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STENCIL CONSIDERATIONS FOR MINIATURE COMPONENTS

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ABSTRACT
SMT Assembly is going through a challenging phase with the introduction of miniature components such as uBGA's, .3mm CSP's and 01005 passives into the assembly process. Example assemblies are cell phones and other hand held devices driven by consumer demand for smaller devices with increased functionality. Printing these miniature devices along with more conventional SMT devices like .5mm QFP's and 0603 and 0805 passives is a challenge. Whereas a 4mil (100 micron) or 5 mil (125 micron) thick stencil provides good paste transfer for the normal SMT devices, stencils with this thickness have very low Area Ratios for the miniature devices. For example a .3mm CSP with a 7.5 mil (190 micron) has a .47 Area Ratio for a 4 mil thick stencil.

This paper is divided into two parts outlining two different approaches to resolve this issue. Part 1 deals with a Two Print Step Stencil Process where small apertures are printed with a thin stencil thus providing acceptable Area Ratios. A second thicker stencil is used for normal SMT devices, RF Shields, and SMT connectors. This stencil has relief pockets formed on the board side of the stencils anywhere paste was printed with the first stencil.

Part 2 deals with different stencil types (technologies) and different aperture wall coatings. Stencil technologies include Laser and Electroform; Aperture Wall coatings include PTFE coatings. Aperture Wall pictures and paste print tests compare the performance of these different configurations and how they influence paste transfer for miniature devices with Area Ratios less than the standard recommended lower limit of .5. In the second case a step stencil is not necessary.

Key Words: Area Ratio, Stencil, Electroform, Laser, Coatings, Step Stencil, Paste Transfer

INTRODUCTION
A printing challenge exists when very small devices coexist on a PCB with components requiring either high volume or high paste height. When printing solder paste for 01005 and / or .3 mm pitch uBGA a thin stencil, normally (50 to 75 um) thick is preferable to achieve sufficient paste transfer efficiency and low paste volume dispersion. If a 100 um thick stencil is used to print these small devices, the area ratio is less than .5 which is lower than the recommended value for both Laser-Cut stencils and E-FAB Electroform stencils. It is very common to print solder paste for RF shields for hand-held devices. Normally, higher solder paste deposits are required because of coplanarity issues with RF shields. To achieve these higher solder paste

deposits a thicker stencil is needed. A step stencil[(1)] is normally used to achieve different solder paste heights. However in many hand-held devices the spacing between the small pitch components and the RF shield is normally very small, in many cases as small as 500 um (20 mils). The design guideline[1] for a normal step-down stencil is that the aperture in the step-down region be positioned at least 890 um (35 mils) from the step-up wall for every 25um (1mil) of step-up thickness. Otherwise the squeegee blade (metal or rubber) does not do a very job of depositing paste into the lower level apertures. In the case of RF shields a stencil thickness of 150 to 175 um (6 to 7 mils) may be required to achieve the desired solder paste height. The height difference; 75um (3 mils) thick stencil for the small components and 150um (6 mils) thick stencil, prevents a normal step stencil to be used for this application.

PART 1 "TWO-PRINT STENCIL PROCESS"
This type of step allows for very small spacing between the apertures of the smaller components and apertures of the RF shield. The objective of this study is to determine the smallest spacing between small component apertures and RF shield apertures for the Two-Print stencil process. Another objective is to determine the minimum clearance between the relief pocket of the 2nd print stencil and the 1st print stencil without paste smearing in the relief pocket.

Two-Print Stencil Test Plan
The Two-Print stencil process consists of two stencils. The 1st print stencil is used to print .3 mm pitch uBGA (198um circular apertures), .4 mm pitch uBGA (244 um circular apertures), 01005 chip components (178um circular apertures), and 0201 chip component apertures (300um square apertures). Two 1st print stencils were fabricated. Both were E-FAB Electroform stencils; one was 50um (2 mils) thick and the other was 75um (3 mils) thick. The 2nd print stencil is used to print RF shields and a SMT connector and some large capacitor apertures. Four 2nd print stencils were manufactured with four different stencil thicknesses; each stencil had a relief pocket etched in the area where solder paste was printed with the 1st stencil. The design is summarized in Table 1. The manufacturing process for the 2nd print stencils was to Chem-Etch the Relief pockets in the metal foil then to Laser-Cut the apertures for the RF shields and other devices in this stencil. The 2nd print stencil is designed to have different spacing's between the apertures in the 1st print stencil and the apertures in the 2nd print stencil. This design is shown in

Figure 1. As seen the spacing is 250um (10 mils) for Image 1, 500um (20 mils) for Image 2, 750um (30 mils) for Image 3 and 100um (40 mils) for Image 4. Figure 1 is a schematic drawing of the aperture layout and relief pockets for the 2nd print stencil. As seen in Figure 1 there is 0 swell for Image 1. This means that the relief etch pocket edge was designed to line up with the edge of the apertures in the 1st stencil. No etch compensation was used for this relief pocket. When the pocket is etched it not only etches down but it also etches out making the pocket larger. The increase in pocket size depends on how deep the pocket is etched. The increase in pocket size is about ½ of the depth of the relief pocket. As an example in the case of the 175um (7 mil) thick stencil with a relief pocket 125um (5 mils) deep the increase in size of the relief pocket is 64 um (2.5 mils). The layout of the 1st print stencil is shown Figure 2. A photograph of the 1st print E-FAB stencil is shown in Figure 3. Figure 4 shows a picture of the 2nd print stencil, a Laser-Cut / Chem-Etch stencil, showing the apertures along with the relief pockets.

Print Results

The test boards used in this experiment were bare copper clad FR4 with 3 fiducials for registration between the 1st print and 2nd print stencil. A Speedline Momentum printer along with E-Blade Electroformed squeegee blades were used. The printer set-up and Printing test procedure are shown in Table 2. Figure 5 shows solder bricks printed with the 1st and 2nd stencil for Image 1 with 250 um (10 mils) spacing between the 1st and 2nd print. This print sequence used a 50 um (2mil) thick E-FAB 1st print stencil and a 175 um (7 mil) Laser-Cut / Chem-Etch with a 125 um (5 mil) relief pocket 2nd print stencil. Note that the spacing between the .3 mm uBGA and the RF shield is 250 um (10 mils). Figure 6 shows the same print sequence but for the 01005 chip component solder bricks next to the FR shield solder brick. Spacing is 250 um (10 mils) but a slight smearing of the 01005 solder brick can be seen. Figure 7 shows a close up of the 2nd print stencil which is 175 um (7 mils) thick with a 125 um (5 mil) deep relief pocket. Notice that the spacing from the wall of the relief pocket is 175 um (7 mils) to the RF shield aperture. This is as expected for the Image 1 since the relief pocket increased about 64 um (2.5 mils) from the original starting position of 250 um (10 mils) from the RF shield aperture. Figure 8 shows the same print sequence for Image 2, where the .3 mm uBGA apertures were spaced 500 um (20 mils) from the RF shield aperture. There is no hint of smearing for this configuration.

Additional Testing

The prior “Two-Print Stencil Process” dealt with two sets of stencils; (1) a 50 um (2mil) thick 1st print stencil used with a 175 um (7 mil) thick 2nd print stencil having a 125 um (5mil) deep relief pocket and (2) a 75 um (3mil) thick 1st print stencil used with a 200 um (8mil) thick 2nd print stencil having a 150 um (6 mil) deep relief pocket. In order to establish the minimum clearance height required between the 1st print stencil and the thickness of the relief pocket of the 2nd print stencil a third set of stencils were tested. A 50 um (2mil) thick 1st print stencil was used with a 125 um (5mil) 2nd thick 2nd print stencil having a 75 um (3mil) deep relief pocket. Print results for this test are shown in Figures 9 to Figures 11 for the Image 1 configuration [250 um (10mils) spacing between apertures in the 1st and 2nd print stencils]. Figure 9 shows the position of the .3 mm uBGA solder paste bricks with respect to the RF shield solder paste bricks. Figure 10 is a close-up of the same image. This image shows slight smearing in the corner of the uBGA array caused by contact with the corner of the relief pocket. Figure 11 shows solder bricks for the 01005 chip component with respect to the RF shield solder brick. Again slight smearing is observed on the solder brick closest to the relief pocket. Figure 12 demonstrates that no smearing was observed when the spacing between apertures in the 1st stencil and 2nd stencil was increased to 500 um (20mils). It can be concluded that with a spacing as low as 25 um (1mil) between the 1st print stencil thickness and the depth of the relief pocket on the 2nd stencil no paste smearing occurred during the 2nd print as long as the clearance between apertures is between 250 um (10mils) and 500 um (20 mils). Although not specifically confirmed by tests, I believe a safe keep-out spacing between apertures in the 1st print stencil and the 2nd print stencil is 380 um (15mils). This is based on the fact that only the outer half of the .3 mm uBGA solder brick touched the relief pocket at a spacing of 250 um (10mils) as seen in Figure 18.

Conclusion Part 1

It has been demonstrated that “A Two-Print Stencil Process” is an effective solution to print solder paste when different paste heights are required. The spacing between apertures requiring different heights can be as small as 380 um (15mils). It has also been demonstrated that the depth of the relief pocket in the 2nd print stencil can be as low as 25 um (1mil) more than the thickness of the 1st print stencil. It should also be noted that aperture spacing between apertures in the 1st and 2nd print stencil is independent of the thickness of the 2nd print stencil. This is very useful when very thick paste heights are required from the 2nd print stencil. The “Two-Print Stencil Process” offers a new solution to cell phone and hand-held SMT assemblers. Thick solder paste for RF shields can be printed very close to solder paste bricks for very small devices like .3 mm uBGA and 01005 chip components. A design decision must be made as to which apertures are to be included in the 1st print stencil and which apertures are to be included in the 2nd print stencil.

Future Work Part 1

The work presented here had relief pockets positioned in close proximity to apertures in the 1st and 2nd print stencils. The relief pockets encompassed the entire area of the device printed in the 1st print stencil. The largest relief pocket was 6.8 mm x 6.8 mm (.270” x .270”). There was no support issue regarding the 2nd print stencil flexing down to touching solder bricks printed by the 1st stencil, even when there was only 25 um (1mil) clearance.

As a future project it should be determined how large the relief pocket could be designed without flexing to touch 1st print solder bricks. The future project should also address the size and spacing of support pillars between apertures when the 1st print stencil has a high density of apertures.

References

(1) William Coleman and Michael Burgess "Step Stencils", Global SMT and Packaging, October 2006

Table 1

Two-Print Stencil Test Plan:

1st print stencil is an E-FAB Electroform stencil and prints solder paste for .3 mm and .4 mm uBGA's, 01005 and 0201 chip components.

Two stencils were manufactured:

- 50 um (2mil) thick E-FAB stencil
- 75 um (3mil) thick E-FAB stencil.

2nd print stencil is a Laser-Cut / Chem-Etch stencil with apertures for RF Shields, capacitors, and a SMT connector. This 2nd print stencil has relief pockets anywhere paste is printed by the 1st print stencil.

Four 2nd print stencils were manufactured:

- 8 mil thick with a 6 mil deep relief pocket
- 7 mil thick with a 5 mil deep relief pocket
- 6 mil thick with a 4 mil deep relief pocket
- 5 mil thick with a 3 mil deep relief pocket

Design of the aperture spacing between 1st and 2nd print stencil and relief pocket (4 images in the stencil):

- Image 1 250 um (10mil) spacing between apertures in 1st and 2nd stencil
- Image 2 500 um (20mil) spacing between apertures in 1st and 2nd stencil
- Image 3 750 um (30mil) spacing between apertures in 1st and 2nd stencil
- Image 4 1000 um (40mil) spacing between apertures in 1st and 2nd stencil

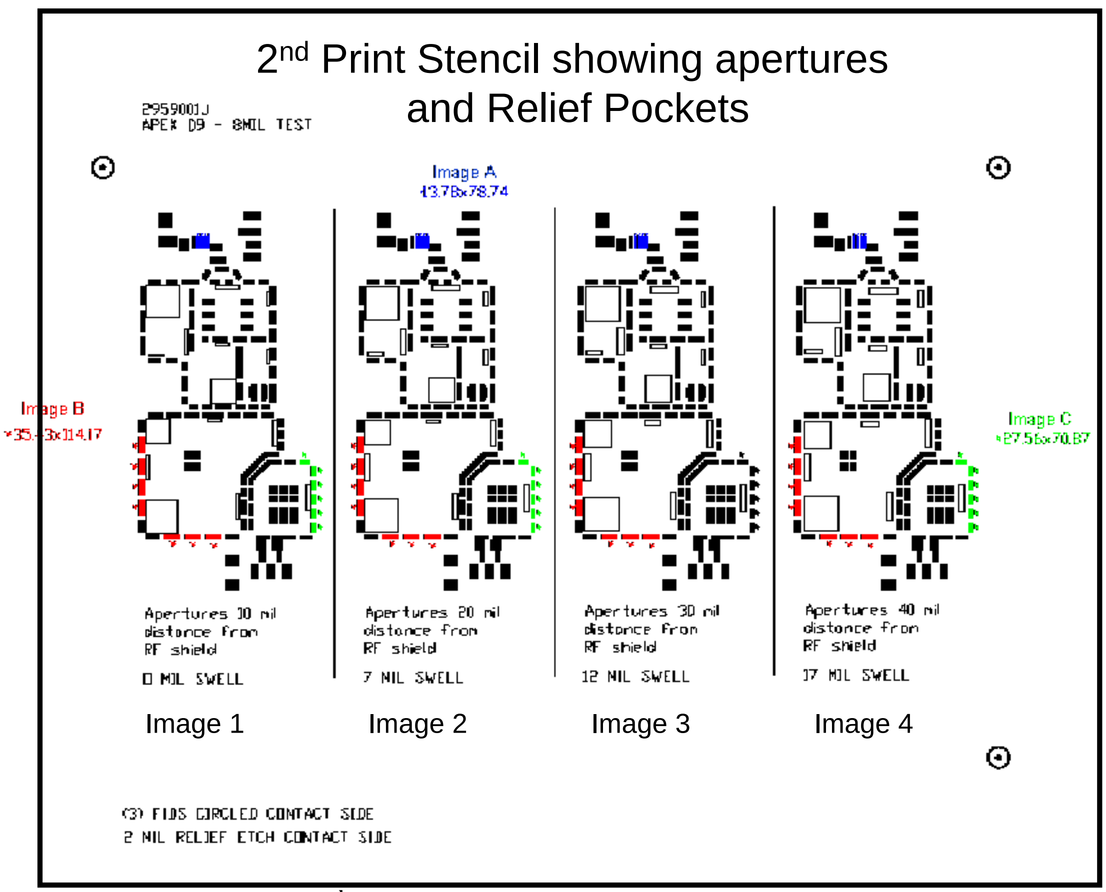


Figure 1 Schematic Layout of 2nd Print Stencil

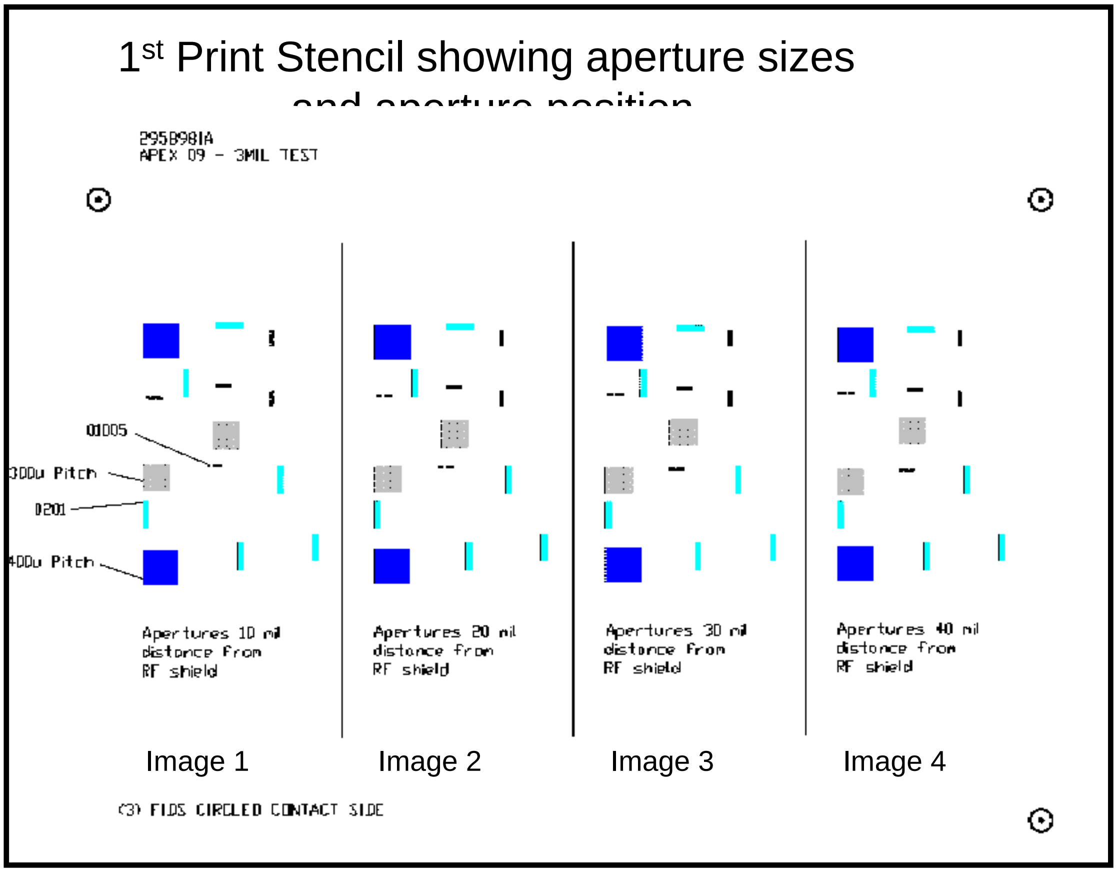
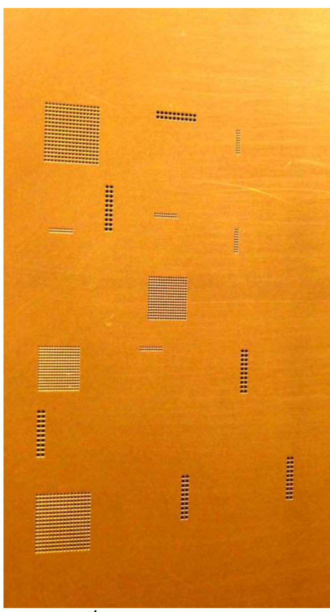


Figure 2 Schematic layout of 1st Print Stencil



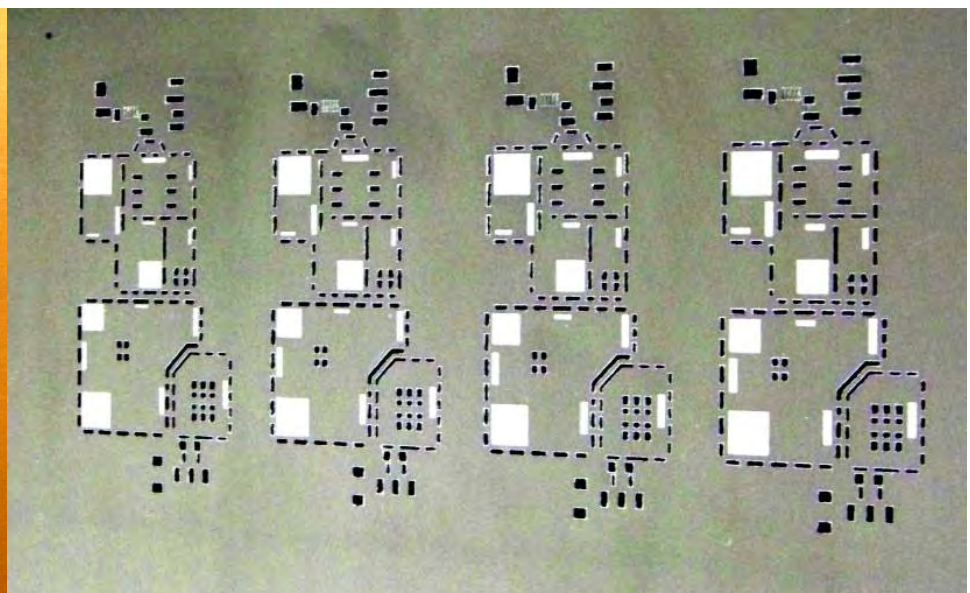


Figure 3 1st Print E-FAB Stencil **Figure 4 2nd Print Laser-Cut Chem-Etch Stencil**

Table 2 Printer Set-Up

Printer:	Speedline Momentum
Squeegee:	E-Blade Electroformed blade
Board:	Blank Copper Clad FR4 with Fids
Print Speed:	1 inch / sec
Print Pressure:	11 lbs.
Paste:	Type 5 Heraeus BD72 SAC 305
Print Sequence:	Print 1st print stencil then immediately print 2nd print stencil while 1st print still wet

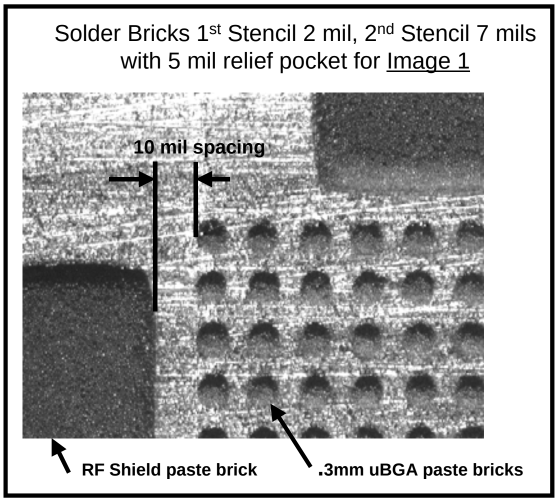


Figure 5 Solder Bricks .3 mm uBGA Image 1

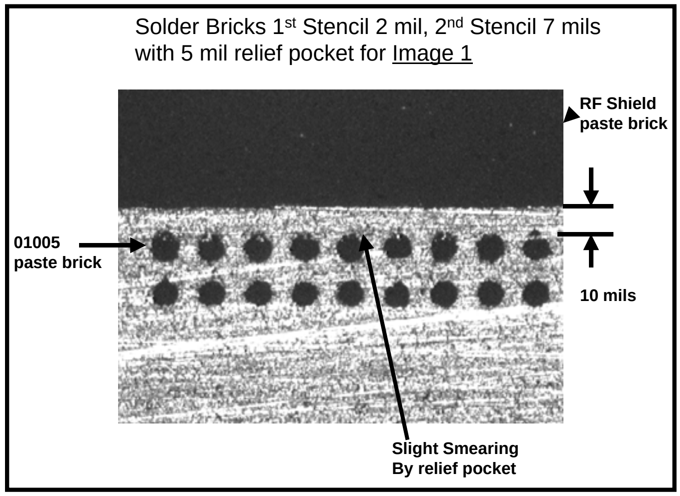


Figure 6 Solder Bricks 01005 Image 1

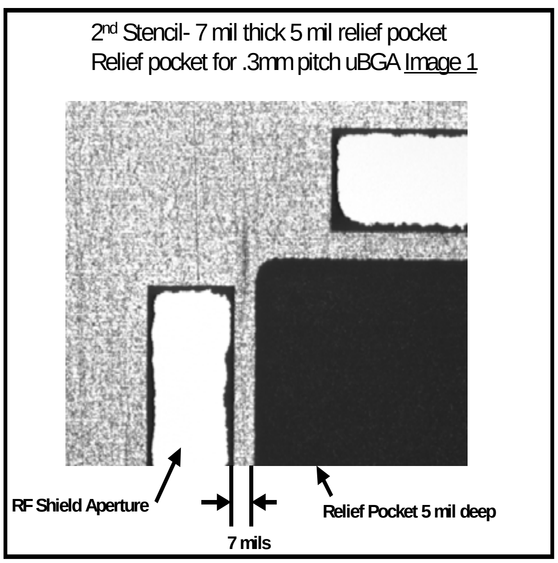


Figure 7 Relief Pocket for .3 mm uBGA Image 1

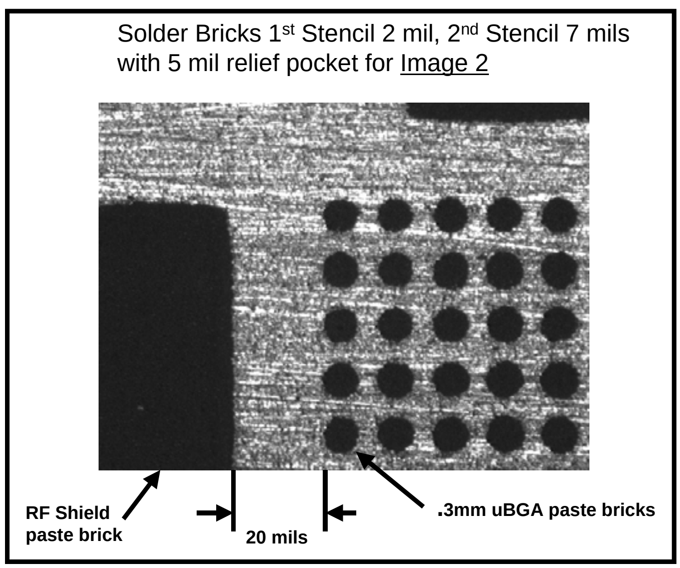


Figure 8 Solder Bricks .3 mm uBGA Image 2

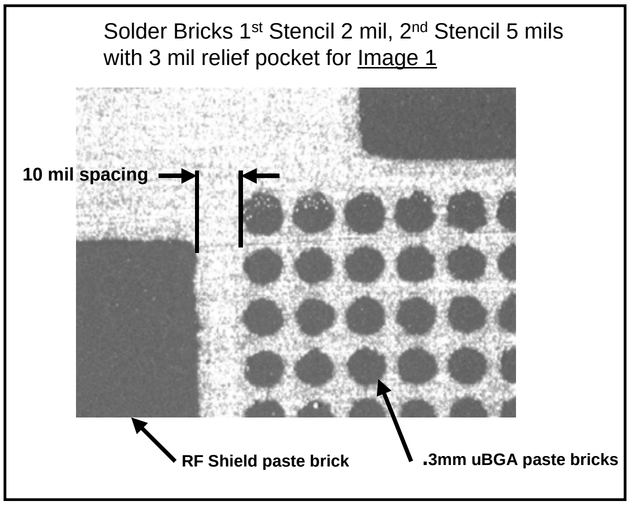


Figure 9 .3 mm uBGA solder bricks 2 mil with 5 mil

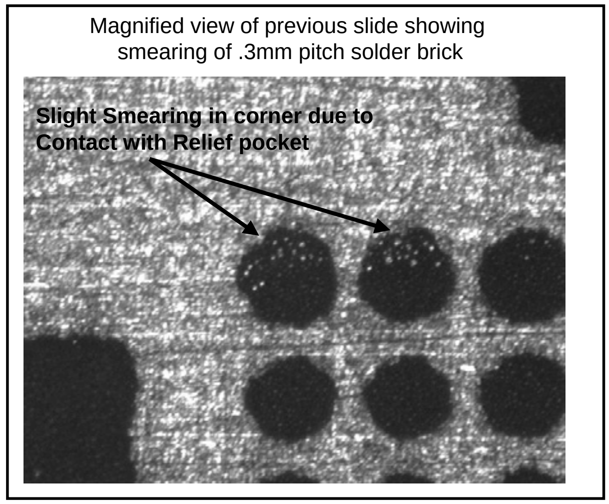


Figure 10 Magnified view of 17 showing smearing

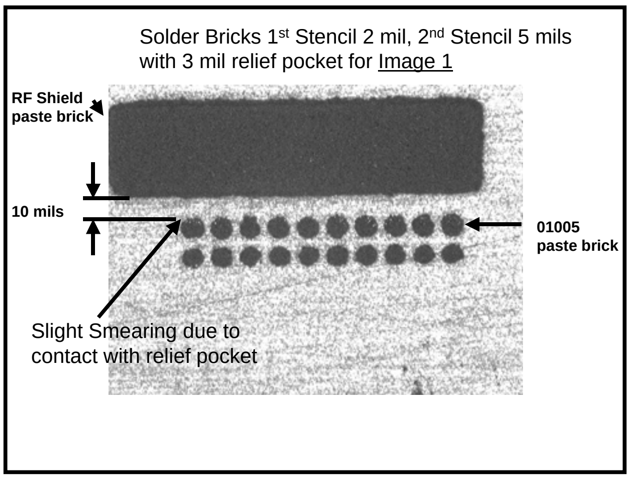


Figure 11 01005 solder bricks, slight smearing

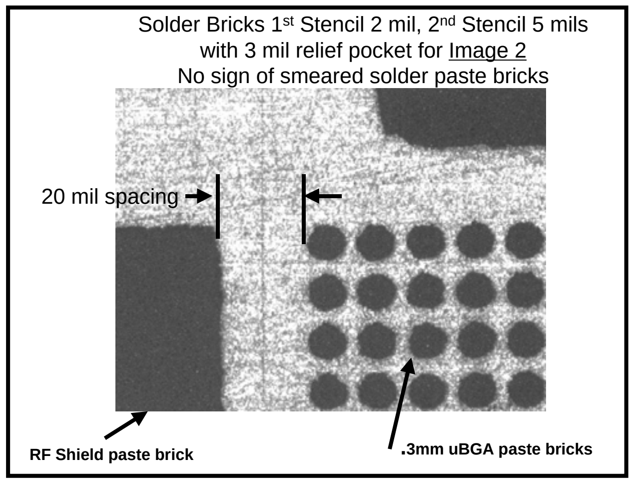


Figure 12 .3mm uBGA solder bricks with 20 mil spacing

PART 2 STENCIL TECHNOLOGIES AND STENCIL COATINGS

Previously four stencil technologies were evaluated for print performance[2]. In this study Electroform, laser, Laser with Electropolish, and Laser with Electropolish and Nickel plating were studied. In the present study Electroform with and without PTFE aperture wall coating, Laser-Cut with and without PTFE aperture wall coating, and Laser-cut Fine Grain stainless steel with a grain size in the 6 micron region were included. Eight stencils were used in the test; 4 were 100 microns (4 mils) thick and 4 were 125 microns (5 mils) thick. Table 3 describes the stencils by technology, material type and coatings if any. Three different aperture sizes were the main focus for the 125 micron (5 mil) thick stencils; 200 micron (8 mil) with Area Ratio (AR) of .4, 250 micron (10 mil) with AR of .5, and 300 micron (12 mil) with AR of .6. Six different aperture sizes were the main focus of the 200 micron (4 mil) stencils; 150 micron (6 mil) with an AR of .38, 175 micron (7 mil) with AR of .44, 200 micron (8 mil) with Area Ratio (AR) of .44, 225 micron (9 mil) with an AR of .56, 250 micron (10 mil) with AR of .63, and 275 micron (11 mil) with an AR of .69.

Aperture Walls for 125 Micron (5 mil) Thick Stencils

Pictures of the aperture walls were taken at 230 magnification a Micro Touch microscope at 4.4 degree angle to look inside the aperture. Both top light and back light only were used. Figures 13 shows the large aperture (700 micron (28 mil)), with top light on the right and back light on the left. It can be observer that the side walls of the Electroformed stencil is smother than the other 3 laser stencils. Figures 14 (back light) and Figure 15 (top light) show the small aperture (150micron (6 mil)). Again it is observed that the Electroform stencil walls are smoother than the 3 laser stencils.

Paste Left in the Stencil Apertures after Print for 125 Micron (5 mil) Thick Stencils

A Speedline Momentum printer was used to do all the printing. This printer has a visual inspection that looks up at the apertures to see if paste is remaining in the apertures and also looks down at the board to see the paste bricks that have been printed. Print speed was 1" (2.54cm) per second with a print pressure of 9 lbs (4 kgms) using 8" (200 mm) Electroform E-Blade squeegee blades. Indium 8.9HF-NoClean type 4 solder paste was used. Figures 16 (200 micron (8 mil) aperture)), 17 (250 micron (10 mil aperture)), and 18 (300 micron (12 mil)) show the residual paste left in the apertures for all 4 stencils. Figure 16 shows clogged apertures for the 3 laser stencils and all but 3 apertures clogged fort he Electroform stencil. Figure 17 shows that stencil 4 (DuraAlloy) has all apertures clogged while stencil 1 and 2 have all but a couple apertures clogged. The Electroform stencil, stencil 3, has more than 50% of unclogged apertures. Figure 18 shows stencil 3 (Electroform) with all apertures free of clogging except for 4 or 5 apertures with partial clogging. The other 3 stencils have a majority of clogged apertures.

Paste Deposits for 125 Micron (5 mil) Thick Stencils

Figures 19, 20 and 21 show paste deposits for the 3 different aperture openings (150 micron (6 mil), 200 micron (8 mil) and 250 micron (10 mil)). In all cases it can be seen that stencil 3 (Electroform) has better paste transfer than the other 3 stencils.

Aperture Walls for 100 Micron (4 mil) Thick Stencils

The objective of this portion of the study was to compare the performance of two stencil types Electroform and Laser with and w/o PTFE coatings on the inner aperture walls. The coating was performed at room temperature using a hot wire Chemical Vapor deposition (CVD) process. Six different aperture sizes were studied 150 micron (6 mil) up to 275 micron (11 mil) in 1 mil increments. The AR ranged from .38 for the smallest aperture to .69 for the largest aperture. Figure 22 shows aperture pictures of all four stencils with top light and back light. It is a little easier to see the wall smoothness using back light only. There is no obvious difference in wall smoothness with and w/o PTFE coating at 230 magnification for the four stencils. However the Electroform stencils demonstrates better wall smoothness that the Laser-Cut apertures, which is an expected result.

Paste Left in the Stencil Apertures after Print for 100 Micron (4 mil) Thick Stencils

Figure 23 shows paste remaining in the apertures after printing for the two Electroform stencils; stencil 7 having PTFE coating and stencil 9 having no coating. Paste remaining in the apertures for the 175 micron (7mil) aperture, with an AR of .44, looks about the same for coated or non coated stencils, almost complete clogging. However, for the 225 micron (9 mil) aperture with an AR of .56 the coated stencil has less blockage that the non coated stencil. The 275 micron (11 mil) aperture has no blockage in the coated or non coated stencils. Figure 24 shows the blockage for the two stencils for a 250 micron (10 mil) with an AR of .63. The coated stencil has blockage in 4 apertures while the non coated has blockage in 12 apertures. It appears that the PTFE coating has a positive effect on paste release from an aperture blockage point of view.

Figure 25 compares blockage for the two laser cut stencils for three aperture sizes. Results are somewhat mixed. The 175 micron (7 mil) aperture shows complete blockage for both, the 225 micron (9 mil) aperture shows complete blockage for the coated stencil but a few open apertures for the non coated stencil. The 275 micron (11 mil) aperture shows slightly less blockage for the coated stencil compared to the non coated stencil.

Paste Deposits for 100 Micron (4 mil) Thick Stencils

Figures 26, 27, 28, and 29 show solder deposits at 230 magnification for 4 aperture sizes; 175 micron (7 mils), 225 micron (9 mil), 250 micron (10 mil), and 275 micron (11 mil). Comparing PTFE coated to non coated there appears to be no definitive improvement in paste release for either the Electroform or the Laser stencils compared to the non coated stencils. It is obvious that both Electroform stencils have better formed solder deposits compared to the Laser stencils.

Conclusion Part 2

Of the four 125 micron (5 mil) thick stencils the Electroform stencil clearly had smoother aperture walls and better paste release over the range of apertures tested. All stencils exhibited complete aperture blockage for the 200 micron (8 mil) aperture with an AR of .4. The Electroform stencil exhibited less than 50% blockage for the 250 micron (10 mil) aperture, with an AR of .63, while the other 3 laser stencils exhibited almost complete aperture blockage with just a couple of partial blocked apertures. The 300 micron (12 mil) apertures, with an AR of .63 were completely open for stencil 3, Electroform, while stencils 1, 2, and 4, the laser stencils, had considerable blockage. It does appear that stencils 1 and 2, made with Fine Grain stainless steel had slightly less blockage than the normal Stainless Steel stencil (DuraAlloy). In any case the data seems to confirm the AR rule of thumb; .66 or more for Laser stencils and .5 or more for Electroform stencils.

The objective of testing the four 100 micron (4 mil) thick stencils was to see if PTFE coatings of the aperture walls would improve paste transfer. No clear cut answer could be derived from the data. From aperture blockage it appeared like the PTFE coating gave slightly better performance for both Electroform and Laser stencils. However in looking at the solder deposits the uncoated stencils seemed to give a better looking paste deposit. The Electroform stencils, stencil 7 and 9, provided better paste deposits and less aperture blockage than the laser stencils, 6 and 8.

The overall conclusion is that the normal Area Ratio "rule of thumb" of > .5 for Electroform and >.66 for Laser is still a good guideline. Coatings and Laser-Cut Fine Grain stainless steel did not change this guideline which should be followed for .3 mm uBGA's and 01005 devices.

Future Work Part 2

As a follow on project solder paste volume measurements and the deviation of solder paste volume will be performed on all eight stencils. This will be very helpful in defining the performance of each stencil. Two more stencils will be added to the group for this study; a Nickel plated Laser-Cut Fine Grain stainless steel stencil and an Electorpolished and Nickel plated Laser-Cut Alloy 42 stencil.

REFERENCES

William Coleman "Stencil Print Performance Studies", SMTAI Conference, October 2001

Table 3 Description of Stencils used in the Test

	Test Stencils Descreption		
Number	Type	Post processing	Thickness
1	Laser Datum FG (LPKF Micro-cut)	Sanding only	125 u (5 mil)
2	Laser Datum FG (LPKF 6080 fiber optic)	Sanding only	125 u (5 mil)
3	E-FAB	none	125 u (5 mil)
4	Laser DurAlloy	Sanding only	125 u (5 mil)
6	Laser DurAlloy	PTFE coating one side	100 u (4 mil)
7	E-FAB	PTFE coating one side	100 u (4 mil)
8	Laser DurAlloy (LPKF 6080 fiber optic)	Sanding only	100 u (4 mil)
9	E-FAB	none	100 u (4 mil)

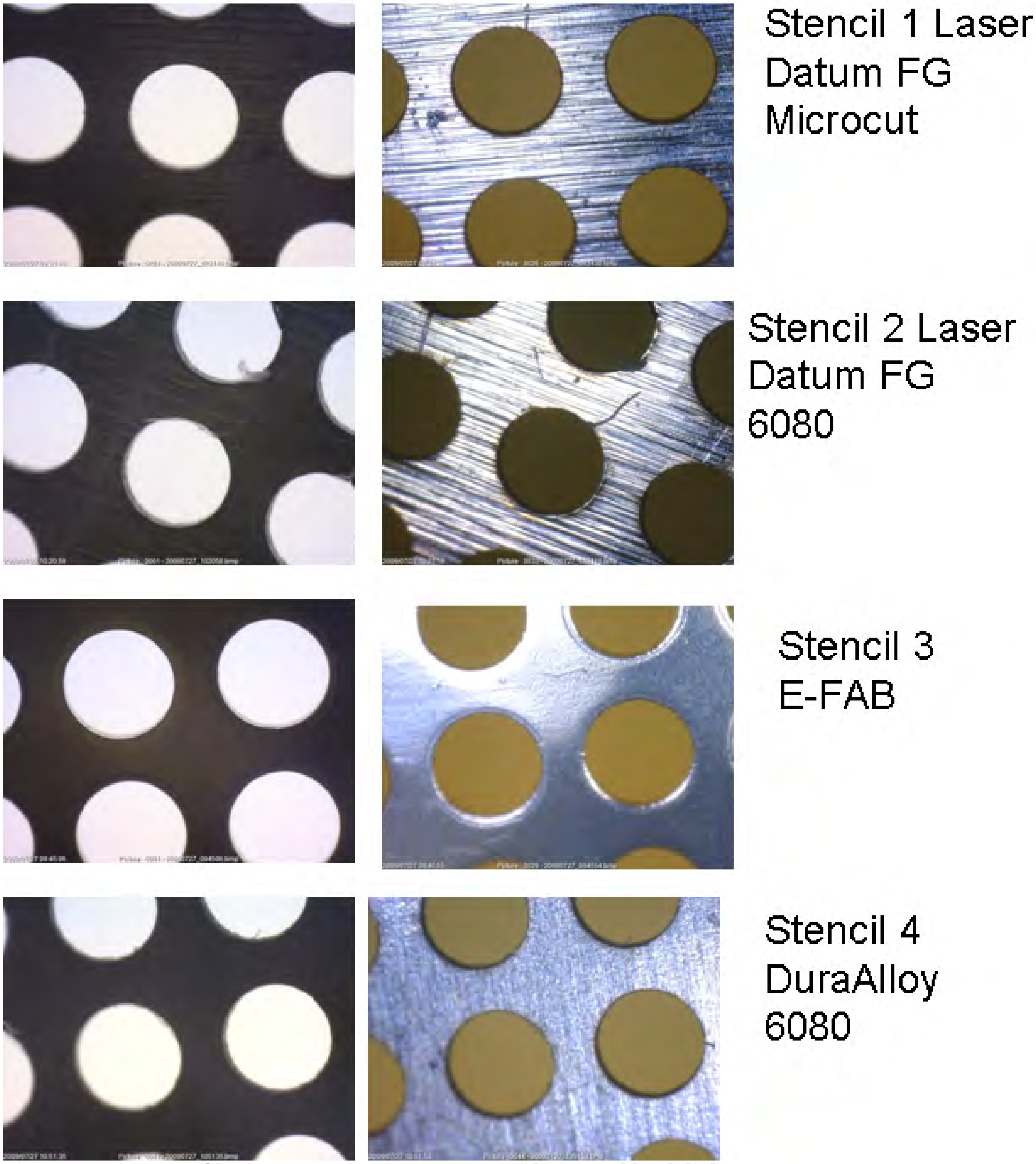


Figure 13 Pictures of large apertures, 1-4, at 230 x with top and back light

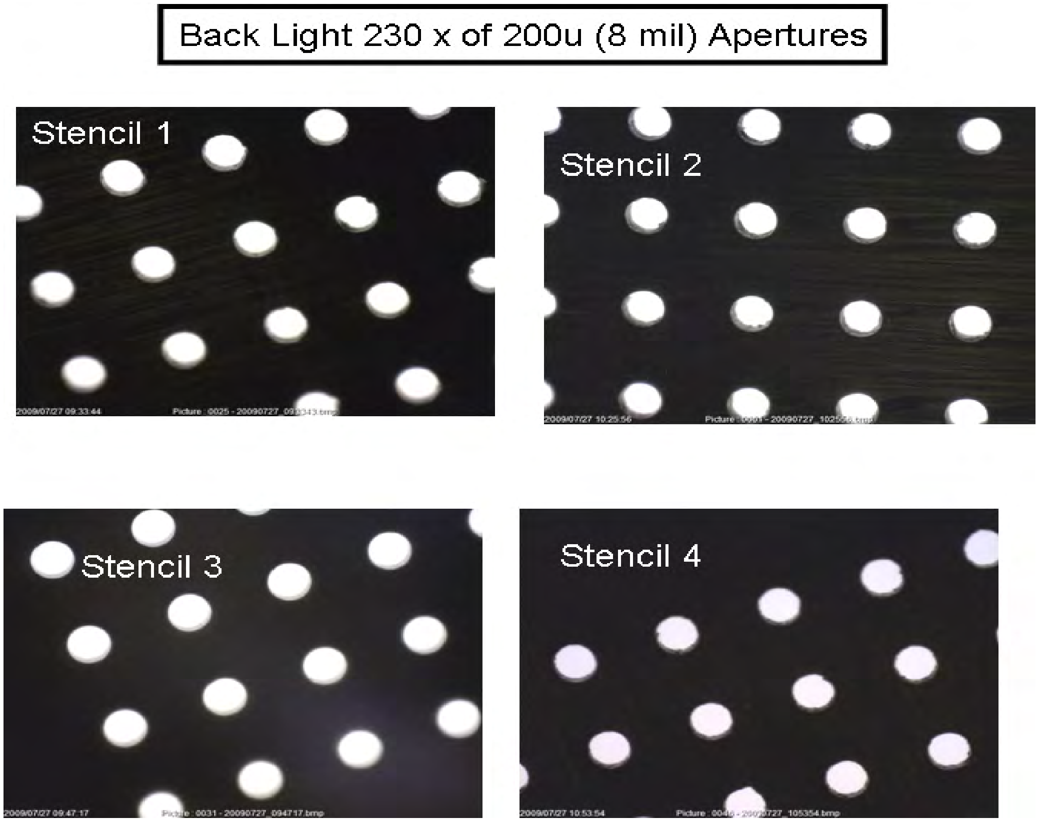


Figure 14 Back Light at 230 x of Laser stencils 1, 2, 4 and Electroform stencil 3

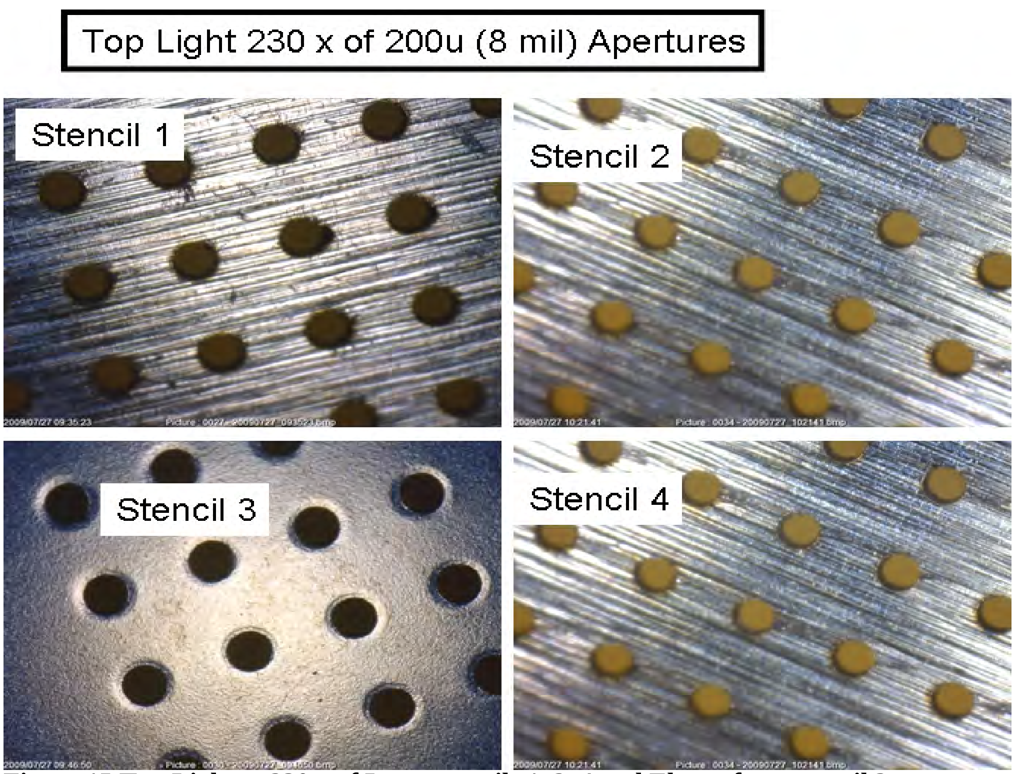


Figure 15 Top Light at 230 x of Laser stencils 1, 2, 4 and Electroform stencil 3

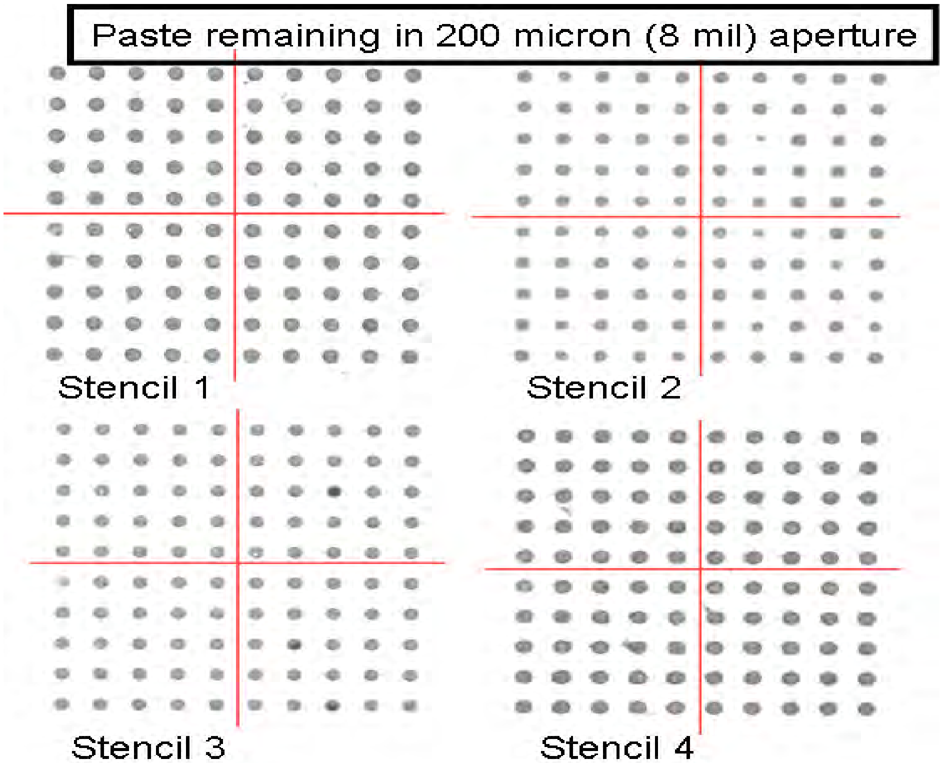


Figure 16 Paste remaining in apertures of 200u aperture: Laser 1, 2, 4 Electroform 3

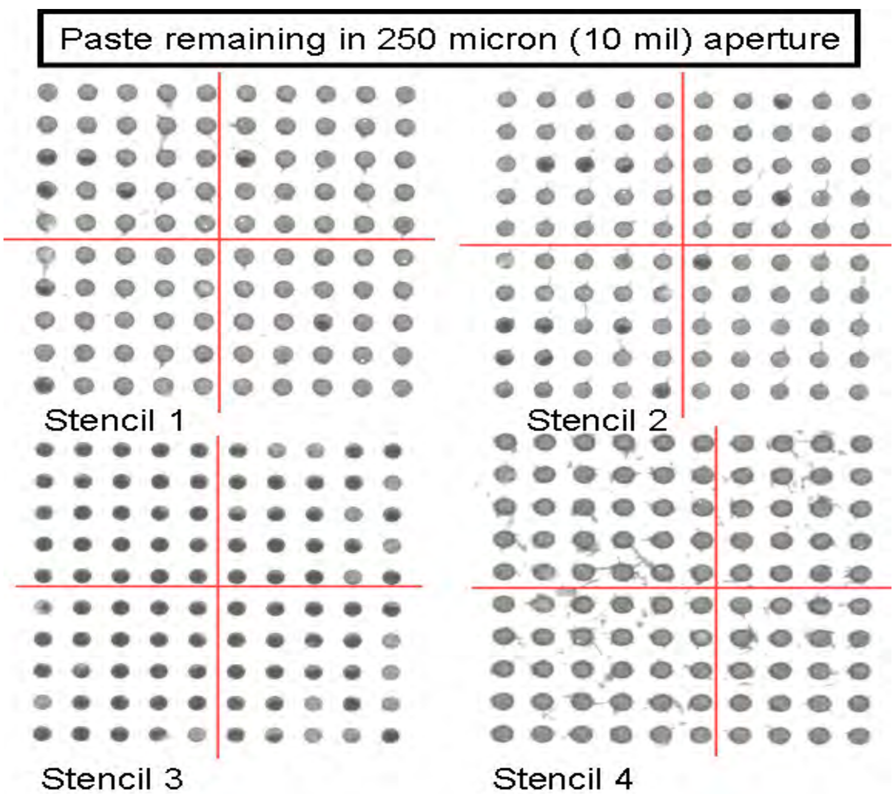


Figure 17 Paste remaining in apertures of 250u aperture: Laser 1, 2, 4 Electroform 3

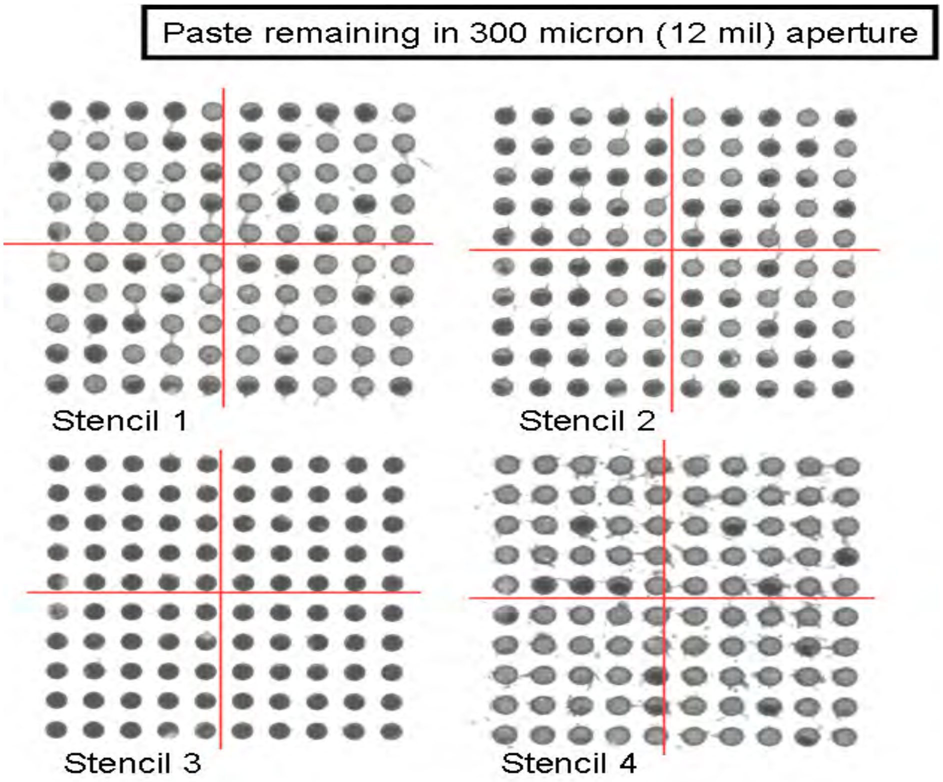


Figure 18 Paste remaining in apertures of 300u aperture: Laser 1, 2, 4 Electroform 3

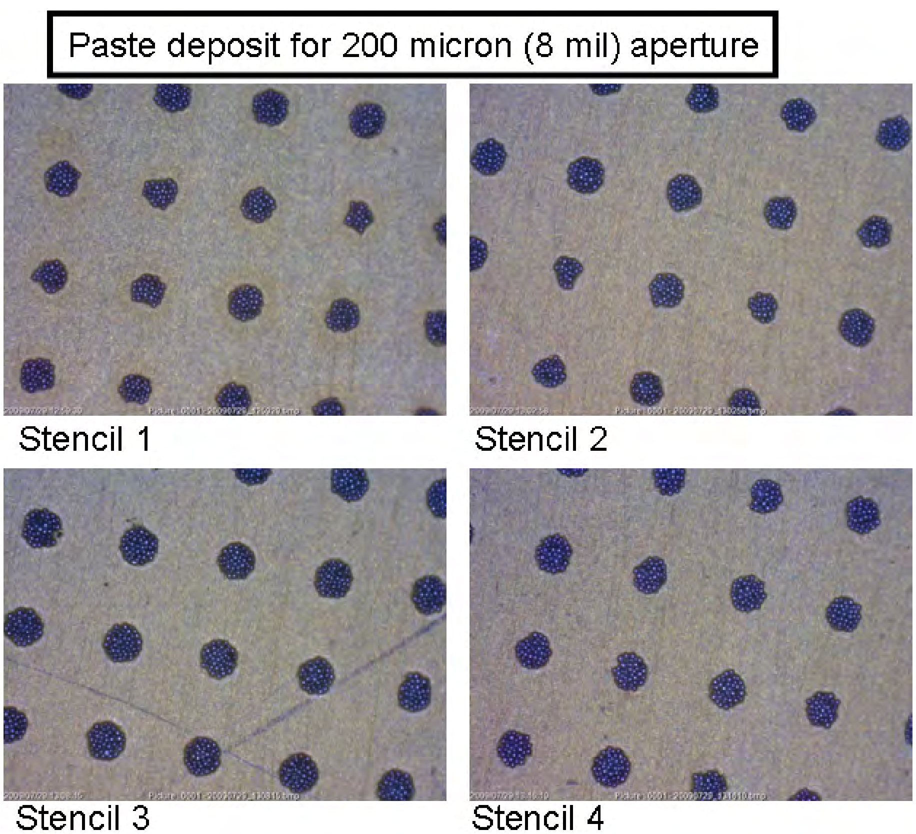


Figure 19 Paste deposits for 200u apertures: Laser 1, 2, 4 Electroform 3

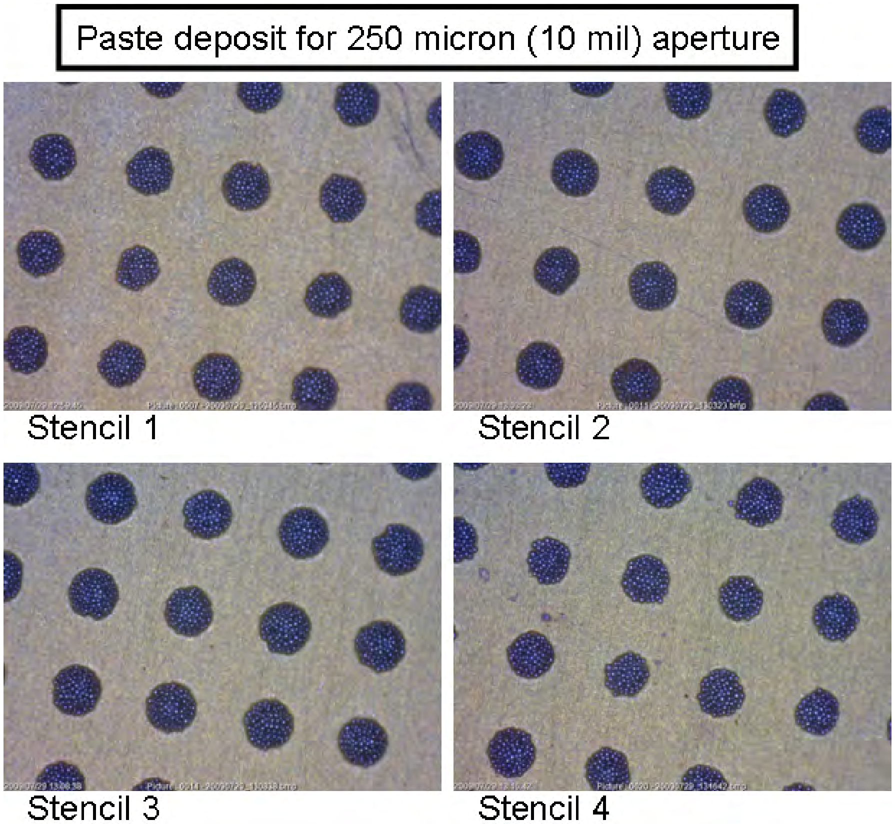


Figure 20 Paste deposits for 250u apertures: Laser 1, 2, 4 Electroform 3

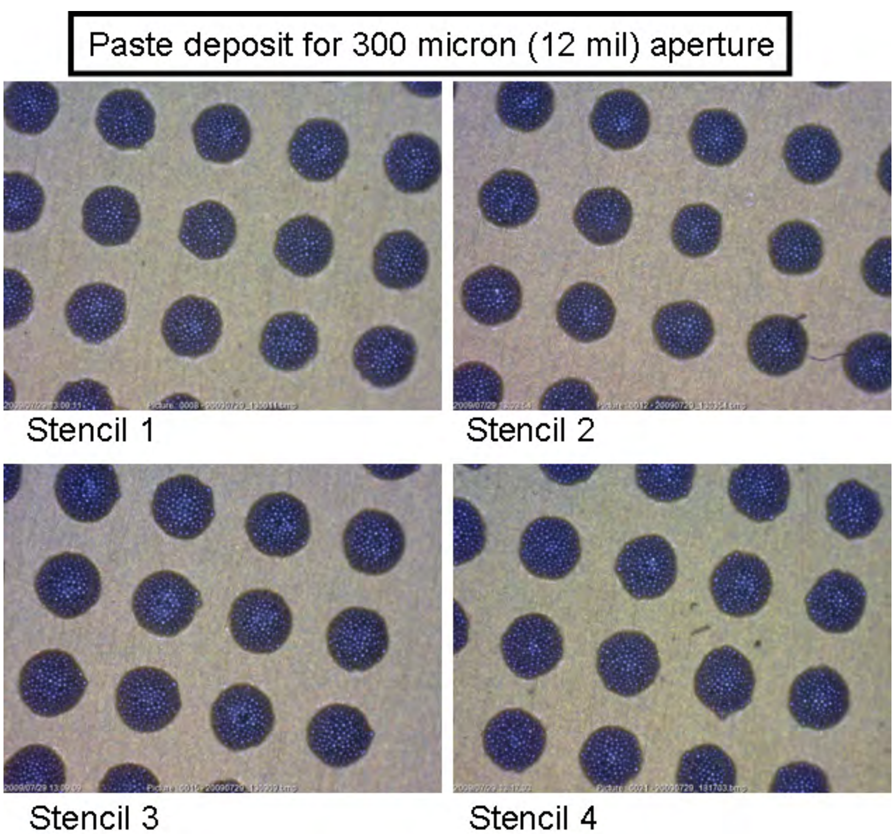


Figure 21 Paste deposits for 300u apertures: Laser 1, 2, 4 Electroform 3

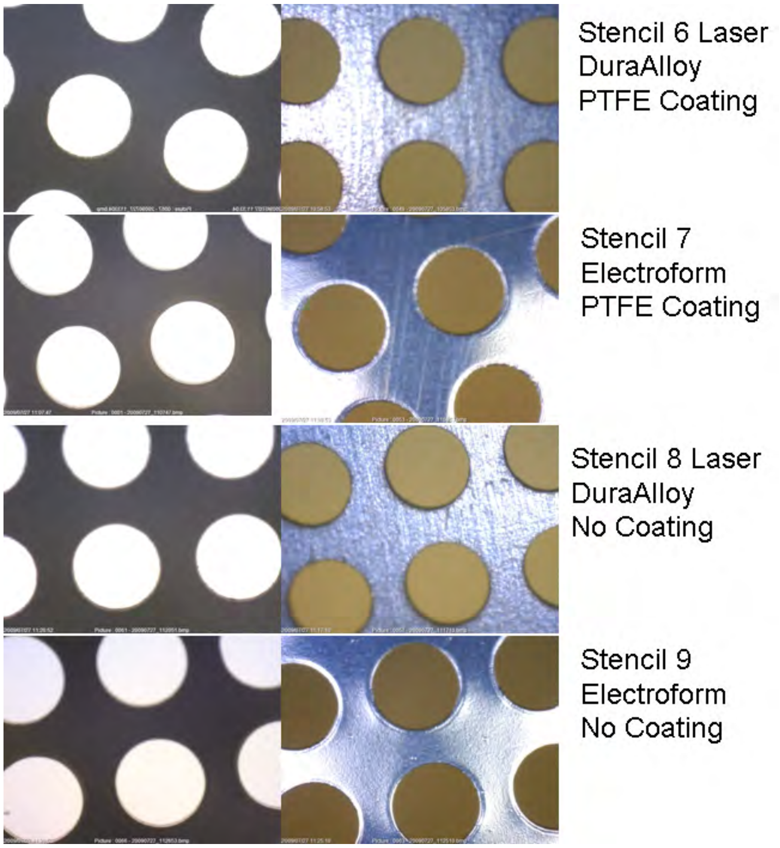


Figure 22 Back Light (left), top (right),700u aperture

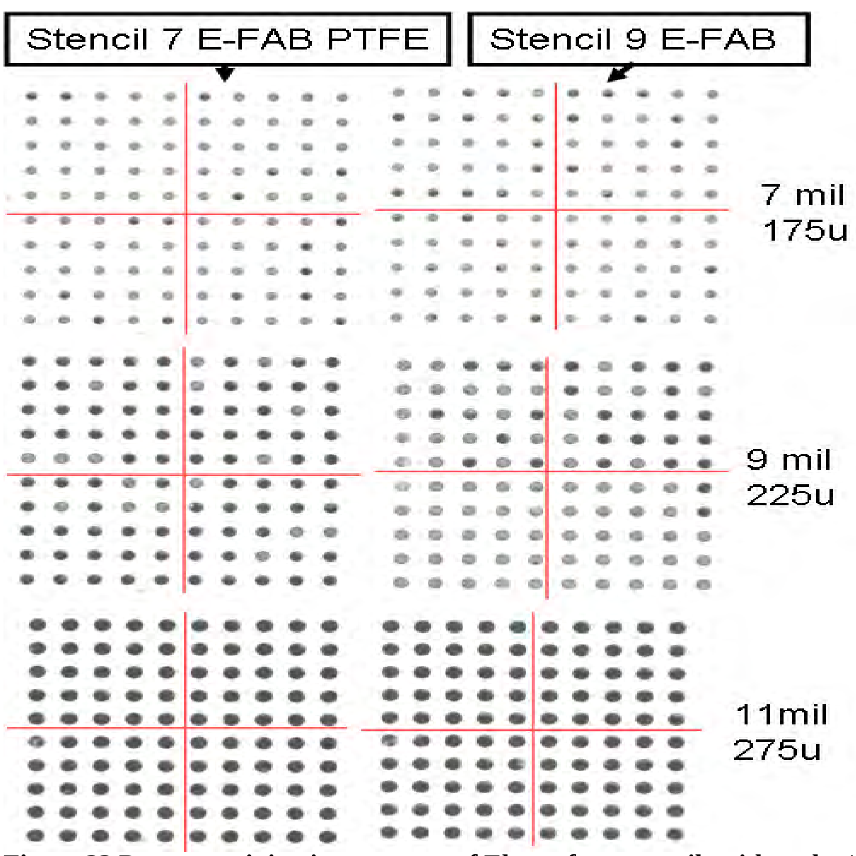


Figure 23 Paste remaining in apertures of Electroform stencils with and w/o PTFE coatings

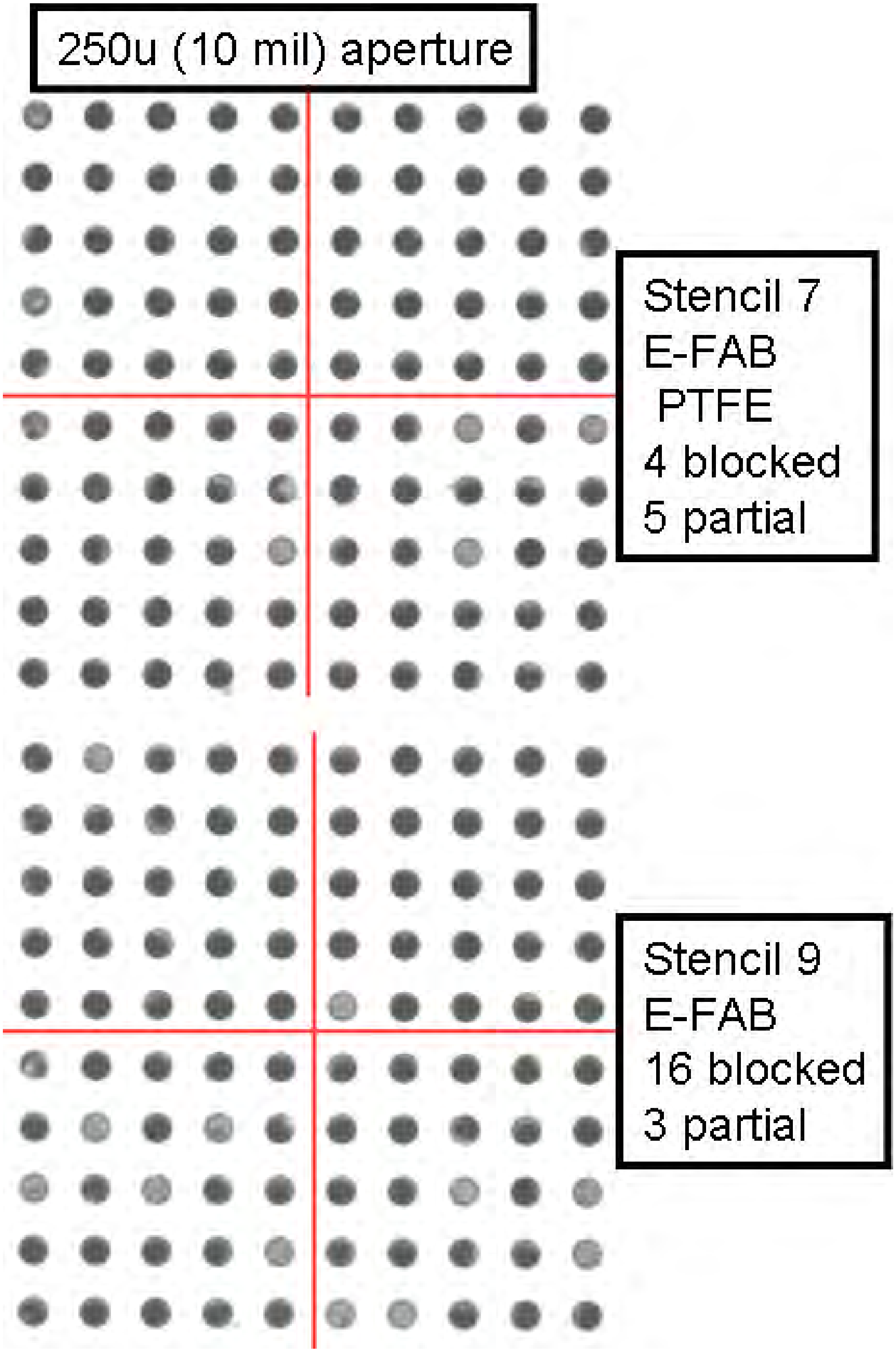


Figure 24 Paste remaining in apertures of Electroform stencils with and w/o PTFE coatings; 250u apertures

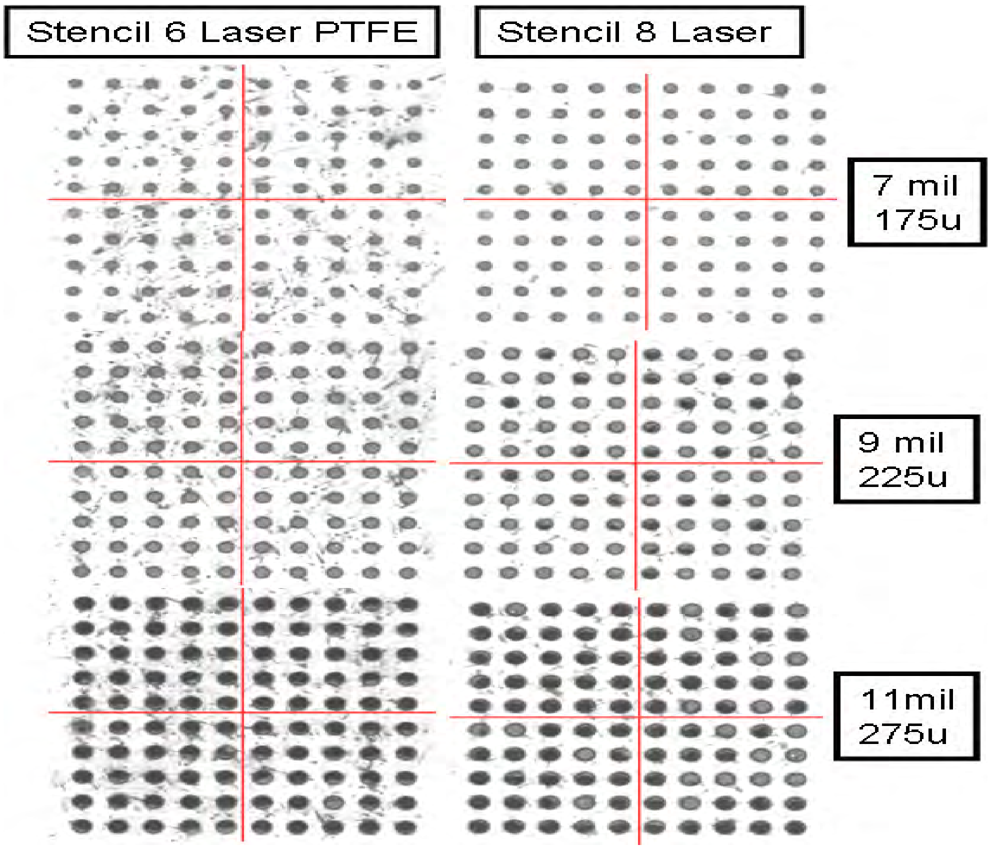


Figure 25 Paste remaining in apertures of Laser-Cut stencils with and w/o PTFE coatings

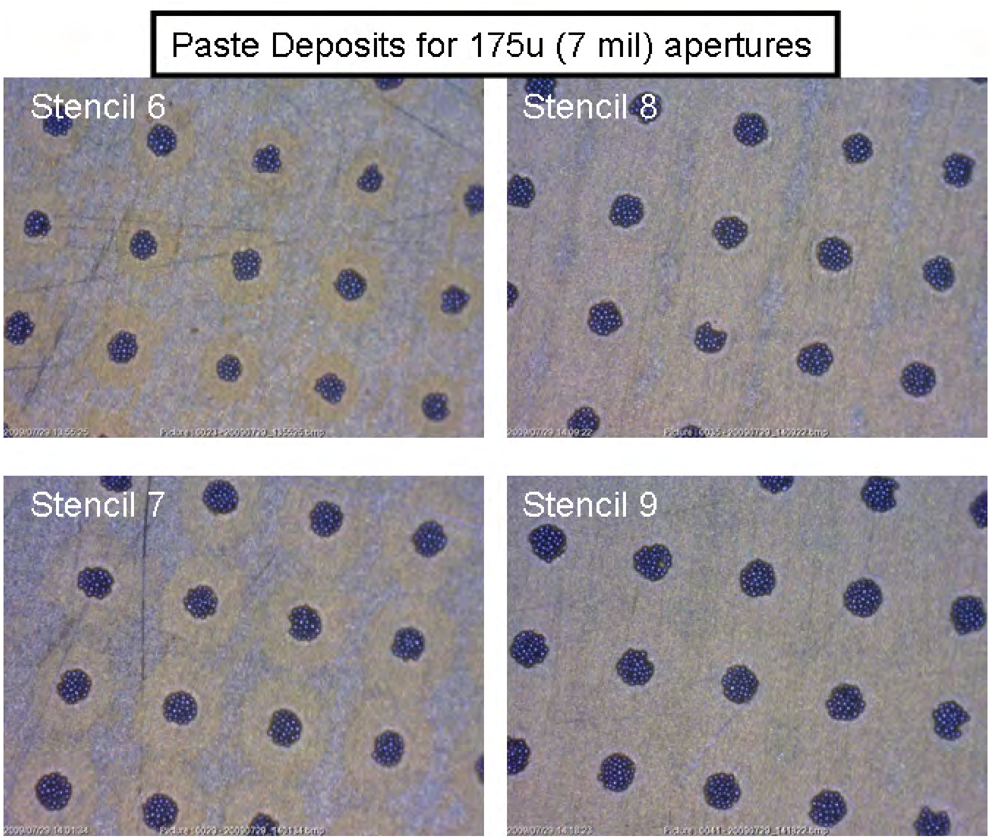


Figure 26 Paste deposits 175u: 6 Laser with PTFE, 8 Laser w/o coating, 7 E-FAB with PTFE, 9 E-FAB w/o coating

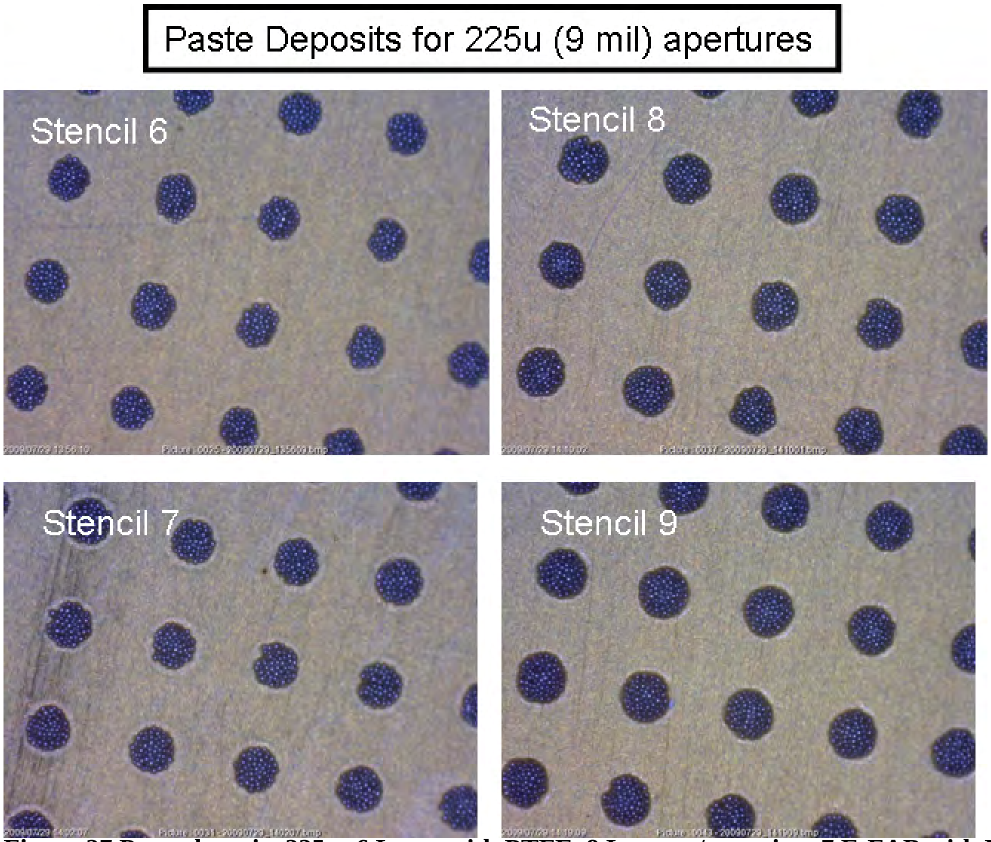


Figure 27 Paste deposits 225u: 6 Laser with PTFE, 8 Laser w/o coating, 7 E-FAB with PTFE, 9 E-FAB w/o coating

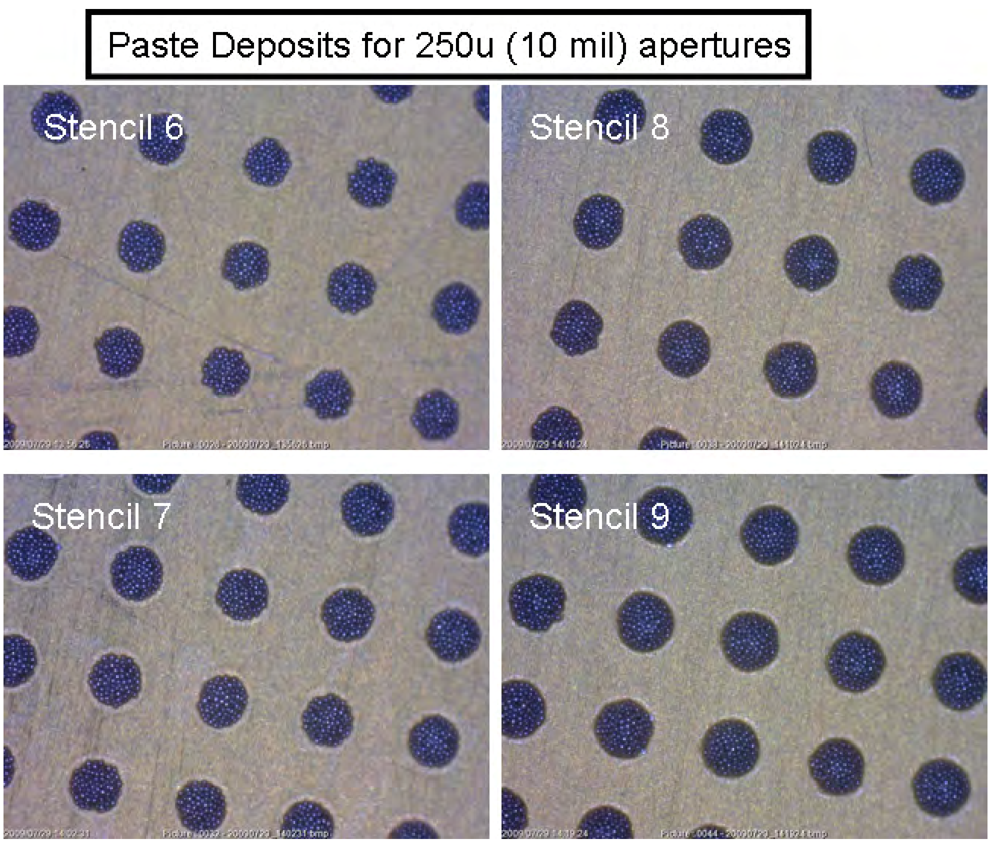


Figure 28 Paste deposits 250u: 6 Laser with PTFE, 8 Laser w/o coating, 7 E-FAB with PTFE, 9 E-FAB w/o coating

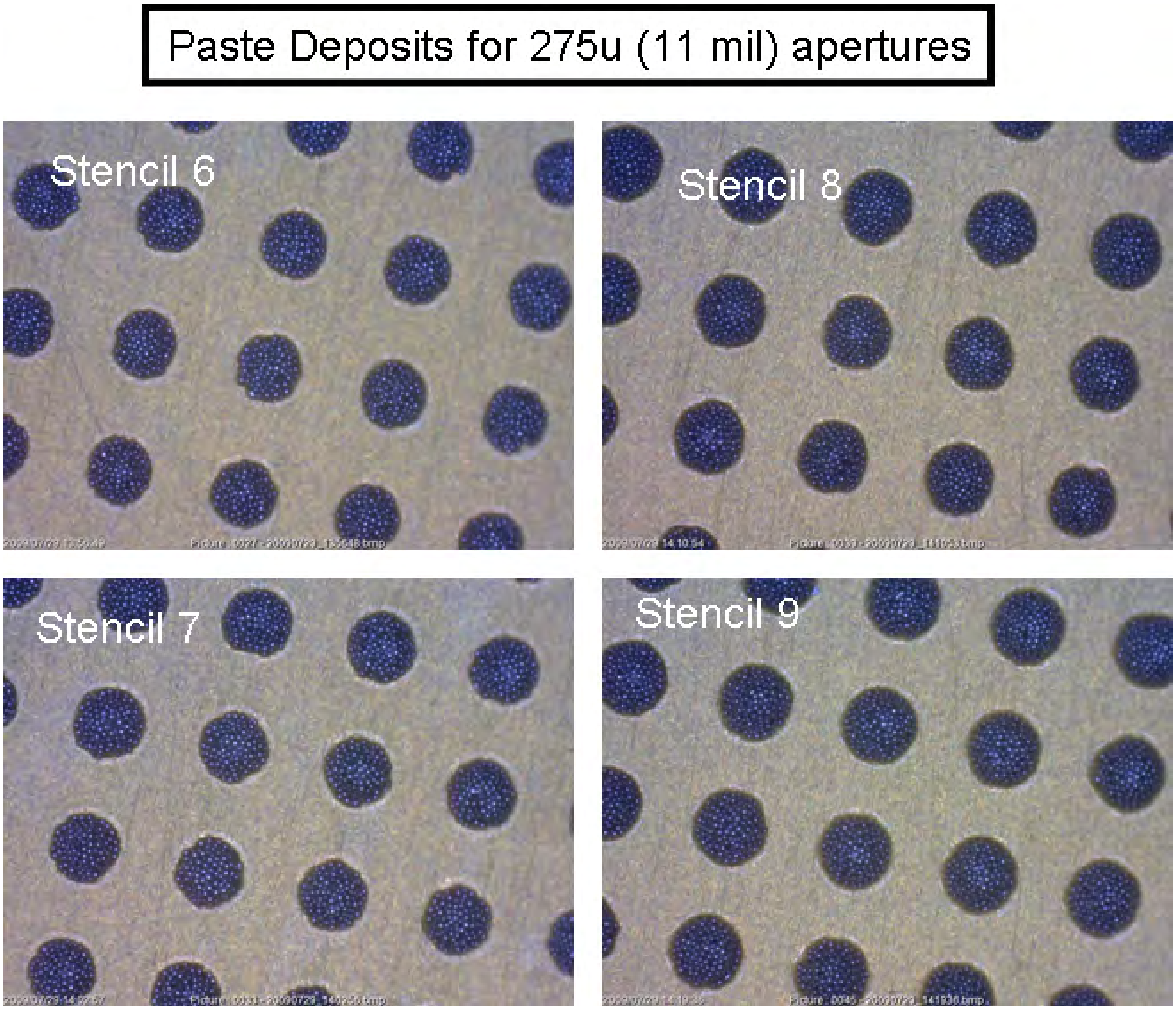


Figure 29 Paste deposits 275u: 6 Laser with PTFE, 8 Laser w/o coating, 7 E-FAB with PTFE, 9 E-FAB w/o coating