IEC JEITA

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PUBLICLY AVAILABLE SPECIFICATION

PRE-STANDARD

**Mechanical standardization of semiconductor devices –
Part 6-19: Measurement methods of package warpage at elevated temperature and the maximum permissible warpage**

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CONTENTS

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MECHANICAL STANDARDIZATION OF SEMICONDUCTOR DEVICES –

Part 6-19: Measurement methods of package warpage at elevated temperature and the maximum permissible warpage

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The text of this PAS is based on the following documents	This PAS was approved for publication by the P-members of the committee concerned as indicated in the following document:
Draft PAS	Report on voting
47D/691/NP	47D/707/RVN

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MECHANICAL STANDARDIZATION OF SEMICONDUCTOR DEVICES –

Part 6-19: Measurement methods of package warpage at elevated temperature and the maximum permissible warpage

1 Scope

This PAS stipulates the package warpage criteria and the package warpage measurement methods at elevated temperature for BGA, FBGA, and FLGA

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document applies.

JEITA EDR-4701/301, *Resistance to soldering heat for surface mounting devices (SMD)*

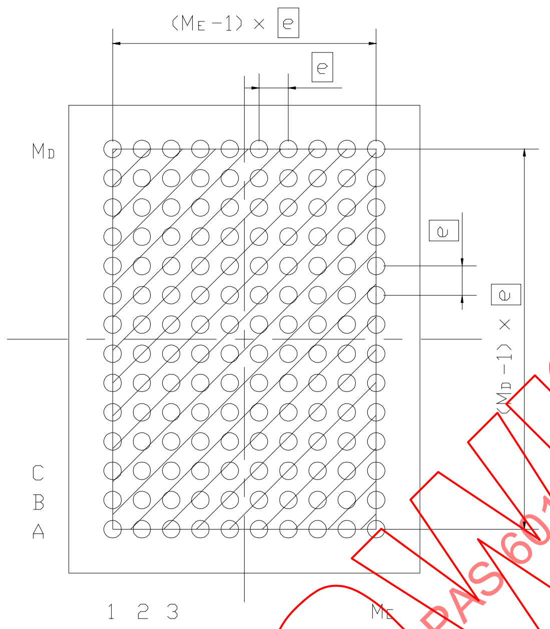
3 Terms and definitions

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

3.1
measuring zone
area to be measured to determine the package warpage

NOTE 1 For the packages whose stand-off height is more than 0,1 mm, such as BGA and FBGA, the measuring zone is the area where terminals are located. This area is bordered by the lines connecting the centers of the outermost neighboring solder balls (see Figure 1 and Figure 2). If there are thermal balls at the package centre, their area is also considered as a part of the measuring zone

NOTE 2 For the packages whose stand-off height is 0,1 mm or less, such as FLGA, the measuring area is the substrate surface except certain edge margin (see Figure 3, dimension *L*). The width of this margin *L* depends on the capability of each measuring instrument (0,2 mm recommended).



NOTE The hatched area indicates the measuring zone.

Figure 1 – Measuring zone of BGA and FBGA in full grid layout

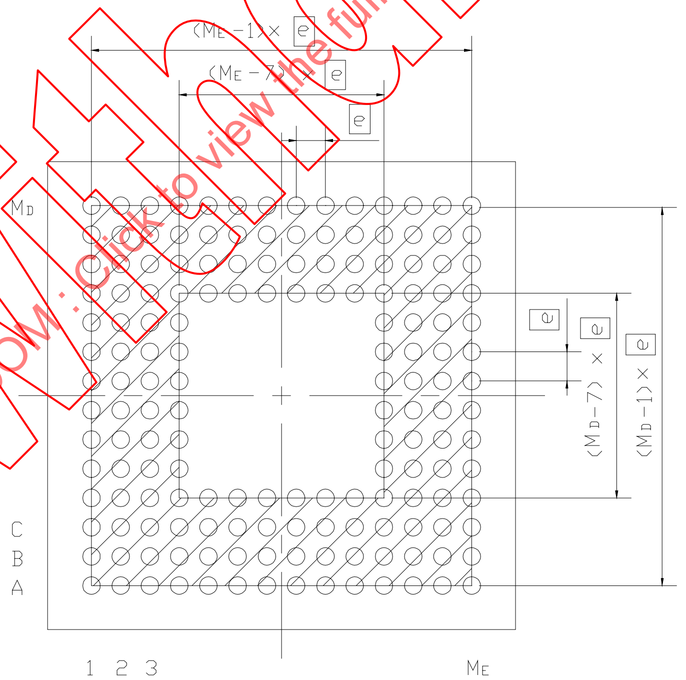
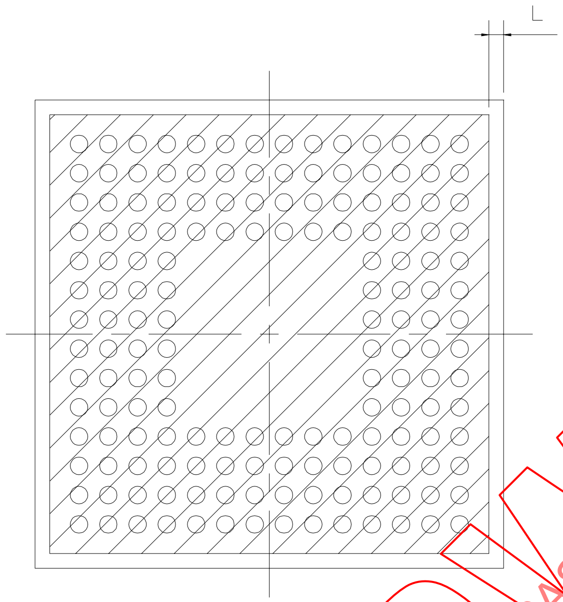


Figure 2 – Measuring zone of BGA and FBGA perimeter layout with 4 rows and 4 columns



NOTE The edge margin *L* indicates the exempt area from measurement to avoid measurement noise depending on the instrument capability. Recommended edge margin *L* = 0,2 mm.

Figure 3 – Measuring zone of FLGA perimeter layout with 4 rows and 4 columns

3.2
convex warpage
arched top surface (not interconnect side) of package being mounted on PWB

NOTE The sign of the convex warpage is defined as plus.

3.3
concave warpage
inward-curving top surface (not interconnect side) of package being mounted on PWB

NOTE The sign of the concave warpage is defined as minus.

3.4
package warpage sign
plus or minus sign of package warpage determined by the sign of the sum of the largest positive displacement and the largest negative displacement of the package profile on both measurement zone diagonals

NOTE These diagonals are regarded as base lines connecting the outermost opposite corners of the measuring zone. The sign of the package warpage is defined as the sign of:

$$(AB_{MAX}+AB_{MIN}+CD_{MAX}+CD_{MIN})$$

AB_{MAX} is the largest positive displacement and AB_{MIN} is the largest negative displacement of the package profile on the diagonal AB; (The sign of AB_{MAX} is plus and AB_{MIN} is zero in Figure 4.)

CD_{MAX} is the largest positive displacement and CD_{MIN} is the largest negative displacement of the package profile on the diagonal CD; (The sign of CD_{MAX} is plus and that of CD_{MIN} is minus in Figure 4.)

The concave or convex impression of the package warpage can differ from the above defined sign, in critical cases.

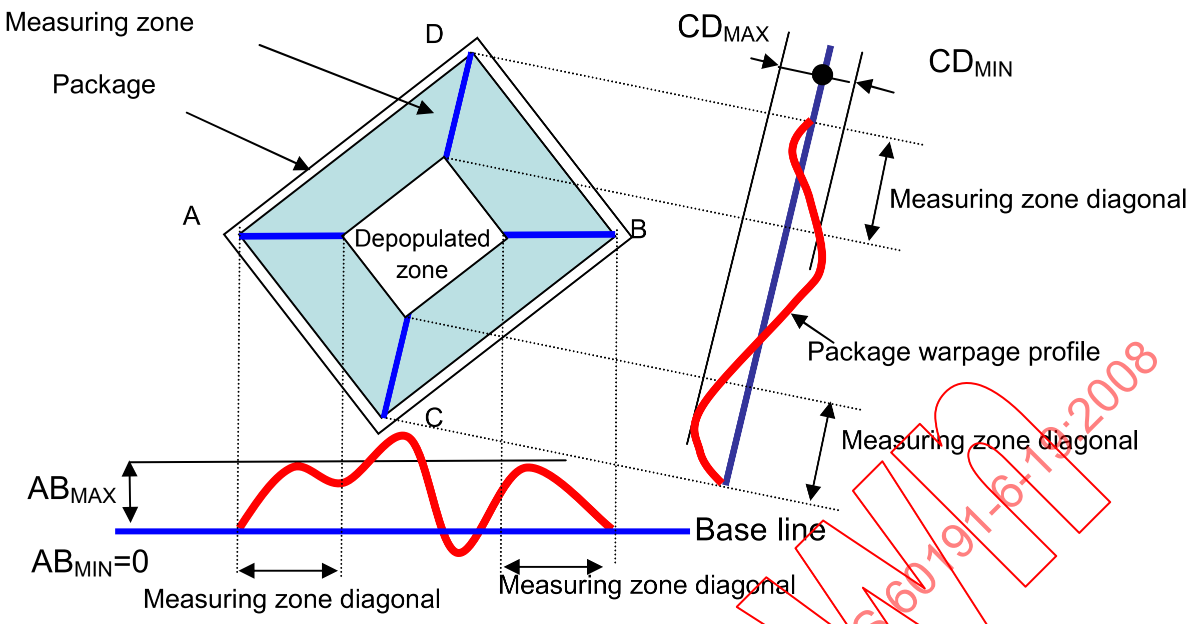


Figure 4 – Calculation of the sign of package warpage

3.5
package warpage
difference of the largest positive and the largest negative displacements of the package warpage in the measuring zone with respect to the reference plane, preceded by package warpage sign

NOTE This reference plane is derived using the least square method with the measuring zone data. For example, the absolute value of the package warpage |C| is obtained by the sum of the absolute value of the largest positive displacement |A| and that of the largest negative displacement |B|. This is in respect to the reference plane which is derived by using the least square method, as shown in Figure 5. Package warpage sign precedes |C|.

$$|C| = |A| + |B|$$

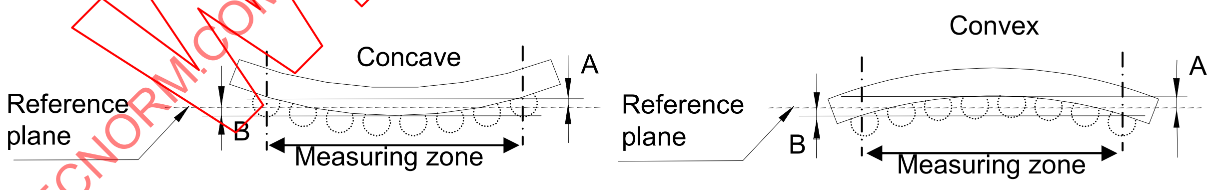


Figure 5 – Package warpage

4 Sample

4.1 Sample size

At least three samples are required for each measurement condition.

4.2 Solder ball removal

If the measurement method of the package warpage requires the elimination of the solder balls from a package, it is recommended to use mechanical removal rather than hot reflow. If the samples are prepared without solder balls for the convenience of the measurement, the package shall be subjected to the thermal history of the solder ball attachment process.

4.3 Pre-treatment conditions

The bake and moisture soak conditions shall conform to the moisture sensitivity level specified in JEITA ED-4701/301. The peak temperature of the package warpage measurement shall meet the specification of the product.

4.4 Maximum time after pretreatment until measurement

It is recommended to measure the warpage no longer than 5 h after the pretreatment.

4.5 Repetition of the reflow cycles for the sample

The same sample shall not be subjected to the repetition of the reflow cycles. The sample can only be subjected to more than one cycle of reflow for remeasurement, if reproducibility of test data was evaluated prior to the test.

5 Measurement

5.1 General description

The package warpage is measured by "shadow moiré method" or "laser reflection method".

Samples are subjected to heating and cooling while measuring the package warpage at the temperatures specified in 5.2. The measurement points shall not be on the crown of solder balls but on the substrate surface of the package. Only when the behaviour of the top surface of the package (mostly marking surface) is verified to coincide with that of the substrate surface, the measurement on the top surface is allowed.

5.2 Temperature profile and the temperatures for measurements

5.2.1 The temperature profile for the warpage measurement does not necessarily simulate that for production. Higher priorities are placed on

– maintaining the temperature constant during the measurement,

– never exposing the samples more than necessary duration at high temperature. Samples shall be proceeded to the next measurement as soon as possible,

– avoiding a temperature surge to prevent the overshoot, and

– Minimizing the temperature difference between the top and bottom surfaces.

5.2.2 The temperatures for measurements are as follows:

– room temperature;

– melting point;

– peak temperature;
– solidification point;
– room temperature after cool down.

The melting point and the solidification point are 220 °C for Sn-3.0Ag-0,5Cu solder as a reference. Other solder composites may take different temperatures. The peak temperature basically conforms to the package classifications specified in JEITA ED-4701/301, but to be exact, it shall follow the supplier's recommended max temperature.

5.2.3 It is recommended that a thermocouple of gauge 30 (ϕ0,25 mm) or flat tip type be used.

5.2.4 The thermocouple is attached on the centre of the package body using either thermally conductive epoxy or heat-resistant polyimide tape. When polyimide tape is used, thermally conductive sheet shall be applied between the thermocouple bead and the package surface to enhance thermal conductivity as a thermal interface material.

5.2.5 When a measuring instrument is being set up, the temperature of the molded side of the package facing a heater is also measured. The temperature difference from the substrate surface shall preferably be less than 10 °C by adjusting the heating mechanism and the temperature profile.

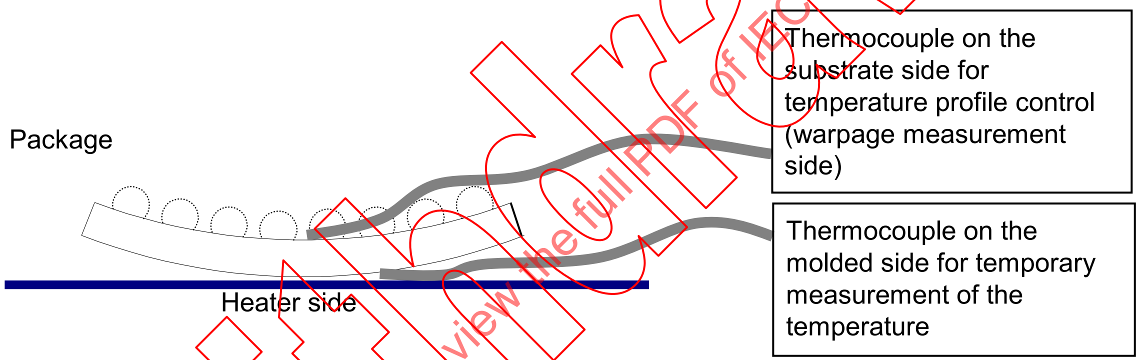


Figure 6 – Thermocouple placement

5.3 Measurement method

5.3.1 Shadow moiré method

Solder balls shall be removed prior to the measurement on the substrate surface. Measurements are conducted by placing the grating (low CTE glass with transparent and opaque stripes) parallel to the sample. Then, the projection of light beam at an angle of approximately 45° through the grating produces the stripe pattern on the sample. Observation of the stripe pattern through the grating results in the moiré fringe pattern (geometric interference pattern). Image processing and the analysis of the patterns provide the displacement from planarity over the substrate surface. The instrument is capable of setting the measuring zone and measuring the warpage at elevated temperatures including the peak temperature.

5.3.2 Laser reflection method

Solder balls shall be removed when the solder ball pitch is not large enough for the laser beam to measure the warpage on the substrate surface. Samples are placed on the measurement table. The displacement from the flatness is measured by the laser displacement sensor. The warpage is generally measured by scanning the laser beam over the terminal lands or between balls throughout the measuring zone. The grid pitch of the measurement points is preferably less than the solder ball pitch. The instrument is capable of setting the measuring zone and measuring the warpage at elevated temperatures including the peak temperature.

5.3.3 Data analysis (data table, diagonal scan graph, 3D plot graph)

The magnitude of the warpage is obtained from the data table of the measurements or 3D plot graph (warpage distribution diagram over the measuring zone). The sign of the warpage (warpage direction) is then determined from the diagonal scan graph and precedes the value.

6 Maximum permissible package warpage at elevated temperature

The criteria for maximum permissible package warpages (absolute values) for BGA and FBGA are specified in Table 1, and those for FLGA are specified in Table 2.

Table 1 – Maximum permissible package warpages for BGA and FBGA

Dimensions in millimetres

Solder ball pitch	0,4	0,5	0,65	0,8		1,0	1,27
Condition of ball height	0,20	0,25	0,33	0,35	0,40	0,50	0,60
Maximum permissible package warpage (absolute value)	0,10	0,11	0,14	0,17	0,17	0,22	0,25

Table 2 – Maximum permissible package warpages for FLGA

Dimensions in millimetres

Land pitch	0,4	0,5	0,65	0,8
Condition of thickness of molten solder paste	0,08	0,10	0,11	0,13
Maximum permissible package warpage (absolute value)	0,08	0.10	0,11	0,13

7 Recommended datasheet for the package warpage

7.1 Measurement temperatures for data sheet

Typical measurement temperatures for data sheet are room temperature, melting point, peak temperature, solidification point and room temperature after cooling.

7.2 Data sheet

The data sheet is composed of

– temperature dependency of the package warpage (see Figure 7),

– surface topography at each temperature in 3D plots (optional),

NOTE 1 If the sign of warpage is opposite, explanation is required; see Figure 8.

– diagonal profile of the package at each temperature (optional),

NOTE 2 If the sign of warpage is opposite, explanation is required; see Figure 8.

– explanatory figure of the sign of the package warpage (optional),

– temperature profile for measurement,

7.3 Example of data sheets

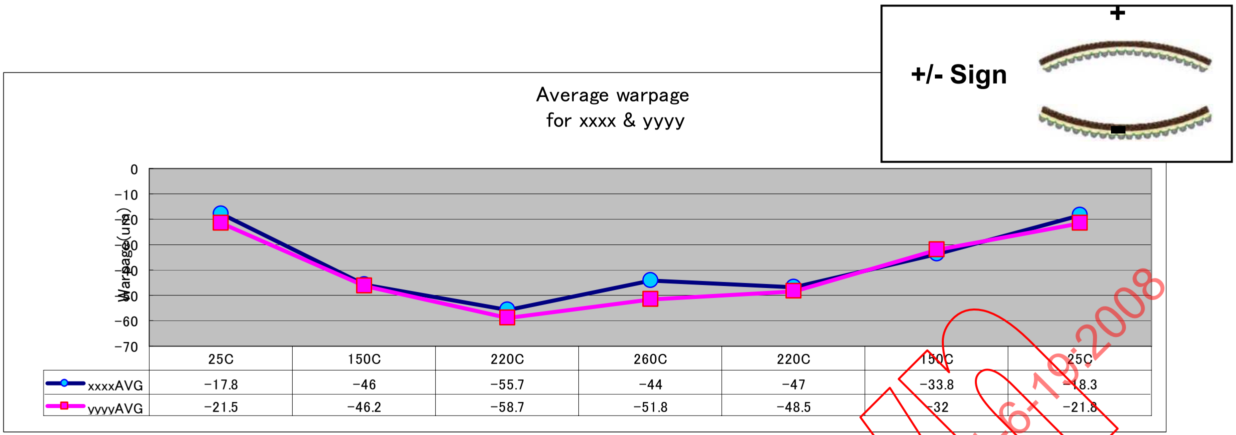


Figure 7 – Temperature dependency of the package warpage

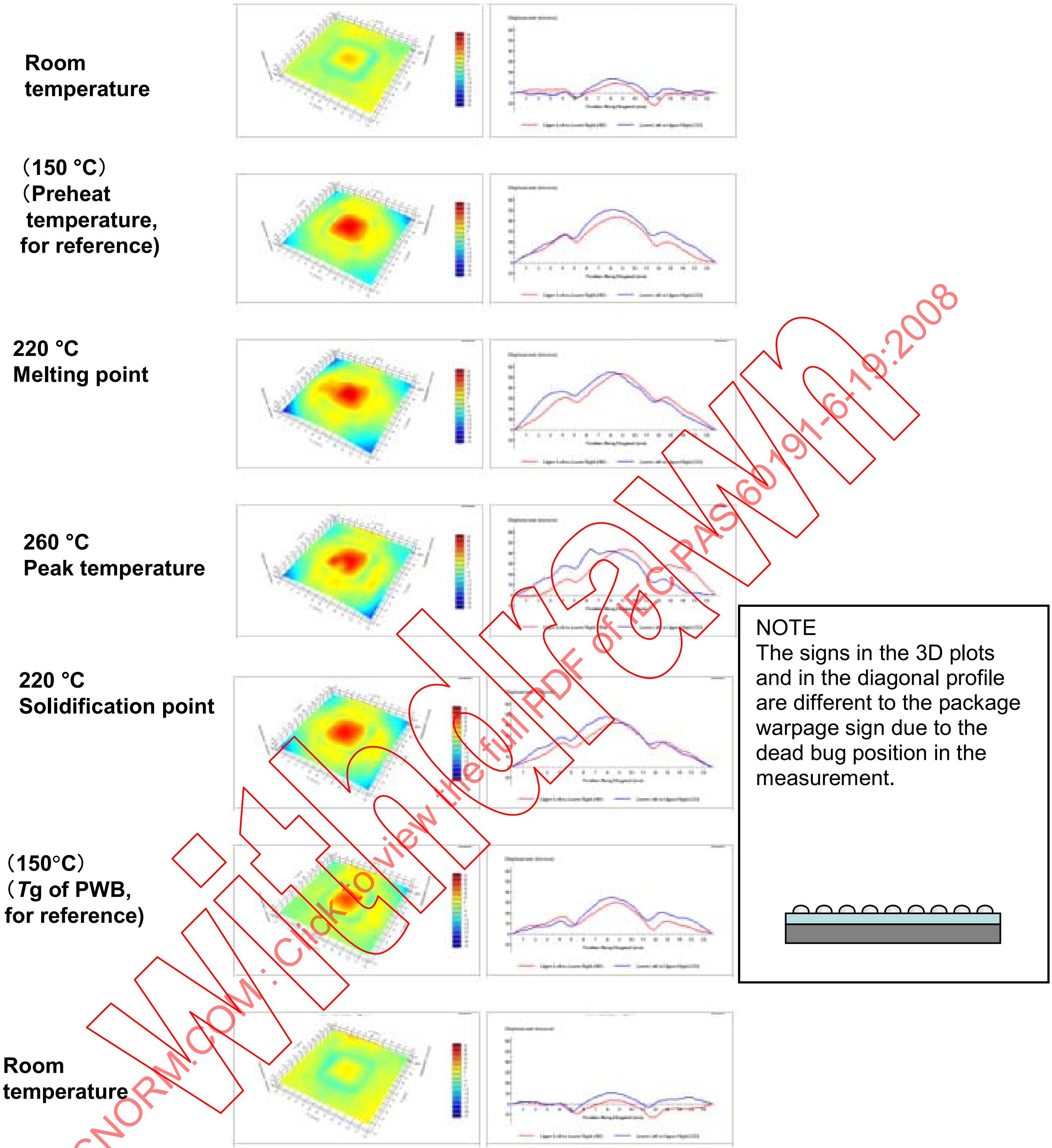


Figure 8 – Recommended data sheet

Annex A
(informative)

Explanatory notes

NOTE Annex A is intended as an explanation of this PAS and also of related issues.

A.1 Purpose of the establishment

In an environment marked by the higher speed and miniaturizing trend of electronic products, BGA packages have been used in most of the electronic products thanks to the advantages of higher pin count and compact body size features. Along with high volume usage of BGA packages, analysis data of soldering failures have accumulated and the package warpage at elevated temperature has been gaining attention as a cause of these failures. This phenomenon reveals that the package warps during the rising temperature of the reflow process and solder joints fail in an open or short mode, even if the package meets the coplanarity requirement at room temperature.

Migration to thinner package body, finer pitch balls and lead-free material has increased package warpage during the reflow process and raised problems of open solder joints or solder bridges between balls. It is known that the more a package is moisturized, the more the package warps. The Subcommittee reached an agreement that semiconductor suppliers should specify the maximum permissible package warpage at elevated temperature. It is similar to the package delamination specification at reflow stress. This PAS aimed at agreement of common terms, unification of measurement methods and establishment of the criteria.

A.2 History of deliberations

Previously, the technical subcommittee focused on the standardization of dimensions of packages. Recent expansion of the task of this subcommittee into the field of package reliability has triggered standardization activity on the package warpage at elevated temperature, as requested by customers.

The standardization task force on the measurement method of the package warpage at elevated temperature was formed on 23rd June 2005. The activity plan was to establish a standard for package warpage measurement by April 2006, as phase 1, and criteria for warpage by December 2006, as phase 2. The deliberations started by listing the factors that might affect measurement methods and gathering experimental data from task force members. After evaluating all factors, the PAS was drafted. During deliberations, the task force referred to JESD22B-112. The task force discussed the measurement method based on this specification with the basic policy of maintaining international harmonization.

A.3 Brief content of deliberations

A.3.1 Measurement methods of the package warpage at elevated temperature

The task force reached agreement on the following facts after reviewing the experimental data from member companies:

a) The absorption of moisture increases the magnitude of the warpage.

b) There is stronger correlation of the magnitude of the warpage with temperature rather than the temperature profile including duration of heat stress or temperature ramp rate. Also if the temperature profile in the measurement simulates the reflow temperature profile forcibly, high temperature ramp rate may cause temperature overshoot or larger temperature difference between the top and bottom sides of the package, making the measurement inconsistent. Therefore, the approximation of the temperature profile to the reflow condition is not a high priority.

c) The warpage data for re-measurement are usually consistent, but some reports claimed poor reproducibility in re-measurement. Therefore, the repetition of the measurement cycles to the same sample is not recommended.

d) Warpage data measured by the shadow moiré method agreed with those measured by the laser reflection method as far as the measuring zone was concerned.

e) It was confirmed that 0 h to 5 h waiting time after pre-treatment and until measurement did not show any difference in measurements.

Based on these agreements, the measurement methods and conditions of package warpage at elevated temperature were established and agreed.

A.3.2 Maximum permissible package warpage at elevated temperature

This PAS was initially drafted as a standard for the measurement method of package warpage and it was planned to specify criteria in each package design guide. However, the subcommittee decided to specify the maximum permissible package warpage of BGA, FBGA, and FLGA in this specification. This was because a comprehensive specification provides an overall explanation for the budget allocation of the maximum relative displacement and well-aligned criteria by ball pitch.

For stackable packages, the premise of the budget allocation, i.e. 80 % of the maximum relative displacement to package and 20 % to PWB, is not valid; therefore, stackable packages have not been included in the scope in this specification.

The task force drafted the PAS based on the theoretical approach to the mechanisms of open solder joints and solder bridges, as well as the experimental approach to those through soldering the artificially warped package. Maximum permissible package warpage of BGA is given 80 % of the maximum relative displacement that does not cause open solder joints or solder bridges. The other 20 % of the displacement is reserved for a tolerance of the PWB warpage and the fluctuation of the paste thickness.

On the other hand, the maximum permissible package warpage of FLGA is defined to be 100 % of the maximum relative displacement. It is defined to be the height of the molten solder paste, which does not cause open-solder joints. Any tolerance is reserved for the warpage of PWB because the maximum permissible warpage is already very close to the coplanarity requirements. It implies how difficult it is to mount FLGA. There are some means to generate some extra tolerance to allow for some PWB warpage, such as thick pre-coated terminals, reserving some collapse height of FLGA during reflow. However, this specification does not go into such detail.

A.3.3 Open solder joints after BGA board level assembly

The behaviours of package warpage and solder paste during the reflow process are described as follows:

NOTE BGA is used to illustrate such behaviour as it indicates larger warpage at elevated temperature.

a) The package shall be flat with acceptable coplanarity at room temperature and PWB is ideally flat in all conditions.

b) Package warpage increases with rising temperature. Just below melting point, some solder balls crowns may even separate from the surface of the solder paste at the package corners, where the warpage is greatest.

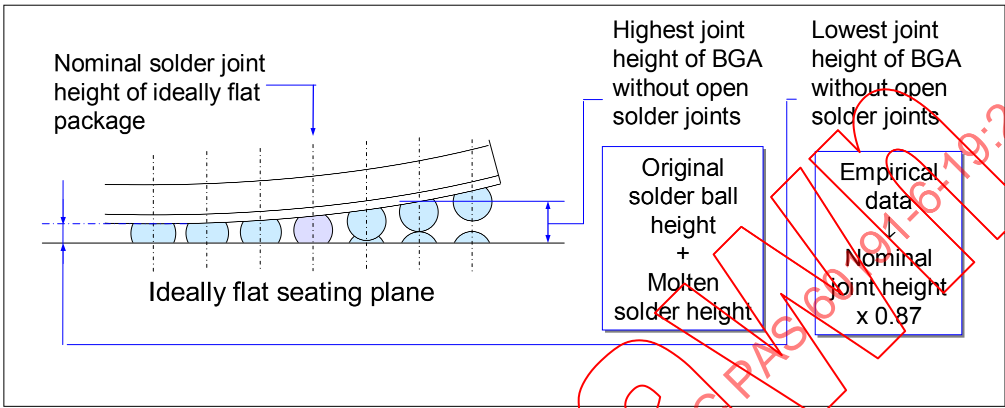
c) As temperature rises further and exceeds the melting point of solder, the solder balls and paste melt and collapse.

d) Even if the crowns of some solder balls separate from the solder paste at just below melting point, the collapse of the balls produces good solder connection with the activated solder paste.

e) Acceptable solder joints are formed after reflow.

f) Where the package warps in excess of expectations, the crowns of these balls does not touch the paste when the balls collapse; it causes the open solder joints.

Bearing in mind points a) to f), if the sum of package warpage at elevated temperature and the lowest stand-off height is smaller than the sum of the original solder-ball height and the thickness of the molten solder paste, good solder connection can be expected after the board assembly, and vice versa (see Figure A.1).



NOTE Maximum relative displacement is defined as the difference between the highest and lowest solder joint heights of BGA package mounted on an ideally flat seating plane, where none of the solder joints are open.

Figure A.1 – Calculation of maximum relative displacement immune from open solder joints

A.3.4 Solder ball bridges after BGA board level assembly

The occurrence of the solder ball bridges depends on how much the package warps during the reflow process. The mechanisms of the solder ball bridges are described below:

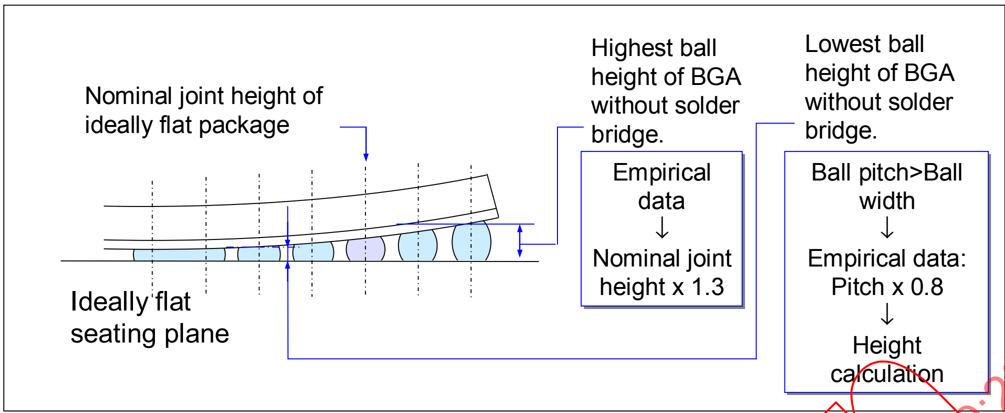
a) If the package warpage is less than the maximum permissible warpage just above the melting point, all solder balls are soldered just once to the lands on the PWB.

b) Further elevation of the temperature makes some balls flattened while others are stretched due to the increase in package warpage.

c) The collapsed balls have larger diameters, while the stretched balls become thinner but are still connecting the package and PWB owing to surface tension.

d) When the diameters of the collapsed balls expand beyond a certain percentage of the ball pitch (80 % of the ball pitch obtained from experimental data), the failure rate of the short-circuits increases.

Therefore, the maximum relative displacement of the package without the solder bridge is the difference between the height of the stretched balls (the highest joint height) and that of the flattened balls (the lowest joint height) whose diameter is 80 % of the ball pitch (see Figure A.2).



NOTE 1 Maximum relative displacement is defined as the difference between the highest and lowest solder joint heights of BGA package mounted on an ideally flat seating plane, where none of the solder joints bridge.

NOTE 2 Constants of calculations are obtained from the experiment and used for simplicity.

Figure A.2 – Calculation of maximum relative displacement immune from solder ball bridges

A.3.5 Maximum permissible package warpage of BGA and FBGA

a) The maximum permissible package warpage of BGA and FBGA is described in Table A.1, which is calculated from the experimental data.

b) Given that PWB is an ideally flat seating plane, the maximum relative displacement from the seating plane is the difference between the highest and lowest joint heights of BGA which is immune from the open solder joints or solder ball bridges.

c) The maximum permissible package warpage of BGA and FBGA is determined to be 80 % of the maximum relative displacement, where either open solder joints or solder ball bridges have not appeared. The other 20 % is for permissible warpage of PWB. The ratio reflects the difficulty in maintaining the package in an unwarped state versus PWB at elevated temperature, i.e. complexity in the materials and structure of package vs. PWB.

d) The criteria of maximum permissible package warpage for solder joints without open- or short-circuits are obtained separately. Less than 10 um difference indicates that the open solder joints and solder bridges are phenomena caused by the same reason but viewed from opposite sides. The current magnitudes of package warpage barely satisfy the budget allocation of the tolerance, i.e. 80 % to the package. However, along with progress in technology, the methodology to reduce package warpage will be established, and then the criteria will be reviewed.

Table A.1 – Maximum permissible package warpage for BGA and FBGA – Explanatory table

Dimensions in millimetres

Solder ball pitch	0,4	0,5	0,65	0,8		1,0	1,27
Condition of solder ball height[a]	0,20	0,25	0,33	0,35	0,40	0,50	0,60
Condition of solder paste thickness after reflow[b]	0,08	0,10	0,11	0,13		0,14	0,15
Nominal solder joint height of the ideally flat package	0,18	0,23	0,29	0,31	0,36	0,43	0,5
Highest solder joint height of BGA without open solder joint[c]	0,28	0,35	0,44	0,48	0,53	0,64	0,75
Lowest solder joint height of BGA without open solder joint[d]	0,16	0,20	0,25	0,27	0,31	0,37	0,44
Highest solder joint height of BGA without solder bridge[e]	0,24	0,29	0,38	0,40	0,46	0,55	0,66
Lowest solder joint height of BGA without solder bridge[f]	0,12	0,15	0,20	0,19	0,25	0,28	0,34
Max relative displacement of BGA without open solder joint[g]	0,12	0,15	0,19	0,21	0,22	0,27	0,31
Max relative displacement of BGA without solder bridge[h]	0,12	0,14	0,18	0,21	0,21	0,28	0,32
Max permissible package warpage (Absolute value)[i]	0,10	0,11	0,14	0,17	0,17	0,22	0,25
Coplanarity at room temperature (for reference)	0,08	0,08	0,10	0,10	0,10	0,20	0,20

NOTE Assumptions concerning the calculations are as follows:

- The structure of the lands on PWB is non-solder mask defined.
- The diameter of the lands on PWB is the same as that of package.
- Solder joint height between package and PWB is the distance between the face-to-face copper lands.
- Thicknesses of the metal masks for solder paste printings are
  - 0,10mm for 0,4 mm pitch FBGA,
  - 0,12mm for 0,5 mm and 0,65 mm pitch FBGA, and
  - 0,15mm for 0,8 mm, 1,0 mm, and 1,27 mm pitch BGA.
- Opening diameter of the solder printing mask is the same as that of the lands on PWB.

a It follows the specification in JEITA EDR-7315 and JEITA EDR-7316.

b It is the thicknesses of molten solder paste on copper lands without any component attached, supposed 50 % of solder paste is metal content (solder).

c It is the sum of the solder ball height and the molten solder-paste thickness, where the solder connections are immune from open circuit.

d It is 87% of the nominal standoff height of the ideally flat package. The ratio is obtained from the empirical data taken from the intentionally concave-warped sample.

e It is 130% of the nominal standoff height of the ideally flat package. The ratio is obtained from the empirical data taken from the intentionally convex-warped sample.

f It is the sum of the molten solder and the solder ball height of which ball diameter is 80 % of the ball pitch. It is because the ball does not cause short circuit, if the balls do not collapse more than 80 % of the ball pitch

g It is the difference between the highest and the lowest solder joint height, where open solder joint is not seen.

h It is the difference between the highest and the lowest solder joint height, where solder ball bridge is not seen.

i It is 80 % of the maximum relative displacement.

A.3.6 Maximum permissible package warpage of FLGA

Given that PWB is an ideal seating plane, the maximum package warpage is defined to be the thickness of molten solder paste (see Figure A.3). However the maximum permissible