As originally published in the IPC APEX EXPO Proceedings.

Effect of Nano-Coated Stencil on 01005 Printing

Rita Mohanty Ph.D., Speedline Technologies, Franklin, MA
S. Manian Ramkumar Ph.D., CEMA, Rochester Institute of Technology, Rochester, NY
Chris Anglin, Indium Corporation, Clinton, NY
Toshitake Oda, Bon Mark Co. Ltd., Japan

Abstract

The demand for product miniaturization, especially in the handheld device area, continues to challenge the board assembly industry. The desire to incorporate more functionality while making the product smaller continues to push board design to its limit. It is not uncommon to find boards with castle like components right next to miniature components. This type of board poses a special challenge to the board assemblers as it requires a wide range of paste volume to satisfy both small and large components. One way to address the printing challenge is to use creative stencil design to meet the solder paste requirement for both large and small components. Examples of stencil design include step stenciling, dual printing, over-size apertures, etc. The stencil printing process, at its most basic level, involves pushing solder paste through a stencil (with various size apertures) by a squeegee blade. As the squeegee blade and the stencil are in constant contact with the paste during the printing process, their surface characteristics play an important role in the printing process. The most important attribute of a stencil is its release characteristic. In other words, how well the paste releases from the aperture. The paste release, in turn, depends on the surface characteristics of the aperture wall and stencil foil. The recent introduction of a new technology, nano coating for both stencil and squeegee blades, has drawn the attention of many researchers. As the name implies, nano-coated stencils and blades are made by conventional method such as laser-cut or electoform then coated with nano-functional material to alter the surface characteristics. This study will evaluate nano-coated stencils for passive component printing, including 01005. Various print experiments will be conducted using different stencil technology, stencil thicknesses, aperture size, aperture orientation, aperture shapes, and selected paste type, with optimal print parameters to understand the effect of chosen factors on the print quality. Print quality will be determined by visual inspection and 3D measurement of the paste deposit to understand the volume transfer efficiency.

Key words: Nano-coated stencil, broadband printing, stencil technology, area ratio, transfer efficiency (TE)

Introduction

From the introduction of Surface Mount Technology (SMT) in the mid-80s to today, there has been a natural size reduction of passives and die packages. The necessity to accommodate smaller components on the circuit boards that also must contain various other, larger components has become a necessity owing to the increasing demands from the industry. Stencil printing of solder paste as a cost-effective and reliable material deposition technology continues to dominate board assembly process. However, developing a robust printing process to accommodate very small devices, such as 01005 passives and 0.4mm CSP/BGA, along with larger components, such as SMT connectors and RF shields, has become high priority for board assemblers.

Stencil printing is a complex process that is driven by many known and unknown factors. Printing machine, stencil type, and solder paste are among the top three. The main function of a stencil is to deliver a known and controlled volume of solder paste to device pads on the PCB. The printing process involves two steps: (1) the aperture fill process, where solder paste fills the stencil aperture, and (2) the paste release process, where solder paste is transferred from the stencil aperture to the PCB pad. The fill process depends largely on the solder paste, squeegee blade, solder paste roll, print speed, and aperture orientation with respect to print direction. Paste release, on the other hand, depends on the stencil technology and its wall smoothness, the stencil aperture design as related to the area ratio, solder paste, and the board separation speed from the stencil. The paste transfer process can be viewed as a competing process where the pad on the PCB below the stencil aperture is pulling the solder paste out of the aperture while the aperture sidewalls are holding the solder paste inside the aperture. When thinking of the paste transfer process in this manner, it is easy to understand why the area ratio and aperture sidewall smoothness have such a dramatic influence on paste transfer. Typical sidewall pictures for various stencil technologies are shown in Figure 1. As it can be seen from this figure, based on the stencil technology, the wall smoothness varies. The smoother the wall surface, the better the paste release mechanism. The focus of this paper is to compare a relatively new stencil technology, nano-coated stencil, with traditional technologies, such as laser-cut and electroform, to understand the paste transfer capability of each of the technologies.

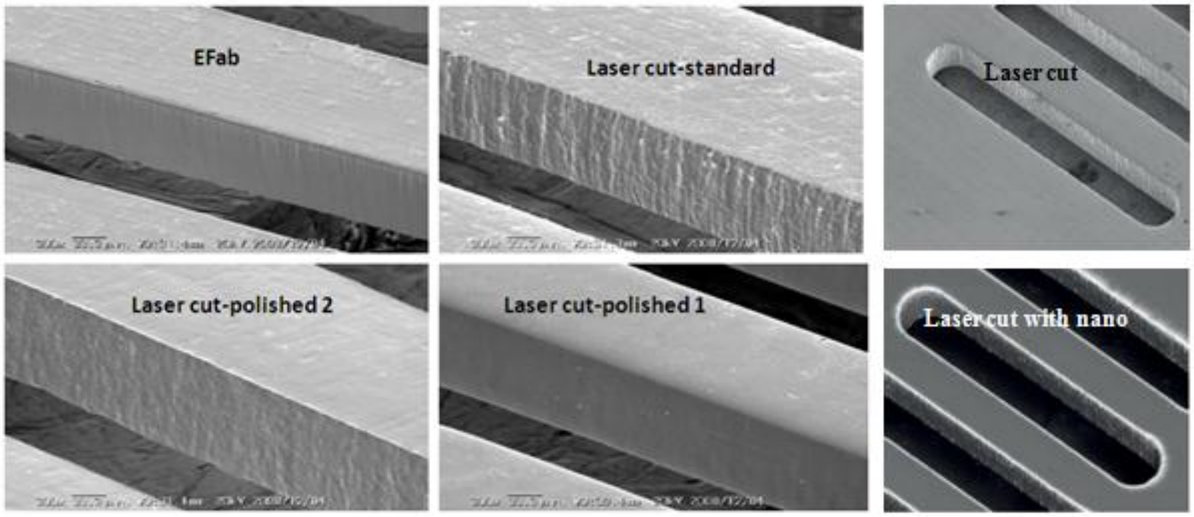

Figure 1. Comparison of Stencil Technologies

There are many different types of stencil technologies available to a board assembler. Common types are laser-cut stainless steel & nickel, chemical etched, and electroformed. Laser-cut electroformed nickel and laser-cut stainless steel stencils are very similar with respect to aperture size accuracy, aperture taper and the variability around both the size and the taper. In addition, both of these stencils have very similar aperture wall smoothness. The electroformed stencil on the other hand has similar size accuracy, but narrower size distribution around the average. The electroformed stencil, because of the manner in which it is made, has a significantly smoother wall surface than the laser-cut stencils, and also has sharp aperture edges on both squeegee and PCB contact sides, which enables a smooth solder filling (process) and prevents solder paste from spreading over the PCB contact side of the stencil. These two things together produce a more stable paste deposition than is generally obtained with laser-cut stencils. One of the objectives of this study is to understand the effect of various stencil factors in the paste transfer efficiency while dealing with broadband printing.

In addition to the conventional stencil technologies, a new technology, nano-coated stencil, has surfaced over the last couple of years that not only improves the wall smoothness, but also improves interaction between stencil and the board. As the name implies, a nano-scale functional coating is applied to the aperture walls and the PCB contact side of the stencil to modify the surface characteristic of the stencil. Nano-coating has two primary functions [1]:

1. To repel flux from the aperture wall resulting in minimum-to-no sticking of the paste.
2. Prevent solder paste from contaminating (spreading to) the bottom side of the stencil, resulting in a cleaner performance.

Experimental Approach

The detail of the test vehicle, stencil design and experiment methodology is described below.

Test vehicle

Figure 2 shows the test vehicle used for this study. The test vehicle was a 10” x 8” x 0.062”, four-layer FR-4 board with ENIG surface finish. The test vehicle is divided into four quadrants with the same pad layout in each quadrant. The top half of the board is a “step and repeat”, while the bottom half is the “mirror image” of the top half. This board layout is created to understand the interaction between pad orientations, pad location, and board and stencil stretch. Each quadrant is incorporated with a wide range of commercially available components and packages that include both miniature components (01005, 0201 passives, 0.4mm CSP) and larger components (256BGA, 180QFP, etc.).

Stencil Design

Eight different stencils were investigated as part of this experiment. This included two different stencil thicknesses (100 and 120 microns) and four different stencil technologies. The four different technologies included Laser-Cut with Electropolish (Laser), Laser-Cut with Special Polishing Process and Nano Coating (Laser with Nano), Electroform with Nano Coating (E-Form with Nano) and Polished Electroform Stencil with Nano Coating (Polished E-Form with Nano). The stencils with the following key characteristics are expected to provide better Transfer Efficiency (TE) and lower Standard Deviation (STD).

1. Sharp Opening Edge – Provides smooth solder filling
2. Smooth Wall Surface – Provides good solder release
3. Stencil Thickness Uniformity – Provides stable solder transcription (lower STD)
4. Ideal Tension and Roughness on Substrate Side – Provides smooth stencil release (snap-off)

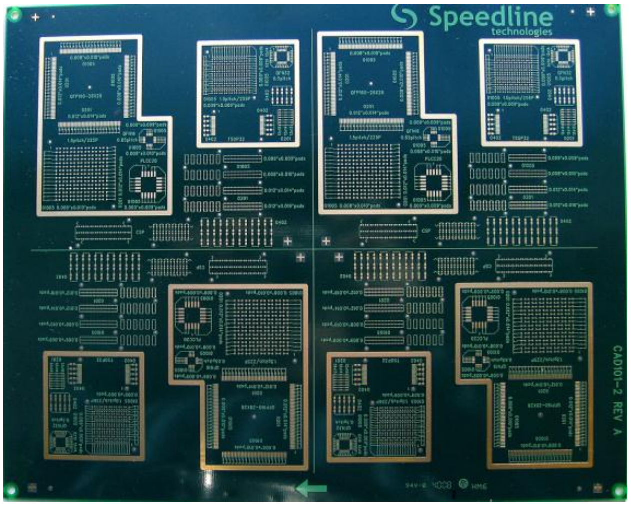

Figure 2. Test Vehicle

The laser-cut stencil finished with the special polishing process is characterized with a smoother wall surface and relatively sharp opening edges on both squeegee and PCB sides. The nano coating provides better solder release and stable solder deposition. The electro-forming stencil is processed to make its bottom side intentionally rough. This coarse surface on the PCB side has a positive impact on better stencil release (snap-off). It is also characterized with sharp opening edges on both the squeegee and PCB sides. In addition, it has nano coating to provide a smoother wall surface. The polished electro-forming stencil is polished by a grinder, in order to obtain thickness uniformity and is characterized with smooth wall surface and even thickness. The polishing causes rather dull opening edges on the PCB side and nano coating is applied for better release. Figure 3 shows the two distinct types of edge finish and its expected effect on the solder deposit.

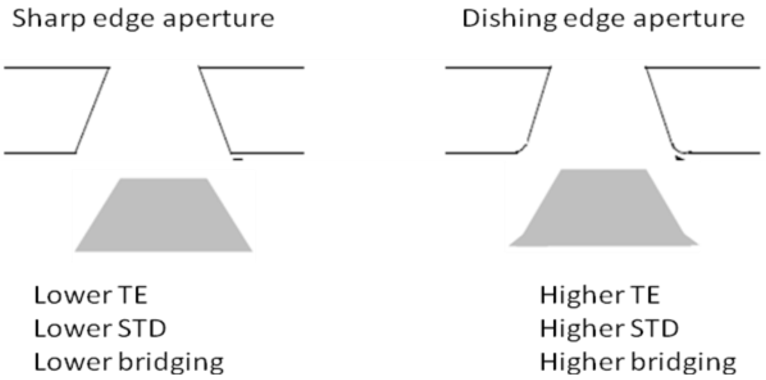

Figure 3. Effect of Edge Finish on Paste Transfer

Selected stencil apertures for the 01005 and 0201 components were modified, as shown in Figure 4, to understand the effect of the AR on paste TE. Table 1 below summarizes the aperture dimension and its relationship to the graphs presented in the results and analysis section. In addition to various aperture shapes, the stencil design also incorporated a vertical and horizontal layout with “sharp edge” and “dishing edge” finish for both square and rectangular shaped apertures. The sharp and dishing edge apertures are represented by “S_Corner” and R_Corner”, respectively. A sample SEM image of the aperture shapes is shown in Figure 5.

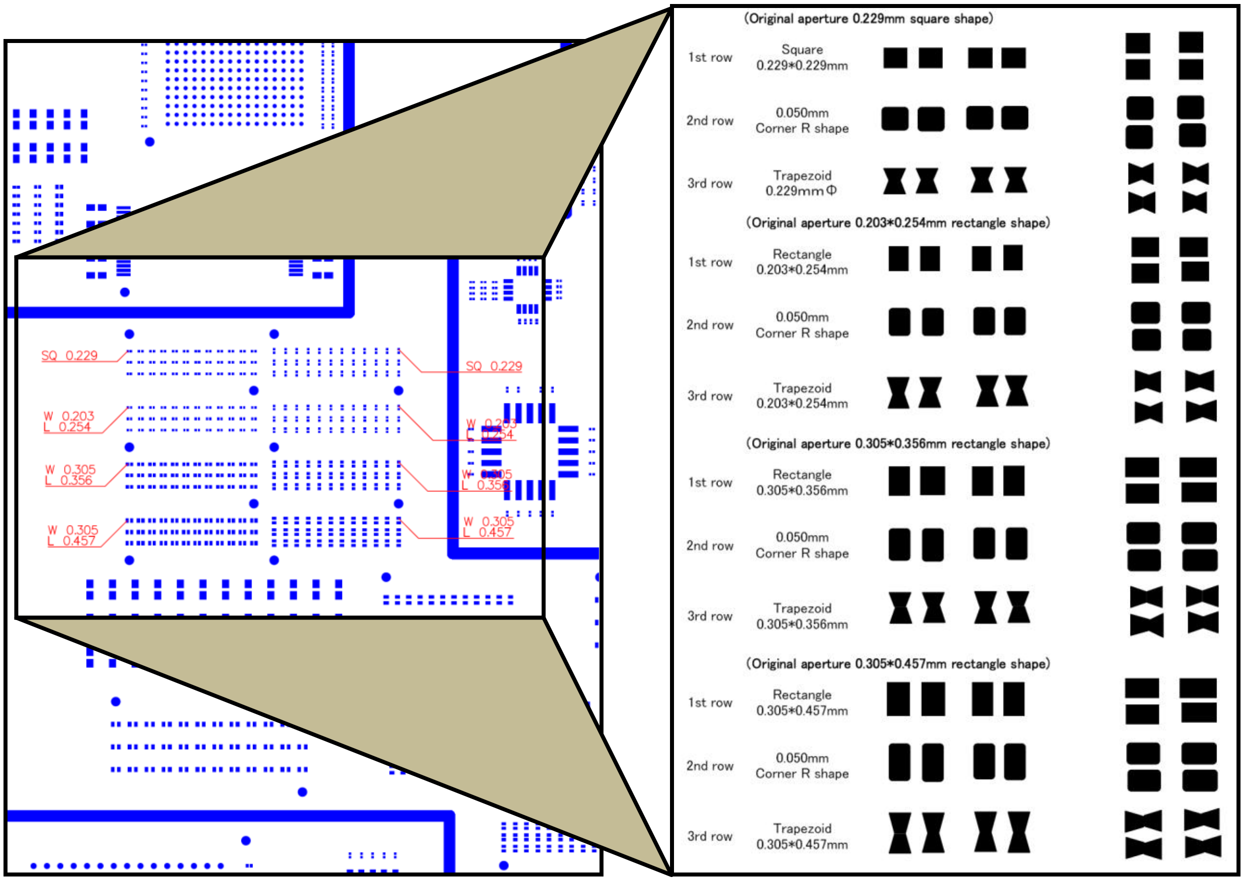

Figure 4. Modified Section of the Test Vehicle

01005			**0201**		
Ap. Shape	**Figure 3 (mm)**	**Graph (mils)**	**Ap. Shape**	**Figure 3 (mm)**	**Graph**
Square	0.229x0.229	9x9	*Rectangle*	0.305x0.356	12x14 Hor. / 12x14 Ver.
Trapezoid	0.229x0.229	9x9 Hor. / 9x9 Ver.	*Trapezoid*	0.305x0.356	12x14 Hor. / 12x14 Ver.
Rectangle	0.203x0.254	8x10 Hor. / 8x10 Ver.	*Rectangle*	0.305x0.457	12x18 Hor. / 12x18 Ver.
Trapezoid	0.203x0.254	8x10 Hor. / 8x10 Ver.	*Trapezoid*	0.305x0.457	12x18 Hor. / 12x18 Ver.
			Square		13x13

Table 1. Aperture Dimensions and Graph Representations

Experiment Methodology

The experiment was carried out by blocking the runs on one stencil type per day. The two thicknesses for each stencil type were used in the same day. A 3D Solder Paste Inspection (SPI) system was used to measure paste volume. The experimental matrix is presented below:

Variable factors:
- Stencil Technology
- Area Ratio
  - Stencil thickness – to provide required area ratio
  - Aperture shape – to provide required area ratio & shape effect
- Aperture orientation

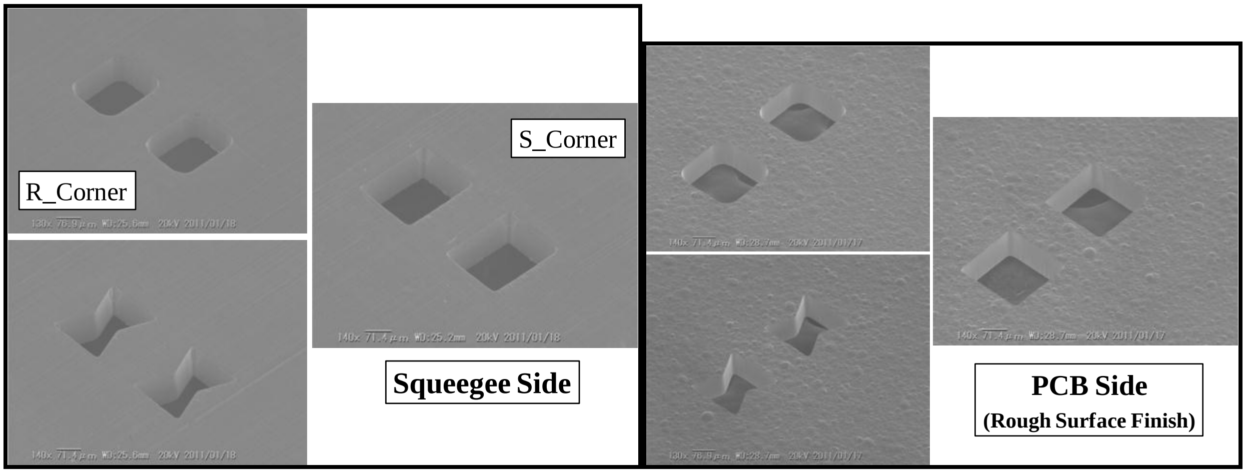

Figure 5. E-Form w/Nano Stencil (Rectangular and Trapezoidal Aperture)

Fixed factors:
    Paste type – Indium Type IV, lead-free paste
    Print speed – 1” per second
    Print pressure – 16 lbs.
    Separation method – zero snap off
    Stencil wipe method – dry wipe after each print with vacuum suction
    Print direction – both rear-to-front (R2F) and front-to-rear (F2R)
    Number of replicates – three per stroke direction
Blocked factor:
    Time (one stencil per day)
Equipment:
    Printer – MPM Momentum
    SPI – Koh Young (KY-3020T)

Results and Analysis

Presenting the detailed results and analysis for this experimental work is beyond the scope of this paper. Hence, selected results for the passive components only will be presented here. Additional results and analysis will be presented elsewhere. Initial analysis will focus on the effect of various factors on the TE and STD for 01005 components. Future analysis will include detailed statistical analysis to validate the initial observation. The analysis was carried out primarily by using box plots, to reveal the mean and STD of the data.

The first step in the analysis was to identify if there was considerable difference in the TE (referred to as volume (%) in the graphs) behavior of the stencils during the forward and reverse stroke of the squeegee. This was to separate the data in case of major differences in the mean and STD within the data. Figure 6 reveals that the directions had similar performance in most of the cases, except a higher STD in the case of forward stroke direction with Polished E-Form with Nano, for 0402 components. There was no specific attributable cause for this spread, at this stage of the analysis. Therefore, the data was not separated based upon stroke direction, for further analysis.

Figures 7, 8, and 9 reveal the TE with respect to the area ratio (AR). The AR ranged from 0.34 – 0.61 for 01005, from 0.49 – 0.95 for 0201, and from 1.67 – 2.0 for 0402. The range of the AR for each passive component was obtained by varying the aperture size, and stencil thickness. As one would expect, TE improves with a higher AR for both 01005 and 0201. However, 0402 shows the opposite trend. Additional analysis is required to understand this phenomenon. Figures 7, 8, and 9 show the TE as a function of the AR for 01005, 0201, and 0402 respectively. We see from the figures below, in addition to observing higher TE for 01005 and 0201, we also observe lower STD with increased AR.

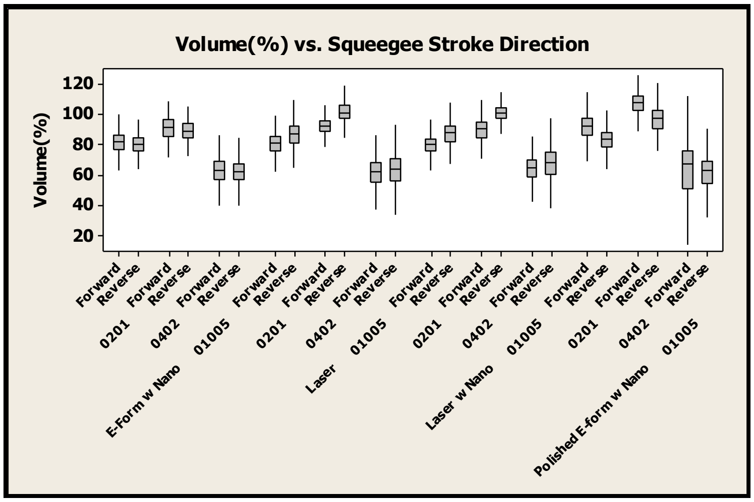

Figure 6. Volume Transfer Performance and Squeegee Stroke Direction

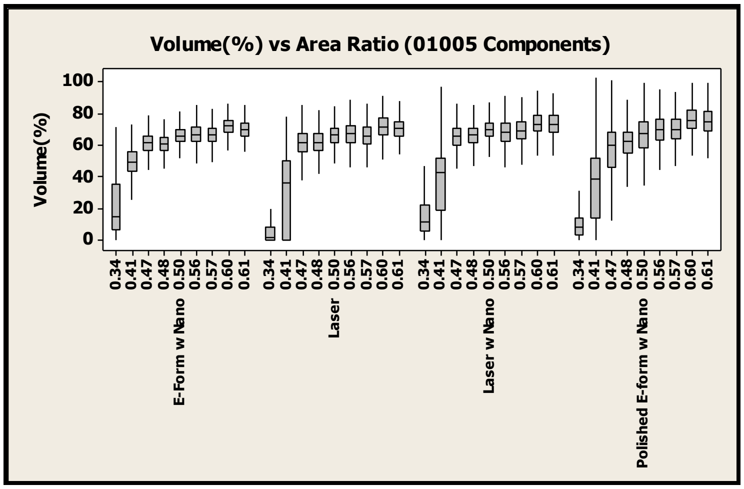

Figure 7. Volume Transfer and AR for 01005

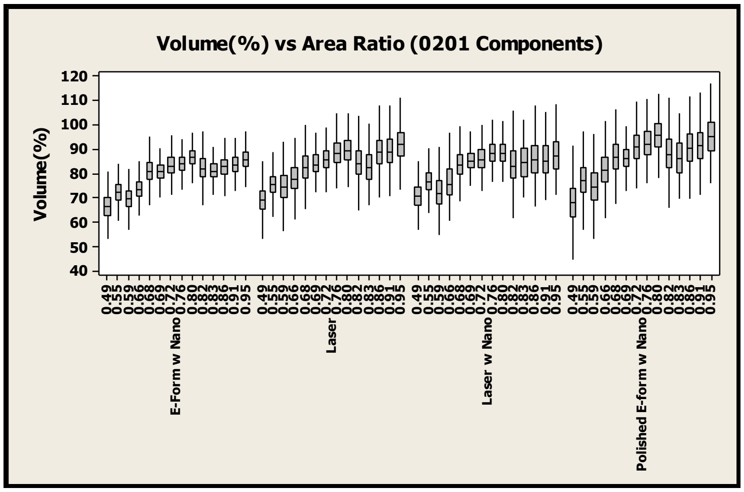

Figure 8. Volume Transfer and AR for 0201

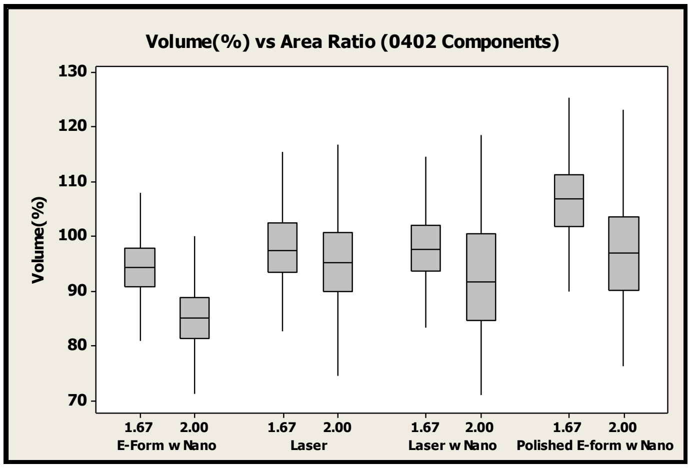

Figure 9. Volume Transfer and AR for 0402

As the focus of this study was to understand the effect of various stencil technology on 01005 component printing, the remainder of the discussion will be restricted to 01005 components only. Figure 10 shows the TE for the AR and stencil types. TE improves with the AR regardless of the stencil type. In general, for an AR $\leq$ 0.5, Laser with Nano gives slightly higher TE, but the standard deviation is also high. For an AR >0.5, Polished E-form with Nano gives a higher volume transfer, but the standard deviation is also high, especially for Polished E-form with Nano stencil. The anomaly that is seen with a 0.38 and 0.41 AR is attributed to extremely low AR combined with trapezoidal aperture shape. Therefore, further analysis is done by separating the trapezoidal aperture shape data and grouping the remaining AR into two groups (0.45 < AR < 0.55 and 0.55 < AR < 0.65).

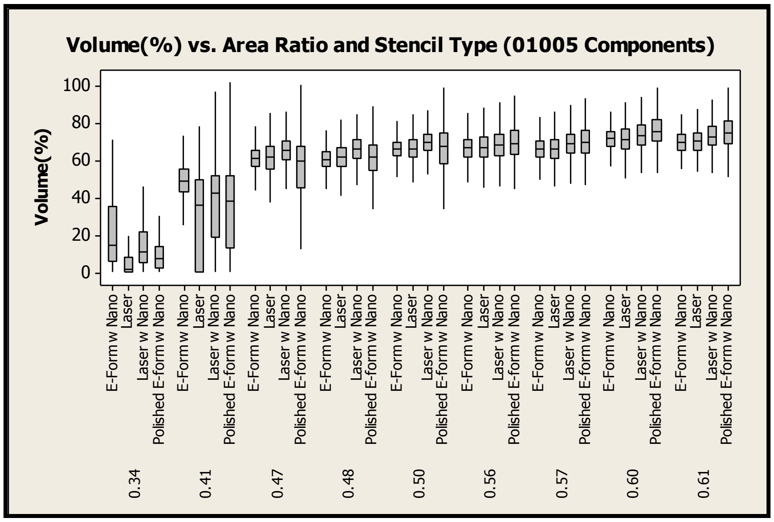

Figure 10. Volume Transfer vs. Stencil Type and AR for 01005 Components

Figure 11 shows the influence of the the AR on the aperture shape for the rectangular and square apertures. The rounded corners do show a slightly higher volume transfer for all stencil types. The E-Form with Nano shows lesser STD than the other stencils for both AR range and aperture shapes. The STD with the Polished E-Form with Nano stencil is more pronounced in the lower AR range.

Figure 12 shows the influence of the AR on the aperture size and the orientation of the aperture. A slight increase in volume transfer is noticed with both E-Form stencils, but not between the two Laser stencils. There is no substantial difference between the rectangle and square aperture shapes for the stencil types except for Polished E-Form with Nano. E-Form with Nano stencil shows lesser STD than the other stencils for both AR range. There is no significant difference between the horizontal and vertical orientation of the apertures.

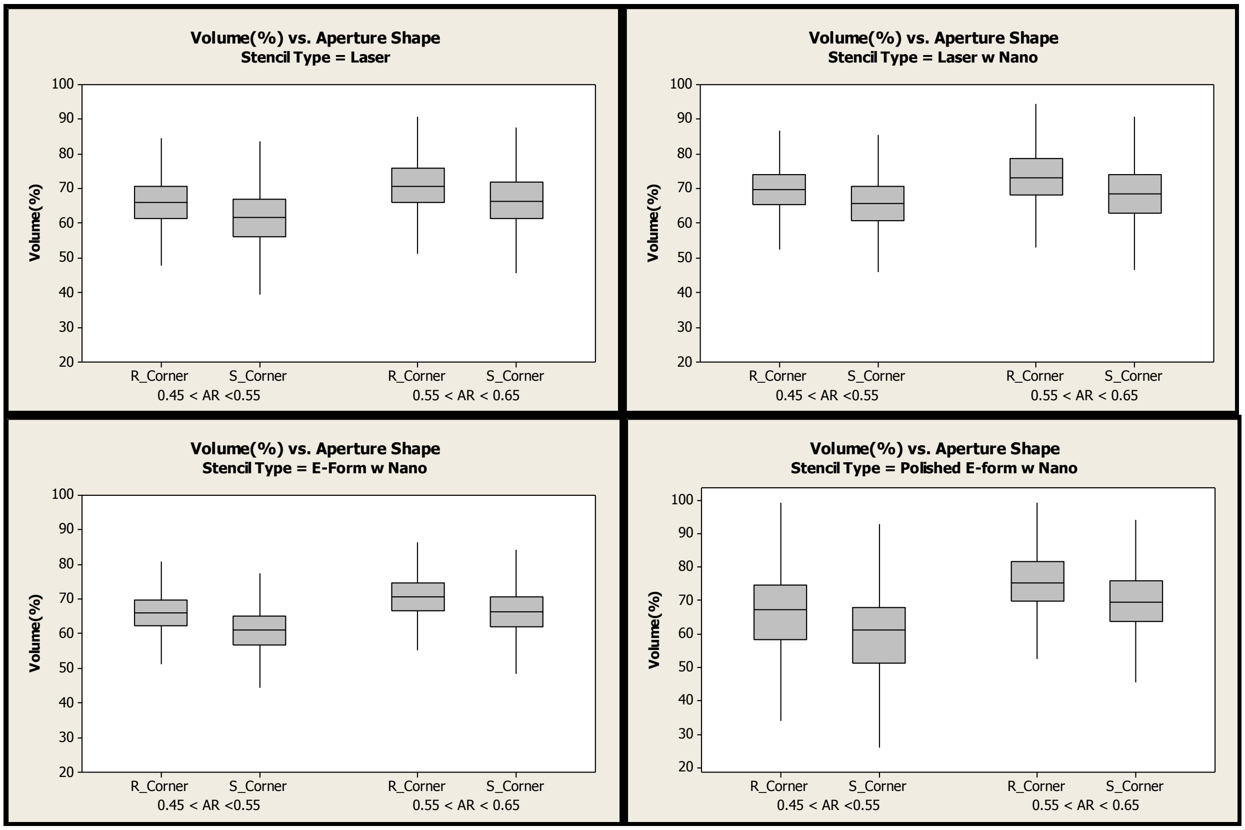

Figure 11. Volume Transfer vs. Aperture Shapes for Rectangular and Square 01005 Apertures

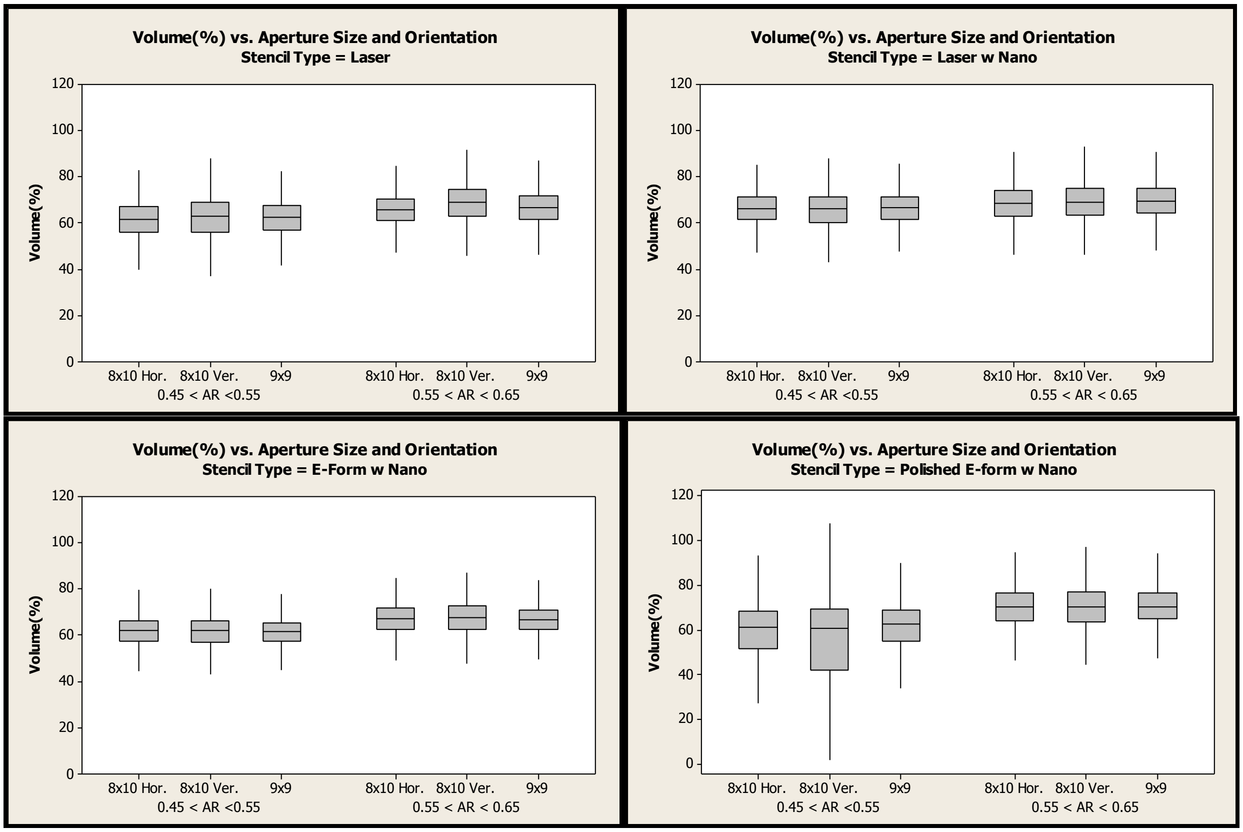

Figure 12. Volume Transfer vs. Aperture Size and Orientation for Rectangular and Square 01005 Apertures

In addition to various box plot analysis, a process capability (Cp) analysis based on a specification of ± 40% of the nominal (100%) TE value is presented in Figure 13. It is clear from this that plot E-Form with Nano stencil is the only one that is capable of reaching an acceptable Cp value for an AR under 0.5.

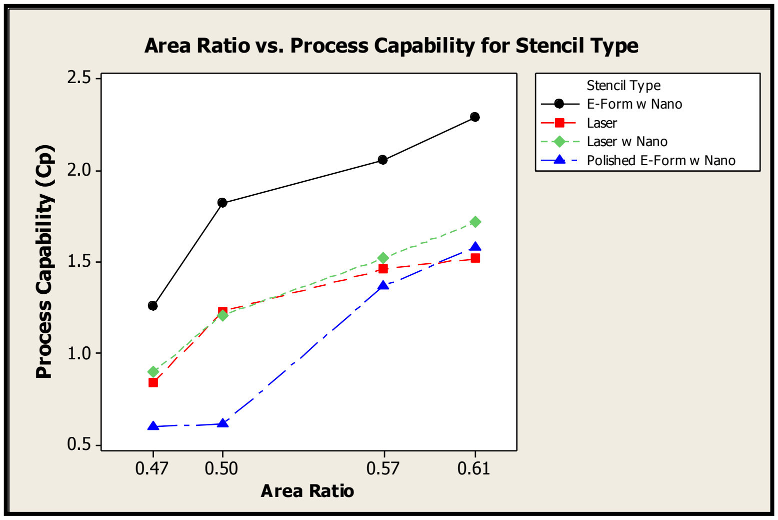

Figure 13. Process Capability vs. Area Ratio for Stencil Types

Summary/Conclusion

1. An extensive experimental work was conducted using four different types of stencil technology and a wide range of area ratios. Based on current study and preliminary data analysis, we can make the following conclusions. In general, TE increases and STD decreases with an increased AR for passives, with the exception of 0402. The anomaly observed for 0402 needs further investigation.
2. Based on the TE analysis, nano-coated stencils show a slightly better performance as compared to those without nano coating, for 01005 components. This is consistent with other reported results [1, 2].
3. Among the three types of nano-coated stencils, the advantage appears to be AR dependent.
4. The stencils with dishing edges provide higher volume transfer, but inadequate control of the volume transfer.
5. For ARs between 0.45 to 0.55, Laser with Nano stencil seems to provide the highest TE, while for ARs between 0.56 to 0.65, Polished E-form with Nano seems to be the better choice. Further investigation is required to confirm this finding.
6. Based on the preliminary analysis, rounded corner apertures appear to provide slightly higher TE compared to square corners. This is consistent with the theory presented earlier. Also, there was no significant difference between the 8x10 rectangular apertures and the 9x9 square apertures.
7. Finally, the Cp analysis for various AR and stencil types shows a distinct advantage of electroform with nano coating over other stencil technologies. Initial results indicate that with electroform with nano stencil may have the capability to be effective for AR of 0.48 and above. This finding needs to be validated with additional experimental work.

Future work/Recommendations

As it was mentioned at the beginning of the analysis, presenting the entire experimental work was beyond the scope of this paper. The authors will continue to analyze the data for more conclusive answers. Confirmation runs will be necessary to further strengthen the conclusion presented here. In addition we suggest further investigation of the other benefits associated with nano stencil such as reduction in stencil cleaning frequency.

Acknowledgements

The authors would like to acknowledge the invaluable support provided by Jeff Lonneville and Adam Lynes, lab technician and graduate research assistant, respectively, in the Center for Electronics Manufacturing and Assembly, for setting up the assembly line and also executing the experiment runs. The authors would also like to extend their sincere gratitude to Harris RF Communications for supporting their need for true 3D volume measurement by providing access to the measurement system within their facility.

References

1. Mohanty, R., et al, ”Evaluation of Nano Coated Stencil for Ultra Fine Pitch Component Assembly”, Proceedings of Surface Mount International Conference, October 2010.

2. Manessis, D., et al, “Evaluation of Innovative Nano-Coated Stencils in Ultra-Fine Pitch Flip Chip Bumping Processes,” IMAPS 41st International Symposium on Microelectronics, November, 2008