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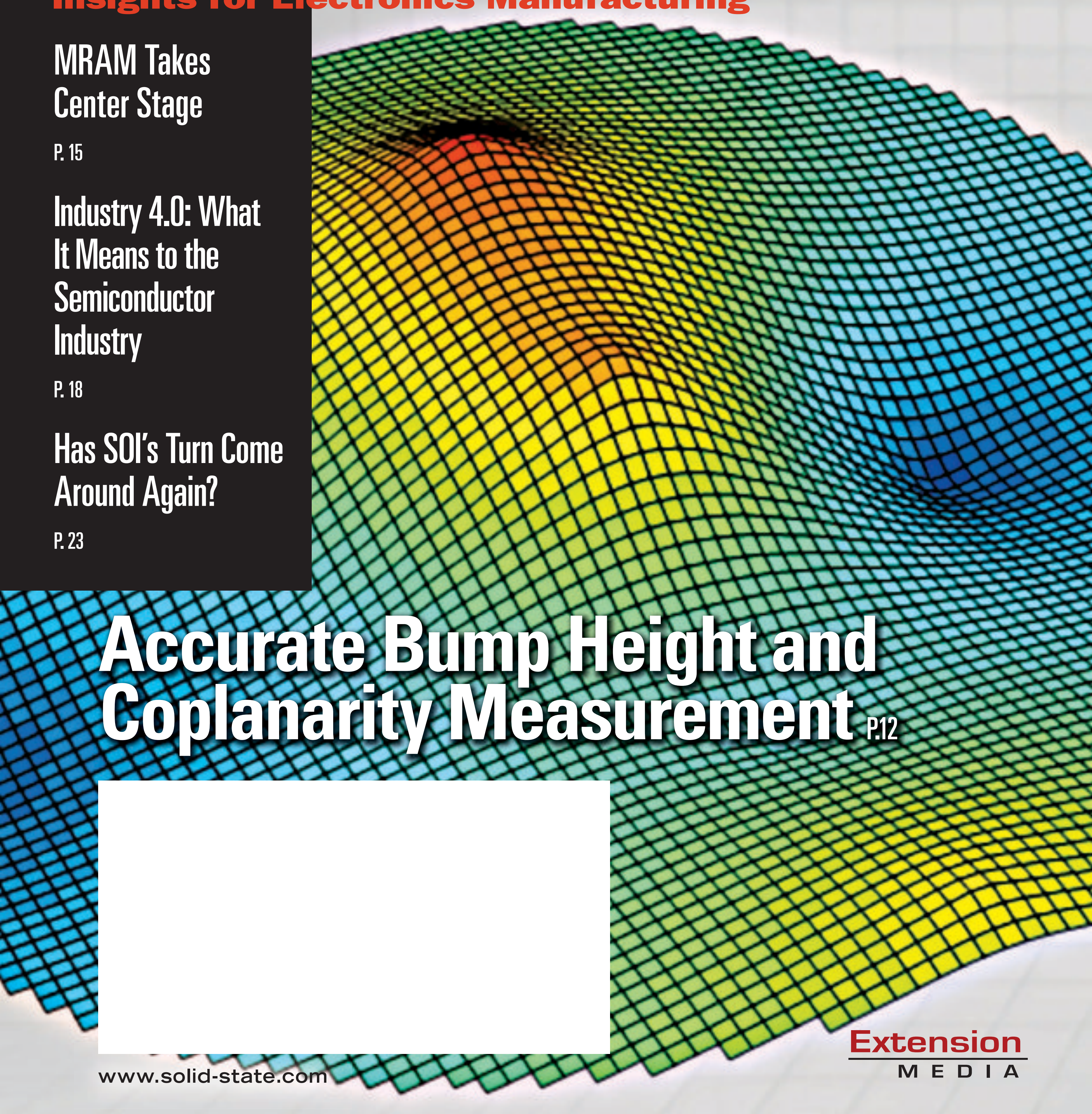

Accurate Bump Height and Coplanarity Measurement

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Improving the accuracy of bump height and coplanarity measurement

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A new approach to bump height measurements uses an interferometric technique to accurately measure bump height and PL thickness

Solder bumps are used to connect die to various package components in advanced packaging processes. Bump height and coplanarity are critical to ensuring reliable connections. A bump that is not high enough will not connect, while one that is too tall may prevent connection by neighboring bumps or even damage an electrical tester's probing card. Measuring true bump height quickly and accurately has proven to be a challenge.

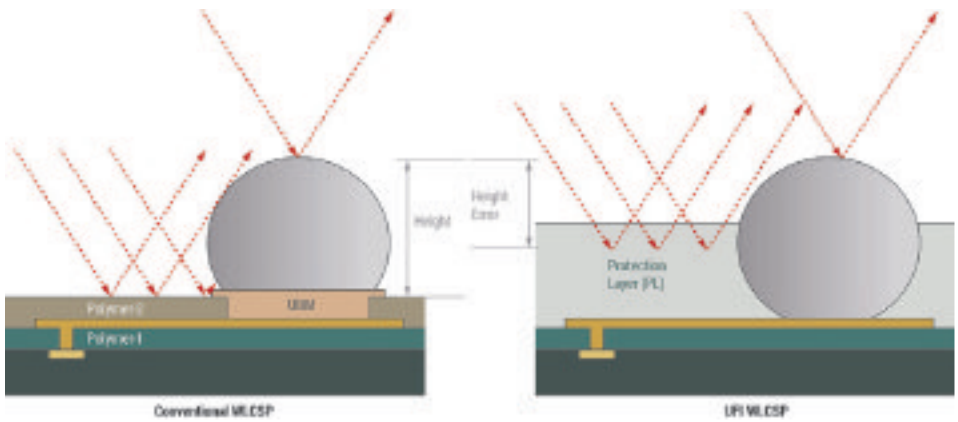

FIGURE 1. UFI processes use a protective layer that is semitransparent and varies in thickness. It introduces significant error in bump height/coplanarity measurements.

The measurement has become more challenging with the introduction of processes that eliminate the under bump metal (UBM) layer, used in conventional wafer-level chip scale packages (WLCSP) to improve the bond between the solder ball and the copper redirect pad. Wafer-level chip scale packages have been limited in chip size and ball pitch by the fragility of the solder ball-redirect connection. The intermetallic compounds (IMC) formed there are mechanically weak and subject to fracture under the thermally induced mechanical stress generated by the different expansion coefficients of the silicon die and the package substrate. In UBM-free integration (UFI), the UBM is eliminated and the solder connects directly to the redirect pad. A thick polymer protection layer (PL), usually polyimide (PI) or polybenzoxazole (PBO), helps secure the solder in place and provides stress relief

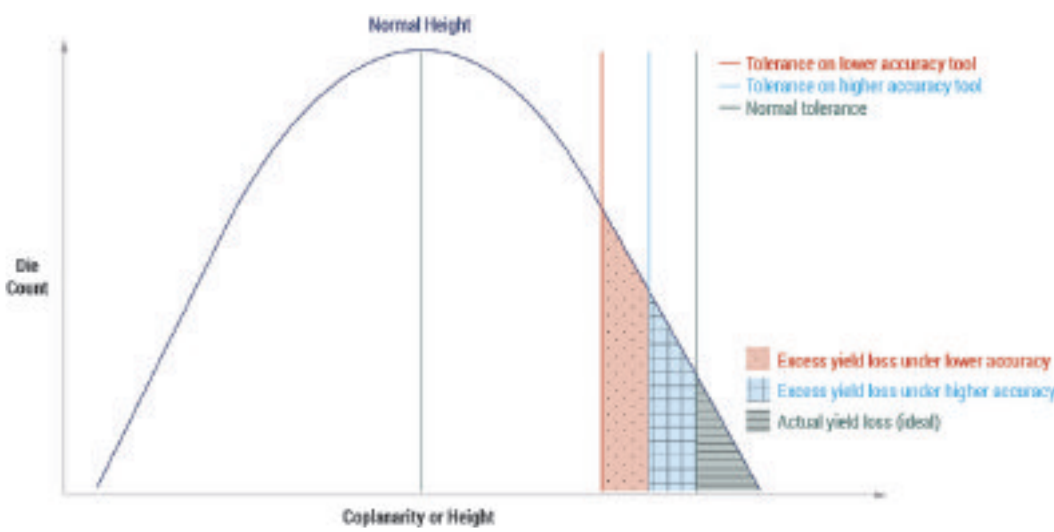

FIGURE 2. Inaccurate measurements force process engineers to set a needlessly low tolerance to ensure that true bump height does not fall outside the process window.

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between the chip and the substrate. In addition to eliminating the IMC as a source of failure, UFI reduces package cost and cycle time by eliminating layers, and allows a significant reduction in final package thickness. Unfortunately, the PL layer, which is semitransparent and varies in thickness, introduces errors in bump height measurements (**FIGURE 1**).

Many technologies are available that can accurately measure bump height but are too slow to inspect the millions of bumps on a full wafer. Laser triangulation (LT) is fast enough but has difficulty accurately measuring the top surface of the protection layer (PL), which defines the bottom of the bump height measurement. LT measurements consistently locate that surface somewhere within the PL thickness, returning a bump height measurement that is too high. Manufacturers have worked around this problem by subtracting an offset value from the LT measurement. But the correct offset is a function of PL thickness, which can vary across the wafer and from wafer to wafer, thus limiting the accuracy and repeatability of the bump height measurement. To accommodate the deficiencies of the measurement, process engineers must lower the tolerance limit on the process, with the net result being an unnecessary yield loss as bad measurements reject good wafers (**FIGURE 2**). In addition, inaccurate measurements create unnecessary review work as operators revisit inaccurately measured bumps.

Calibrated measurements

A new approach to bump height measurements uses an interferometric technique to accurately measure bump height and PL thickness at representative locations across the wafer, then calculates offsets to apply to LT measurements in a subsequent, high speed, 100% inspection (**FIGURE 3**).

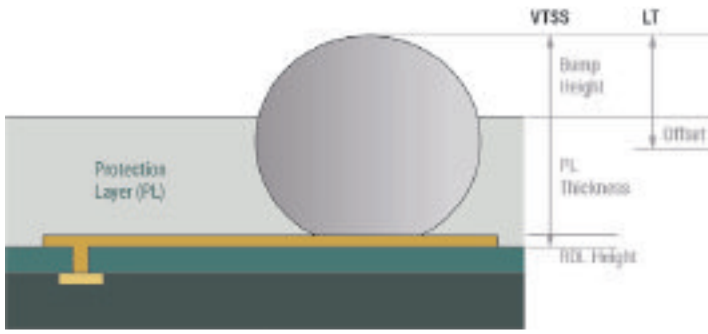

FIGURE 3. The VTSS sensor has the required accuracy but is not fast enough for 100% inspection. However, it can be used to calibrate faster LT measurements.

A visible thickness and shape sensor (VTSS) combines the principles of interferometry and reflectometry to accurately detect the top of the bump, the top of the PL and the bottom of the PL. It can also measure step heights at the edges of opaque materials underlying a transparent layer. The VTSS is capable of nanometer scale accuracy and repeatability. It is particularly strong, relative to other measurement technologies, such as chromatic confocal (CC), in its ability to measure thin films. As films become thin, the intensity peaks returned by CC measurements begin to overlap, making it difficult to distinguish top and bottom. PL films are typically in the 3-6µm range, too thin for accurate CC measurements. In contrast, the peaks returned by VTSS are sharp and easily distinguished on films of this thickness (**FIGURE 4**).

Results

FIGURE 5 compares VTSS and LT measurements of bump height. The LT measurements report a bump height consistently higher than the VTSS measurements. The data for each representative bump (x-axis) is an average of ten repeat measurements. The difference between the two measurements in this set of data is nearly constant with an average offset of 2.123µm.

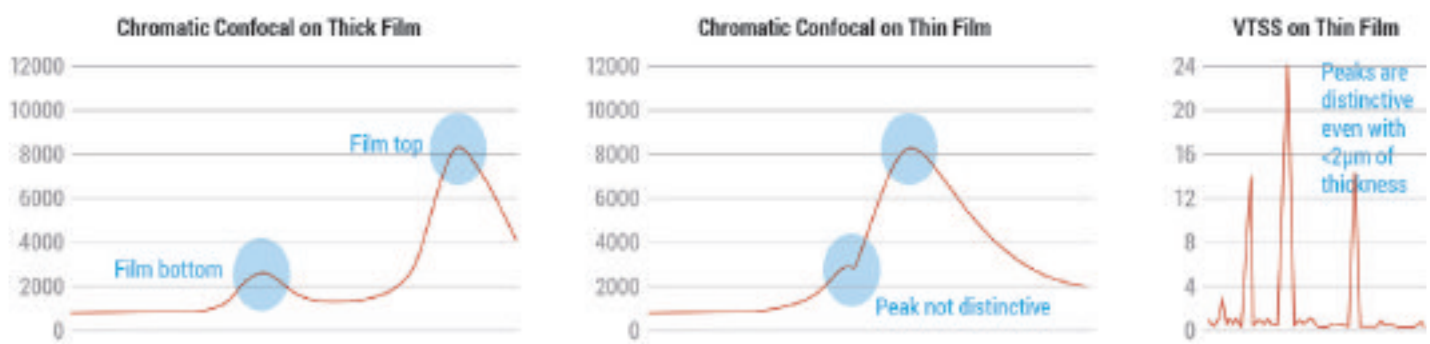

FIGURE 4. Other technologies, such as chromatic confocal measurements, provide accurate measurements of thick films (left - 800µm thick film), but have difficulty as the film becomes thin and the signal peaks from the top and bottom surfaces begin to overlap. On the right, VTSS clearly resolves top and bottom surface signals from a 2µm thick film. PL films are typically 3µm – 6µm thick.

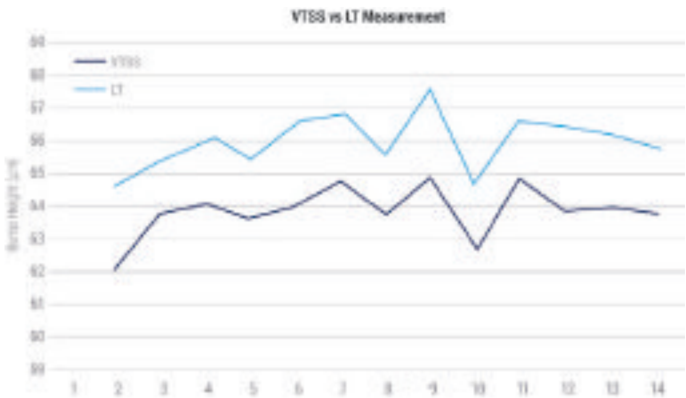

FIGURE 5. A comparison of VTSS and LT bump height measurements shows a consistent offset. In this example the LT measurement exceeds the more accurate VTSS measurement by an average of 2.123µm.

FIGURE 6 shows the results of a repeatability study in which bump heights were measured for ~12,000 bumps from 13 dies across a wafer. The accompanying wafer map shows the locations of the sampled die. 3D height inspection was performed using 5µm spot sensors. The repeatability test was dynamic, meaning the wafer was unloaded and reloaded after each run.

FIGURES 7 and **8** show the results of whole wafer scans reporting the corrected LT measurements of bump height and coplanarity for all bumps on the wafer. As shown in **FIGURE 9**, the operator can drill down to find results for individual bumps. The pass/fail criteria limit is smaller than the offset provided by the VTSS, meaning that without the pre-measurement the majority of the bumps would be incorrectly reported as failed.

Conclusions

Accurate bump height and coplanarity measurements are essential to minimize unnecessary yield losses of good but incorrectly measured die and to reduce time spent reviewing incorrectly flagged good die. Laser triangulation is fast enough for 100% inspection but shows consistent measurement errors. This problem is further exacerbated as bump heights shrink and the relative height ratio of the the PL film increases. VTSS measurements, though too slow for 100% measurements, can be used to accurately calibrate LT measurements. In the data presented here the VTSS data demonstrated a repeatability of approximately 0.05µm (average 3 sigma), and the LT measurements a repeatability of approximately 0.362µm (average 3 sigma). Combining the two sensor technologies provides fast, accurate measurements, eliminates unnecessary yield loss and reduces the time spent needlessly reviewing good die. ◈

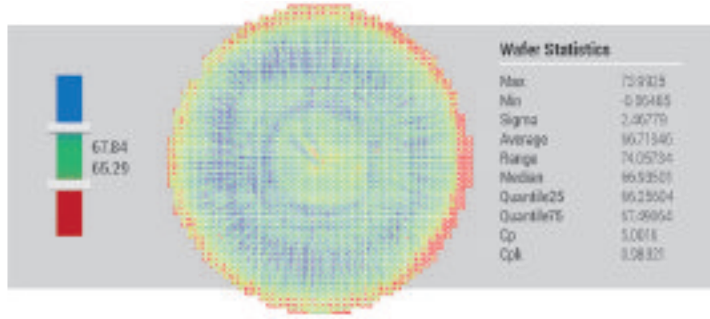

FIGURE 7. Corrected LT bump height measurements from a full wafer 100% inspection.

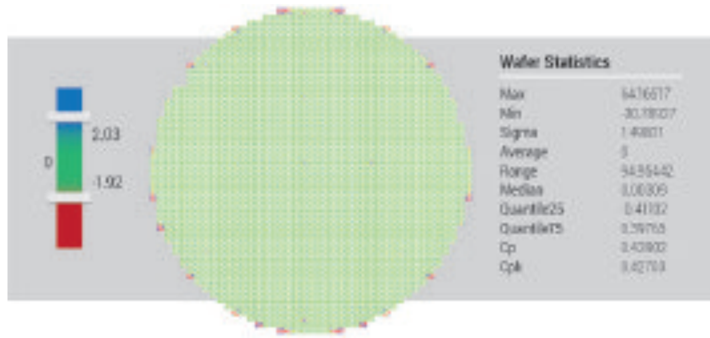

FIGURE 8. Corrected LT coplanarity measurements from a full wafer 100% inspection.

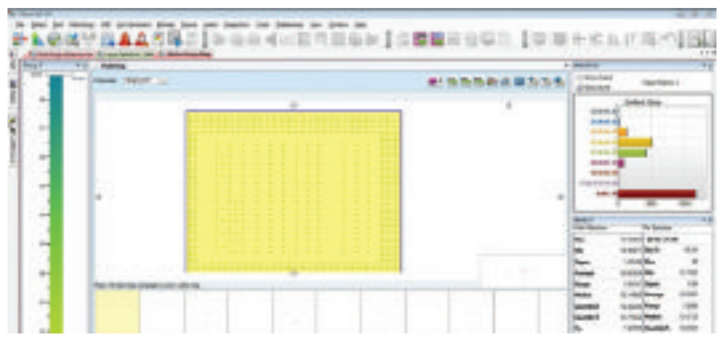

FIGURE 9. The operator can recall results for individual bump measurements.

5µm Sensor	Height	Std	3Std
Average	63.60042	0.120691	0.362072
Minimum	59.73904	0.031298	0.093893
Maximum	66.28025	0.429421	1.288262

5µm Sensor	Coplanarity	Std	3Std
Average	-1.29E-09	0.115457	0.346372
Minimum	-1.96661	0.02008	0.060239
Maximum	2.095955	0.455163	1.365488

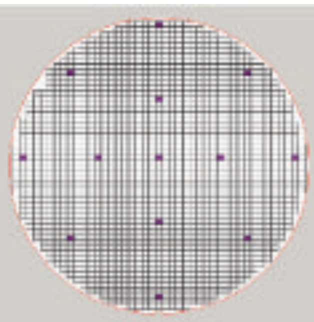

FIGURE 6. This repeatability study measured ~12,000 bumps on 13 die distributed at representative locations across the wafer.