EXTENDING 3D MRS SENSOR TECHNOLOGY TO ADDRESS CHALLENGING MEASUREMENT AND INSPECTION APPLICATIONS

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ABSTRACT

There is an increasing need for highly accurate 3D inspection and measurement capabilities for applications in SMT, semiconductor and metrology markets.

3D Multiple Reflection Suppression (MRS) sensor technology has been effectively combined with Automated Optical Inspection for several years and is now being utilized for many SPI applications such as microelectronics and sub-100-micron solder paste deposits and other challenging applications, like packaging, automotive, medical and other applications with stringent quality requirements. In addition to inspection, there is an increasing need to capture coordinate measurements in-line.

Phase shift profilometry (PSP) is widely used for 3D automated optical inspection (AOI) by electronics manufacturers assembling printed circuit boards (PCB) using automated surface mount technologies (SMT). Conventional PSP measurements are significantly challenged by inaccuracies caused by multiple reflections between surfaces on the inspected object. Multiple Reflection Suppression (MRS) sensor technology addresses this challenge. The sensor's unique optical architecture and the system's proprietary image fusing and processing algorithms provide fast, accurate 3D characterization capabilities that are well suited to other important applications, including solder paste inspection (SPI) and measurements typically performed by coordinate measurement machines (CMM).

Coordinate measurements can now be attained in seconds, rather than the hours or days it would take a traditional coordinate measurement machine. MRS sensor technology provides significant advantages in speed, accuracy and resolution over the alternate technologies. This technology is a key building block for achieving high accuracy at production speed for Automated Optical Inspection (AOI), Solder Paste Inspection (SPI) and Coordinate Measurement (CMM) applications.

Key words: AOI, 3D Inspection, SPI, multiple reflection suppression, MRS, CMM

INTRODUCTION

Phase shift profilometry (PSP) is a Moire projection technique for measuring 3D shapes. PSP projects a pattern of fringes onto the object. When the projected pattern is viewed from an angle differences in surface height introduce shifts in the fringe pattern (figure 1). Intensity varies sinusoidally across the fringes, allowing the shifts to be characterized as phase shifts. The magnitude of the shifts is a straightforward geometric function of the difference in surface height and the angle between the projector and the viewer. Sophisticated image processing techniques can measure the shifts very precisely to construct an accurate 3D model of nearly any object.

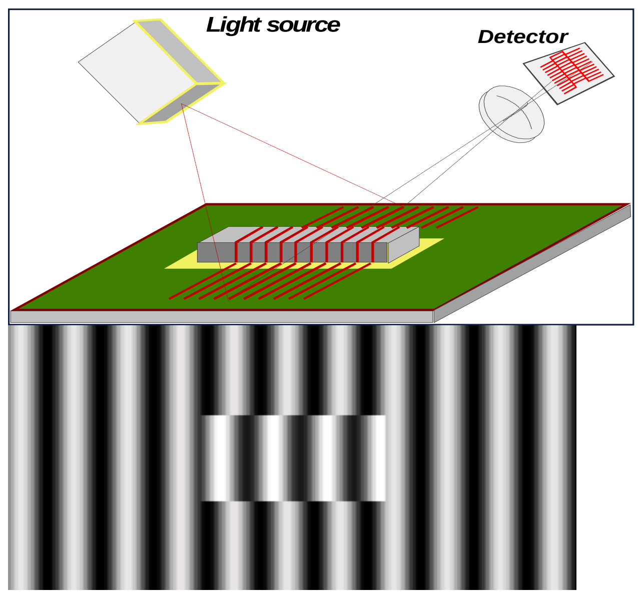

Figure 1. (Left) The principle of phase shift profilometry. (Right) Fringe pattern projected on a rectangular block resting on a flat surface and viewed from an angle. PSP projects a fringe pattern onto the inspected object. When the pattern is viewed from an angle, the fringes shift. Differences in surface height can be calculated from measurements of the phase shift.

All PSP systems share some limitations. Some of these challenges derive from the nature of the measurement technique. Others are more specific to measuring electronic assemblies, particularly Surface Mount Technology (SMT) Printed Circuit Boards (PCBs). These include ensuring complete measurement of low components near tall components, the avoidance of measurement errors caused by multiple reflections among components, and the demand for fast measurements in an industry driven to achieve economies of scale in high-volume production.

RANGE AND SENSITIVITY

The most fundamental challenge is the difficulty of establishing an absolute reference for discontinuous fringes and a practical compromise that imposes a trade-off between range and sensitivity. All fringes are identical, like a ruler with no numbers. For discontinuous fringes, like those crossing the block in figure 1, the fractional component of the shift is readily apparent, but the number of whole cycles is not. The fringes in figure 1 appear to have shifted by about $^1/_3$ of a cycle where they cross the block, but it could be $1^1/_3$ or $2\,^1/_3$ cycles. This problem can be addressed in practice by limiting the maximum allowable feature height to less than one fringe cycle. In the case of a PCB (or any object resting on a flat surface) the surface of the board itself is an easily recognized reference plane and all components can be assumed to extend above that surface. All observed shifts can be assumed to be fractional and measured with reference to the nearest fringe in the direction of the board surface. Limiting the measurement range to less than one cycle can be restrictive. The range can be increased by decreasing the frequency of the pattern but this reduces the change in contrast for an incremental change in height and thereby decreases the sensitivity of the measurement. Most PSP systems address this trade-off between range and sensitivity by acquiring data at multiple fringe frequencies, using a low frequency to establish absolute height and a higher frequency to fill in detail, but in most cases, multiple high frequency fringes would be generated and the unwrap would be determined based on the fact that they are not harmonically related.

SHADOWING BY TALL COMPONENTS

Automated 2D inspection of PCBs has been conducted for many years, followed by 3D inspection. The addition of 3D capability increased the value in a broader range of applications. 3D AOI technology is typically based on 3D SPI technologies, which generally had small height differences (i.e. less than 750 µm). Unlike solder paste inspection, these SMT assemblies often contain capacitors and other components that are tens of millimeters tall. When illuminated or viewed from an angle, as required to generate phase shift in the fringe pattern, tall features may shadow or obscure nearby low features (figure 2). Two dimensional AOI systems typically acquire images with a single camera from a top down perspective. The easiest way to add 3D capability is to project the fringe pattern from an angle and use the existing camera for imaging. To avoid shadowing, multiple projectors are arranged around the camera, typically at azimuths of 0°, 90°, 180°, and 270°. These must each separately project multiple fringe patterns at different frequencies as the camera acquires a sequence of images from which the system computes the 3D shape. A typical sequence may include more than 20 separate images. This arrangement addresses the shadowing problem but significantly slows the inspection process.

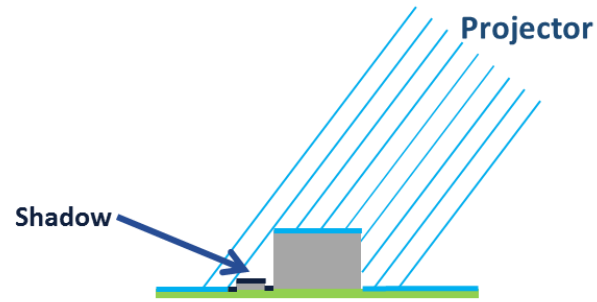

Figure 2. If the pattern is projected at an angle, tall features may cast a shadow, preventing measurement of nearby low features.

MULTIPLE REFLECTIONS

Another challenge common in SMT inspection is multiple reflections between components, which distort the fringe pattern and cause errors in the 3D measurement. Finished circuit boards often contain components and materials with shiny surfaces, including solder joints, tinned leads, and metal oscillators. Specular reflections from these features may reflect again from nearby features, ultimately entering the imaging system and causing anomalous height measurements. The problem is common among solder joints that are often located near one another (figure 3).

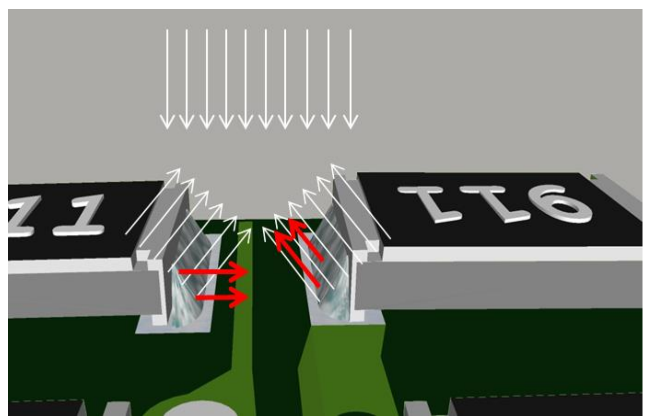

Figure 3. Multiple specular reflections among shiny features, such as solder joints, tinned leads and metal oscillators, can cause distortions in the fringe pattern and errors in the height measurements.

MEASUREMENT TIME

Perhaps more than any other industry, relentless competition drives electronics manufacturers to achieve high production rates and volumes in order to enhance profitability and realize economies of scale. Inspection is no exception. The number of images required to obtain 3D information is commonly an order of magnitude higher than the number needed for 2D inspection. Additional time is also required for image processing and specialized 3D inspection tasks. Some manufacturers feel hard-pressed to add 3D inspection when they are barely keeping up with production rates using 2D inspection. Some also find that adding 3D inspection pits process and quality engineers against production managers responsible for line utilization and production capacity. Any solution that reduces measurement time adds value as managers seek to balance the need for quality and reliability against the cost of inspection in terms of both capital investment and production throughput.

MRS SENSOR TECHNOLOGY

The MRS (multiple reflection suppression) sensor developed by CyberOptics Corporation was designed from the ground up for high-performance 3D inspection. Its combination of a unique optical architecture, proprietary image fusing and analysis algorithms, and multiple reflection suppression capability allows it to deliver metrology-grade accuracy at the speed of production.

Architecture

The sensor consists of a top-down digital fringe projector, coupled through an image splitter to a co-axial, top-down 2D inspection camera, and four oblique view cameras (figure 4) for fringe image capture. Since the projection is vertical, there are no areas shadowed from the fringe pattern, and because it is digital, the projector can create fringe patterns of any frequency and orientation. The four oblique cameras permit observation of the fringe pattern in all areas, including those near the bases of tall features (figure 5). Most importantly, the four oblique cameras can acquire fringe images simultaneously, providing a speed advantage of at least 4X over the sequential image acquisition that is required in designs using a single camera and obliquely mounted projectors.

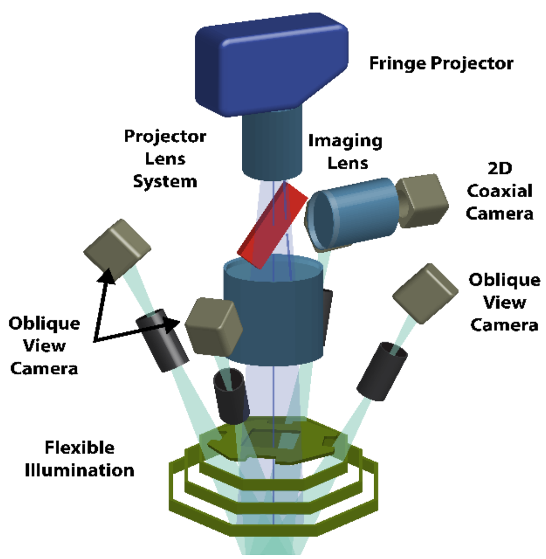

Figure 4. The MRS sensor is designed specifically for 3D measurements. It uses a single top-down fringe projector coupled through an image splitter to a top-down 2D camera, and four oblique-view fringe cameras. The digital projector can generate fringes at multiple frequencies and orientations. The ability of the four oblique cameras to capture images in parallel significantly reduces image acquisition time.

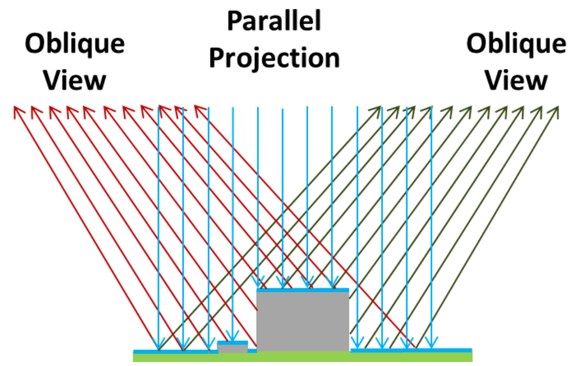

Figure 5. Vertical projection eliminates shadowing by tall components and the availability of 4 oblique cameras ensures viewing of the full fringe pattern, including areas close to tall features.

Image Fusing

Although a significant speed advantage accrues from the multiple camera architecture, the oblique viewing angle means that the X, Y coordinates corresponding to each camera pixel are also a function of Z height (figure 5). To successfully combine the images, the X, Y locations for every pixel must be precisely calibrated throughout the entire Z measurement range. This amounts essentially to calibrating the ray slope for every camera pixel. If the calibration is performed properly, the X, Y locations can be decoded unambiguously to micron-level accuracies. Sophisticated image fusing algorithms combine the calibrated images into a single 3D image of the inspected field of view. Other routines stitch adjacent fields together in a composite image that permits inspection of objects larger than a single field.

Multiple-Reflection Suppression

MRS technology suppresses height measurement errors induced by multiple reflections by careful analysis of the image data sets from multiple cameras and multiple fringe pattern frequencies and orientations. As described above, PSP systems use multiple pattern frequencies to provide sufficient Z measurement range and sensitivity. Multipath reflections are most troublesome with low frequency patterns where the period of the pattern is large relative to the size of the feature. In these cases, the multipath reflection can add coherently to the direct reflection (figure 6 left) and the potential error is influenced by the relative strengths of the direct reflection and the multi-path reflection. Figure 6 (right) illustrates the effect of a multipath reflection with a high frequency pattern. The multiple reflections add incoherently and may reduce fringe contrast but have little effect on phase.

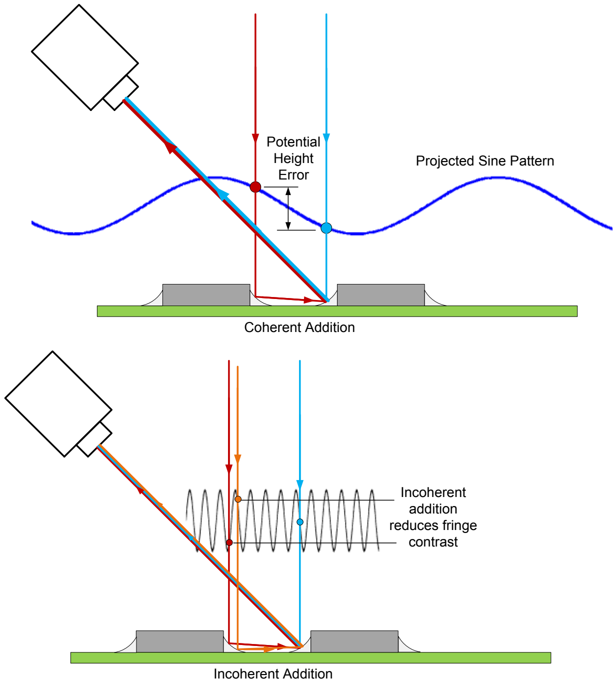

Figure 6. With a low frequency fringe pattern, the multipath reflection can add coherently to the direct reflection, causing errors in height measurement. With a high frequency pattern, the multipath reflection adds incoherently, reducing fringe contrast, but having little effect on phase.

Importantly, each oblique view camera will be affected by a multiple reflection differently and multiple heights will be reported by different cameras at the location of the reflection. These discrepancies can be exploited during analysis to identify areas of multiple reflections. By analyzing a rich data set including the fringe contrast, the effective surface reflectance, and calculated phase for each frequency pattern from each of the oblique view cameras at each of the identified locations, the system can effectively suppress the errors caused by multiple reflections.

EXTENDING APPLICATIONS

Surface Mount Technologies

Electronic assemblies using SMT typically have overall dimensions ranging from millimeters to tens of centimeters. They may be densely populated with active and passive components that constitute large, abrupt changes in overall topography. MRS-based inspection can measure up to $50cm^2$/sec and X,Y resolution of 7.2µm and Z resolution of 0.5µm, depending on the sensor option chosen, making it ideal for even the smallest (0201) SMT component. MRS eliminates troublesome multiple reflection errors, commonly generated by solder joints and other highly reflective materials. Detected detects may be reviewed online or offline. Training is straightforward, using multiple 3D images to setup, test, and verify. The system can measure and report tombstone and billboard angle, height, and lift, down to 1µm. It can also measure subtly lifted leads, down to 1µm. Three-dimensional solder measurements can detect excess or insufficient solder. Character recognition can identify components and record text to an external file.

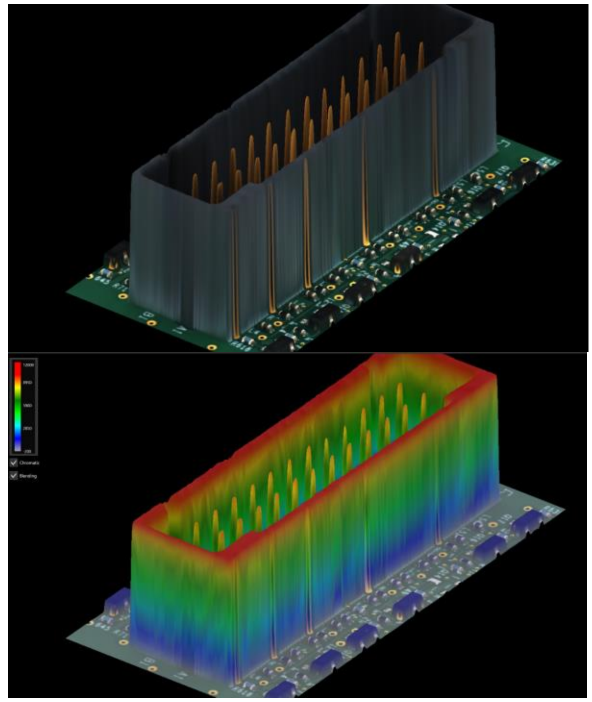
Figure 7. MRS sensors can inspect and measure various assemblies with small components shadowed by tall components and shiny surfaces with a high degree of accuracy.

MRS technology has proven effective for flux inspection, wire bond inspection, dye-attached applications, shiny flip chip packaging and various other challenging applications.

Solder Paste Inspection Applications

Solder paste inspection does not generally involve extreme topography but does bring its own set process specific requirements. 3D SPI adds important information not available from conventional 2D inspection, including height and volume. These allow detection of excess or insufficient paste. Bridging can be detected by bridge test, high area, or high volume. Configured for solder paste inspection, MRS-based measurements can inspect up to $50cm^2$/sec with X,Y resolution of 7.2µm and Z resolution of 0.5µm with a better gage R&R (repeatability and reproducibility.) Blob analysis can detect solder splash and contamination with 2D or 3D analysis, quantifying blob count, size and shape. SPI programming routines can import and convert Gerber, ODB++, Mycronic, JSON and other files. Cross section tools are available for manual or automatic analysis.

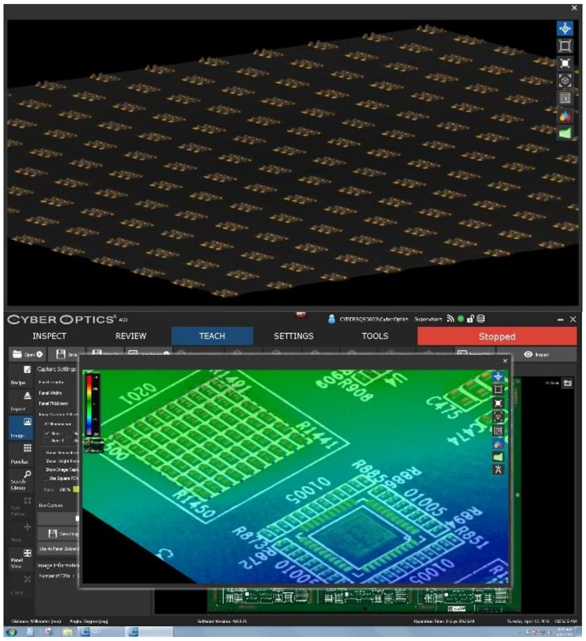

Figure 8 and 9. MRS for SPI is ideally suited to applications such as microelectronics, sub-100 micron solder paste deposits, very small LEDs - micro LEDs, mini LEDs, as well as paste printing onto chip products.

Semiconductor Applications
In the back-end of semiconductor fab processes, MRS sensor technology is being used for packaging inspection. It is also being utilized for other applications in the semiconductor environment. The ultra-high-resolution MRS sensor has been demonstrated as highly effective for IC packaging (Figure 10), wafer bump inspection (figure 11) and mid-end semiconductor applications where it delivers a high degree of accuracy and precision with a significant speed advantage.

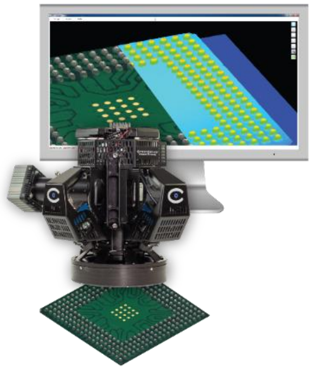

Figure 10. Semiconductor IC packaging inspection

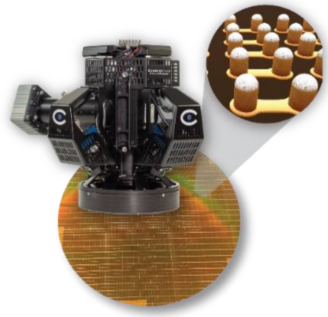

Figure 11. Semiconductor wafer bump inspection

Coordinate Measurement
Coordinate measurement machines typically use a contact probe to measure spatial coordinates at a series of points on the object surface, a very slow process that can take hours or days to complete. There are also optical CMMs which use a variety of optical processes. MRS measurements can capture every point on the surface in seconds. Two CMM configurations are available. The standard MRS sensor delivers X,Y resolution of 10µm, Z resolution of 1µm, minimum feature size of 10µm and maximum feature height of 24mm for up to 50cm^2/sec. An ultra-high resolution MRS sensor provides X, Y resolution of 7µm, Z resolution of 1µm, minimum feature size of 7µm and maximum feature height of 10mm for up to 15cm^2/sec. Accuracy and repeatability are both specified at 2µm. Specialized CMM software extracts dimensions from the measured surface in seconds and can export them in SPC-compatible format. Partial or full surfaces can be exported to STL/PLY models.

MRS-based measurements are well-suited for various challenging applications where it can deliver high-precision accuracy and speed advantages. For example, socket metrology (figure 12 and 13) where there are thousands of pins on a socket and before a CPU or a GPU is mounted, it is critical to ensure all of the pins are correct in heights, dimensions and angles before introducing the CPU or GPU. Today, typically what is being done is CMM inspection that involves sampling of pins. It takes hours, is not accurate enough and does not provide 100% inspection. With MRS sensor technology deployed for coordinate measurements, 100% inspection of thousands of pins can be accomplished in less than ten or fifteen seconds.

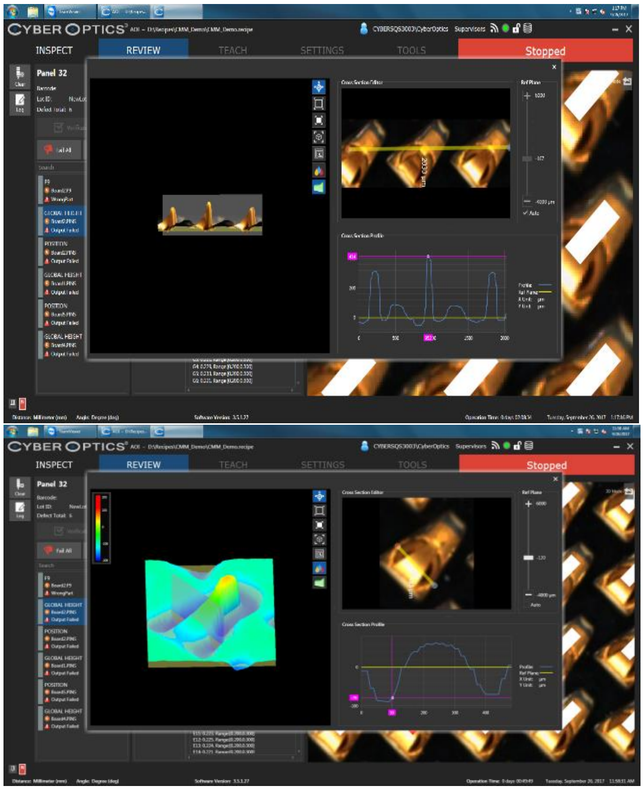

Figure 12 and 13. MRS sensor utilized for socket metrology application

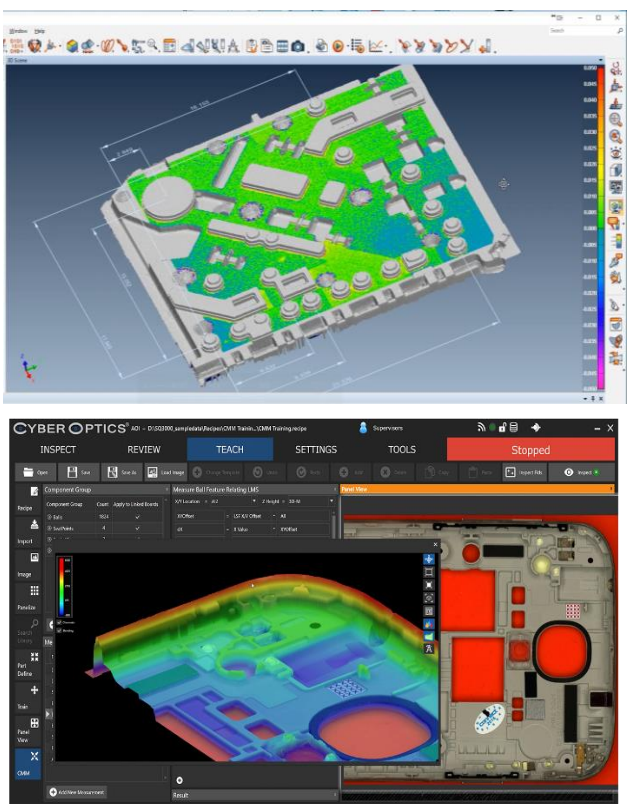

Figure 14 and 15. From cell phone cases and frames, various machined and molded parts, to socket metrology, MRS technology can acquire highly precise measurements at a much faster speed than alternate technologies.

CONCLUSION

MRS sensor technology delivers much needed improvements in 3D inspection applications. Its combination of a unique optical architecture, sophisticated image fusing algorithms and multiple reflection suppression addresses important limitations of more conventionally-designed systems. Its ability to provide metrology-grade results at the speed of production promises to further expand its use in challenging automated optical inspection of surface mounted assemblies, solder paste inspection and various coordinate measurement applications.