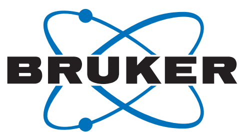
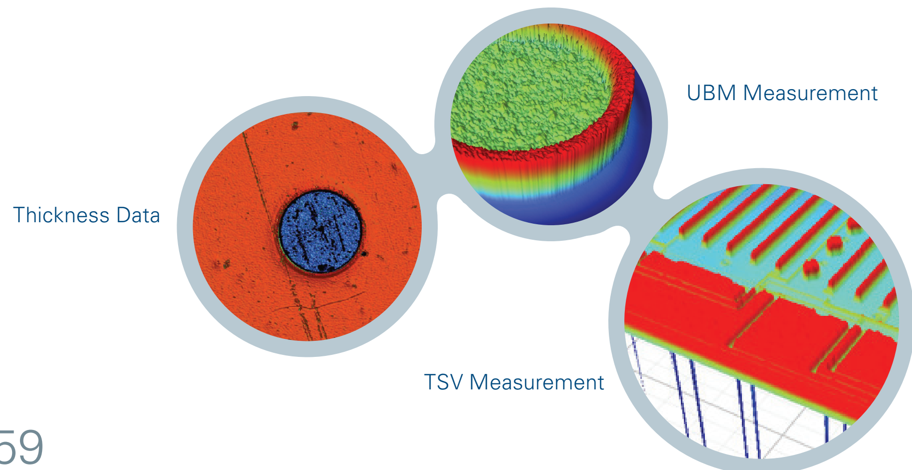




Application Note #559

Performing Comprehensive Wafer Inspection with Non-Contact 3D Optical Profiling

3D optical profiling provides many advantages over other measurement techniques for non-contact inspection of semiconductor packaging front-end process research and control. These advantages range from fully automated measurements and non-destructive inspection to custom analyses and fast measurement speeds. Today's most advanced optical profilers provide fast, accurate surface measurements to quantify a variety of properties about surfaces under inspection. These systems are used in engineering, research, and production process control around the world for an extremely wide range of markets, including precision machining, medical, microelectronics, MEMS, semiconductor, solar, data-storage, automotive, aerospace, and material science.

Measurement Advantages of White Light Interferometry

3D optical profiling allows industry-leading measurement speed while maintaining the same nanometer Z accuracy at all optical magnifications. This combination enables the measurement of a very wide range of surface parameters, such as surface roughness, step heights, pitch, curvature, lateral displacement and waviness, all in a single measurement and on nearly any surface. The coherence scanning interferometry measurement technique, also known as white light interferometry or WLI (as detailed in Figure 1), can quickly determine three-dimensional surface shape and surface finish over large lateral areas, up to 8 millimeters in a single measurement, and vertical heights up to 10 millimeters. To measure even larger lateral surface areas, a stitching algorithm can be applied that allows multiple lateral images to be taken and stitched into one image for analysis. These capabilities have led to many metrology applications to meet the evolving wafer manufacturing needs.

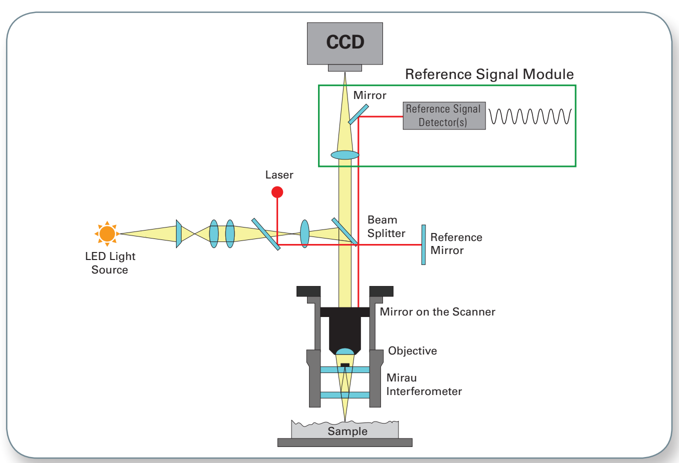
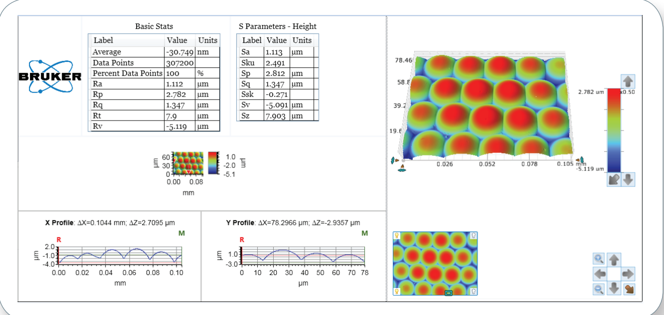


Figure 1. Basic white light interferometry with self-calibrating HeNe laser assembly.

3D Optical Metrology Analyses for Wafer Manufacturing

In general, wafer fabrication consists of sequential process steps to build components onto a silicon wafer, which eventually ends up as a complete functional device for a wide range of end products, from computer or memory chips to LEDs. As consumer electronics component sizes continue to decrease, there is a corresponding need for increased wafer metrology to refine and control the manufacturing of these complicated devices.

Below is a description of a few typical applications where 3D optical profiling is improving the manufacture and performance of wafers. All examples were performed with a ContourGT® 3D Optical Profiler utilizing Vision64® software (Bruker, San Jose, CA).



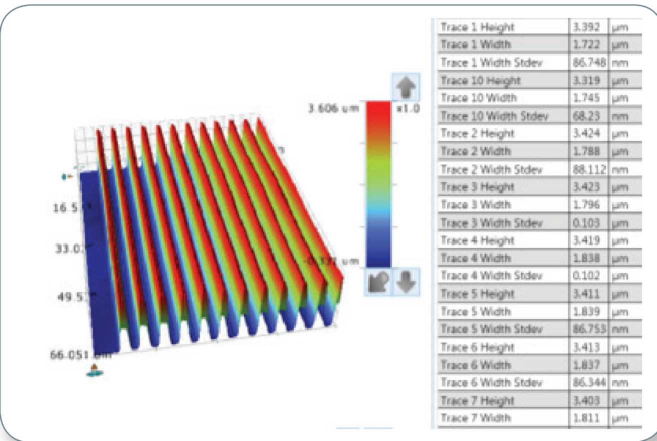
Label	Value	Units
Average	-30.749	nm
Data Points	307200	
Percent Data Points	100	%
Ra	1.112	µm
Rp	2.782	µm
Rq	1.347	µm
Rt	7.9	µm
Rv	-5.119	µm

Label	Value	Units
Sa	1.113	µm
Sku	2.491	
Sp	2.812	µm
Sq	1.347	µm
Ssk	-0.271	
Sv	-5.091	µm
Sz	7.903	µm

Figure 2. 3D optical profiling enables custom analyses of textured surfaces.

Trace Analysis

Most components designs utilize traces for electrical connectivity or device etching on the solid state device itself. Optical profiling can detect both vertical or horizontal lines and traces, as seen in Figure 3, where a Trace Analysis module automatically performed these measurements. The trace analysis was then able to report such parameters widths and heights for each trace, including the surface finish of traces and the spaces between them.



Trace 1 Height	3.392	µm
Trace 1 Width	1.722	µm
Trace 1 Width Stdev	86.748	nm
Trace 10 Height	3.319	µm
Trace 10 Width	1.745	µm
Trace 10 Width Stdev	68.23	nm
Trace 2 Height	3.424	µm
Trace 2 Width	1.788	µm
Trace 2 Width Stdev	88.112	nm
Trace 3 Height	3.423	µm
Trace 3 Width	1.796	µm
Trace 3 Width Stdev	0.103	µm
Trace 4 Height	3.419	µm
Trace 4 Width	1.838	µm
Trace 4 Width Stdev	0.102	µm
Trace 5 Height	3.411	µm
Trace 5 Width	1.839	µm
Trace 5 Width Stdev	86.753	nm
Trace 6 Height	3.413	µm
Trace 6 Width	1.837	µm
Trace 6 Width Stdev	86.344	nm
Trace 7 Height	3.403	µm
Trace 7 Width	1.811	µm

Figure 3. Trace analysis.

Multiple Region Analysis

Copper pillar, solder bumps, and through silicon via (TSV) are very critical manufacturing electrical and mechanical connections. A Multiple Region Analysis will automatically detect peaks, valleys, or levels from the terms removal reference plane (as seen in Figure 4). Once the regions of interest are automatically detected, different parameters of these features, such as surface finish, area, volume, height, depth, width, and pitch can be logged and controlled.

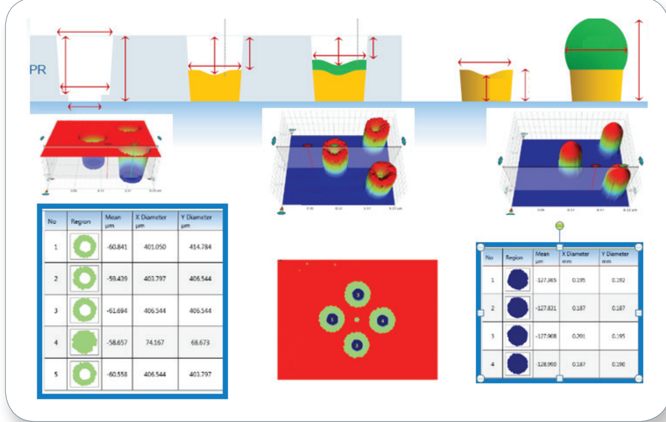
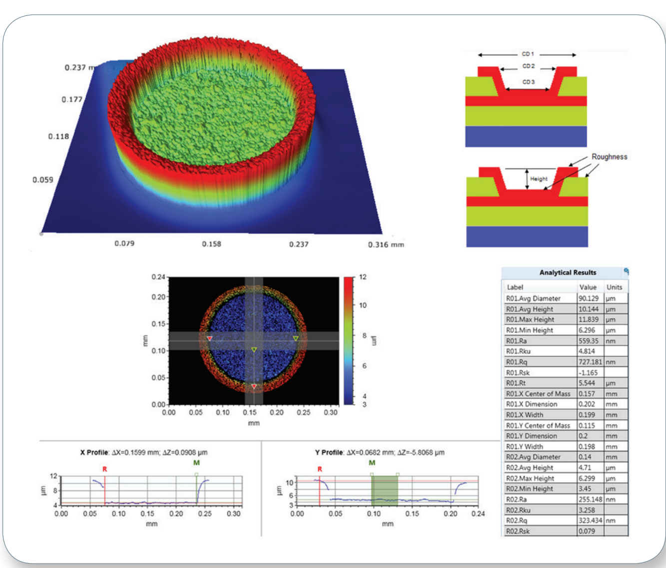


Figure 4. Multiple region analysis.

SureVision Analysis

Similar to multiple region analysis, a SureVision Analysis has the additional ability to pattern match to a feature in the field of view, align that feature or features to a template, then perform image masking, region modification, and analysis of up to 100 distinct regions in an image. This analysis option is very useful for under-bump metallization (UBM), which is commonly used for electrical or mechanical connection from the silicon die to a solder bump, as shown in Figure 5.



Label	Value	Units
R01.Avg Diameter	90.129	µm
R01.Avg Height	10.144	µm
R01.Max Height	11.839	µm
R01.Min Height	6.296	µm
R01.Ra	559.35	nm
R01.Rku	4.814	
R01.Rq	727.181	nm
R01.Rsk	-1.165	
R01.Rt	5.544	µm
R01.X Center of Mass	0.157	mm
R01.X Dimension	0.202	mm
R01.X Width	0.199	mm
R01.Y Center of Mass	0.115	mm
R01.Y Dimension	0.2	mm
R01.Y Width	0.198	mm
R02.Avg Diameter	0.14	mm
R02.Avg Height	4.71	µm
R02.Max Height	6.299	µm
R02.Min Height	3.45	µm
R02.Ra	255.148	nm
R02.Rku	3.258	
R02.Rq	323.434	nm
R02.Rsk	0.079	

Figure 5. UBM measurement utilizing SureVision analysis.

Subtract Images

Profilers with advanced software capability can subtract single or stitched images from within a wafer or from wafer to wafer. In this analysis, a reference image or stitched image is first captured, then subtracted from sequential measurements of a similar area. The subtraction software can remove pre-image waviness and form, align images run to run, and apply filtering as needed to the pre- and post-subtraction image. This is very helpful for monitoring height deviations from wafer to growing or lapping steps (as seen in Figure 6).

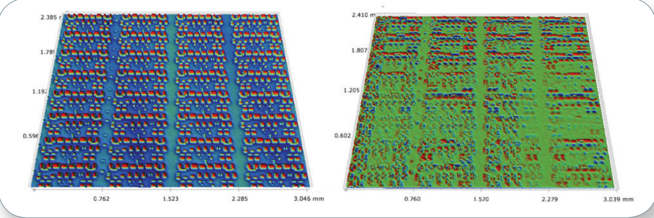


Figure 6. Left: reference image (Z scaled ±70nm), and Right: subtracted image (Z scaled ±0.8nm).

Thick and Thin Film Analysis

Films and coatings are necessary for insulation or isolation of key components within a device. Thick and Thin Film software can analyze metallic dielectrical films and coating material automatically. Film thickness can also be measured, depending on its index of refraction. The film software has the ability to detect modulation peaks on top and bottom of the coating to calculate the thickness of that film, as is shown in the theory example in Figure 7A.

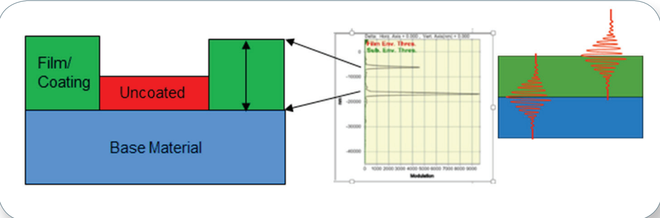
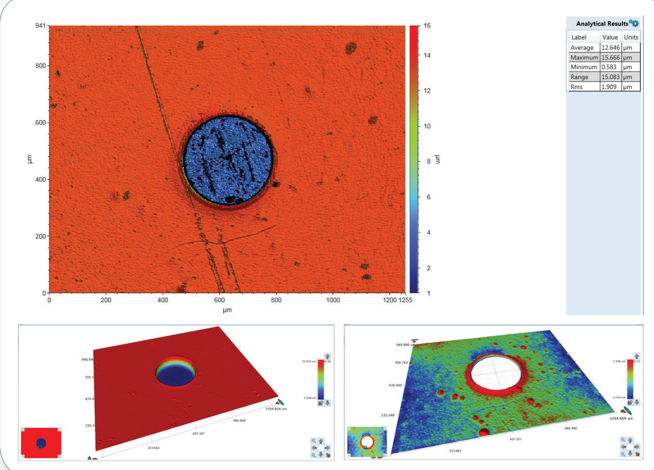


Figure 7A. Film theory.



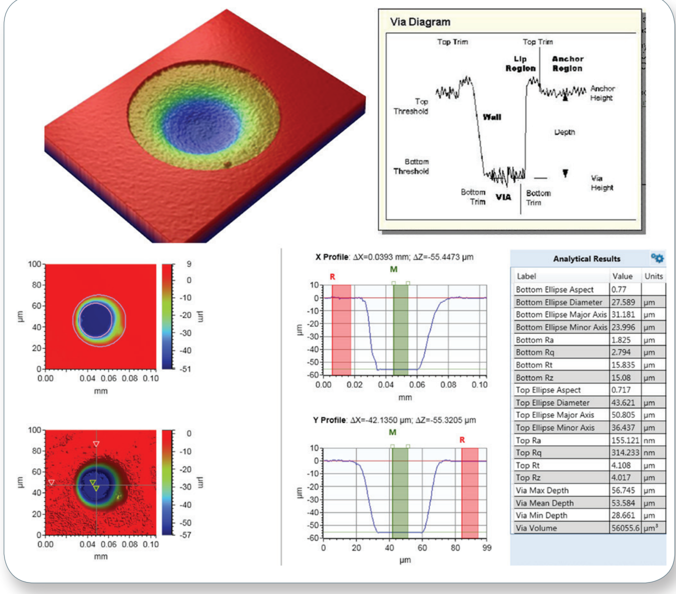
Label	Value	Units
Average	12.646	µm
Maximum	15.666	µm
Minimum	0.583	µm
Range	15.083	µm
Rms	1.909	µm

Figure 7B. Film measurement analysis incorporating top and bottom surfaces.

Once the data is captured, the algorithm can report minimum and maximum thickness along with the surface finish of the top or bottom surfaces, as is shown in Figure 7B. In this example, the film analysis software can also calculate the uncoated pad height in reference to the base material under the coating.

Via Analyses

Advanced 3D optical systems also provide custom software algorithms for unique process analyses. Via Analysis finds the via and calculates a range of statistics, including depth, top and bottom diameters, and roughness of the anchor and via regions. A Glass Via Analysis calculates the via top and bottom diameter and depth, including the height of the glass fiber reinforcement layer using a special measurement mode algorithm. A Solder Resist Analysis finds a hole in the solder resist and calculates the thickness of the solder resist layer, top opening diameter, bottom diameter, and tail diameter and depth (as seen in Figure 8).



Label	Value	Units
Bottom Ellipse Aspect	0.77	
Bottom Ellipse Diameter	27.589	µm
Bottom Ellipse Major Axis	31.181	µm
Bottom Ellipse Minor Axis	23.996	µm
Bottom Ra	1.825	µm
Bottom Rq	2.794	µm
Bottom Rt	15.835	µm
Bottom Rz	15.08	µm
Top Ellipse Aspect	0.717	
Top Ellipse Diameter	43.621	µm
Top Ellipse Major Axis	50.805	µm
Top Ellipse Minor Axis	36.437	µm
Top Ra	155.121	nm
Top Rq	314.233	nm
Top Rt	4.108	µm
Top Rz	4.017	µm
Via Max Depth	56.745	µm
Via Mean Depth	53.584	µm
Via Min Depth	28.661	µm
Via Volume	56055.6	µm³

Figure 8. Via and glass via analysis.

Overlay (Registration) Analysis

Basic and advanced Overlay (Registration) Analysis is used to analyze and characterize “feature-in-feature” geometries to track any relative shift of one surface with respect to the other surface, as seen for basic registry features analysis in Figure 9. More advanced registry and laser-inscribed

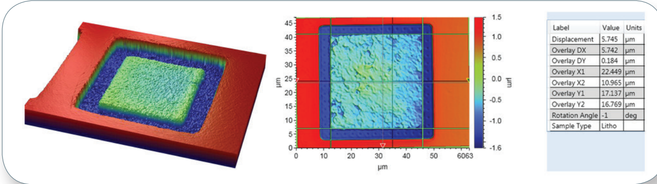


Figure 9. Basic registration features and analysis results.

features can also be analyzed simply by selecting the proper analysis checkbox required for the analysis.

Through Silicon Via (TSV) Measurements

For more challenging TSV measurements, certain measurement objective and field-of-view combinations can be used to measure the aspect ratios of "depth to width" of around 10 to 1. These TSV measurements are very important for wafer level packaging in improving areal density for stacked components (see Figure 10).

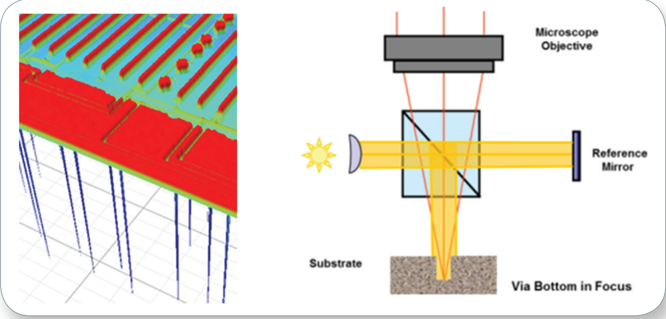


Figure 10. TSV measurement and objective schematic.

Measurement Automation and Wafer Handling

Advanced automation software is what often separates whether a system is truly useful for wafer manufacturing or not. Over the years, Bruker has worked with semi industry leaders to develop multiple stage-automation modes. XY Scatter mode allows the user to place multiple single-point measurement locations randomly throughout the wafer measurement area. XY Grid mode automatically creates a grid of known die size in a given XY pattern of columns and rows. Within each measurement grid die location, multiple measurements can be made (see Figure 11). Lastly, XY MultiGrid mode is similar to XY Grid, but the measurement grid die locations can be randomly placed around the wafer. In addition, XY MultiGrid has the ability to add fiducial alignment points for each measurement grid location while allowing each grid location to perform unique measurements from the other. For each of the stage automations, a separate Vision recipe can be configured for each measurement location, including stitching multiple images together. Each of these measurement locations can also have a unique Z location that the profiler will automatically move to, significantly reducing measurement times. All automation types can also include alignment points that can be fully automated using Cognex pattern-matching capability. In addition to stage automation, Vision64 allows full automation of

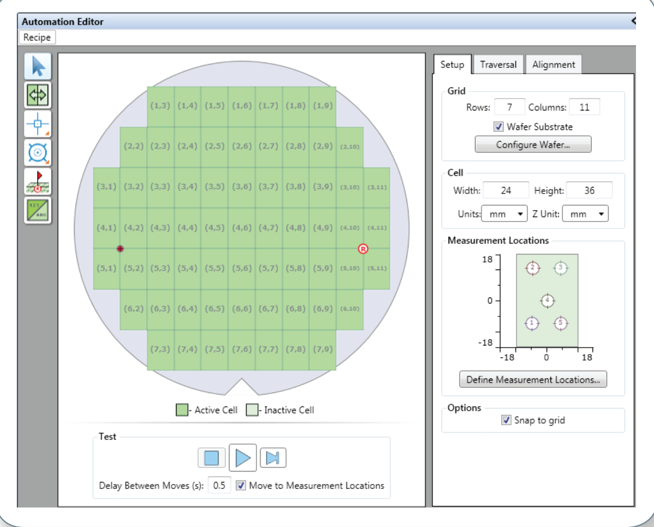


Figure 11. Example of XY Grid wafer automation.

Autofocus, Auto Intensity, and Auto Tip/Tilt. Automatic feature centering in the field of view before measurement using pattern matching improves measurement robustness and repeatability.

Wafers can either be manually loaded onto the profiler stage for analysis, or can be configured with a wafer handler and environmental enclosure, as is shown in Figure 12. Not only does this enable unattended measurement of multiple wafers with integrated FOUP, but also to achieve class 2 type mini environments to meet all wafer manufacturing factory needs.

Figure 12. Bruker's ContourGT-X ARM for wafer manufacturing.

Conclusion

For wafer manufacturing, such as wafer-level packaging, flip-chip packaging, or TSV technology, an advanced 3D optical profiler can give engineers, process designers, researchers, and quality control professionals a significantly improved means of characterizing features for shape, surface finish, and overall functionality. 3D optical profilers are well established throughout a wide range of industries, from medical implants to aerospace components, and

have been shown to outperform other measurement techniques in overall resolution, repeatability, accuracy, and speed. Bruker's 3D optical profilers utilize industry-leading analysis and automation software, and are production-floor ready, providing a preferred metrology option for research, quality inspection, and process control. With dual-LED light sources and sophisticated algorithms, these systems are capable of making surface measurements with any reflectivity. Correlation to stylus measurement systems can be achieved with upfront knowledge of the surfaces being measured and the setup of the stylus tool. The addition of the 3D surface S parameters greatly extends the degree to which surface analysis can uniquely characterize surface shape and functionality. Bruker's 3D optical profilers offer the most advanced improvement in measured data for the wafer industry.

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