Wafer Bumping Stenciling Techniques with Solder Paste

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Abstract
Wafer bumping using thin electroformed nickel stencils with ultra fine powder solder paste continues to gain popularity as a cost effective alternative to ball drop and electroplated technologies. This paper describes the results of an extensive study involving 120,000 bumps conducted using eutectic and lead free water soluble wafer bumping solder pastes to achieve high bump height to pitch ratios down to 150 micron pitch. The printing process, stencil designs and bump measurement methods are described in full detail. Additionally, results from the most recent work on a 200mm test wafer with pitches down to 100 microns defining the effect of various squeegee materials on bump height for lead free solder pastes is discussed. Lead free wafer bumping solder pastes with powder types 5, 6, 7 & 8 are also compared and contrasted for their bump height capability to bump pitches below 200 microns. In addition to the material deposition tools and techniques, the reflow and cleaning processes are described. Finally, preliminary results on UBM pad size effects on bump height are presented.

Introduction
Wafer bumping using solder paste can be done by two different processes. One process is proprietary and involves printing directly onto a wafer with dry film over the bump side of the wafer. Blind holes in the dry film are formed photo lithographically with the UBM (Under Bump Metallization) at the base of the hole. This process is capable of producing high height to pitch ratios at pitches at or below 70µ[1]. Fine powder solder paste is printed multiple times to completely fill the blind dry film hole and reflowed in an inert atmosphere. The dry film resist is then stripped off of the wafer, the bumps are re-fluxed and reflowed a second time to form their final truncated spherical shape.

The other process uses a thin typically electroformed nickel stencil to print directly onto the wafer surface. This paper will exclusively discuss this process. Fine powder solder paste is usually overprinted over the UBM, reflowed in an inert atmosphere and cleaned. For full grid arrays round or square apertures are used, for staggered or perimeter arrays ovals or rectangular apertures can be used to increase the bump height to pitch ratio. Current pitches that are capable of being bumped with this process are limited to 150 micron (5.9 mils) pitch and greater although some sub 100 micron pitch experimental work has been published[2]. Stencil fab technology is predominantly electroformed nickel in the 1-3 mil thickness range. Electroformed nickel stencils are "grown" or electroplated onto a mandrel with apertures defined with photo imaged plating resist. After extraction from the mandrel this pure nickel stencil is mounted on a screen frame via a mesh that places the stencil foil in tension. This stencil technology offers the best aperture dimensional accuracy. The low surface energy and smooth aperture wall surface finish that are offered by this technology are required for good paste release from the apertures during printing. For this reason electroformed (*E-Fab*) stencils were exclusively used in this study. Final bump formation is achieved by reflow in a convection oven in low O_2 ppm nitrogen, typically in the 12-20 ppm range. Post reflow flux residues are removed by cleaning with chemistries matched to the flux formulation. Most paste formulations for wafer bumping are water soluble to facilitate flux removal with simple aqueous cleaners. Solder powders are typically type 5 (15-25µ) and type 6 (5-15µ) and available in a variety of alloys to suit the application. New finer powders (types 7 and 8) have now become commercialized and will be discussed later in this paper. Wafer bumping with printed solder paste can utilize standard SMT printing tools with a few additional process elements not typically common in standard SMT printing. Research on this subject suggests the requirement for a print gap or "off contact" printing for very high aperture density wafers[3], although all printing on the various coupons in this paper were done with contact printing due to their relatively low overall bump density.

Early Test Challenges
In the development of a wafer bumping benchmark program, the test coupon, stencil and measurement equipment were pushed beyond their limits. For the test coupon, at 150µ pitch using a standard FR4 laminate thickness and ½ oz copper, the pads were bridged at etch. The solution for the next generation coupon was to halve the laminate thickness and use ¼ oz copper. For the first stencil, square apertures were destroyed at the mandrel removal step due to very thin inter-aperture webbing (45µ) as in Figure 1. From this experience a guideline was generated that the stencil webbing (distance between aperture edges) must be ≥1.2 X stencil thickness for square apertures and ≥0.8 X for round apertures.

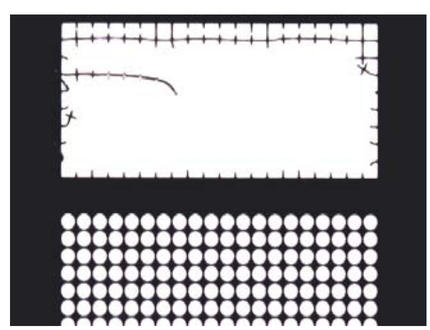
Figure 1 Aperture Webbing

Of equal challenge to forming bumps is measuring them accurately. One of the difficulties encountered in the first study was measuring the bump height with laser triangulation. With this sensor technology, a point of light emitted from a laser diode passes through an objective, reflects off the surface to be measured and a portion of this reflection excites a detector array yielding an index of height. If the portion of the reflection is occluded then no height data is returned from the sensor. The surface must also be sufficiently reflective. For PCB laminate this can be problematic in that the material has considerable spectral absorption properties. On the other hand, if the material is too reflective, as in a polished wafer, then no light is scattered and sent to the sensor, again no height data is returned from the sensor. For these reasons a new measurement technology was required for this study. For this new study a Confocal Point Sensor was used to capture bump heights. The advantage of the confocal principle is its ability to measure surface structures independent of the reflectivity of surface materials and is very important for wafer bump structures; because it does not produce artifacts at sharp edges like holes or interrupted areas that are common with laser triangulation. A laser diode illuminates a small pinhole which is focused via a high precision movable objective lens onto the surface of the specimen. Only when the illuminated spot of the surface is exactly in focus does the detector get a signal. The signal processing software assesses the signal intensity and the position of the lens which is equivalent to the relative Z coordinate of the surface point measured. If the illuminated surface point is out of focus (left and right drawings in Figure 2) then there is no signal and therefore no surface point will be detected. The design of the sensor requires high precision optics, optical alignment and accurate fast movement of the objective lens without additional optical aberration.

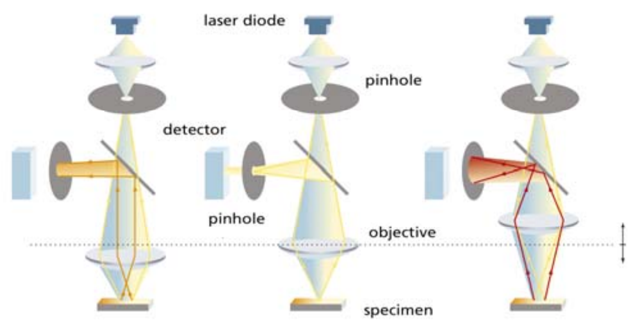

Figure 2 Confocal Point Sensor

Determining Maximum Bump Height to Pitch Ratio

Since the goal of this study was to push various solder paste formulations to yield the highest H/P ratio, stencil apertures had to be sized to the maximum. This meant that to get the largest apertures, the stencil webbing needed to be pushed to the minimum possible to get a usable stencil. A 50µ thick stencil was designed that was intended to push the solder paste to bridging, which occurs when two printed deposits are too close to each other, and to print release failures when the Print Area Ratio (PAR) is too low. PAR is the area under the aperture divided by the aperture wall area. The aperture design objectives were:

1. Test both square and round apertures.
2. Largest aperture will have minimum stencil web width.
3. Smallest aperture will be ½ the UBM pitch.

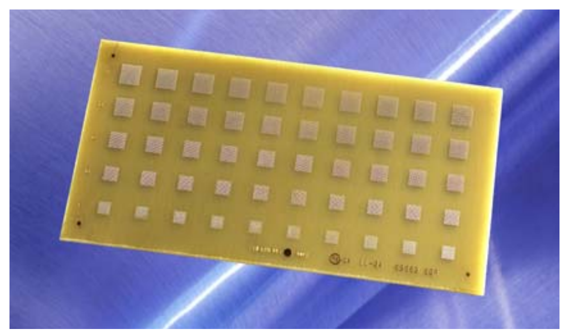
Figure 3 H/P Ratio Test Coupon

Table 1 B/H Study Coupon Aperture Dimensions

Pitch	Square	Square	Square	Square	Square	Round	Round	Round	Round	Round
250	190	174	158	141	125	125	146	168	189	210
225	165	152	139	126	113	113	131	149	167	185
200	140	130	120	110	100	100	115	130	145	160
175	115	108	101	94	88	88	99	111	123	135
150	90	86	83	79	75	75	84	93	101	110
Pitch	PAR	PAR	PAR	PAR	PAR	PAR	PAR	PAR	PAR	PAR
250	0.94	0.86	0.78	0.70	0.62	0.62	0.72	0.82	0.93	1.03
225	0.81	0.75	0.68	0.62	0.55	0.55	0.64	0.73	0.82	0.91
200	0.69	0.64	0.59	0.54	0.49	0.49	0.57	0.64	0.71	0.79
175	0.57	0.53	0.50	0.46	0.43	0.43	0.49	0.55	0.61	0.66
150	0.44	0.42	0.41	0.39	0.37	0.37	0.41	0.46	0.50	0.54

The stencil design essentially yielded 50 aperture design experiments per coupon with 20,000 bumps on each coupon as can be seen in Figure 3. The top row is 250µ pitch, second row is 225µ pitch, third row is 200µ pitch, fourth row is 175µ pitch and the bottom row is 150µ pitch. Each grid is a 20 X 20 array of bumps. Table 1 shows the aperture design details as well as PAR calculations. PAR figures are color coded, yellow (0.6 - 0.66), orange (0.5 - 0.6), red (0.4 - 0.5), magenta (0.3 - 0.4) and green is any PAR over 0.66. All dimensions in the table are in microns. Stencil release problems are not expected if the PAR $\geq$ 0.66.

With the coupon and stencil aperture designs established and the measurement method selected the test matrix needs to be identified. Focusing on the goal of determining the maximum H/P ratio for the F510 water soluble wafer bumping flux formulation, two main formulation variables surfaced as potentially having an effect. Both powder size (type 5 and type 6) and alloy (Sn/Pb and Sn/Ag/Cu) were studied. Two stencils were used (45µ and 53µ) with the majority of the data being measured on the 53µ stencil due to cost and time constraints. There were a total of 120,000 bumps measured comprising 300 individual experiments. Each experiment was a grid of 400 bumps.

Four coupons were printed for each paste-stencil combination. Coupons were contact printed at 25mm/s with a medium durometer polymer squeegee. All coupons were reflowed in nitrogen after a 2 hour purge. The reflow O2 level stabilized at 12 – 20 ppm. The reason for this very low O2 requirement stems from the extremely high surface area of Type 5 and 6 solder powders. Standard Sn63 and SAC ramp-to-spike profiles were replicated on this new coupon. All coupons were cleaned with an in-line cleaner in DI water at 135°F/60psi. Cross-section specimen clips were attached in such a way as to prevent the top mesh belt in the cleaner from marring the delicate bumps during the cleaning cycle. One coupon of each of the paste-stencil combinations was 100% measured, yielding individual bump heights and grid coplanarity.

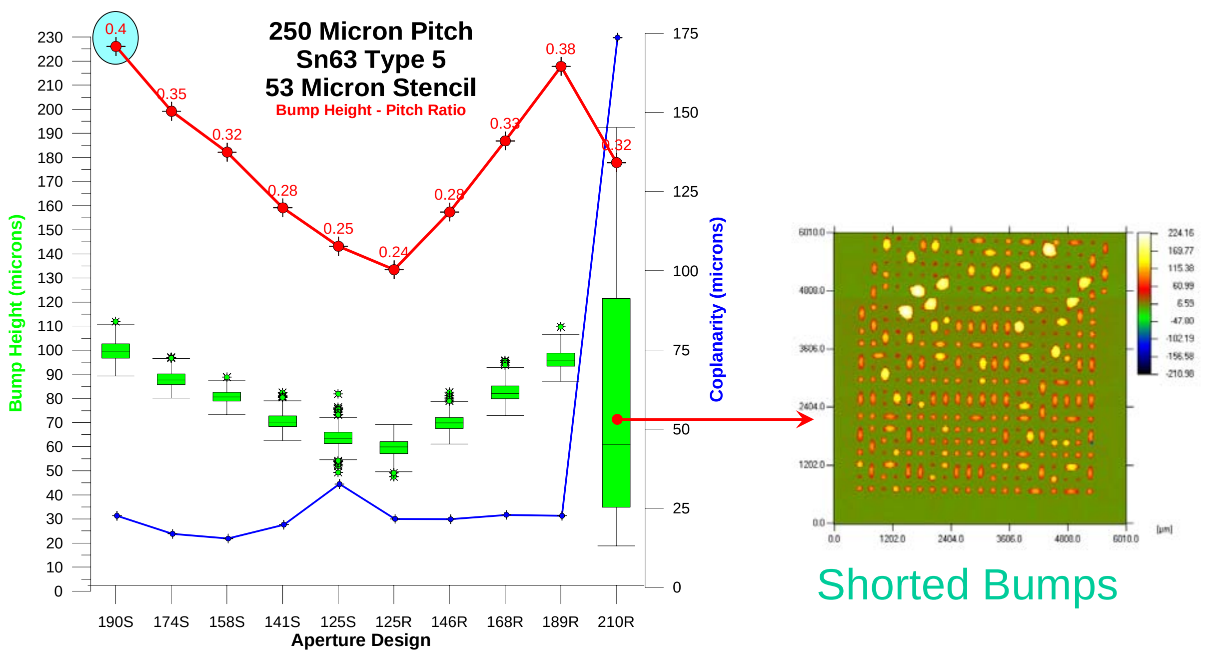

Figure 4 - Data Analysis Plot

Data Analysis

Several factors had to be considered when selecting the maximum H/P ratio. The calculation was simply taking the average bump height and dividing by the pitch. Since the stencil design pushed the aperture size to the maximum, it also pushed the paste printing and slump properties to their respective limits. This resulted, in some cases, with bridging on some of the largest aperture designs. Since it was assumed that the maximum H/P ratio is defect free and manufacturable, both the coplanarity of each grid and the data distribution were considered. The coplanarity was simply the largest bump minus the smallest bump. The data distribution for each grid was viewed in a box-whisker format. When all three data attributes were plotted together (Figure 4) the selection of the maximum usable H/P ratio became obvious. In these combination plots, the red line is the H/P ratio, the blue line is coplanarity and the green boxes are the box-whisker plots. The highest H/P ratio that demonstrated a tight box-whisker plot, minimal outliers and a low coplanarity relative to the other data in the pitch series was selected and highlighted (cyan circle) for each paste-stencil-pitch combinations[4]. Further analysis was done on the final H/P ratio data (Table 2) to for look for trends.

Significant Trends

As expected the finer type 6 powder yielded a higher average H/P ratio. This was due to the higher packing density which resulted in simply more solder metal deposited per cubic micron of printed solder volume. This trend is independent of solder alloy and was more pronounced with the thicker stencil.

Round apertures produced the majority of the maximum H/P ratios. This may be due to the simple fact that the single point aperture to aperture proximity leads to less inter-bump bridging than the square apertures. This tendency is independent of the smaller stencil webbing (closer apertures) used with the round designs.

Somewhat unexpected was the trend plotted in Figure 5. This trend shows that as pitch increases, so does the H/P ratio. Since the denominator of the ratio is pitch it was anticipated that the H/P ratio should be straight line when plotted against pitch. One theory for this trend is simply that the larger apertures, typical of larger bump pitches, transfer paste more efficiently than the smaller apertures found in low bump pitches.

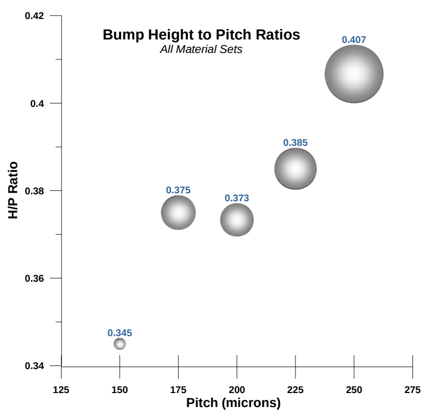

Figure 5 B/H Ratio Trends

Table 2 Maximum Bump Height to Pitch Ratios

Stencil	Alloy	Type	Pitch	Ratio	Shape	Size	Area
46	Sn63	6	150	0.35	R	110	9503
	Sn63	6	175	0.38	R	135	14314
	Sn63	6	200	0.36	R	160	20106
	Sn63	6	225	0.33	S	165	50625
	Sn63	6	250	0.37	R	189	27981
46	Sn63	5	150	0.3	R	101	8051
	Sn63	5	175	0.35	R	123	11906
	Sn63	5	200	0.39	R	160	20106
	Sn63	5	225	0.35	R	167	21871
	Sn63	5	250	0.39	S	190	62500
53	Sn63	6	150	0.41	R	101	8051
	Sn63	6	175	0.39	R	123	11906
	Sn63	6	200	0.41	R	160	20106
	Sn63	6	225	0.38	R	167	21871
	Sn63	6	250	0.42	S	190	62500
53	Sn63	5	150	0.34	R	101	8051
	Sn63	5	175	0.37	R	123	11906
	Sn63	5	200	0.34	R	145	16513
	Sn63	5	225	0.37	S	165	50625
	Sn63	5	250	0.4	S	167	62500
53	SAC	6	150	0.4	R	110	9503
	SAC	6	175	0.44	R	135	14314
	SAC	6	200	0.35	R	145	16513
	SAC	6	225	0.45	R	185	26880
	SAC	6	250	0.46	S	190	62500
53	SAC	5	150	0.27	S	90	22500
	SAC	5	175	0.32	S	115	30625
	SAC	5	200	0.39	R	145	16513
	SAC	5	225	0.42	R	167	21871
	SAC	5	250	0.4	S	174	36100
	Note: All Dimensions are in microns						

Current Work on Test Wafers

With the implementation of a new confocal measuring system with 10 nanometer height resolution and a 200mm test wafer with just under 300 aperture designs, extensive studies in wafer bumping are well underway. The wafer is divided into 4 quadrants that vary the size of apertures in "test modules" that have up to 75 different pitch, aperture size and shape combinations.

Squeegee Effects

The first study involved the quantitative comparison of a pure nickel squeegee and a more traditional high durometer polymer squeegee. Larger (1mm and 500 micron) pitches as well as smaller (125 and 100 micron) pitches than the previous studies described were bumped and measured. Over 28,000 bumps were measured in this mini-study. Table 3 details the aperture size matrix tested. All apertures tested were square in shape. The same type 6 SAC405 alloy lead free water washable solder paste was used in this study.

Table 1 Wafer Test Grids

Pitch	Zone1	Zone2	Zone3	Zone4
1mm	848u	874u	901u	924u
500u	348u	374u	401u	424u
250u	161u	176u	192u	206u
200u	111u	126u	142u	156u
175u	86u	101u	117u	131u
150u	61u	76u	92u	106u
125u	N/A	51u	67u	81u
100u	N/A	N/A	N/A	56u

As can be seen in Figures 6 and 7 there was much tighter bump height distributions in the larger pitches when using the nickel metal squeegee blade (*E-Blade*). This was directly correlated to measured solder volume prior to reflow, as can be seen in Figure 8. As with standard SMT, the metal squeegee blades not only helped to prevent scooping but helped to deliver more paste volume. A comparison of two high definition confocal scans of paste prints in one of the 1mm pitch grids visually confirmed the paste scooping effects of the polymer squeegee.

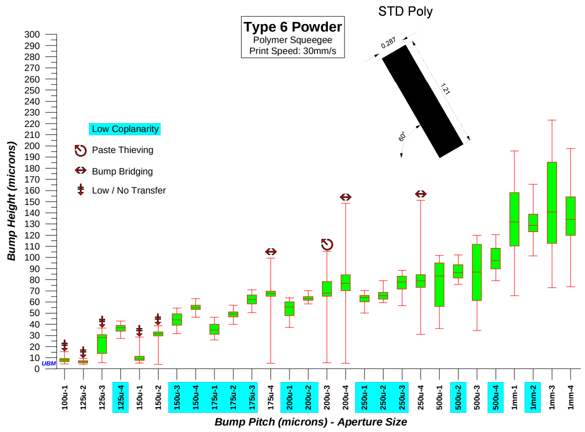

Figure 6 Polymer Squeegee Results

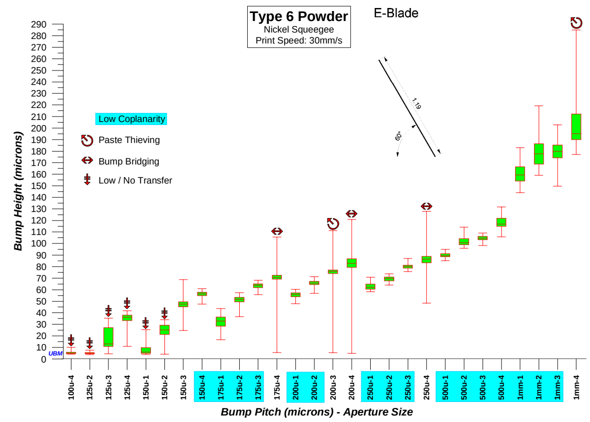

Figure 7 Nickel Metal Squeegee

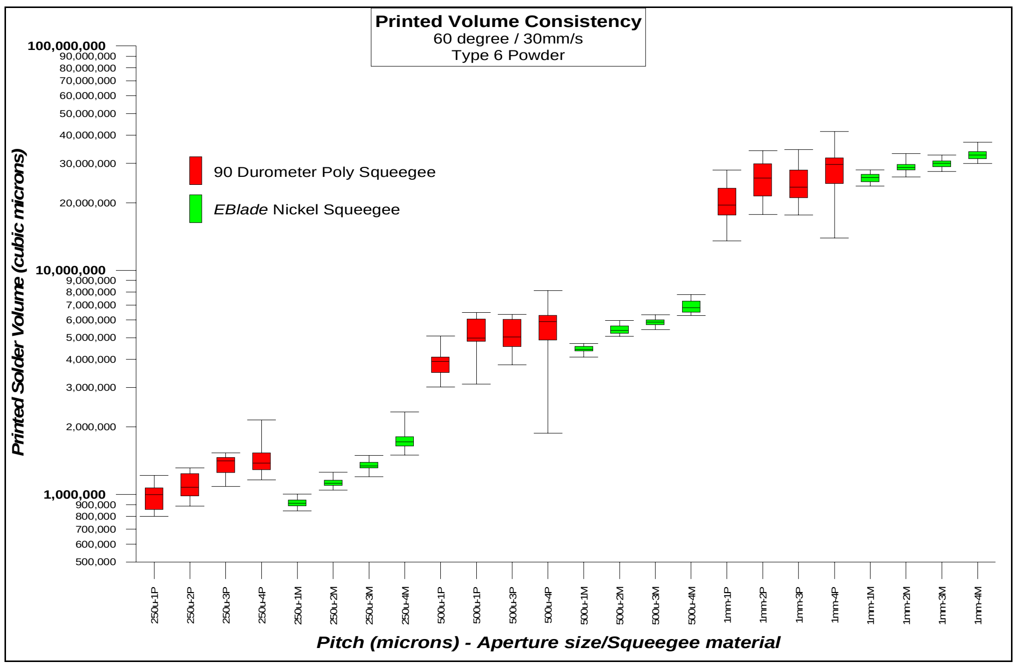

Figure 8 Printed Solder Volumes

Powder Size Effects

Typical powder size classifications for wafer bumping pastes are in the type 5 and 6 ranges. Recently type 7 and 8 powder sizes have been introduced to the market in both lead free and tin-lead alloys. The graphic in Figure 9[2] shows the application of these finer powders to finer bump pitch ranges as well as the range of particle size. Typical particle size distributions (PSD) for powder type 6 and type 8 are shown Figures 10 and 11 respectively.

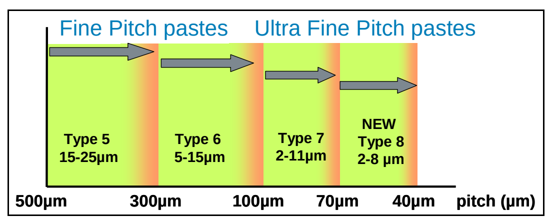

Figure 9 Powder Type - Bump Pitch

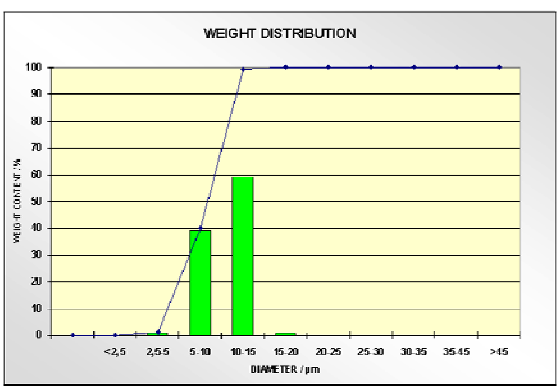

Figure 10 Type 6 Powder PSD

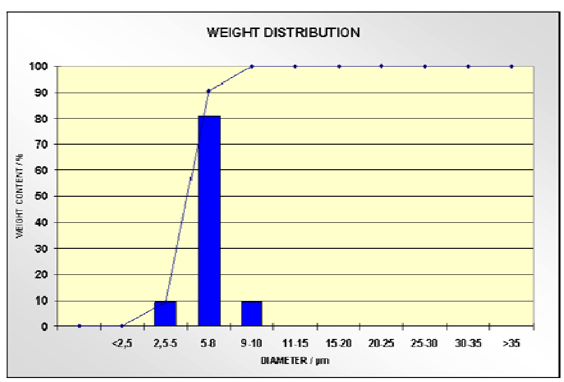

Figure 11 Type 8 Powder PSD

The effects of powder size in bumping paste on bump height was studied with the same test wafer, process and measurement conditions as described for the squeegee study. The exception was that only the fine pitch was measured (≤ 200µ pitch). For this mini-study the polymer squeegee was used and a total of 32,400 bumps were measured for peak bump height. When comparing the mean bump height achieved for the aperture size/bump pitch combinations that demonstrated good coplanarity, a general trend of increased bump height related to finer powders is evident[5] as plotted in Figure 12.

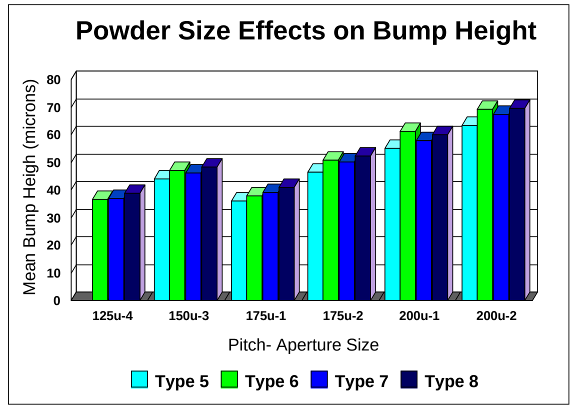

Figure 12 Powder Size Effects on Bump Height

Printed paste volume consistency was studied via a different in-house design from print studies previously published[3]. This design has over 4,500 100 bump grids completely covering a 200mm polished wafer. For this extreme density design, a 3mm snap-off was required to provide a controlled separation. The apertures are 165µ diameter on a 229µ pitch. A 50µ thick *E-Fab* stencil was used in this study. Measurement was accomplished with the same confocal system as described but paste volume was measured instead of bump height. Wafers were printed with identical print and measurement setups. Pastes with the largest wafer bumping powder (Type 5) and the smallest (Type 8) were formulated with the same flux system, viscosity range, solids and SAC lead free alloy in order to study the effects of powder size on paste volume consistency. Photographs of a sample of the print show some paste deposit shape variability with the type 5 paste sample, but not with the type 8 paste sample, as can be seen in figures 13 and 14. A sample of 2,500 print deposits was measured for each paste. The paste volume data distributions in Figure 15 illustrate the much tighter distribution of paste volumes with the type 8 powder[5]. Tighter paste volume distributions will equate to tighter bump height and volume distributions as well as lower coplanarity. It is also worthy to note that a higher mean paste volume was achieved with the finer powder as expected. The mean bump print volume for the type 5 paste was 580,076µ³ and 693,783µ³ for the type 8 paste.

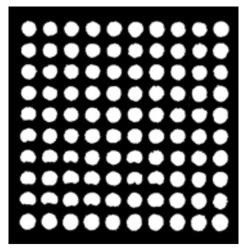

Figure 13 Type 5

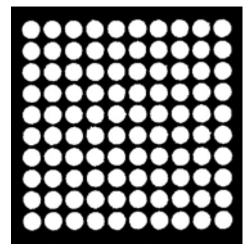

Figure 14 Type 8

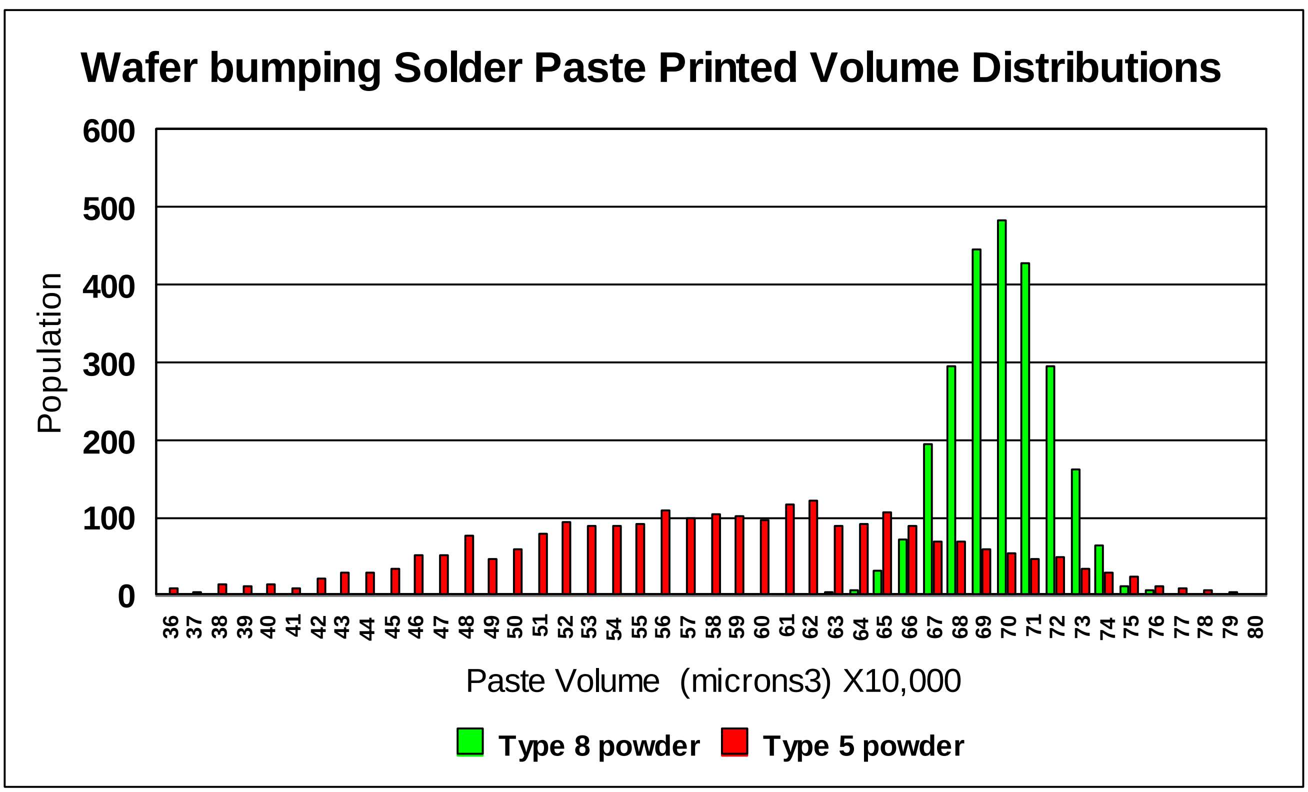

Figure 15 Paste Volume Distributions

UBM Size Effects

When solder paste reflows, due to surface tension, it will attempt to form a perfect sphere. At zero gravity in outer space it will be a perfect sphere. On earth due to gravitational forces it will be a compressed sphere. When soldered to a defined diameter pad or UBM, it will take on a compressed truncated sphere shape. From a recent paper on computing bump height from transferred solder paste volume, Equation 1 has proven to correlate with actual measurements[6].

Equation 1

$$V_{solder} = \frac{\pi}{24}\left(3h\phi_{pad}^{2} + 4ah^{3}\right)$$

Where:
V = volume of transferred solder paste
h = reflowed bump height
a = shape factor (typically 1.15)
ϕ = pad or UBM diameter

A study was completed which further illustrates the effect on bump height (h) by varying pad diameter (ϕ) with constant paste volume (V). On 0.5mm pitch test grids with pad diameters of 100µ, 150µ, 200µ and 250µ, various volumes of solder paste were printed through a 50µ thick stencil. The bump heights were measured and charted as in Figure 16. Several trends were noticed, besides the obvious one that more solder volume equates to a larger bump height. One trend is that the difference in bump height between the largest and smallest bump is larger with the smaller solder pad diameter as the trend chart in Figure 17 illustrates. The other trend was related to bump shape. The SEM cross-sections in Figures 18 and 19 show the smallest solder volume bump shapes between the largest (250µ) and smallest (100µ) diameter pads. The solder volumes were equal in each case. This is also the case with the largest solder volumes as in Figures 20 and 21.

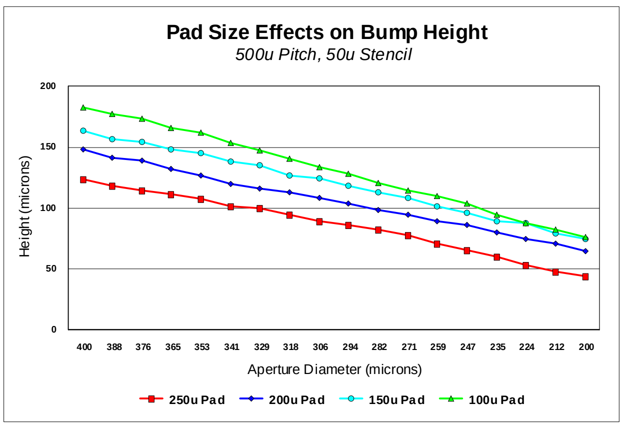

Figure 16 Pad Diameter Effects on Bump Height

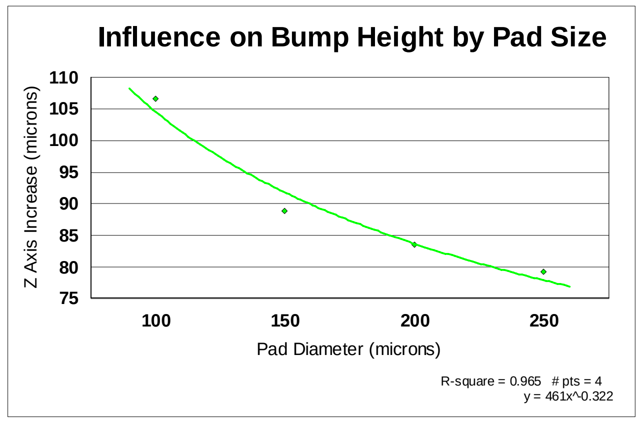

Figure 17 Pad Diameter Effect Trend

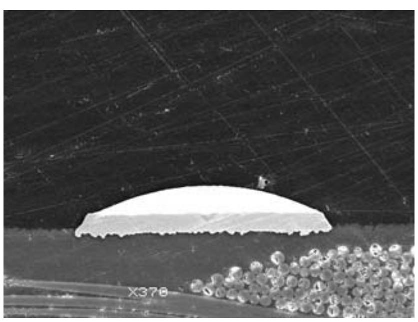

Figure 18 Low Volume/Large UBM

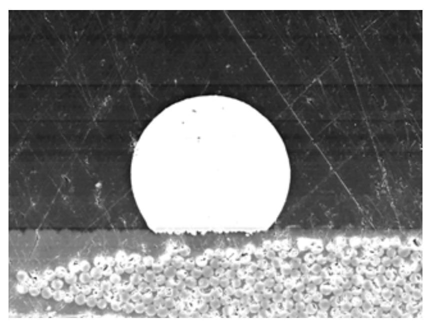

Figure 19 Low Volume/Small UBM

Figure 20 High Volume/Large UBM

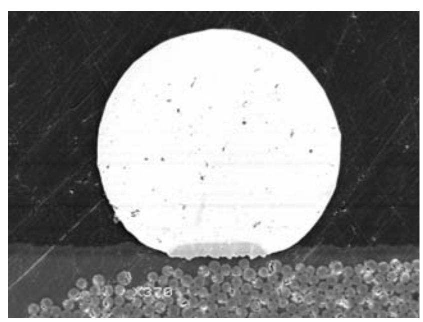

Figure 21 High Volume/Small UBM

Conclusions

- Type 6 powder produces higher bump H/P ratios than Type 5 in both Sn63 and lead free SAC alloys.
- Nickel metal squeegee helps to prevent scooping in large apertures resulting in tighter bump height distributions.
- Finer powders increase bump height moderately and yield tighter paste volume distributions during printing.
- UBM or solder pad diameter can significantly affect bump shape and height.

Acknowledgements

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Heraeus

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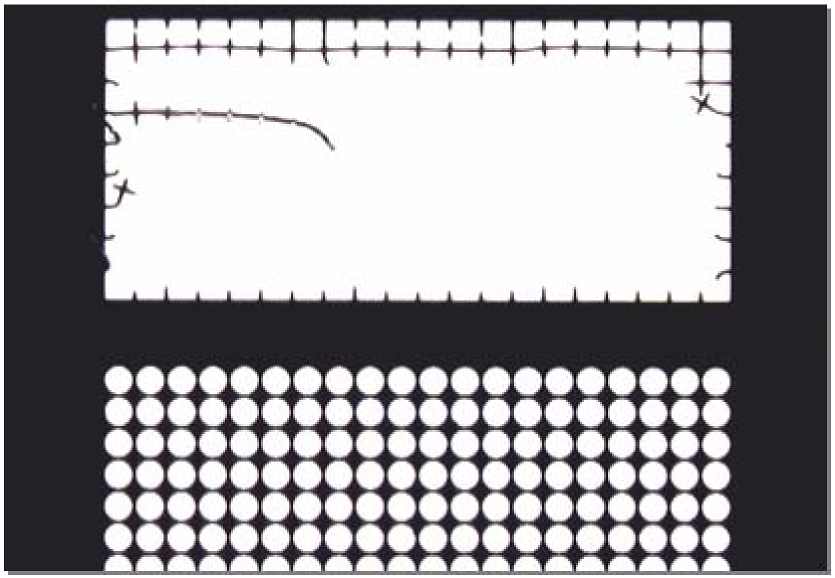
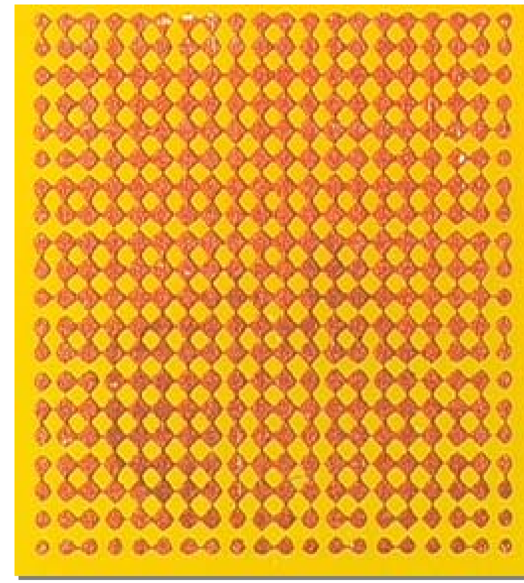
Rick Lathrop

Early Work: Coupon and Stencil Pushed to Failure





Stencil Failure

Webbing 45.2μ

□□ ≥ 1.2X Stencil Thickness

○○ ≥ 0.8X Stencil Thickness

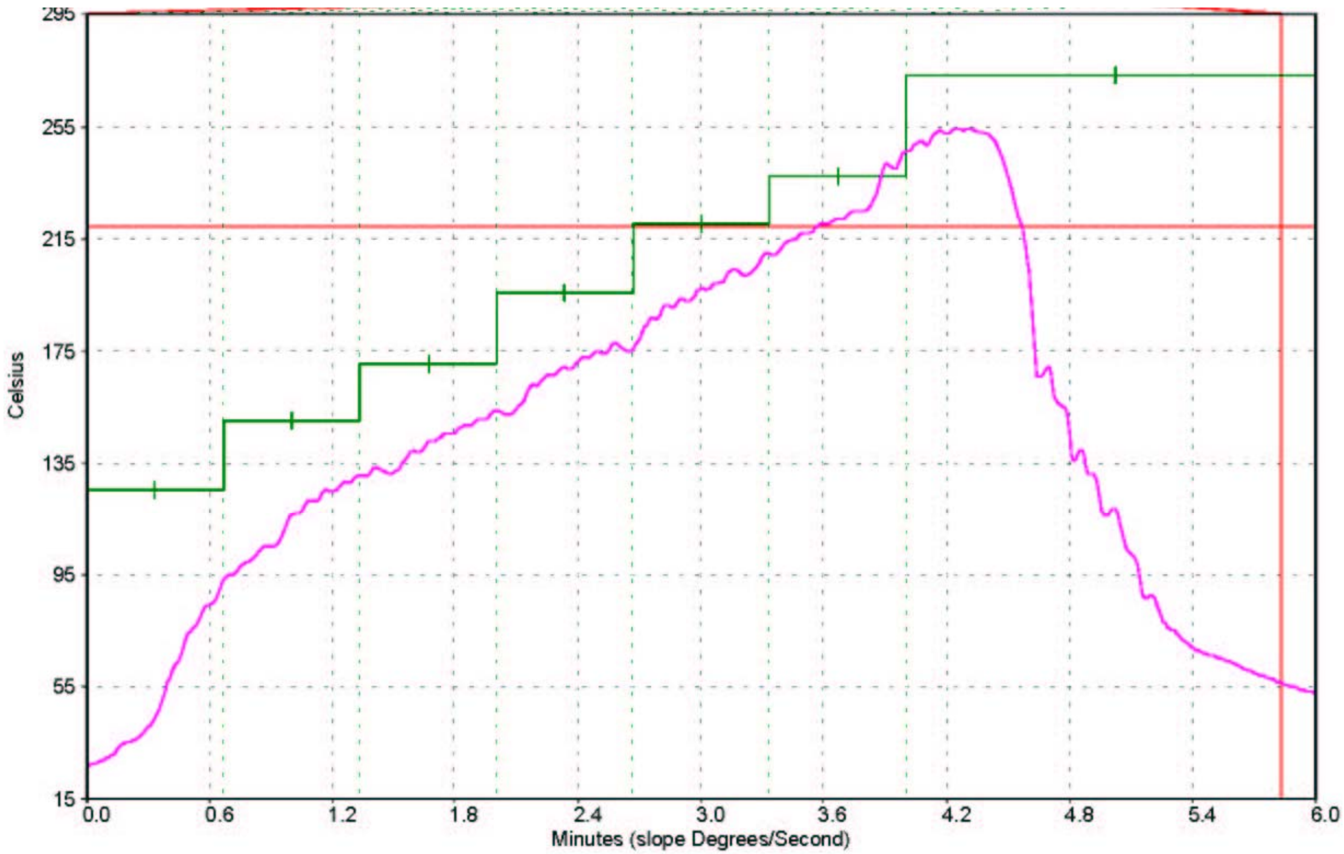
Coupon Failure

Bridged 150μ Pitch

1/4oz Copper

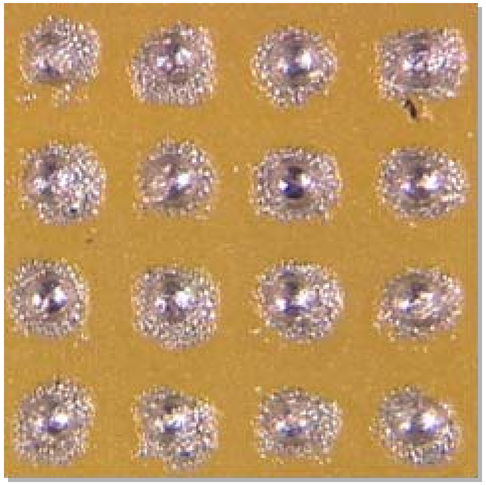
Laminate Thickness Reduced

Lead Free Profile

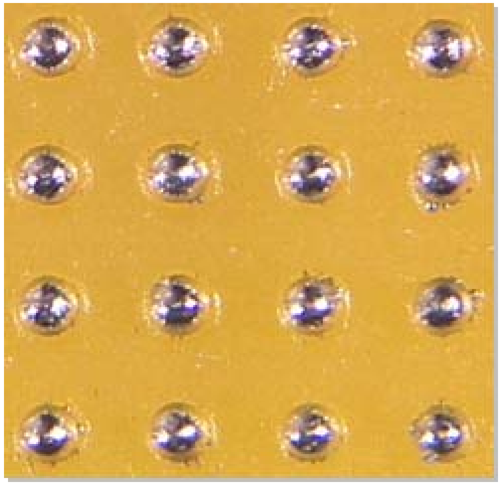


	Peak	Total Time 219
1 SOIC	253.9	60.18

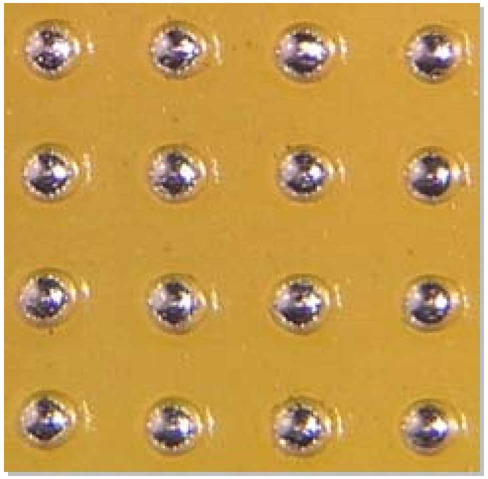
Purging Oven



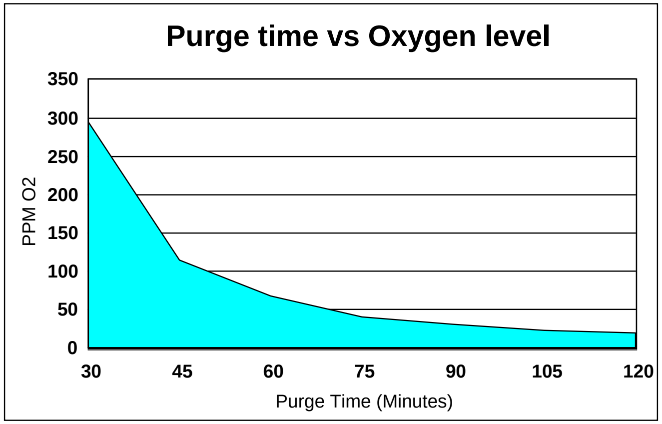
5 min

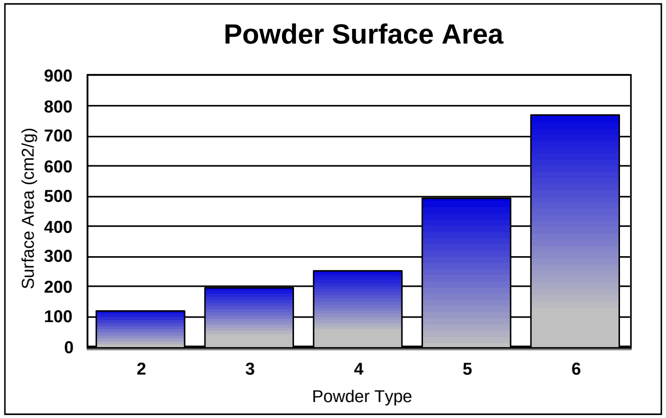


30 min

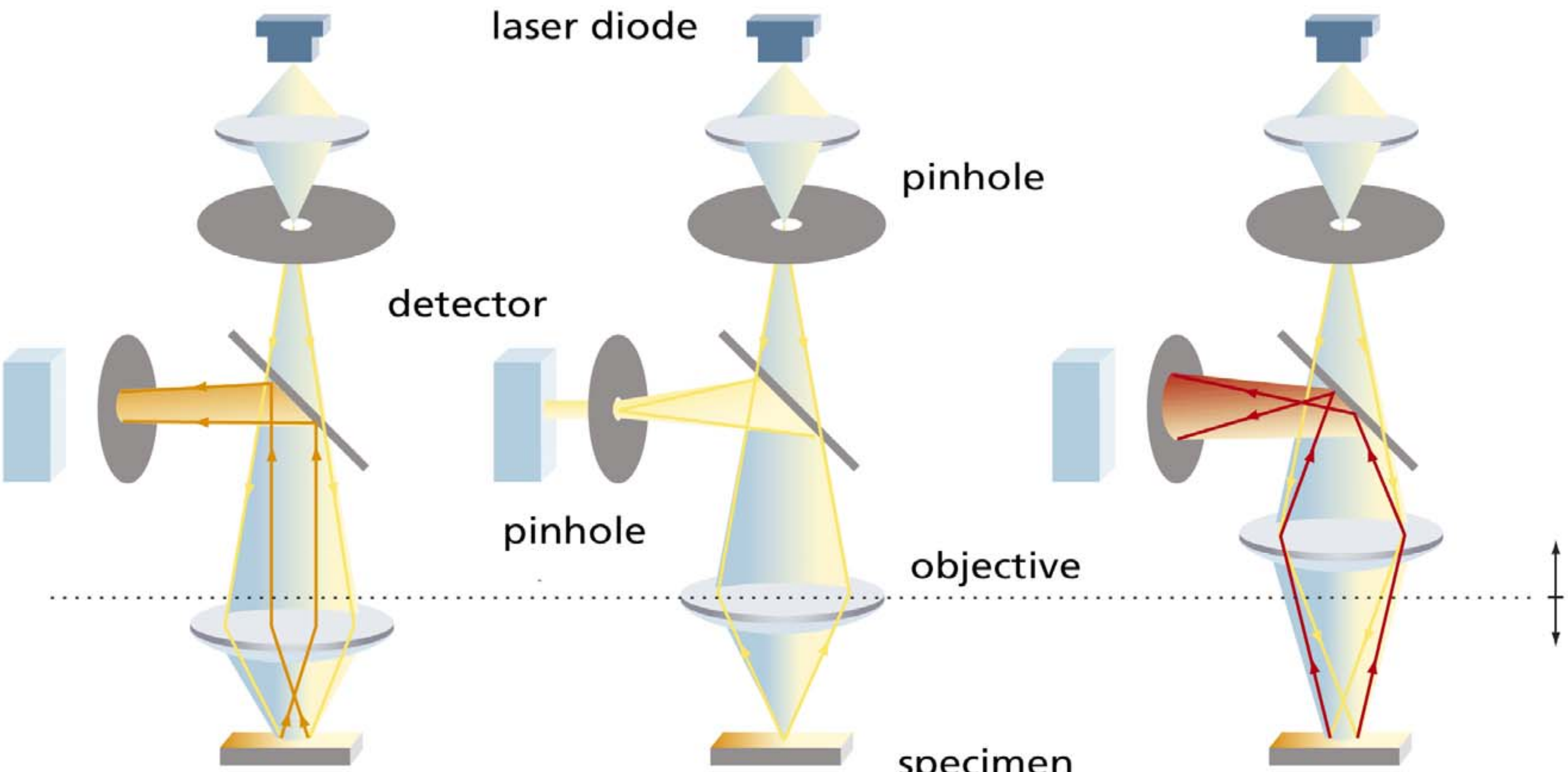


45 min

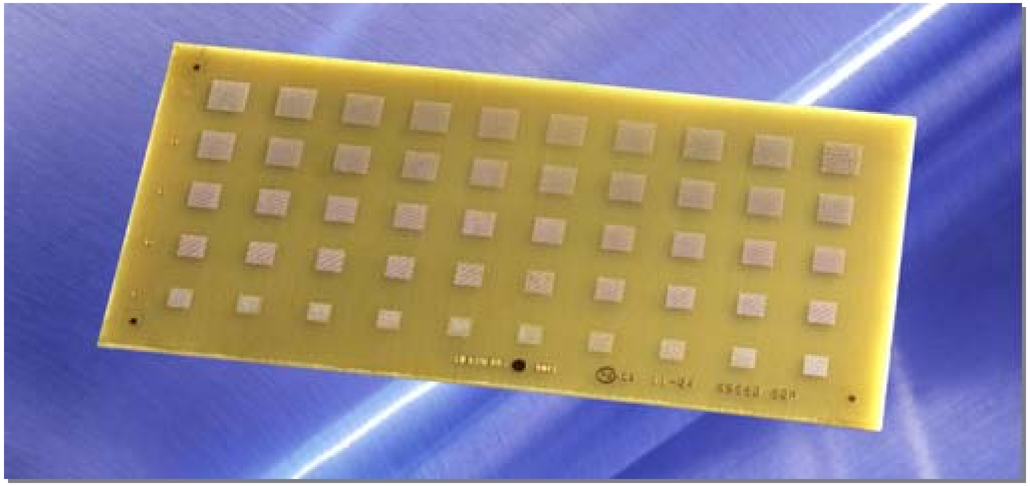




Confocal Point Sensor



Stencil Design Matrix



Pitch	Square	Square	Square	Square	Square	Round	Round	Round	Round	Round
250	190	174	158	141	125	125	146	168	189	210
225	165	152	139	126	113	113	131	149	167	185
200	140	130	120	110	100	100	115	130	145	160
175	115	108	101	94	88	88	99	111	123	135
150	90	86	83	79	75	75	84	93	101	110

Pitch	PAR	PAR	PAR	PAR	PAR	PAR	PAR	PAR	PAR	PAR
250	0.94	0.86	0.78	0.70	0.62	0.62	0.72	0.82	0.93	1.03
225	0.81	0.75	0.68	0.62	0.55	0.55	0.64	0.73	0.82	0.91
200	0.69	0.64	0.59	0.54	0.49	0.49	0.57	0.64	0.71	0.79
175	0.57	0.53	0.50	0.46	0.43	0.43	0.49	0.55	0.61	0.66
150	0.44	0.42	0.41	0.39	0.37	0.37	0.41	0.46	0.50	0.54

PAR Key

>0.66

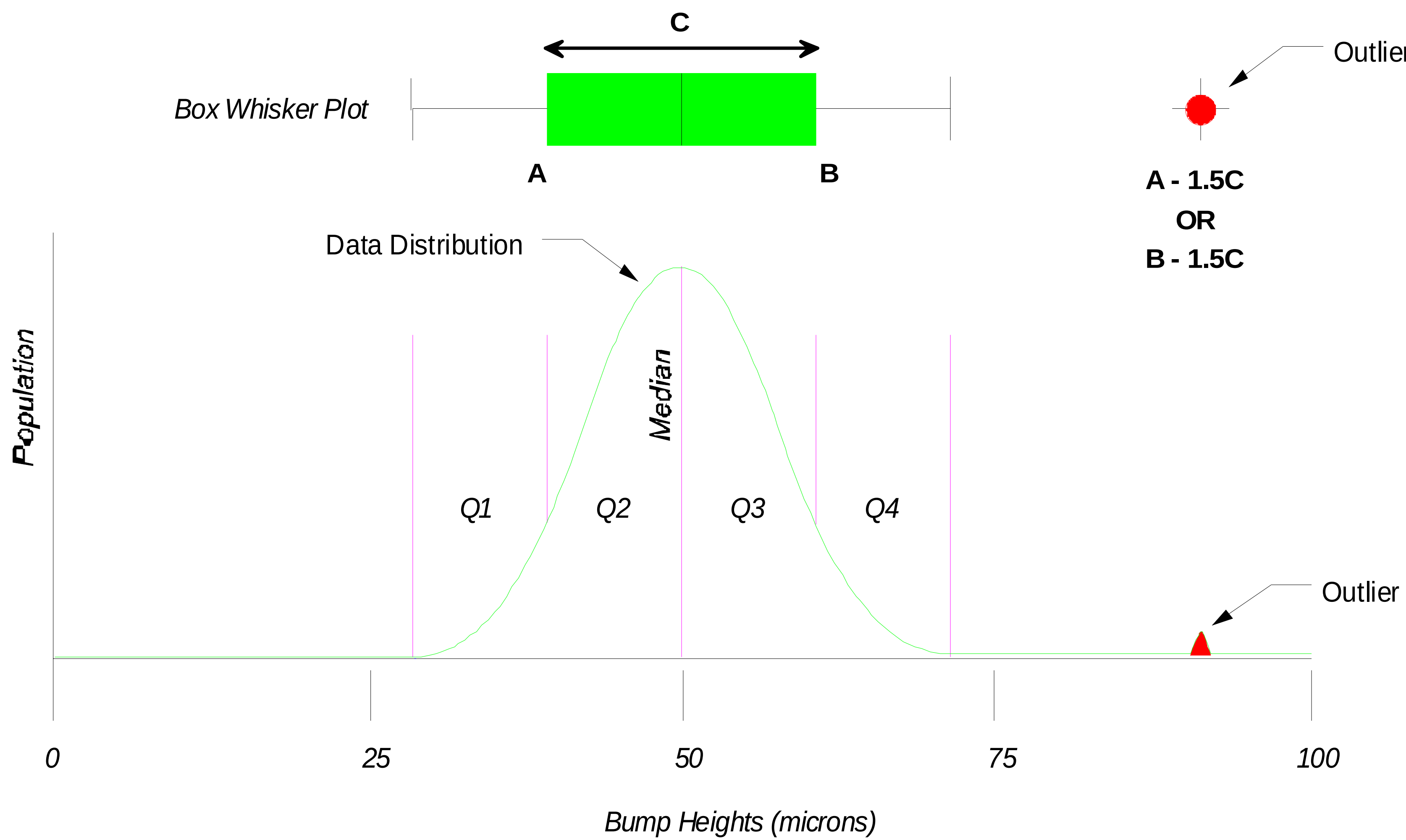
0.6-0.66

0.5-0.6

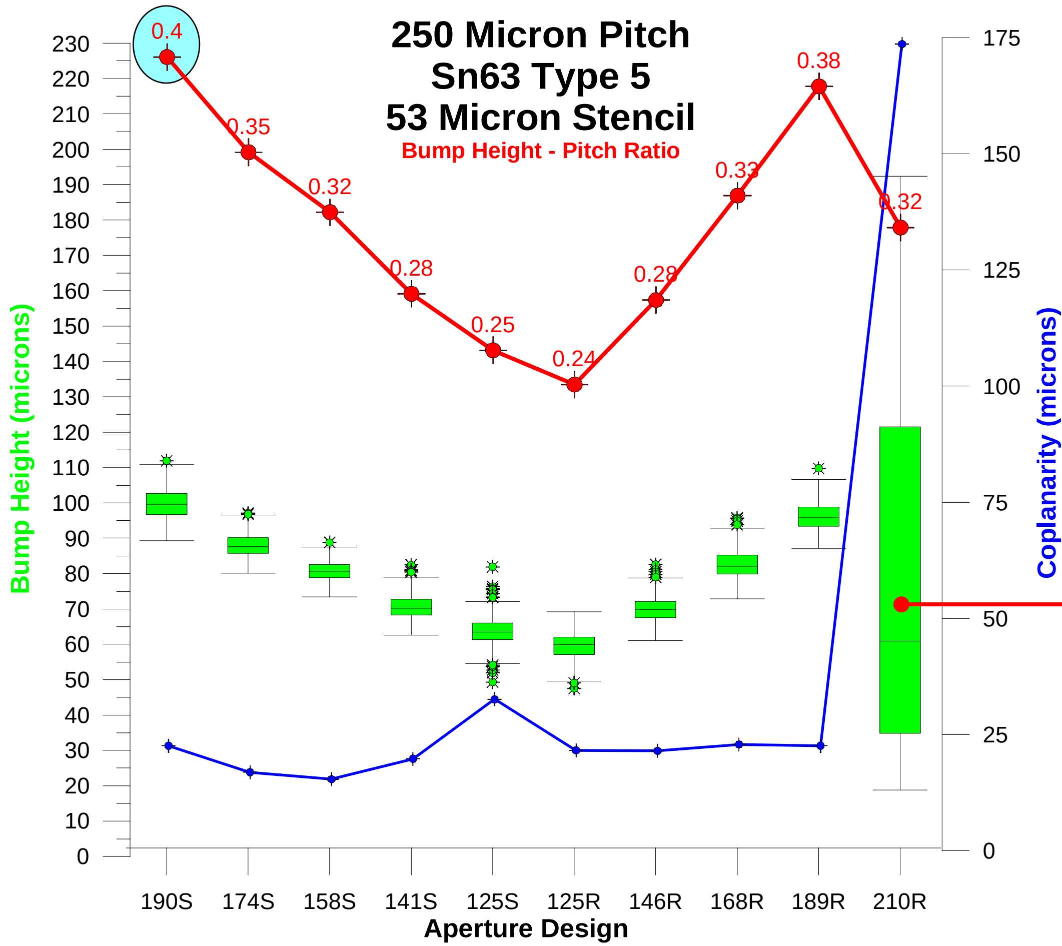
0.4-0.5

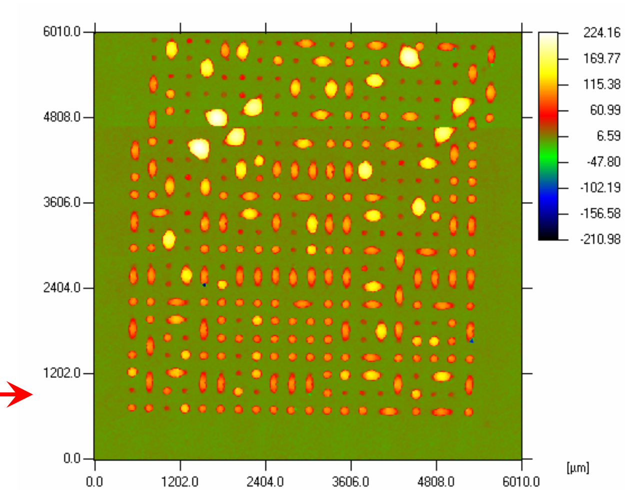
<0.4

Box Whisker Plot – Distribution Comparison



Determining Maximum Height – Pitch Ratio



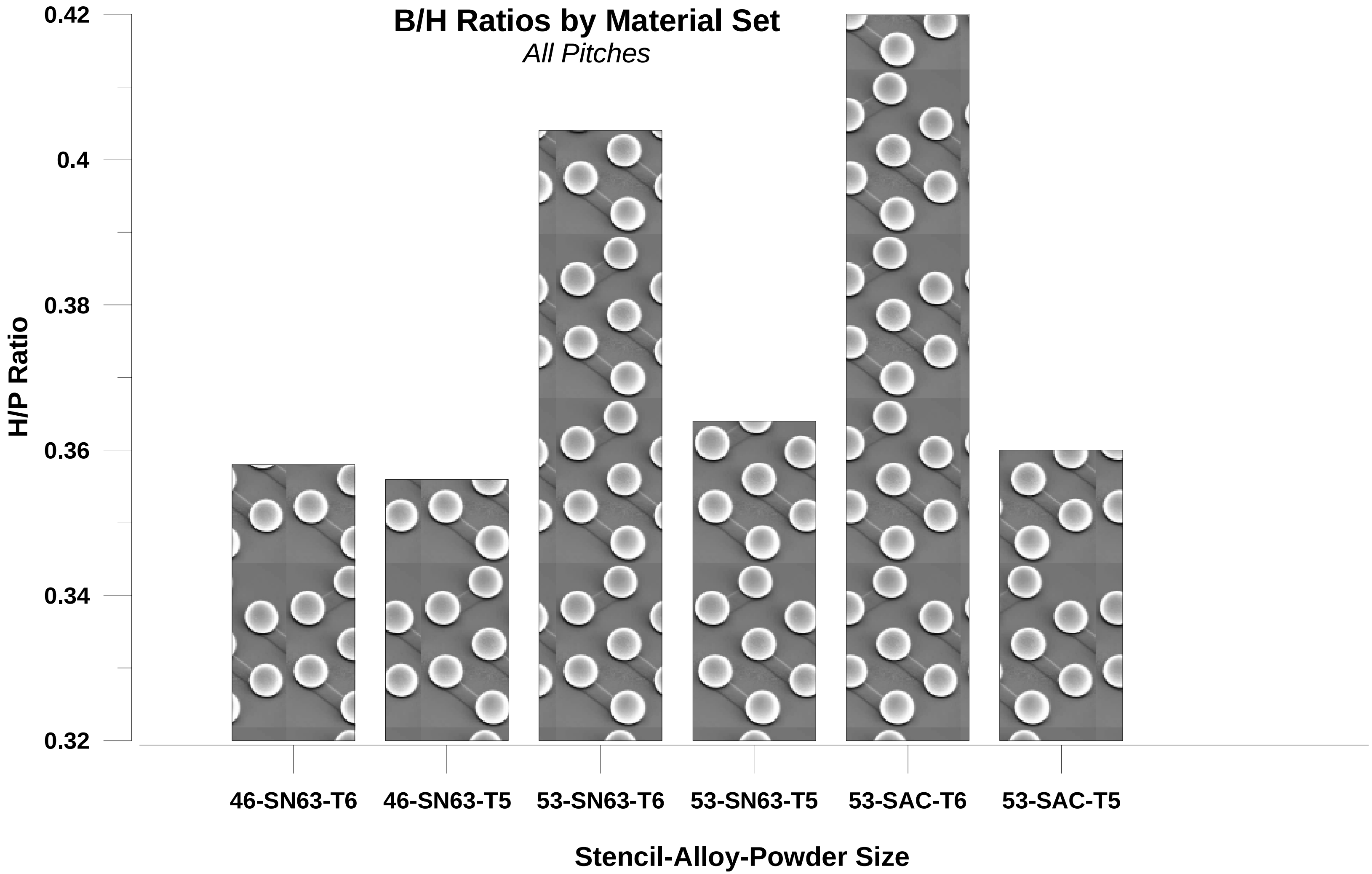


Shorted Bumps

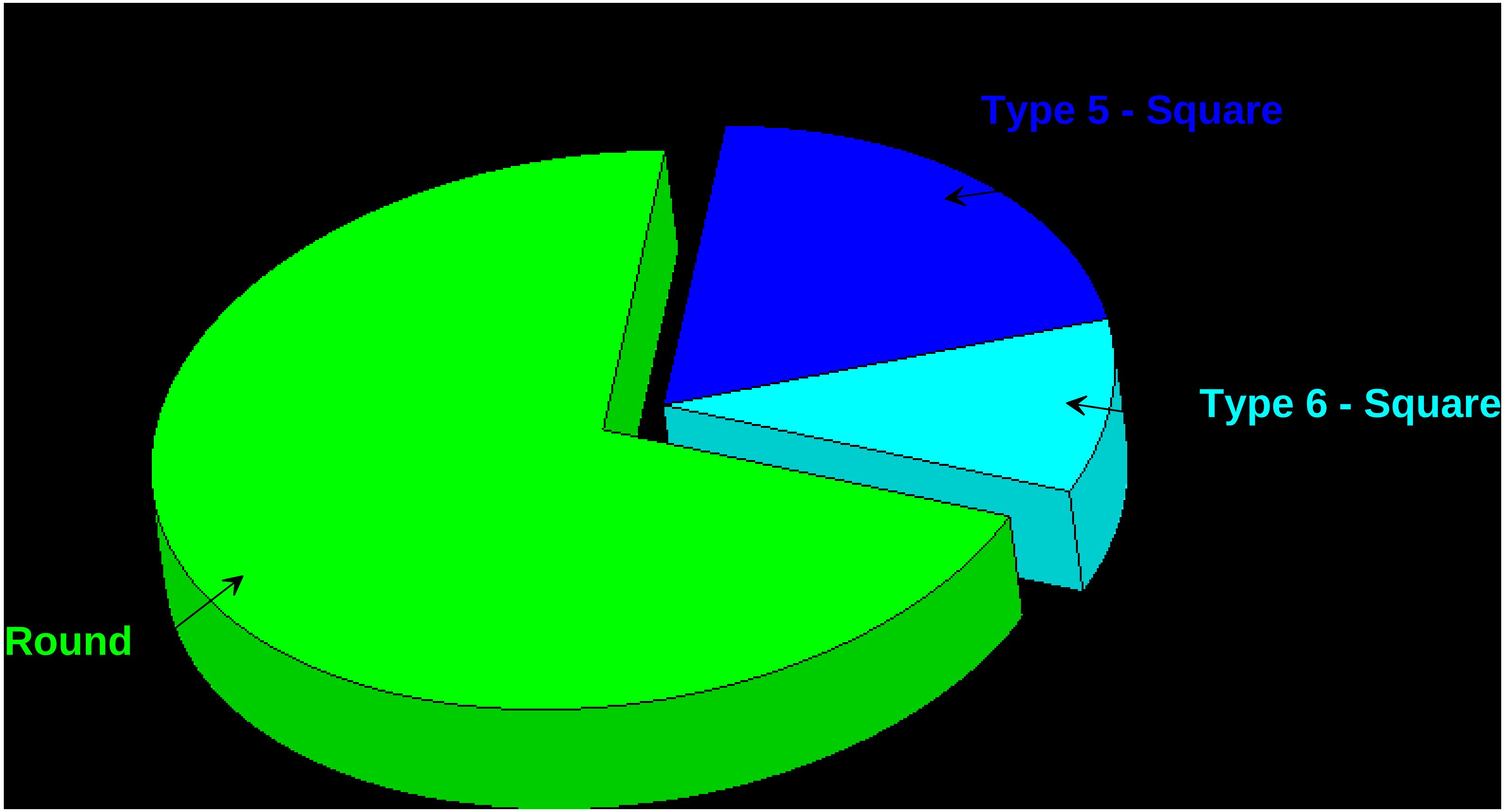
Ratio Results

Stencil	Alloy	Type	Pitch	Max Ratio	Shape	Size	Area
46 Micron	Sn63	6	150	0.35	R	110	9503
	Sn63	6	175	0.38	R	135	14314
	Sn63	6	200	0.36	R	160	20106
	Sn63	6	225	0.33	S	165	50625
	Sn63	6	250	0.37	R	189	27981
46 Micron	Sn63	5	150	0.3	R	101	8051
	Sn63	5	175	0.35	R	123	11906
	Sn63	5	200	0.39	R	160	20106
	Sn63	5	225	0.35	R	167	21871
	Sn63	5	250	0.39	S	190	62500
53 Micron	Sn63	6	150	0.41	R	101	8051
	Sn63	6	175	0.39	R	123	11906
	Sn63	6	200	0.41	R	160	20106
	Sn63	6	225	0.38	R	167	21871
	Sn63	6	250	0.42	S	190	62500
53 Micron	Sn63	5	150	0.34	R	101	8051
	Sn63	5	175	0.37	R	123	11906
	Sn63	5	200	0.34	R	145	16513
	Sn63	5	225	0.37	S	165	50625
	Sn63	5	250	0.4	S	167	62500
53 Micron	SAC	6	150	0.4	R	110	9503
	SAC	6	175	0.44	R	135	14314
	SAC	6	200	0.35	R	145	16513
	SAC	6	225	0.45	R	185	26880
	SAC	6	250	0.46	S	190	62500
53 Micron	SAC	5	150	0.27	S	90	22500
	SAC	5	175	0.32	S	115	30625
	SAC	5	200	0.39	R	145	16513
	SAC	5	225	0.42	R	167	21871
	SAC	5	250	0.4	S	174	36100
	Note: All Dimensions are in microns						

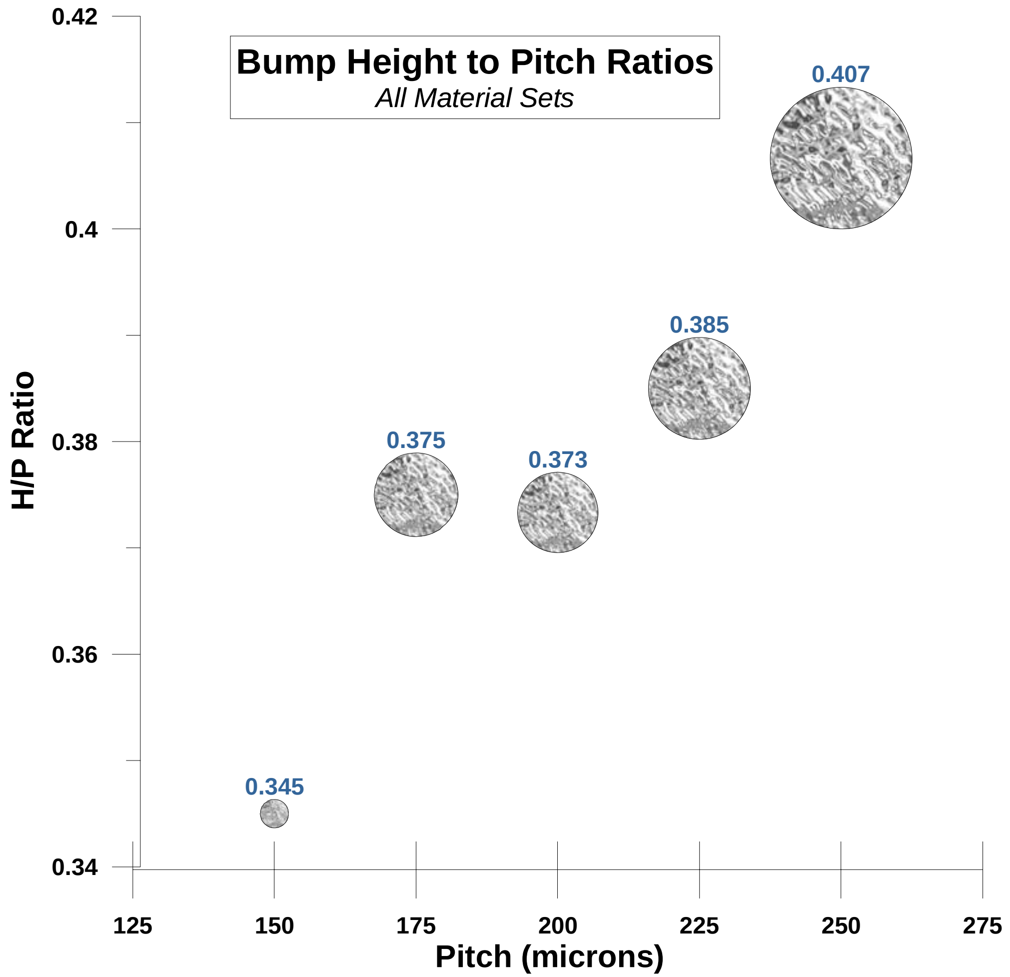
Data Trends: Type 6 Powder Yields Higher Bump Height Ratios



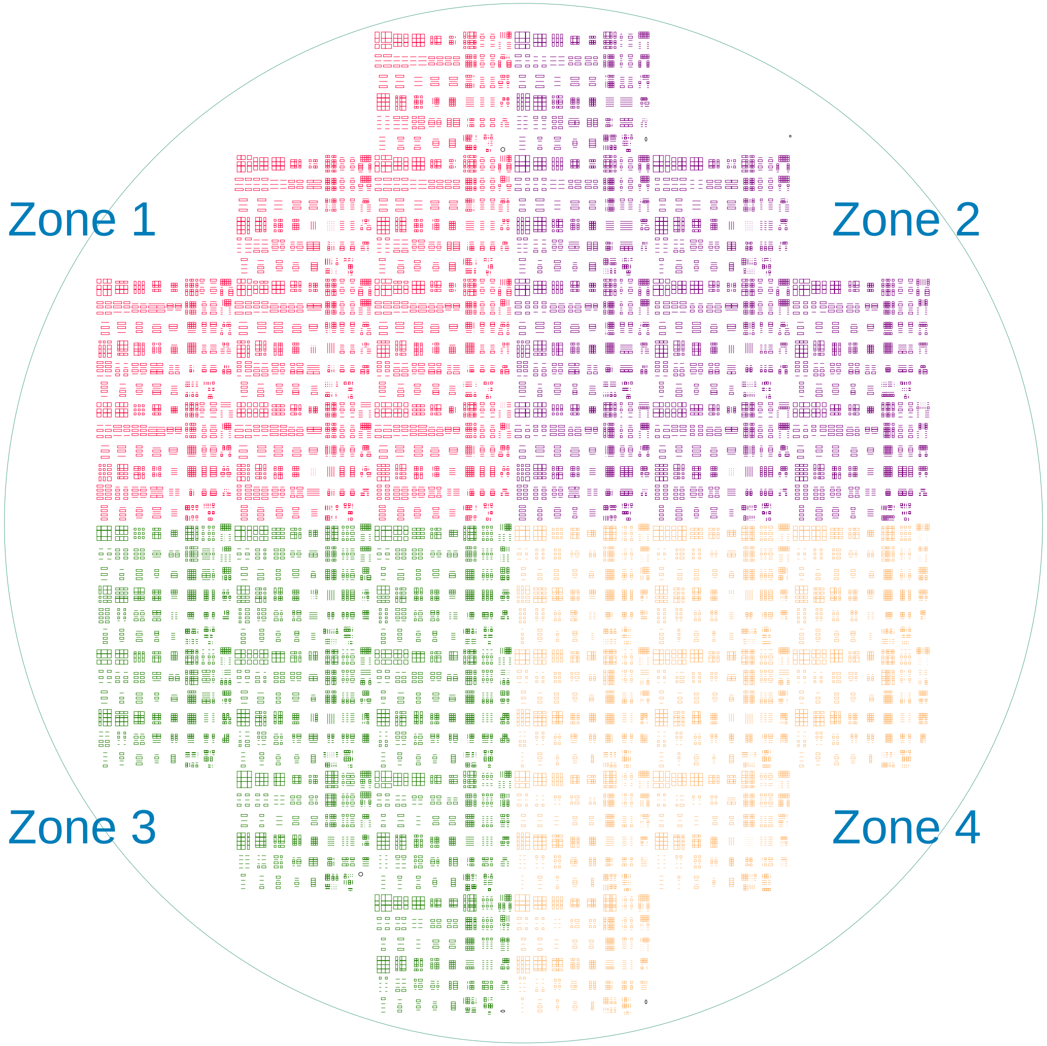
Data Trends: Round Apertures are More Efficient



Data Trends: Larger Pitch = Higher H/P Ratios



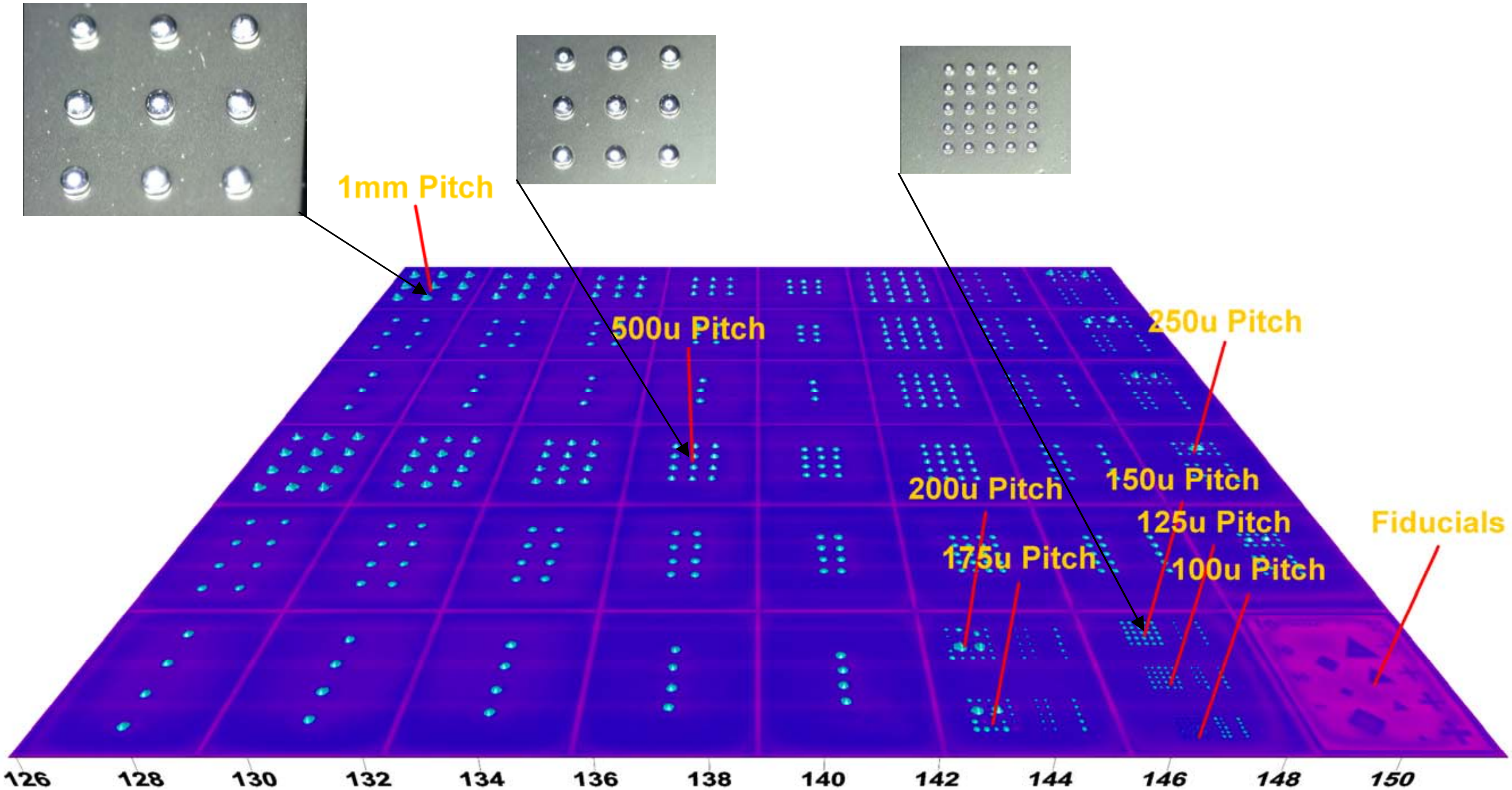
200mm Test Wafer



Stencil Aperture Sizes

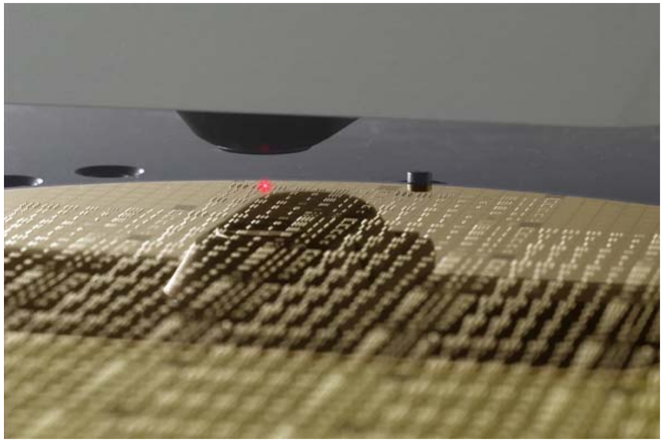
Pitch	Zone 1	Zone 2	Zone 3	Zone 4
1mm	848µ	874µ	901µ	924µ
500µ	348µ	374µ	401µ	424µ
250µ	161µ	176µ	192µ	206µ
200µ	111µ	126µ	142µ	156µ
175µ	86µ	101µ	117µ	131µ
150µ	61µ	76µ	92µ	106µ
125µ	NA	51µ	67µ	81µ
100µ	NA	NA	NA	56µ

Confocal 3D scan of one test module

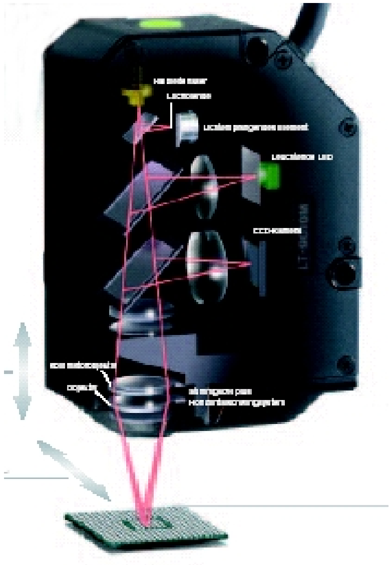


6 million height measurements

Confocal Measuring System



- **Range: 600 microns**
- **Z resolution: 10 nanometers**
- **X-Y resolution: 100 nanometers**



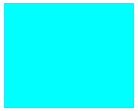
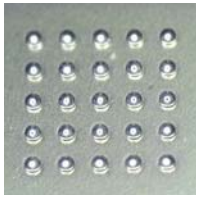
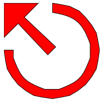
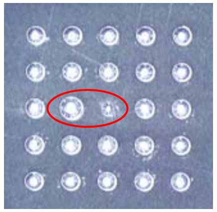
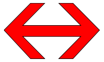
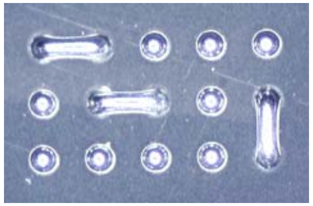
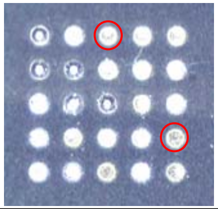
Bump Height Measurement

- **Align fiducials**
- **Raster Scan bump grid**
- **Level raster to wafer surface with polynomial algorithm**
- **Filter raster (low pass)**
- **Compute peak height of individual bumps**
- **Step and repeat**
- **Export data file to spreadsheet for graph prep.**
- **Box – whisker plot**
- **Visual conformation of defect types**

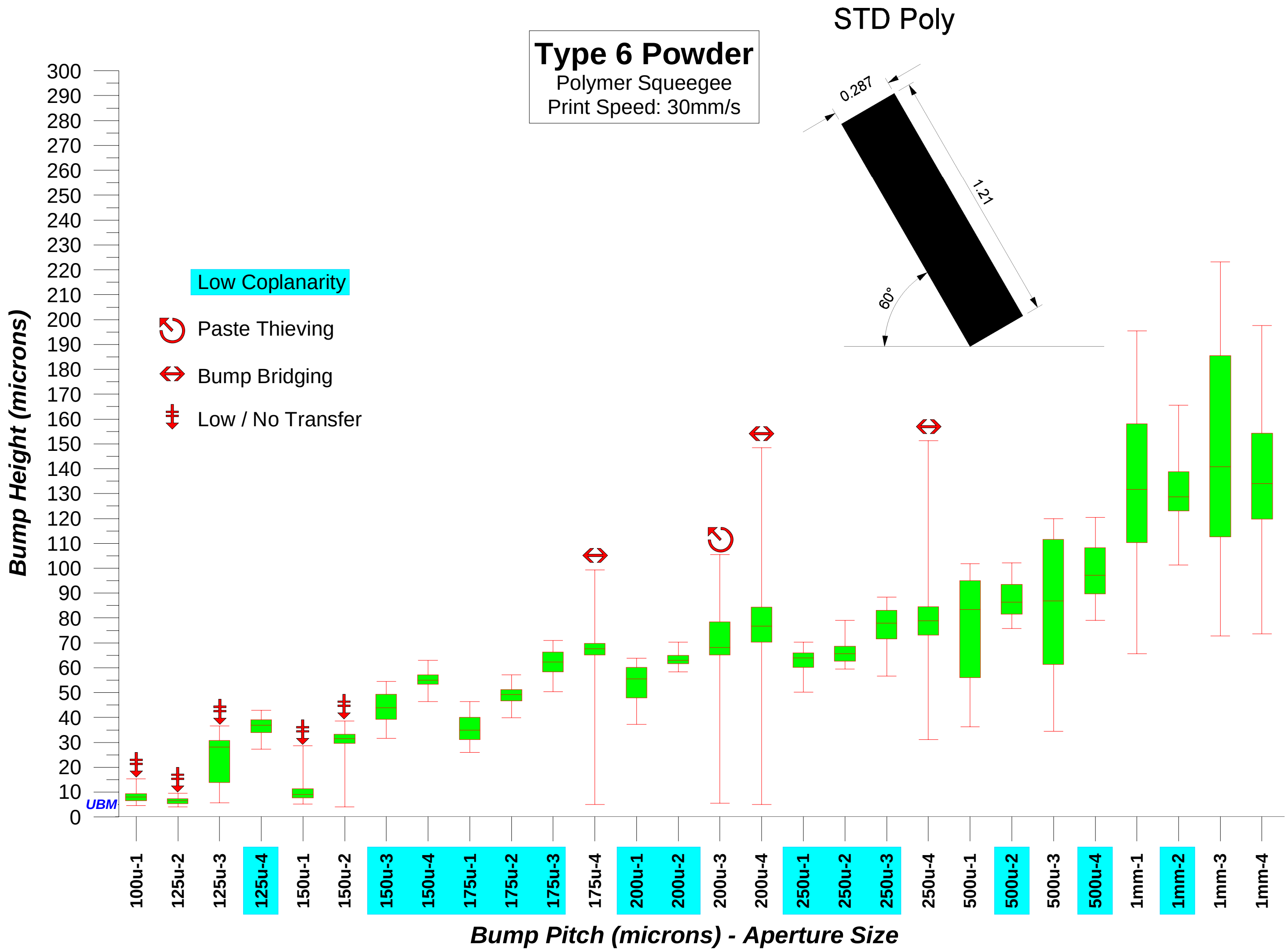
Test Wafer Mini Study – Squeegee Effects

- **F510Cu0.5 90H6 (SAC405 LF , type 6 powder)**
- **40µ thick E-Fab® electroformed nickel stencil**
- **Print Process**
  - **30mm/s print speed**
  - **0.1mm/s separation speed for 2mm**
  - **4-6kg pressure**
- **Squeegee (250mm)**
  - **95 durometer polymer trailing edge @ 60° (5kg)**
  - **PumpPrint® machined polymer @ 45° (6kg)**
  - **E-Blade® electroformed nickel (4kg)**

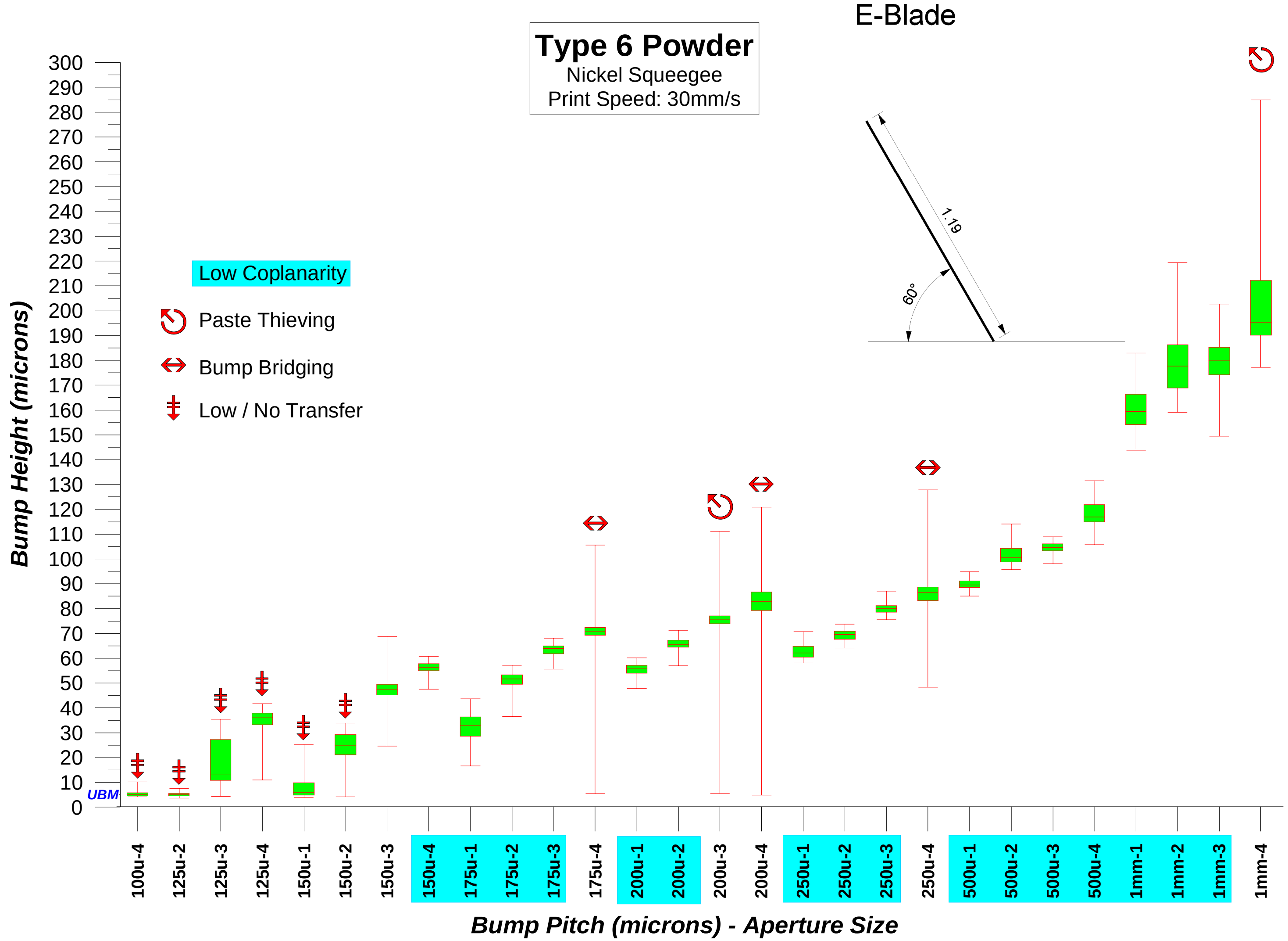
Phase 4 Mini Study – Squeegee Effects

Attribute	Chart Symbol	Example
Good - Low Coplanarity		
Defect - Paste Thieving		
Defect – Bump Bridging		
Defect – Low/No Transfer		

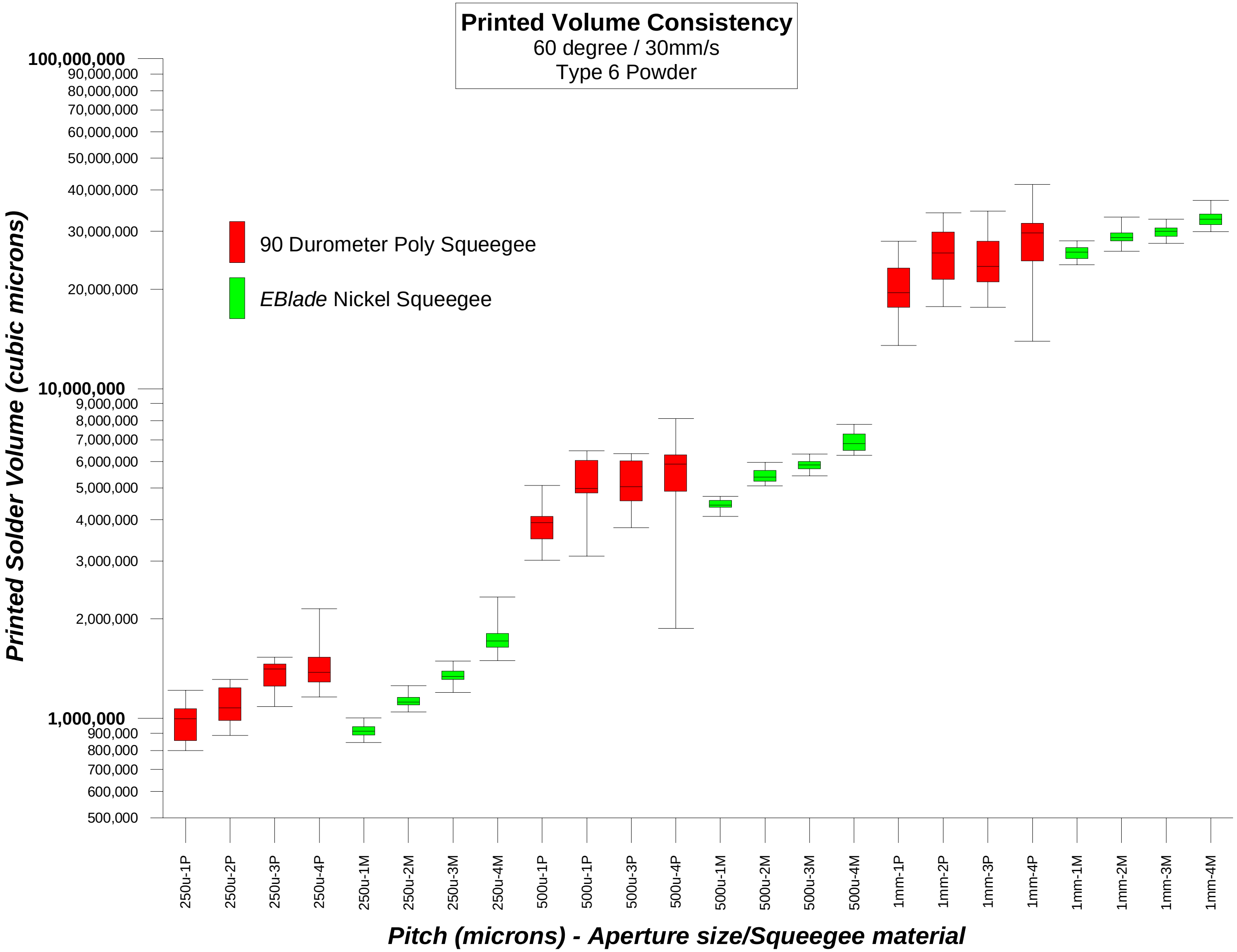
Test Wafer Mini Study – Polymer Squeegee Effects



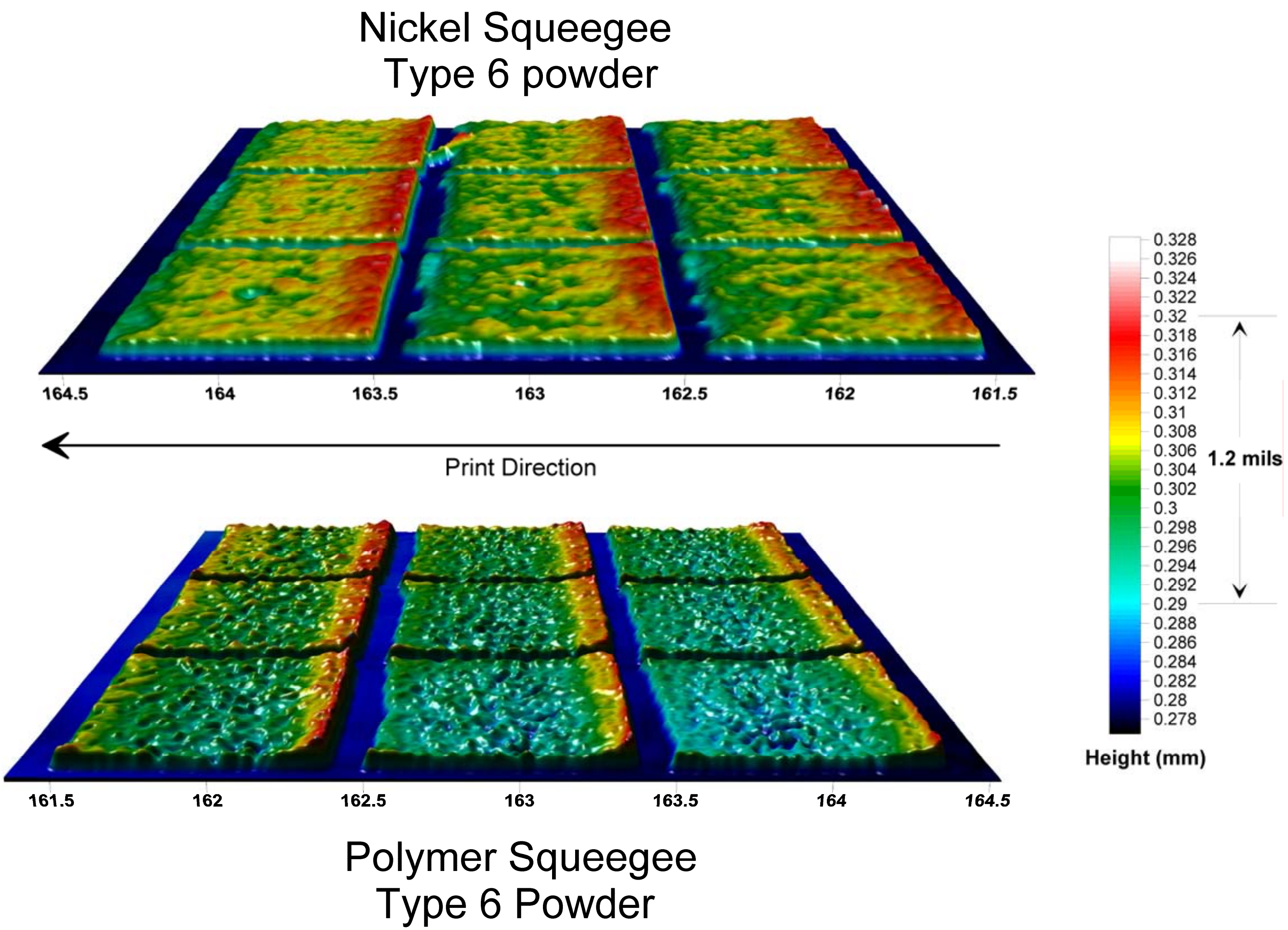
Test Wafer Mini Study – Nickel Squeegee Effects



Test Wafer Mini Study – Polymer Vs Nickel Paste Volume



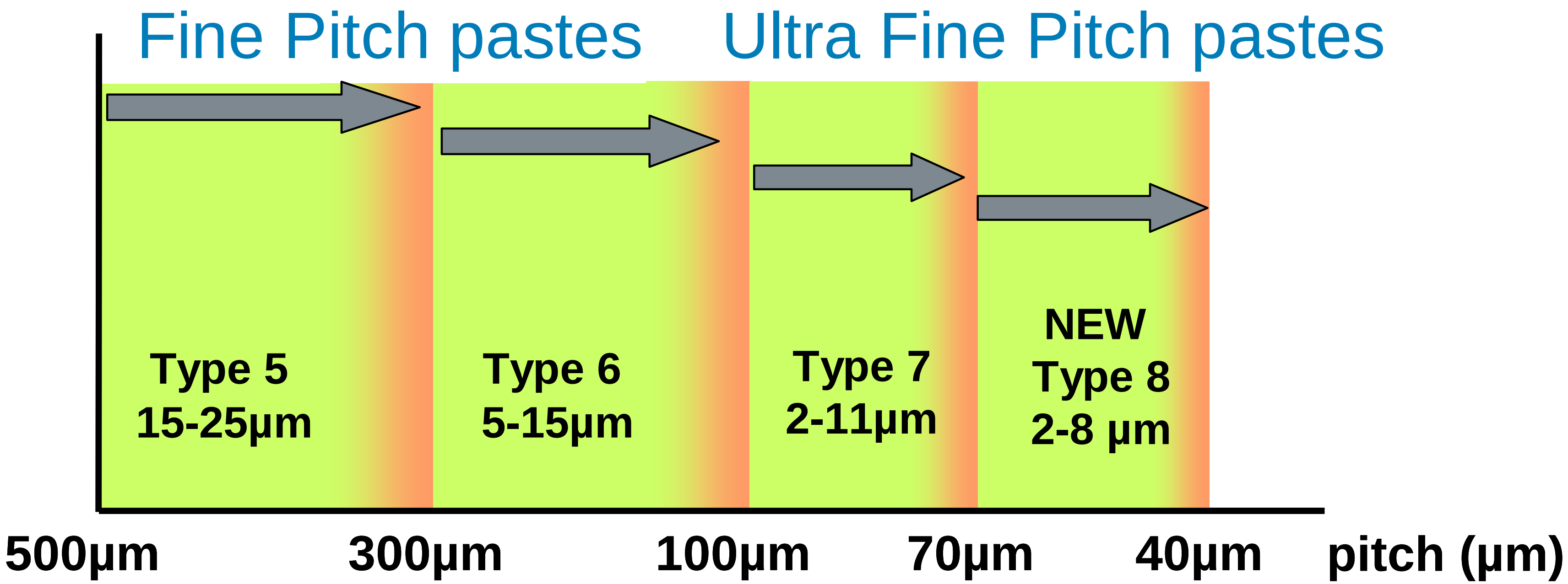
Test Wafer Mini Study – Polymer Vs Nickel Paste Scooping



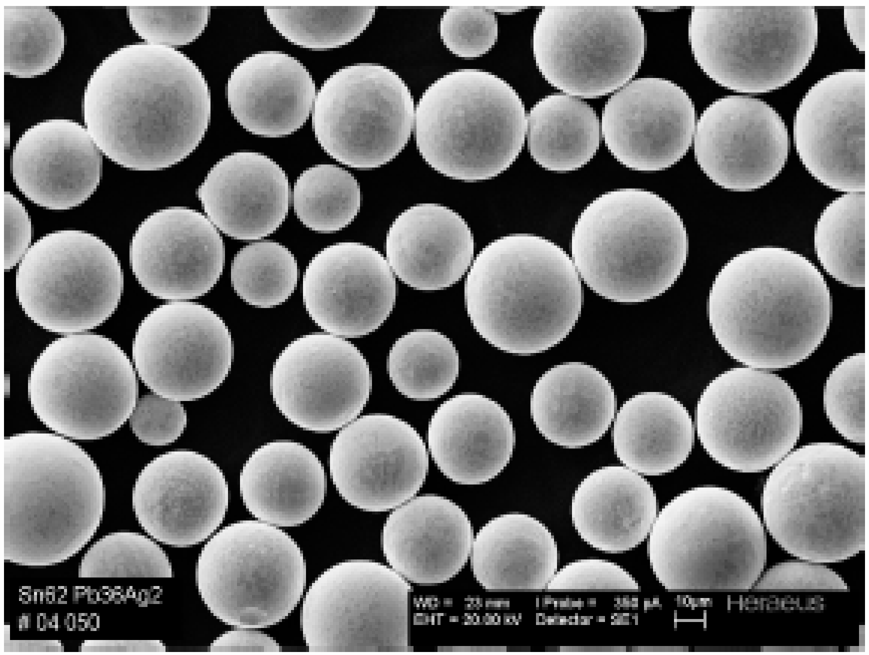
Test Wafer Mini Study – Powder Size Effects

- **Four F510 Lead Free (SAC405) pastes**
  - **Solids and viscosity kept constant**
  - **Powder Types varied - 5, 6, 7 & 8**
- **Polymer squeegee used**
- **Slow print speed**
  - **10mm/s**
- **Slow separation speed**
  - **0.1mm/s**
- **200µ, 175µ, 150µ, 125µ & 100µ pitches measured**
  - **32,400 total bumps measured for mini study**

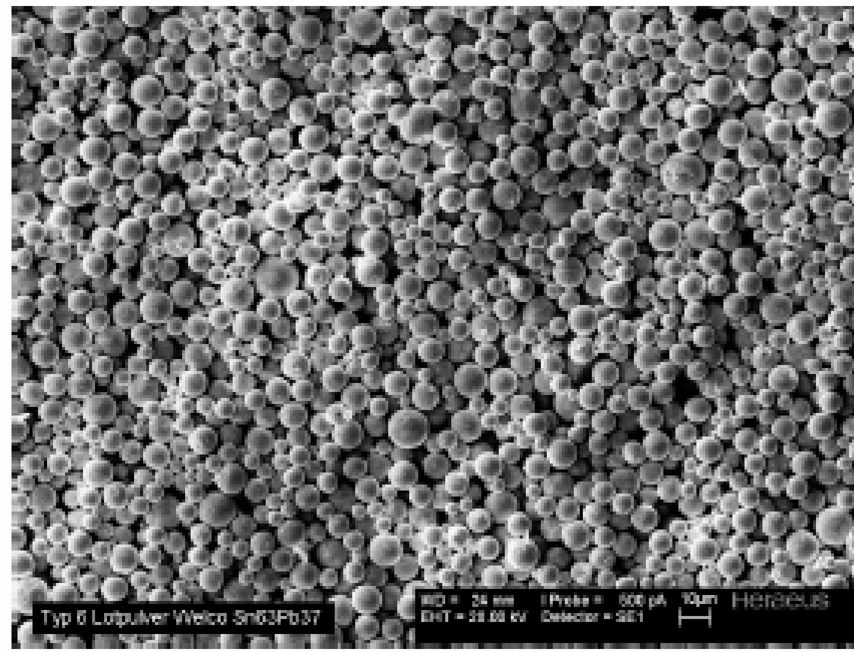
Powder Size Applications



400X Comparison

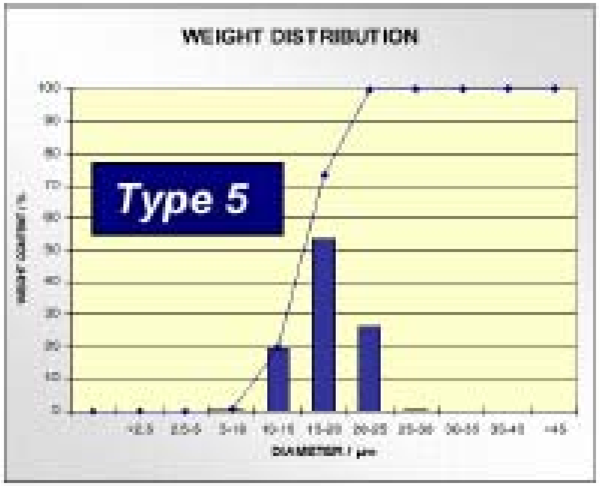


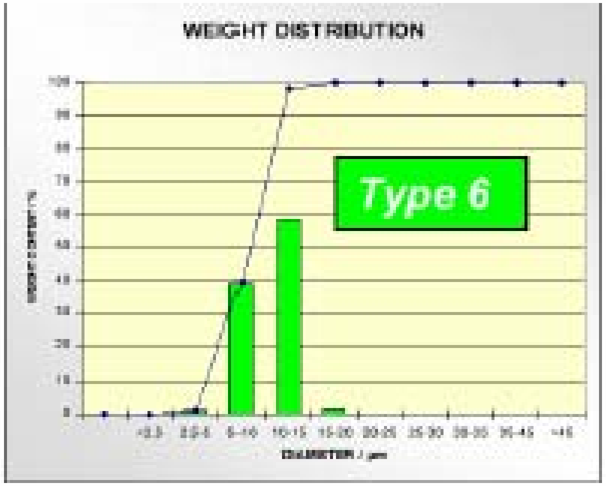
Type 3 25 – 45 µm

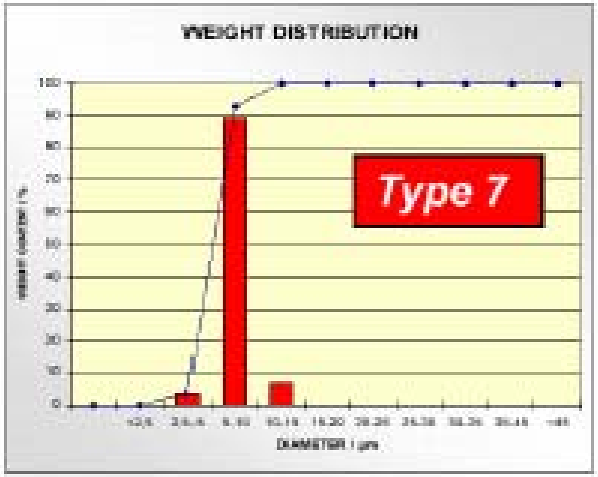


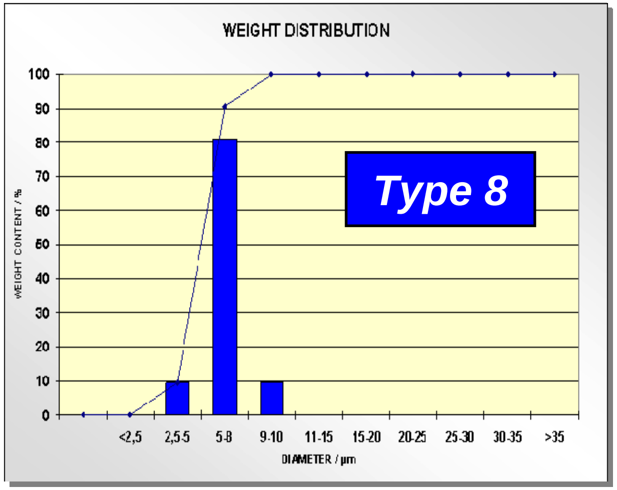
Type 6 5 – 15 µm

Powder Particle Size Distributions

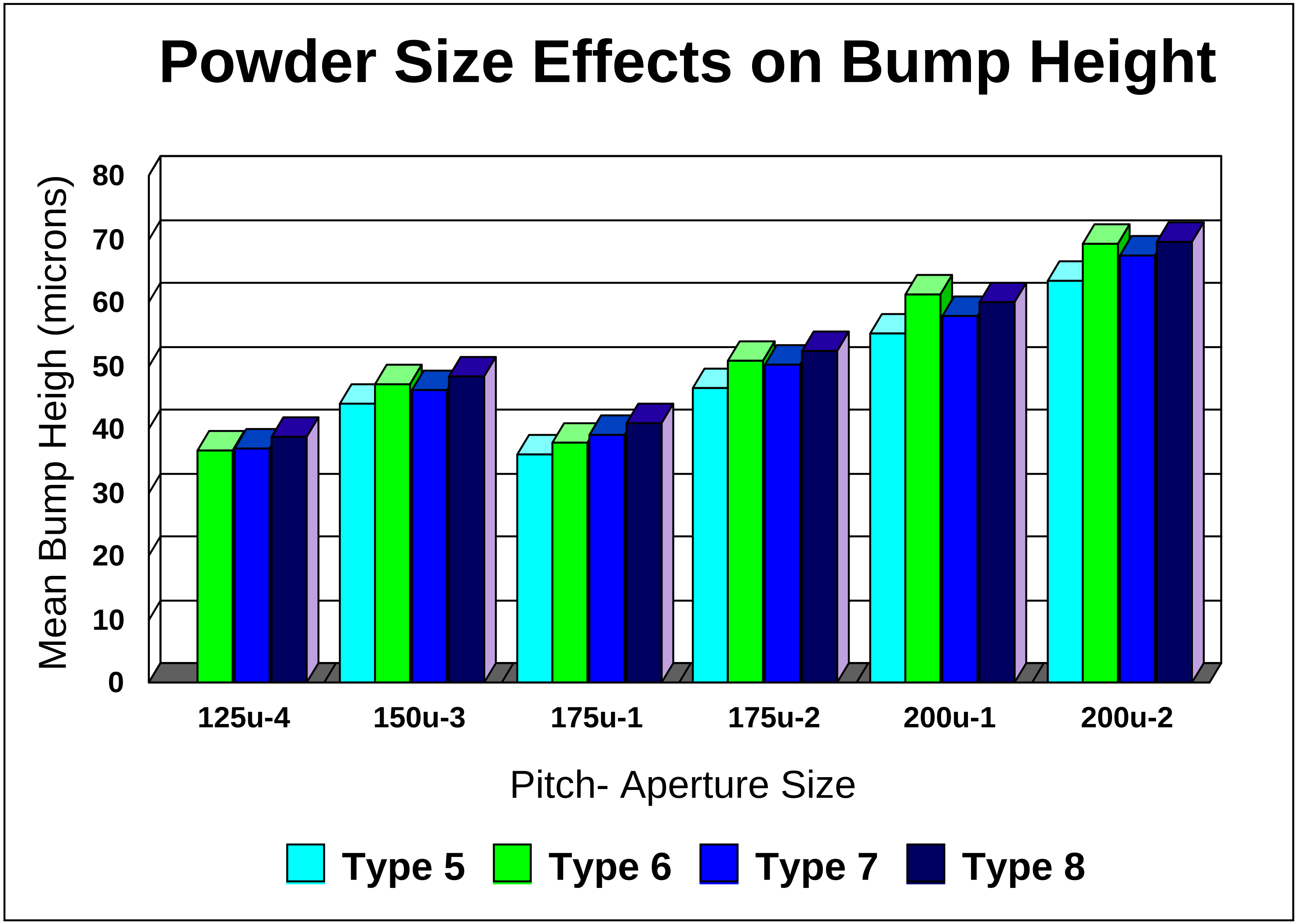




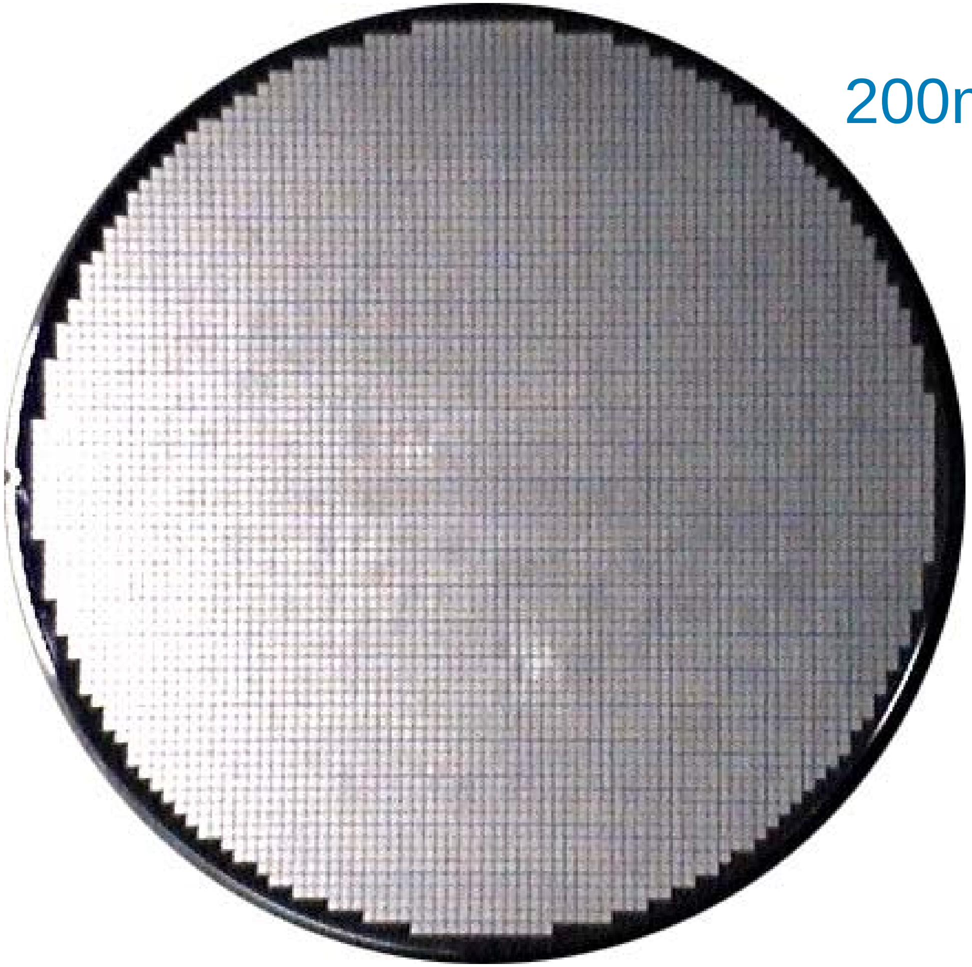




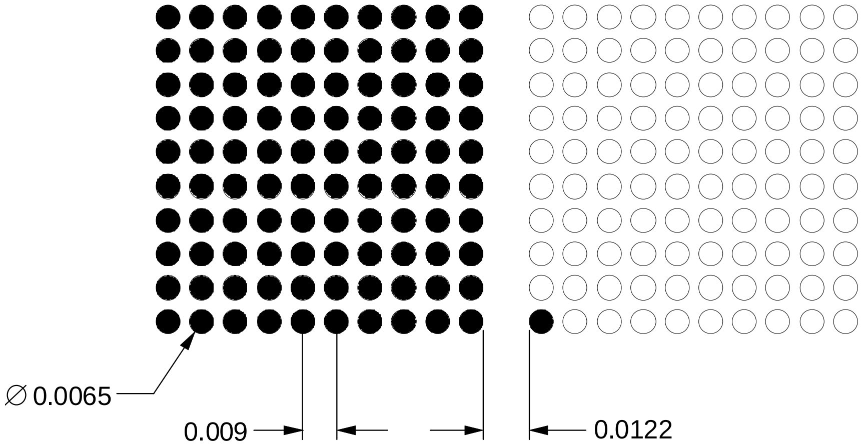
Test Wafer Mini Study – Powder Size Effects



Solder Volume Comparison

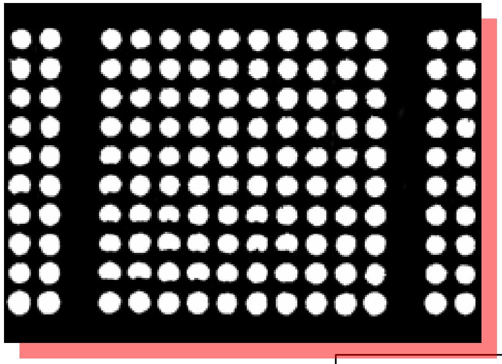


200mm Wafer

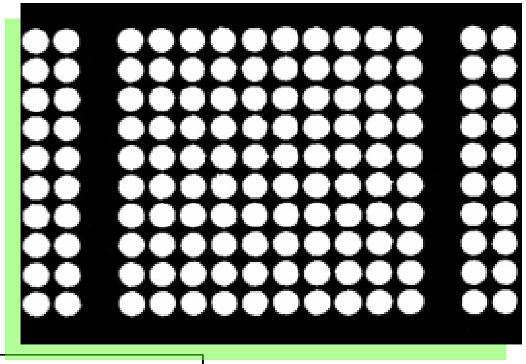


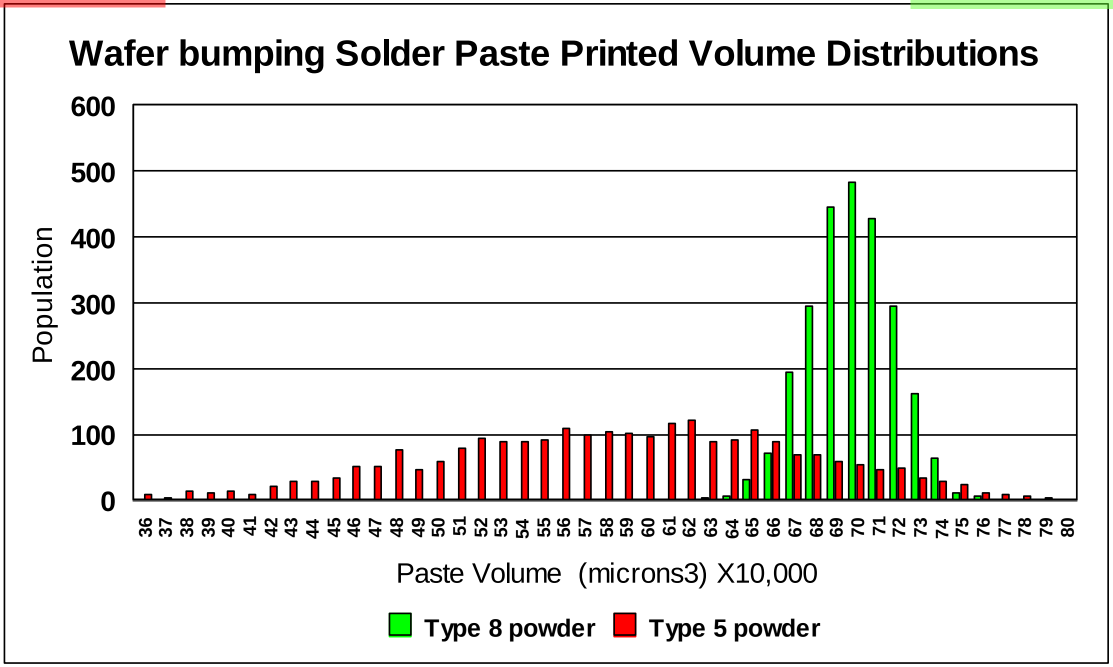
453,000 Apertures

Type 5 Vs Type 8 Printed Volume Comparisons



2500 deposits measured
for each paste



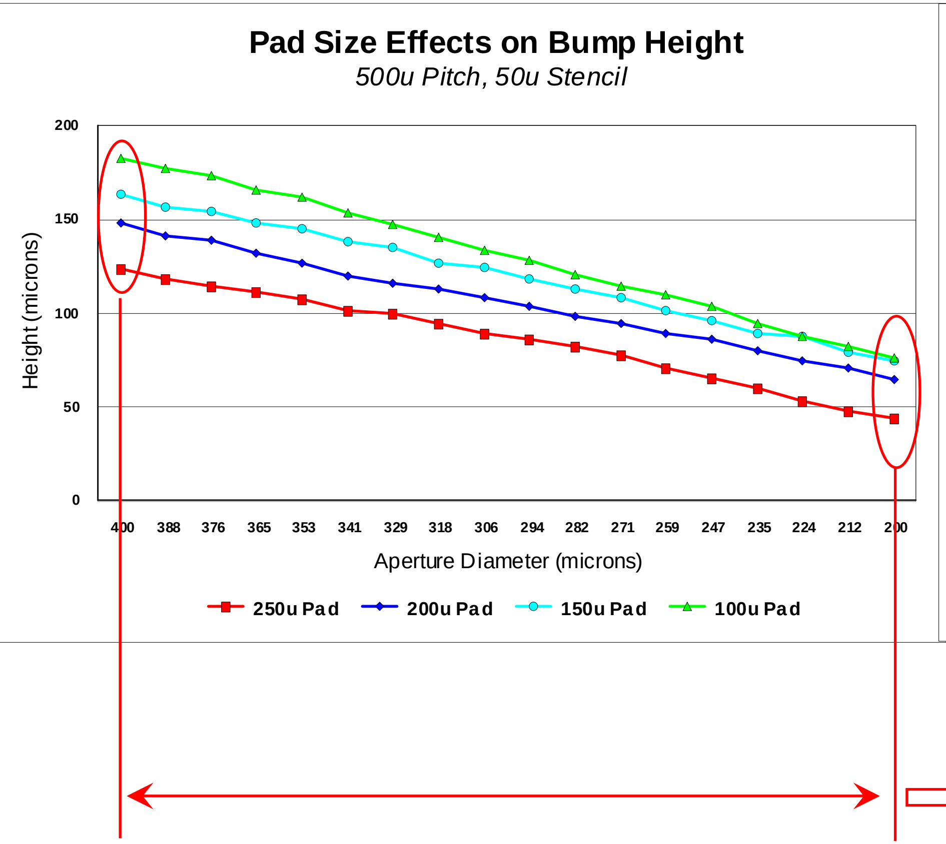


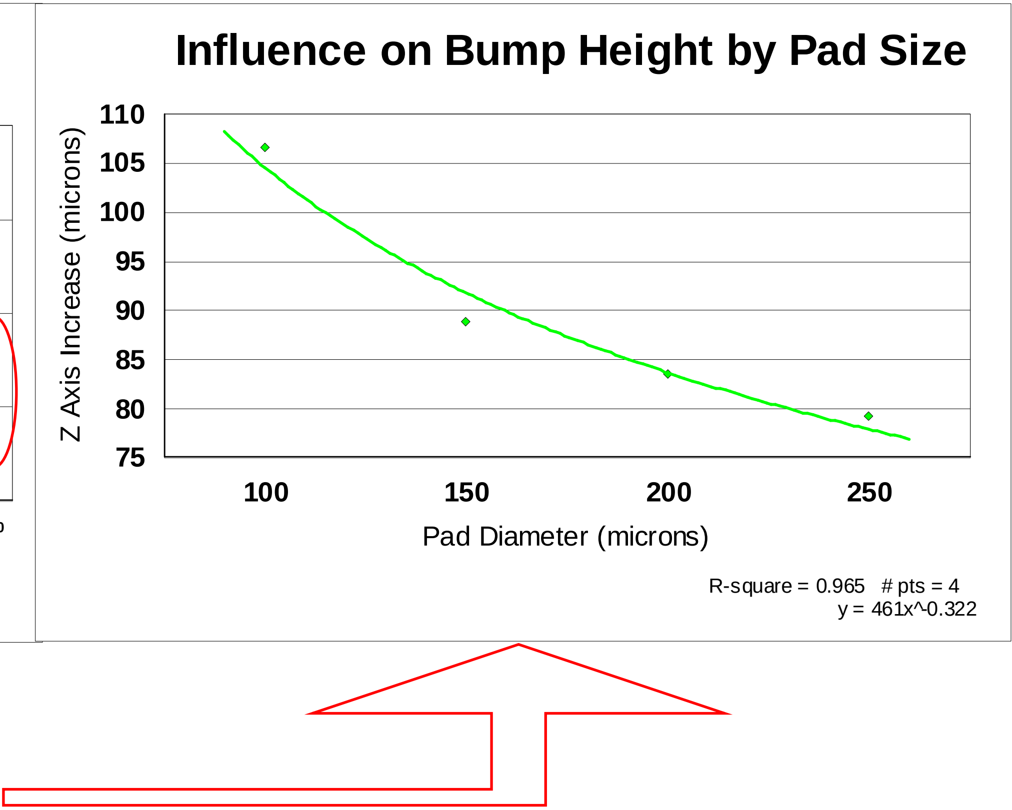
Effect of UBM Diameter on Bump Height

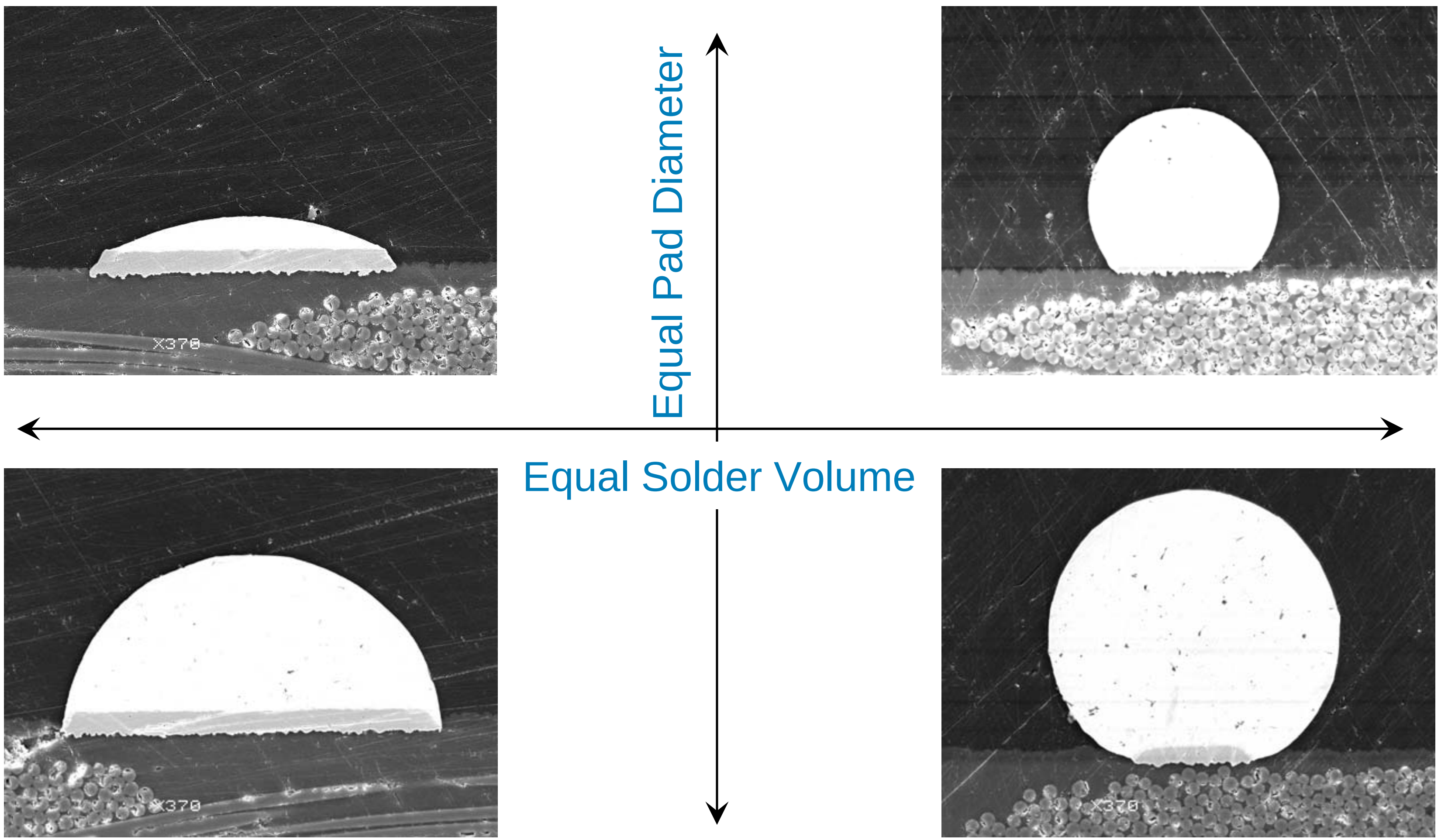
$$V_{solder} = \frac{\pi}{24}\left(3h\phi_{pad}^{2} + 4ah^{3}\right)$$

Where:
V **= volume of transferred solder paste**
h **= reflowed bump height**
a **= shape factor (typically 1.15)**
ϕ **= pad or UBM diameter**

Formula courtesy of Dr. N. Popelar @ IC Interconnect


Pad Size Effects on Bump Height
500u Pitch, 50u Stencil
Height (microns)
200
150
100
50
0
400
388
376
365
353
341
329
318
306
294
282
271
259
247
235
224
212
200
Aperture Diameter (microns)
250u Pad
200u Pad
150u Pad
100u Pad


Influence on Bump Height by Pad Size
Z Axis Increase (microns)
110
105
100
95
90
85
80
75
100
150
200
250
Pad Diameter (microns)
R-square = 0.965 # pts = 4
y = 461x^-0.322


Equal Pad Diameter
Equal Solder Volume
X370
X370
X370

Conclusions

- **Minimum stencil webbing is a function of stencil thickness.**
  - **1.2X for rectilinear shaped apertures, 0.8X for round apertures**
- **Type 6 powder produces higher bump H/P ratios than Type 5.**
- **Finer powders increase bump height moderately.**
- **Nickel metal squeegee helps to prevent scooping in large apertures resulting in tighter bump height distributions.**
- **Finer powders yield tighter paste volume distributions.**
- **Smaller UBM diameters with equal solder volume can increase bump height.**

Questions?