructure. Data logging equipment supporting four and more channels is available. The thermocouples' thermal effects on the apparent temperature of the test point (plastic surface or the solder joint) are minimized when:

a) the thermocouple is fabricated with fine wire

b) the junction of the metallic couple or "bead" is small

c) the junction is in good thermal contact with, or is well coupled to, the surface to be measured

d) the attachment medium is not too thick

e) the attachment medium has an emissivity not significantly different from that of the surface being measured

f) the wires lie flat against the surface of interest, for a distance of > 20X the diameter of the wire

5.1.1 Mounting concerns

It should be a noted caution that the apparent surface temperature will tend to be that of the air temperature if the junction and wire are not in contact with the surface being measured. Therefore, one must ensure proper attachment and contact are made to the surface where the temperature is being measured. Erroneous results, due to ambient flows, can be obtained if contact is not ensured. Embedding the thermocouple in the component will minimize this concern. The temperature lag between the surface and the interior of the package will be a function of the thermal conductivity and thermal diffusivity of the package materials. The component surface temperature may be different than that of the solder joints if the package terminations are connected to large/thick/wide grounds or electrical traces.

The following discussion assumes that the surface of interest is the top surface of the component.

Averaged package temperature readings may be obtained by drilling a hole into thicker packages, barely larger than the T/C or by contacting the bulk package material with the T/C junction and securing the T/C in position with thermally conductive epoxy. For thin package components, attachment of the T/C to the package surface should be sufficient to reflect the average package temperature.

5.1 Thermocouple (T/C) used to measure component temperature (cont'd)

5.1.2 Wire material

In general, fine wire, on the order of 0.003 – 0.020 inch (AWG 40 to AWG 24) in diameter is acceptable for monitoring dynamic temperature performance under temperature cycling and solder reflow conditions. However, AWG 40 to AWG 36 is recommended for accuracy, especially in cases where the package is small and the wire gauge can cause significant heat sinking with respect to the mass of package. Type K (chromel-alumel) or Type T (copper-constantan) thermocouple materials are generally used for peak temperature range (200 °C – 400 °C) and in either oxidizing or neutral atmospheres. These materials are accurate enough for component temperature monitoring in either temperature cycling chambers or solder reflow operations. Thermocouple wire less than AWG 36 may result in significantly shorter operating life and increased thermocouple resistance. Temperature reading errors can be reduced from the normal +/-2 °C obtained with standard grade wire to +/-1 °C by utilizing high purity wire.

The resistance of the thermocouple assembly should be measured before using and must be compatible with the measuring device input specifications. Thermocouple wire can change resistance at high temperature and thus induce error in measurement. It is recommended the thermocouple wire be chosen for accuracy within the temperature range of interest.

5.1.3 Thermocouple fabrication

Thermocouples may be fabricated using a fine oxy-hydrogen welding torch, a capacitive discharge micro spot-welding technique, or any industry acceptable method which fuses the two wires into a homogenous bead. Not recommended are metal joining techniques such as eutectic solder or wire twisting which could result in a thermocouple junction far removed from where the wires appear to cross. Poor joining techniques could result in monitoring errors and/or performance instabilities.

5.1.4 Thermocouple response time

The thermocouple response time is proportional to the surface area of the active junction to the diameter of the round wire of which the T/C is formed. A spherical or ball-shaped T/C junction has the smallest ratio. Response times of round wire T/C are typically in the range of milliseconds to seconds, dependent on the thermocouple gauge and attachment technique, with the finer wire and more refined attachment technique having the faster response time.

5.1.5 Location of the thermocouple

Center the T/C "bead" on the topside of the package body; maintain the bead in contact with the package surface. If solder joint temperature is being measured, locate the T/C "beads" on the solder joints of interest.

5.1 Thermocouple (T/C) used to measure component temperature (cont'd)

5.1.6 Attachment material

It is recommended that thermally conductive adhesives or appropriate solders should be used, either alone or to enhance thermal conduction. Use only enough adhesive to provide conduction from the package surface to the T/C bead or only enough solder to provide conduction from the component leads. Notes: Generally a thin glue line of unfilled material offers lower thermal resistance than a thicker glue line of filled material. For solders, care should be taken not to damage the component or pwb during the attach process.

If a thermally conductive adhesive or appropriate solders are not applicable in a given situation, caution must be used if a non-thermally conductive medium, such as polyimide tape, aluminum tape or structural adhesive, is used to position the T/C bead. Minimize attachment material over the "bead," as well as total thermal mass, to prevent a lag in thermal response. Where possible and where the data is available, use adhesives with emissivity and thermal conductivity similar to that of the package epoxy molding compound. Note: Some high temperature tapes may be either ineffective or lose contact with repeated use and are therefore not recommended for this application.

5.1.7 Thermocouple calibration

Calibrate each T/C at two temperatures bracketing the temperature range of interest. Refer to calibration procedure in ASTM E 220.

5.2 Data acquisition and recording

Data acquisition systems chosen for any of the thermometric measurement techniques should be fast enough to capture the data with a sufficient number of recording channels to obtain the profile of necessary data along with the requisite process calibration points. Acquisition systems should be capable of incorporating the necessary thermometric calibration points such as a temperature reference point for thermocouple measurements.

6 Summary

The following details shall be specified in the appropriate temperature measurement logs:

a) Sensor type(s).

b) Sensor physical characteristics

c) Sensor calibration information

d) Adhesives used and qualitative notes on use

e) Sensor instrumentation information

f) Attachment location/ area measured for temperature

g) Temperature profiles

h) Sensor accuracy

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