BGA and QFN Repair Process

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Abstract
Repairing a PCB with a defective BGA, uBGA, or QFN is often a difficult and tedious task. The conventional method is to remove the defective device from the PCB; clean the pads on the PCB, then print solder paste on the pads with a mini-stencil. The stencil footprint needs to be small enough to fit into the area of the removed part, which is normally surrounded by other devices in close proximity.

This paper will describe an alternative repair method. Instead of printing solder paste on the PCB pads this system prints solder paste directly on the QFN pad or the BGA solder balls. The repair tool is simple and easy to operate. A package can be inserted in the tool, printed and placed on the PCB in about 30 seconds. The tool is made up of two components: a universal master tool, which can be reused for all packages and a unique component, which is designed for a specific package. The unique components consist of a stencil and a device holding fixture. Both are free standing metal foils with laser cut or electroformed apertures.

The Problem
Printing paste with a mini stencil can be a problem for BGA's when other components are positioned very close to the BGA. Figure 1 is a good example of a PCB with 0603 and 0402 devices positioned close to the BGA. This figure also shows a typical mini stencil for hand printing solder paste onto the PCB. It is easy to see that there is insufficient room for the normal mini repair stencil to print paste on the pads of the BGA.

QFN's typically have package sizes ranging from 3 mm up to 14 mm with pitches from 0.5 mm up to 0.8 mm. In addition the pads are on the bottom side of the package and the length of the pad is typically less that 2 times the width. A typical pad size for a 0.5mm pitch QFN is 0.25 mm x 0.4 mm. Using a mini stencil to print small pads over a small area is very difficult. Figure 2 shows a 3mm and a 4mm QFN package.

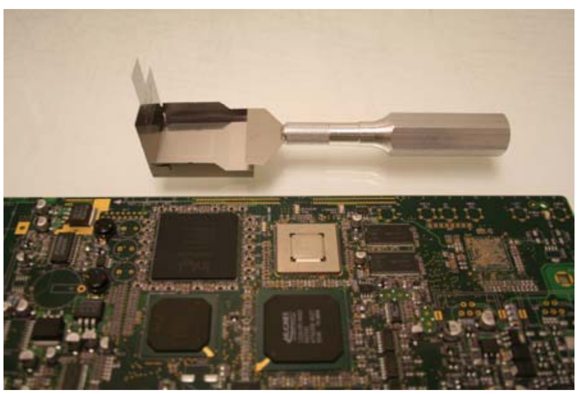

Figure 1- 35 mm BGA with closely spaced chips

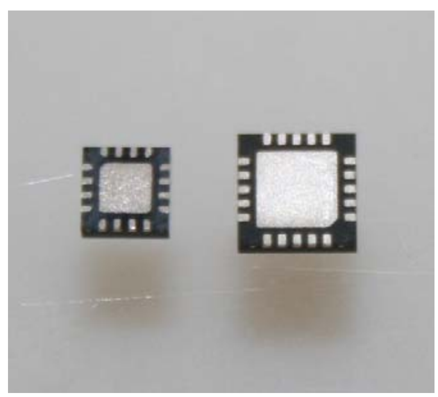

Figure 2 – 3 mm and 4 mm QFN's

Solution – QFN Repair Tool
An objective of the QFN rework process is to have a universal tool that can be fitted with a stencil and a package holding tool specific to different QFN packages. It should be easy to load and unload the QFN package from the tool. The following sequence of pictures shows how the QFN repair tool works. Figure 3 shows the Universal tool. The fixture on the left side hold the QFN package holding fixture as well as the stencil for printing paste on the QFN. The fixture on the right is the package hold down fixture. The Universal QFN fixture of Figure 3 is 70 mm x 70 mm and can accommodate QFN packages up to 20 mm. There are two 2 permanent pins and two puller pins that hold and align the stencil and package holding tool. Figure 4 shows the QFN package holding tool being placed on the registration pins. Figure 5 shows the stencil being placed on the same pins. Figure 6 shows the QFN package placed in the holding tool. Figure 7 shows the holding tool being placed over the QFN package. Figure 8 shows paste being printed onto the QFN pads. A razor blade mounted in an Exacto knife works well as a squeegee tool. Figure 9 shows the top surface of the stencil after printing. Note the paste is still in the stencil apertures and releases from the stencil when the QFN is removed as is shown in Figure 10. Finally Figure 11 shows past

printed on the QFN pads. In this case the aperture is 1-1 with the pads, which are 0.38 mm square on a 0.65 mm pitch. One of the general design guides for QFN stencil design is to reduce the stencil aperture openings compared to the ground plane by approximately 50%. Normally a windowpane or array of circular apertures is preferred. This allows the solvents to escape during reflow preventing any movement and misregistration of the QFN. Figure 12 shows paste printed on a 10 mm QFN that has pads on 0.5 mm pitch arranged in two rows around the perimeter. The aperture sizes and paste bricks are 0.24 mm x 0. 4 mm. Figure 13 is a magnified view of the paste bricks.

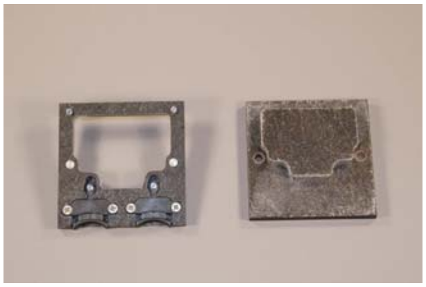

Figure 3 - Universal QFN Tool

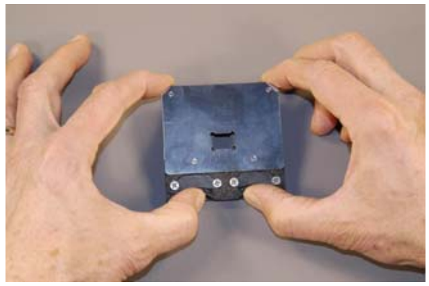

Figure 4 – QFN Holding Tool

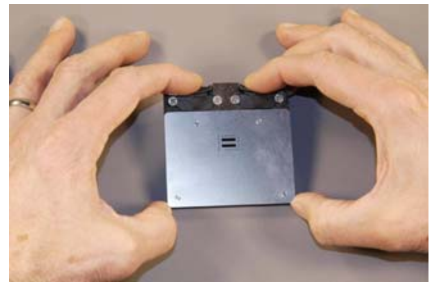

Figure 5 – QFN Stencil

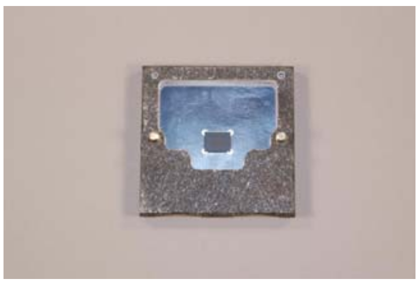

Figure 6 – QFN in Holding Tool

Figure 7 – Hold Down Tool on QFN

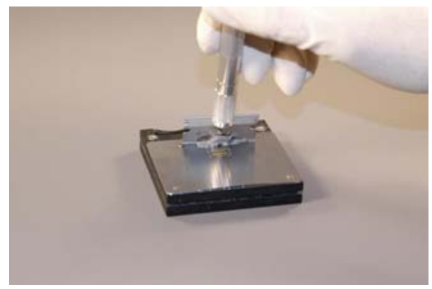

Figure 8 – Printing on Stencil

Figure 9 – Paste on Stencil

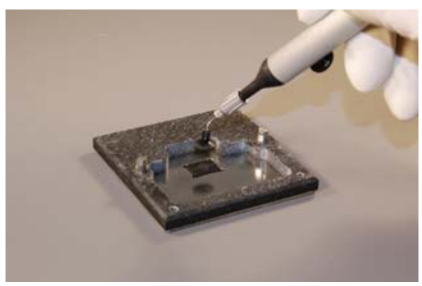

Figure 10 Pull QFN from Stencil

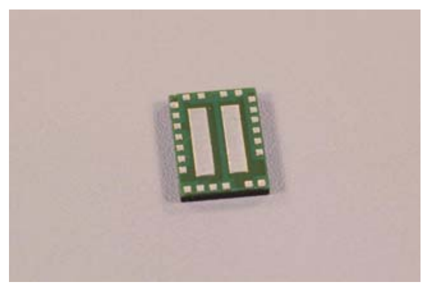

Figure 11 Paste printed on QFN

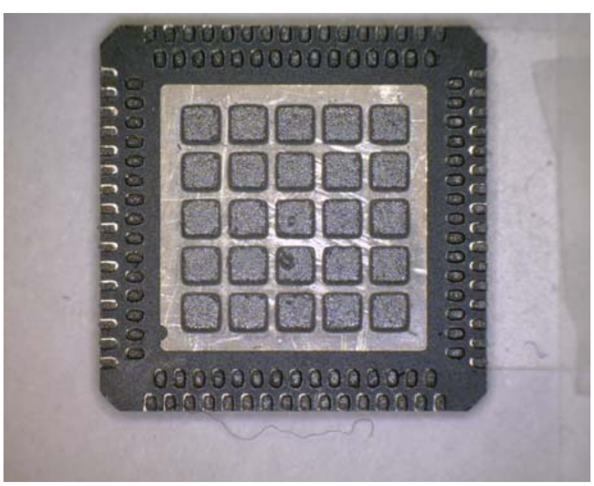

Figure 12 – 10 mm QFN with 0.5 mm pitch pads

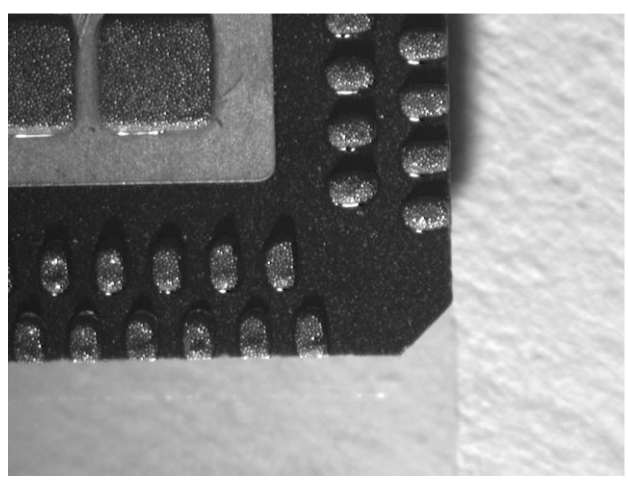

Figure 13 - Magnified view showing paste on the double

Solution - BGA Repair Tool

The BGA repair tool is very similar to the QFN repair. Instead of printing solder paste on a pad, paste is printed on the BGA ball. The Universal BGA tool is larger than the Universal QFN tool, 100 mm square. It can accommodate BGA packages up to 50 mm. Figure 14 shows the Universal BGA fixture with two BGA package-holding fixtures. The holding fixtures are typically 0.50mm thick, 0.25 mm thick and 0.125 mm thick and are either Laser-cut or Chem-etched. A number of holding fixtures are selected to hold the BGA package at a height where the balls seat into the open stencil aperture. Figure 15 shows a 35 mm BGA package placed into the holding fixture. Next, the stencil is placed on the registration pins as seen in Figure 16. Solder paste is then printed on the balls and the package lifted from the holding fixture from the rear. Paste printed on top of the solder balls is shown in Figure 17 and a close up is seen in Figure 18.

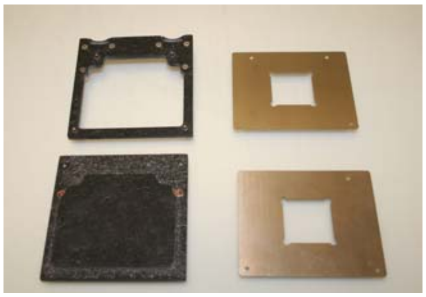

Figure 14 – Universal BGA Tool

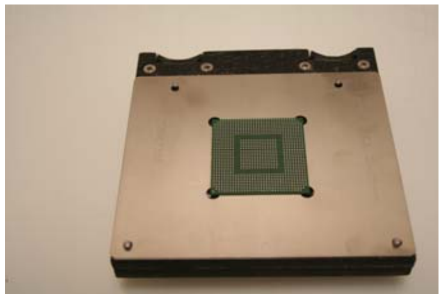

Figure 15 - 35 mm BGA in holding tool

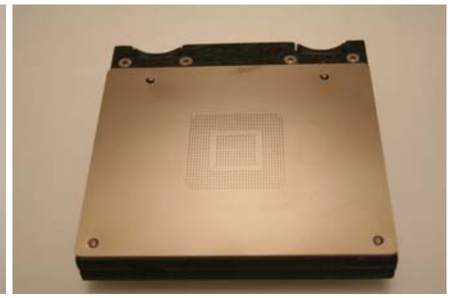

Figure 16 - Stencil in place

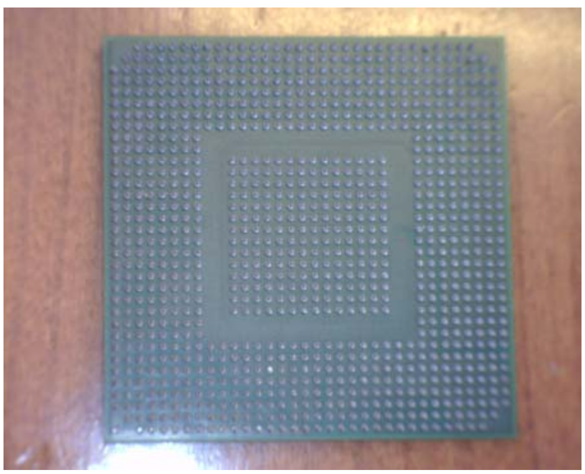

Figure 17 – Solder paste on 35 mm BGA

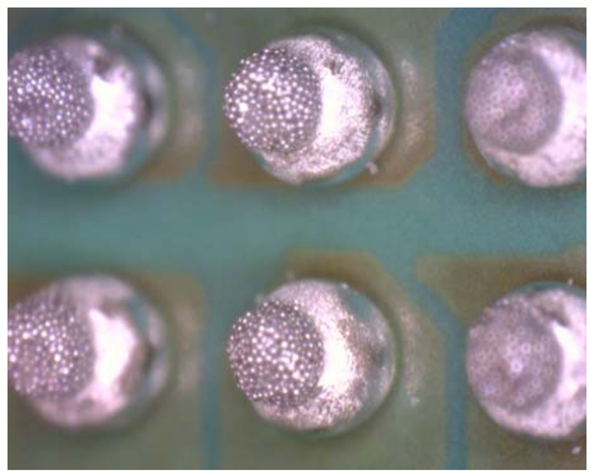

Figure 18 - Close up of printed paste on ball

QFN Stencil Design

The QFN package holding tool is normally laser cut and is designed according to the package dimensional tolerances. The thickness of this tool is selected to bring the package in contact with the stencil when the hold down tool is placed in position. It may be convenient to have more than one package-holding tool to achieve the correct thickness. For a 0.76 mm (30 mil) thick QFN two holding tools, with thickness of 0.51 mm (20 mils) and 0.25 mm (10 mils), would provide the thickness. The stencil apertures are typically small; therefore the Area Ratio[1] must be taken into account. Stencil designs are shown in Table 1 for a 3 mm, 4 mm, and 10 mm QFN's with 0.5 mm pitch.

Table 1 - QFN Stencil Design Guidelines

QFN Repair Stencil Design Guidelines						
Package Size	Pitch	Pad / Aper Width	Pad / Aper Length	Stencil Thickness	Area Ratio	Stencil Type Recommended
10mm	.5mm	9.5	16	5	0.60	E-FAB
4mm	.5mm	10	16	5	0.62	E-FAB
3mm	.5mm	9.5	14.5	5	0.57	E-FAB
Dimensions are in Mils (1 mil = .001" = 25.4 microns)						
Package and Pitch are in mm						

BGA Stencil Design
Some typical BGA's[2] are shown in Figures 19 and 20. Figure 19 shows a 7 mm CSP 108, 0.5 mm pitch, with a 0.3 mm (12 mil) ball on the right, a 10 mm BGA 100, 0.8 mm pitch, with a 0.46 mm (18 mil) ball in the center, and a 17 mm BGA 208, 1 mm pitch, with a 0.6 mm (24 mil) ball on the left. Figure 20 shows a 35 mm BGA 436, 1.27 mm pitch, with a 0.75 mm (30 mil) ball on the right and a 35 mm BGA 1156, 1 mm pitch, with a 0.63mm (25 mil) ball on the left.

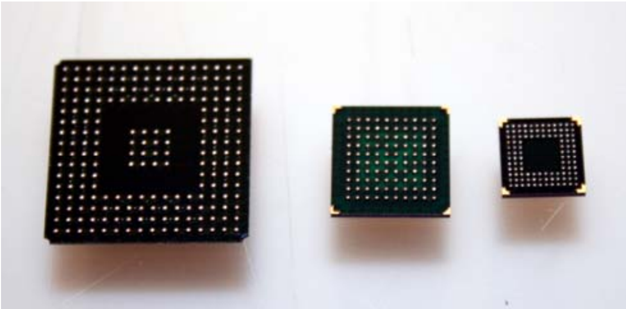

Figure 19 – 1mm, .8 mm pitch BGA and .5 mm pitch CSP

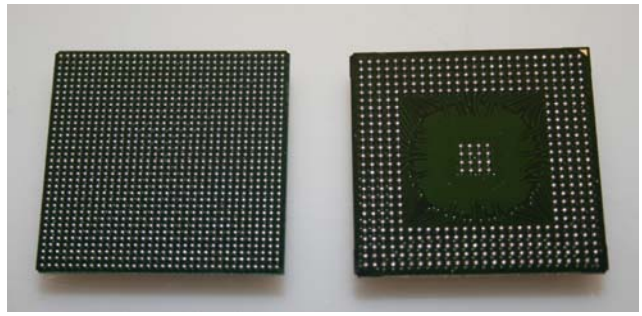

Figure 20 - 1 mm and 1.27 mm pitch BGA

In the case of BGA's, it is desirable to have the stencil gasket to the BGA ball at a point, which is less than the diameter of the ball. Another condition is that the ball cannot extend beyond the topside of the stencil; otherwise the ball would interfere with the squeegee during printing. Another condition is to have an acceptable Area Ratio. Given these conditions it is desirable to optimize the solder volume printed on top of the BGA ball. Figure 21 shows a picture of the stencil gasketing to a solder ball.

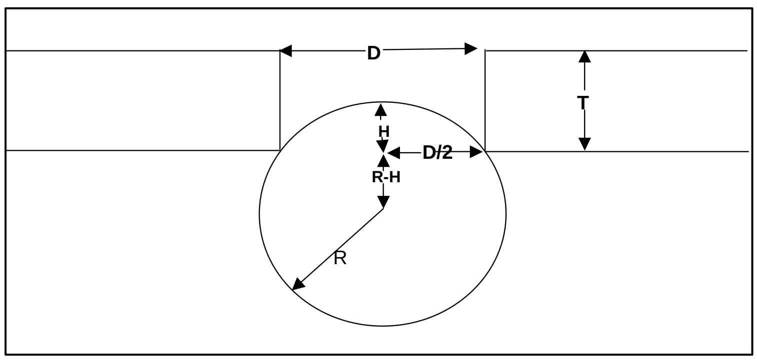

Figure 21 – Solder Ball Gasketing to the Stencil

T = Thickness of Stencil
R = Radius of BGA Ball
H = Height that Ball protrudes into Stencil Aperture
D = Radius of Stencil Aperture

Volume of the Stencil Aperture $V_1 = \pi D^2 T/4$

Volume of the Solder Ball sphere in the Stencil Aperture $V_2 = 1/3\pi H^2(3R-H)$

Useful relationship between D and R $R^2 = (D/2)^2 + (R-H)^2$

Volume of Solder Paste printed on the Ball $V_3 = V_1 - V_2$

$V_3 = \pi T(R^2-(R-H)^2) - 1/3\pi H^2(3R-H)$

Table 2 shows the solder paste volume as a function of stencil aperture diameter for 100 micron (4mil), 125 micron (5mil) and 150 micron (6 mil) thick stencils for a 0.3 mm (12mil) BGA ball. Stencil thickness, ball radius, height ball protrudes into stencil aperture and diameter of stencil aperture are dimensioned in mils (.001" = 25.4 microns = 0.0254mm). Paste Volume and ball volume are in cubic mils.

The preferred stencil design is highlighted in yellow. Note that the 100 micron (4 mil) stencil has a maximum paste volume with an Area Ratio of 0.65 and an E-FAB Electroform stencil is recommended. The maximum volume for the 125 micron (5 mil) thick stencil occurs at an Area Ratio of 0.52. However this combination is not recommended because of low the Area Ratio value. Although the combination with an Area Ratio of 0.58 gives slightly lower theoretical paste volume is recommended as a more robust design. A 150 micron (6 mil) stencil was not recommended because of low Area Ratio's.

Similar data was compiled for 0.4 mm (16 mil), 0.5 mm (20 mil), 0.61 mm (24 mil), and 0.76 mm (30 mil) balls. A summary of the stencil design recommendations is given in Table 3 for these ball sizes.

The BGA package holding tool must be the correct thickness to allow the BGA ball to securely gasket in the stencil aperture when the hold down tool pushes the package up against the stencil. As with the QFN package holding tool, multiple BGA package holding tools may be stacked up to achieve the required thickness. Positional accuracy of the package holding tool is not as critical for BGA's compared to QFN's since the balls self center into the stencil apertures when pushed against the stencil.

Table 3 Recommended Stencil Designs for various ball sizes

BGA Repair Stencil Design Guideline							
D Ball Size	T Stencil Thickness	H Height of Ball in Aper.	H/T Ratio	A Aperture Dia. of circle	Area Ratio	Stencil Type Recommended	Paste Vol. as % of ball Volume
12	4	3	0.75	10.4	0.65	E-FAB	21.9%
12	5	4.5	0.90	11.6	0.58	E-FAB	26.9%
16	4	3.5	0.88	13.2	0.83	Laser	13.4%
16	5	3.5	0.70	13.2	0.66	E-FAB	19.8%
20	5	4	0.80	13.0	0.80	Laser	13.6%
20	6	4.5	0.75	16.7	0.70	Laser	18.5%
24	6	4.5	0.75	18.7	0.78	Laser	13.6%
24	7	5	0.71	19.5	0.70	Laser	17.6%
30	7	5.5	0.79	23.2	0.69	Laser	12.1%
30	8	6	0.75	24.0	0.64	Laser	15.2%
Dimensions are in Mils (1 mil = .001" = 25.4 microns = .0254 mm))							

Conclusion

Increased component densities on printed circuit boards have made repair by printing solder paste directly on the component pads on the board using normal mini repair stencils difficult. This paper describes an alternate approach where solder paste is printed directly on the package itself, either QFN or BGA, and the component, with paste on pad, is placed on the printed circuit board prior to reflow.

With proper stencil and component holding tool design successful solder paste printing for a dual row pad layout having 124 I/O on 0.5 mm pitch for a 10 mm QFN has been demonstrated.

Successful paste printing on a 1156 I/O 1 mm pitch 35 mm BGA has also been demonstrated.

Stencil design guidelines for QFN and BGA packages are also provided in this paper.

References

(1) W. Coleman and M. Burgess "Using the Area Ratio Calculator for stencil Design" PCB 007, May 15, 2006

(2) BGA and QFN packages were provided by Top Line

BGA and QFN Repair Process

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PHOTO STENCIL
PRINT BETTER.

IPC PRINTED CIRCUITS EXPO APEX and the DESIGNERS SUMMIT

The Challenge

Repair of defective BGA, uBGA, or QFN SMT devices

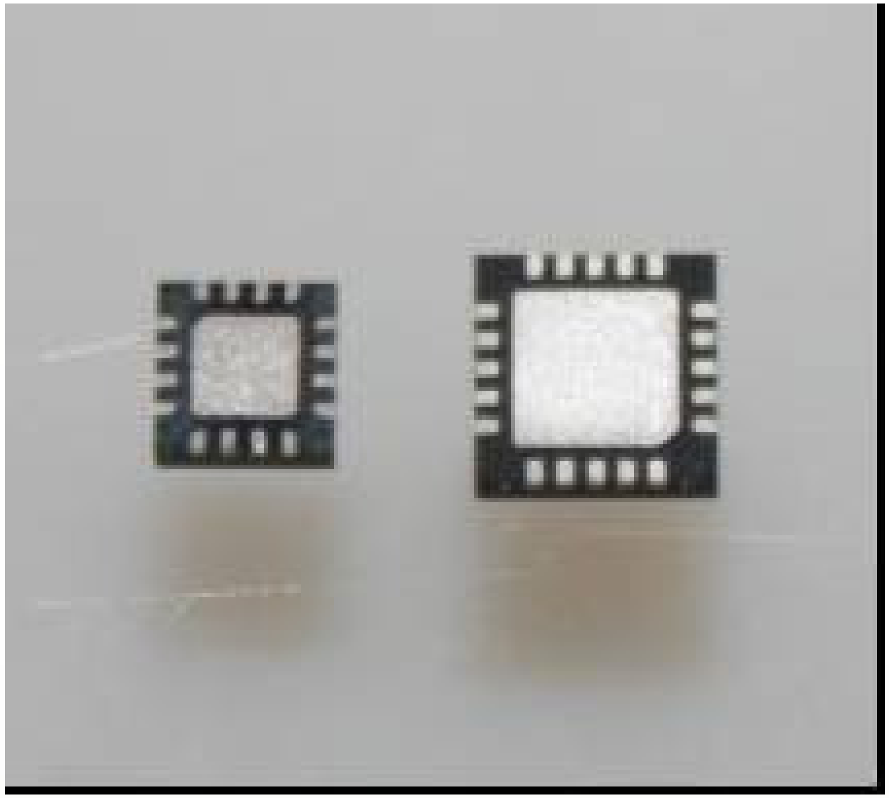
After removing the defective devices two repair options

1- Print solder paste on PCB and place new package

2- Print solder paste on the new package and place

Paste Stencil for BGA with tight spacing

3mm and 4mm QFN packages



Paste Printing on PCB pads with mini stencils

Difficulties:

Insufficient clearance when packages have other devices close by.

Small mini stencils for small QFN's difficult to handle.

Print Solder paste on the package leads / balls

Considerations for this process:

Easy to load and unload the package from the tool

Easy self registration of package to stencil

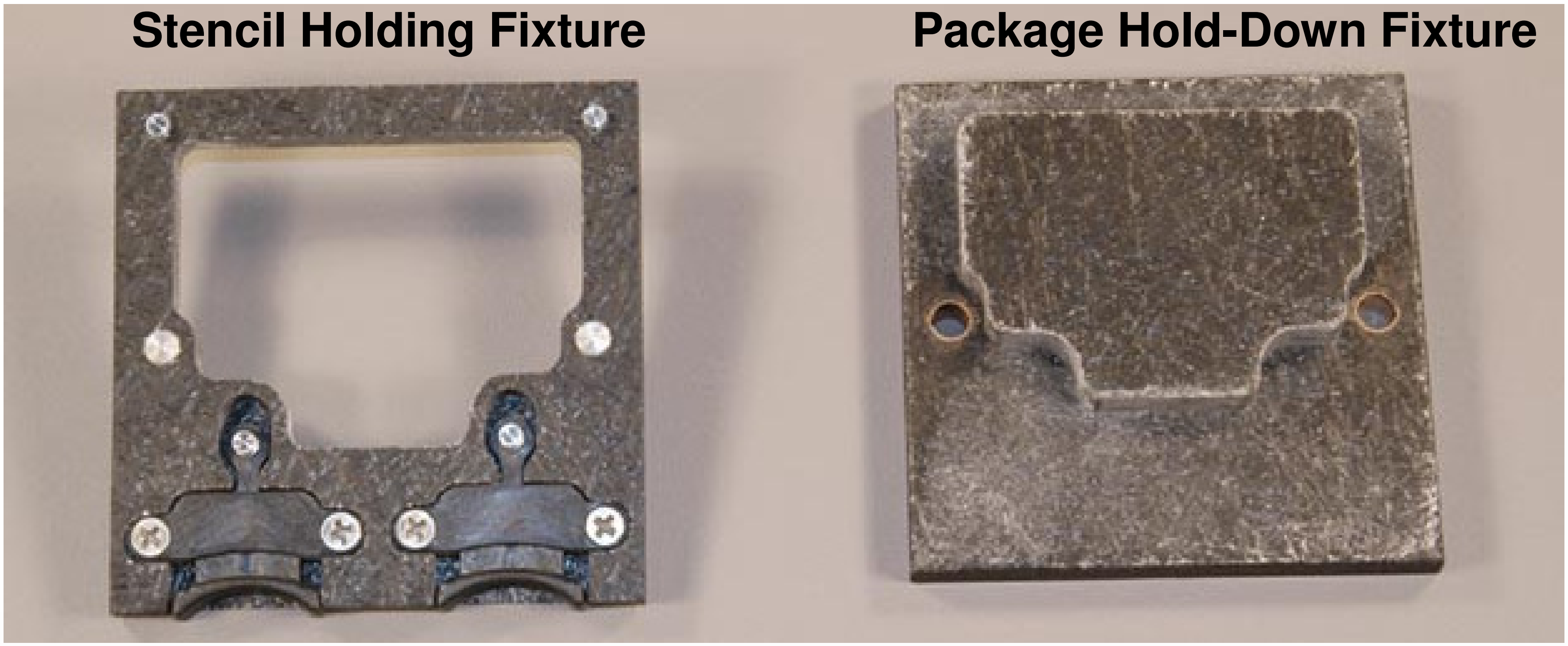
Simple hand printing of paste on the package

Pull the package away from stencil and place on PCB

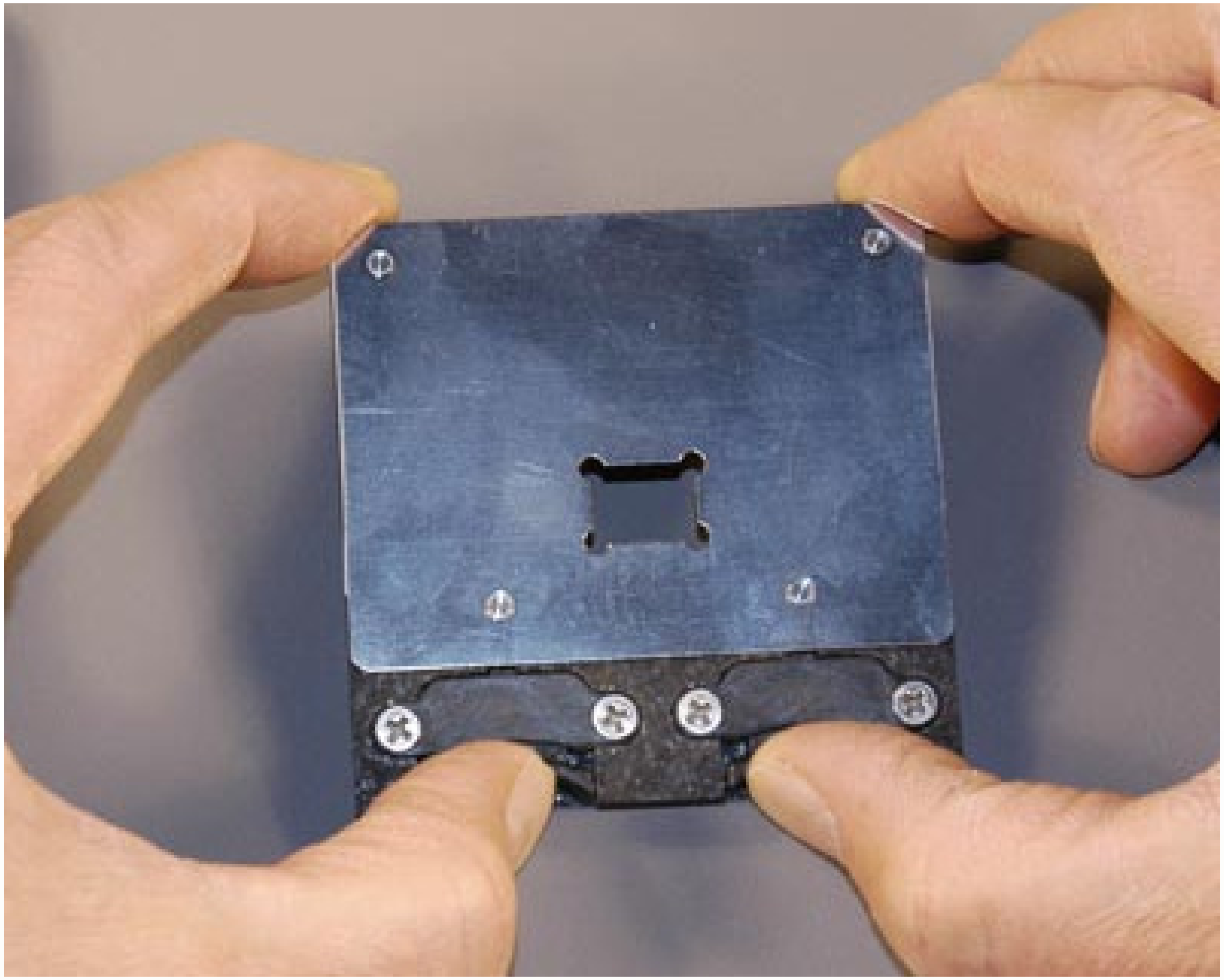
Universal tool with dedicated package specific fixtures

Economical, Effective and Quick

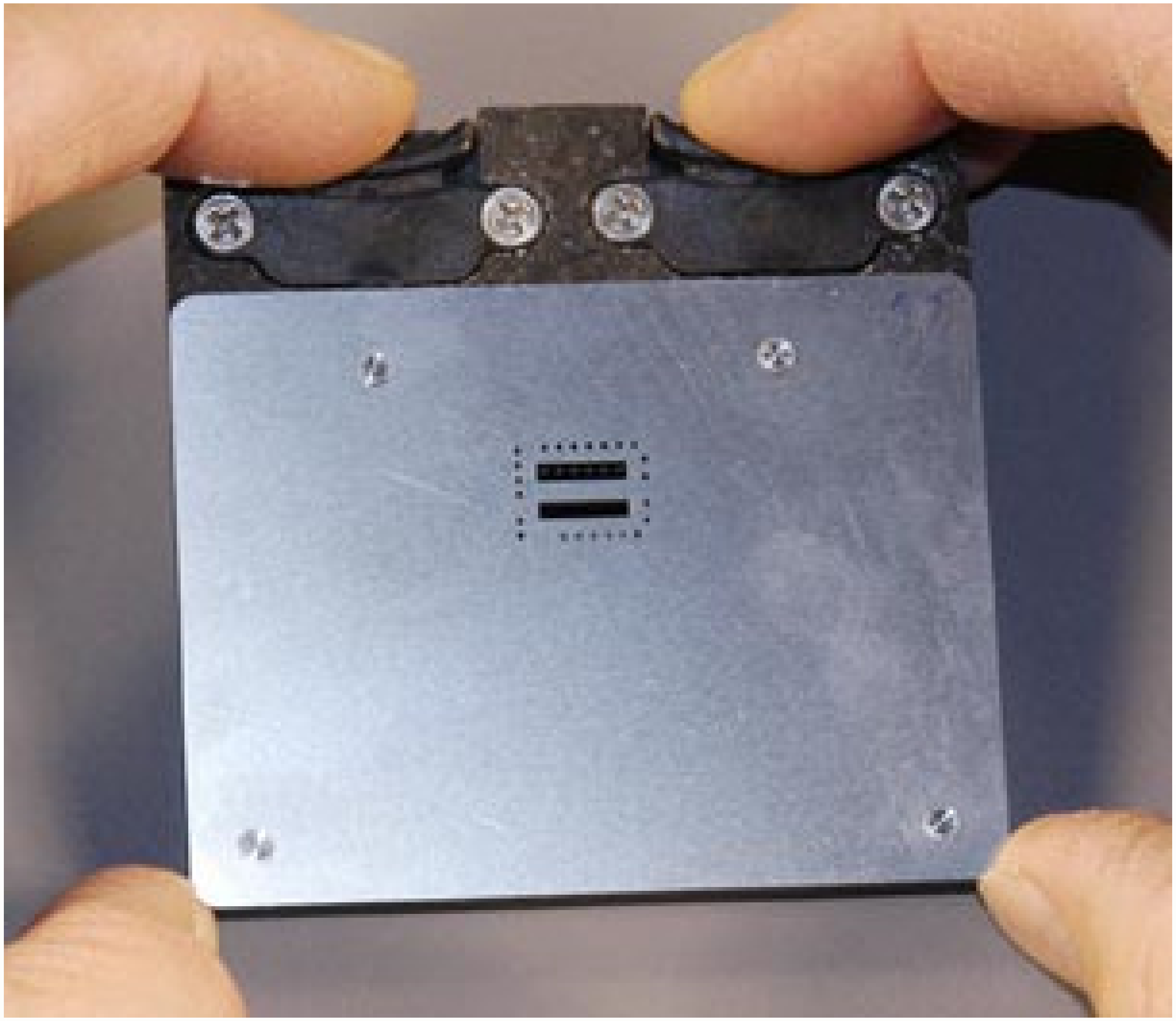
QFN Universal Fixture 2.75” x 2.75”



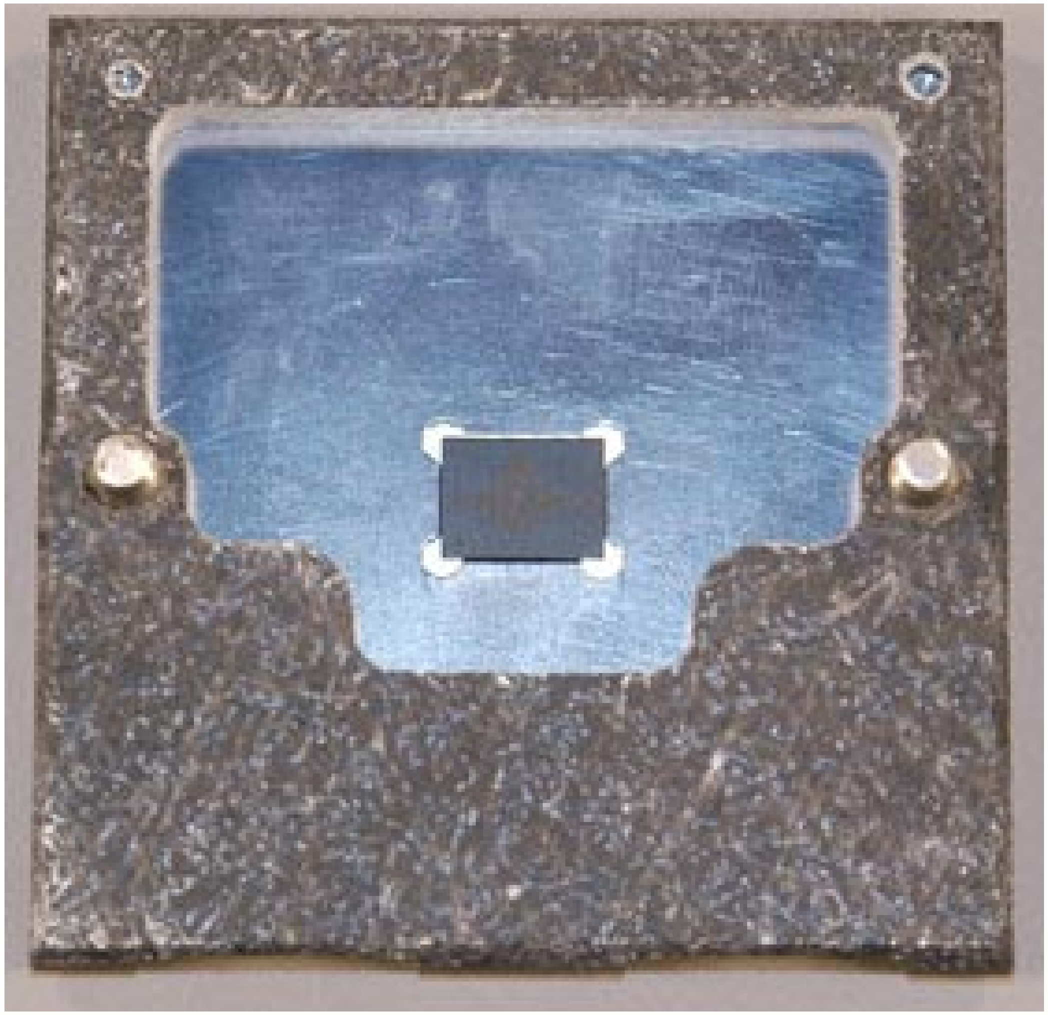
Installing the Package Holding Fixture



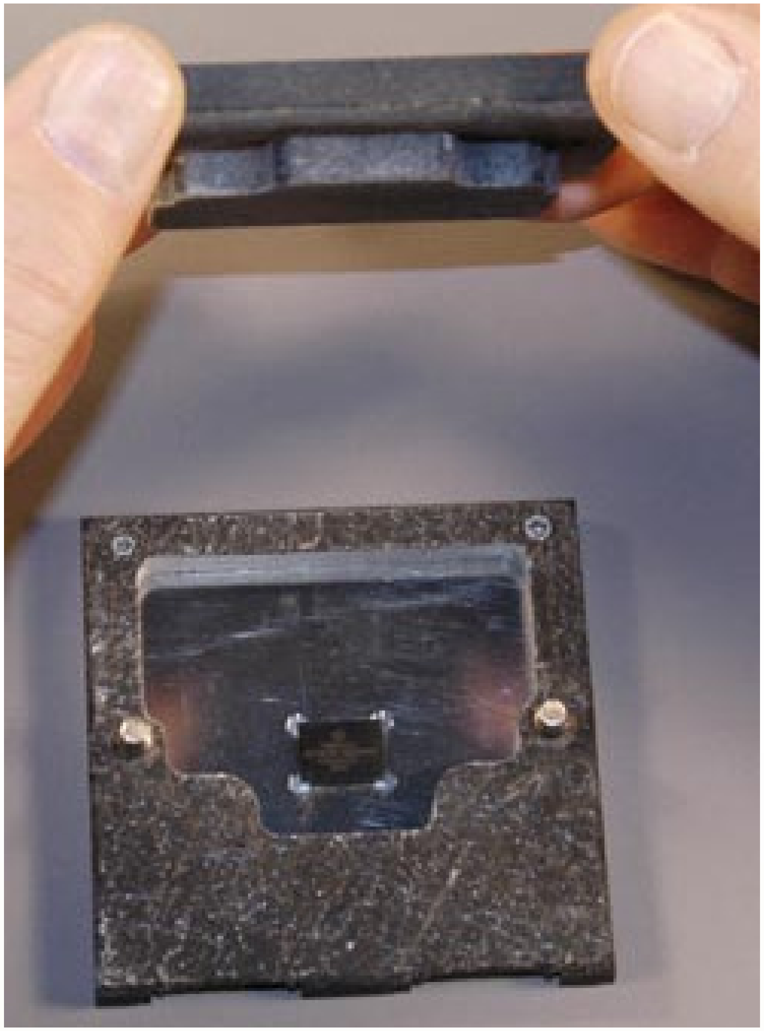
Stencil Installed



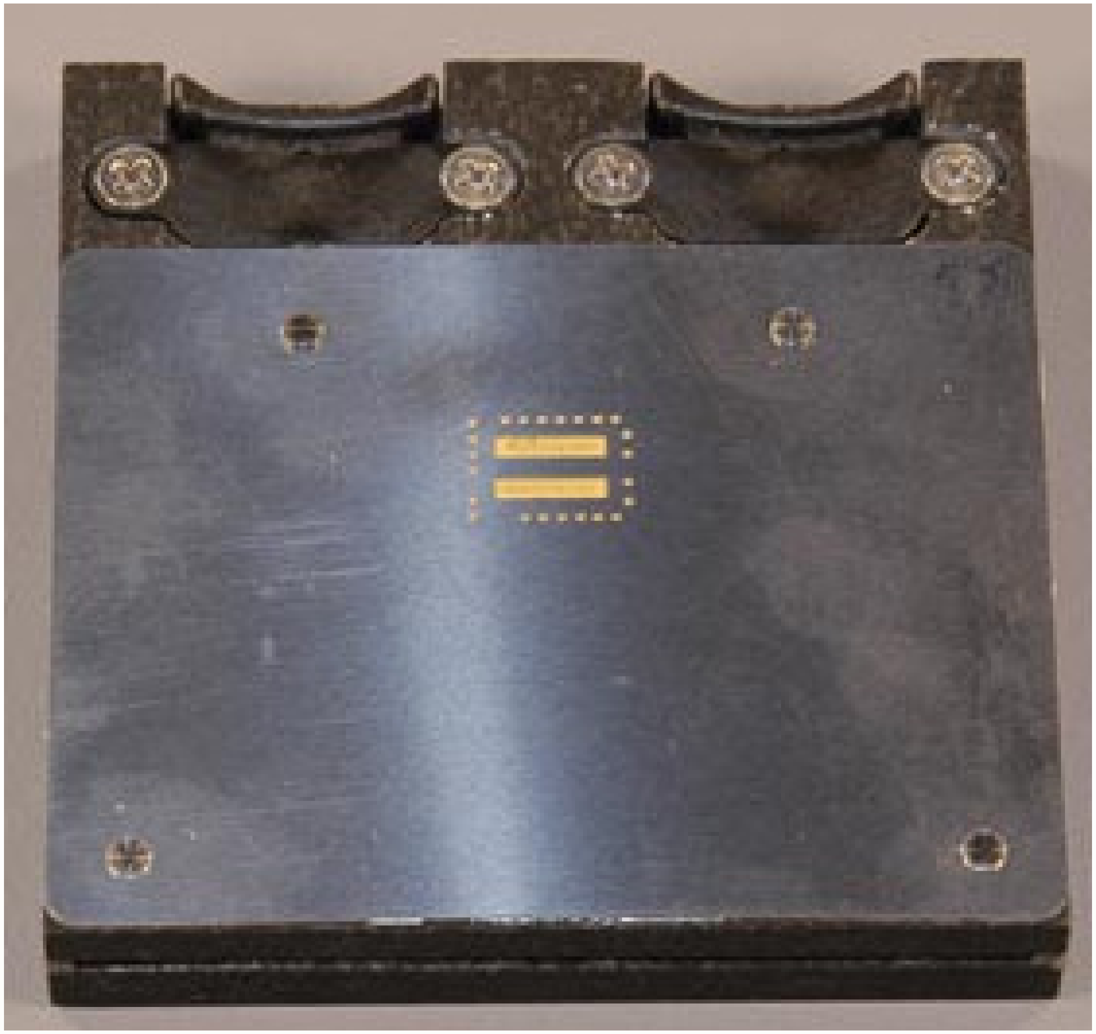
QFN placed in Holding Tool



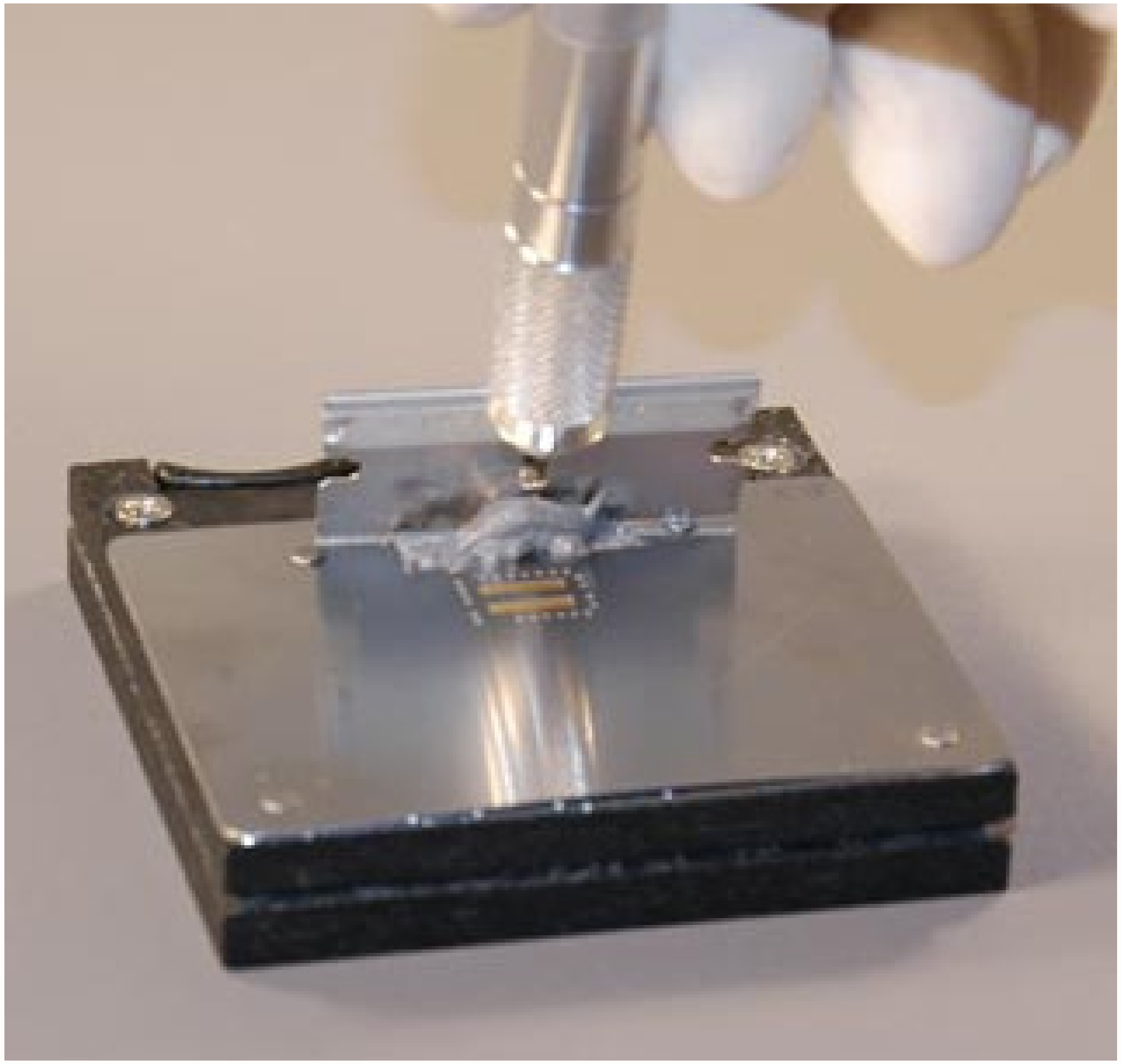
Package Hold-Down fixture is snapped into place



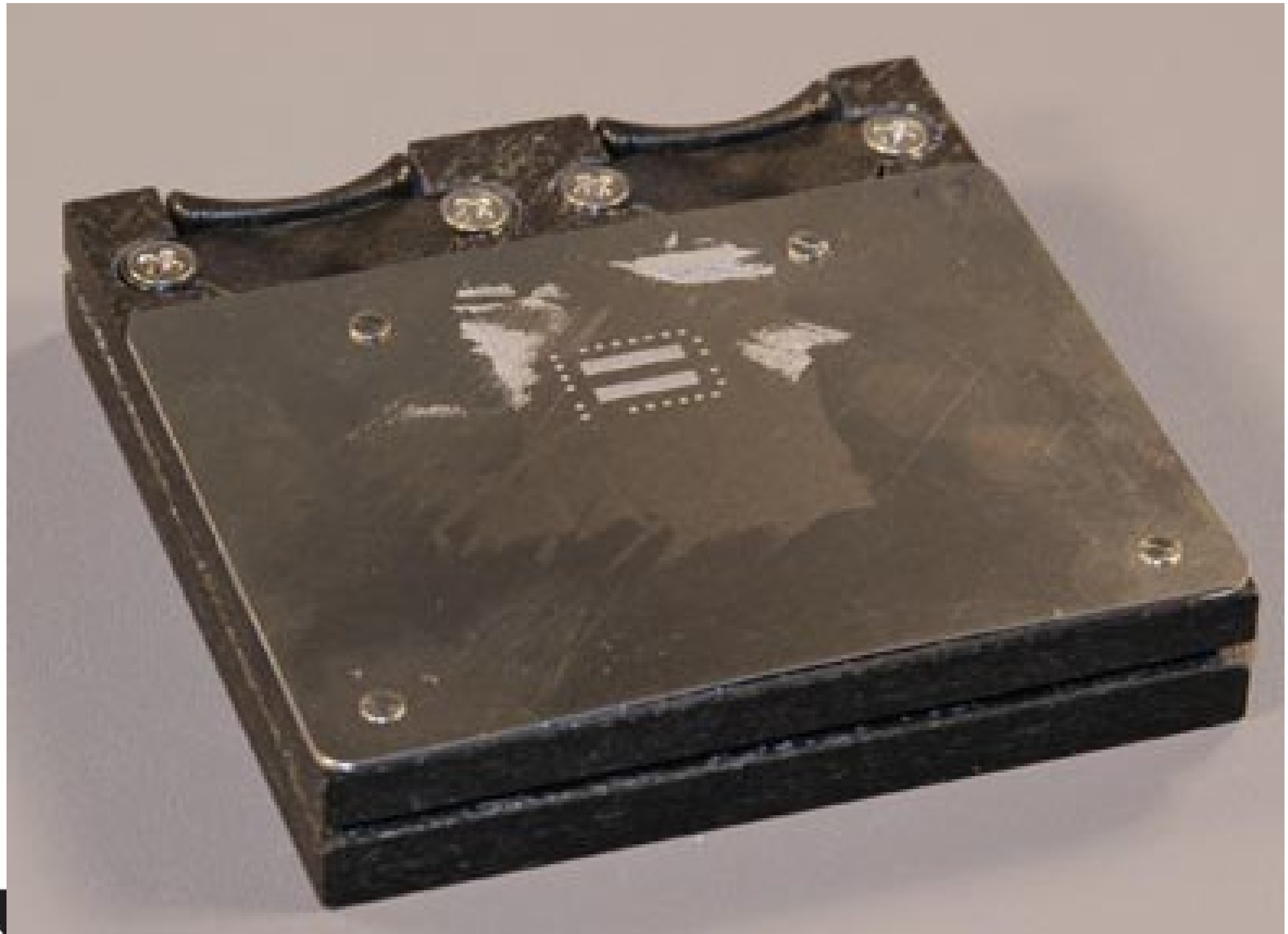
Package held in place against stencil ready for printing



Solder paste is printed onto the QFN package pads

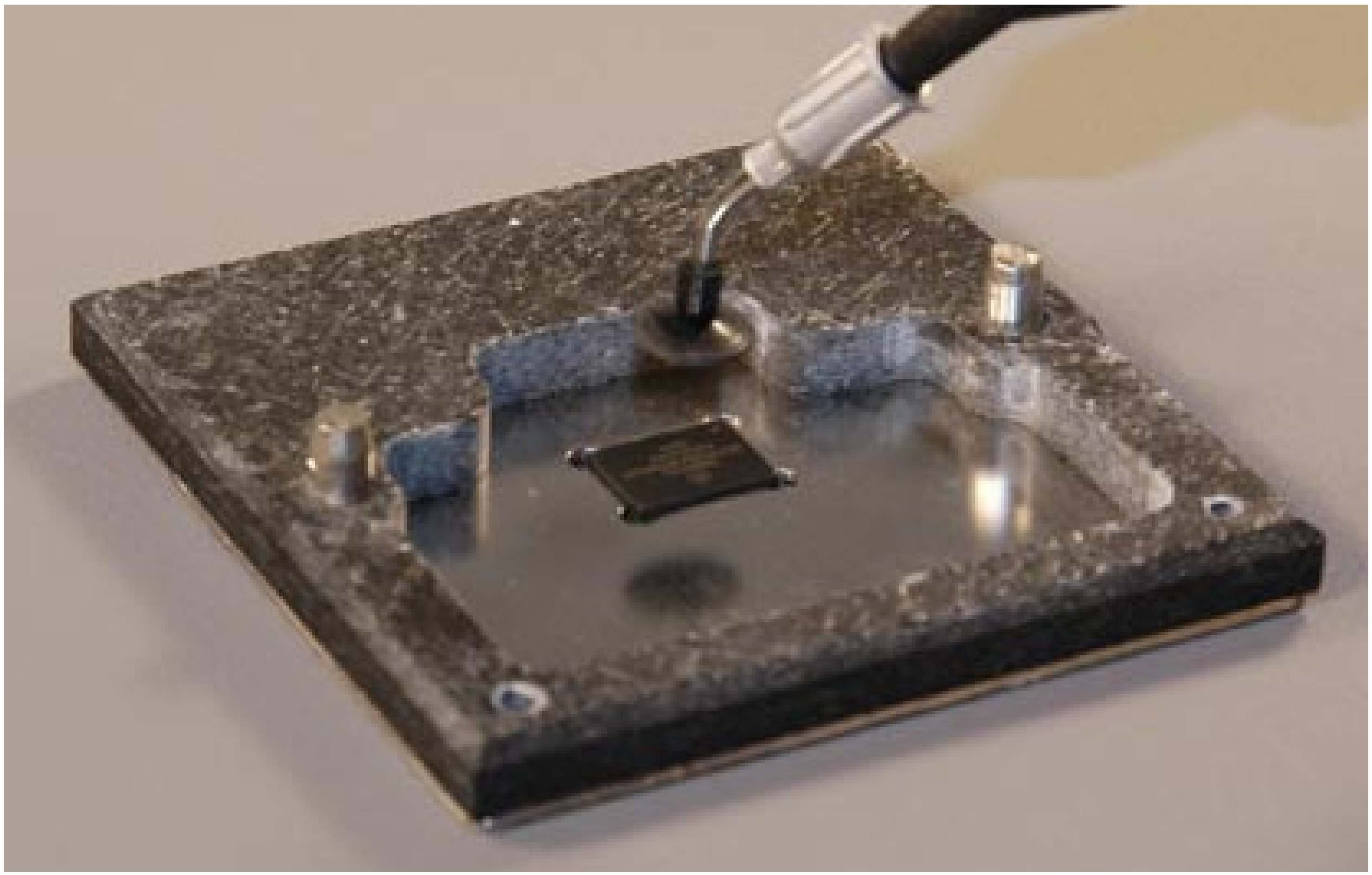


Solder paste has been printed.

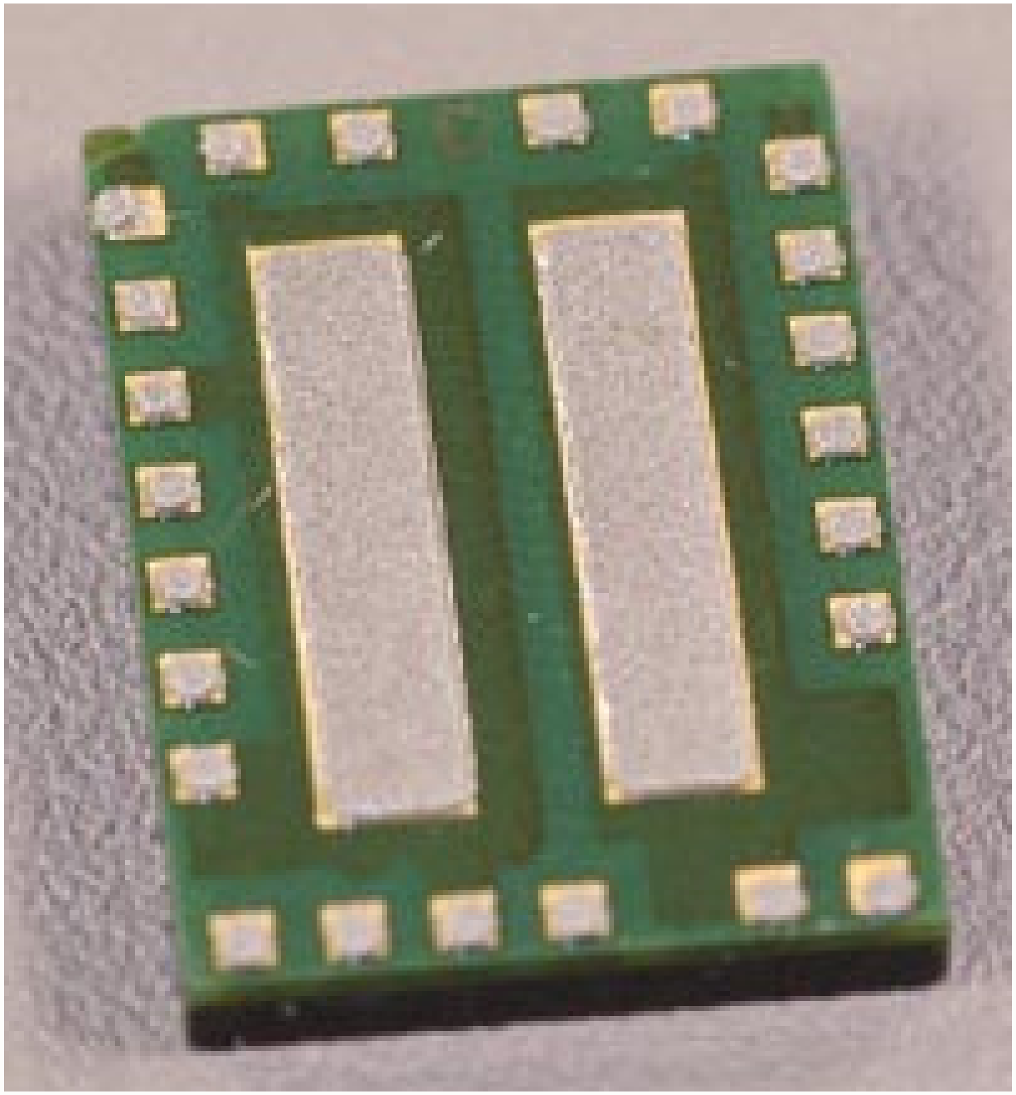


Package Hold-Down fixture is removed

Vacuum Pick lifts the QFN from the fixture and places it on the PCB.



Paste Printed on QFN pads



QFN Tool Design

Hold Fixture aperture is cut 5 mils (125 micron) larger than Max Package dimension

Shim tools with openings larger that holder openings can be used to achieve correct package thickness

Stencil Apertures are typically 50% of the area of the ground plane to prevent floating during reflow

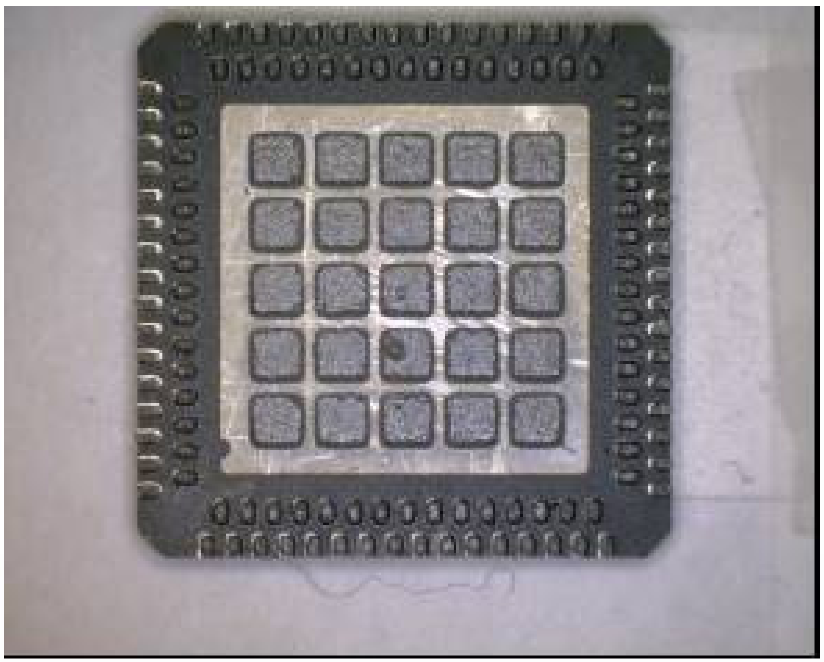
QFN Repair Stencil Design Guidelines

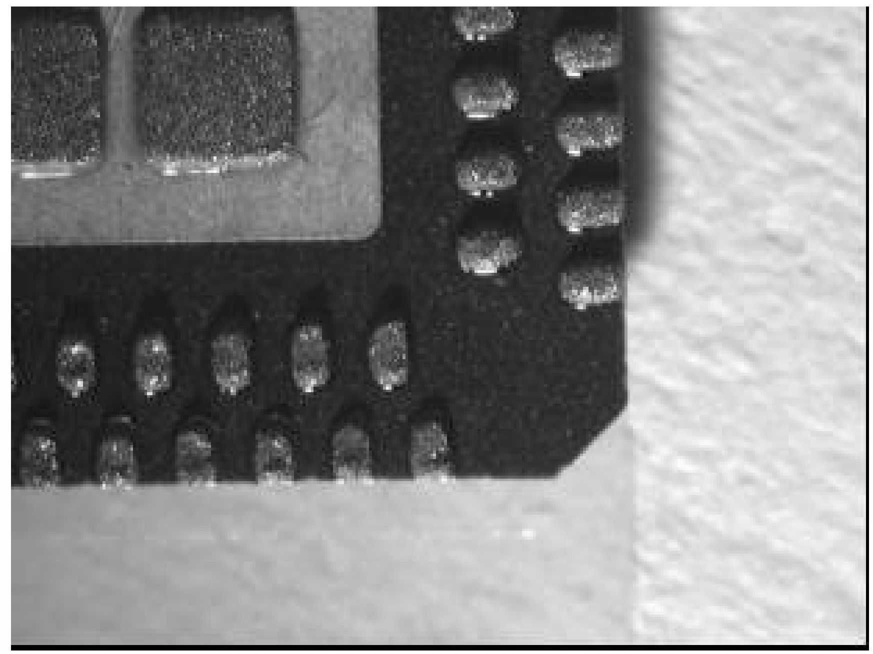
Package Size	Pitch	Pad / Aper Width	Pad / Aper Length	Stencil Thickness	Area Ratio	Stencil Type Recommended
10mm	.5mm	9.5	16	5	0.60	E-FAB
4mm	.5mm	10	16	5	0.62	E-FAB
3mm	.5mm	9.5	14.5	5	0.57	E-FAB

Dimensions are in Mils (1 mil = .001" = 25.4 microns)

Package and Pitch are in mm

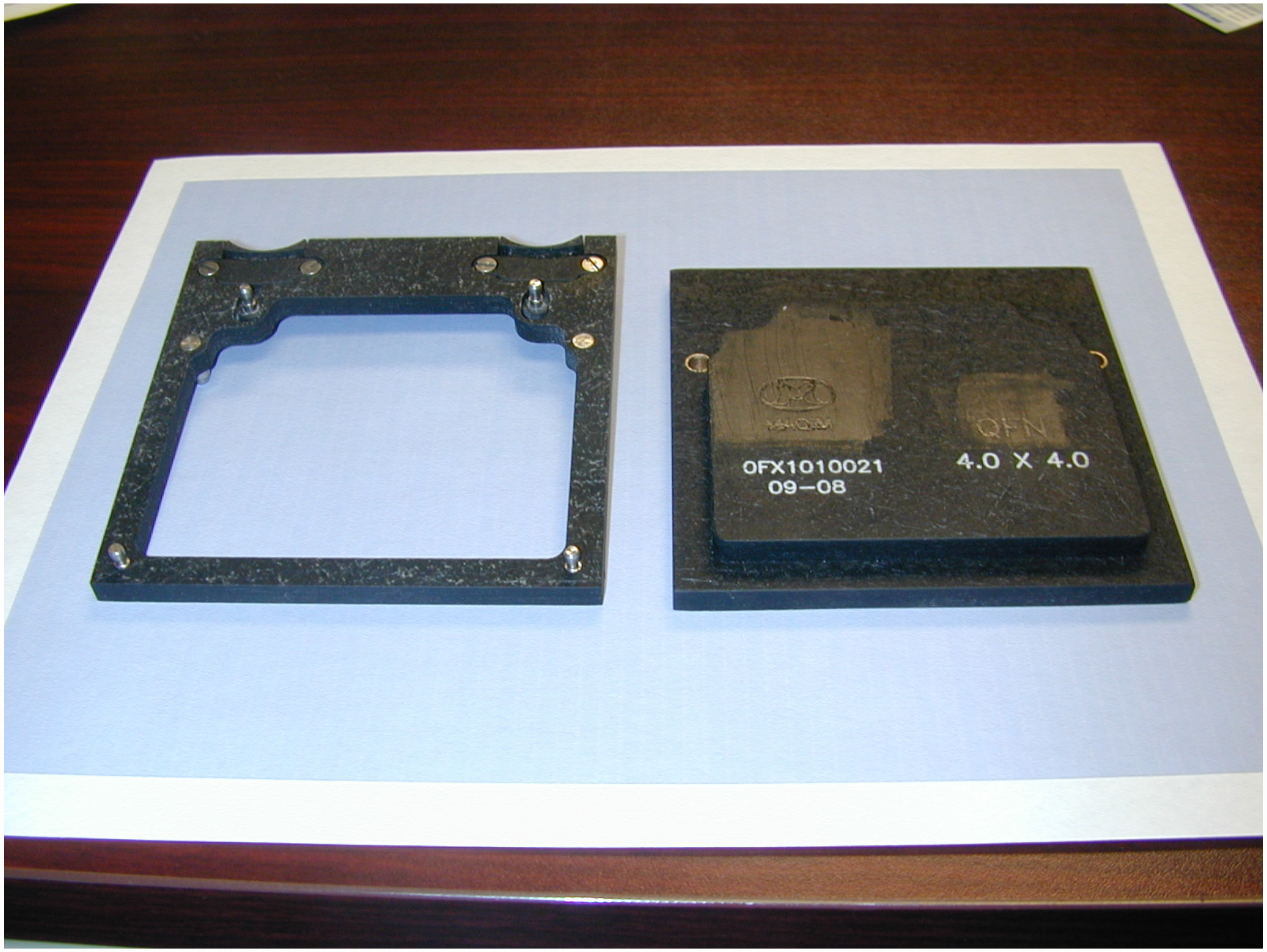
10 mm QFN, .5mm pitch,double row 124 I/O
Aperture 9.5 mil (240u) x 16 mil (406u)
E-FAB Stencil 5 mil (125u) thick, Area Ratio .60



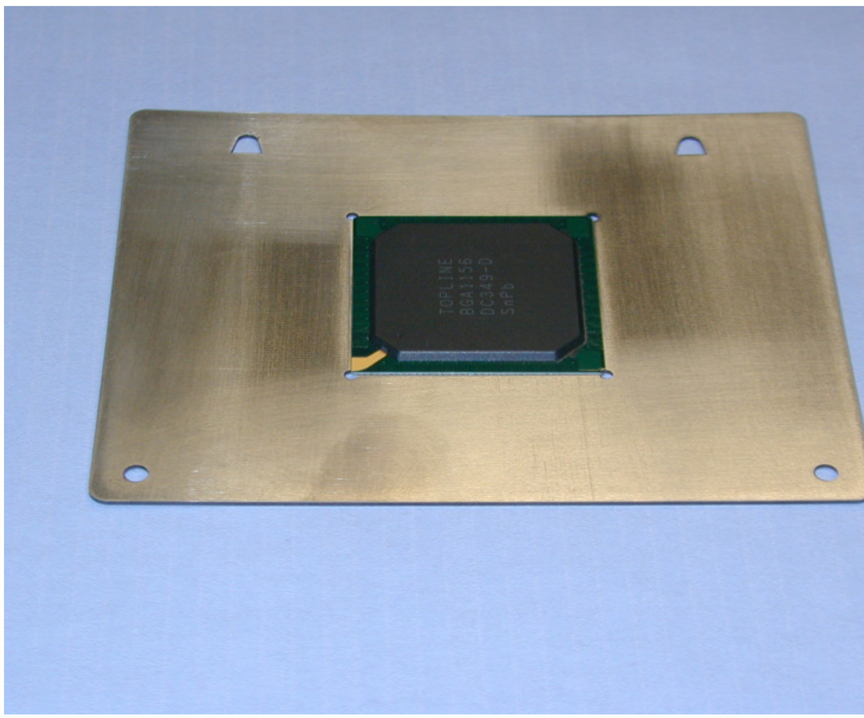


BGA Universal Fixture 4.0” x 4.0”

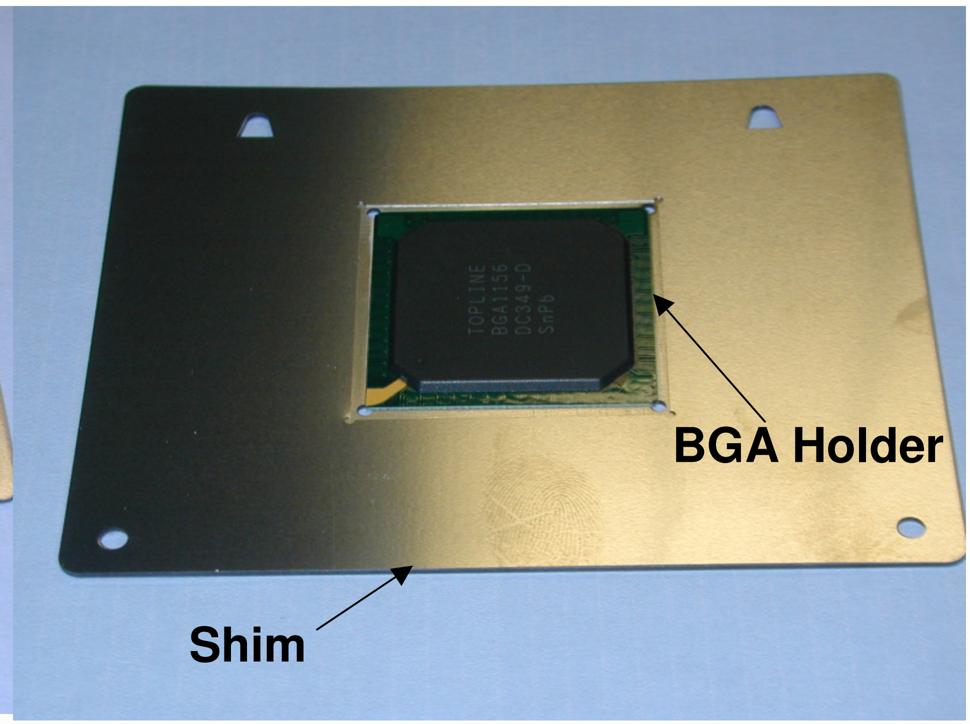
Stencil Holding Fixture **Package Hold-Down Fixture**



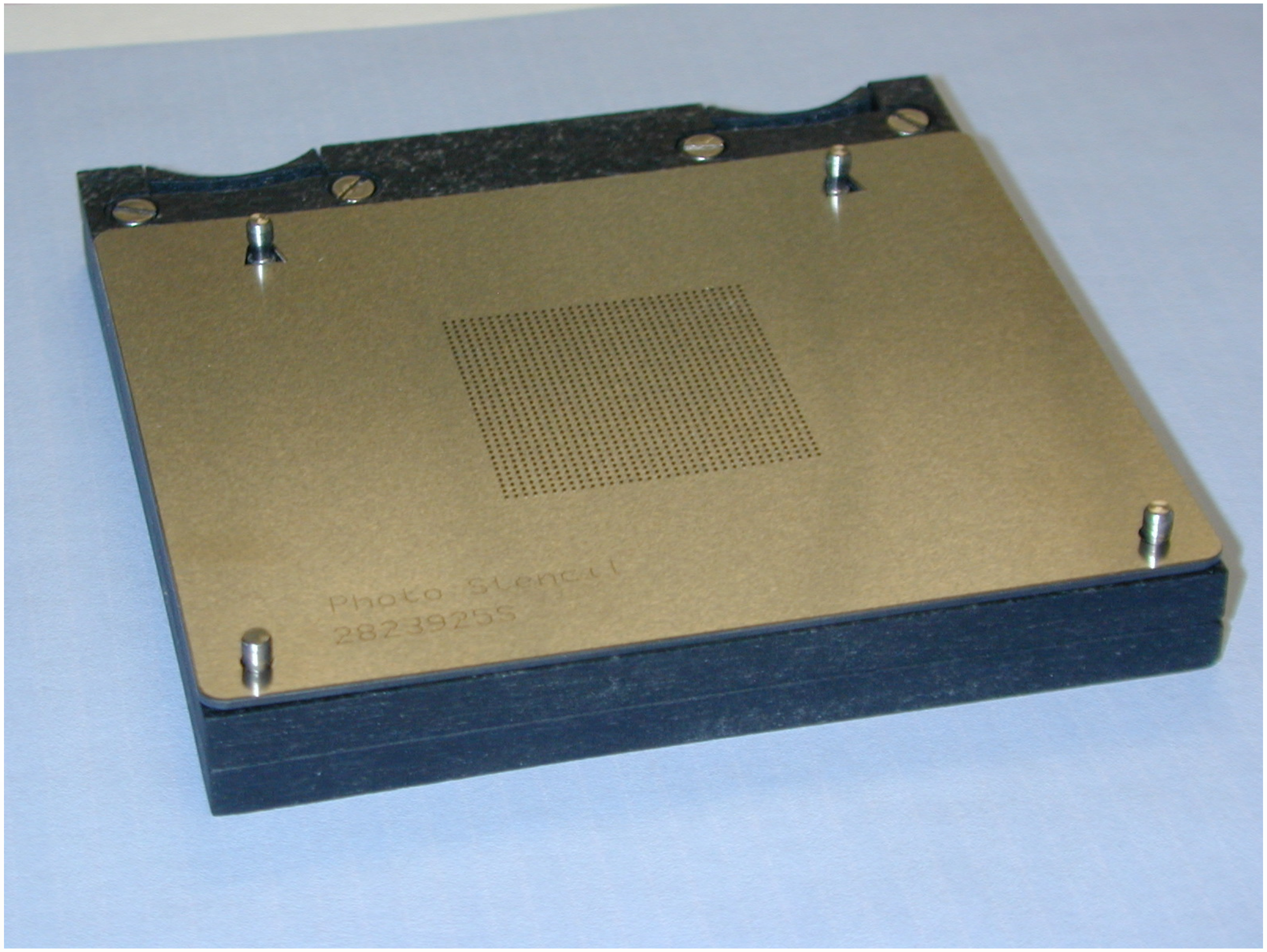
35mm Package in Holder



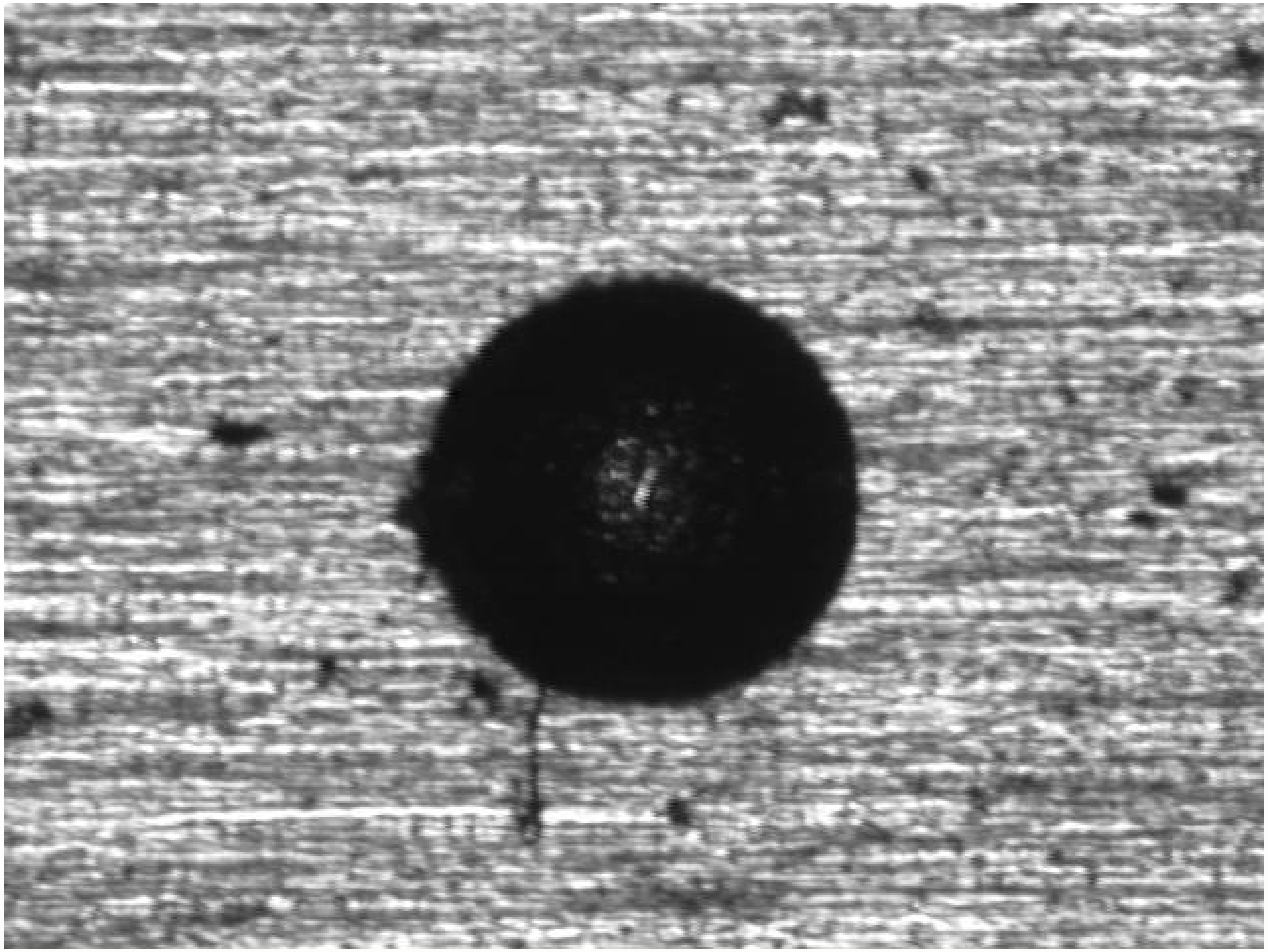
Shim and Package holder



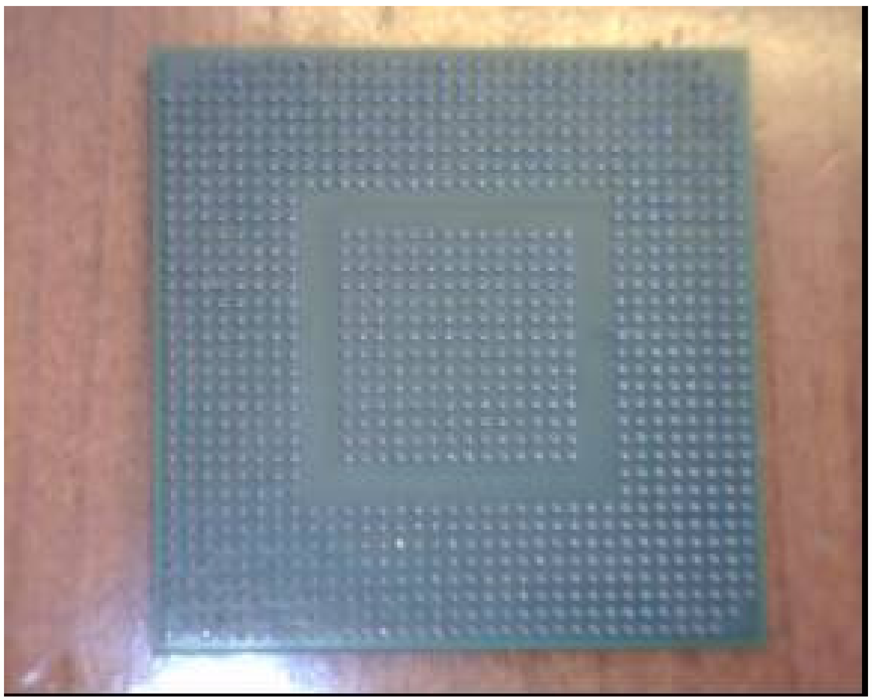
Stencil for 35mm,1mm pitch, 1156 I/O BGA

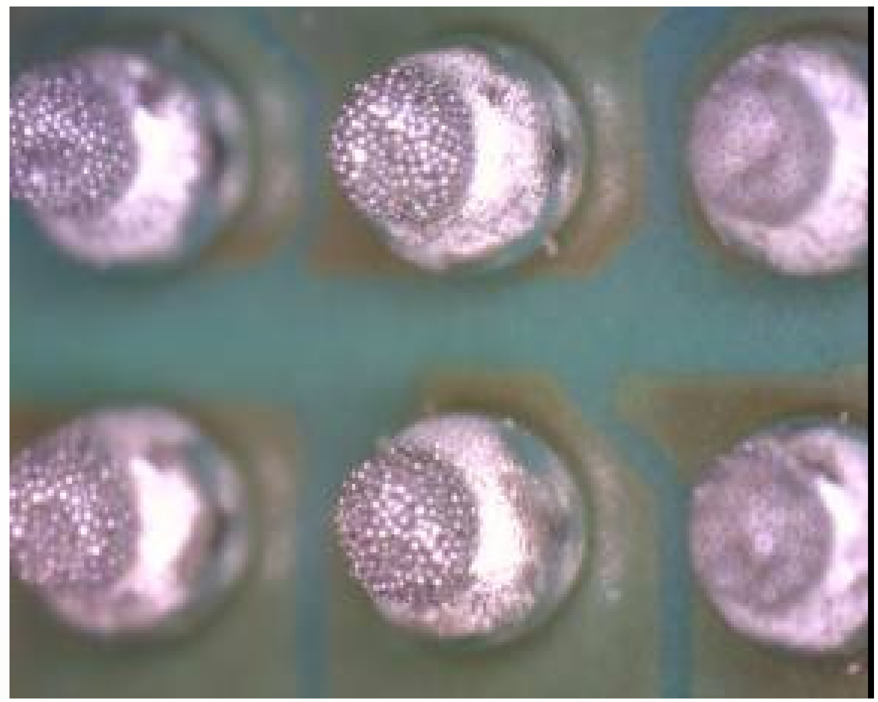


24 mil ball gasketing to18.7 Stencil Aperture



35mm BGA, 1mm pitch, 1024 I/O, 24 mil (600u) ball
Aperture 18.7 mils (475u)
Laser-Cut, 6 mil (150u) thick, Area Ratio .78
Paste as % of Solder Sphere Ball Volume 13.6%





BGA Stencil Design

Considerations:

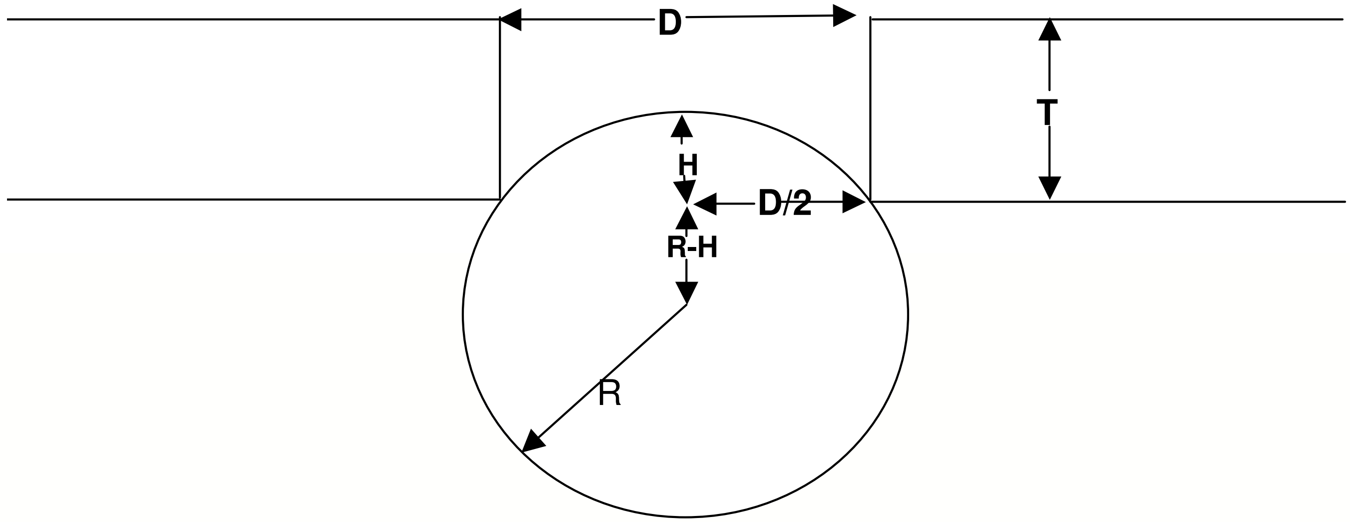
Ball needs to gasket to stencil aperture

Ball cannot extend above stencil surface

Need acceptable Area Ratio

Optimize paste volume on top of ball

Paste Volume printed on Solder Ball



T = Thickness of Stencil
R = Radius of BGA Ball
H = Height that Ball protrudes into Stencil Aperture
D = Radius of Stencil Aperture

Volume of the Stencil Aperture $V_1 = \pi D^2 T/4$
Volume of the Solder Ball sphere in the Stencil Aperture $V_2 = 1/3\pi H^2(3R-H)$
Useful relationship between D and R $R^2 = (D/2)^2 + (R-H)^2$
Volume of Solder Paste printed on the Ball $V_3 = V_1 - V_2$
$V_3 = \pi T(R^2-(R-H)^2) - 1/3\pi H^2(3R-H)$

			12 mil diameter ball					
Thickness of Stencil	Radius of BGA ball	Height ball sticks up into aper.	Volume of solder paste printed	Diameter of Stencil aper.	Area Ratio	Stencil Type Recommended	Volume of BGA ball	% paste of BGA ball Volume
4	6	0.5	67.64	4.80	0.30		905	7.5%
4	6	1	120.37	6.63	0.41		905	13.3%
4	6	1.5	158.96	7.94	0.50		905	17.6%
4	6	2	184.21	8.94	0.56		905	20.4%
4	6	2.5	196.90	9.75	0.61		905	21.8%
4	6	3	197.82	10.39	0.65	E-FAB	905	21.9%
4	6	3.5	187.75	10.91	0.68		905	20.8%
4	6	4	167.47	11.31	0.71		905	18.5%
4	6	4.5	137.77	11.62	0.73		905	15.2%
4	6	5	99.43	11.83	0.74		905	11.0%
4	6	5.5	53.25	11.96	0.75		905	5.9%
4	6	6	0.00	12.00	0.75		905	0.0%
5	6	0.5	85.70	4.80	0.24		905	9.5%
5	6	1	154.91	6.63	0.33		905	17.1%
5	6	1.5	208.42	7.94	0.40		905	23.0%
5	6	2	247.01	8.94	0.45		905	27.3%
5	6	2.5	271.48	9.75	0.49		905	30.0%
5	6	3	282.60	10.39	0.52		905	31.2%
5	6	3.5	281.16	10.91	0.55		905	31.1%
5	6	4	267.95	11.31	0.57		905	29.6%
5	6	4.5	243.74	11.62	0.58	E-FAB	905	26.9%
5	6	5	209.33	11.83	0.59		905	23.1%
5	6	5.5	165.50	11.96	0.60		905	18.3%
5	6	6	113.04	12.00	0.60		905	12.5%
6	6	0.5	103.75	4.80	0.20		905	11.5%
6	6	1	189.45	6.63	0.28		905	20.9%
6	6	1.5	257.87	7.94	0.33		905	28.5%
6	6	2	309.81	8.94	0.37		905	34.2%
6	6	2.5	346.05	9.75	0.41		905	38.2%
6	6	3	367.38	10.39	0.43		905	40.6%
6	6	3.5	374.58	10.91	0.45		905	41.4%
6	6	4	368.43	11.31	0.47		905	40.7%
6	6	4.5	349.72	11.62	0.48		905	38.7%
6	6	5	319.23	11.83	0.49		905	35.3%
6	6	5.5	277.76	11.96	0.50		905	30.7%
6	6	6	226.08	12.00	0.50		905	25.0%

16 mil diameter ball

Thickness of Stencil	Radius of BGA ball	Height ball sticks up into aper.	Volume of solder paste printed	Diameter of Stencil aper.	Area Ratio	Stencil Type Recommended	Volume of BGA ball	% paste of BGA ball Volume
4	8	0.5	91.19	5.57	0.35		2145	4.25%
4	8	1	164.33	7.75	0.48		2145	7.66%
4	8	1.5	220.19	9.33	0.58		2145	10.27%
4	8	2	259.57	10.58	0.66		2145	12.10%
4	8	2.5	283.25	11.62	0.73		2145	13.21%
4	8	3	292.02	12.49	0.78		2145	13.62%
4	8	3.5	286.66	13.23	0.83	Laser	2145	13.37%
4	8	4	267.95	13.86	0.87		2145	12.49%
4	8	4.5	236.68	14.39	0.90		2145	11.04%
4	8	5	193.63	14.83	0.93		2145	9.03%
4	8	5.5	139.60	15.20	0.95		2145	6.51%
4	8	6	75.36	15.49	0.97		2145	3.51%
5	8	0.5	115.53	5.57	0.28		2145	5.39%
5	8	1	211.43	7.75	0.39		2145	9.86%
5	8	1.5	288.49	9.33	0.47		2145	13.45%
5	8	2	347.49	10.58	0.53		2145	16.20%
5	8	2.5	389.23	11.62	0.58		2145	18.15%
5	8	3	414.48	12.49	0.62		2145	19.33%
5	8	3.5	424.03	13.23	0.66	E-FAB	2145	19.77%
5	8	4	418.67	13.86	0.69		2145	19.52%
5	8	4.5	399.17	14.39	0.72		2145	18.61%
5	8	5	366.33	14.83	0.74		2145	17.08%
5	8	5.5	320.93	15.20	0.76		2145	14.96%
5	8	6	263.76	15.49	0.77		2145	12.30%
6	8	0.5	139.86	5.57	0.23		2145	6.52%
6	8	1	258.53	7.75	0.32		2145	12.05%
6	8	1.5	356.78	9.33	0.39		2145	16.64%
6	8	2	435.41	10.58	0.44		2145	20.30%
6	8	2.5	495.20	11.62	0.48		2145	23.09%
6	8	3	536.94	12.49	0.52		2145	25.04%
6	8	3.5	561.41	13.23	0.55		2145	26.18%
6	8	4	569.39	13.86	0.58	E-FAB	2145	26.55%
6	8	4.5	561.67	14.39	0.60		2145	26.19%
6	8	5	539.03	14.83	0.62		2145	25.13%
6	8	5.5	502.27	15.20	0.63		2145	23.42%
6	8	6	452.16	15.49	0.65		2145	21.08%

BGA Repair Stencil Design Guideline

D Ball Size	T Stencil Thickness	H Height of Ball in Aper.	H/T Ratio	A Aperture Dia. of circle	Area Ratio	Stencil Type Recommended	Paste Vol. as % of ball Volume
12	4	3.0	0.75	10.4	0.65	E-FAB	21.9%
12	5	4.5	0.90	11.6	0.58	E-FAB	26.9%
16	4	3.5	0.88	13.2	0.83	Laser	13.4%
16	5	3.5	0.70	13.2	0.66	E-FAB	19.8%
16	6	4.0	0.66	13.9	0.58	E-FAB	26.6%
20	5	4.0	0.80	13.0	0.80	Laser	13.6%
20	6	4.5	0.75	16.7	0.70	Laser	18.5%
24	6	4.5	0.75	18.7	0.78	Laser	13.6%
24	7	5.0	0.71	19.5	0.70	Laser	17.6%
30	7	5.5	0.79	23.2	0.69	Laser	12.1%
30	8	6.0	0.75	24.0	0.64	Laser	15.2%

Dimensions are in Mils (1 mil = .001" = 25.4 microns = .0254 mm))

What about Flip Chip

Paste Printed on solder bumps?

Application from customer

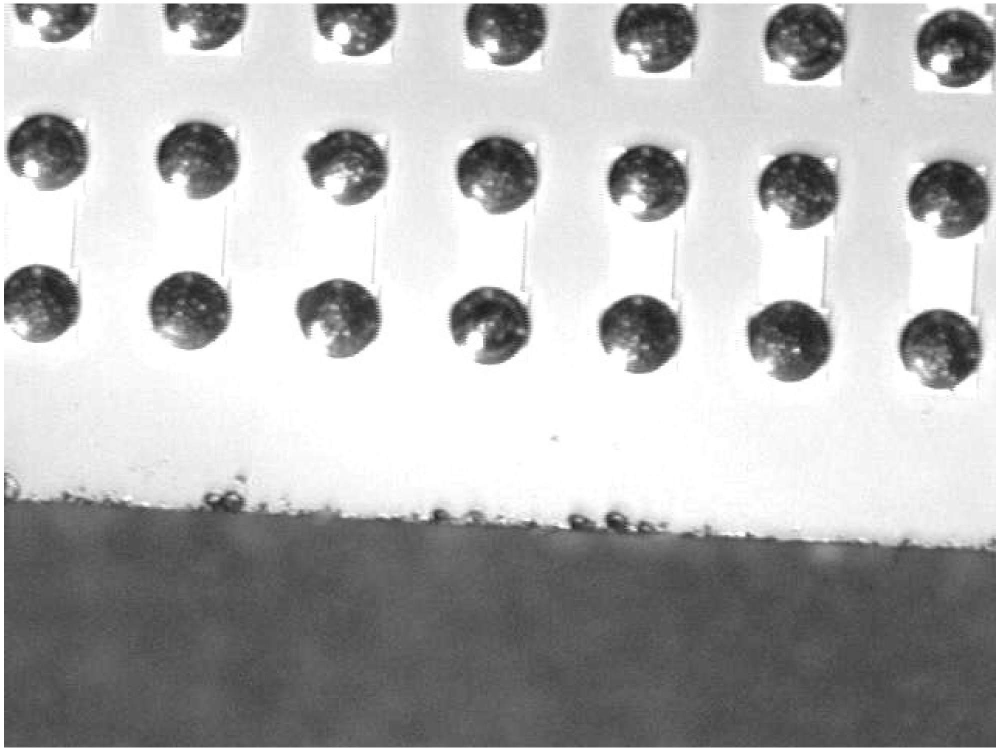
Assemble small number of F/C

5mm square die, 250u pitch, 125u bumps, 317 I/O

Flip Chip Stencil Design

			5 mil diameter ball					
Thickness of Stencil	Radius of BGA ball	Height ball sticks up into aper.	Volume of solder paste printed	Diameter of Stencil aper.	Area Ratio	Stencil Type Recommended	Volume of BGA ball	% paste of BGA ball Volume
2	2.5	0.5	12.30	3.00	0.38	None	65	18.79%
2	2.5	1	18.32	4.00	0.50	AMTX	65	27.99%
2	2.5	1.5	18.84	4.58	0.57	AMTX	65	28.79%
2	2.5	2	14.65	4.90	0.61	AMTX	65	22.39%

Paste on 125u Bump



Customer Feedback:
Charles Mitchell Harris Semiconductor
80% of die have paste on all 317 bumps

Conclusions

Successful paste printing on 10 mm QFN, .5 mm pitch, 124 double row I/O

Successful paste printing on 35mm BGA, 1 mm pitch, 24 mil (609u) balls,1024 I/O

Design Guideline presented for QFN and BGA stencil, package holder, package shims

BGA balls and FC bumps self center in the stencil apertures facilitating alignment

Marginal success printing paste on 5 mm FC, 250u pitch, 125u bumps, 317 I/O