RESERVOIR PRINTING IN DEEP CAVITIES

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ABSTRACT
With advancements in board designs, and widespread application of stencils into the solar/optics fields, new challenges arise leading to new stencil solutions. Extensive work has been done in the past to print glue [1], solder paste [2, 4], and/or flux [3] into cavities using reservoir printing. The reservoir depths for these applications ranged from 75 microns to 355 microns, with aperture sizes from 65 microns to 200 microns. This paper focuses on printing solder paste into multiple cavities with depths ranging from 355 microns to 450 microns, and with varying cavity wall angles and various stencil thicknesses ranging from 100 microns to 150 microns. Apertures varying in area ratio were placed in these cavities and experiments were conducted to analyze the print performance of the stencils. The goal was to create guidelines for future stencil designs and aperture placement in cavities. Dispense viscosities of paste and pump printing were recommended to ensure printing in deeper cavities and to obtain a good print volume. Details on stencil design, paste material selection, experimentation, and print results will be presented in this paper.

INTRODUCTION
The world of electronics continues to evolve with a focus on smaller, lighter, faster, and feature-enhanced high-performing electronic products, regardless of industry and application [2]. The LED industry also has various applications that need LEDs or dies to be placed in cavities and enclosing them with phosphors to increase luminescence. Traditionally, the dipping process or dispensing process was used to deposit solder paste, flux, or glue on uneven surfaces. However, this takes a longer time when compared to printing when using a stencil printer. Reservoir printing, using a stencil printer, has potential applications not only related to printing into cavities, but also, in cases when two stencils are used consecutively to print different materials for instance, printing solder paste, followed by printing glue [1].

Finding the correct combination of solder paste and machine settings can be challenging as well. This paper will explore printing solder paste with different metal loads into the cavities of PCBs, PWBs, and other substrates using traditional printing methods. As the size of the components and boards or substrates get smaller and smaller, placement of components closer to the cavity walls needs to be assessed as well. An experimental reservoir test stencil containing reservoir pockets was designed and electroformed to test the feasibility of this concept. The circuit board to be printed was constructed with large copper pads located in multiple cavities with a depth of 14mils, 16mils, and 18mils mils below the topside surface, within different cavity sizes of 1.25″, 0.8″, and 0.125″. Circular apertures of various sizes to meet area ratios of 0.45 and 0.55 were used to test the theory of pulling solder paste from the reservoir above. These apertures were placed as close as 0.003” from the stencil pocket walls to analyze the printability at this proximity. This paper will present the experimental design and print results.

STENCIL DESIGN
The stencil was grown using the electroforming process, has a uniform thickness throughout, and has pockets or cavities of different sizes, depths, and wall angles. Circular apertures with area ratios 0.45 and 0.55 were laser cut into the cavities of this stencil with varying distances from the pocket walls, the closest one being 3mils. Stencil geometry and various stencil design details, for which the conceptual idea was tested, are as shown below.

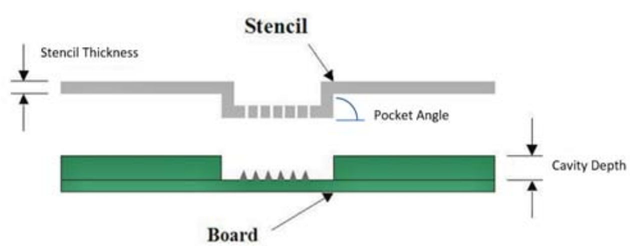


Figure 1. Stencil geometry details, with apertures placed in the stencil pockets.

Table 1. Various stencil design parameters incorporated in the stencil design.

Cavity Depth (mils)	Stencil Thickness (mils)	Cavity Angle (degrees)	Area Ratio	Apt Shape	Cavity Size
14 (356um) (Image B)	4 (100um)	45	0.45	circle	1.2″
16 (406um) (Image A)	6 (150um)	75	0.55	–	0.8″
18 (457um) (Image C)	–	90	–	–	0.125″

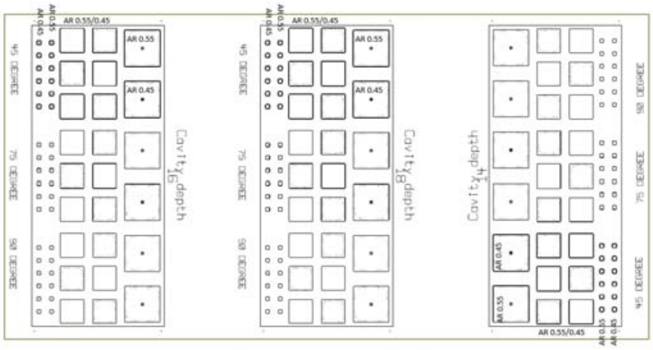


Figure 2. Stencil design with three images incorporating all the design parameters.

Two stencils of 4mil and 6mil thicknesses each were used for the print test. Each stencil has three images, and each image corresponds to a given pocket depth.

BOARD DESIGN

A board was designed to match the image on the stencil design. Three different sets of boards, one set per pocket depth, were manufactured by Circuits West Inc., Longmont, Colorado. Large flat copper pads were designed in the pockets for the ease of analysis, instead of designing individual pads to match the corresponding apertures.

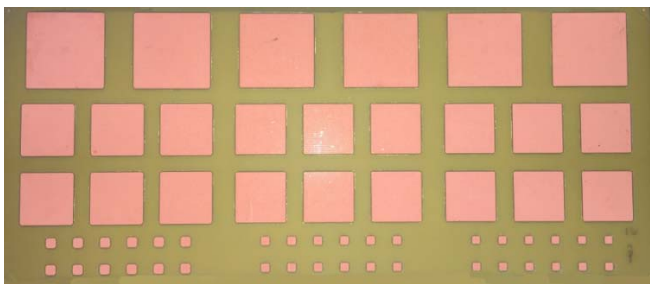


Figure 3. Board manufactured by Circuits West, to match each stencil image

PASTE MATERIAL SELECTION

To explore the process window for printing in these deep cavities, several materials were chosen. One halogen-free no-clean paste flux was used with several different SAC305 powders of different particle size distributions (see Table 2).

Table 2: Particle sizes and metal loads for this halogen-free no-clean solder paste.

Particle Size Name	Size Range (microns)	Metal load in solder paste
T4	20-38	88.25%
T5	20-25	For Reference
T5-MC	15-25	88.25%
T6	<20	For Reference
T6-SG	5-15	88 and 80%

In addition to the materials above, a halogen-free no-clean tacky flux was also stencil printed with a significantly lower squeegee pressure. A competitive benchmark solder paste was also chosen for printability comparison.

EXPERIMENTATION

Each stencil pattern was printed onto boards that had cavities to match the depth of the stencil pocket. The stencil printer was industry standard, fitted with edge rails (Figure 4) to secure the board, stationary tooling pins for support, and rubber squeegee blades (30cm).

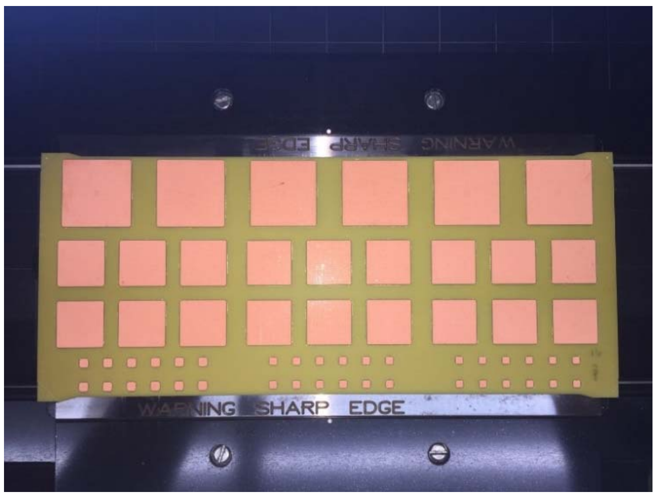
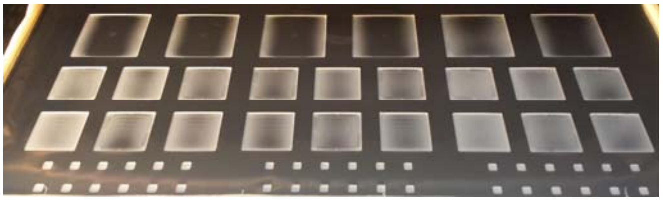
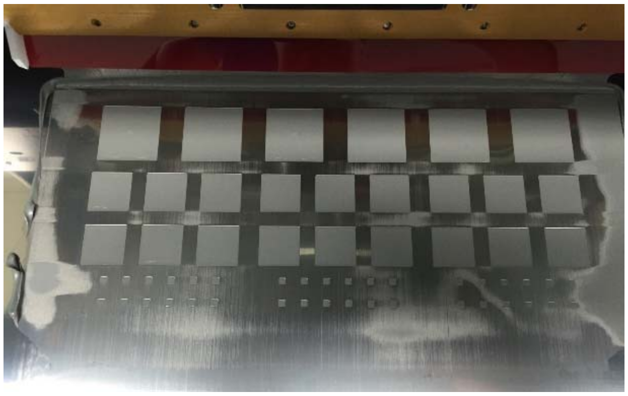


Figure 4. Cavity board inside stencil printer with edge rails installed.

For process development, a moderate print speed of 50 mm/s was used with an optimized squeegee pressure to achieve a relatively clean top of the stencil and to avoid scooping paste out of the pockets (Figure 5). Typically, the pressure was around 6kg and did not exceed 8kg. Squeegee pressure was adjusted when printing different materials.



(a)



(b)

Figure 5. Top side view of stencil after printing. It is critical to adjust squeegee pressure to see even fill in the cavities: (a) indicates scooping and (b) shows no scooping.

The printed boards were then visually examined for print quality and missing deposits. The goal was to determine how close to the cavity walls the prints were possible. Further studies will use a solder paste inspection unit to quantify the volumes of the solder paste deposits.

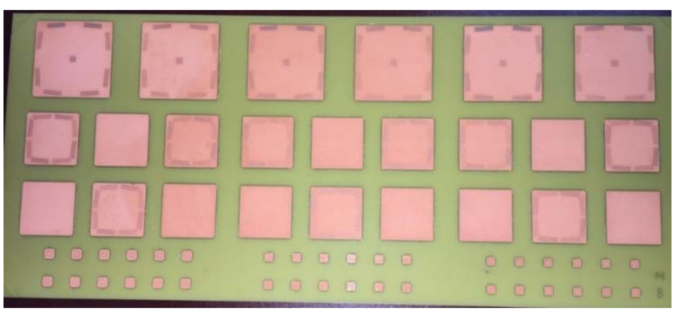


Figure 6. Printed board with 14 mil cavity depths, printed through 3 patterns on stencil image with differing wall angles (45°, 75°, and 90°).

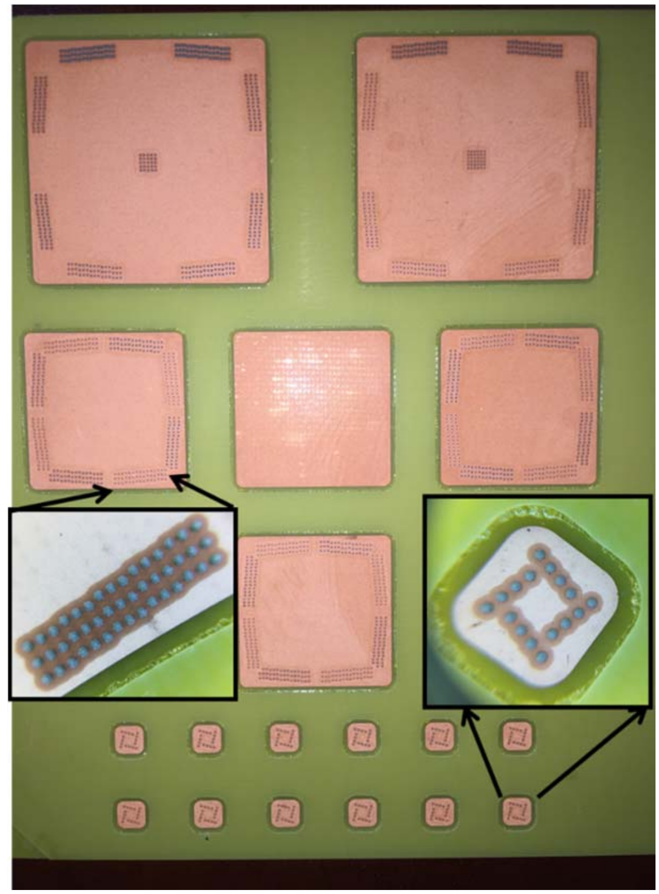


Figure 7. Single pattern, showing detail of completely printed designs.

RESULTS AND DISCUSSION

As mentioned in the previous section, boards with different cavity depths were printed using the stencil image with corresponding pocket depths. Images of each print were taken to compare pockets of different sizes and wall angles to analyze any visible variation in print performance. No significant difference was observed in the print performance with respect to substrate cavity depth and the stencil design variables used such as, stencil pocket angle, pocket size, and print material. Different images of prints per the paste material and stencil used are shown in the Figure 8. As for the optical inspection, apertures with AR of 0.55 resulted in larger print volumes than apertures with AR of 0.45. Similarly, the print volume seemed to increase with stencil thickness.

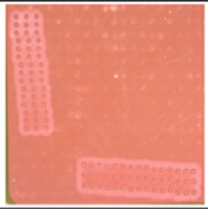
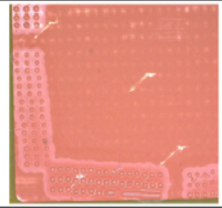
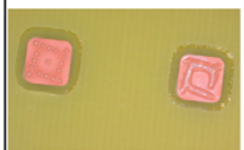
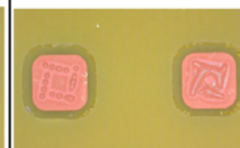
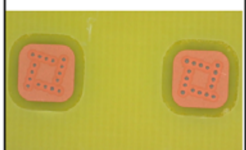
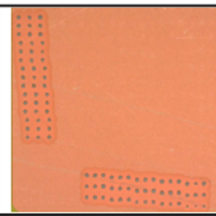
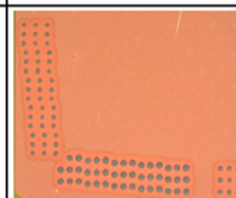
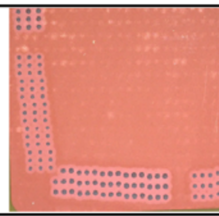
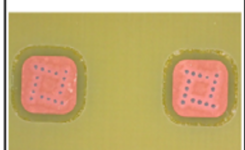
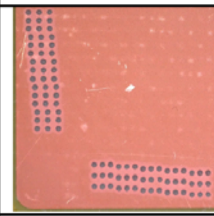
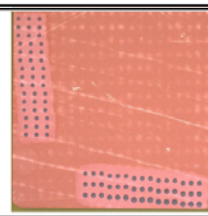
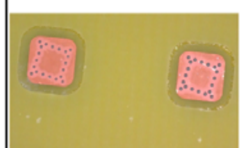
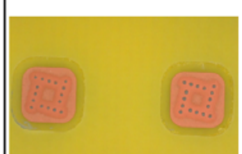
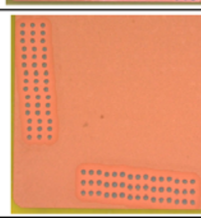
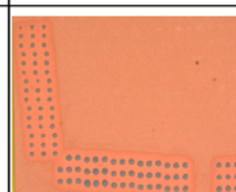
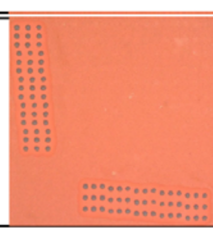
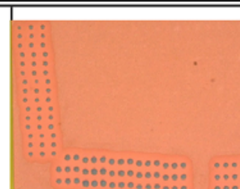
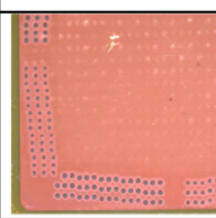
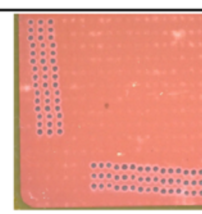
Print material	Stencil thickness	Pocket Depth: 14mil/16mil/18mil Pocket wall angle: 45/75/90 degrees		
Flux	4			
	6			
T5 MC 88.25% metal	4			
	6			
T6 SG 80% metal	4			
	6			
T4 88.25% metal	6			
Competitive Benchmark paste	6			

Figure 8. Images taken from test board after printing with different flux and paste materials (Thickness in mils).

CONCLUSION

This experiment demonstrated reservoir printing as a successful printing process into cavities of the board as deep as 18mils (455um). For the scope of this experiment and the various paste materials and fluxes used, printing was observed as even from the aperture as close as 3mils (75µm) from the pocket wall irrespective of stencil thickness, aperture size, pocket wall angle, and pocket size. This implies that the components can be placed as close as 75µm to the cavity wall of the substrate. For the same pocket depth and wall angles, further analysis will be conducted (a) by placing apertures much closer to the pocket wall to determine the closest component pad placement in the cavity; (b) by placing apertures with different area ratios, smaller than 0.45, to determine the smallest printable aperture; and (c) to perform quantitative analysis (print volume and any variation in the print volume) with respect to the various stencil design factors involved.

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REFERENCES

[1] W. Coleman and A. Wadhwa, “Metal Stencils for Adhesive Printing”, Proceedings of APEX 2002.

[2] M. Burgess and J. Robbins, “Reservoir Solder Paste Printing, M. Burgess and J. Robbins”, Proceedings of SMTAI 2007.

[3] W. Coleman and M. S. Read, “Flux Reservoir Stencil Printing”, Proceedings of SMTAI 2012.

[4] R. Miller-Short, “3D Electroform Stencils for Two-Level PCB”, , Proceedings of SMTAI 2014.