

JEDEC STANDARD

High Temperature Package Warpage Measurement Methodology

JESD22B112

MAY 2005

JEDEC SOLID STATE TECHNOLOGY ASSOCIATION



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Introduction

When integrated circuit packages are subjected to the high-temperature solder reflow operation associated with the mounting of devices to a printed circuit board, deformation and deviation from an ideal state of uniform planar flatness, i.e., warpage, often results. The deviation of the package from planarity during board assembly can cause the package terminals to have open or short circuit connections after the reflow soldering operation. (Certain package types such as ball grid arrays (BGAs) have been found to be more susceptible to the effects of component warpage.) Intrinsic package warpage is largely driven by coefficient of thermal expansion mismatch between the various packaging material constituents. Package warpage is therefore temperature dependent and the final warpage state is a function of the entire temperature history or reflow profile, that is typically nonlinear in time. The presence of moisture can also introduce hygroscopic strain effects which further contribute to changes in total package body warpage.

JESD22-B108A measures the deviation of the device terminals from coplanarity only at room temperature. The worst case deviation from flatness may be at room temperature, maximum reflow temperature, or any temperature in-between. Package warpage cannot be determined by the condition of the package once it has been reflowed and cooled back to room temperature, but must be characterized during the entire reflow soldering thermal cycle. Critical engineering evaluations of the package and printed circuit board warpage must therefore be conducted in the laboratory under simulated reflow conditions.

Package Warpage Test for Surface-Mount Integrated Circuits

(From JEDEC Board Ballot JCB-05-84, formulated under the cognizance of the JC-14.1 Subcommittee on Reliability Test methods for Packaged Devices.)

1 Scope

The purpose of this test method is to measure the deviation from uniform flatness of an integrated circuit package body for the range of environmental conditions experienced during the surface-mount soldering operation.

2 Terms and definitions

ball grid array (BGA): A package in which the external connections to the package are made via a rectangular array of ball-type connections, all on a common plane.

concave warpage: Warpage resulting in the package corners being farther from the seating plane than the center of the bottom surface of the package. (See Figure 1.)

convex warpage: Warpage resulting in the package corners being closer to the seating plane than the center of the bottom surface of the package. (See Figure 1.)

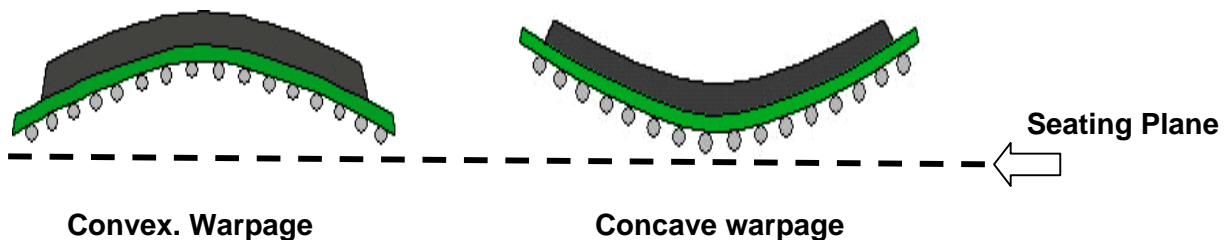


Figure 1 — Package warpage convention

deviation from planarity: The difference in height between the highest point and the lowest point on the package body bottom surface measured with respect to the seating plane.

fringe order: The nth fringe in a sequence of interference fringes.

peak reflow temperature: The maximum package reflow temperature as specified in J-STD-020 depending on package dimensions and whether the product is intended for eutectic Sn-Pb or Pb-free reflow soldering.

rated moisture sensitivity level (MSL): The moisture sensitivity level as determined by J-STD-020.

2 Terms and definitions (cont'd)

seating plane: The plane formed by the three terminal apexes that exhibit the greatest perpendicular distance from the package substrate, provided that the triangle formed by those three apexes encompasses the projection of the center of gravity (COG) of the component. (See Figure 1.)

shadow moiré method: An optical noncontact method to measure warpage using a moiré fringe pattern resulting from the geometric interference between a flat reference grating and the projected shadow of the grating on a warped test object.

thermal shadow moiré method: A method to measure surface deviation using shadow moiré interference fringes as the package goes through high temperature reflow soldering.

3 Applicable documents

JEP113, *Symbols and Labels for Moisture Sensitive Devices.*

J-STD-020, *Moisture/Reflow Sensitivity Classification for Nonhermetic Solid State Surface Mount Devices.*

JESD22-A113, *Preconditioning of Nonhermetic Solid State Surface Mount Components Prior to Reliability Testing.*

JESD22-B100, *Physical Dimensions.*

JESD22-B108, *Coplanarity Test for Surface-Mount Semiconductor Devices.*

4 Measurement instrument requirements

4.1 General metrology considerations

Warpage metrologies such as Shadow Moiré, 3D Digital Image Correlation, and various forms of line scanning and/or high-resolution focusing based tools have been successfully applied and validated under ambient test conditions. A few of these tools have been successfully adapted and commercialized to support in-situ package warpage measurements at elevated temperatures. This specification focuses solely on the application of Thermal Shadow Moiré as the tool for warpage measurement. Nonetheless, any of the above mentioned techniques and perhaps others not listed in this document are potentially adaptable to elevated temperature warpage measurements and could be considered.

4 Measurement instrument requirements (cont'd)

4.1 General metrology considerations (cont'd)

The tool used for elevated temperature warpage metrology should be verified using a warpage standard that is invariant to temperature changes across the temperature range of interest, as outlined in clause 5. Measurement accuracy should be verified at temperature extremes such as through the use of a concave or convex ground glass manufactured from ultra-low-expansion material such as Zerodur® optical ceramic with a coefficient of linear expansion between 20 °C and 300 °C of $0.05 \pm 0.10 \times 10^{-6}/^{\circ}\text{C}$. Periodic repeatability measurements should be conducted at elevated temperature using the high temperature warpage standard.

Reproducibility of test data should be initially evaluated with respect to any operator-to-operator, day-to-day, or other extrinsic factors which may potentially influence tool performance. Once successfully validated, the tool should be routinely calibrated and monitored on a periodic basis. Sample preparation, temperature profiling, and sample temperature distribution guidelines should be followed according to clause 6 of this document.

4.2 Shadow Moiré apparatus, (Figure 2)

4.2.1 Camera to capture shadow moiré pattern

4.2.2 Ronchi ruled grating made from low CTE glass, specifically defined lined pitch grating through which light passes to cast a shadow moiré pattern onto the sample.

4.2.3 Light source to project white light through the grating and to cast a shadow moiré pattern onto the sample.

4.2.4 Electromechanical Z stepping sample stage for phase shifting and acquiring fringe pattern at different heights.

4.2.5 Computer controlled display system for fringe pattern display, storage, retrieval, printing and analysis.

4.2.6 Sample Holder used to hold and align the sample and to prevent it from moving during measurement.

4.2.7 NIST traceable calibration block using step height changes.

4.2.8 A curved glass standard made of ultra low expansion glass of known bend radius is also recommended for tool validation at elevated temperature.

4.2.9 Thermal chamber used to heat the samples for in situ warpage measurements.

4.2.10 Thermocouples attached to the sample or attached to a second identical reference sample used for measuring elevated temperature response.

4 Measurement instrument requirements (cont'd)

4.2 Shadow Moiré apparatus, (Figure 2) (cont'd)

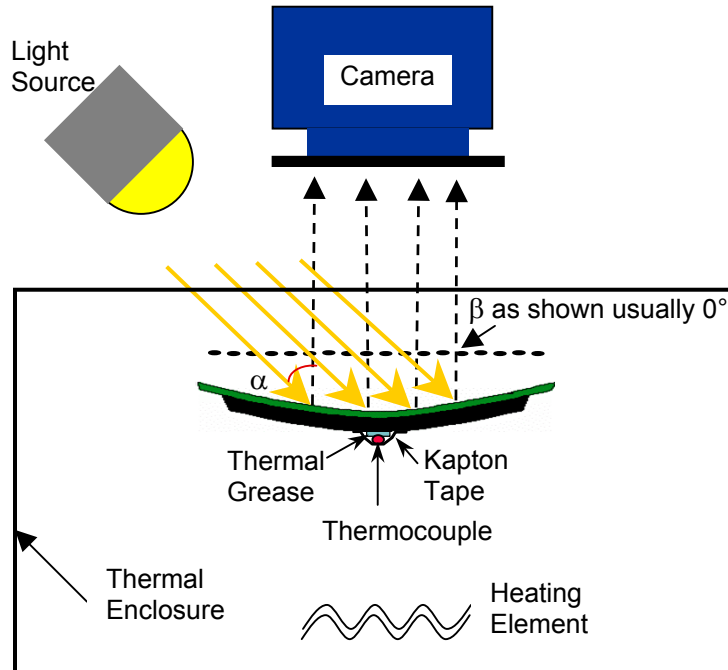


Figure 2 — Shadow Moiré Geometry

4.3 Thermal Shadow Moiré

Thermal Shadow moiré is perhaps the most commonly employed metrology for conducting elevated temperature warpage measurements. Measurements are conducted by placing the Ronchi ruled grating and sample of interest into a thermally insulated enclosure, see Figure 2. A heat source is then used to ramp the temperature of the sample under test.

A shadow of the reference grating is cast onto the surface of the specimen below by projecting a beam of white light at a specified angle through the grating. Moiré fringe patterns are produced as a result of the geometric interference pattern created between the reference grating and the shadow grating.

The Ronchi grating line spacing and overall planarity of the glass substrate are generally invariant to changes in temperature. Thermal Shadow Moiré measurements are successfully conducted and recorded as the temperature of the sample is increased to the peak reflow temperature and returned to near room temperature.

NOTE In the case where the specimen is flat and aligned parallel to the reference grating, no moiré fringe pattern is produced. If a small “wedge angle” is deliberately introduced between the flat test surface and the reference grating, a series of straight parallel fringes results. In the general case where the surface of the specimen is curved, or warped, a more complex full field fringe pattern results.

4.3 Thermal Shadow Moiré (cont'd)

4.3.1 Shadow moiré fringe

An accurately calibrated fringe constant is required to convert a whole field shadow moiré fringe pattern into a 3D surface map of package warpage. The shadow moiré fringe count is related to out-of-plane deformation (warpage) using the fringe constant calibration formula (1).

$$W = \frac{Np}{\tan \alpha + \tan \beta} \quad (1)$$

where:

N = Fringe order

p = grating pitch

α = angle of illumination

β = angle of observation

W = out of plane (normal) displacement or warpage

In typical shadow moiré systems the imaging plane is directly over the object such that the observation angle $\beta=0^\circ$ and the light source illumination angle $\alpha \geq 45^\circ$.

Phase shifting is routinely implemented as a means of converting whole field fringe patterns into continuous 3D plots of surface topography, see Figure 3. A precise computer controlled stepper motor is utilized to displace the sample stage with respect to the glass grating and in doing so generates a series of discrete phase shifted fringe patterns. Typically four such patterns are acquired although numerous schemes exist that utilize 3 or more phase shifted patterns.

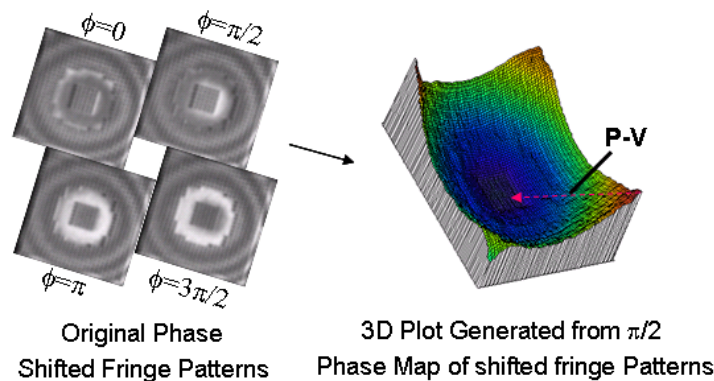


Figure 3 — Package substrate phase shifted fringe pattern sequence and resulting 3D Surface Profile.

The Ronchi rule grating line frequency is typically in the range of 100 to 300 lines/inch and the physical gap required between the grating and sample is typically on the order of several millimeters. The physical gap between the grating and the sample is adjusted to optimize fringe contrast of the generated fringe pattern. Following equation (1), finer pitch gratings yield increased measurement sensitivity but require a smaller gap between the grating and sample in order to achieve good contrast. An operator should strive to conduct measurements using the finest possible grating pitch in order to maximize the fundamental sensitivity of the instrument.

4.3 Thermal Shadow Moiré (cont'd)

4.3.1 Shadow moiré fringe (cont'd)

The Ronchi grating should generate a minimum of 2 circular or irregular concentric fringes when the sample is symmetrically oriented and nominally running parallel with respect to the plane of the Ronchi grating. If geometric considerations or the height of other assembled electronic components restrict the proximity of the grating to the package surface, a coarser grating must then be considered that will necessarily permit a greater grating to sample gap.

Fringe analysis is applied to solve for the phase angle at each pixel location across a region of interest. Phase angle is then converted to displacement through use of the sensitivity relationship given by equation 1. The multi-step phase shifting technique has the added benefit of enhancing the overall system sensitivity since the ability to track small pixel to pixel intensity variations translates into fractional fringe resolution. Critical factors that ultimately limit phase shifting assisted resolution are fringe contrast, spatial noise, surface artifacts, CCD camera A/D bit resolution, and mechanical phase stepping accuracy and calibration.

5 Calibration requirements

5.1 A calibration routine using a warpage standard that is guided by the machine software should be utilized to initialize the instrument at room temperature before a series of measurements are made on any package style.

5.2 Measurement accuracy and tool repeatability at elevated temperature may be independently validated through the use of a ultra-low-expansion glass warpage standard which exhibits no measurable changes in warpage with increased temperature. The radius of curvature or warpage of the spherical glass standard should be independently established using a laser interferometer of higher overall accuracy.

5.3 Figure 4 depicts a sequence of fringe patterns used to generate a phase map and resulting 3D surface profile of a circular concave warpage standard generated using shadow moiré. The phase map was cropped to a circumscribed square.

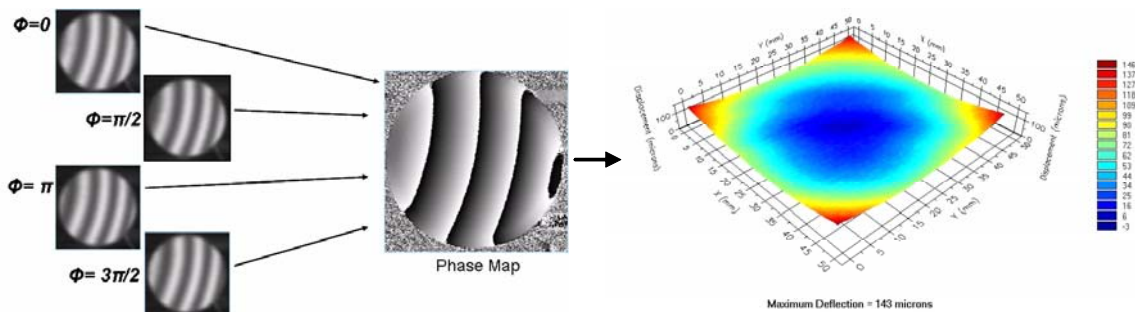


Figure 4 — Warpage calibration using an ultra-low-expansion concave warpage standard.

6 Test sample preparation

For area array packages, warpage measurements should be viewed on the substrate side to effectively collect data for the entire planar region of the package footprint. Test samples should be prepared without solder balls attached in order to avoid possible measurement errors caused by light scattering from the solder balls. A simulated solder ball attachment process is recommended to subject the components to the thermal process used to attach the solder balls. For components containing solder balls, these should be removed by either reflow solder wicking, mechanical polishing, or chemical etching. For any process to remove the solder balls, care should be taken not to disturb the structural integrity of the package that will ultimately affect the final warpage characteristic of the component. Verification of the technique used to remove the solder balls must be conducted.

For lead frame based packages, either the top or bottom for the package body surface can be measured. All measurements should maintain the (+/-) warpage convention, see Figure 1.

6.1 Sample Size

A minimum of 3 samples shall be measured to determine variation within an assembly lot. It is recommended that samples be measured in both the moisture soaked and dry states. The minimum moisture soaked condition shall be the rated moisture sensitivity level per J-STD-020.

NOTE This test is primarily intended for characterization of a package. If any changes to materials are made then the package should be re-characterized. If this test method is used for monitoring then the package warpage may be measured in only the dry state.

6.2 Thermal Moiré Considerations

Painting of the measurement surface may be required for enhancing light reflectivity and to achieve rated instrument accuracy.

6.3 Thermocouple Placement

Accurate temperature measurement of the sample body temperature is required during the thermal exposure in the chamber of 4.2.9 and will require that proper thermocouple type and attachment procedures are followed. It is recommended that a thermocouple of gauge 30 or finer is used and that the thermocouple is attached to the center of the package body using either a thermally conductive epoxy or attached using high temperature kapton tape. When kapton tape is used, it is recommended that a thermal paste, such as Fujipoly GR-HN, should be applied between the thermocouple bead and the surface of the test sample to reduce the thermal contact resistance, thereby producing a more accurate and consistent body temperature measurement.

6 Test sample preparation (cont'd)

6.4 Temperature Ramp Rate

The temperature ramp rate during both heating and cooling will influence the measured warpage and therefore is an important factor. Ideally, a temperature ramp rate that can closely match the thermal profile response as seen during board assembly should be used. However, if equipment limitations prevent the achievement of assembly matched ramp rates, the equipment should be configured to achieve as fast a ramp rate as possible without introducing significant delta temperature differences between the top and bottom of the package body. Thermal chambers equipped with assisted convective heating and cooling instead of 100% radiant heat transfer are highly recommended.

NOTE Excessively long profiles or large temperature gradients may also introduce cracking and/or delamination of the packages as a result of moisture and/or reflow damage which may then result in erroneous warpage measurements.

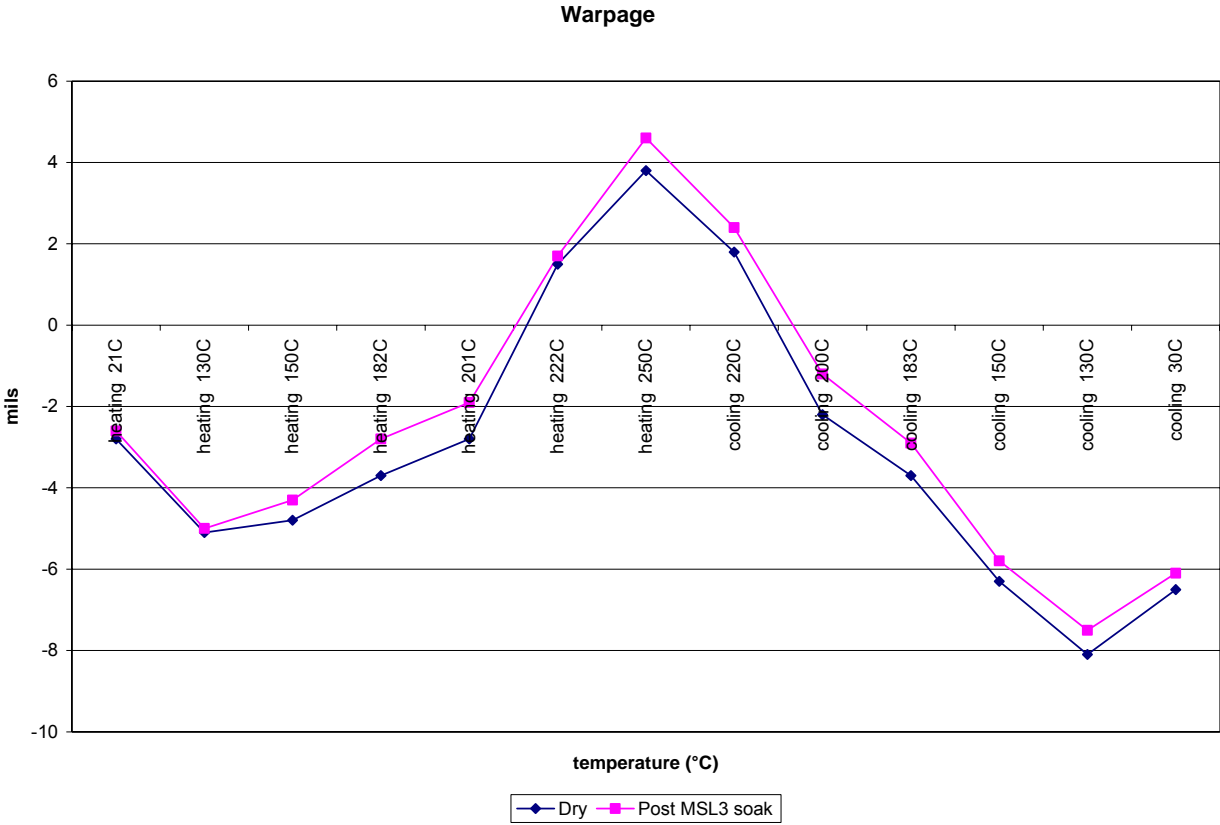
7 Parameters to be measured

- 7.1 Total warpage magnitude or peak to valley between the test surface and reference datum across the x-y spatial dimensions of the component as a function of body temperature up to the peak reflow temperature.
- 7.2 Magnitude of the package warpage assigning a positive warpage magnitude as convex in shape and negative as concave, e.g., positive magnitude assigned for packages with the corners warped down towards the seating plane "frowning", refer to Figure 1 and see Annex A.1 and A.2
- 7.3 A plot showing total warpage magnitude versus temperature with the (+) and (-) conventions assigned. See Annex A.1
- 7.4 3-D contour plots of package shape as a function of peak reflow temperature. Such plots should be carefully reviewed in conjunction with peak to valley data order to determine whether reported peak to valley readings are reliable and not skewed by any image processing artifacts such as sharp edge discontinuities or surface irregularities of the test sample. See Annex A.2
- 7.5 Diagonal line scans showing total warpage magnitude across the diagonal of the component. See Annex A.2

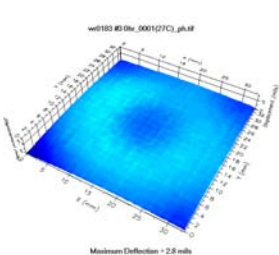
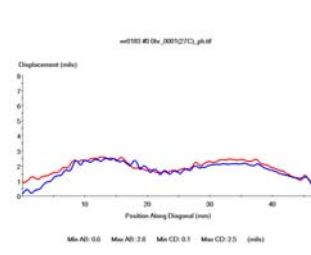
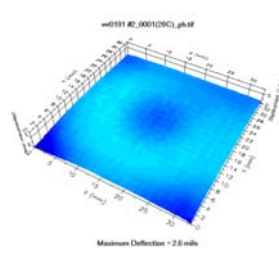
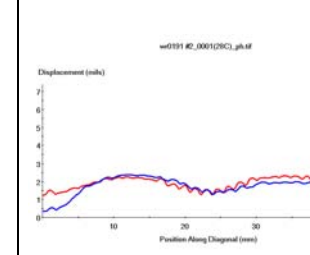
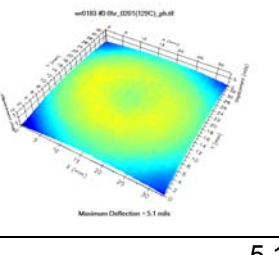
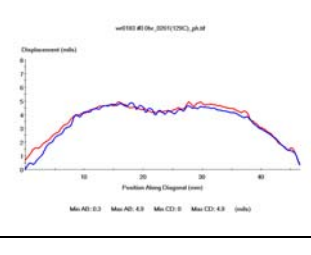
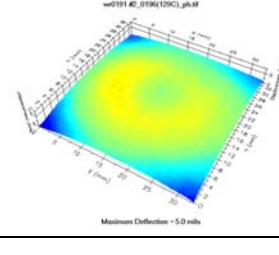
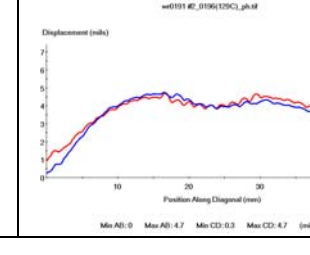
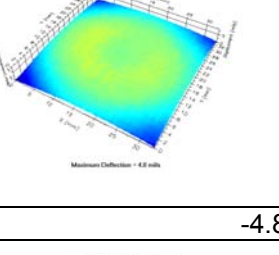
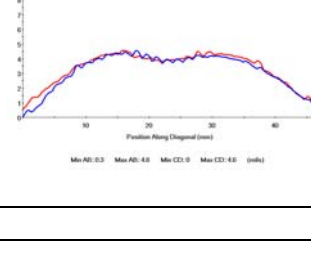
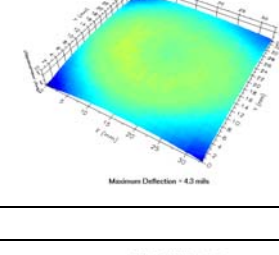
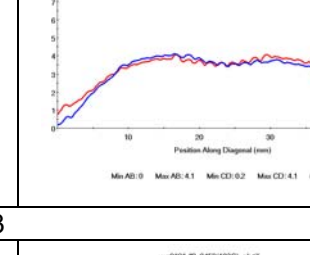
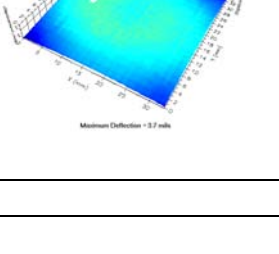
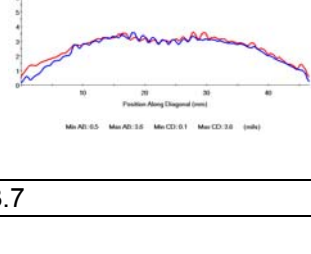
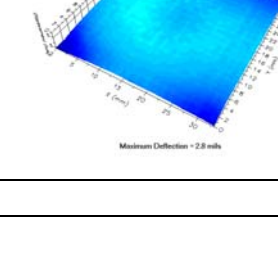
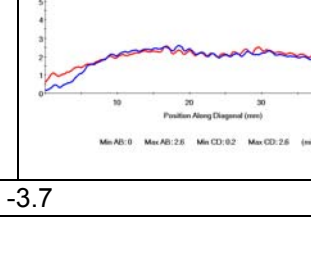
Annex A Sample Warpage data report: Warpage of device at various temperatures of simulated surface mount reflow (Dry and Post moisture soak)

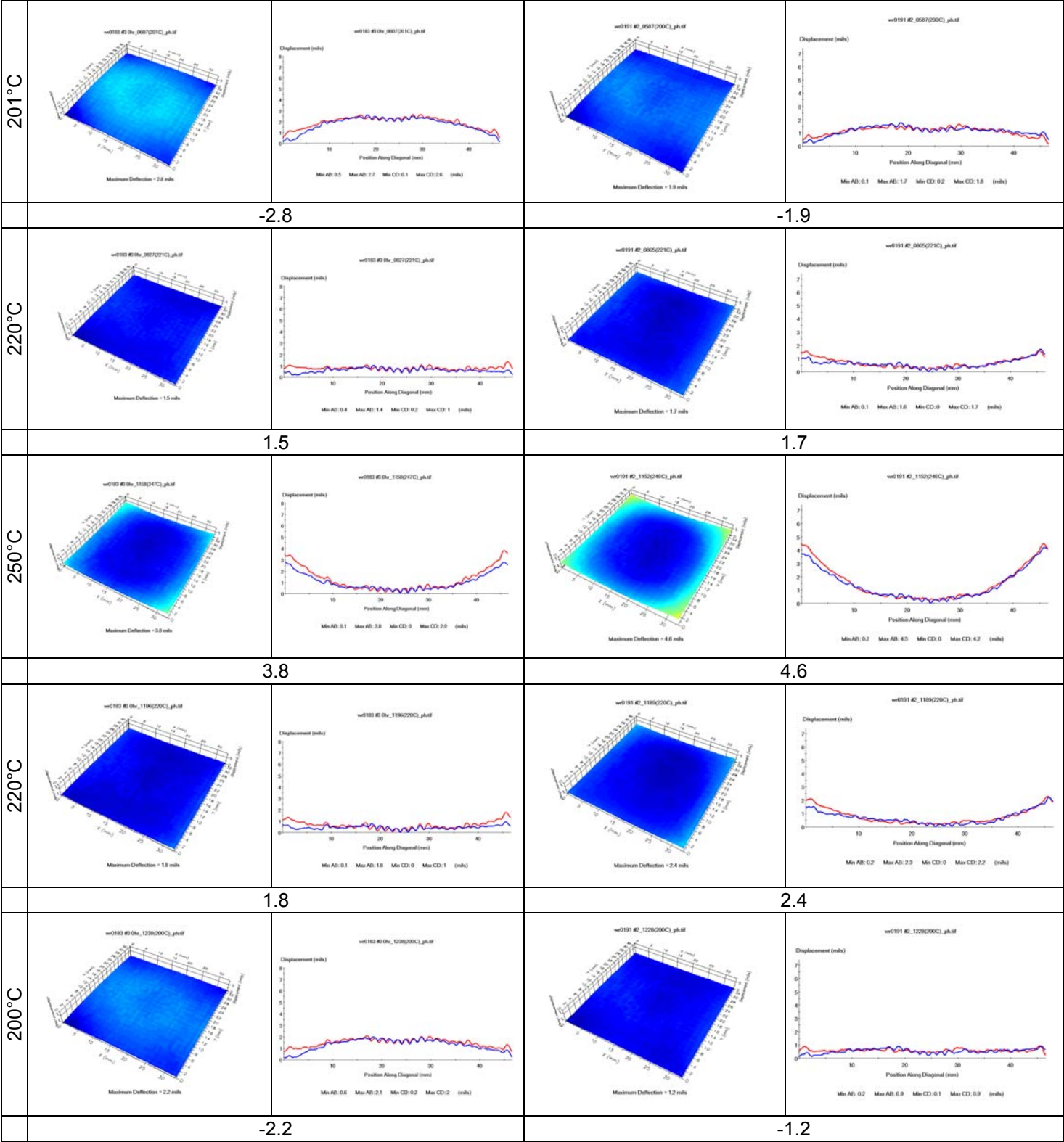
Device: Sample1 serialization
Package information: dimensions, BOM, etc

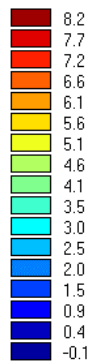
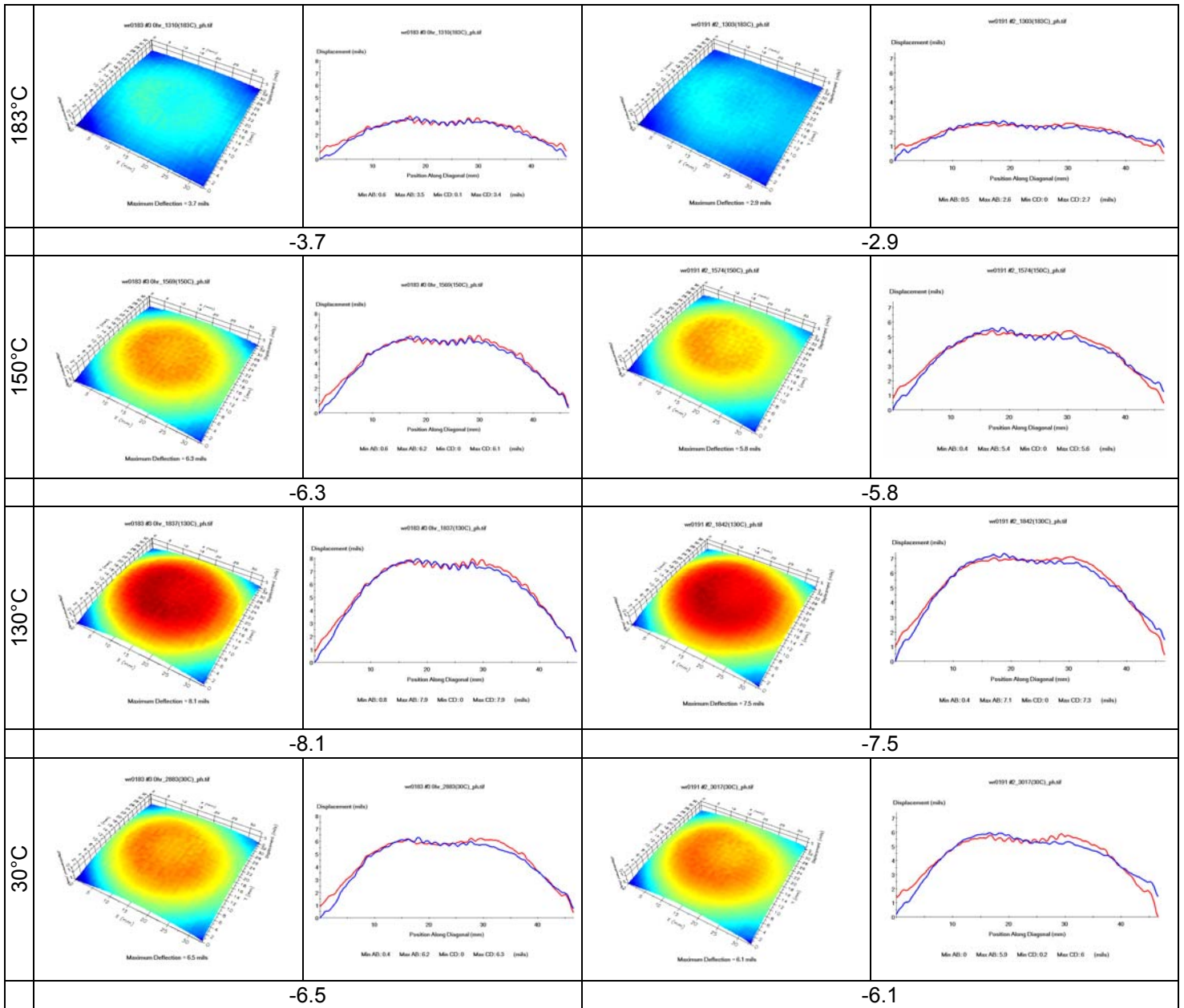
A.1 Plot of Warpage vs Temperature



A.2 Graphical representation of measured warp at temperature (Samples in “dead bug” position, in mils)

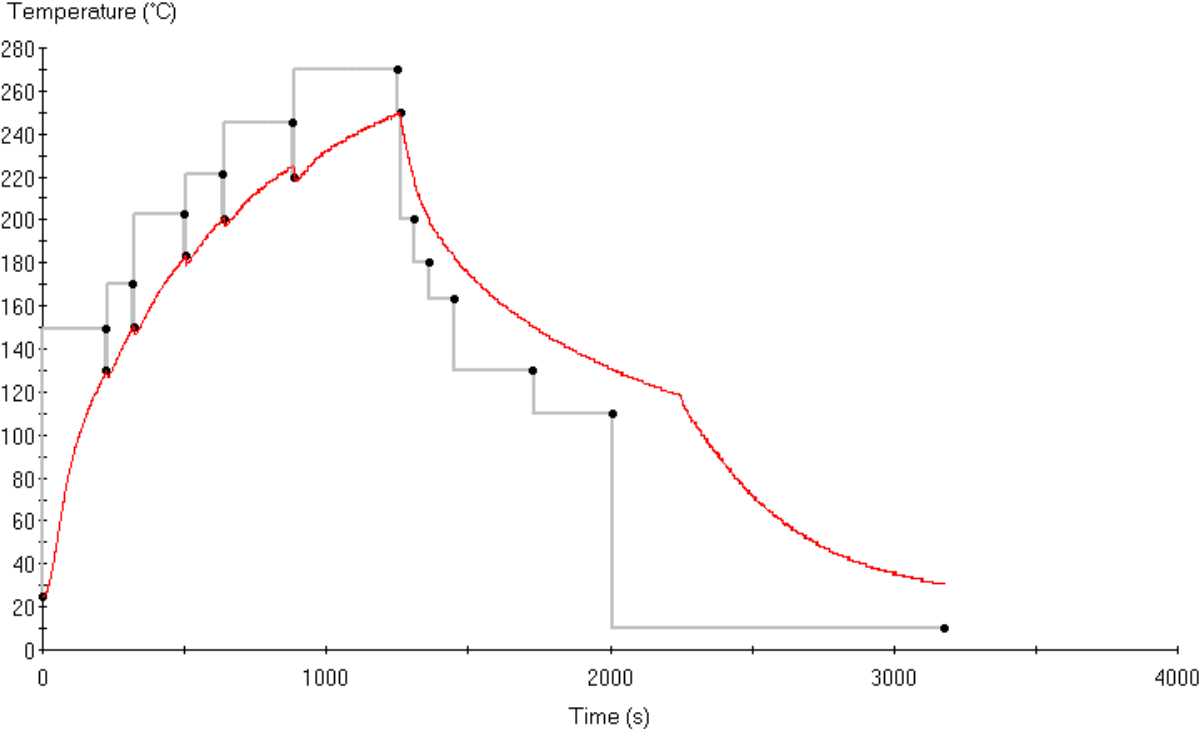
	Post Bake		Post MSL soak	
	3D contour plots	Diagonal line scans Corner to Corner	3D contour plots	Diagonal line scans Corner to Corner
Room Temperature °C				
	-2.8		-2.6	
130°C				
	-5.1		-5	
150°C				
	-4.8		-4.3	
183°C				
	-3.7		-3.7	





A.3 Plot of package body temperature vs time

Part: wr0190 #3
Profile: overshoot 250C_in.bt



— Desired Profile • Measurement Points — Process 1



Standard Improvement Form

JEDEC JESD22B112

The purpose of this form is to provide the Technical Committees of JEDEC with input from the industry regarding usage of the subject standard. Individuals or companies are invited to submit comments to JEDEC. All comments will be collected and dispersed to the appropriate committee(s).

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1. I recommend changes to the following:

Requirement, clause number _____

Test method number _____ Clause number _____

The referenced clause number has proven to be:

Unclear Too Rigid In Error

Other _____

2. Recommendations for correction:

3. Other suggestions for document improvement:

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