Optoelectronic Package Stability Verification with 3D Image Correlation

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Abstract

3D image correlation provides the ability to measure 3D displacements and the true surface strains of materials without contact or without many difficulties associated with these measurements. Micro scale measurements are also now possible. This unique capability allows the equipment to be used for rapid full-field strain measurement in the test lab for tensile and fatigue testing with minimal preparation and providing the full-field results.

In addition, 3D image correlation can be used for measurements in extreme environments. In thermal conditions, it is used for fine measurements to well over 300˚C, as well as in vibration conditions. There are also incredible capabilities for the photonics packaging industry.

3D image correlation is a general purpose strain measurement tool able to measure full-field deformation and strain in a broad variety of environments on most materials. This paper will look at a variety of applications and discuss the methods for its implementation.

3D Image Correlation

The object under load is viewed by a pair of high resolution, digital CCD cameras for the 3D deformation measurements. The 3D image correlation technology is a unique combination of two camera image correlation and photogrammetry. A random or regular pattern with good contrast is applied to the

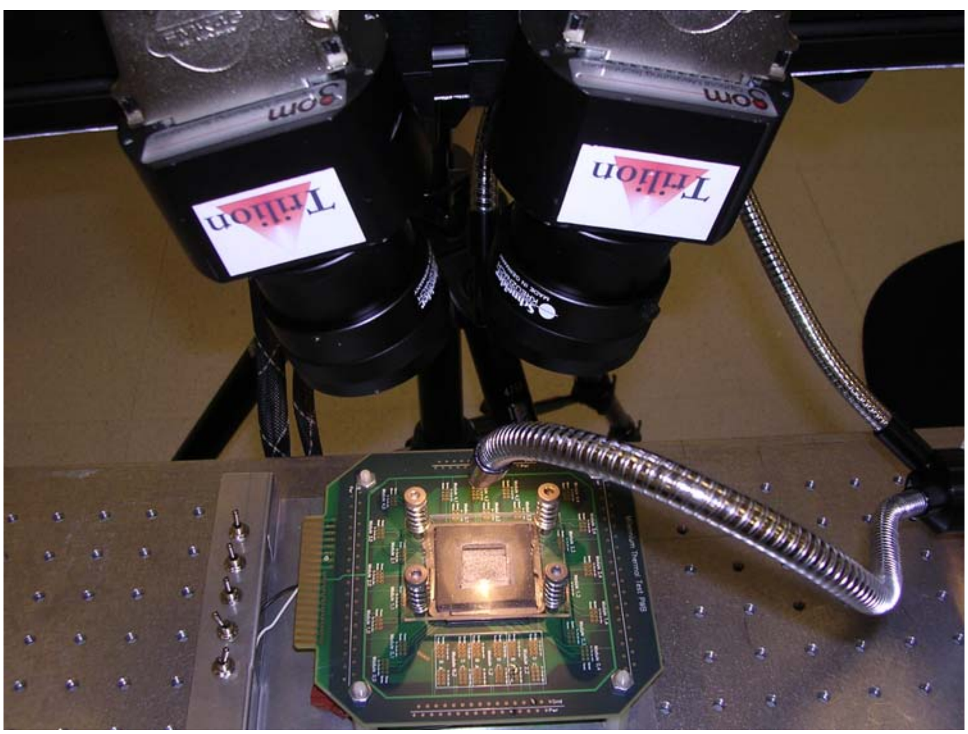


Figure 1 - ARAMIS 3D image correlation setup for the measurement of 3D displacements and strains in microelectronic packaging from thermal expansion or applied loads, either statically, dynamically or in shock, such as drop tower tests.

surface of the test object and which deforms along with the object. The deformation of this structure under different load conditions is recorded by the CCD cameras and evaluated. The initial image processing, the image correlation, defines unique correlation areas known as macro-image facets, typically 5-20 pixels square, across the entire imaging area, each one a measurement point. These facets are tracked in each successive image with sub-pixel accuracy. Then, using photogrammetric principles, the precise 3D coordinates of the entire surface of the specimen is precisely calculated. The results are the 3D contour of the component, the 3D displacements, and the plane strain tensor. An example of ARAMIS configured for 3D measurement with a portable computer is shown in Figure below.

The ARAMIS system requires application of a stochastical (random) pattern to the test object. This is generally achieved by sputtering black spray paint over a uniform whitish background. The size of the black spots must decrease as the field of view decreases, so that each spot ideally occupies 3-5 pixels on the cameras, as was shown in Figure 3. To achieve this on the small sample provided, an airbrush would normally be used to spray a fine pattern. This has proved to be a simple and effective method. At first a fine mist from a can of spray paint was applied, this was extremely fast and efficient, but the dots were a little bigger than optimal. Later we used the airbrush which produced a very fine pattern and finer results (better special resolution).

The samples were typically prepared with a base coating of flat white paint and flat black paint was speckled across the surface. The ARAMIS system was calibrated for a 15 x 12 mm field of view, and the sample was simply fixtured on the lab table. Camera system was adjusted so that the area of interest was in the center of the calibrated volume.

ARAMIS has a wide range of triggering capability, and the standard high-resolution cameras can acquire images at up to 12Hz, depending on the required exposure time (20 Hz with optional cameras). The standard setup has the ARAMIS system triggering off of the test machines displacement and load sensors. Trilion also offers a variety of high-speed cameras with ARAMIS, with interframe delays as short as 100 nanoseconds, and works with variety of pulsed light sources to as short as 7 nanoseconds.

Microelectronic Package Thermal Expansion Analysis

It is well known that ball grid array package warpage due to mismatch of CTEs among materials in structure and geometric asymmetry affects the reliability of solder joint in BGA devices. In this study, package warpages under various temperatures from testing temperature to room temperature were measured by a rapid full field deformation and strain measurement tool using three-dimensional (3D) image correlation method and high-resolution digital CCD cameras. This measured warpage can be implemented for simulation verification, prediction of design or manufacturing defect, and introduction of

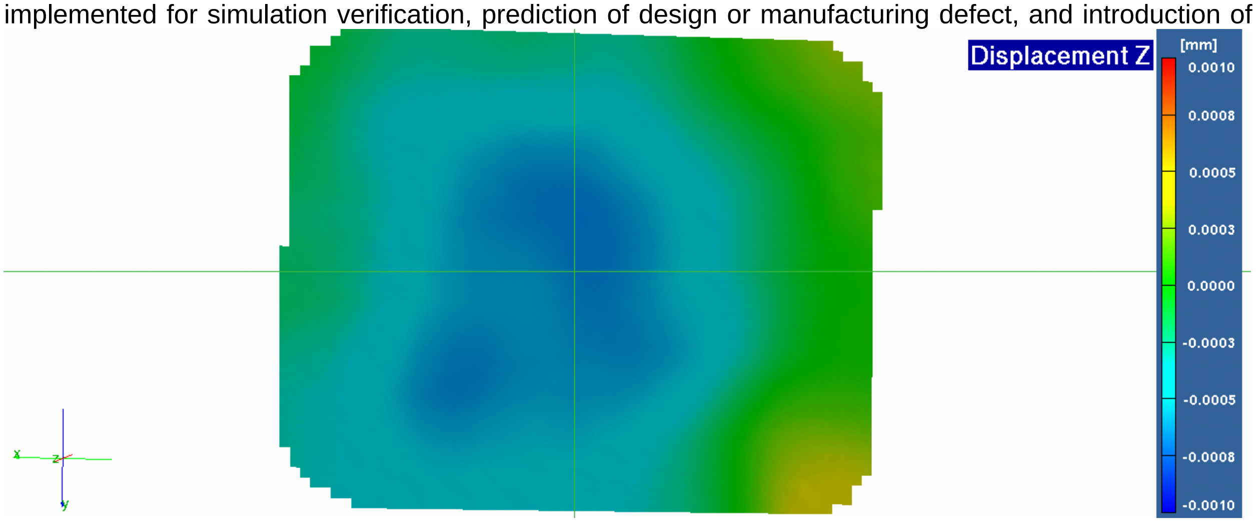


Figure 2 – Ceramic BGA warm-up with TE-cooler. Images were collected every 40 seconds. Result shows substantial local displacement out-of-plane at the lower right corner, stressing the solder balls.

an enhanced package because the warpage characteristic was identified as an important design parameter for optimum mechanical/thermal solution for BGA packages.

Further warpage of plastic ball grid array package under controlled thermal load is measured by using the 3-D image correlation system for the 3D surface and flatness measurement. The measurement system is able to give us precise knowledge about the package warp deformation in the temperature range of interest. Although, only two image sets are required to measure the change from minimum to maximum temperature, multiple image sets provide a progressive measurement of the deformations and strains. This measurement can also be performed at any thermal change rate. The color plot of out-of-plane displacements shows generally symmetrical behavior, which is expected under the thermal condition applied. The spreading of the maximum displacement to the lower edge on the right side was consistent during the cool-down process. The increased bulging at that area indicates possible defects such as an internal debonding or other anomaly. Figure 3 plots out-of-plane displacements along the diagonal section line shown in figure 2 indicating warpage. Figure 4 shows series of images with fixed scale showing progression of warping during cool-down. Note that the "hot spot" at the top edge shows consistently. It will be the first place to be considered for failure analysis. However, simulation requires verification process including adjustment for assumptions made during analysis. Three-dimensional, measuring total deformation of complex objects and their shape, rather than relative deformation is necessary for that reason. Either purpose of verification or direct use of measurement asks for a more robust and less expensive measurement system.

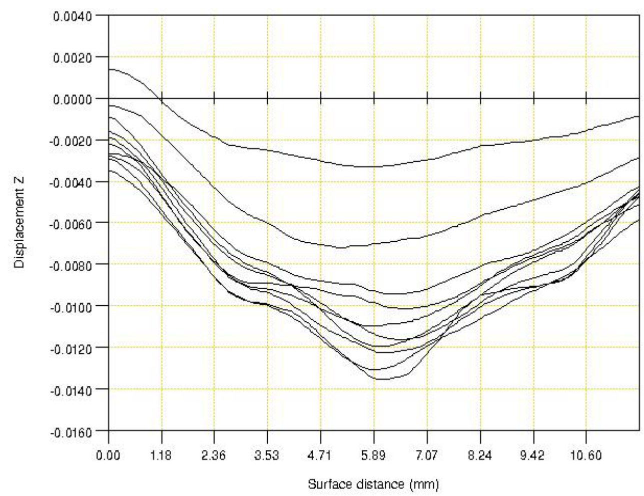


Figure 3 -- Plots of out-of-plane Displacement along the Diagonal Section Line indicating Warpage

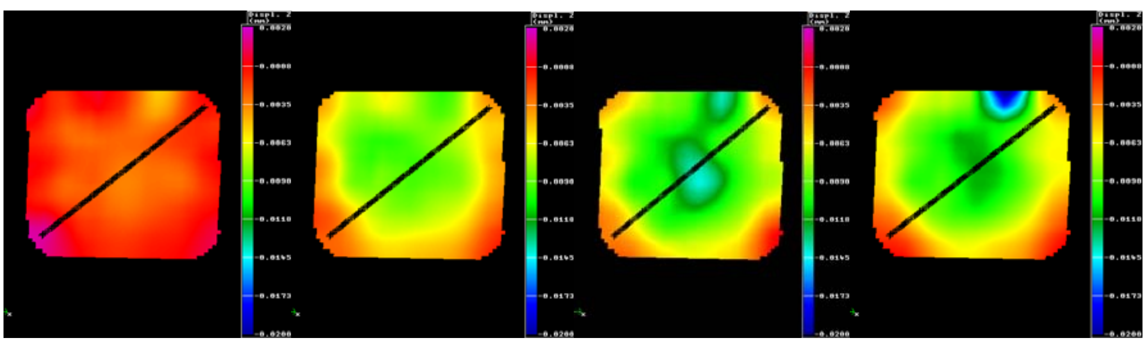


Figure 4 - Color Image series of Plastic BGA showing progression of warping during cool-down.

Ball grid array package warpage due to mismatch of the coefficients of thermal expansion and asymmetric geometry has created many troubles in solder joint reliability. In order to control design factors influencing warpage and collect detailed information through reaction during operation, various measurement systems as well as simulation methodology have been developed and introduced in the field of microelectronics. These methods include electronic speckle pattern interferometry (ESPI), shearography and moiré.

It was found that non-contact and material independent determination of three-dimensional deformation and surface strain using 3-D image correlation method can be implemented for measuring package warpage, without high cost and tedious time consuming preparation. As an example, for composites failure analysis, this technology is hundreds of times less sensitive to vibration interference than ESPI, can collect data 30 times faster, and has a much higher dynamic range of deformation measurement. As an improvement of the Moiré method, 3D image correlation can simply track the 3D coordinates, 3D displacements and surface strains of multiple objects, on multiple planes, even unrelated surfaces.

Uncoated Silicone Wafer Shape Measurement

It was desired to measure the 3D shape or flatness of a ceramic disk. We tested this against both coated and uncoated samples, showing better results with the uncoated due to the paint thickness.

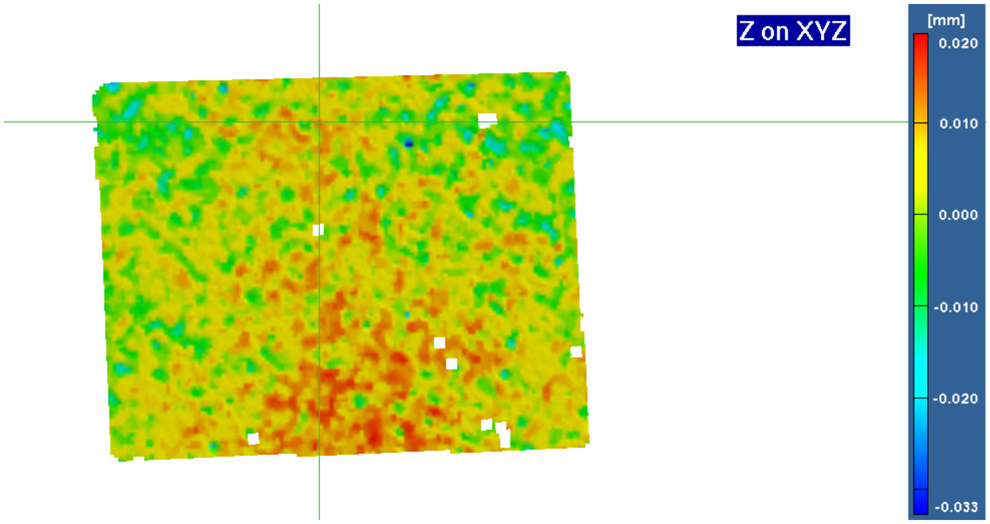
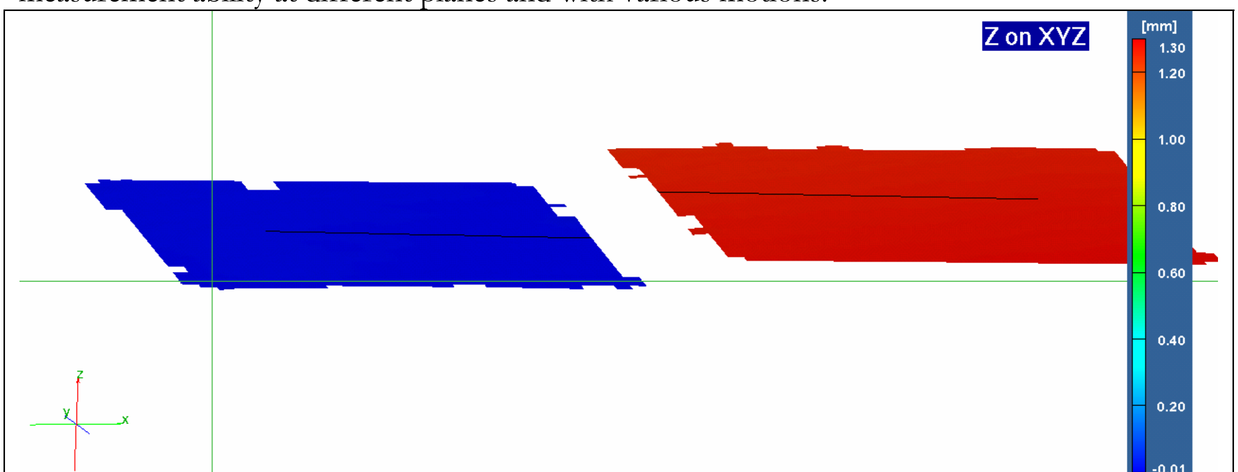


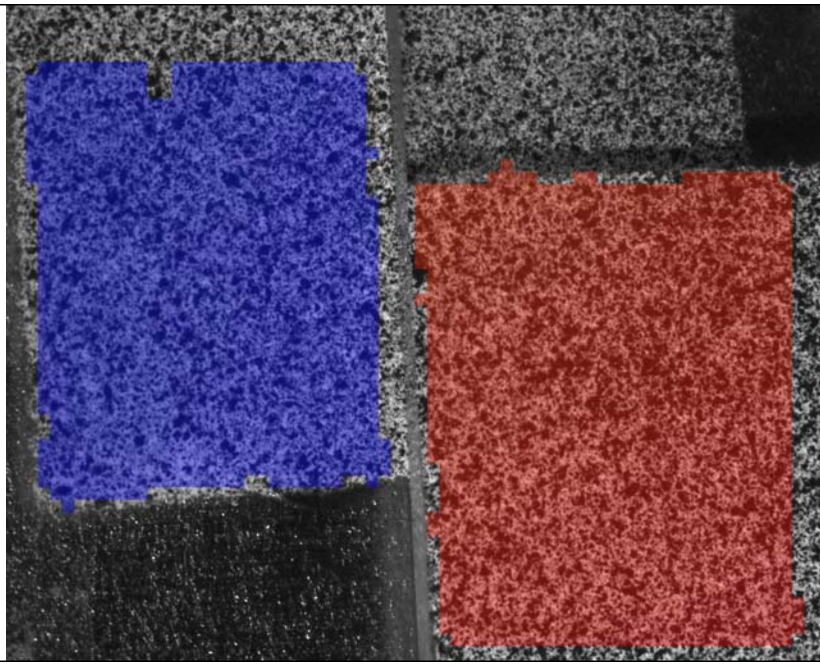
Figure 5 - This shape result showed a reddish bulge in the center of the disk that was about 20 microns above the edges, using a wide 50mm field of view.

3D Coordinates and 3D Displacement Tests of Multiple Planes

For the following tests a number of glass slides were prepared with a pattern on part of its surface. We mounted these slides on a translation stage at various levels. The 15mm calibration used has a substantial depth of measurement of 12mm. It was desired to confirm the system's measurement ability at different planes and with various motions.



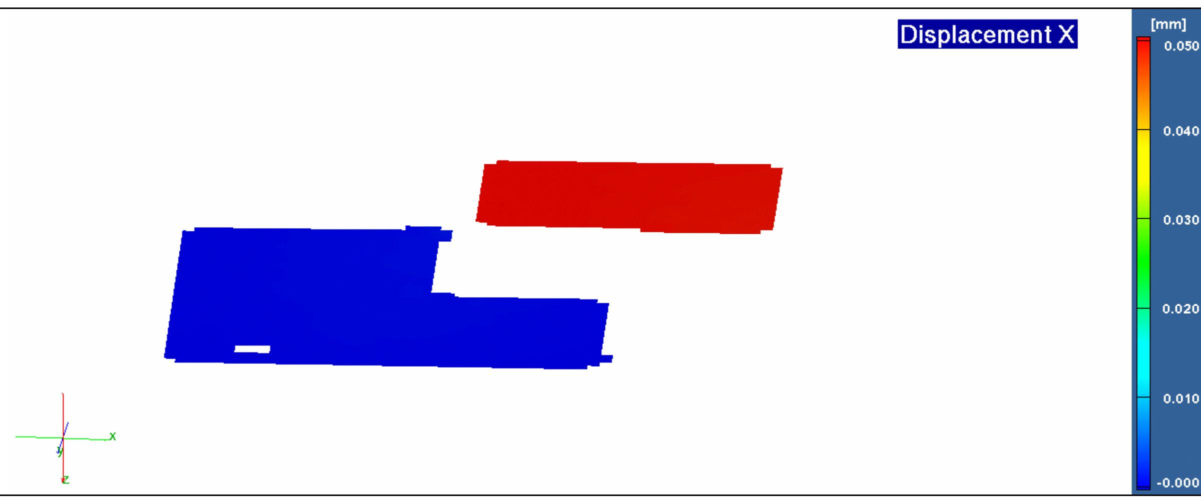
The planar measurement showed 1.30mm, which included the glass slide (1.22mm) and the adhesive pad (unmeasured) used to hold the slides together.



This result showed the full-field picture of the two glass slides and the height data overlaid onto these images. The facet size can be seen as the step along the edges. A mask could have been used to create a perfect edge. This result edge was automatically detected.

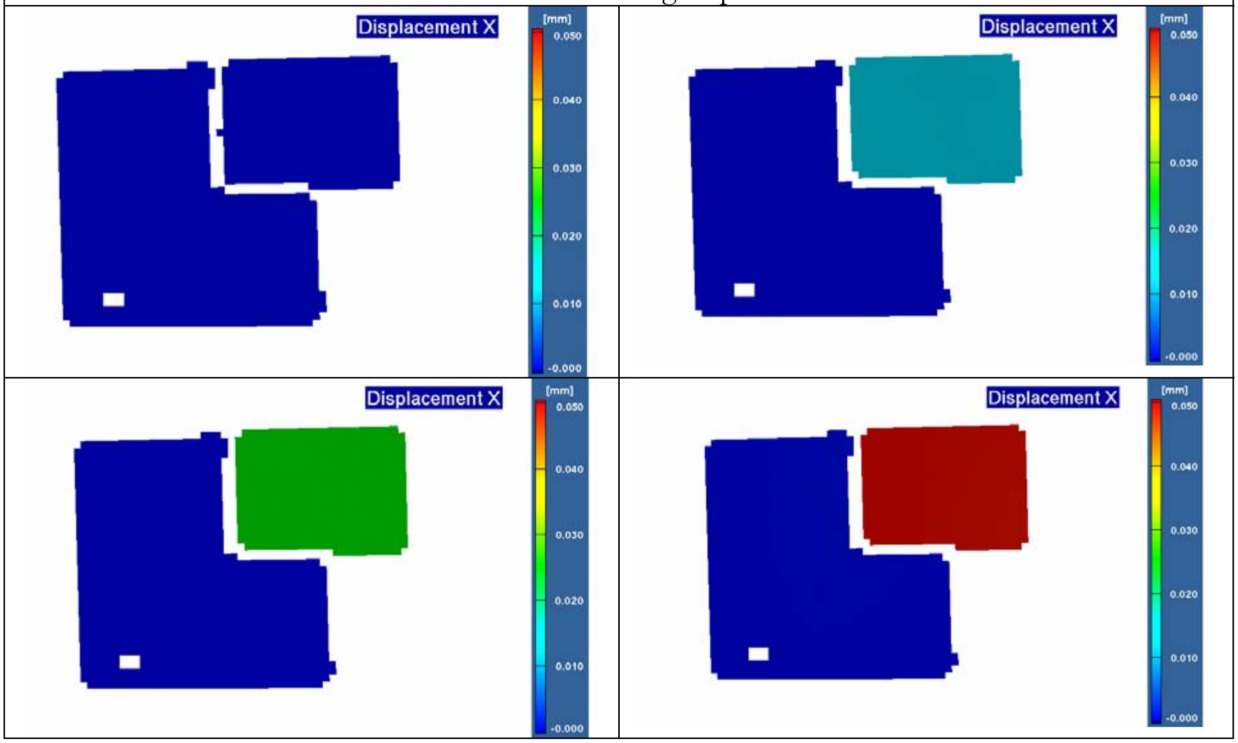
In order to study the ability to measure displacements, we measured two slides, one mounted on the translation stage and one mounted on the unmoving translation stage frame. The stage had 0.0001 inch (2.5 micron) fine divisions, which gave us an estimated +/- 2 micron apparent positioning accuracy.

Step	***Manually Applied***	***Measured***
1	**12.5 microns**	**12.3 microns**
2	**25.4 microns**	**26.2 microns**
3	**50.8 microns**	**50.0 microns**



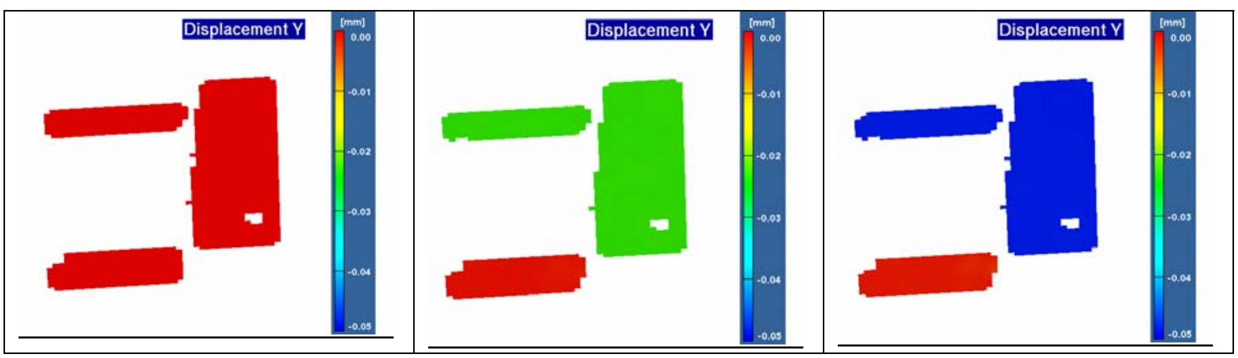
Displacement X shows the measurement of 50 microns of motion in the X direction, as viewed at an angle to show the separation of the planes.

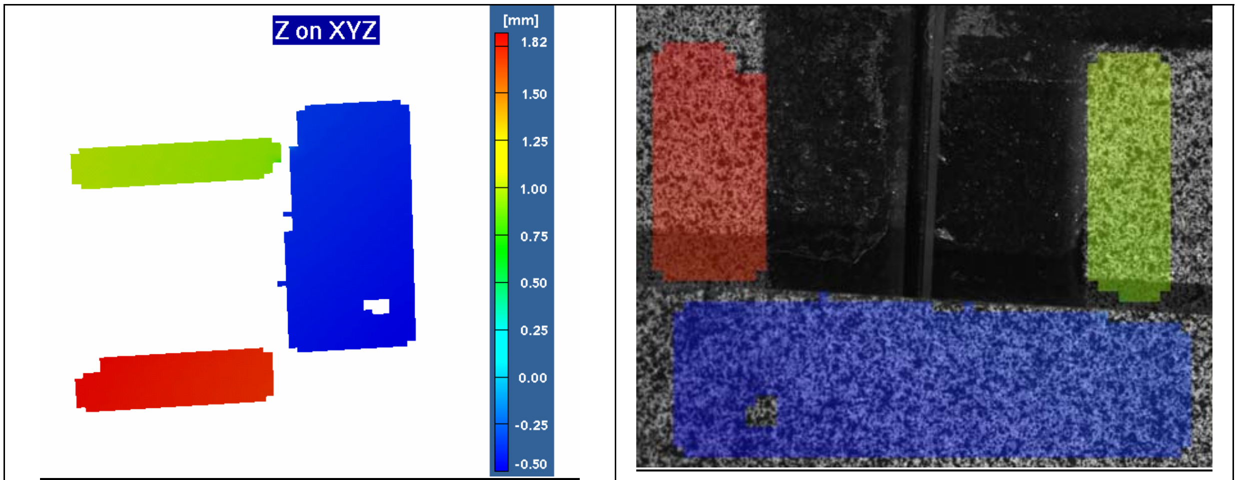
With fixed scaling, the X Displacement results can be shown as
a “movie” of increasing displacement.



We then repositioned the cameras to measure three separate planes simultaneously. Two were on the translation stage and one was on the frame.

Step	***Manually Applied***	***Measured***
1	**25 microns**	**22 microns**
2	**50 microns**	**47 microns**





The shape measurement (ZonXYZ) shows the Z-axis location of all three planes, as a 3D graphic or overlaid onto a original image. There is no limit to the number of planes measurable or their complexity of motion.

Photonic Packaging: Precision Fiber Coupling

The fiber optics revolution has brought about the need for compact optical assembly methods so that simple optics assemblies can be condensed into the smallest possible packages. Throughout the 1990's, the majority of packaging efforts focused on the need to optically couple single devices, like lasers and detectors, to single mode fibers in hermetic packages. Traditional free-space techniques, such as those used in single mode DFB lasers, typically use at least one lens, often two, to collect light from a waveguide device, and focus it into a fiber, or visa versa.[1] Another similar technique is to eliminate intermediate lenses and use a lens-tip fiber in close proximity to the device.[2] Both methods rely on micron or sub-micron fiber positioning to achieve optimum coupling. In cases where one or more lenses are employed, it is usually possible to place the lenses with a tolerance of several microns, and recover all or most of the light by adjusting fiber position—for this reason fiber positioning is usually the final step in free-space device packaging applications.

A variety of mechanical means have been employed to achieve sub-micron fiber positioning, and only a few of the most common or best performing methods will be mentioned here. One of the earliest and most widely deployed techniques is to laser-weld "coaxial" assemblies of flanges and tubes configured to allow three sliding degrees of freedom prior to welding.[3] Typical laser weld shifts are of order several microns, and it is usually necessary to employ laser hammering to coax the fiber back into optimum position. This technique is proven and reliable, and is a great tool for applications where it acceptable to position the fiber outside the package in an extended fiber boot. It is an unwieldy approach for applications that require the fiber to be placed within the walls of a package or on top of a thermo-electric cooler (TEC). Recently developed fiber mounting techniques make use of very compact, laser welded clips to position and attach fibers onto a mounting surface next to the device to be coupled.[4][9] These techniques necessarily include processes designed to compensate for several-micron weld shifts.

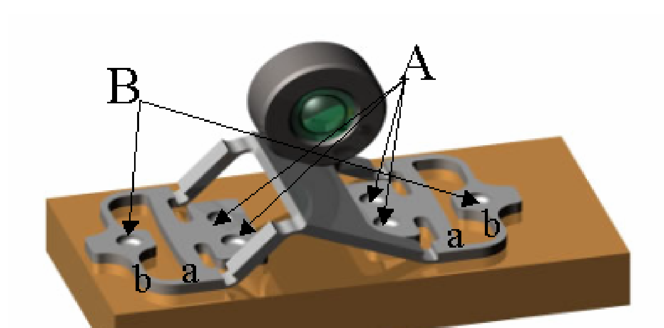


Figure 6 - Phasebridge's three-hinge weld clip.

The need for lower cost, smaller size, and the drive towards modular sub-systems, has resulted in increased demand for hybrid-integrated modules. Free space optics provides one important means of integrating non-custom off-the-shelf components, since mode mismatch, device CTE and other inherent device incompatibilities can be managed using free space optics to shape and locate beams as needed. Also, free-space optical coupling will have continuing relevance to optical packaging, since many components such as MEMS devices, isolators, and very compact high contrast variable optical attenuators (VOA's) are not available as waveguide devices.

Figure 6 depicts the WaveClip mounting structure developed at Phasebridge. It's most notable features are: 1. the three-hinge upper structure converts sliding degrees of freedom of two flat feet into three degrees of adjustment at the lens; 2. the feet are manipulated by downward pressing electrodes (not shown) that maintain contact pressure during spot welding at points "A" for coarse positioning, and points "B" for final fine-adjustment; and 3. the feet themselves consist of two sets of flexible beams, one set far stiffer than the other, which work in concert to attenuate final weld shift.

Figure 7 - View from ARAMIS system of Phasebridge lens clip, lens, and fiber ferrule in L-Block assembly. Barely visible "+" symbols indicate location of macro image facets—as the system tracks motion these area increments are tracked by the signature defined by each small local pattern.

The extreme importance of temperature behavior in optical mounting assemblies, and optical packages in general, has led us to pursue more generalized approaches for understanding temperature performance of complex small sized assemblies. The standard industrial procedure is to design and build prototypes, and then use a combination of throughput data and modeling to identify causes of thermal motion. This approach tends to break down when material and interface properties are unknown, or if the system complexity grows to the point where there are too many free parameters to reliably identify a source of undesired or unexpected motion. We are using our brackets as test cases to help identify diagnostic tools and approaches that may allow us to quickly and easily identify and locate thermally induced motions in complex assemblies. Also, bracket performance over temperature is so critical as to merit additional diagnostics to minimize any uncertainty over this issue.

The ideal diagnostic tool for temperature related packaging studies would be capable of tracking relative motion between multiple points in complex structures and assemblies. The most basic challenge in achieving this is that any probe, contact or non-contact, that measures or tracks distance from the probe to the object under study, must be held in a stable position relative to the object throughout temperature cycling or other types of loading. Contact-based probes, fiber optic proximity probes, and even many optical interferometric probes, all present serious challenges in tracking motion to tenth-micron precision.

One very promising tool we have identified, the ARAMIS system distributed by Trilion Quality Systems, uses two high resolution digital cameras and highly developed 3D image correlation software to view a random marking sprayed on to the entire device under test using an air brush and paint or dye. Before thermal or mechanical loads are placed on the object, image-processing software defines 'macro-image facets' which are seen as barely visible "+" marks in the image of Figure 6. As the structure deforms and moves, these facets are tracked relative to each other in each successive image with sub-pixel accuracy. Using photogrammetric principles, the 3D coordinates are calculated precisely throughout well defined flat or curved surfaces within the range of focus of the cameras.

It is possible to achieve order tenth-micron level resolution over an area of roughly one square centimeter using cameras placed more than four inches from the object under test. Interestingly, the quality of the measurement is unaffected by motion or drift between the camera system and the device under test—the system simply tracks the motion, and points distributed throughout the test object are seen to translate together in the event of camera drift. No special measures are required to stabilize camera position, and a conventional tripod, resting on the floor or bench top, is adequate.

The displacement map in Figure 7 tracks selective areas, in a different view, of the same assembly of Figure 6. The image in the upper right is that of the fiber ferrule; top center corresponds to a patch on the lens, bottom right to a portion of the floor of the package, and middle left to a flat area of the weld clip. The color plot allows one to roughly estimate relative motion of any two or more selected areas *even across separate disconnected regions.* (Viewers of black and white copies are restricted to relative motion within a given region, but the overall description of the technique still is conveyed by this discussion.) Note that much of the relative motion observed in the figure is strictly due to thermal expansion of the materials; this is best seen by examining the flat regions in the lower right and middle left. In fact these measurements can be used to provide self contained rough validation of any given scan, provided that material CTE is known. If the technique is used properly, a given series of measurements can be roughly calibrated by insuring that good images are captured for measuring CTE expansion of a well defined feature with well-known material CTE. In applications where complex optical systems are under-performing due to shifts of several tenths of microns, this extent of calibration is adequate to identify the source of trouble. This is also true for the “study” shown here where the point was to provide further validation of the results obtained using the apparatus of Figure 4; the main motivation was to insure that the very sound temperature performance suggested by Figure 5 represents a truly stable assembly, and is not the product two or more unexpected motions that cancel each other by coincidence.

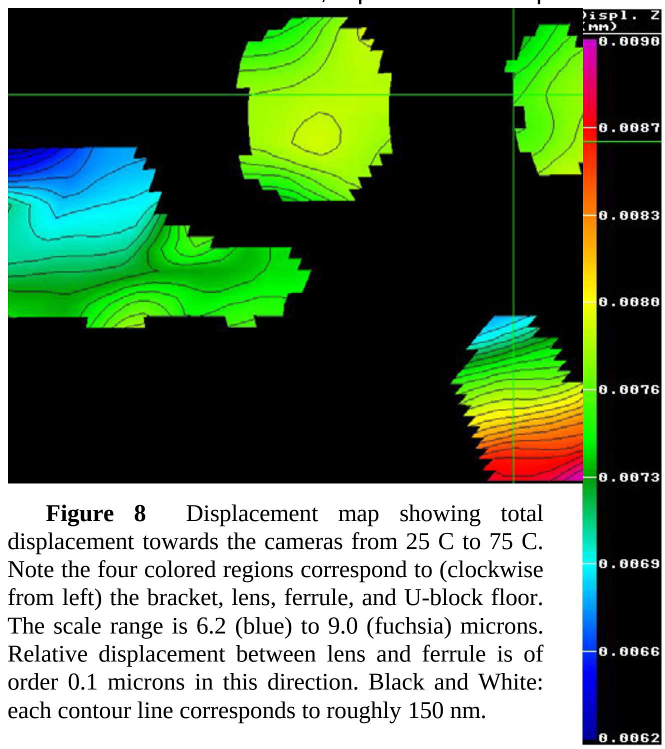
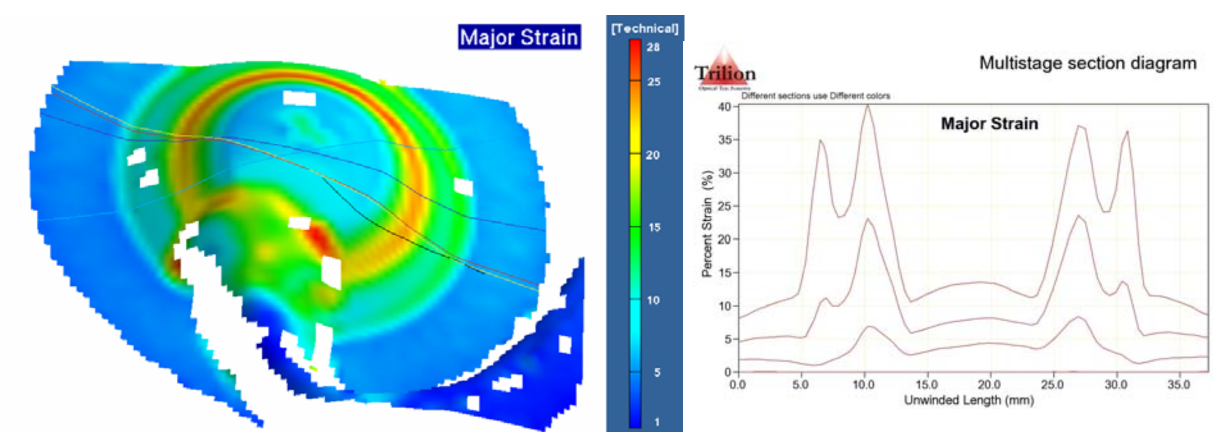


Figure 8 Displacement map showing total displacement towards the cameras from 25 C to 75 C. Note the four colored regions correspond to (clockwise from left) the bracket, lens, ferrule, and U-block floor. The scale range is 6.2 (blue) to 9.0 (fuchsia) microns. Relative displacement between lens and ferrule is of order 0.1 microns in this direction. Black and White: each contour line corresponds to roughly 150 nm.

Complex Shape Measurements

Measurements even of complex assemblies can be easily made and rapidly analyzed with 3D image correlation, providing a non-contact, full-field response.



Conclusions

3D Image Correlation has proven itself as a powerful new tool for the microelectronics and photonics industries. It is unique in its ability to simultaneously measure micron level 3D coordinates, 3D deformations and surface strains, on multiple, unrelated components. These measurements can be made statically or dynamically, even in shock (drop tower), or in an environmental/thermal chamber. For optics train analysis in the photonics industry, nothing can match its non-contact 3D coordinate measurement ability, for ease and simplicity of measurement.

Acknowledgments

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