JEDEC STANDARD

Temperature Cycling

JESD22-A104E

(Revision of JESD22-A104D, March 2009)

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JEDEC SOLID STATE TECHNOLOGY ASSOCIATION

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TEST METHOD A104E
TEMPERATURE CYCLING

(From Board Ballot JCB-00-16, JCB-05-82, JCB-09-20, and JCB-14-45, formulated under the cognizance of the JC-14.1 Committee on Reliability Test Methods for Packaged Devices.)

1 Scope

This standard applies to single-, dual- and triple-chamber temperature cycling and covers component and solder interconnection testing. It should be noted that this standard does not cover or apply to thermal shock chambers. In single chamber cycling, the load is placed in a stationary chamber and is heated or cooled by introducing hot or cold air into the chamber. In dual-chamber cycling, the load is placed on a moving platform that shuttles between stationary chambers maintained at fixed temperatures. In triple-chamber temperature cycling there are three chambers and the load is moved between them.

This test is conducted to determine the ability of components and solder interconnects to withstand mechanical stresses induced by alternating high- and low-temperature extremes. Permanent changes in electrical and/or physical characteristics can result from these mechanical stresses.

2 Terms and definitions

2.1 load: The sample(s) and associated fixtures (trays, racks, etc.) in the chamber during the test.

2.2 working zone: The volume in the chamber(s) in which the temperature of the load is controlled within the specified conditions.

2.3 sample temperature (T_s): The temperature of the samples during temperature cycling, as measured by thermocouples or equivalent temperature measurement apparatus affixed to, or imbedded in, their bodies.

NOTE The thermocouple, or equivalent temperature measurement apparatus, attachment method used should ensure that the entire mass of the sample(s) is reaching the temperature extremes and the soak requirements.

2.4 maximum sample temperature: ($T_{s(max)}$): The maximum temperature experienced by the sample(s) as measured by thermocouples, per 3.3.

2.5 minimum sample temperature: ($T_{s(min)}$): The minimum temperature experienced by the sample(s) as measured by thermocouples, per 3.3.

2 Terms and definitions (cont'd)

2.6 load transfer time: The time it takes to physically transfer the load from one temperature chamber and introduce it into the other. Load transfer applies to dual and triple chamber cycling.

2.7 maximum load: The largest load that can be placed in the chamber and still meet the specified temperature cycling requirements as verified by thermocouples, per 3.3.

2.8 nominal ΔT: The difference between nominal $T_{s(max)}$ and nominal $\boldsymbol{T_{s(min)}}$ for the Temperature Cycling Test Condition; see Table 1.

2.9 soak time: The total time the sample temperature is within a specified range of each nominal $\boldsymbol{T_{s(max)}}$ and nominal $\boldsymbol{T_{s(min)}}$. This range is defined as the time $\boldsymbol{T_s}$ is at –5 °C to +10 °C /+15 °C (dependent on the Test Condition tolerance) of $\boldsymbol{T_{s(max)}}$ nominal for the upper end of the cycle and the time $\boldsymbol{T_s}$ is +5 °C to –10 °C of $\boldsymbol{T_{s(min)}}$ nominal for the lower end of the cycle.

2.10 soak temperature: The temperature range that is –5 °C to +10/+15 °C (dependent on the Test Condition tolerance) of $\boldsymbol{T_{s(max)}}$ nominal and +5 °C to –10 °C of $\boldsymbol{T_{s(min)}}$ nominal.

2.11 (temperature) cycle time: The time interval between one high-temperature extreme to the next, or from one low-temperature extreme to the next, for a given sample; see Figure 1.

2.12 ramp rate: The rate of temperature increase or decrease per unit of time for the sample(s).

NOTE 1 Ramp rate should be measured for the linear portion of the profile curve, which is generally the range between 10% and 90% of the test condition temperature range; see points **a** and **b** in Figure 1.

NOTE 2 Ramp rate can be load dependent and should be verified for the load being tested.

2.13 test conditions: The various temperature cycle range options listed in Table 1.

2.14 soak mode: The categorization nomenclature that defines minimum soak time at soak temperature(max) & soak temperature(min) in minutes.

NOTE 1 Each Test Condition will have four possible Soak Modes. These Soak Modes are listed in Table 2.

NOTE 2 The soak mode selected is dependent on the failure mechanism of interest.

2.15 nominal $\boldsymbol{T_{s(max)}}$: The temperature of the sample required to meet the maximum nominal temperature for a specific test condition; see Table 1.

2.16 nominal $\boldsymbol{T_{s(min)}}$: The temperature of the sample required to meet the minimum nominal temperature for a specific test condition; see Table 1.

3 Reference documents

JEP 140, *Beaded Thermocouple Measurement of Semiconductor Packages.*

JEP 153, *Characterization and Monitoring of thermal Stress Test Oven Temperatures*.

JESD94, *Application Specific Qualification using Knowledge Based Test Methodology.*

IPC-SM-785, *Guidelines for Accelerated Reliability Testing of Surface Mount Solder Attachments.*

4 Apparatus

The chamber(s) used shall be capable of providing and controlling the specified temperatures and cycle timing in the working zone(s), when the chamber is loaded with a maximum load. Direct heat conduction to sample(s) shall be minimized. The capability of each chamber achieving the sample temperature requirements shall be verified across each chamber by one or both of the following methods:

a) Periodic calibration using instrumented parts and a maximum load, and continual monitoring during each test of such fixed tool thermocouple temperature measurement(s) as adequate to ensure run-to-run repeatability.

b) Continual monitoring during each test of an instrumented part or parts placed at worst-case temperature locations (for example, this may be the corners and middle of the load).

5 Procedure

Sample(s) shall be placed in such a position with respect to the air stream such that there is substantially no obstruction to the flow of air across and around each sample(s). When special mounting is required, it shall be specified. The sample shall then be subjected to the specified temperature cycling test condition for the specified number of cycles (e.g., JESD47 for qualification or as agreed to between the supplier and user). Completion of the total number of cycles specified for the test may be interrupted for interim end-point testing, test chamber loading or unloading of device lots, electrical test of samples at specified intervals or as the result of power or equipment failure. However, if the aggregate number of times of all interruptions exceeds 10% of the total number of cycles specified, the test must be restarted from the beginning. If the thermocouple is affixed to the sample body, the amount of glue or tape used shall be minimized to insure proper temperature measurements. The thermocouple, or equivalent temperature measurement apparatus, attachment method used should ensure that the entire mass of the sample(s) is reaching the temperature extremes and the soak requirements.

5.1 Nominal cycle rates

Nominal cycle rates are dependent on the Soak Mode selected.

5.1.1 Component cycle rates

Typical component level temperature cycle rates are in the range of 1 to 3 cycles per hour (cph). Typical failure mechanisms include, but are not limited to, fatigue (such as metal circuit fatigue) and delamination. For certain failure mechanisms, such as ball bond integrity, faster rates, >3 cph can be used, if the temperature cycling chambers are capable of meeting the T_s nominal and soak requirements for the given Test Condition.

5.1.2 Solder interconnect cycle rates

Typical solder interconnect cycle rates are slower, in the range of 1 to 2 cph, when solder joint fatigue evaluations are performed. These include flip chip, ball grid array and stacked packages with solder interconnections. Cycle frequency and soak time is more significant for solder interconnections.

5.1.3 Tin whisker cycle rate

Tin whisker cycle rate shall be about 3 cycles per hour as stated in JESD22-A121.

5.2 Maximum and minimum temperature

The maximum and minimum sample temperatures measured shall be within the range stated in Table 1 for the specific test condition being used. Typical boundary values of +10°C for $T_{s(max)}$ and -10°C for $T_{s(min)}$ are discretionary and depending on equipment capability and test objectives.

Table 1 — Temperature cycling test conditions

Test Condition*	Nominal $T_{s(min)}$(°C)	Nominal $T_{s(max)}$(°C)
A	-55	+85
B	-55	+125
C	-65	+150
G	-40	+125
H	-55	+150
I	-40	+115
J	-0	+100
K	-0	+125
L	-55	+110
M	-40	+150
N	-40	+85
R	-25	+125
T	-40	+100

***CAUTION**: Care should be taken when selecting Test Conditions, since: 1) the $T_{s(max)}$ requirement for a specific Test Condition may exceed the glass transition temperature of some package materials which may induce failure mechanisms not normally seen during design application conditions in the field, 2) large thermal gradients between and across the devices under test (DUT) need to be avoided in order to preserve the test data integrity and 3) CTE differences over the test condition temperature range can produce premature failure of plated through holes in the test board, thus limiting electrical readout capability for the parts on test. Test Conditions that exceed 125 °C for $T_{s(max)}$ are not recommended to Pb/Sn solder compositions due to potential dynamic recrystallization.

Selection of the thermal cycling test condition should correspond with its test objective, and application use condition. In some cases, characterization of material responses to the extreme temperatures for the chosen test selection may be critical to avoid unintended outcomes as mentioned above.

Thermal cycling profiles commonly used for device qualification are referenced in JESD47; yet, any other profile listed in this document (or custom profiles) may be utilized in accordance with JESD94 (knowledge based test methodology) or investigative purposes.

NOTE Temperature cycling test conditions different from Table 1 can be used. However, test conditions should meet the soak, cycles per hour and ramp rate recommendations for the failure mechanism being tested. These conditions must be documented as indicated in 7(f).

5.2 Maximum and minimum temperature (cont'd)

Table 2 — Soak mode conditions

Soak Mode	Minimum Soak Time at Soak Temperature(max) & Soak Temperature(min) (minutes)
1	1
2	5
3	10
4	15

NOTE Soak Modes different from Table 2 can be used, however, test conditions should be appropriate for the failure mechanism being tested. These conditions must be documented as indicated in 7(f).

5.3 Upper and lower soak times

Upper and Lower Soak Times vary by the Soak Mode selected; see Table 2. During this soak time the specimen shall reach the required nominal temperature, either $T_{S(max)}$ or $T_{S(min)}$.

5.4 Upper and lower soak temperatures

Upper and Lower Soak Temperatures vary with the Test Condition selected; see Table 1.

5.5 Soak modes

Soak Modes are listed in Table 2. Soak Modes with longer soak times than those shown in Table 2 are not compatible with standard cycle rates and should be selected only as required for a specific failure mechanism.

5.5.1 Component soak mode

In component temperature cycling, Soak Mode 1 is typically used.

5.5.2 Interconnect soak mode

Soak Modes 2, 3 and 4 are generally used for solder fatigue and creep testing associated with interconnections such as flip chip or BGA solder joints.

5.5.3 Tin whisker soak mode

Tin whisker soak mode shall be 5 to 10 minutes as stated in JESD22-A121. This equates to soak mode 2, see Table 2.

5.6 Nominal cycle time

Nominal cycle times vary with the Soak Mode selected. Table 3 lis ts typical cycle rates for components versus test condition and soak m ode. For solder interconnections, cycle tim es less than 30 minutes are not recommended.

Table 3 — Typical frequency and soak mode for test conditions

Condition	Typical Cycles/Hr.	Typical Soak Mode
A	2 – 3	1, 2 & 3
B	2 – 3	1 & 2
C	2	1 & 2
G	< 1 – 2	1, 2, 3 & 4
H	2	1 & 2
I	1 – 2	1, 2, 3 & 4
J	1 – 3	1, 2, 3 & 4
K	1 – 3	1, 2, 3 & 4
L	1 – 3	1, 2, 3 & 4
M	1 – 3	1, 2, 3 & 4
N	1 – 3	1, 2 & 3
R	1 - 2	1 & 2
T	1 - 2	3 & 4

5.7 Ramp rate

5.7.1 Component ramp rate

Ramp rate is not critical for m ost component testing with the exception of interconnects, see 5.7.2.

5.7.2 Interconnect ramp rate

When testing interconnections for solder joint fatigue, it is important to avoid transient therm al gradients in the sam ples on test. Sam ples with large thermal mass and low heat tr ansfer efficiency require ramp rates slow enough to comp ensate for the thermal mass. The temperature of the sample should be within a few degrees of the ambient temperature during the temperature ramps. Typical r amp rate for this situation is 15 °C/minute or less for any portion of the cycle, with a preferred rate of 10 °C to 14 °C/m inute. For sam ples of large therm al mass, use of a single zone chamber may be required to achieve the best ramp rate.

NOTE 1 The preferred cycle rate is based on a balance between proper testing for solder joint fatigue and thermal cycling test efficiency.

NOTE 2 Air to air or li quid to liquid thermal shoc k chambers should not be substituted for therm al cycling chambers since the ramp rate of the DUT is important and too fast a rate can produce unrealistic damage during interconnect testing. Also large ther mal gradients on the DUT (s) can r esult in a varied acceleration factor across the chamber load.

NOTE 3 It is critical to control ramp rates as one may involuntarily generate a therm al shock test environment should the stated guidance be surpassed.

5.7.2 Interconnect ramp rate (cont'd)

Typical test requirements for solder interconnection are listed in Table 4. The combination of ramp rate and soak time are important when testing solder interconnections.

Table 4 — Recommended test conditions for solder interconnection temperature cycling

Test Condition*	Soak Mode	Ramp Rate (°C/minute)	Cycle Rate (cph)
G, I, J, K, L, T	2	Thermal Mass Dependent	2
G, I, J, K, L, T	3	Thermal Mass Dependent	≤2
G, I, J, K, L, T	4	Thermal Mass Dependent	<1
R	1	Thermal Mass Dependent	2

* **CAUTION**: Care should be taken in selection of Test Conditions since the $T_{s(min)}$ may cause cracking of the Printed Wiring Board plated through holes and/or wiring, thus inhibiting electrical readouts associated with the solder interconnections being tested.

5.8 Load transfer time (Dual chamber only)

Load transfer time shall be less than 1 minute, in order to maintain a uniform temperature profile across the load.

5.9 Measurements

Visual examination and electrical measurements, which consists of parametric and functional test, shall be performed as specified in the applicable procurement document or data sheet. Electrical test may be performed either in-situ or at an ambient or extreme temperature. Failure resistance criteria must be adjusted based on the temperature of the sample at time of test. In addition, hermeticity test(s) per JESD22-A109 shall also be performed for hermetic devices.

6 Failure criteria

Failure criteria shall include, but not be limited to, hermeticity for hermetic devices, parametric limits, functional limits, mechanical damage and warpage. Parametric and functional limits shall be defined by the applicable procurement document. Mechanical damage shall not include damage induced by fixturing or handling or the damage is not critical to the package performance in the specific application.

7 Summary

The following details shall be specified in the applicable procurement documents:

a) Special mounting, if applicable; see section 4.

b) Temperature extremes; see Table 1, soak time; see Table 2, sample cooling and heating ramp rate and number of cycles, or specific component requirements.

c) Interim measurement intervals, when required.

d) Special acceptance criteria for examinations, seal tests (for hermetic packages), internal bond integrity tests and electrical tests if other than those specified in the device specification.

e) For qualification testing, sample size and quality level.

f) Temperature extremes other than in Table 1. Specify the number of cycles, temperature extremes, soak time, cycles per hour, tolerance on temperature extremes (if different from Table 1), ramp rate and interim measurements, if required.

Annex A (informative) Temperature Profile

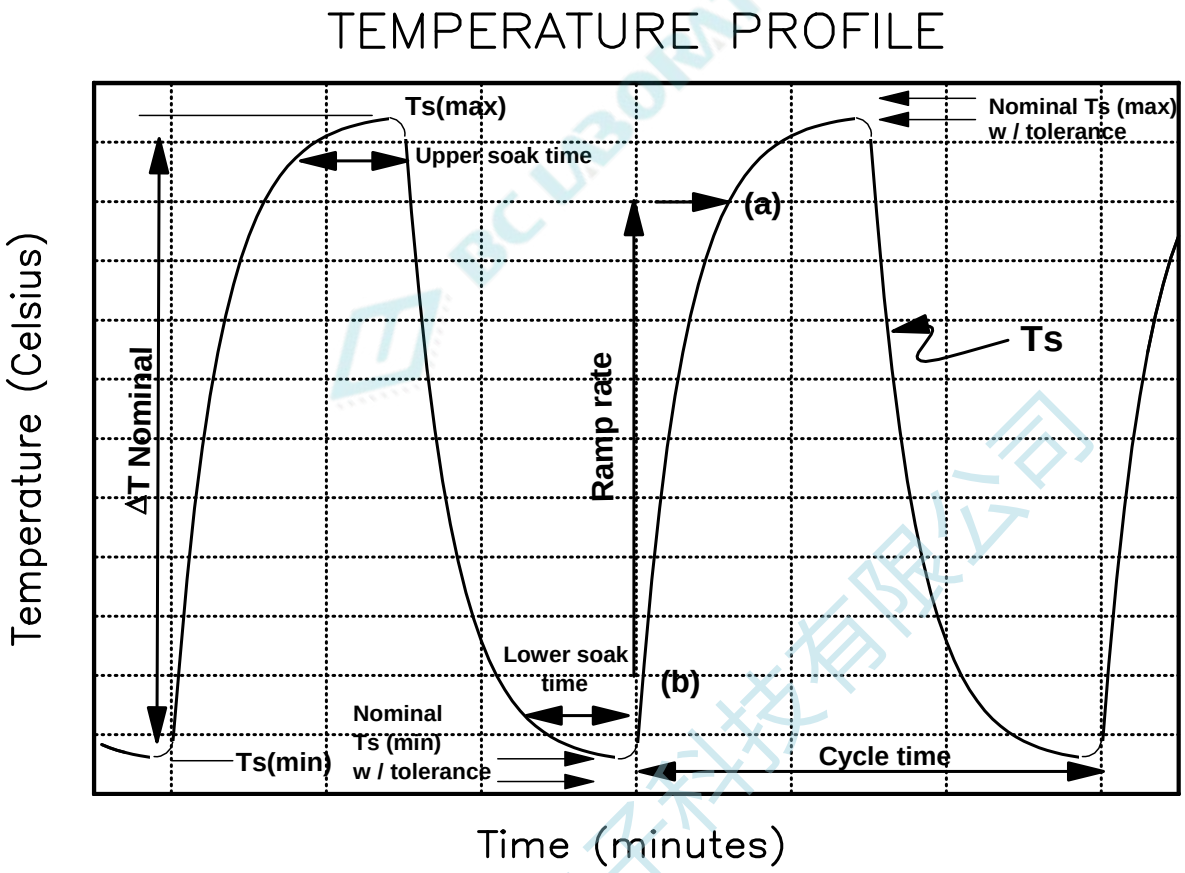

Figure 1 — Representative temperature profile for thermal cycle test conditions

NOTE Ramp rate should be measured for the linear porti on of the profile curve, which is generally the range between 10% and 90% of the Test Condition temperature range; see points a and b in Figure 1.

Annex B (informative) Differences between JESD22-A104E and JESD22-A104D

This table briefly describes most of the changes made to entries that appear in this standard, JESD22A104E, compared to its predecessor, JESD22-A104D (March 2009). If the change to a concept involves any words added or deleted (excluding deletion of accidentally repeated words), it is included. Some punctuation changes are not included.

Clause	Description of change
3	Terms and Definition - Added JESD94 reference - Added IPC-SM-785 reference
5.2	Revise Table 1 - added (2) new T/C profile – TCR, TCT - Revise column (Upper and Lower tolerances) - Test condition selection considerations - Ref. to JESD47 and other considerations for thermal cycling profile selection
5.6	Revise table 3 - Soak recommendations for (2) new T/C profile – TCR, TCT
5.7.2	Revise table 4 – Solder interconnect recommendations for (2) new T/C profile – TCR, TCT

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The referenced clause number has proven to be:

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