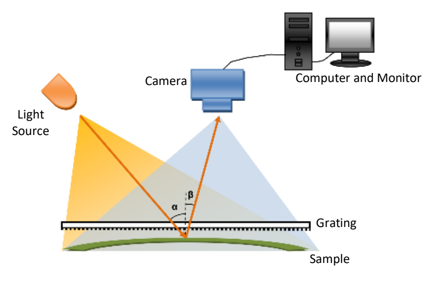
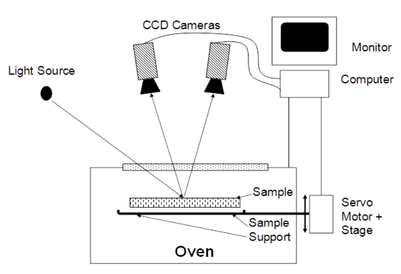
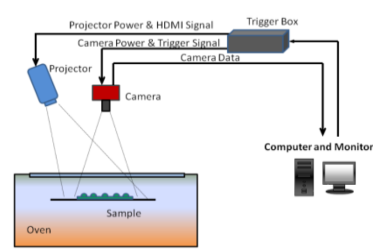
Akrometrix – Technology Overview

Akrometrix Optical Techniques:

Three full-field optical techniques, shadow moiré, digital image correlation (DIC), and fringe projection (performed by the DFP-M) are used at Akrometrix for measuring flatness. For temperature dependent measurements the DIC and DFP systems operate as add-ons to the AXP 2.0 model. Shadow moiré is used for TherMoiré test plans. See the table below for practical and technical explanations.

	Shadow Moiré	DIC	Fringe Projection
Which Technique to Use	Easily the most popular choice for current service work, as most Akrometrix systems are based on the shadow moiré technique. This is the technique used in TherMoiré pricing quotes. The method is robust and flexible to a variety of different sample types and sizes, and is the only choice for samples with ROI above 90×120 mm. Warpage measurement resolution is between 2.5 and 1.0 microns.	The only system that can perform in-plane measurements (strain, CTE). Out-of-plane data can also be taken and reported, but at limited effective in-plane resolution. The DIC can also handle "non-continuous" surfaces. Only customers looking at in-plane movements should request DIC instead of shadow moiré or fringe projection. The maximum FOV is 75x75 mm. Strain resolution is 100 microstrain.	Fringe Projection is capable of measuring non continuous surfaces with high data density. The surfaces can be step heights or islands of data. Multifield capability was recently added to Akrometrix fringe projection technology, allowing for a FOV that can be adjusted between 36x48 and 90x120 mm. Warpage measurement resolution is between 2.5 and 4 microns.
Technical Explanation	Shadow moiré uses geometric interference between a reference grating and its shadow on a sample to measure relative vertical displacement at each pixel position in the resulting interference pattern image. It requires a Ronchi-ruled grating, a white line light source at approximately 45 degrees to the grating, and a camera perpendicular to the grating. The optical configuration is integrated with the heating chamber of most Akrometrix systems, with the grating being beneath the clear lid of the oven. The exception is the Table Top Shadow Moiré system (TTSM), which is designed for room temperature measurements and has no oven. A technique, known as phase stepping, is applied to shadow moiré to increase measurement resolution and provide automatic ordering of the interference fringes. This technique is implemented by vertically translating the sample relative to the grating.	Digital Image Correlation is an optical method for measuring both in-plane and out-of-plane displacements of an object surface. A high contrast, random speckle pattern is applied to the surface of interest. Two cameras are mounted above the oven, viewing the sample from different angles as shown in the figure below. Two simultaneous images from both cameras are digitized. Software identifies the same point on the surface from both perspectives, using pattern recognition of the speckles within a small pixel window. Using the principle of stereo triangulation, the spatial position of the pixel window relative to the cameras is determined in 3D space. Stepping the pixel window across the sample, the flatness of the surface can be mapped out.	Fringe projection is a non-contact, full-field optical technique for out-of-plane topography measurement. A set of fringe patterns are projected onto the sample surface from an angle. Fringes will be distorted by the shape of the sample. Fringe patterns include phase-shifted patterns and gray code patterns. Phase-shifted patterns allow the DFP system to achieve high measurement resolution. Gray code patterns generate a unique coding across the full field, allowing for the fringe order of the phase-shifted patterns to be unambiguously identified, allowing step heights to be measured. The figure below shows the configuration of the fringe projection system. Data analysis is similar to that for shadow moiré.
Diagrams			

Akrometrix Surface Characterization Outputs:

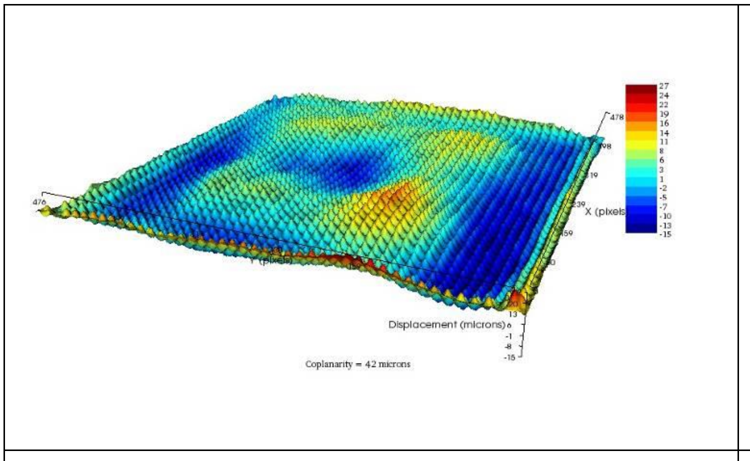
Various sample types shown with 3D Surface Plots:

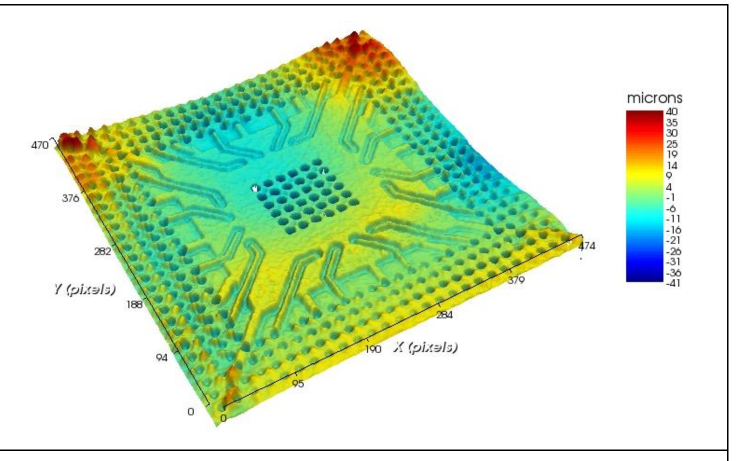
Test results are divided into many different part types. Though Akrometrix software is capable of a number of different outputs, the 3D surface plot is shown in this section as the most effective visual method for communicating surface shape. Additionally, primarily the shadow moiré technique is shown. Results from the DFP and DIC modules are shown in some examples that highlight the strengths of each tool. In many cases samples measured with the shadow moiré technique could have also been measured by either the DFP or DIC module.

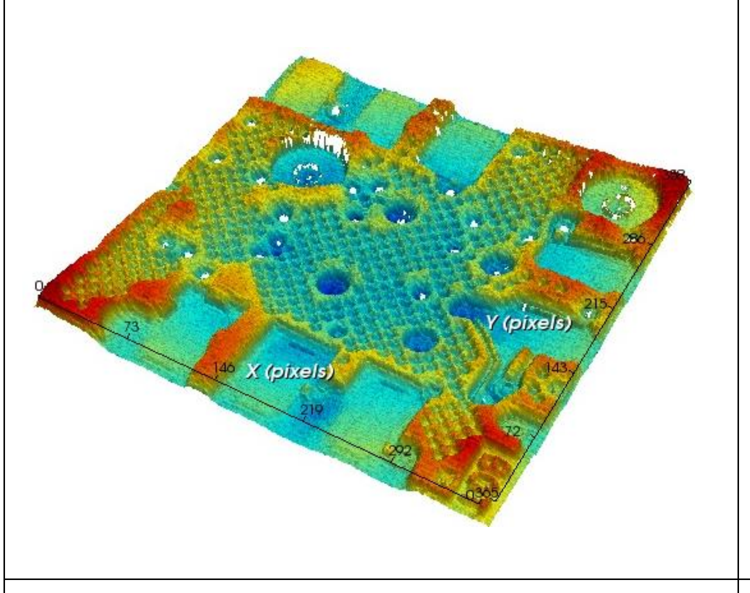
Components – PCB Side

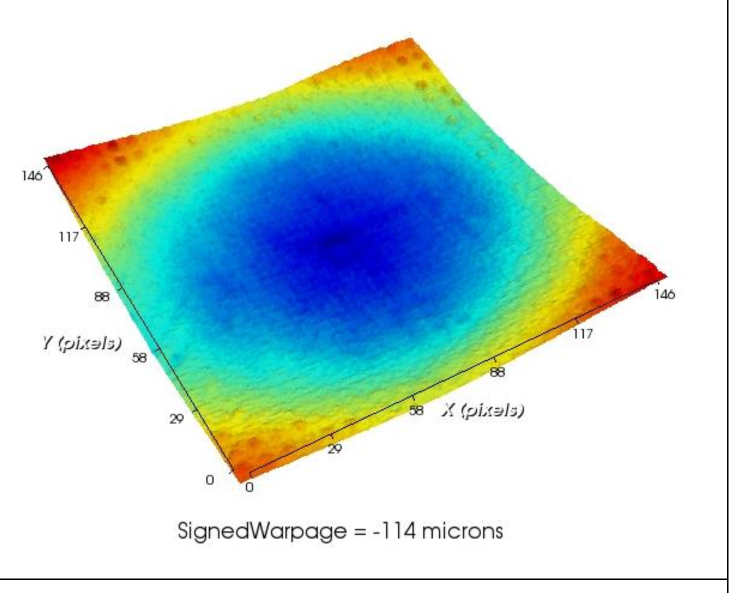
Possible applications include: BGA, LGA, Flip Chip, PoP, QFP, QFN, CSP, TSOP, MLF, etc.

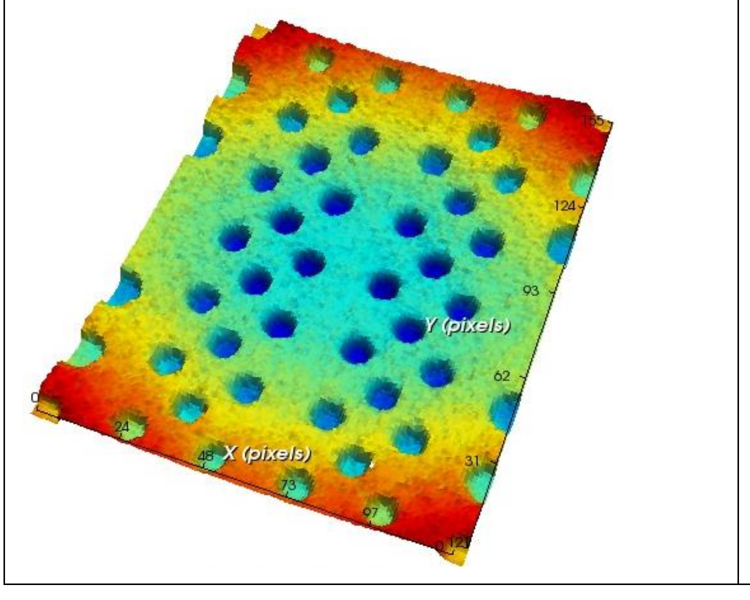
- *Shadow Moiré Results*

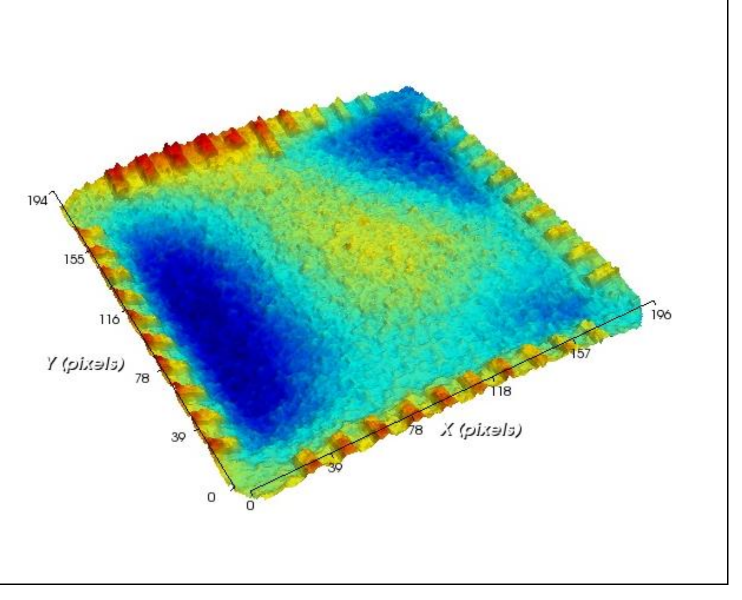




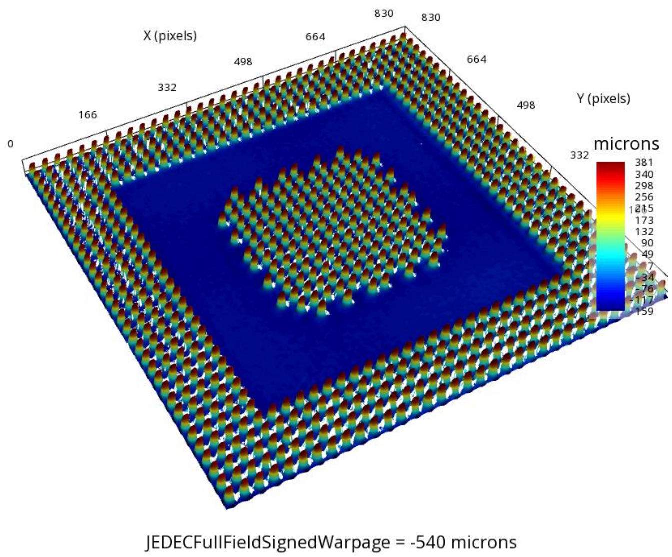


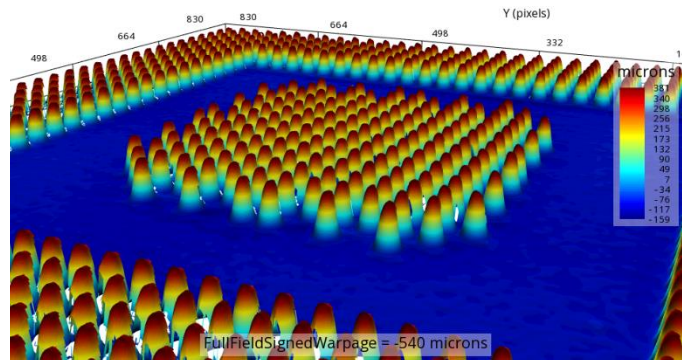


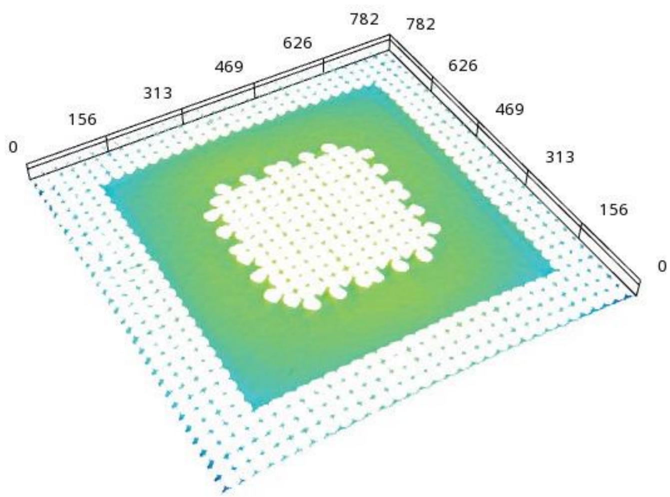




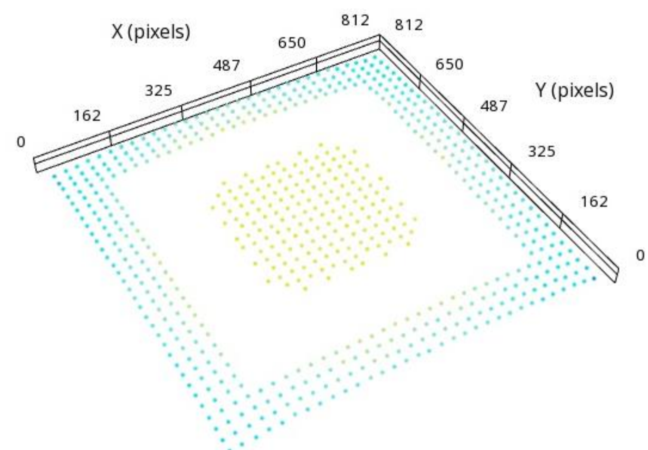
- *DFP Module Results*





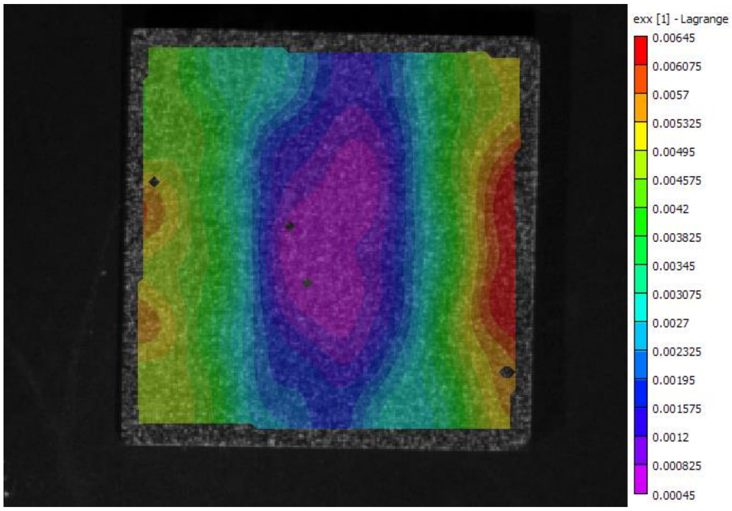
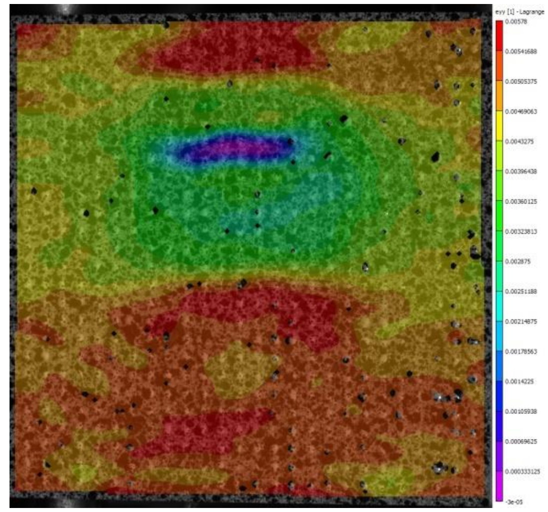


[Substrate only from BGA with Solder Balls]



[Solder Ball Peaks]

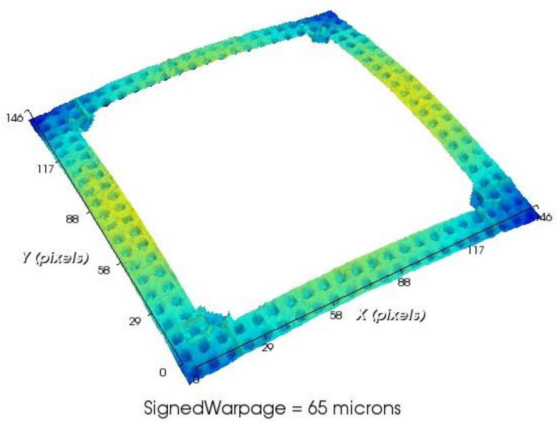
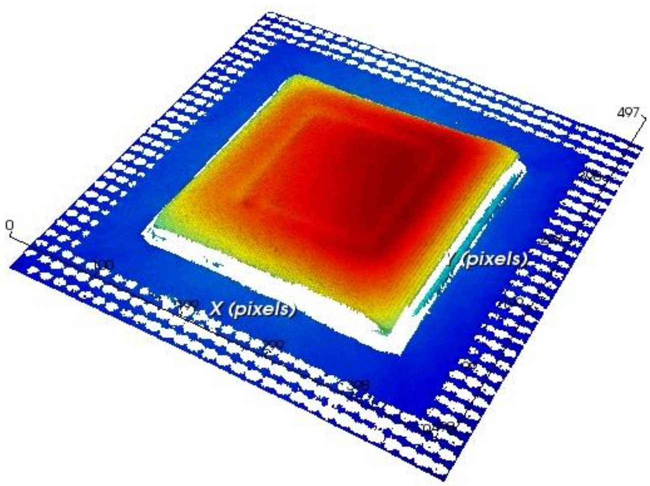
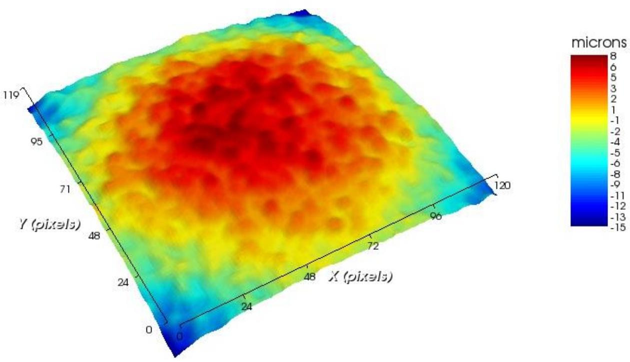
- *DIC Module Results*

 [X-Strain Map]	 [Y-Strain Map]

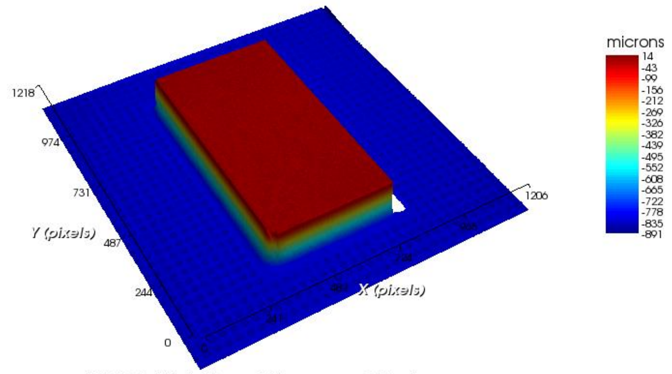
<u>*Components – Top Side*</u>

Possible applications include: BGA, Flip Chip, Die surface, PoP, Molder surfaces, QFP, TSOP, etc.

- *Shadow Moiré Results*

 [PoP: Topside of Bottom Component]	
 [10 x 10 mm Die Surface]	

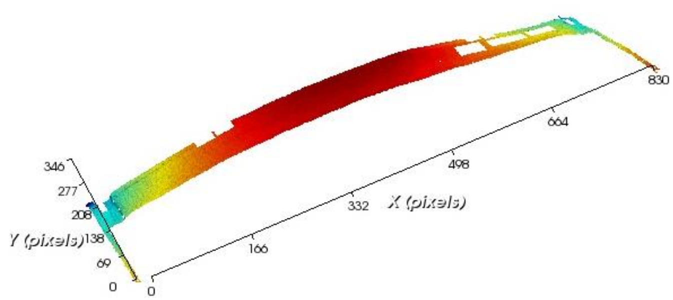
- DFP Module Results

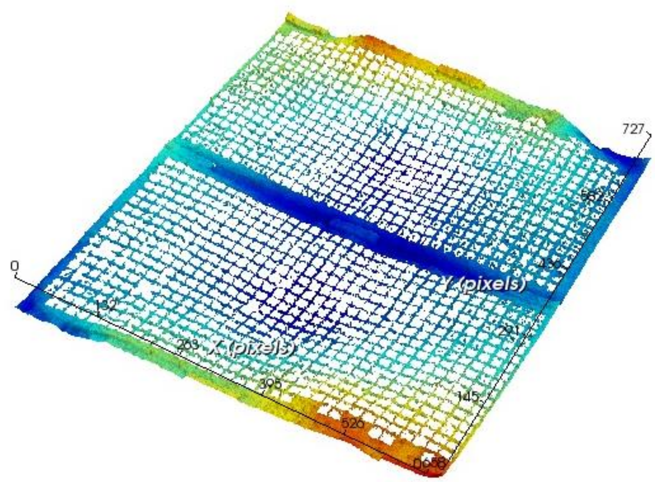


JEDECFullFieldSignedWarpage = 905 microns

<u>*Connectors and Sockets*</u>

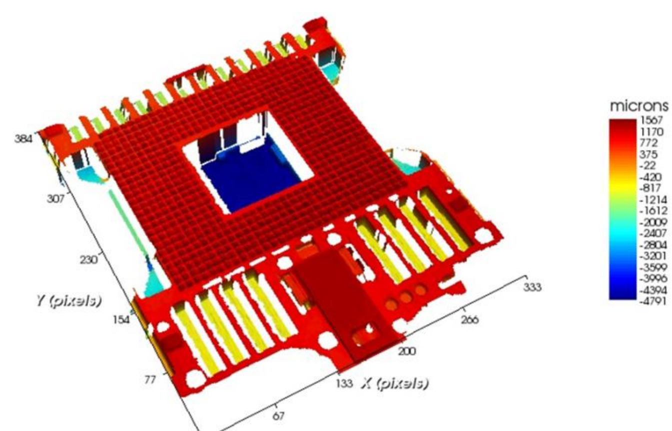
- Shadow Moiré Results





Coplanarity = 246 microns

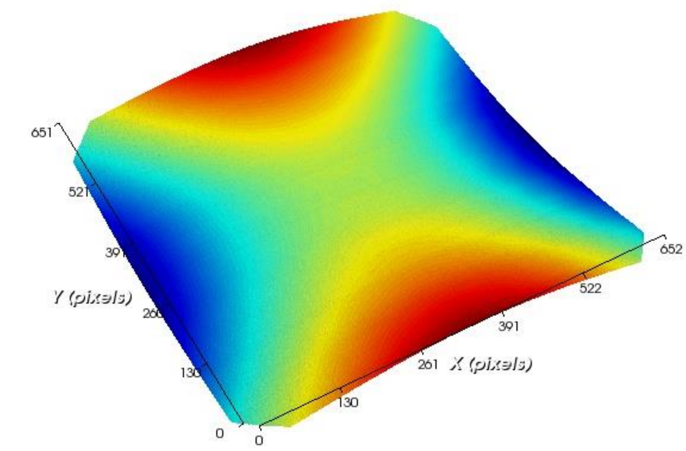
- DFP Module Results

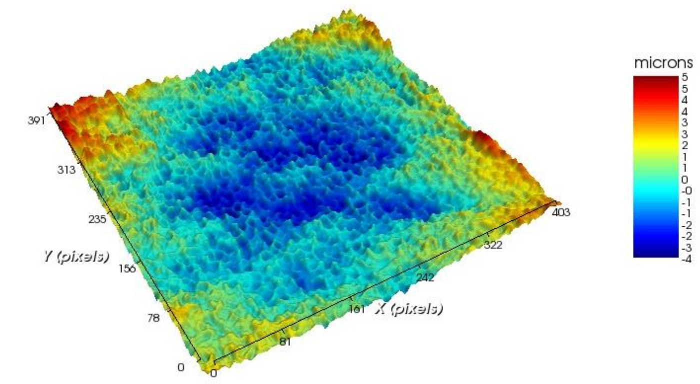


FullFieldSignedWarpage = -6358 microns

<u>*Wafer Level and Bare Silicon*</u>

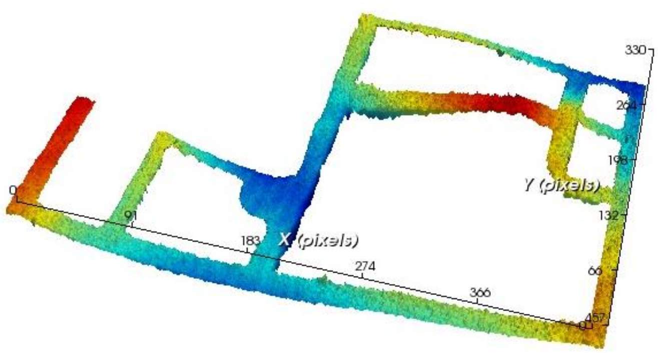
- Shadow Moiré Results

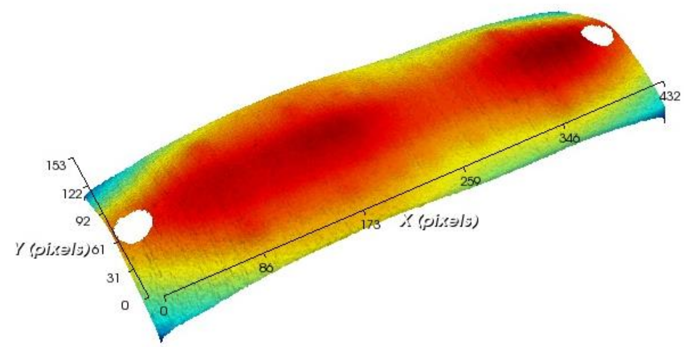


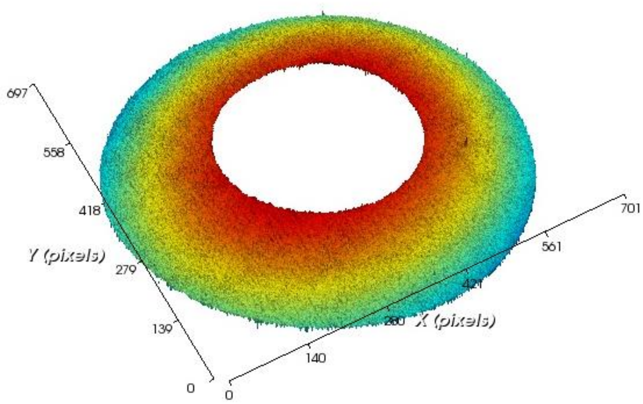


<u>*Shields, Heatsinks, and Brake Rotors*</u>

- Shadow Moiré Results

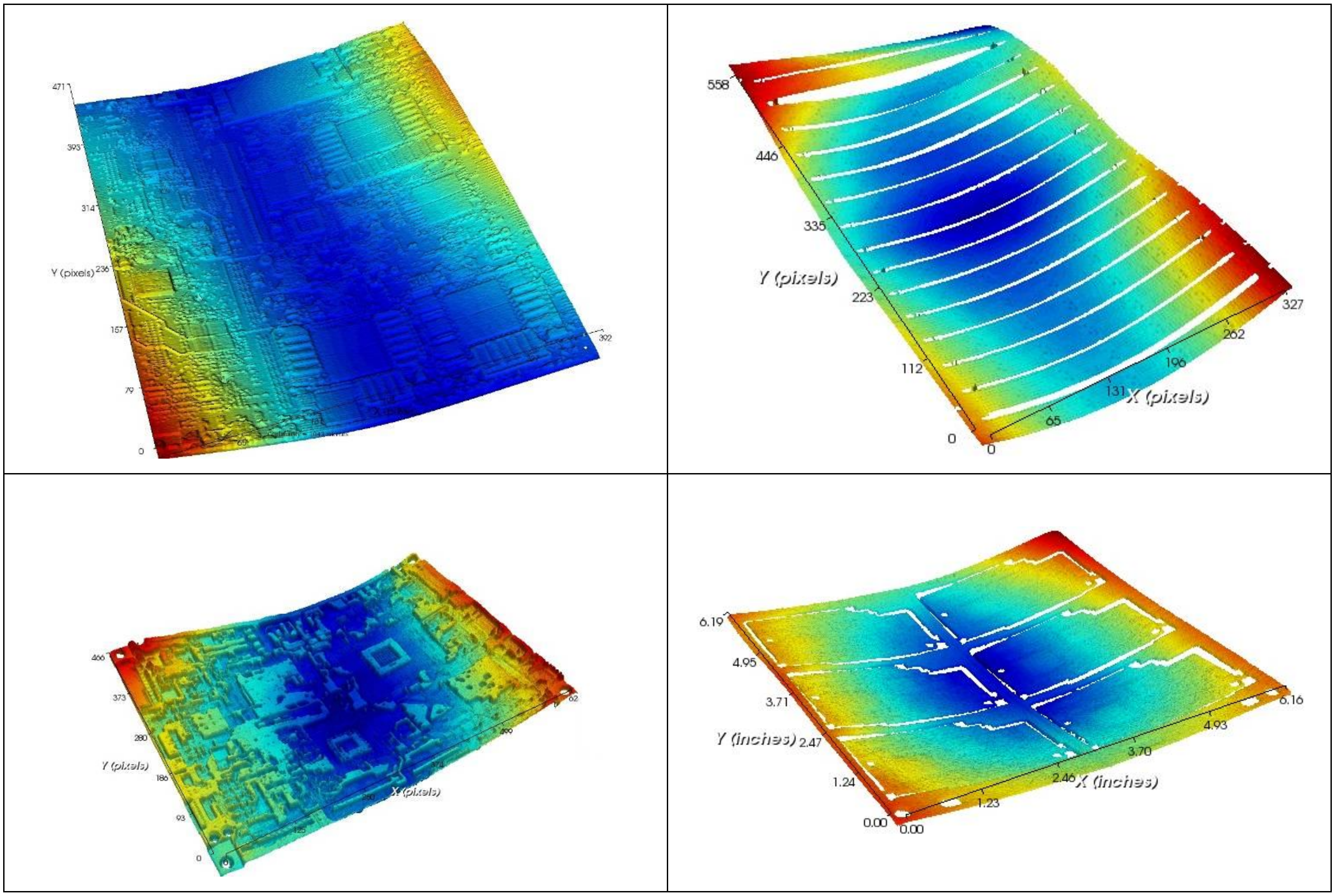




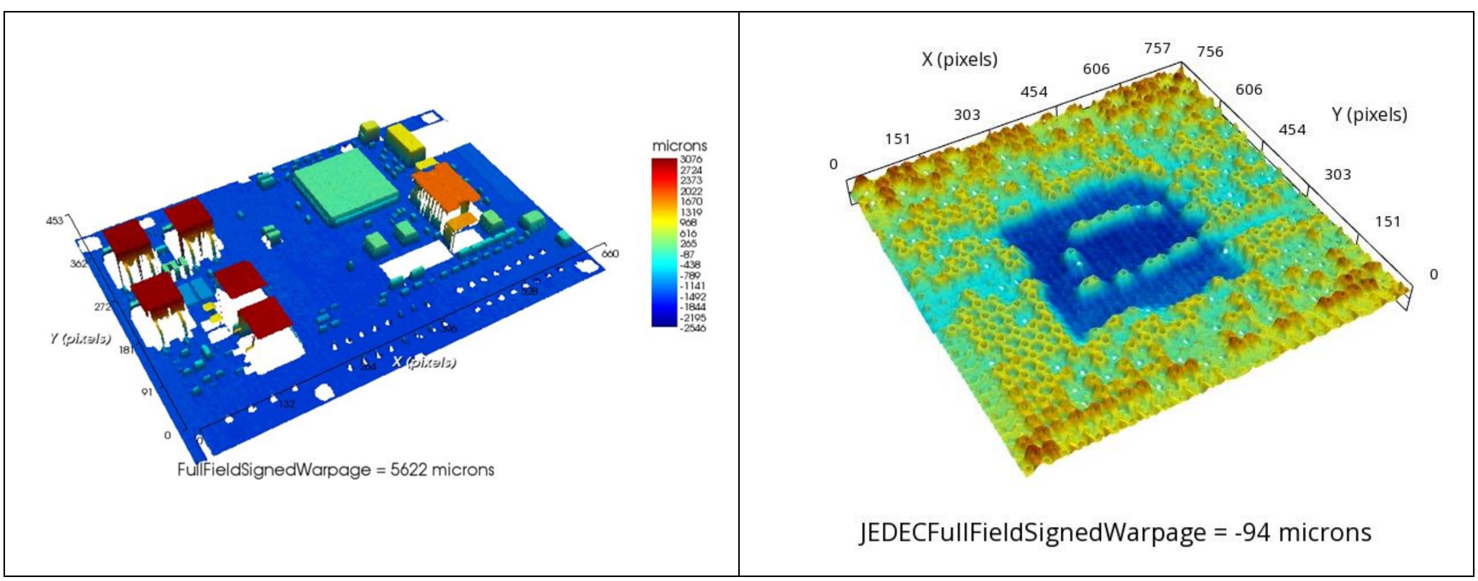


<u>*PCB Global, Assembled Boards, PCB Cutout Arrays, PCB Locals, Component Strips, Solid State Disks, Memory Devices*</u>

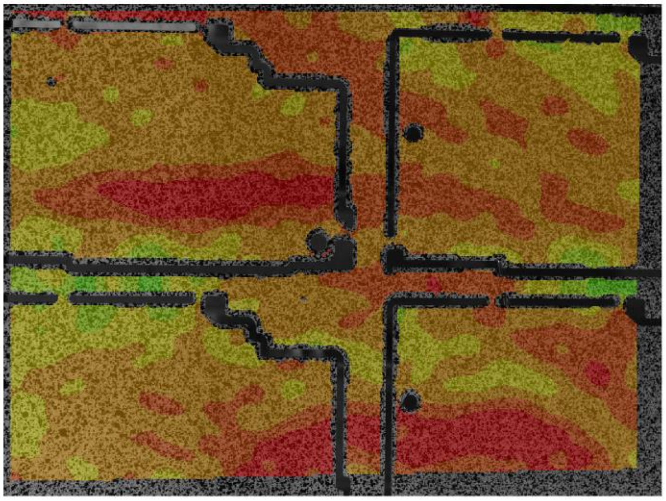
- Shadow Moiré Results



- DFP Module results



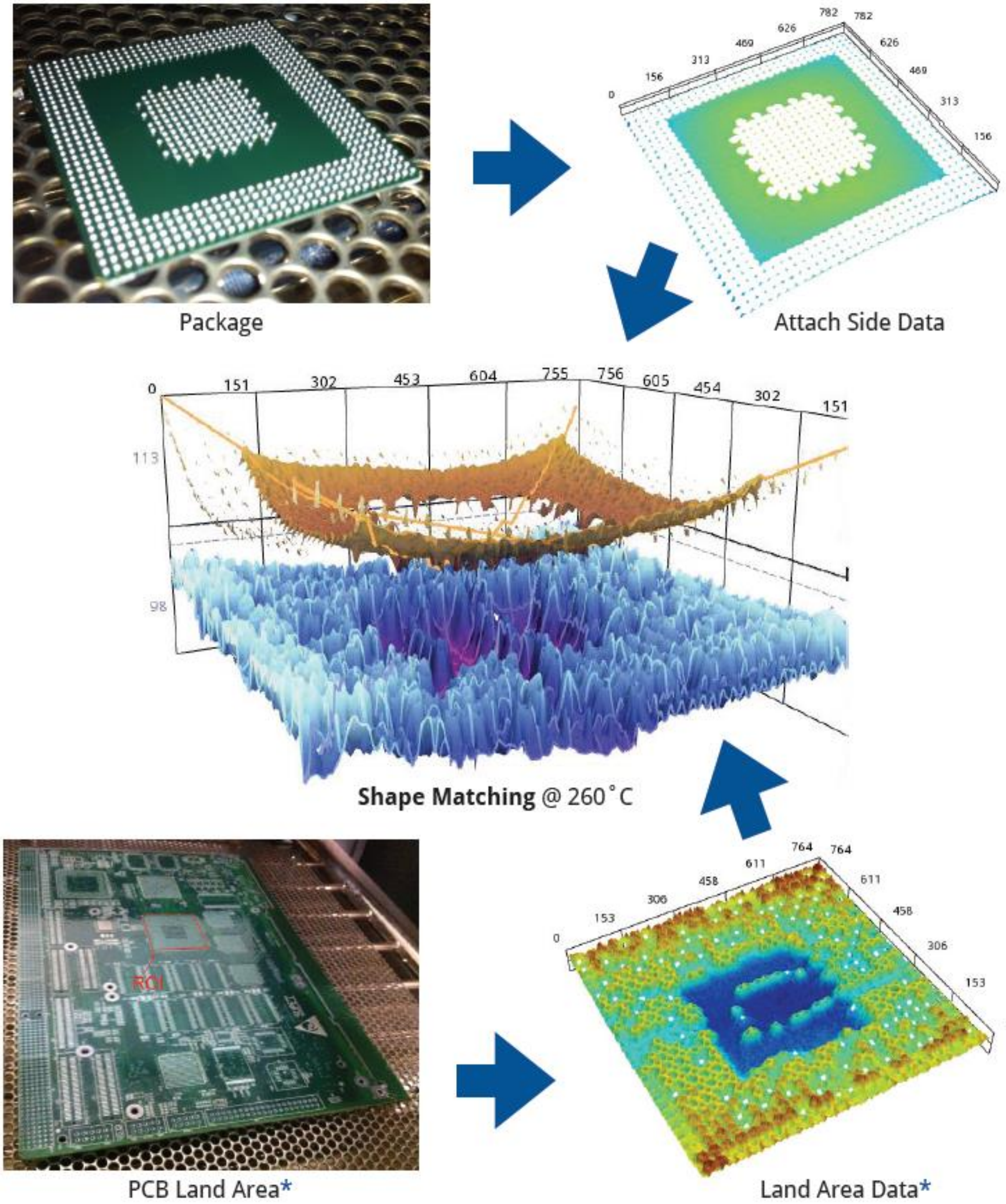
- DIC Module results

Other Output Result Formats:

Interface Analysis:

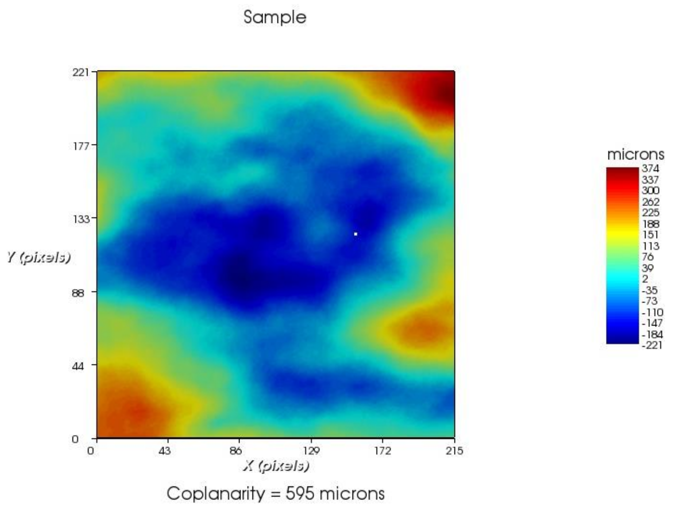
This software exists as a separate entity from the Studio software. The purpose of Interface Analysis is to allow high-level and in-depth review of the attachment interface between two surfaces that warp during the reflow process. Using Interface Analysis, you can check both Macro characteristics of the interface such as 'Maximum Gap' for all surfaces across all temperatures, and micro details such as the predicted gap between a single interconnect location, at a particular temperature.

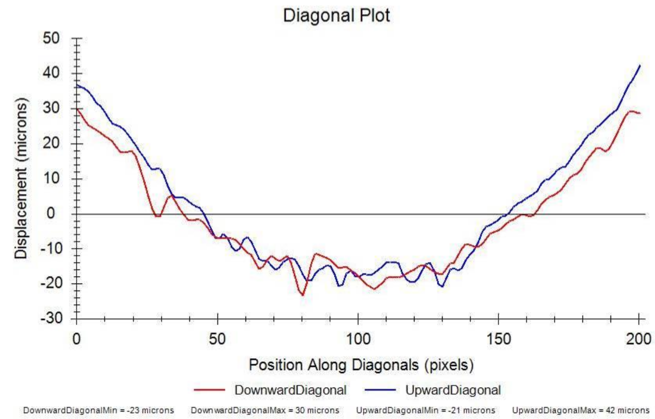


*(Measured per the new IPC-9641 Standard)

3D Contour Plots:

An overhead contour map of 3D surface data (below)



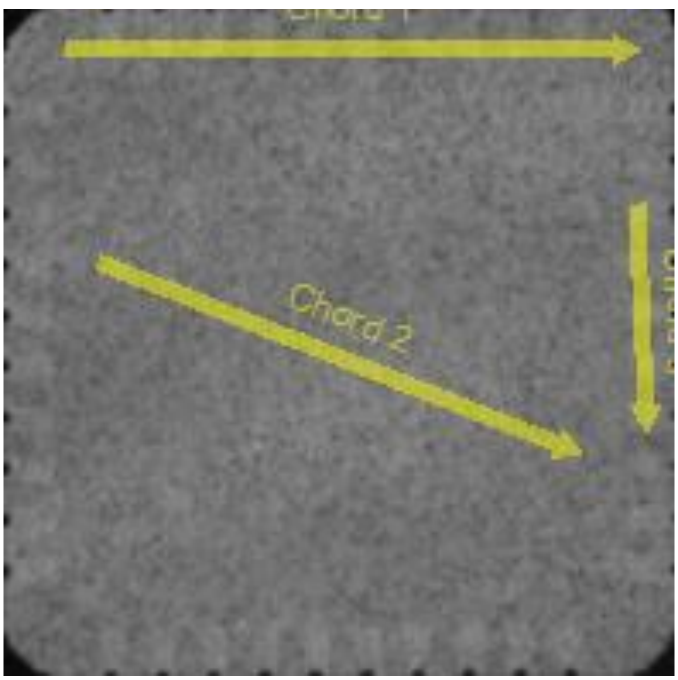


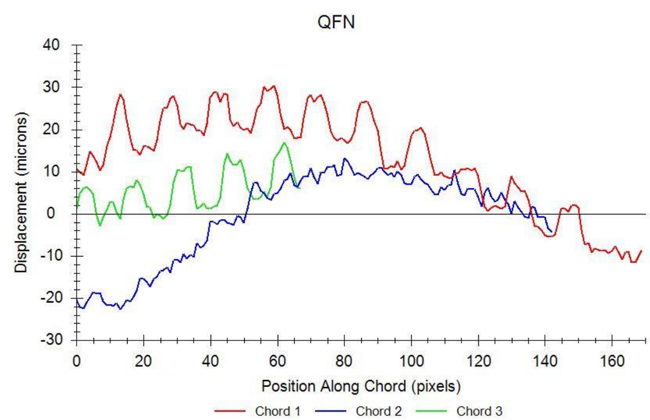
Pre-defined Chord Plots:

Includes diagonals, edges, and centerline line plots (above)

Custom Chord Plots:

User defined chord plots. Specific line plots are drawn on an image of the part and plotted as lines (below)



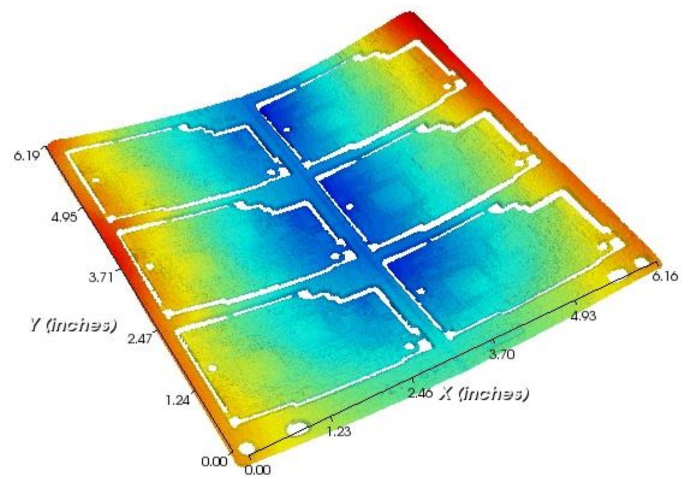


Displacement Matrices:

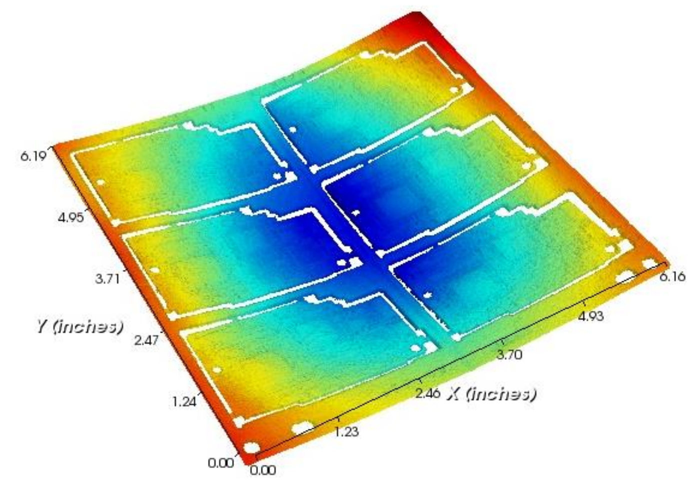
A matrix of values where the "height" is shown in each pixel value and in-plane location is shown by cell location in the matrix.

Relative Plots:

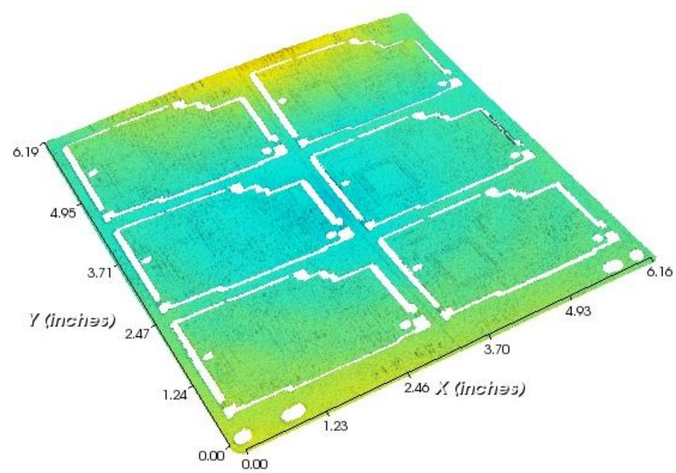
Akrometrix has the ability to take two data sets of the same size, subtract them from one another, and graph (visually or through displacement matrices) these results. This is particularly useful when comparing BGA bottoms to local PCB areas, top and bottom PoP packages, the same part at various temperature, or smoothed/fit data versus raw data (below).



[Sample at Room Temperature]



[Sample at 220 °C]



[Relative plot of change between room temperature and 220 °C]

Gauges:

Coplanarity

Coplanarity is the difference between the highest and lowest data points within the Region of Interest. It is always positive.

Center Deflection

Center Deflection is an Akrometrix specific function defined as the difference between the average height of the four corners and the height at the center:

$$((\mathrm{Z(UpperLeft)} + \mathrm{Z(LowerRight)} + \mathrm{Z(UpperRight)} + \mathrm{Z(LowerLeft)})/4) - \mathrm{Z(Center)}$$

Signed Warpage

Signed Warpage has a magnitude equal to the coplanarity, and a sign (or polarity) determined by a special algorithm to distinguish between convex and concave curvature of the surface. This implementation uses the curvature of the diagonals AB and CD in **Figure 1**, where the endpoints of the diagonals are adjusted to zero and the sign of the Signed Warpage Gauge is the same as the sign of the equation below**.**

$$\max(AB) + \max(CD) + \min(AB) + \min(CD) \quad (1)$$

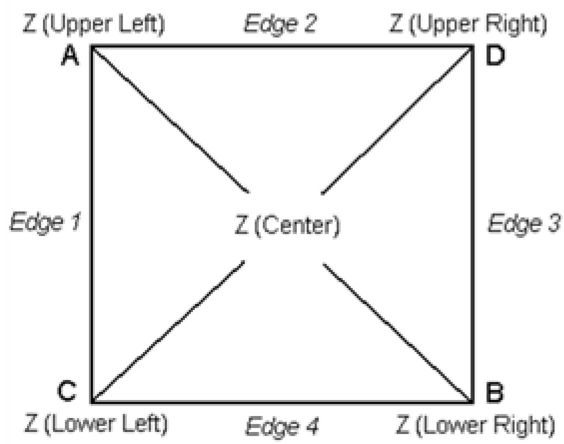


Figure 1. Coordinate Definitions for Gauges

Signed Warpage Dead Bug

Signed Warpage Dead Bug has a value equal to -1×Signed Warpage. Dead bug gauges flip the concave/convex sign to give warpage values for parts tested with their leads up. This is necessary when comparing warpage values to the JEDEC warpage standard, which defines direction with the part leads face down.

Full-field Signed Warpage

Full-field Signed Warpage has a magnitude equal to the coplanarity, and a sign (or polarity) determined by a special algorithm to distinguish between convex and concave curvature of the surface. First, the full surface displacement data is fit to a 2nd order polynomial. Then the polarity is assigned according to the sign of "$-(e + f)$", the curvature of the surface along the X and Y axes.

Full-Field Signed Warpage Dead Bug

Full Field Signed Warpage Dead Bug has a value equal to -1×Full Field Signed Warpage. Dead bug gauges flip the concave/convex sign to give warpage values for parts tested with their leads up. This is necessary when comparing warpage values to the JEDEC warpage standard, which defines direction with the part leads face down.

JEDEC Full-field Signed Warpage

JEDEC Full-field Signed Warpage has a magnitude equal to the coplanarity, just as Full-field Signed Warpage does, but has additional complexity to account for non-square shapes in the shape measurement algorithm. The surface is fit to a 2nd order polynomial just as in Full-field Signed Warpage. The polarity of the shape is then defined as "$-(em^2 + fn^2)$" where m = # of pixels in X and n = # of pixels in Y.

Because this gauge has improved accuracy in determining the shape of non-square surfaces, Akrometrix recommends it over its predecessors Signed Warpage and Full-Field Signed Warpage.

JEDEC Full-Field Signed Warpage Dead Bug

JEDEC Full Field Signed Warpage Dead Bug has a value equal to -1×JEDEC Full Field Signed Warpage. Dead bug gauges flip the concave/convex sign to give warpage values for parts tested with their leads up. This is necessary when comparing warpage values to the JEDEC warpage standard, which defines direction with the part leads face down.

Signal Strength

Signal Strength (abbreviated SS) is a quantitative measure of the directionality of a surface in relation to warpage direction. This gauge will return results from 0%, or maximally negative, to just over 100%, or maximally positive. Similar to JEDEC Full-field Signed Warpage, Signal Strength is calculated using a second-order polynomial fit, determined by the following equation:

$$SS = \left| \frac{em^2 + fn^2}{4 \times \text{Coplanarity}} \right| \quad (1)$$

where m = # of pixels in X and n = # of pixels in Y.

If Signal Strength is less than 25%, the warpage of the part is not highly directional, and the part is likely to have a flat or complex shape. In this case, signed warpage as assigned by one of the previous signed warpage gauges will be a metric with limited use, because the part will not be strongly concave or convex.

Signal Strength Signed Warpage

Signal Strength Signed Warpage, or 3S Warpage, is similar to JEDEC Full-field Signed Warpage, but with additional complexity to account for flat or complex (twisted, saddle shaped, M, W, etc.) shaped surfaces. Its magnitude is equal to the coplanarity, and its sign is determined in two steps. First, the Signal Strength of the surface is calculated. If Signal Strength is less than 25%, then the shape is considered transitional – the surface shape deviates too much from the simple concave/convex model that warpage sign typically represents. Transitional 3S Warpage is reported as TX, where X is the coplanarity, instead of +X or -X. In warpage vs. temperature plots produced in reports, transitional gauge values are plotted with a vertical line from positive to negative on the plot. If Signal Strength is greater than 25%, then the sign is determined using the same method as JEDEC Full-field Signed Warpage.

Signal Strength Signed Warpage Dead Bug

Signal Strength Signed Warpage Dead Bug has a value equal to -1×Signal Strength Signed Warpage. Dead bug gauges flip the concave/convex sign to give warpage values for parts tested with their leads up. This is necessary when comparing warpage values to the JEDEC warpage standard, which defines direction with the part leads face down.

Radius of Curvature (ROC)

The ROC (Radius of Curvature) gauge returns the radius of a sphere used to fit a three-dimensional surface. A positive ROC sign represents a convex curvature (viewed from above) and a negative sign represents concave curvature. The sign definition is in accordance with JEDEC Standard No. 22B112. Radius of Curvature gauge units are always meters.

To calculate the ROC, the 3D surface is first fitted with a sphere using the least squares algorithm. The function of the sphere can be expressed as $(x-a)^2 + (y-b)^2 + (z-c)^2 = r^2$, where (a, b, c) is the sphere center and r is the sphere radius. In this sphere function, we define a constraint as follows: $2(z_{max} - z_{min}) > min[(x_{max} - x_{\min}), (y_{max} - y_{min})]$, which requires that the sample surface should not be warped more than a semi-sphere shape.

The ROC gauge is designed for use with a near-sphere-segment shaped surface where there is only one surface curvature center and all four corners are warped in the same direction. The result will be less accurate shapes that do not meet these criteria such as saddle, cylinder, or asymmetric, nearly flat surfaces.

Twist

According to the IPC-TM-650 Test Methods manual, *twist* is a measure of the skewness of the opposite edges of a PCB, or equivalently, the extent to which one corner of the PCB lies above or below the plane defined by the other three corners.

For a given ROI, Twist is calculated as:

$$\frac{Z(UpperLeft) + Z(LowerRight) - Z(UpperRight) - Z(LowerLeft)}{Diagonal} \quad (2)$$

where

Diagonal = physical distance of $\overline{AB}$ or $\overline{CD}$ based on user specified phase image dimensions

Units are scaled such that the result is unit less and reported as a percentage.

Bow

According to the IPC-TM-650 Test Methods manual, *bow* is a measure of the curvature of the sample along its edges. *Bow* is reported to be the maximum bow calculated at any point along the four edges of the ROI.

The bow value at any edge point P along the ROI is determined by:

$$\text{bow}(P) = {}^{b}/_{L} \quad (3)$$

where b is the displacement measured relative to a chord connecting the edge endpoints and L is the edge length based on user specified phase image dimensions. Units are scaled such that the result is unit less and reported as a percentage.

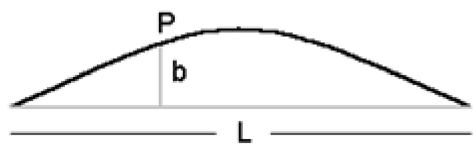


Figure 2. Parameter Definitions for Bow

Die Tilt Angle

Die Tile Angle (abbreviated DTA) measures the maximum angle in degrees of the diagonals of a part. The angle is derived from the ratio of the height difference between diagonal end points to the length of that diagonal. Die Tilt Angle is calculated for both diagonals, with the larger result being used. The calculation is done using this equation:

$$DTA = \sin^{-1}\left(\frac{a-b}{L}\right) \quad (\mathbf{2})$$

where *a* is the z-value at the higher of the diagonal end points, *b* is the z-value at the lower of the diagonal end points, and *L* is the length of that diagonal based on user specified image dimensions.

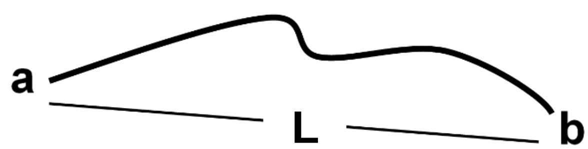


Figure 3. Die Tilt Angle Parameter Definitions

HD Coplanarity

HD Coplanarity is the difference of the median of the top 0.1% and bottom 0.1% of the current data set. Reference plane will affect this gauge just as it does regular Coplanarity.

Top Left Corner

This gauge reports the z-value of a single pixel at the top left corner of a surface. If the surface does not have data in its top left corner, the diagonal will be checked up to a distance of 5% of the diagonal length in pixels. Beyond this point, the answer will be reported as n/a.

Top Right Corner

This gauge reports the z-value of a single pixel at the top right corner of a surface. If the surface does not have data in its top right corner, the diagonal will be checked up to a distance of 5% of the diagonal length in pixels. Beyond this point, the answer will be reported as n/a.

Bottom Left Corner

This gauge reports the z-value of a single pixel at the bottom left corner of a surface. If the surface does not have data in its bottom left corner, the diagonal will be checked up to a distance of 5% of the diagonal length in pixels. Beyond this point, the answer will be reported as n/a.

Bottom Right Corner

This gauge reports the z-value of a single pixel at the bottom right corner of a surface. If the surface does not have data in its bottom right corner, the diagonal will be checked up to a distance of 5% of the diagonal length in pixels. Beyond this point, the answer will be reported as n/a.

Corner Gap

The corner gap is the largest difference between the values of the four corner gauges. It is always positive.

Center Point

The center point is the z-value of a single pixel at the center of the surface. If the surface has an even number of pixels in any dimension, then the center pixel on the bottom right is used.

Second Order Fit Coefficients

This gauge reports the coefficients for a second order polynomial fit of the surface. There are six different reported coefficients: x^2, y^2, xy, x, y, and a constant, a. Note that x^2 and y^2 are the same as the values of e and f used to calculate Full-field Signed Warpage, JEDEC Signed Warpage and Signal Strength.

Shape Name

This gauge uses the coefficients from a second order polynomial fit to characterize a surface as one of several shapes. The shapes used by this gauge are Upward Twist, Downward Twist, Complex/Flat, Y Pipe, X Pipe, Bowl, Dome, X Saddle, and Y Saddle.

Measurement Result Applications:

Failure Analysis:

Many customers use Akrometrix tools when they are seeing a specific problem that may be related to warpage. A common example would be a solder ball crack or open that is found through quality inspection after the reflow process. The warpage data from Akrometrix can often be correlated with failing part types, in locations when warpage is high and/or does not match between solder ball mating surfaces.

Warpage or strain data can also correlate to other problems found in packages, including: bridges, open/cracked leads, head-in-pillow, pad cratering, die cracking and surface delamination.

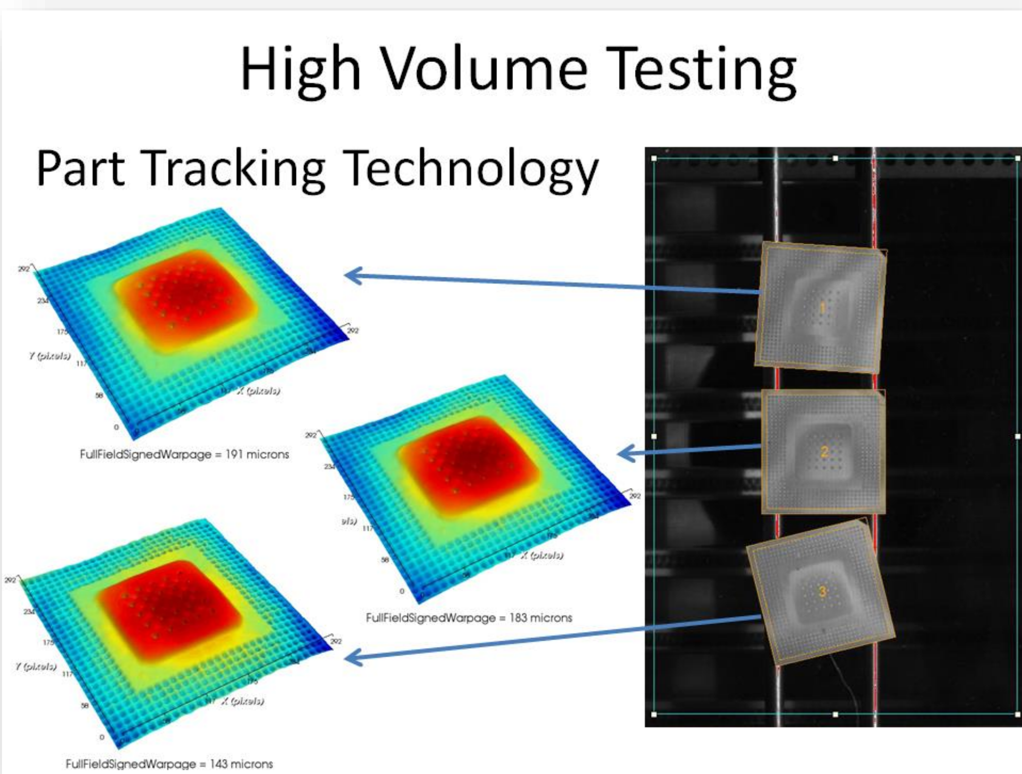
Quality Assurance/Reliability:

The TherMoire and TTSM tools can quantify warpage criteria for customer products. Real world observation of product failures in either outgoing functionality tests or 1-year warranty replacements can be correlated with measured warpage values to find if product failures are specific to warpage levels.

The TTSM device is particularly useful for nondestructive onsite testing, as it is designed to take rapid room temperature measurements and can handle a large volume of parts using the technology described below.

High Volume Testing (HVT):

Technology introduced to the Studio software in 2011 allows the automatic locating and cropping of multiple samples within the measurement area. This feature, called Part Tracking, is built in to the measurement acquisition software (Surface Measurement). This approach is ideal for the measurement throughput necessary for lot sampling under thermal characterization, for customers doing high volume testing. Additionally, Automated Report Generation (ARG) was added in 2016 to allow automated report creating through data mining of metadata retained within measurement files. The addition of ARG allows an easier path for organizing large and complex data sets into a readable format.



Pass/Fail decisions versus industry standards:

Both JEDEC and JEITA have set industry standards for package warpage. Akrometrix can provide exactly what a customer needs to compare their package with these standards. In fact, many of the example result plots in both of these standards were generated by Akrometrix equipment.

Matching and comparing shape of package and local site on PCB:

Often the most important information can be, not how much a package warps, but how much does it warp in comparison to its mounting surface. Industry standards for package warpage do not take into account the local site warpage of the PCB attachment area. Akrometrix can quantify and compare both surfaces to best understand where package and PCB shape are mismatched. Refer to the section on Interface Analysis. Specific problems observed include:

- Die-Substrate delamination
- PCB-BGA cold joint/bridging
- Stacked Die delamination
- Head in Pillow and Head on Pillow defects

Material and Design Choices for like Form Factors:

Another common design consideration where Akrometrix data can be helpful is in choosing between different materials or designs for the same form factor. A customer may see no difference between three prototypes until they use an Akrometrix system to see which prototype shows favorable warpage characteristics; engineers can then make choices that will lead to more reliable solder joints.

The same decisions can also be aided with CTE calculations and strain maps found with the DIC add-on module.

Characterization of Local Features:

Particularly with the DFP module for larger step heights, Akrometrix can measure associated heights and consistency of these heights on local features. The ability to draw 2D chord plots is often helpful in these cases. Examples include:

- Solder ball height
- Solder mask versus bond pad height
- Solder mask versus metal trace height
- Flatness between connector leads
- Socket pin flatness

FEA Model Validation:

Many companies will predict sample warpage under thermal conditions using FEA modeling software. Actual surface data from a sample through reflow in Akrometrix systems is often used to validate the results of these models. In these cases, Displacement Matrices are particularly useful as they can be imported into many FEA programs.