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EVALUATING THE NEXT GENERATION OF STENCIL STEPPING TECHNOLOGIES

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ABSTRACT

Component miniaturization isn't just for phones anymore. The explosion of wearable and IoT connected electronics is accelerating the adoption of smaller packages in many markets, creating a "New Normal" for the SMT assembly industry. To capture and retain business, PCB assemblers can no longer wait for the more intricate processes to be proven out in mobile products and slowly work their way into the mainstream; instead they must proactively develop and demonstrate robust processes to print, place and reflow the emerging smaller components on the same boards as standard SMT components.

With the presence of 01005's and 0.3mm pitch devices on the increase, and even smaller devices such as 008004's on the near distant horizon, evaluating new tools for the print process is very important. Stepped stencils, or stencils where the foil thickness is locally decreased to apply more precise volumes of solder to smaller components or increased to provide greater volumes to larger components, can accommodate the needs of smaller or larger components while still depositing appropriate volumes to standard parts. Stepped stencils have been used for decades, but the technology that creates the steps has changed in the past few years.

Traditional stencil steps were created by chemically etching the material away, resulting in thickness and surface topography variations that negatively influenced print quality. New stepping technologies include micro-milling and laser welding. These offer more precise options than chemical etching, are far more environmentally friendly, and safer for manufacturing personnel.

This paper explains and explores the new stencil technologies. It compares print quality from differently produced stencil steps and different step designs. It also investigates keepout zone and thickness differentials to develop new design guidelines and help users select the right stepping technology for any given board design.

BACKGROUND

Previous studies, as early as 2012[1], demonstrated that welded steps required smaller keepout zones than their chemically etched counterparts, on which IPC guidelines[2] are based. A 2016[3] study further showed that both welded and machined steps could effectively employ the smaller keepout zones, and that the welded and machined steps produced far more consistent solder paste transfer.

EXPERIMENTAL DESIGN

Test Vehicle

The test used the miniaturization test vehicle shown in Figure 1. It contains numerous miniaturized components that were used for evaluation in these tests:

- Eight 0.3 mm BGAs
- Nine 0.4 mm BGAs
- Eight blocks of 01005 (0402M) components
- Four blocks of 008004 (0201M) components

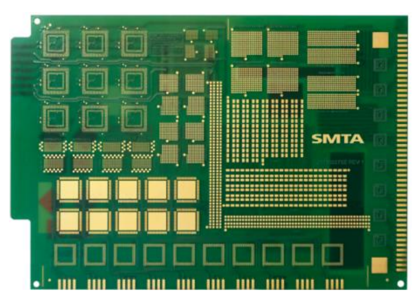

Figure 1. Test PCB

Stencils

Five stencils were tested, in thickness and step configurations common to miniaturized PCB assembly. All of them were coated with a commercial ceramic nanocoating. Table 1 shows their step designs used in this test.

Table 1. Stencils used in test

Foil thickness	Step down thickness	Purpose
2 mil (50 µm)	No step	Baseline data
3 mil (75 µm)	No step	Baseline data
4 mil (100 µm)	3 mil (75 µm)	Welded step eval.
4 mil (100 µm)	3 mil (75 µm)	Milled step eval.
4 mil (100 µm)	2 mil (50 µm)	Milled step eval.

All stencils were laser cut from fine grain stainless steel and coated with a ceramic nanocoating, as this most accurately reflects the stencil materials most often ordered for miniaturized processes.

All step downs were from the top (squeegee side), to promote good stencil-PCB contact and gasketing.

The area ratios of the miniaturized components are shown in Table 2. Area ratios for half-mil (12 µm) increments are tabulated for illustration purposes; full mil (25 µm) increments were tested.

Table 2. Area Ratios for miniaturized components used in the test

Component Size		Type	Pad Size		Stencil Aperture Size		Area Ratios *Stencil Thickness - mil (µm)*				
Imperial	Metric		mil	µm	mil	µm	2 (50)	2.5 (68)	3 (75)	3.5 (88)	4 (100)
008004- ALT-1	0201M	Chip	4.7 x 5.7	120 x 145	4.7 x 5.7	120 x 145	0.64	0.52	0.43	0.37	0.32
008004- ALT-1 Rev 1.0	0201M	Chip	5.1 x 6.3	130 x 160	5.1 x 6.3	130 x 160	0.70	0.56	0.47	0.40	0.35
12 mil or 0.3mm pitch		BGA	6 - round	150 - round	6 x 6[1]	150 x 150[1]	0.75	0.60	0.50	0.43	0.38
16 mil or 0.4mm pitch		BGA	7.5 - round	190 - round	7.5 x 7.5[1]	190 x 190[1]	0.94	0.75	0.63	0.54	0.47
01005	0402M	Chip	8x8 (7 mil gap)	200 x 200	8 x 8	200 x 200	1.00	0.80	0.67	0.57	0.50
01005- ALT-1	0402M	Chip	8x8 (8 mil gap)	200 x 200	8 x 8	200 x 200	1.00	0.80	0.67	0.57	0.50
20 mil or 0.5mm pitch		BGA	10- round	250 - round	10 x 10[1]	250 x 250[1]	1.25	1.00	0.83	0.71	0.63

[1] - Square apertures with radiused corners

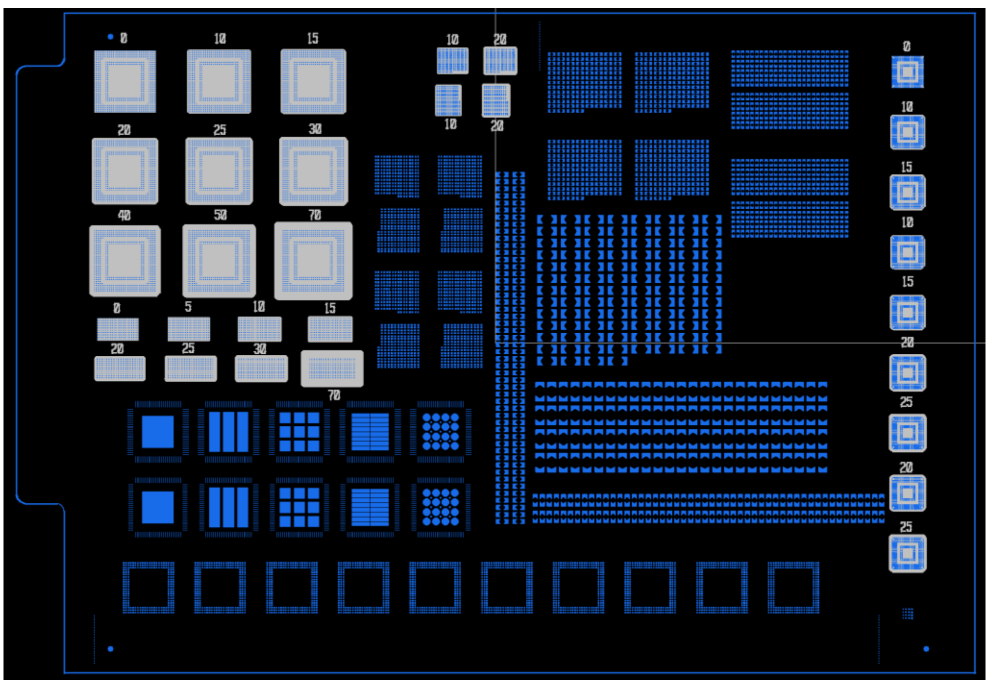

Figure 2. Test stencil design

The keepout zone, or the distance from the edge of the outermost aperture to the edge of the step were varied for individual BGAs and blocks of discrete components. The keepout zones and distances are shown in Figure 2.

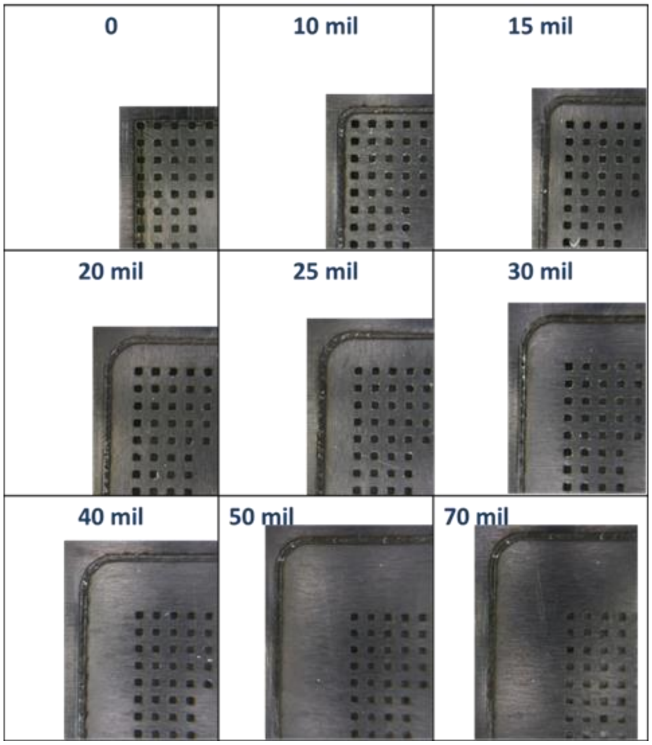

Figure 3a. Welded stencil steps

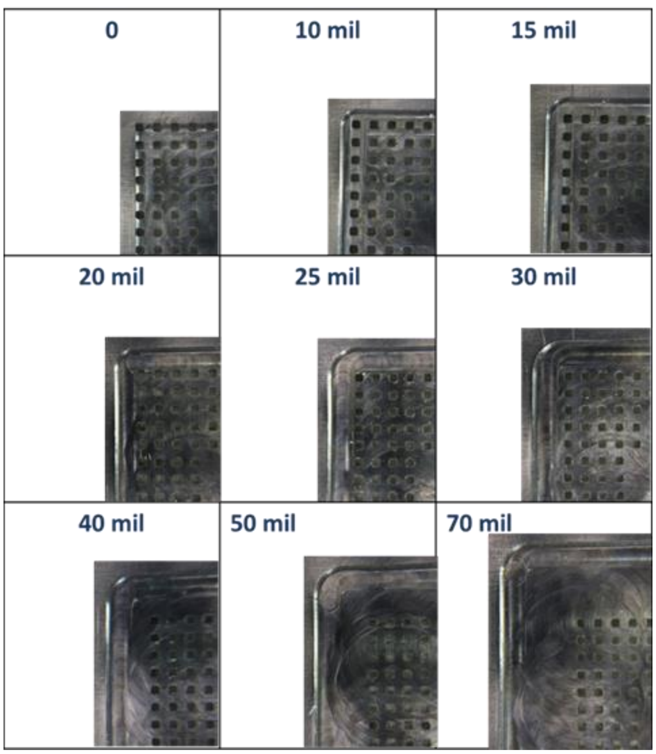

Figure 3b. Machined stencil steps

Closeup views of the steps and apertures are shown in Figures 3a and 3b.

Solder Paste

The solder paste used was a popular no-clean, type 4, lead-free formulation.

Print Tests

The solder paste print parameters were optimized for the 01005 (0402M) and 0.3 mm BGA using a 3 mil foil. The same parameters were used for all print tests:

- Squeegee speed: 1.5 in/sec
- Squeegee pressure: 1.5 lb./in (8 mm tall surgical steel squeegee blades)
- Separation speed: 0.2 in/sec; Distance 0.10 in,; Continuous motion
- Wipe: Dry-Vac-Vac every board

Each test consisted of 2 dummy prints to get the solder paste into its working viscosity range and 6 live prints that would immediately be inspected.

The printer setup used:

- MPM Edison
- A custom vacuum tooling plate to ensure solid support

Inspection

The printed boards were immediately inspected on a PARMI Sigma X SPI machine using a 15 µm threshold. Volume, area and height data were collected and analyzed.

Prior to executing the tests, the printer capability was verified using CeTaq[4] measurements, and the SPI was calibrated using its built-in calibration tool.

DATA ANALYSIS

Data was formatted in Excel for analysis.

First, the averages and standard deviations for each component location were calculated and used to determine Coefficients of Variation and Cpks. These calculations provide an overall snapshot of the deposits for each component, and therefore each keepout distance, but do not explicitly identify the effect of the step on the closest apertures.

In order to see the effects of the step edge on deposit volumes and variations, the volume data for the 0.4 mm BGAs (04BGA) and 0.3 mm BGAs (03BGA) was manipulated in a pivot table, and sorted by the pin's row and column numbers to visually represent the positions of each volume dataset relative to the component itself.

The spreadsheet cells were then formatted as heat maps. The heat maps show varying colors depending on the dataset volumes and standard deviations for each pin, illustrating the effect of the keepout zone on print quality.

RESULTS & DISCSUSSION

Prints from the 2 mil (50 µm) foils and the 4-2 mil (100-50 µm) stepped foils showed more variation than the 3 mil (75 µm) and 4-3 (100–75 µm) stepped foils. Type 4 solder paste, with particle sizes typically in the 20-38 µm range, are the likely cause of the variation. 2 mil (50 µm) single-thickness foils require finer powders to achieve adequate aperture fill. The 4-2 likely achieved better results because the step down allowed more of the paste particles to remain above the 2 mil pocket's top surface.

First analysis: 0.5 mm pitch BGA. This is one of the simplest to print components on the board, and is used as a checkpoint to ensure tests were executed properly. There were no steps on the 0.5 mm footprints, therefore the welded and machined steps were absent, and the foils were 4 mils thick. Expected volumes for these apertures are typically 350-400 mils^3 using a 4 mil foil, and around 300-325 mils^3 using a 3 mil foil, and CVs are typically in the 8% range. The as-expected results shown in Table 3 indicate successful test execution.

Table 3. Results of 0.5mm BGA Volumes (no steps on 05 BGAs)

		3 mil foil		4-3 weld		4-3 mill	
Component	Keepout (mil)	Average of Volume mils^3	Coefficient of Variation %	Average of Volume mils^3	Coefficient of Variation %	Average of Volume mils^3	Coefficient of Variation %
05BGA01	0	320	8	396	7	403	8
05BGA02	0	324	8	397	7	402	8
05BGA03	0	324	7	392	7	405	10
05BGA04	0	325	7	390	7	399	8
05BGA05	0	319	8	385	7	396	7
05BGA06	0	318	7	387	7	398	8
05BGA07	0	316	8	389	7	396	7
05BGA08	0	320	7	392	7	400	7
05BGA09	0	321	7	395	7	396	7
05BGA10	0	316	7	394	8	393	7

CV ≤ 10%	10 < CV ≤ 15%	CV > 15%

The 04BGA showed average volumes of 186 mils^3 for the 3 mil foil and 4-3 welded foil, and an average volume of 197 mils^3 for the 4-3 milled foils. For the purposes of Cpk calculations, targets are set at 185 for the first two stencils, and 200 for the third. To base them on an overall average of the three differing processes would penalize all Cpk values by beginning with an off-target mean value. Upper and lower control limits were set at +/- 50% of the target. The means and CVs are show in Table 4, and the CVs and Cpks are compared in Table 5.

Table 4. Mean volumes and CVs for 04BGAs

		3 mil foil		4-3 weld		4-3 mill	
Component	Keepout (mil)	Average of Volume mils^3	Coefficient of Variation %	Average of Volume mils^3	Coefficient of Variation %	Average of Volume mils^3	Coefficient of Variation %
04BGA01	0	173	10	196	13	202	13
04BGA02	10	178	9	187	12	207	9
04BGA03	15	182	9	181	14	208	9
04BGA04	20	175	9	192	10	202	10
04BGA05	25	179	8	192	9	203	9
04BGA06	30	182	8	191	9	203	9
04BGA07	40	185	7	195	8	208	9
04BGA08	50	188	7	197	10	209	7
04BGA09	70	190	7	195	8	206	7

CV ≤ 10%	10 < CV ≤ 15%	CV > 15%

Cpk is a composite index that compares the average and spread of the data to the target and control limits. Typically, values of 2.0 or higher are considered excellent (green cells), values between 1.66 and 2.0 are considered very good (yellow cells), values between 1.5 and 1.66 are marginal (red cells) and values below 1.33 are completely unacceptable (grey cells).

Table 5. CVs and Cpks for 04BGAs

		3 mil foil		4-3 welded		4-3 milled	
Component	Keepout (mil)	CV %	Cpk	CV %	Cpk	CV %	Cpk
04BGA01	0	10.3	1.50	13.0	1.07	13.2	1.23
04BGA02	10	8.9	1.81	12.5	1.29	9.1	1.63
04BGA03	15	8.7	1.89	14.1	1.15	9.4	1.57
04BGA04	20	8.8	1.78	9.9	1.50	9.7	1.68
04BGA05	25	8.5	1.90	9.5	1.57	9.0	1.77
04BGA06	30	8.1	2.03	9.2	1.64	9.2	1.73
04BGA07	40	7.3	2.29	8.2	1.73	9.2	1.59
04BGA08	50	6.7	2.35	9.6	1.42	7.3	1.98
04BGA09	70	6.9	2.21	8.4	1.69	7.2	2.12

Table 5 shows that Cpks and CVs do not necessarily correlate, but the general trend is that as keepout areas grow, both the CVs and Cpks improve. The exceptions are the 04BGA05 on the welded stencil and the 04BGA07 on the milled stencil.

The heat maps more clearly illustrate the differences in deposition qualities. In the heat maps based on average volumes, yellow cells indicate volumes 30% or less than the average, green cells indicate average volumes, and navy blue cells indicate volumes 30% or higher above the average.

The single thickness and 4-3 welded foils center on 185 mils^3, as shown in Figure 4.

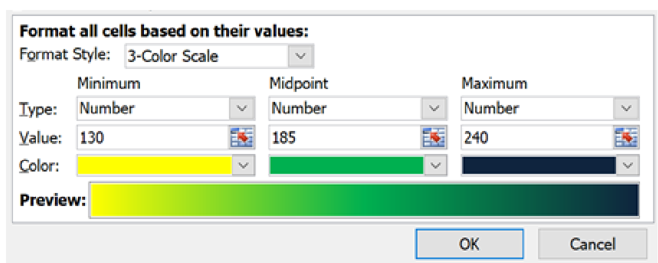

Figure 4. Heat map legend for 04BGAs printed with single thickness 3mil or 4-3 welded foils.

The 4-3 milled foil centers on 200 mils^3, as shown in Figure 5.

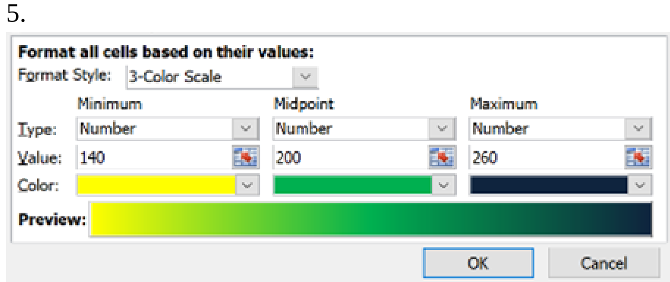

Figure 5. Heat map legend for 04BGAs printed with 4-3 milled foil.

Figures 6a-6cshow the heat maps for the 3 mil, 4-3 welded and 4-3 milled stencils.

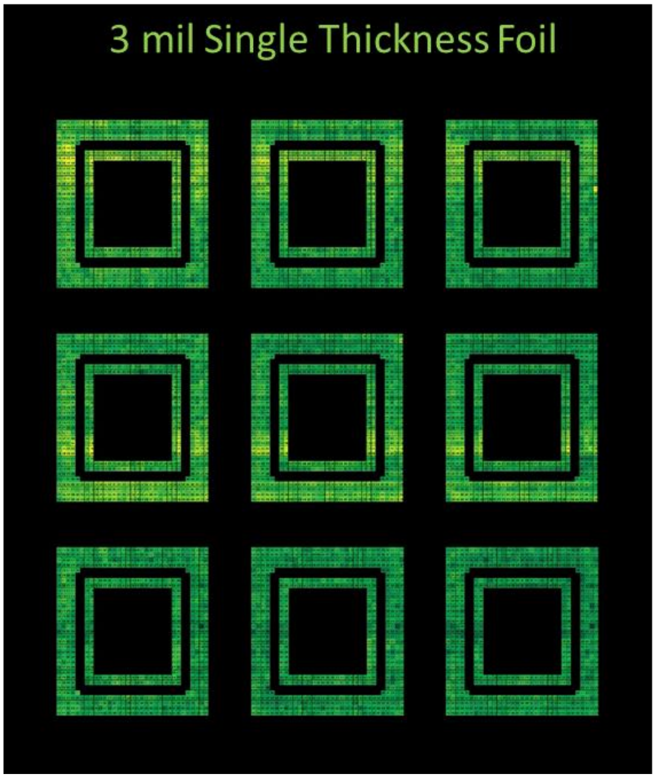

Figure 6a. Deposit volume heat map for 3 mil single thickness foil

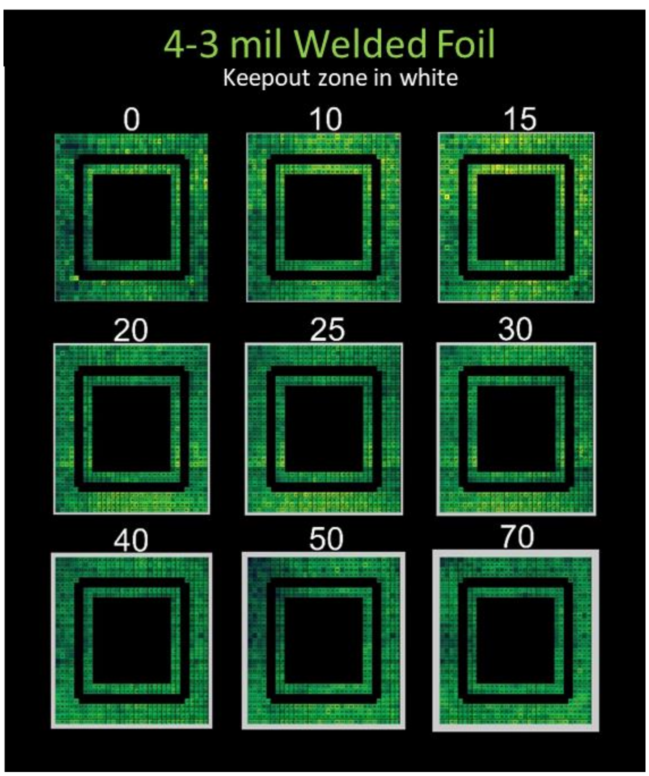

Figure 6b. Deposit volume heat map for 4-3 mil welded foil

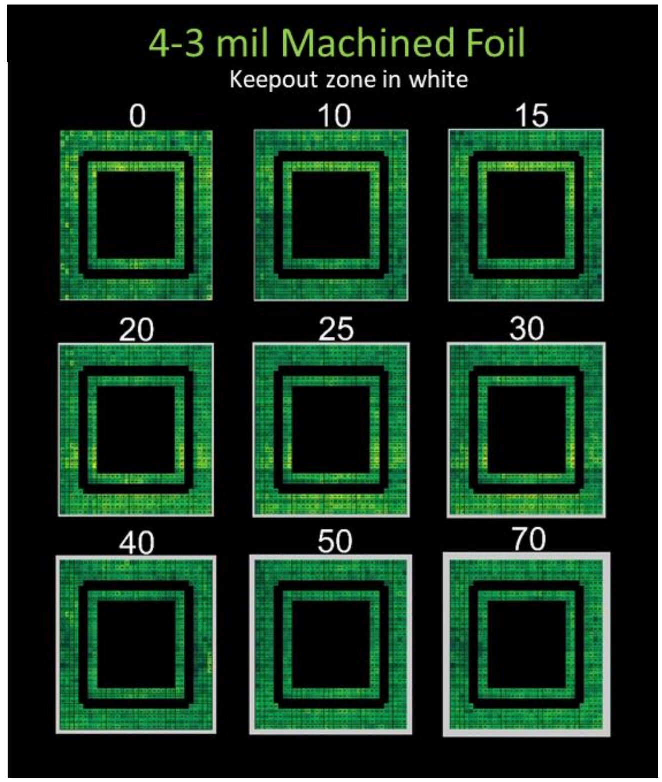

Figure 6c. Deposit volume heat map for 4-3 mil machined foil

"Light streaks" appear near the top of the top row and the bottom of the second row. This is likely because these areas are near the edge of a line scan on the SPI machine where scans are stitched together. These lighter areas don't show up as defects when running print tests, because tolerance levels are typically set at +/- 50%, whereas the heat maps reflect +/- 30% differentials. The SPI machine can be reprogrammed to eliminate this artifact.

Comparing the deposit volume heat maps of the single thickness and stepped foils, it appears that the welded steps show some very high volume deposits with the 0 mil keepout zone. Volume differentials continue with the 10 and 15 mil keepouts, and comparable volumes start appearing in the 20-25 mil keepout range.

The machined steps also show a lot of volume differentials at the 0 mil keepout zone, but start showing stable volume performance in the 10-15 mil keepout range.

Consistent volumes from print-to-print are as critical as consistent volumes from pin-to-pin. Therefore, heat maps were generated to review variation at each deposit site. The standard deviation heat maps shown in Figures 7a – 7c are two-color: any cells that are yellow have standard deviations <10% of their average; red cells have standard deviations >10% of their average.

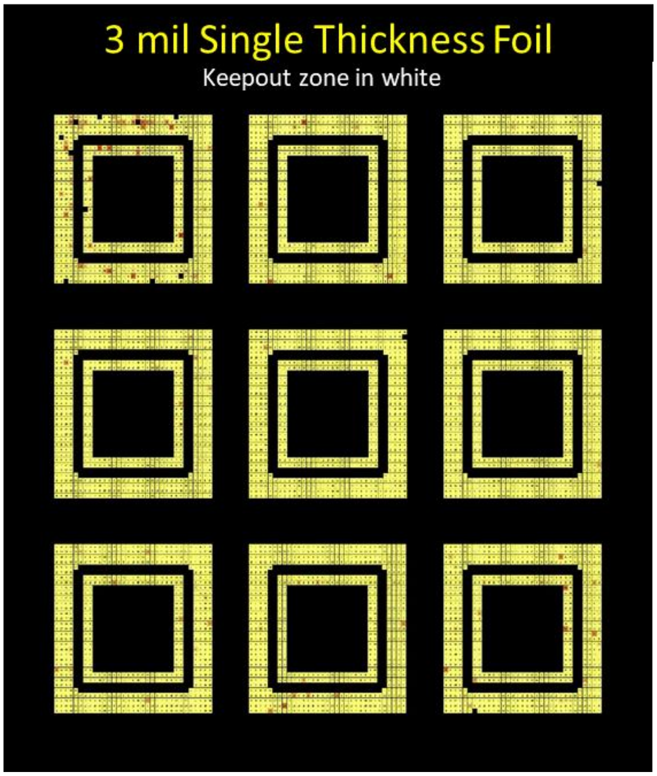

Figure 7a. Standard deviation of deposit volume heat map for 3 mil single thickness foil

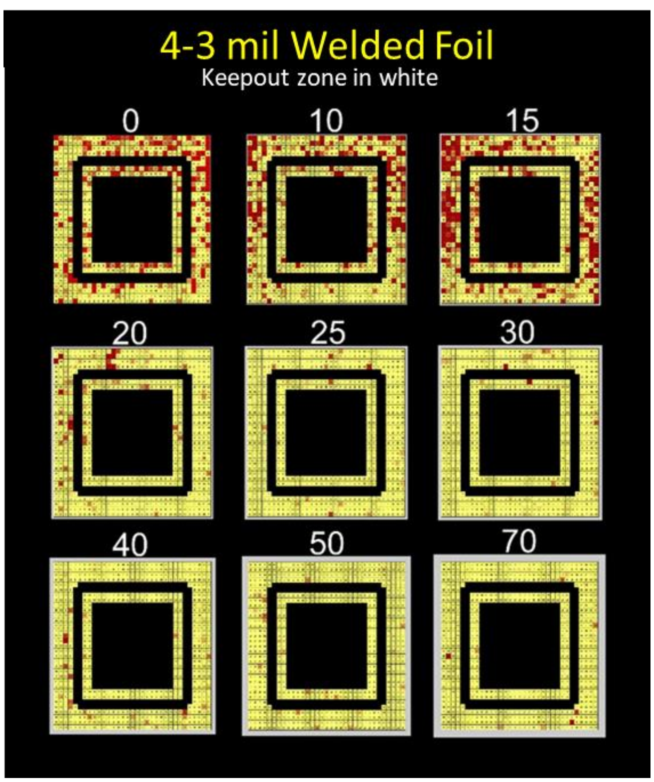

Figure 7b. Standard deviation of deposit volume heat map for 4-3 mil welded foil

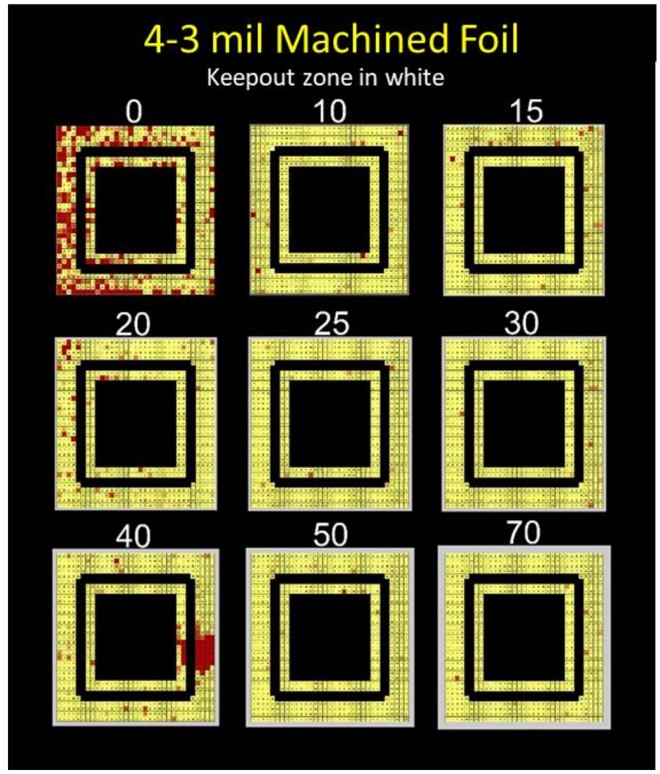

Figure 7c. Standard deviation of deposit volume heat map for 4-3 mil machined foil

The print-to-print variability is unacceptable up through the 20 mil keepouts on the welded foil, but appears acceptable with the 10 mil keepout on the machined foil.

The IPC 7525 specification, which was generated in an era of chemically etched step downs only, calls for a keepout zone of 35 mils per 1 mil step down. General industry guidance calls for a minimum of 25 mils. The data gathered in this test suggests that, on welded steps, a 25 mil keepout zone on a 4-3 foil can produce print results very similar to that of a single thickness 3 mil foil. This addresses numerous concerns about populating 04BGAs on boards requiring stencils thicker than 3 mils for other components.

The data also suggests that a machined step can produce print results comparable to the single thickness foil with a 10 mil keepout zone.

Two very interesting observations were investigated after reviewing the heat maps.

1) Very high volumes – consistently very high volumes – on the welded step with a 50 mil keepout

2) Very high print-to-print variation in a specific area of the machined foil with a 40 mil keepout

Both areas were inspected and photographed for anomalies. None were found with simple, nondestructive methods.

The welded step with the 50 mil keepout that produced consistently high volumes is shown in Figure 8. The topside weld looks typical. The high mean volumes and low variations suggest a systemic root cause.

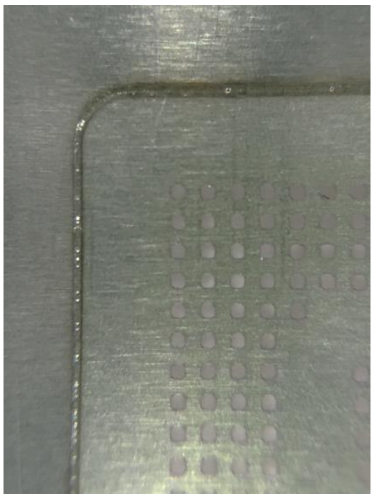

Figure 8. The area of the welded stencil that produced consistently high volumes

The machined step with the 40 mil keepout that produced low average volumes with high variation is shown in Figure 9. The cut looks typical. The low mean volume and high variation scenario suggests one or possibly two bad prints with insufficient deposits. A deeper review of the data will confirm or discredit this suggestion.

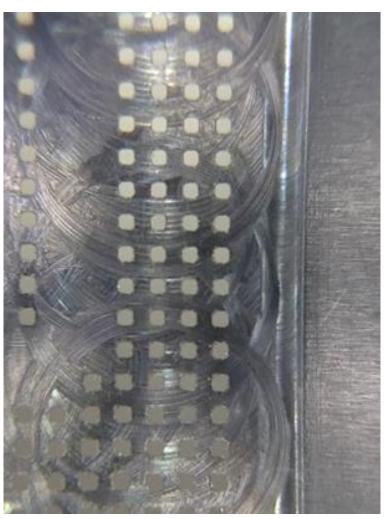

Figure 9. The area of the machined stencil that produced low average volumes and high variation

Recall that the 50 mil keepout welded and 40 mil keepout machined stencils did not follow the CV and Cpk trend shown in Table 5. The trend showed CVs reducing and Cpks increasing as keepouts grew larger, with the movement of both indices indicative of improving print quality. The exceptions to the trend were the cases of the 50 mil keepout on the welded stencil and the 40 mil keepout on the machined stencil. The overall data indicated issues; the heat map pinpointed the areas and differences between them. The 50 mil keepout on the welded stencil had a lower Cpk because of its mean shift but low variation; the 40 mil keepout on the machined stencil had a lower Cpk because although its average was good, the spread of the data was excessive.

The stencils are being preserved for future tests. If the anomalies continue on the next round of print tests, they will be cross sectioned for more detailed analysis.

01005 components (M0402) were also reviewed with different keepout zones. Because their pin numbers are not set up in arrays like the BGAs, heat maps are more difficult to produce. The aperture sizes and shapes are identical to those of the 04BGAs, but they are spaced farther apart than those of the 04BGAs.

The mean volumes, CVs and Cpks for the 01005s are shown in Table 6.

Table 6. Print statistics for 01005s

	Stencil Avg	Keepout	AVG	CV	Cpk
3 mil flat	167	0	156	10.9	1.29
		0	168	8.0	1.93
		0	158	9.3	1.55
		0	172	7.1	2.24
		0	158	9.9	1.46
		0	171	7.3	2.15
		0	159	8.9	1.63
		0	174	6.5	2.49
4-3 weld	183	0	190	9.0	1.57
		5	191	9.0	1.54
		10	174	10.6	1.53
		15	182	11.0	1.45
		20	180	9.5	1.74
		25	180	10.3	1.61
		30	181	10.7	1.53
		70	180	8.8	1.89
4-3 mill	194	0	192	13.5	1.00
		5	202	9.4	1.18
		10	192	8.1	1.69
		15	193	8.5	1.56
		20	191	7.9	1.73
		25	198	8.3	1.46
		30	193	8.1	1.65
		70	191	8.6	1.61

The average volumes deposited by stencil type track with those of the 04BGAs, but the variations are lower. A possible explanation for the differences among apertures of the same size and shape is the density of the spacing. The spaces between the component terminations are on the same 0.4 mm centers as the 04BGAs, but the component-to-component spacing is 0.5mm. Therefore, spacing is consistent at 0.5 mm pitch in one axis and alternates between 0.4 and 0.5 in the other axis, depending on the component orientation in each section. The lower density of apertures may influence the depletion of fill pressure on the rolling solder paste bead.

Overall, 10 mil keepout zones appear sufficient for 01005s, regardless of the stepping technology.

0.3mm BGAs and 008004s (M0201s) showed high enough variation to deem the print processes unacceptable with current type 4 solder pastes. It should be repeated with Type 4.5 and Type 5 products.

CONCLUSIONS

In concurrence with previous investigations, documented stencil stepping keepout zones can be decreased with newer manufacturing technologies. The extent of keepout zone gains is dependent on the method by which the step is created.

Guidelines based on chemically etched steps specify a 35 mil keepout for a 1 mil step down. This experiment demonstrated that a 25 mil keepout is sufficient for a welded step and a 10 mil keepout is sufficient for a machined step~~,~~ when printing 0.4 mm BGAs with 4 mil foils that step down to 3 mils for the miniaturized components.

PCB assemblers interpreting these findings should consider the engineer-led laboratory execution of the print tests versus the capability of their current manufacturing system. Keepout minimums may need to be scaled up based on the capability of the current production printing process.

The design and manufacturing capability tradeoffs can be considered on a case-by-case basis and based on actual print capability, but data-driven DFM decisions can be made at the initial PCB layout level.

The learnings from this experiment offer options to PCB designers and assemblers. If the minimum suggested keepout zones cannot be applied to the layout, then two cost-adding options are available:

1. Accept the smaller keepout zone and absorb the cost of the associated defects, rework and warranty failures later in the product life
2. Employ machined stencil steps throughout the manufacturing life of the product. Machined steps are more expensive than welded steps because they require specialized, precision equipment.

In either case, economics may be the best indicator of the preferred path.

FUTURE WORK

The stencils have been preserved to continue studying print capability on the fine features. The investigation team wants to repeat the tests with type 4.5 and type 5 solder pastes, and plan to include the 2 mil and 4-2 mil stepped stencils in the tests and report results.

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[4] CeTaq, an independent machine capability analysis service provider. https://www.cetaq.com

Originally presented at

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Evaluating the Next Generation of Stencil Stepping Technologies

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Agenda

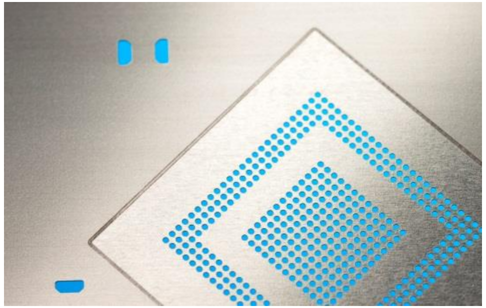
- What is a stepped stencil?
- Established guidelines
- Experiment using different keepout distances
- Results and statistics
- Heat maps
- Conclusions
- Future work

What is a Stencil Step?

Stencil foil thickness is locally changed to manipulate deposit volume

Stepping is critical in many processes, especially when stencil design calculations are being performed based on aperture volumes and area ratios

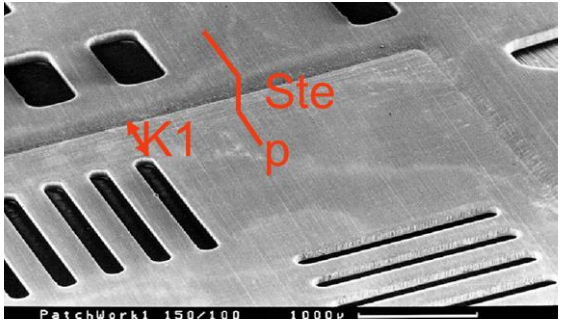
- Steps can be **chemically etched, milled, or welded** prior to laser cutting
- Step Types:
  - **Step Up:** Thickens stencil locally
  - **Step Down:** Thins stencil locally
  - **Top or Bottom side steps,** or both
  - **Angled steps:** Reduce squeegee damage (also w/encl print heads)
  - **Cavity relief:** For labels or other PCB topographical features



- **Chemical etching is rapidly becoming obsolete – Welding and milling are more accurate, environmentally friendly, and economical**

IPC 7525 Stencil Step Guidelines

Step Depth	K1 is distance form the step edge to the nearest aperture in stepped down area
0.010mm, 0.4mil	0.36mm, 14mil
0.025mm, 1mil	0.90mm, 35 mil
0.030mm, 1.2mil	1.08mm, 42mil
0.050mm, 2mil	1.80mm, 71mil
0.080mm, 3 mil	2.88mm, 113mil
0.100mm, 4mil	3.60mm, 142mil



These are currently under review with IPC 7525 committee

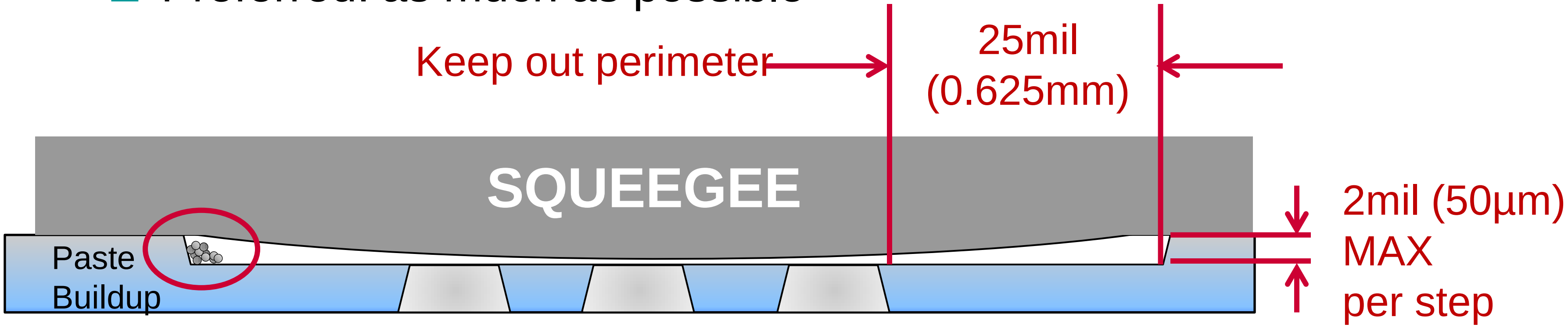
General Guidelines

Depth: no more than 2mil per step

- Will lose fill pressure on solder paste

Keepout zone: distance from aperture to edge of step

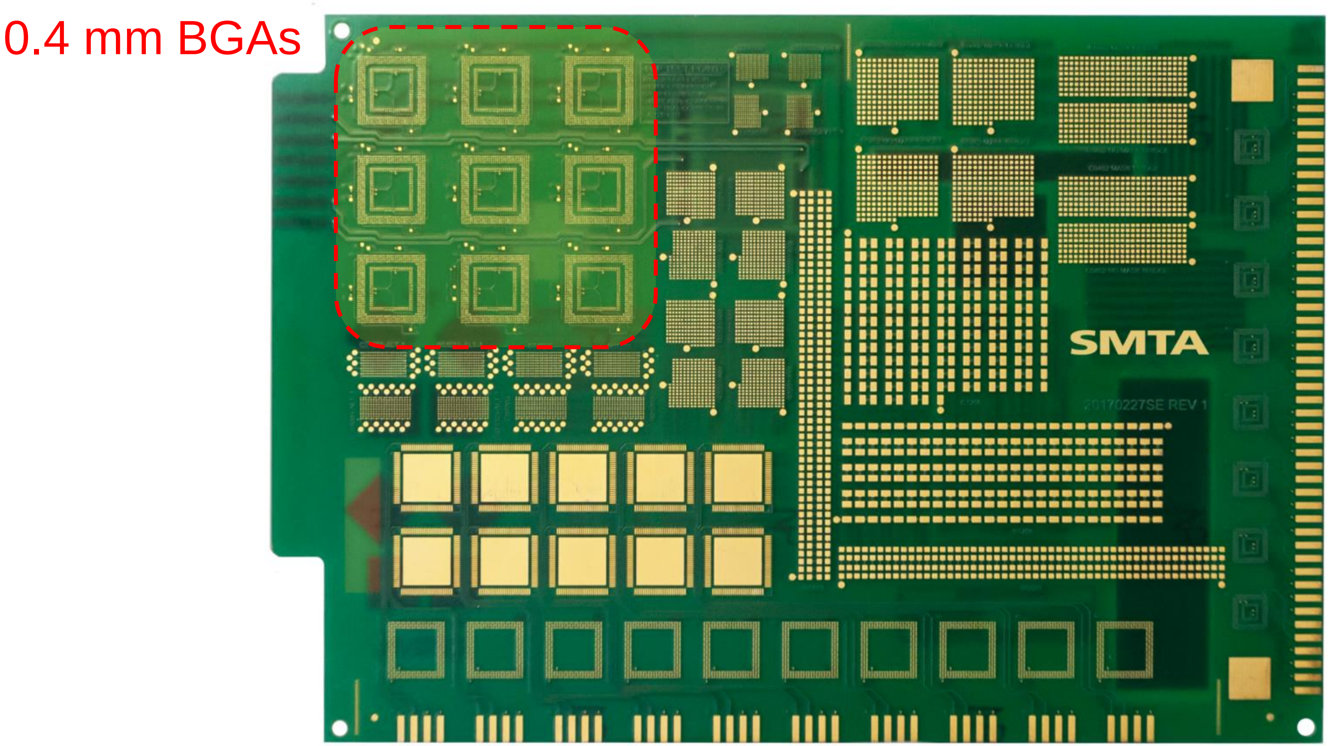
- Minimum recommended: 25mil
- Preferred: as much as possible



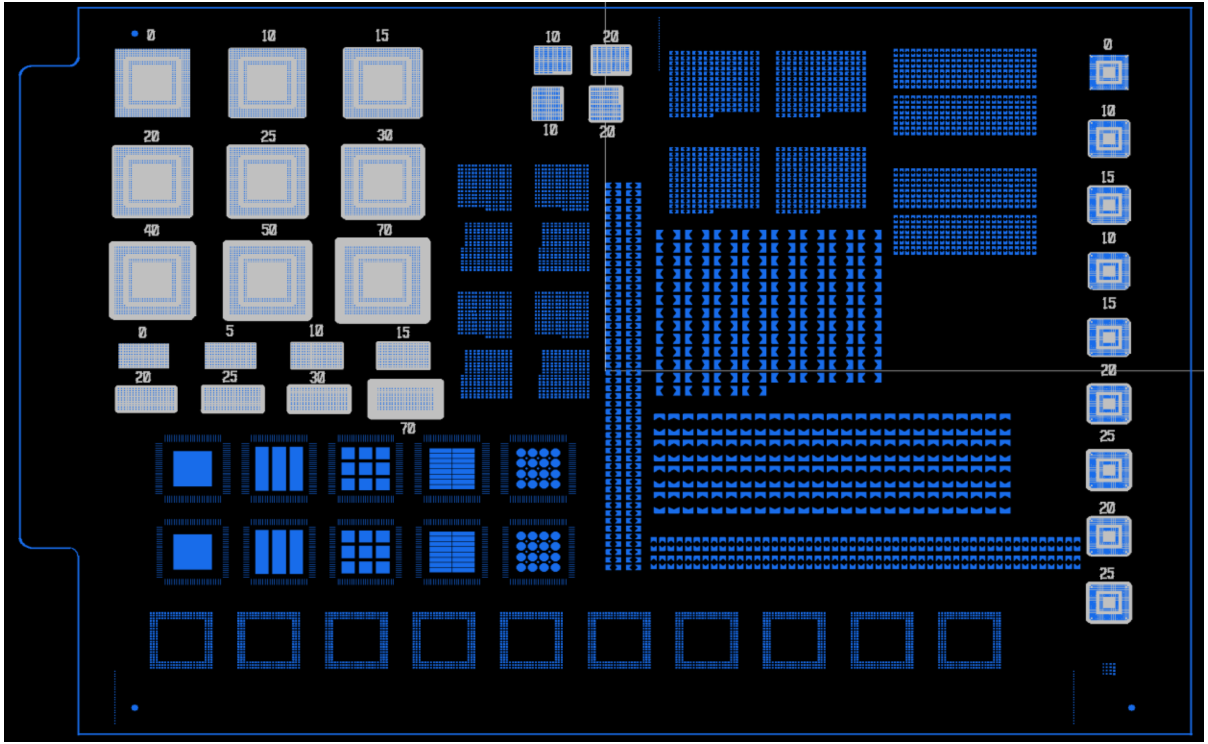
Experiment

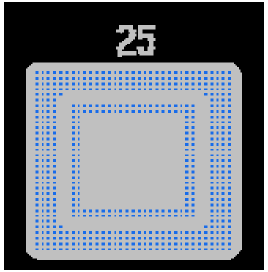
- Purpose: Provide current experiment-based design guidelines for steps
- Approach: Print board with steps that have different keepout zones
- Analyze volumes and variations

PCB Layout



Stencil Steps & Keepouts

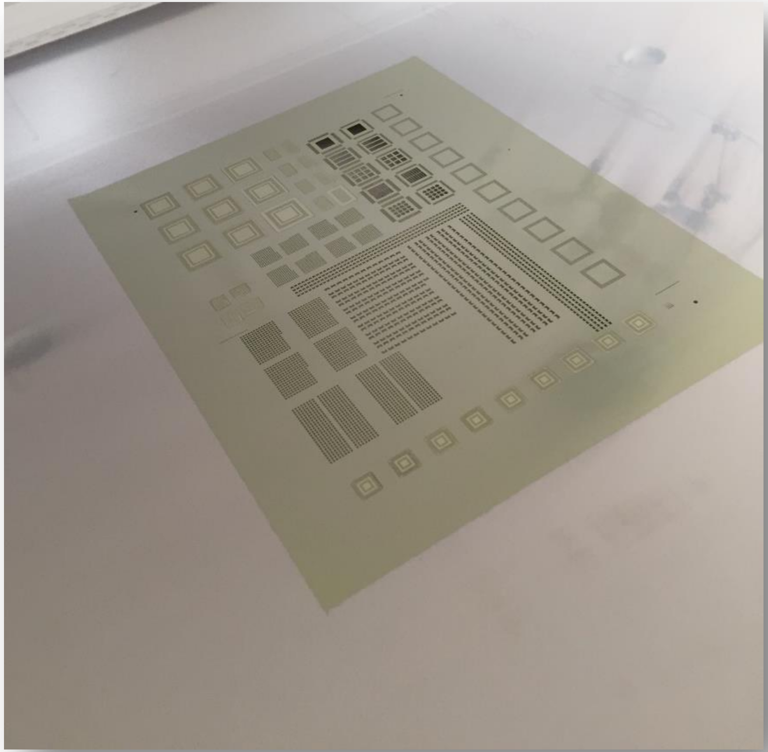




Stencil Specs

Typical Construction

- Premium Stainless Steel
- 29 x 29 Space Saver
- Standard tension
- Polymer nanocoated



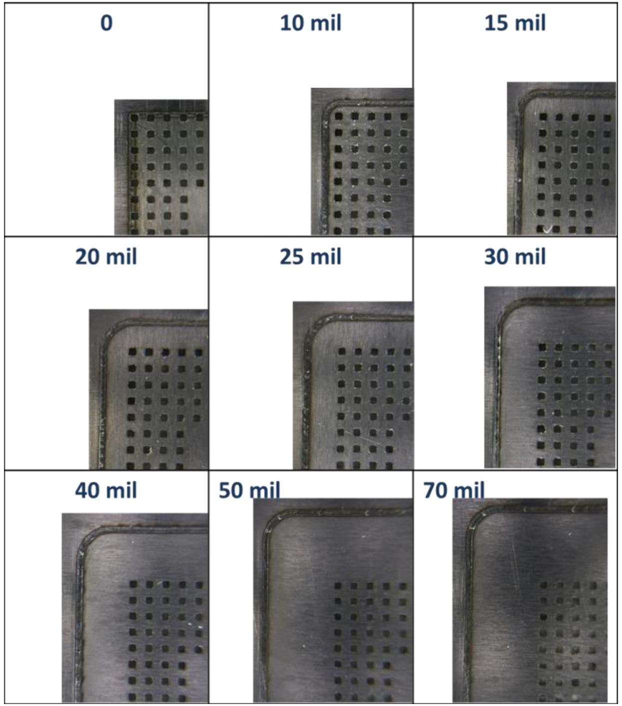
Stencil Thicknesses & Step Types

- 2 mil (50 µm) foil – *too much variation**
- 3 mil (75 µm) foil
- 4-3 mil welded (100 - 75 µm) foil
- 4-3 mil machined (100 - 75 µm) foil
- 4-2 mil machined (100 - 50 µm) foil – *too much variation**

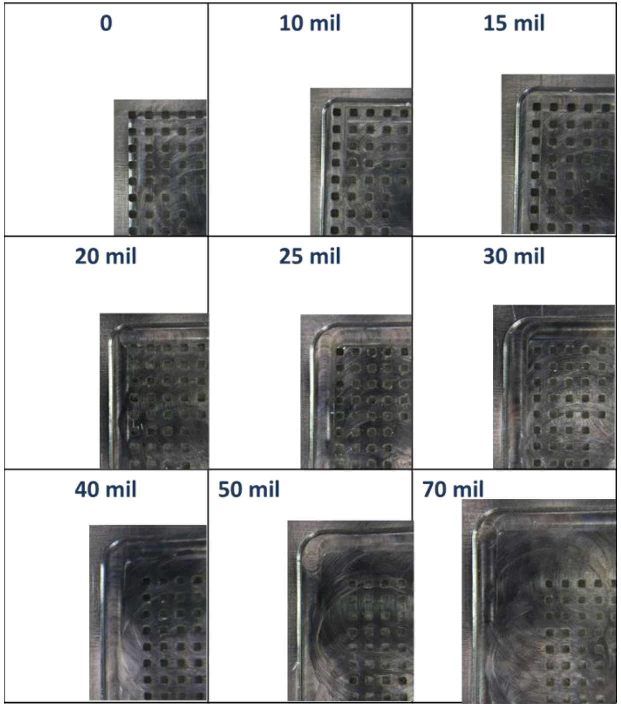
Produced solid data

* Executed with Type 4 solder paste, a likely source of variation when using a 2 mil foil

Step Keepouts



Welded



Machined

Printer & SPI

- MPM Edison and PARMI Sigma X SPI
  - Located in ITW-EAE lab in Hopkinton, MA
  - GR&R performed on SPI and CeTaq performed on printer before beginning tests
  - SPI Measurements at 15 micron threshold for high accuracy
- Print Parameters
  - Squeegee speed: 1.5 in/sec
  - Squeegee pressure : 1.5 lb/in (8 tall surgical steel squeegee blades)
  - Separation speed: 0.2 in/sec; Distance 0.10 in, Continuous
  - Wipe: Dry-Vac-Vac every board
- Solder Paste: Commercially available Type 4 LF no-clean
- 6 boards printed with each stencil

Analysis Methods

- Determine Typical volumes
- Examine CVs
- Calculate Cpks based on typical volumes and +/- 50%
- Run heat maps for 04BGA with 3 mil, 4-3 milled and welded
  - Volumes and standard deviations
- Calculate CVs and Cpks for 01005s
- Look at 0.3 mm pitch just for fun…

Simple Statistics

Coefficient of Variation - CV

- Calculate average and standard deviation
- Divide the standard deviation by the average
- Gives us the standard deviation as a % of the average:
  - **<10%: desired**
  - **10 – 15%: acceptable**
  - **Over 15%: unacceptable**

0.5mm BGA Volumes & Variation

10 mil aperture; area ratio at 3 mil foil thickness = 0.83

		3 mil foil		4-3 weld		4-3 mill		4-2 mill	
Component	Keepout (mil)	Average of Volume $mils^3$	Coefficient of Variation %	Average of Volume $mils^3$	Coefficient of Variation %	Average of Volume $mils^3$	Coefficient of Variation %	Average of Volume $mils^3$	Coefficient of Variation %
05BGA01	0	320	8	396	7	403	8	396	7
05BGA02	0	324	8	397	7	402	8	399	8
05BGA03	0	324	7	392	7	405	10	398	7
05BGA04	0	325	7	390	7	399	8	397	7
05BGA05	0	319	8	385	7	396	7	391	7
05BGA06	0	318	7	387	7	398	8	398	7
05BGA07	0	316	8	389	7	396	7	391	7
05BGA08	0	320	7	392	7	400	7	396	7
05BGA09	0	321	7	395	7	396	7	399	8
05BGA10	0	316	7	394	8	393	7	393	8

CV ≤ 10%	10 < CV ≤ 15%	CV > 15%

- 05BGAs typically run 350-400 cu mils on a 4 mil foil, and about 300-325 on a 3 mil foil
- CVs are less than 10%
- ✓ **Pretty typical process output**

SANITY CHECK:
These are the volumes and variations we expect based on our experience, so the process is producing as expected

0.4mm BGA Volumes & Variation

7.5 mil aperture; area ratio at 3 mil foil thickness = 0.63

		3 mil foil		4-3 weld		4-3 mill		4-2 mill	
Component	Keepout (mil)	Average of Volume $mils^3$	Coefficient of Variation %	Average of Volume $mils^3$	Coefficient of Variation %	Average of Volume $mils^3$	Coefficient of Variation %	Average of Volume $mils^3$	Coefficient of Variation %
04BGA01	0	173	10	196	13	202	13	197	10
04BGA02	10	178	9	187	12	207	9	196	10
04BGA03	15	182	9	181	14	208	9	193	10
04BGA04	20	175	9	192	10	202	10	191	10
04BGA05	25	179	8	192	9	203	9	186	11
04BGA06	30	182	8	191	9	203	9	185	11
04BGA07	40	185	7	195	8	208	9	187	9
04BGA08	50	188	7	197	10	209	7	184	10
04BGA09	70	190	7	195	8	206	7	175	9

CV ≤ 10%	10 < CV ≤ 15%	CV > 15%

Volumes average:

- **186** mil^3 for 3 mil and 4-3 welded stencils
- **197** mil^3 for the 4-3 and 4-2 milled stencils

therefore

Set volume targets at:

- **185** mil^3 for 3 mil and 4-3 welded stencils
- **200** mil^3 for the 4-3 and 4-2 milled stencils

** The volume of a Type 4 solder particle is about 0.5 – 1.5 mil^3*

0.3mm BGA Volumes & Variation

6 mil aperture; area ratio at 3 mil foil thickness = 0.50

		3 mil foil		4-3 weld		4-3 mill		4-2 mill	
Component	Keepout (mil)	Average of Volume $mils^3$	Coefficient of Variation %	Average of Volume $mils^3$	Coefficient of Variation %	Average of Volume $mils^3$	Coefficient of Variation %	Average of Volume $mils^3$	Coefficient of Variation %
03BGA01	**0**	41	**26**	34	**41**	43	**47**	50	**39**
03BGA02	**10**	122	**18**	120	**28**	148	**29**	163	**21**
03BGA04	**10**	135	**15**	129	**22**	169	**16**	168	**15**
03BGA03	**15**	106	**19**	103	**26**	138	**22**	139	**17**
03BGA05	**15**	127	**14**	119	**20**	157	**16**	159	**13**
03BGA06	**20**	137	**12**	133	**16**	169	**12**	170	**11**
03BGA08	**20**	129	**13**	122	**22**	151	**18**	158	**11**
03BGA07	**25**	126	**15**	123	**18**	154	**17**	151	**14**

CV ≤ 10%	10 < CV ≤ 15%	CV > 15%

This process is borderline unstable with Type 4 solder paste, but the data is worth examining…

This package is our next industry challenge. Let's see what we can do now with a std process. Just for fun…

Volumes average:

- **124** mil^3 for 3 mil and 4-3 welded stencils
- **157** mil^3 for the 4-3 and 4-2 milled stencils

Set volume targets at:

- **125** mil^3 for 3 mil and 4-3 welded stencils
- **160** mil^3 for the 4-3 and 4-2 milled stencils

Cpk Values

Process Capability Index- Cpk

- Compares average and standard deviation to specified process window
- A composite index that is frequently used as a production metric
- Gives us an overall indication of fit in process window:
  - **> 2.0 desired (6σ process)**
  - **> 1.66 very good (5σ process)**
  - **> 1.33 need improvement (4σ process)**
  - **< 1.33 unacceptable**

Compare CV and Cpk-0.4mm BGA

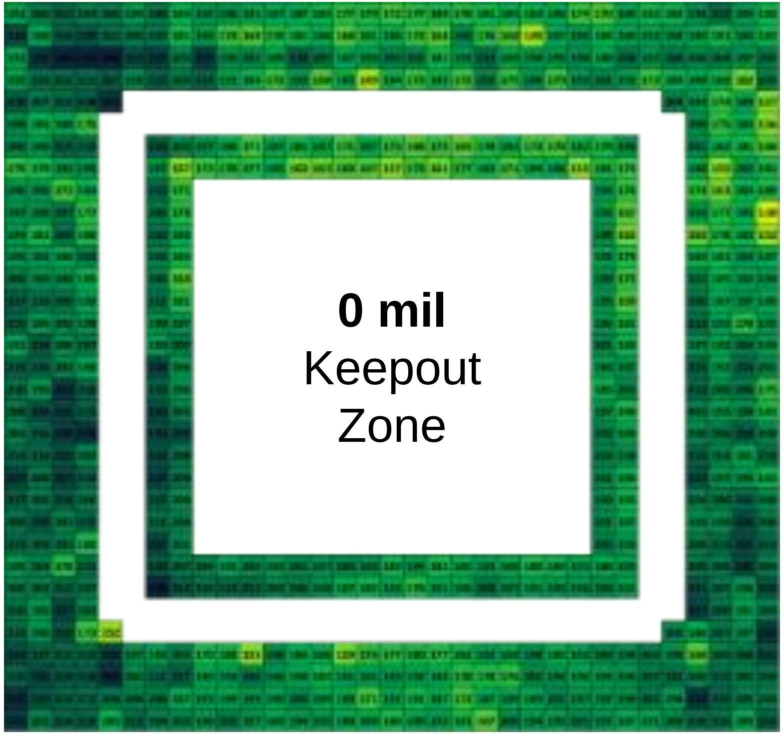
Component	Keepout (mil)	3 mil foil		4-3 welded		4-3 milled		4-2 milled	
		CV %	Cpk	CV %	Cpk	CV %	Cpk	CV %	Cpk
04BGA01	0	10	1.50	13	1.07	13	1.23	10	1.59
04BGA02	10	9	1.81	12	1.29	9	1.63	10	1.66
04BGA03	15	9	1.89	14	1.15	9	1.57	10	1.54
04BGA04	20	9	1.78	10	1.50	10	1.68	10	1.52
04BGA05	25	8	1.90	9	1.57	9	1.77	11	1.42
04BGA06	30	8	2.03	9	1.64	9	1.73	11	1.37
04BGA07	40	7	2.29	8	1.73	9	1.59	9	1.64
04BGA08	50	7	2.35	10	1.42	7	1.98	10	1.59
04BGA09	70	7	2.21	8	1.69	7	2.12	9	1.60

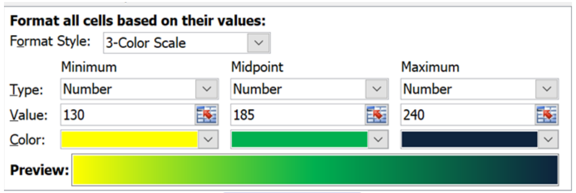
These are the statistics for each component in its entirety. Let's characterize the individual deposits and look at how their location affects their volumes and variability

“Heat Maps” *An Excel function; has nothing to do with soldering*

- “Heat mapping” automatically assigns colors to cells based on their values
- User can define the rules
- Created using the pivot table function with volume and standard deviation data, and indexed by the BGA’s row and pin IDs
- Shows us a color map of volumes and variations

0.4mm BGA Volume Heat Map





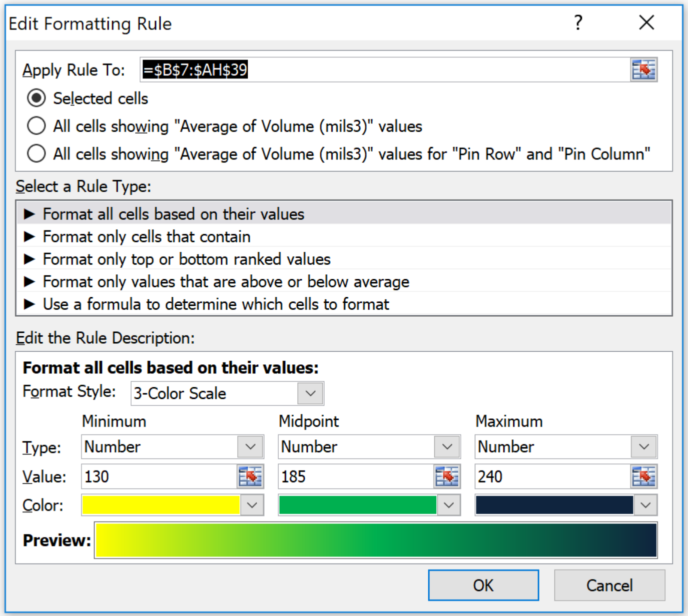
Heat Map Key

Average= 185 cu mils

- 30% = 130 cu mils

+ 30% = 240 cu mils

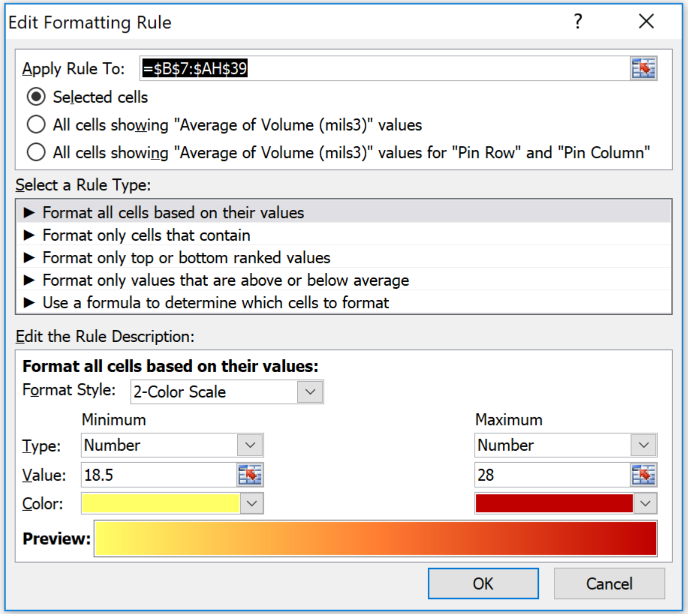
Single Thickness and Welded



Mean Volume

30% less than avg

30% more than avg

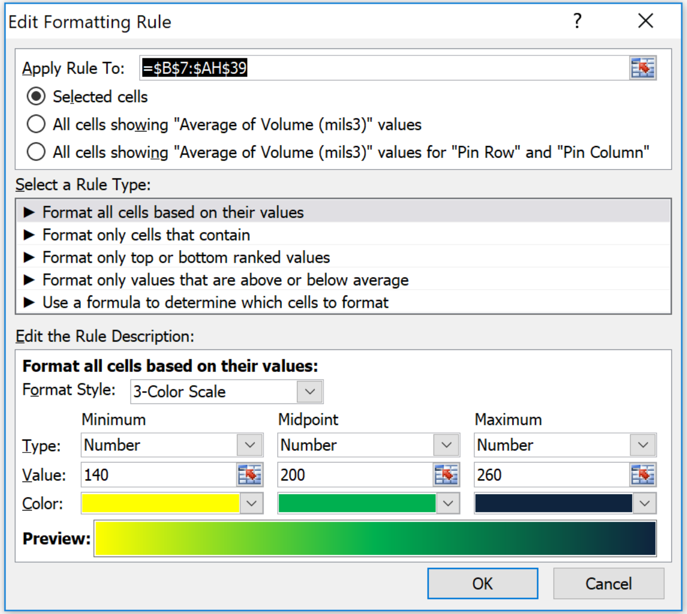


Standard Deviation

10% or less

15% or more

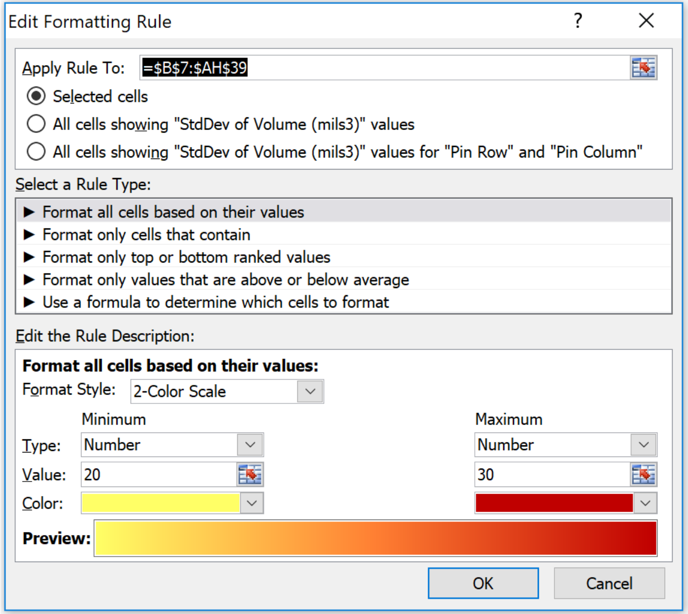
Milled (Micromachined)



Mean Volume

30% less than avg

30% more than avg



Standard Deviation

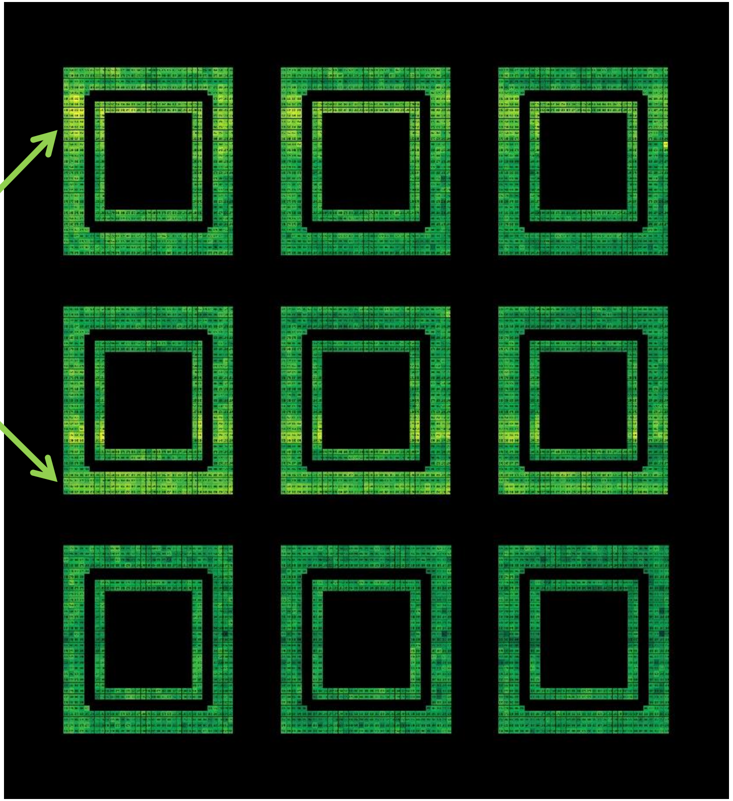
10% or less

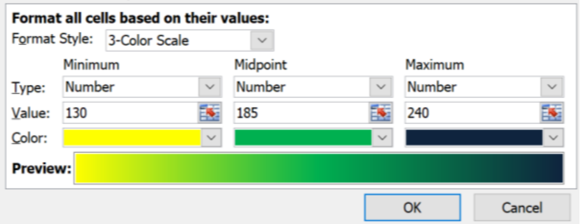
15% or more

Average Volumes – 3 mil foil

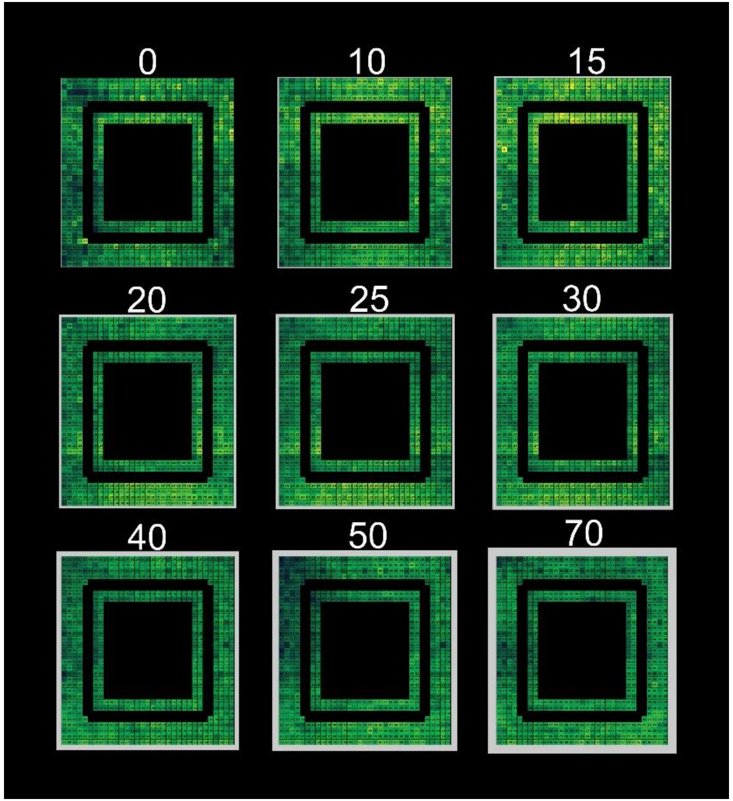
Artifacts of line scan stitching in SPI machine

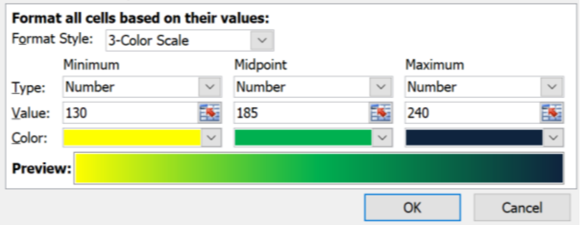
Would not have noticed without heat map because they are all within inspection tolerance



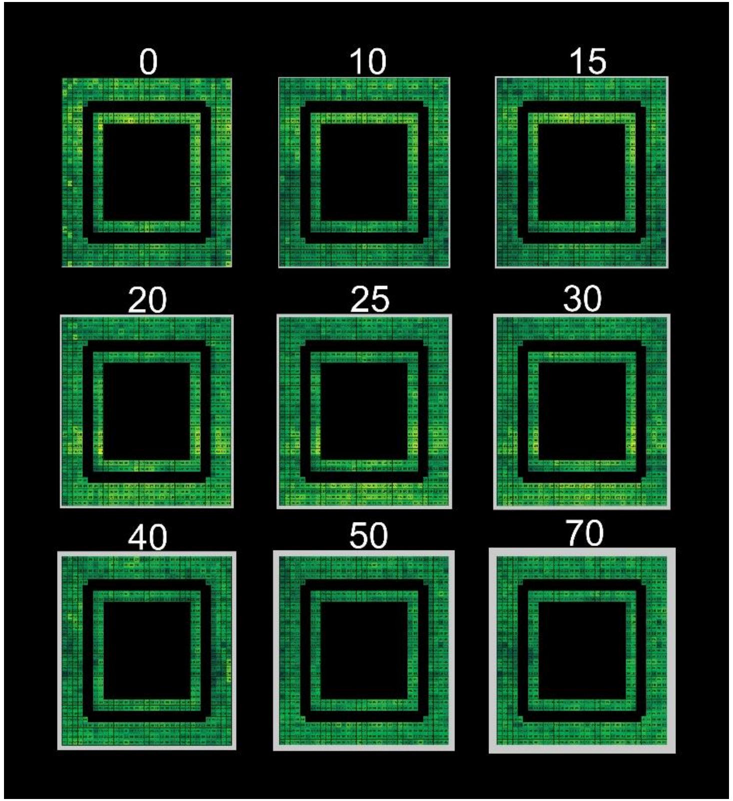


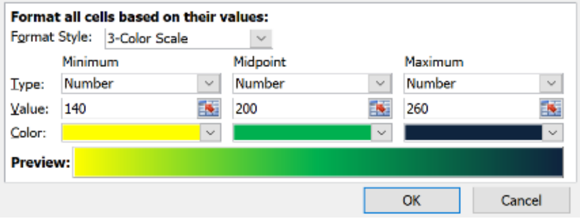
Average Volumes – 4-3 welded foil



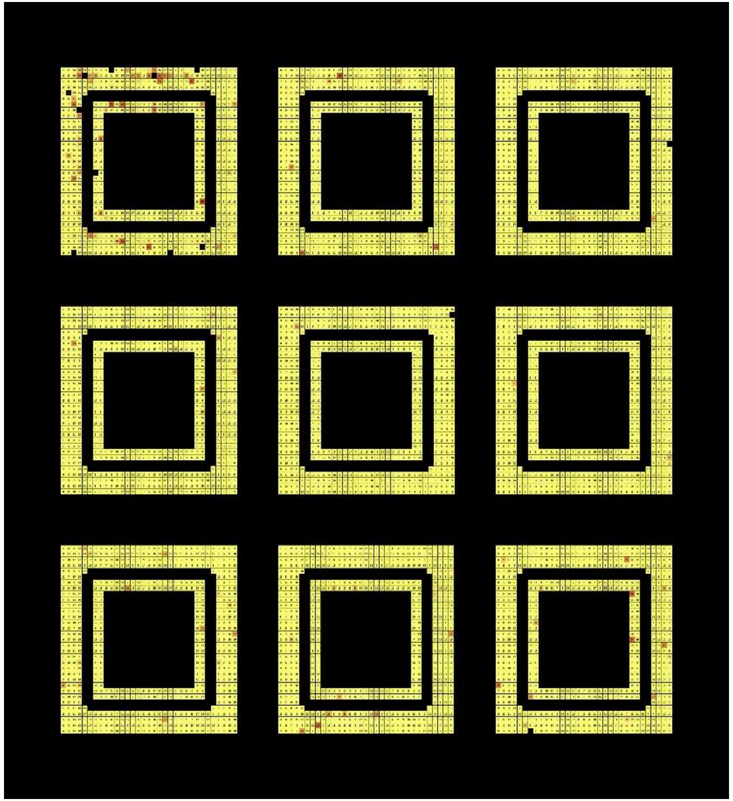


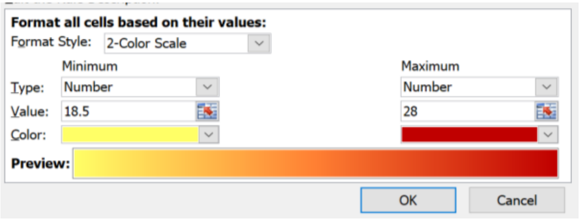
Average Volumes – 4-3 milled foil



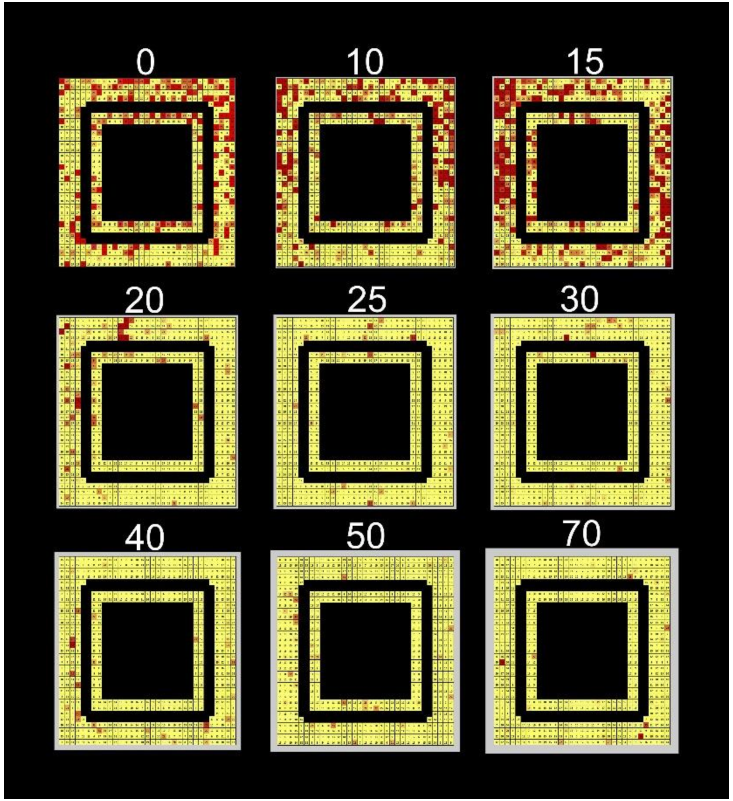


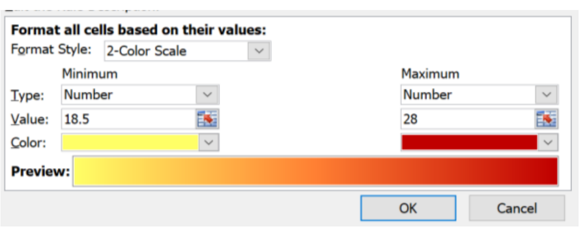
Standard Deviations – 3 mil foil



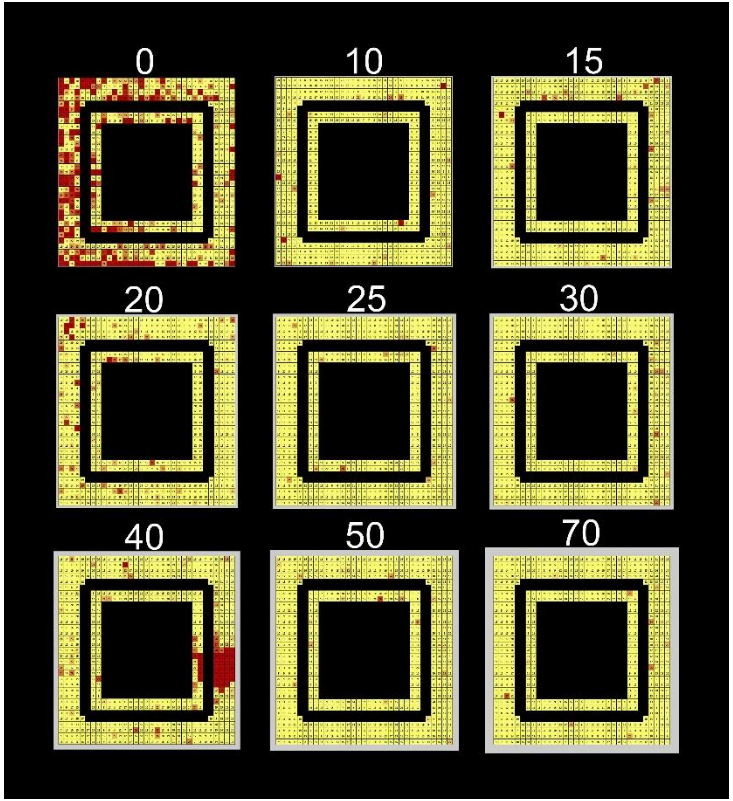


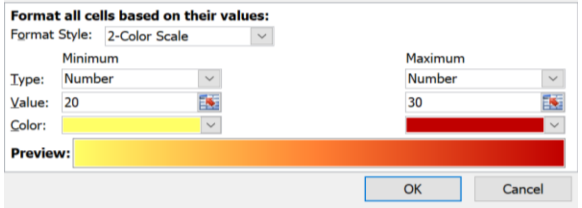
Standard Deviations – 4-3 welded foil



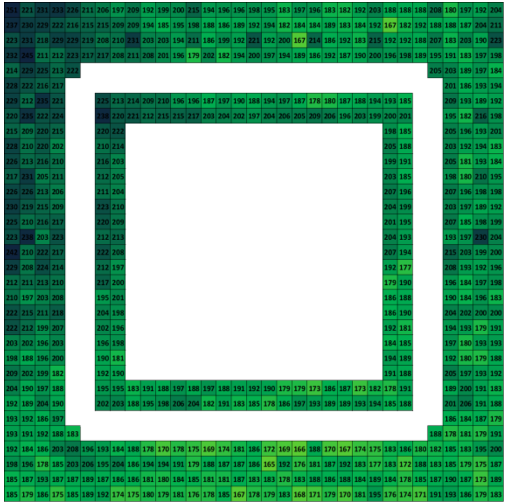


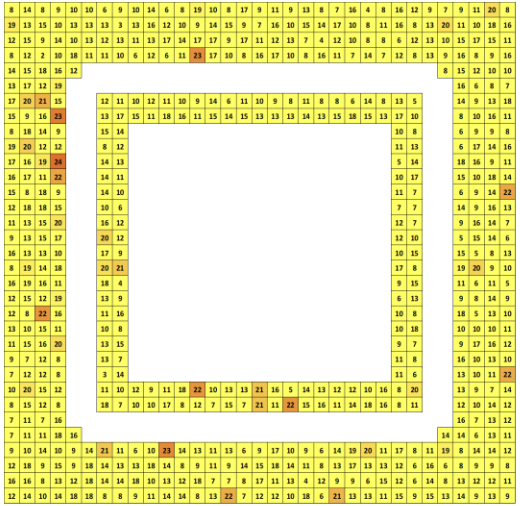
Standard Deviations– 4-3 milled foil

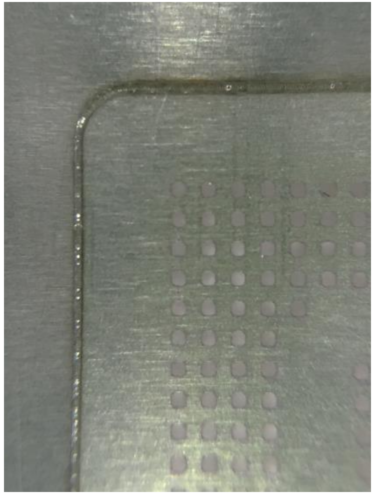




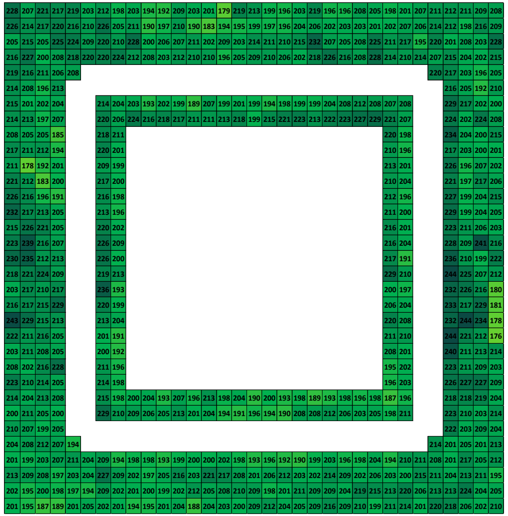
4-3 Welded, 40 mil Keepout

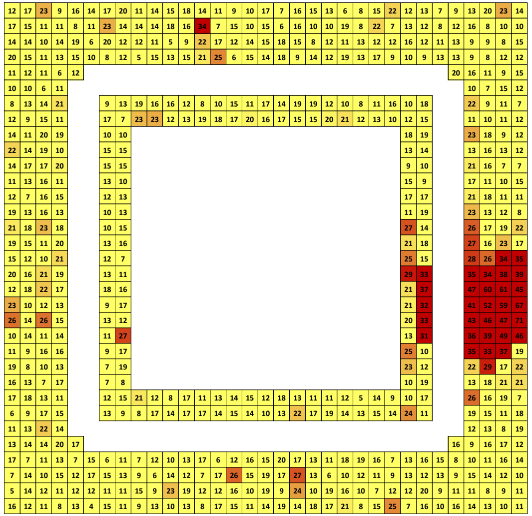


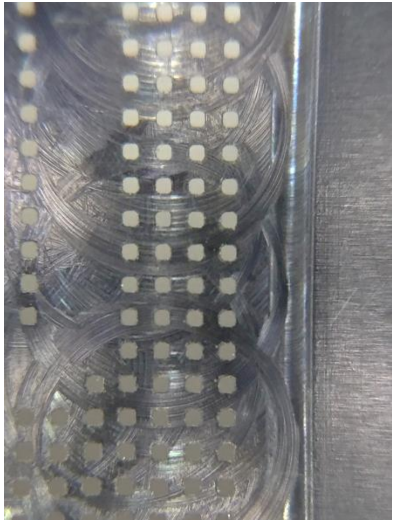




4-3 Milled, 40 mil Keepout







01005s

- Same size aperture as 04BGA
  - Similar volumes but tighter variation
- Coarser spacing between apertures
- Everything except 0 keepout gives pretty consistent results
- Cpk calculations used 180 cu mils as a target, with UCL and LCL at 90 and 270 cu mils

Data shows that volumes stabilize at >10 mil keepout for both welded and milled, and variation is not an issue

Foil	Stencil Avg	Keepout	AVG	CV	Cpk
3 mil flat	167	0	156	11	1.29
		0	168	8	1.93
		0	158	9	1.55
		0	172	7	2.24
		0	158	10	1.46
		0	171	7	2.15
		0	159	9	1.63
		0	174	6	2.49
4-3 weld	183	0	190	9	1.57
		5	191	9	1.54
		10	174	11	1.53
		15	182	11	1.45
		20	180	10	1.74
		25	180	10	1.61
		30	181	11	1.53
		70	180	9	1.89
4-3 mill	194	0	192	14	1.00
		5	202	9	1.18
		10	192	8	1.69
		15	193	9	1.56
		20	191	8	1.73
		25	198	8	1.46
		30	193	8	1.65
		70	191	9	1.61

Conclusions

- For 0.4 mm BGA, a 4-3 stepped stencil can perform equal to or better than a single thickness 3 mil foil if:
  - The keepout zone is held to a minimum **25 mils on a welded foil**
  - The keepout zone is held to a minimum of **10 mils on a machined foil**
- The impact of keepout zone has been quantified in terms of print capability and product quality
- Tests were performed in a laboratory setting by seasoned engineers. Findings should be adjusted appropriately for production settings.

Future work

- Possibilities
  - Try T4.5 or T5 paste on 0.3mm and 01005s
  - Physically analyze stencils more carefully for geometries that caused deposit volume variation
  - Zero in on keepout zones for different solder pastes

Questions?

Thank You

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