# Nano Coated Stencils for Optimized Solder Paste Printing

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**Abstract**
Cost reduction in electronic assembly and soldering is a key issue for economic survival in the global market. Very promising ways to reduce failure costs and increase productivity are: reduce solder paste bridging and reduce soldering failure modes caused by insufficient solder paste depots. Increase line productivity by reduction of cleaning frequency in the stencil printer.
Nowadays highly sophisticated nano-coated laser cut stencils show an increasingly significant role in electronic production. The potential of nano-coated stencils is demonstrated with extensive printing experiments and is shown in this paper, especially for critical area ratios. The stencil design was build up on BGA´s and QFP-structures with an area ratio going down to a value of approximately 0,4.
The coating process is based on a Sol-Gel process and is followed by a temper process to start a multistep polymerisation. The reaction layer is responsible for the high chemical- and mechanical resistance and provides the stencil with a high anti-adhesion effect with a low surface energy. The coating is applied on the bottom side of the stencil and in the aperture walls. The nano-coated surface offers a high functional surface with hydrophobic character and minimized adhesion of the solder paste which results in a high efficiency of the printing process with a significantly reduced failure rate. An additional advantage of the nano-coated stencil is the reduction of cleaning intervals of the stencil bottom side due to the fact, that the adhesion of the solder paste to the stencil is dramatically reduced. Cost saving for less cleaning material is obvious and goes hand in hand with higher production line efficiency.
Further the paper shows the significant increased freedom of design rules due to the fact of smaller area ratio.

**Key words:**
Stencil printing, nano-coated stencils, area ratio, transfer efficiency, production line progression.

**Introduction**
Reduction of failure costs in SMD electronic production is a permanent challenge. Insufficient solder paste deposits lead to a significant number of open solder joints below area array components. Detection of this failure mode as well as the later repair operation is difficult and expensive. There are two main waste producers: solder paste and the stencil printing process. Stencil printers with high performance are state of the art. Stencils, for the solder paste printing process for high area array components and fine pitch components or passive components like 0201 or 01005 components are made by a laser cut -, electroforming - or nickel plating stencils. All these production methods are not able to overcome the big conflict of the stencil printing process. Solder paste must stick in acceptable value to the upper side of the stencil, but should not adhere to the bottom side of the stencil and to the aperture walls. Adhering to the wall causes: missing or insufficient solder paste. Adhering to the bottom side of the stencil causes solder paste smearing. Dealing with this unsolvable production handicap lead to frequently bottom side cleaning – for very advanced boards after every print! This fumbling can not solve the cause of the problem of increasing costs of cleaning material and as a most unlike effect: slowing down the whole SMD-production line.
Nano-coated stencils are a smart solution: top side of the stencil is uncoated, the bottom side and the aperture walls are permanently coated with an anti adhesion effect.
The objective of all finishing technologies is the reduction of the adhesion between solder paste and stencil surface energy of the stencil surface. Because of the fact that the adhesive forces of solder paste to the aperture wall are a decisive factor in paste transfer, an improved paste transfer can be expected. Current research activities deal with the coating of stencils by plasma, PTEE or special nano materials [1] [2] [3]. This paper deals with nano-coated stencils, the process of nano-coated stencils as well as the characteristics of the nano-coated stencils. The focus of this paper is on the printing performance of the nano-coated stencil.
Nano-coatings allow application specific a large multiplicity of advantages in comparison to conventional coatings. On the one hand nano-materials can be processed with the most environment friendly solvent: water. On the other hand nano-coatings show an excellent mechanical and chemical resistance, due to the inorganic basic structure.

**Process of nano-coating**

The flow diagram in figure 1 explains the basic and prinzip of the sol-gel process.

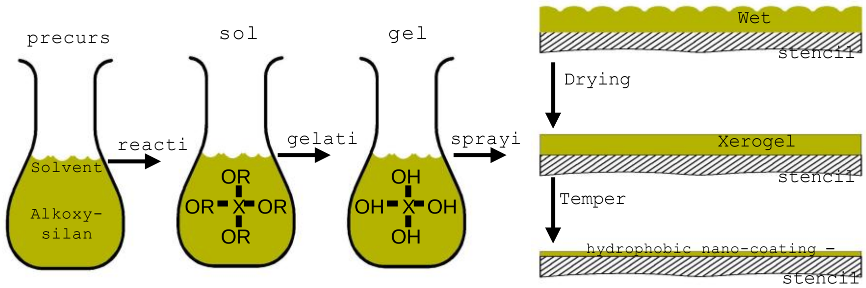


Figure 1- Princip of the sol-gel process

The first step in the production process is a thorough cleaning with purified water and alcohol to provide a clean surface for optimal adhesion of the nano-coating. Figure 2 shows the production line. The gel solution is applied with computer controlled spray coating unit.

**Figure 2 – production line of the nano coating process**

Controlling the process parameters is essentially for a uniform and reliable application of the nano-material. After applying the coating a controlled evaporation of the solvent is responsible for a homogenous nano-coating. The last step is a temper process to functionalize the layer. During this sub process the nano-coating obtain the hydrophobic properties.

**Characteristics of the nano-coating**

The remaining dry film has an average of 1-2µm in thickness only, see figure 3. Figure 3 shows a nano-coated stencil in a cross-section with SEM embedding resin.

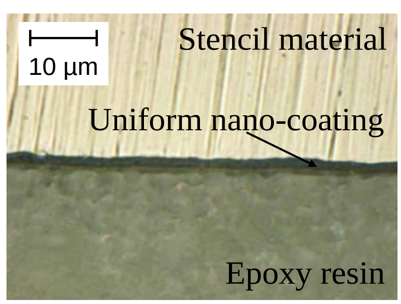


**Figure 3 – cross section of nano-caoted stencil**

The extensive process of nano-coating is carried out to avoid adhesion of the solder paste inside the apertures and on the bottom side of the stencil. Non adhesion on stainless steel can be only achieved by significant decrease of the surface energy, which is controlled by the contact angle measurement, see figure 4. Water is "similar" to solder paste due to the strong polar ingredients. 29% lower surface energy is the save warrantor for a better release of solder paste out of the apertures and from the bottom side of the stencil. This major property can be easily tested by the contact angle, therefore a computer assisted equipment is used for continuous quality control, see figure 5.

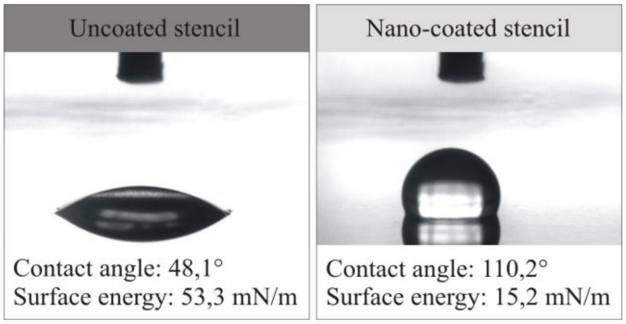


**Figure 4 - Contact angles and resulting surface energies of an uncoated and a nano-coated stencil surface (test fluid: purified water)**

**Figure 5 – computer assisted contact angle equipment**

**Description of the study**

The description of the study is carried out by the Institute for Manufacturing Automation and Production Systems, Friedrich-Alexander-University Erlangen-Nuremberg by Mr. Dipl.-Ing. Michael Rösch.

The potentials of nano-coated stencils are illustrated on the basis of extensive printing experiments. Therefore the printing performances of uncoated and nano-coated stencils are compared. All stencils used within this study are made of stainless steel and manufactured by laser cutting. The thickness of all stencils is 150µm. The stencil layout is illustrated in figure 6 and includes apertures for different component types and sizes as well as test apertures to demonstrate the potential of the nano-coating.

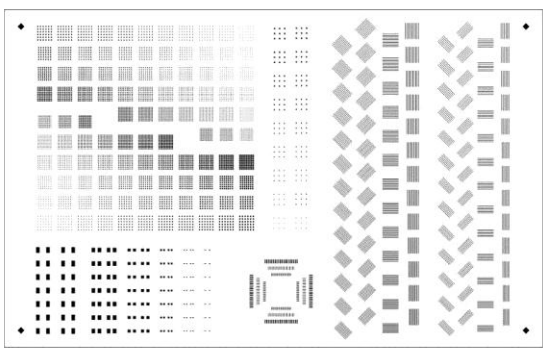

**Figure 6 - Stencil layout 1**

The stencil layout 2 is illustrated in figure 7 and of circular apertures with varying area ratios. Beginning with the an area ratio 0.8, the area ratio is reduced to 0,33 in step of 0.01. In total, 49 circular apertures represent one area ratio value on the stencil. Stencil layout 2 is designed to determine a reliable area ratio value that can be printed using a nano-coated stencil.

Within this study two solder pastes with different powder particle sizes are used. The particle sizes are 25µm to 45µm (type 3) respectively 20µm to 38µm (type4). Both solder pastes F640SA30C5-89M30, and F640SA30C5-89M4 are delivered y Heraeus and have the same flux system and identical metal contents.

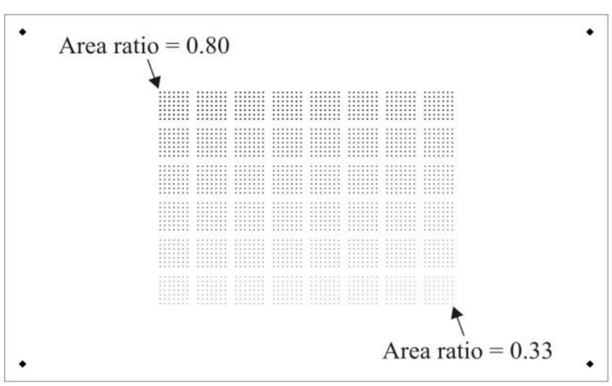


**Figure 7 - Stencil layout 2**

All printing experiments are realized using a stencil printer of DEK (Horizen). The printing experiments are accomplished with varying process parameters. The settings concerning squeegee speed, squeegee force and squeegee angle are listed in table 1.

**Table 1 – Experimental setup of the test series 1 and 2**

| | Test series 1 | Test series 2 |
|---|---|---|
| Stencils | 1 x uncoated<br>1 x nano-coated | 1 x uncoated<br>1 x nano-coated |
| Stencil thickness | 150 µm | 150 µm |
| Stencil technology | Laser cutting | Laser cutting |
| Stencil material | Stainless steel | Stainless steel |
| Stencil layout | 1 | 2 |
| Solder paste | Type 3, 4 | Type 4 |
| Squeegee force | 2,2 N/cm | 3,5 N/cm |
| Squeegee speed | 50 mm/s | 10 mm/s |
| Squeegee angle | 60° | 45° |
| Squeegee material | Stainless steel | Stainless steel |
| Number of boards | 15 | 8 |
| Stencil cleaning | no | yes |

A solder paste inspections system of KOH YOUNG is used to characterize the printing results. The inspection system determines the solder paste volume of each deposit on the basis of phase shift interferometry. After measurement, the inspection system calculates the transfer efficiency of each solder paste deposit and writes the results into a database.
The resulting database is analyzed using the statistical software MINITAB. The transfer efficiency of all deposits is illustrated in a boxplot whereas the transfer efficiency is plotted on the y axis ant the print number on the y axis and the print number respectively the area value is plotted on the x axis. Each box is defined by the median and the lower and upper quartile. Besides the whisker, the boxplot also illustrates the outlier of the distribution.
An optical microscope is used to visualize the print results on the printed boards while the optical coordinate measurement system Werth VideaCheck IP 400 HA is used to illustrate the board side of the printing stencils.

**Printing performance**
Two different test series are realized to demonstrate the potential of the nano-coated stencils. Test series 1 is based on printing parameters that are similar to industrial conditions. Unlike, test series 2 uses modified printing parameters to optimize the critical aperture filling process and to ensure a complete aperture filling. Therefore squeegee speed and squeegee angle are reduced while squeegee force is increased.

**Test series 1**
The comparison of the print result of QFP structures with different pitches after the 5$^{th}$ print, illustrated in figure 8, shows solder paste bridges for structures QFP0,4 and QFP0,3 using an uncoated stencil. Unlike, the usage of a nano-coated stencil does not show any bridging affects after 5$^{th}$ print. Even after fifteen prints there are no solder paste bridges for all QFP structures. Furthermore, the usage of a nano-coated stencil creates more uniform deposit shapes.

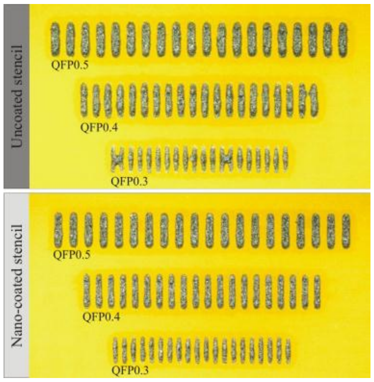


**Figure 8 – Print results of QFP structures with different pitches after the 5$^{th}$ print using an uncoated and a nano-coated stencil (solder paste type 3)**

The reason for the appearance of solder paste bridges is remaining paste on the PCB-side of the stencil. These paste residues occur during the separation process between stencil and printed circuit board when paste can be deflected to the board side of the stencil. Subsequently, the remaining paste prevents a correct positioning of the stencil. This results in a gap between stencil and printed circuit board with consequence that the solder paste bridges increase.
Due to the reduced adhesion between solder paste and nano-coated stencil surface, no paste residues can be identified on the board side of the nano-coated stencil. Unlike, the board side of the uncoated stencil shows numerous paste residues after the 5$^{th}$ print. The differences between uncoated and nano-coated stencil for structures QFP0.5 and QFP0.4 are illustrated in figure 9.

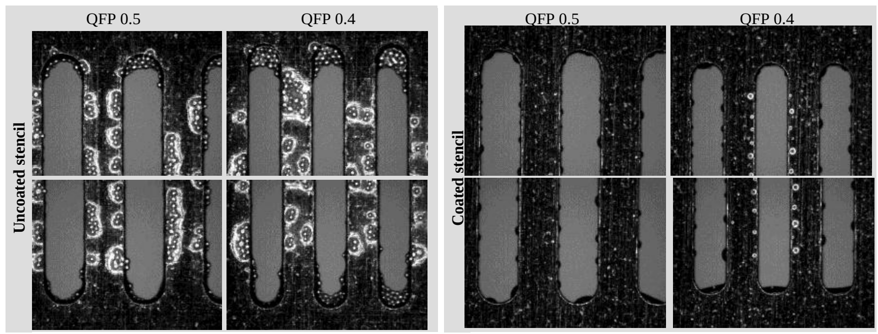


**Figure 10 – PCB sides of an uncoated and nano-coated stencil after the 5$^{th}$ print (solder paste type 3)**

Besides the optical appearance of the board sides of the stencils, the analysis of the transfer efficiencies confirm the differences between uncoated and nano-coated stencil. While the transfer efficiencies of the QFP0.5 increases about 40% within the first seven prints for the uncoated stencil, the transfer efficiencies of the QFP0.5 remains constant at approximately 85% for fifteen prints without cleaning the pcb side of the nano-coated stencil. The printing performance for fifteen prints of the QFP0.5 for the uncoated and the nano-coated stencil is illustrated in figure 11.

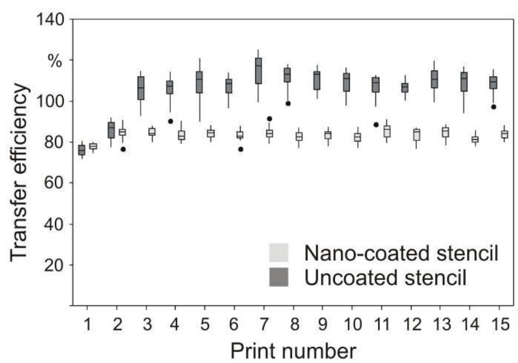


**Figure 11 – Transfer efficiencies of QFP0.5 for an uncoated and a nano-coated stencil as a function of the print number (solder paste type 3)**

The visualization of the transfer efficiencies of the QFP0.4 in figure12 shows an identical behaviour. Furthermore, it becomes evident that the distribution of the transfer efficiencies for nano-coated stencil shows a significant smaller variation.

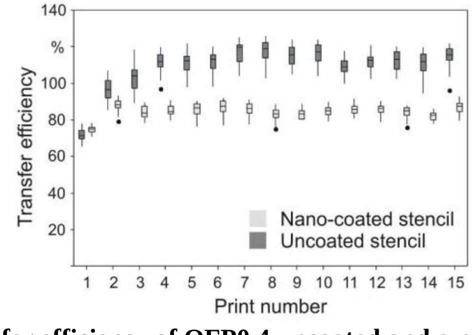


**Figure 12 – Transfer efficiency of QFP0.4 uncoated and a nano-coated stencil as**

**a function of the print number (solder paste type 3)**

Besides the QFP structures, the nano-coating of the stencil also improves the printing behaviour of BGA structures with small area ratio values. Figure 13 illustrates printed solder paste deposits with an area ratio of 0.5 for both stencils and both solder paste types. The usage of a nano-coated stencil results in more uniform solder paste deposits and higher solder paste transfer to the printed circuit board. The increase transfer efficiency is a consequence of the hydrophobic character of the stencil surface and reduces adhesion between solder paste and stencil. As it can be seen from figure 14, there are absolutely no solder paste particles remaining within the aperture of a nano-coated stencil.

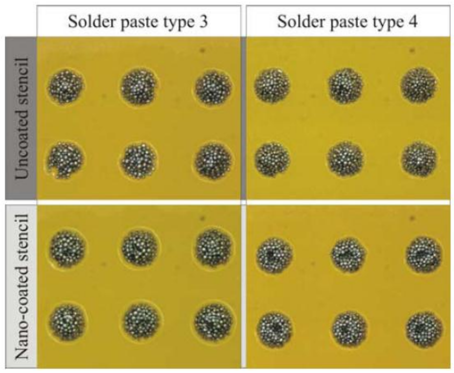


**Figure 13 – Solder paste deposits of an uncoated and a nano-coated stencil with an area of 0.50 using solder paste type 3 and 4**

Particularly, drop-shaped residues of the flux adhere at the aperture wall without reducing the transfer efficiency. Unlike, the aperture wall of the uncoated stencil shows residues of the solder paste particles with the consequence that the transfer efficiency decreases.

The differences in the transfer efficiencies of an uncoated and a nano-coated stencil illustrated in figure 15 for solder paste type 3 and figure 16 for solder paste type 4.

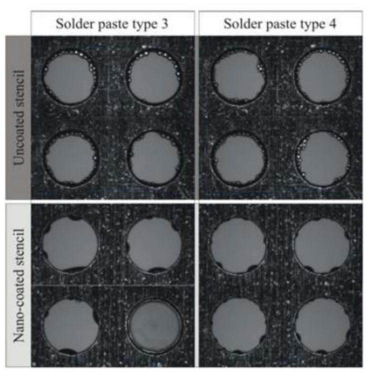


**Figure 14 – Stencil apertures of an uncoated and a nano-coated stencil with an area ratio of 0,67 using solder paste type 3 and 4**

As expected the transfer efficiency decreases with lower area ratio values. For both solder paste types the nano-coated stencil shows significant higher transfer efficiencies in comparison to the uncoated stencil. The lower the area ratio value, the higher the difference in the transfer efficiencies between uncoated and nano-coated stencils. Furthermore, the usage of the nano-coated stencil results in lower variances of the transfer efficiencies.

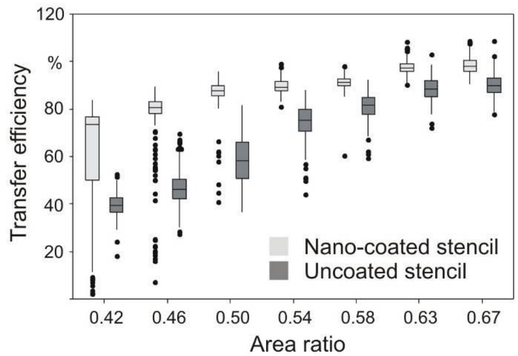


**Figure 15 – Transfer efficiency of an uncoated and a nano-coated stencil at varying area ratios using solder paste type 3**

On Condition that a minimum transfer efficiency of 50% is required, area ratio values of 0.54 for solder paste type 3 and 0.46 for solder paste type 4 can be realized using a nano-caoted stencil. With regard to the general design recommendations of the IPC-7525A the usage of a nano-coated stencil offers a further reduction of the area ratio value using solder paste type 4 [4].

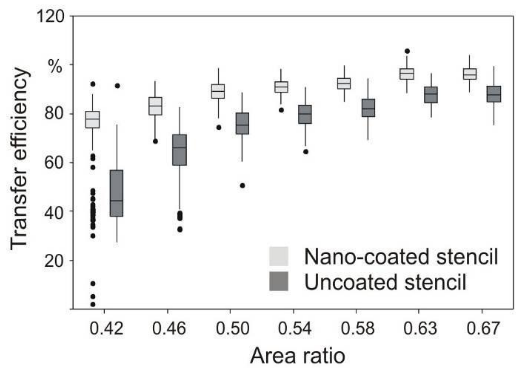


**Figure 16 – Transfer efficiencies of an uncoated and a nano-coated stencil at varying area ratios using solder paste type 4**

Regarding test series 1 it becomes evident that especially the filling process of apertures with very low area ratio values is a critical sub process of stencil printing using nano-coated stencils. The analysis of the transfer efficiency outliers in figure 15 and figure 16 shows that the reduced transfer efficiency is not a consequence of a poor release behaviour, but a consequence of an insufficient aperture filling. It is assumed that an improved aperture filling process leads to a further reduction of the printable area ratio value. For this reason test series 2 is performed using modified process parameters and stencil layout 2.

**Test series 2**

For reasons of clarity tha printing performance of an uncoated and a nano-coated stencil are illustrated in figure 17 and 18. Figure 17 illustrates, that a minimum area ratio value of 0.53 can be reached for the uncoated stencil at a minimum transfer efficiency of 50%.

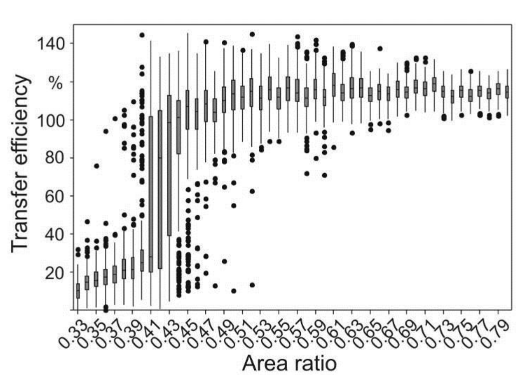


**Figure 17 – Transfer efficiencies of an uncoated stencil at varying area ratios using solder paste type 4**

The printing performance of the nano-coated stencil is illustrated in figure 18. it becomes evident that a nano-coated stencil enables the printing of very small area ratio values.  As it can be seen from figure 18, a minimum area ratio value of 0.36 can be reached for the uncoated stencil at a minimum transfer efficiency of 50%. In comparison to the uncoated stencil, the nano-coated stencil results in higher transfer efficiencies and lower variances.

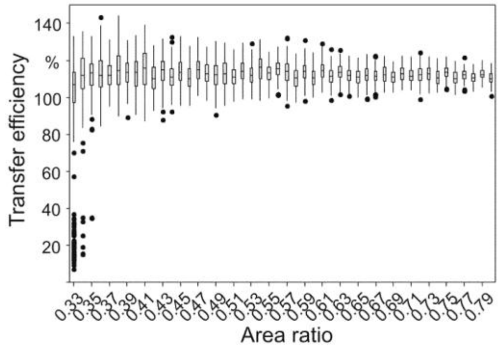


**Figure 18 – Transfer efficiencies of a nano-coated stencil at varying area ratios using solder paste type 4**

The printing performance of the nano-coated stencil is illustrated in figure 16. It becomes evident that a nano-coated stencil enables the printing of very small area ratio values. As it can be seen from figure 16, a minimum area ratio value of 0.36 can be reached for the uncoated stencil at a minimum transfer efficiency of 50%. In compassion to the uncoated stencil, the nano-coated stencil results in a higher transfer efficiencies and lower variances.
Figure 19 illustrates exemplarily the stencil apertures of an uncoated and nano-coated stencils with area ratios of 0.4 respectively 0.48 using solder paste type 4. As it can be seen already from figure 14, there is no solder paste remaining within the apertures of the nano-coated stencil. While the solder paste releases completely from the apertures of the nano-coated stencils, the apertures of the uncoated stencil with area ratios of 0.4 are blocked. A reliable paste release is not possible.

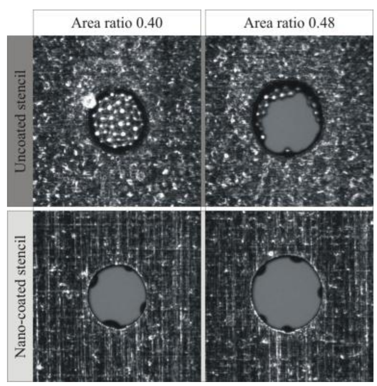


**Figure 19 – Stencil apertures of an uncoated and a nano-coated stencil with are ratios of 0.40 and 0.48 using solder paste type** 4

Due to the reduced adhesion between solder paste and stencil surface, a nano-coated stencil enables a complete solder paste transfer to the printed circuit board. The resulting shape of the solder paste deposit is equivalent to the geometry of the aperture opening. Figure 20 shows two representative solder paste deposits for an area ratio value of 0.36.

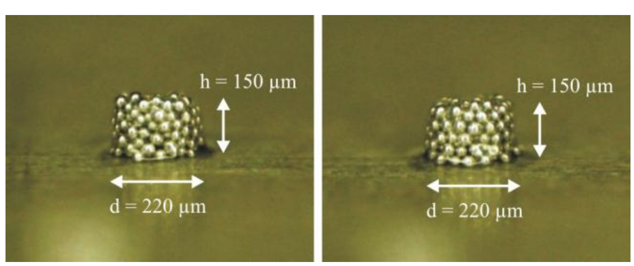


**Figure 20 – Solder paste deposits printed with a nano-coated stencil at an area ratio value of 0.36 (d = deposit diameter, h = stencil height)**

## Conclusion

Nano-technology is nowadays used in all fields of industries. Special sol-gel processes are widely spread to create up surfaces with specific functional properties. Permanent hydrophobic finishes avoid adhesion, range from skillets to nano-coating on chiplevel. Hydrophobic finishes on stencils enable to solve the big conflict in stencil printing. Hydrophobic walls of apertures are no longer clocking. Particles from the solder paste don´t adhere and can not longer reduce the transferred amount of solder paste.

The results:

- Better transfer efficiency = significant lower failure rate on the SMD line.
- More flexibility in stencil design. On condition of a reliable aperture filling area ratio values of 0.4 can be realized.
- Usage of nano-coated stencil offer a more uniform deposit shape and lower variances in transfer efficiency = more robust process. The bottom side stays longer clean without solder paste contamination. No smearing around solder paste deposits = less solder bridges. Less solder paste contamination = less cleaning materials – cost saving and environment protections without additional costs.
- Reduced cleaning frequency = better utilization of the whole SMD production. With an integrated holistic manager view the slightly higher costs of nano-coated stencils outbalance cost savings in production- and quality costs.

## References

[1] W. E. Coleman, “Stencil Considerations for Miniature Components”, Proceedings of SMTA International 2009, San Diego, CA, US, 2009, p. 717-734

[2] M. Haupt, C. Oehr, R. Ruhfaß, R. Schmidt ”Entwicklung von Antihaftschichten auf Schablonen zur Optimierung von Druckprozessen in der Mikroelektronik“, Tagungsband Elektronische Baugruppen – Aufbau- und Fertigungstechnik – Erfolg durch Innovation, 2006, Fellbach, Germany, p. 65-70

[3] M. Rösch, J. Franke “Stencil Design Guidelines for Robust Printing Processes in Electronics Production Considering Stencil and Solder Paste Specific Properties”, Proceedings of SMTA International 2009, San Diego, CA, US, 2009, p. 735-741

[4] IPC-7525A: Stencil Design Guidelines. IPC – Association Connecting Electronics Industries, Bannockburn, IL, USA, 02/2007

# Nano coated stencils for optimized solder paste printing

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# Outline

- Introduction and Background
- Process of Nano-Coating
- Characteristics of the Nano-Coating
- Description of the Study
- Printing Performance
- Conclusion

# Introduction

- The stencil printing process is the most critical process step in electronics production
- Nearly two thirds of all process defects originate in the stencil printing process
- There is a great variety of influencing variables
- One of the most important variables in the printing process is the stencil

# Background

- Stencils differ substantially in their manufacturing technology, the stencil material and the stencil surface finishing
- The area ratio is a key performance indicator of a stencil
- Available stencil technologies enable area ratios of 0.5 using a solder paste type 3
- The innovative nanotechnology enables the manufacturing of stencils with very low surface energies of the stencil material

# Process of Nano-Coating

**Pre-treatment**

**Chemical**

**Pre-treatment**

**of stencil**

**Coating process**

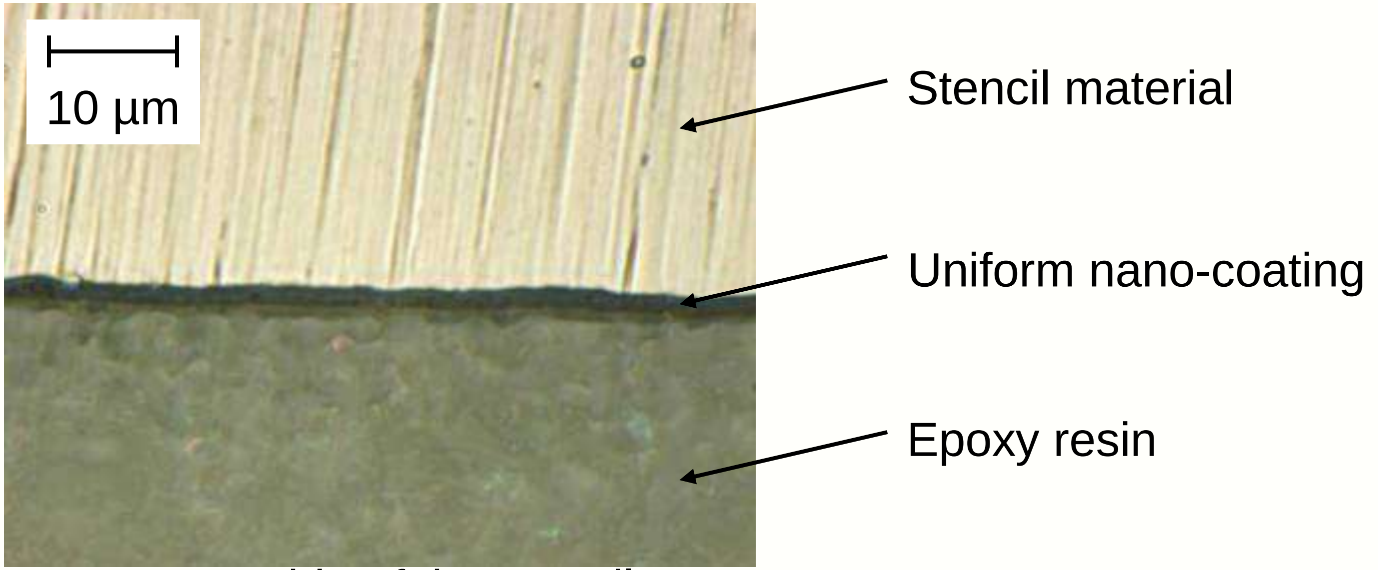
**Drying process**

**Temper Process**

**Quality control**

# Dry Film Thickness of the Nano-Coating

- The dry film thickness of the nano-coating is in a range of 1 µm to 2 µm

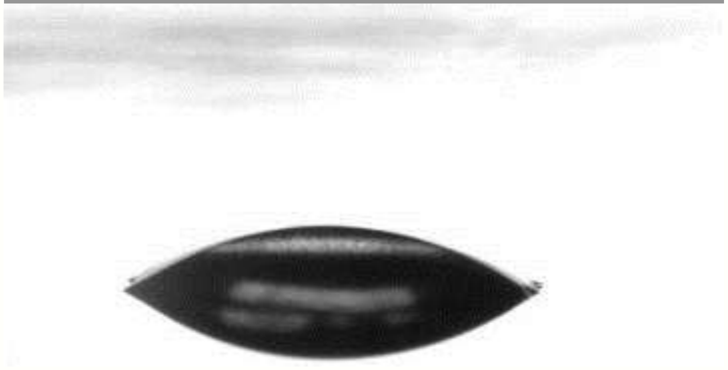



PCB side of the stencil

# Contact Angle and Surface Energy of a Nano-Coated Stencil

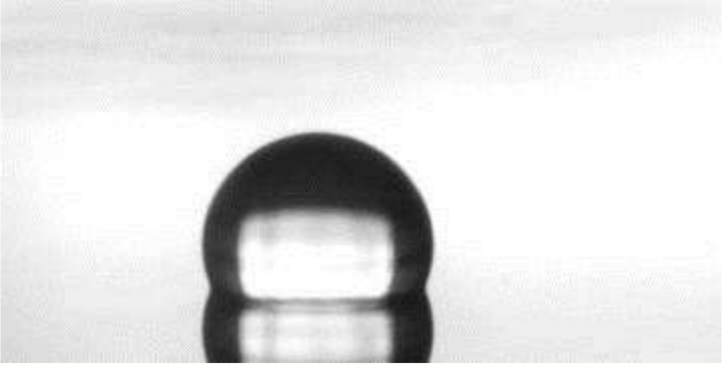
- The nano-coating leads to a significant increase in the contact angle and consequently to a reduced surface energy of the stencil material (test fluid: purified water)

Uncoated stencil



Contact angle: 48,1°
Surface energy: 53,3 mN/m

Nano-coated stencil

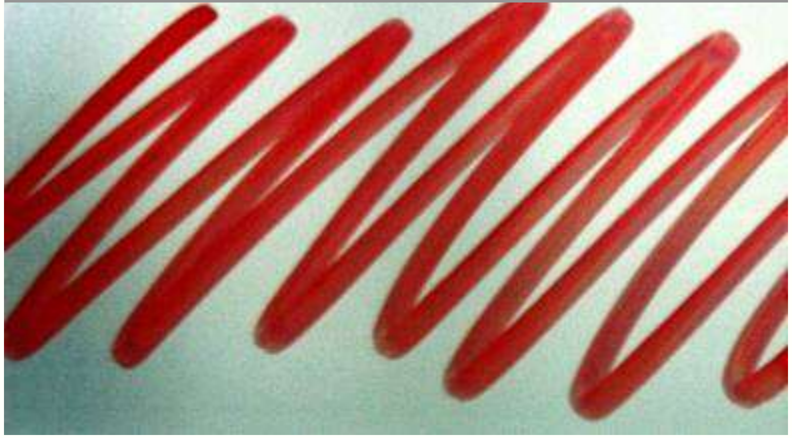


Contact angle: 110,2°
Surface energy: 15,2 mN/m

# Verification of the Nano-Coating Functionality in the Industry

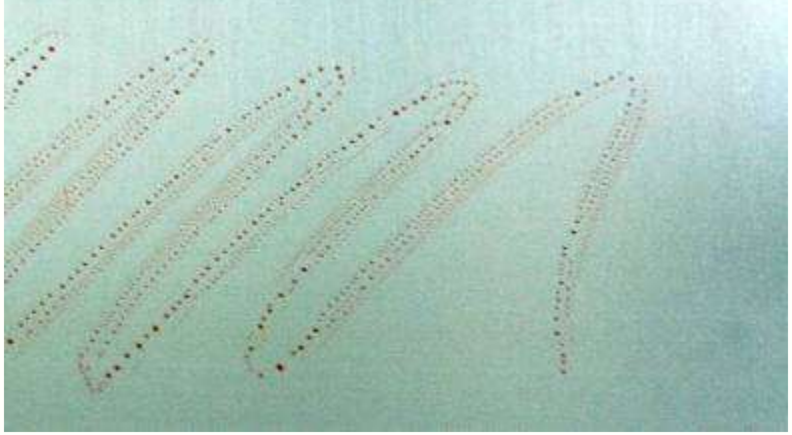
- A wetting test using a permanent marker enables the verification of the nano-coating functionality

Uncoated stencil



Good wetting on the stencil surface

Nano-coated stencil



No wetting on the stencil surface

# Description of the Study

- Objective:
  Comparison of the printing performances of uncoated and nano-coated stencils

- Two test series with two different stencil layouts were performed to evaluate the differences in the printing performance

- All stencils are made of stainless steel and manufactured by laser cutting, the stencil thickness is 150 µm

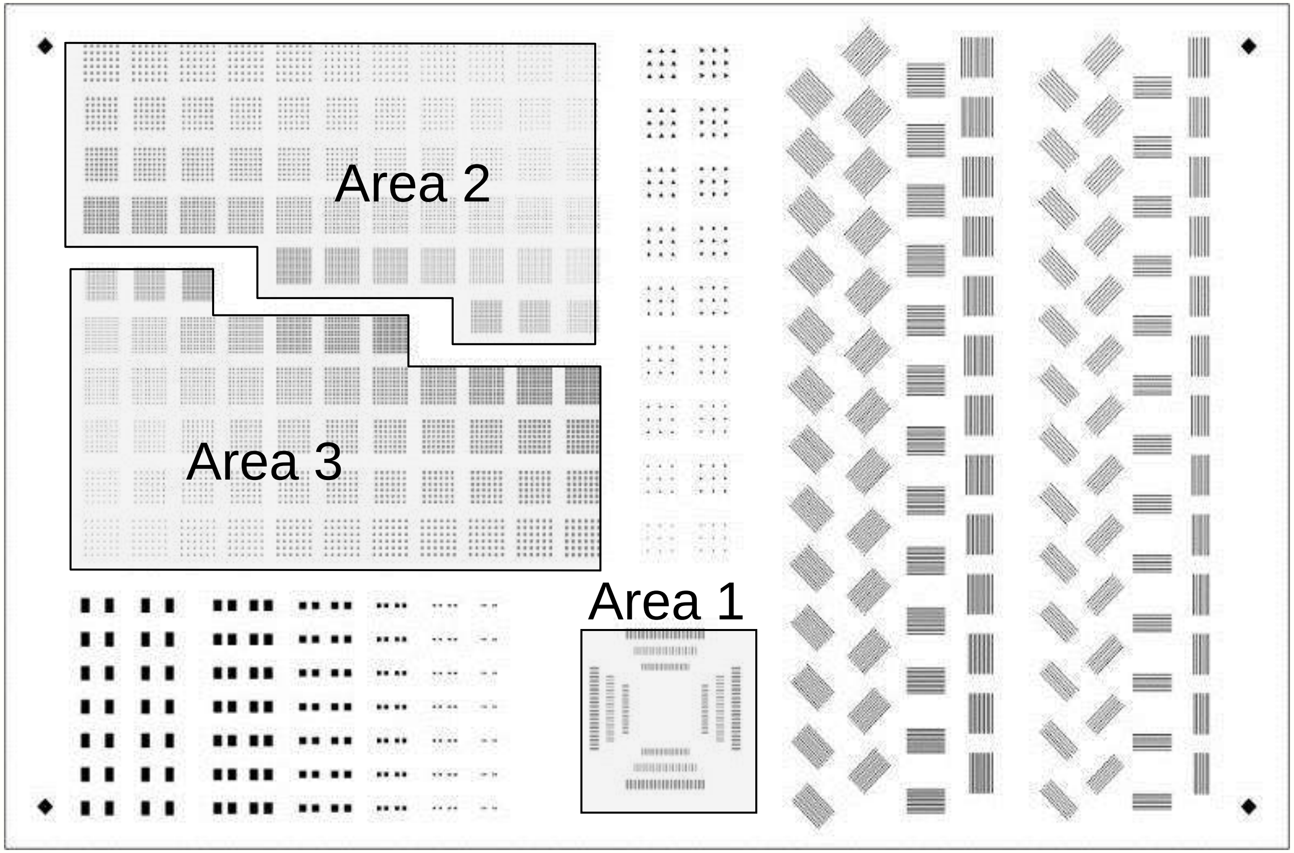
# Description of the Study

- Stencil Printer: DEK Horizon
- Solder Paste: HERAEUS F640SA30C5-89, Type 3 and 4
- Solder Paste Inspection System: Koh Young
- Data Analysis: Statistical Software Minitab
- Optical Microscope: Nikon
- Coordinate Measurement System: Werth VideoCheck

# Test Series 1

- 1 uncoated and 1 nano-coated stencil (stencil thickness 150 µm, stainless steel, laser cutting), stencil layout 1
- Solder Paste Type 3 (particle size: 25 µm to 45 µm) and Type 4 (particle size: 20 µm to 38 µm)
- Process parameters: 2.2 N/cm squeegee force, 50 mm/s squeegee speed, 60° squeegee angle
- 15 boards printed without cleaning of the pcb side of the stencil

# Stencil Layout 1

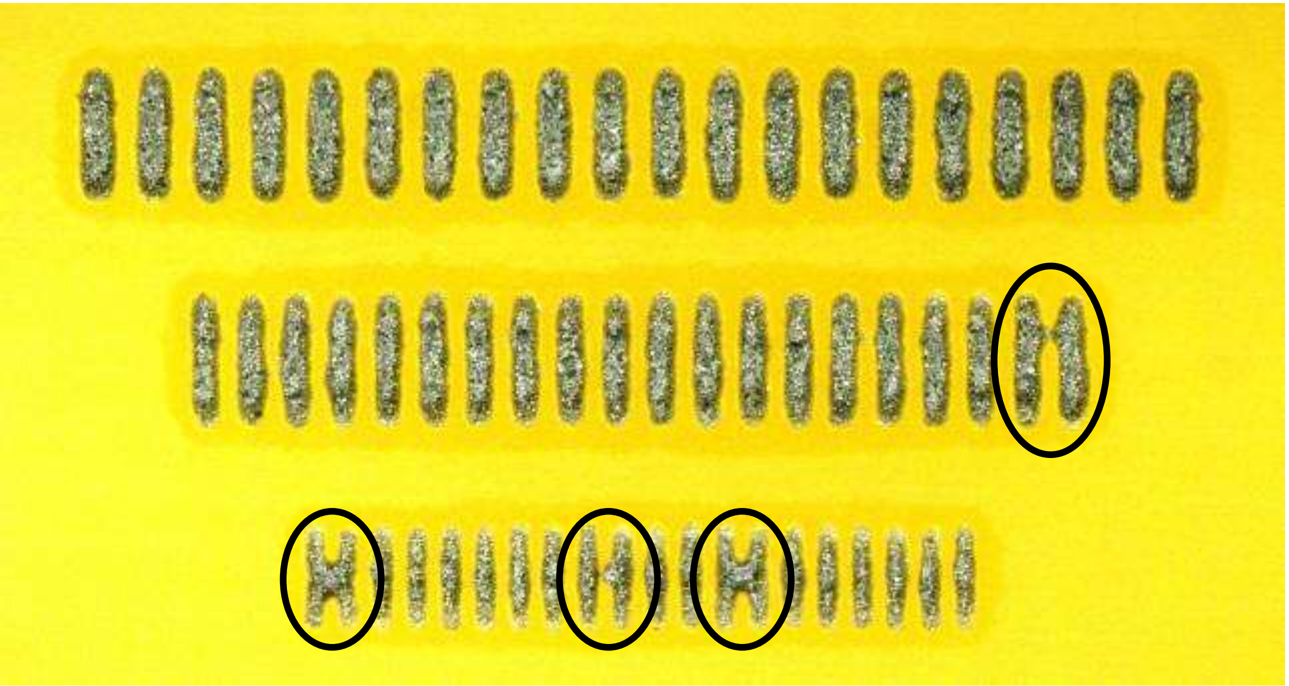


# Print Results of QFP after the 5th Print Using an Uncoated Stencil (Area 1)

QFP0.5

QFP0.4

QFP0.3

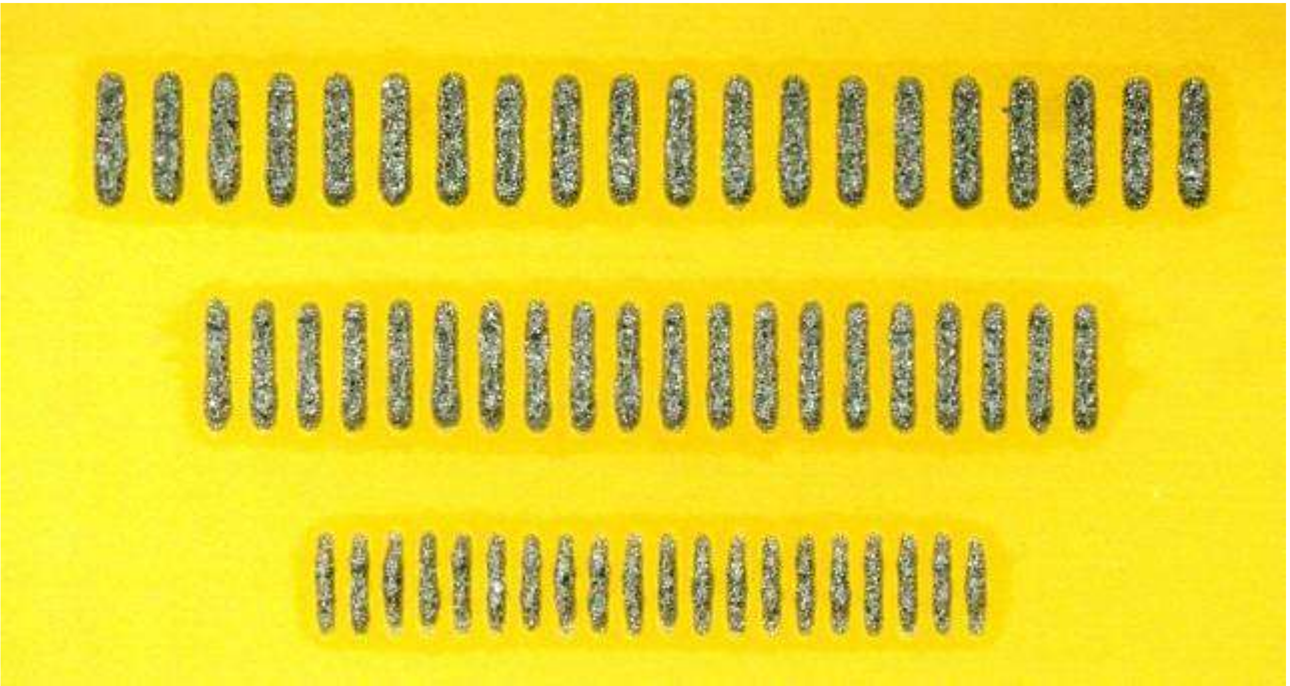


# Print Results of QFP after the 5th Print Using a Nano-Coated Stencil (Area 1)

QFP0.5

QFP0.4

QFP0.3

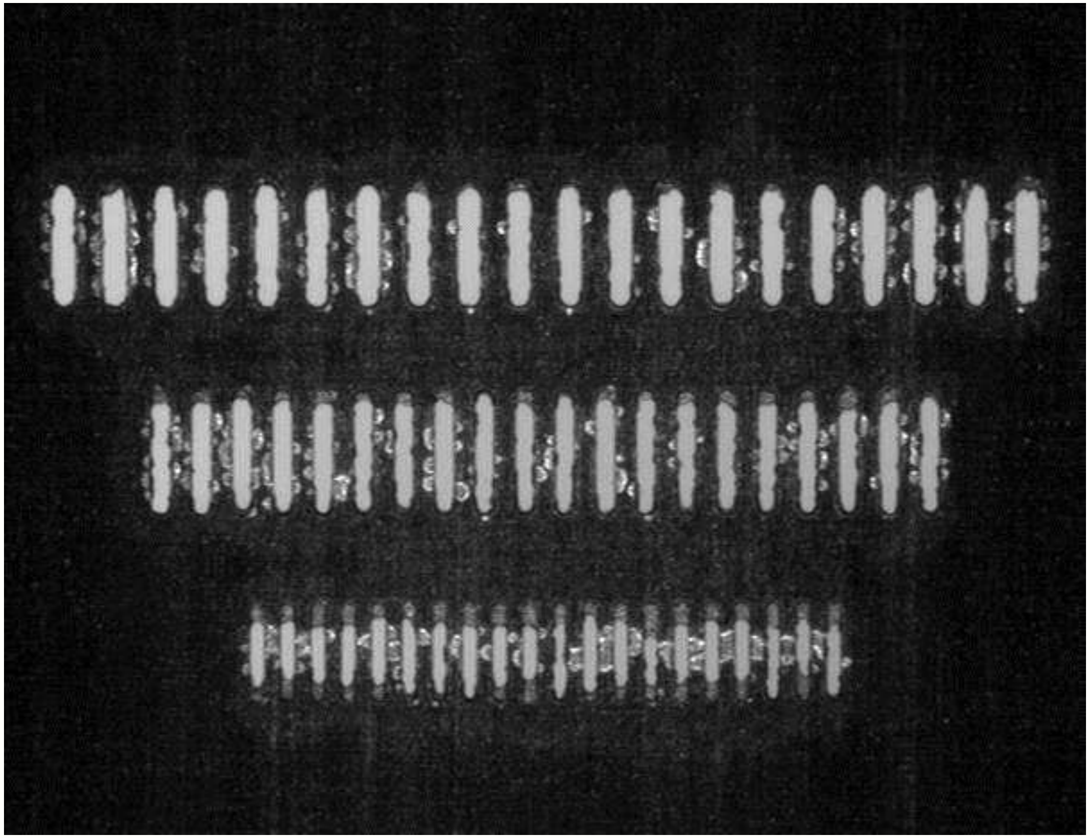


# PCB Side of the Uncoated Stencil after the 5th Print – Overview (Area 1)

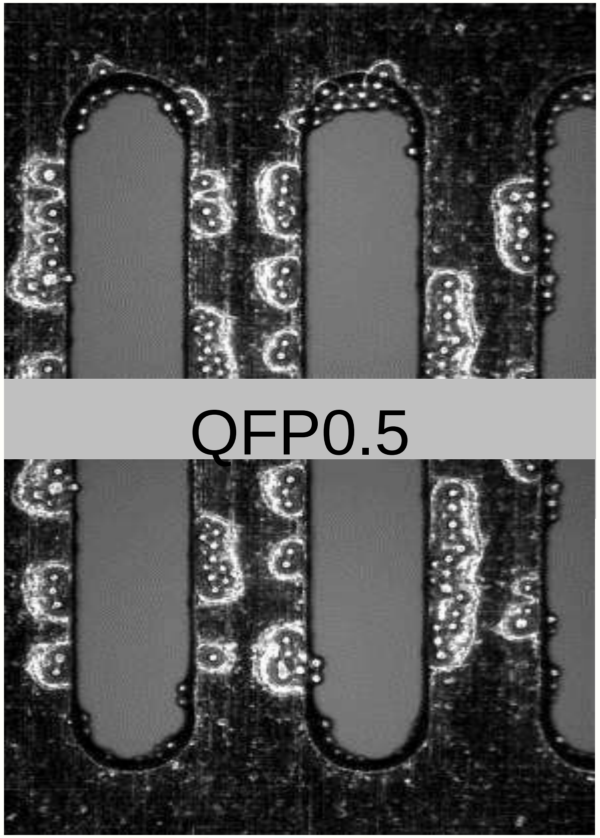
QFP0.5

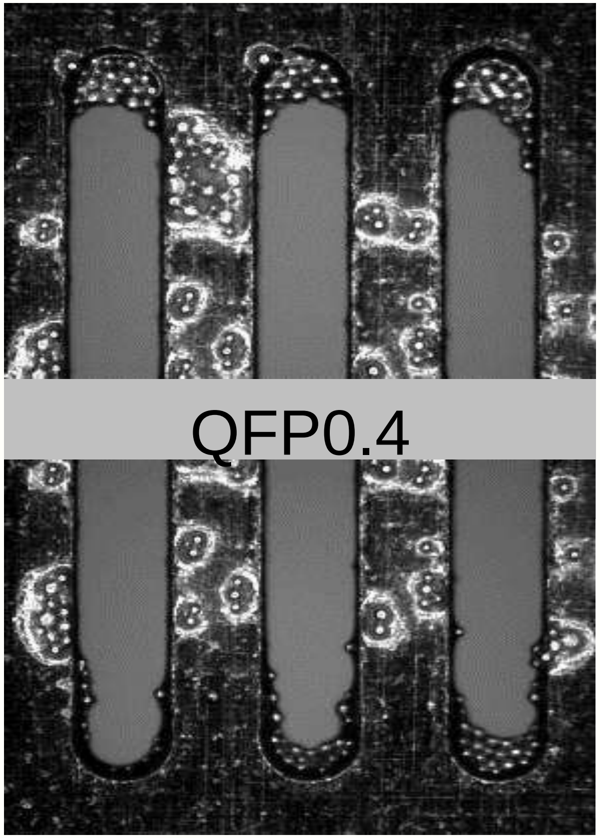
QFP0.4

QFP0.3



# PCB Side of the Uncoated Stencil after the 5th Print – Detail (Area 1)



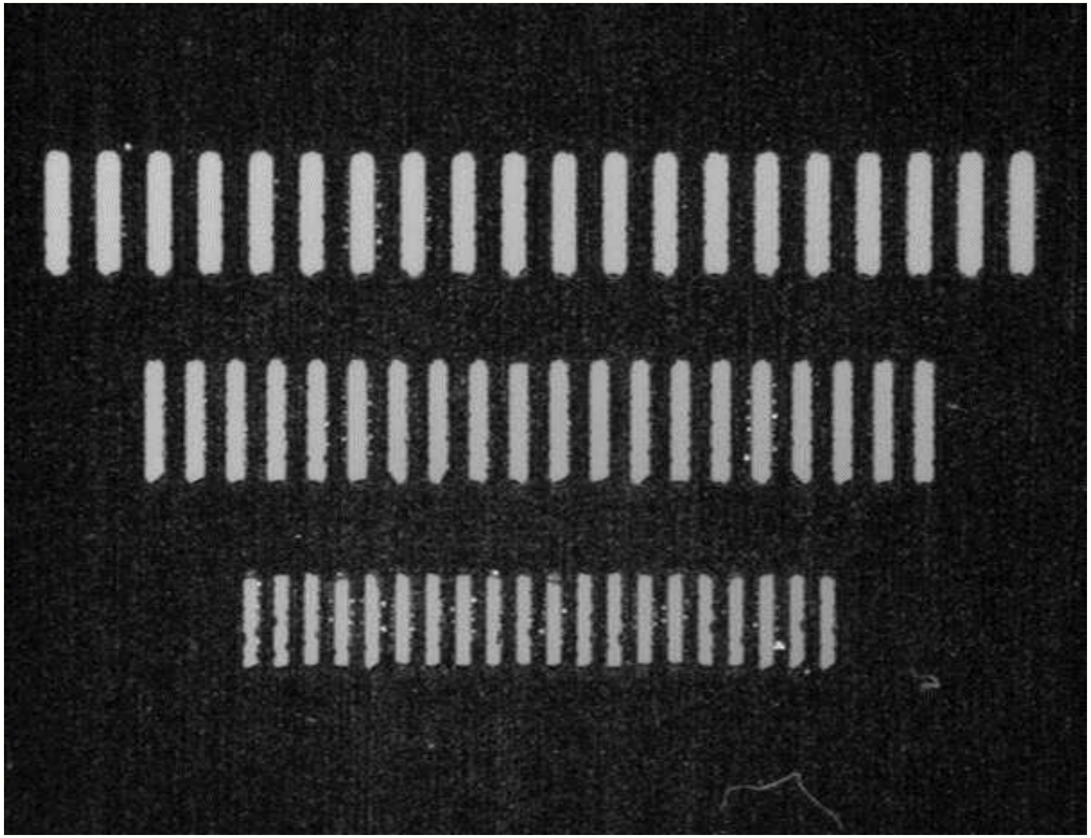



# PCB Side of the Nano-Coated Stencil after the 5th Print – Overview (Area 1)

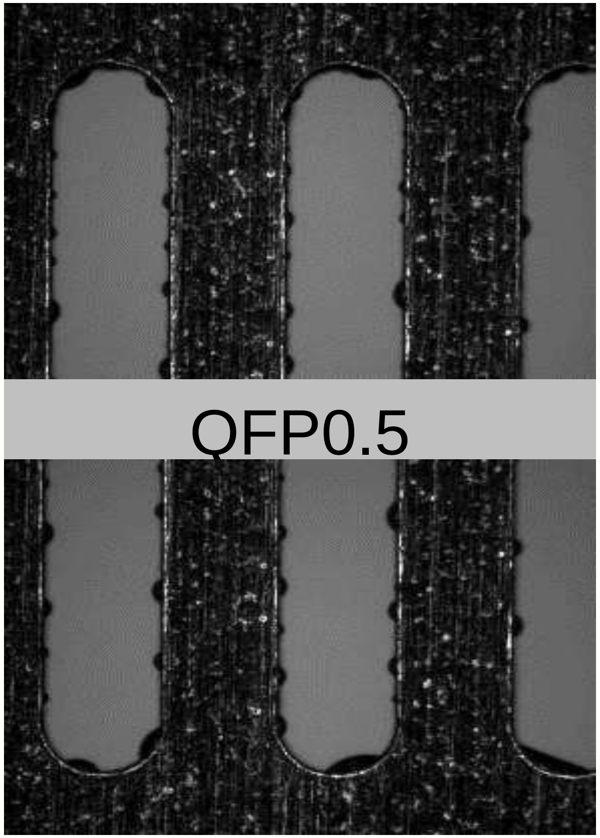
QFP0.5

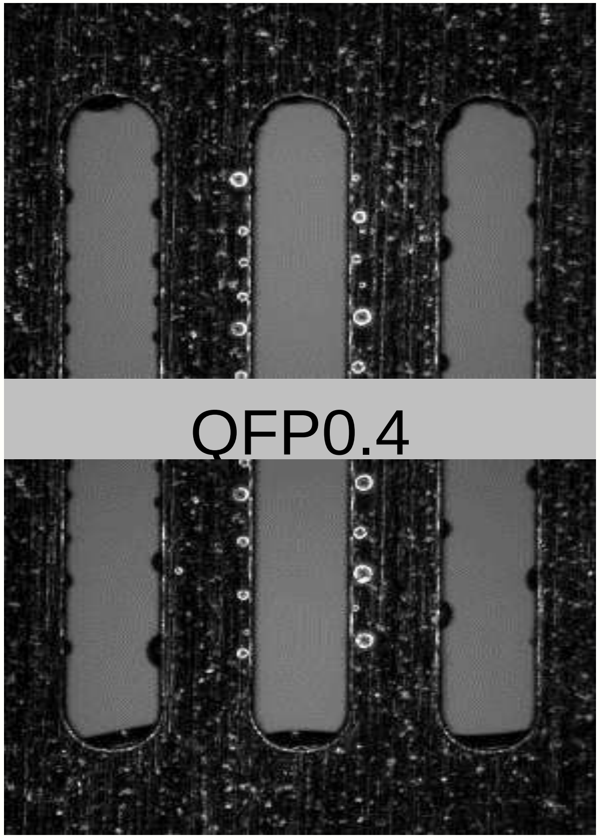
QFP0.4

QFP0.3

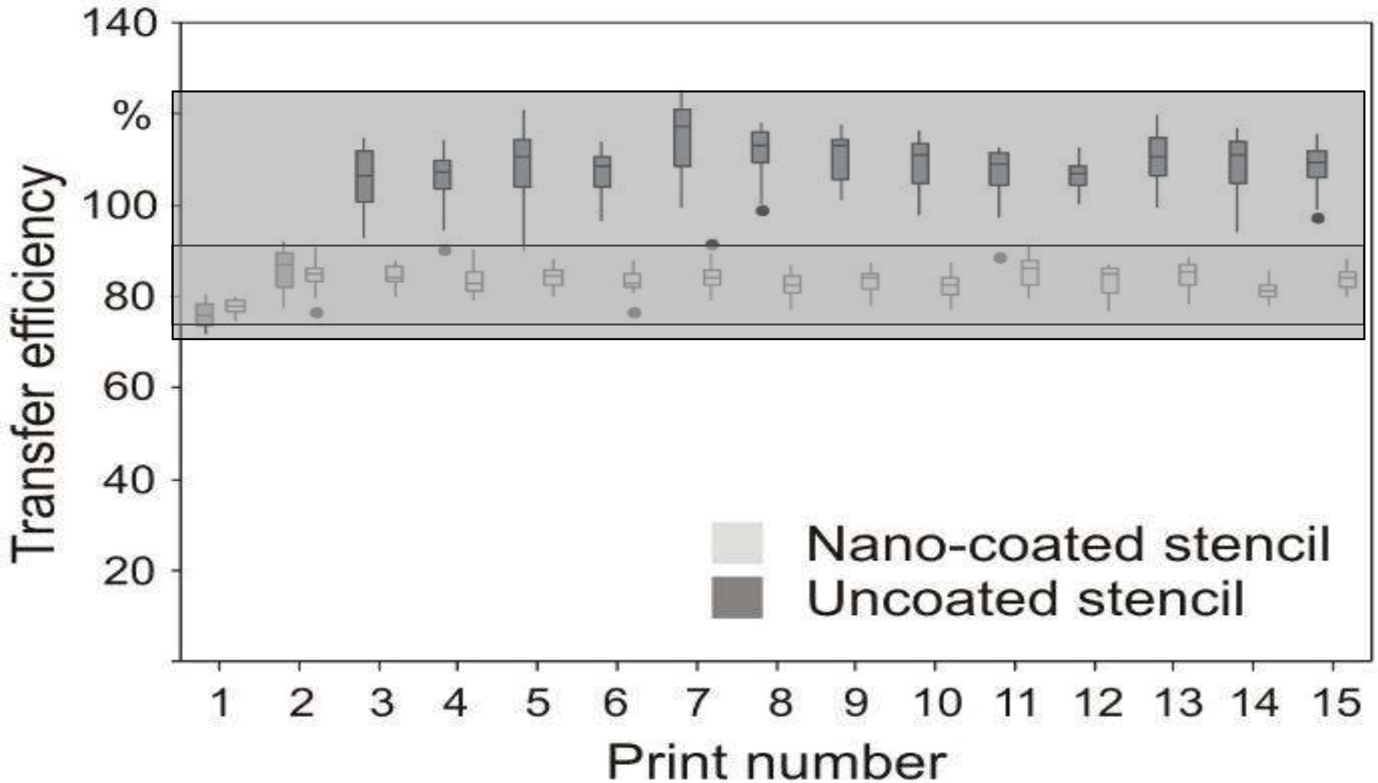


# PCB Side of the Nano-Coated Stencil after the 5th Print – Detail (Area 1)

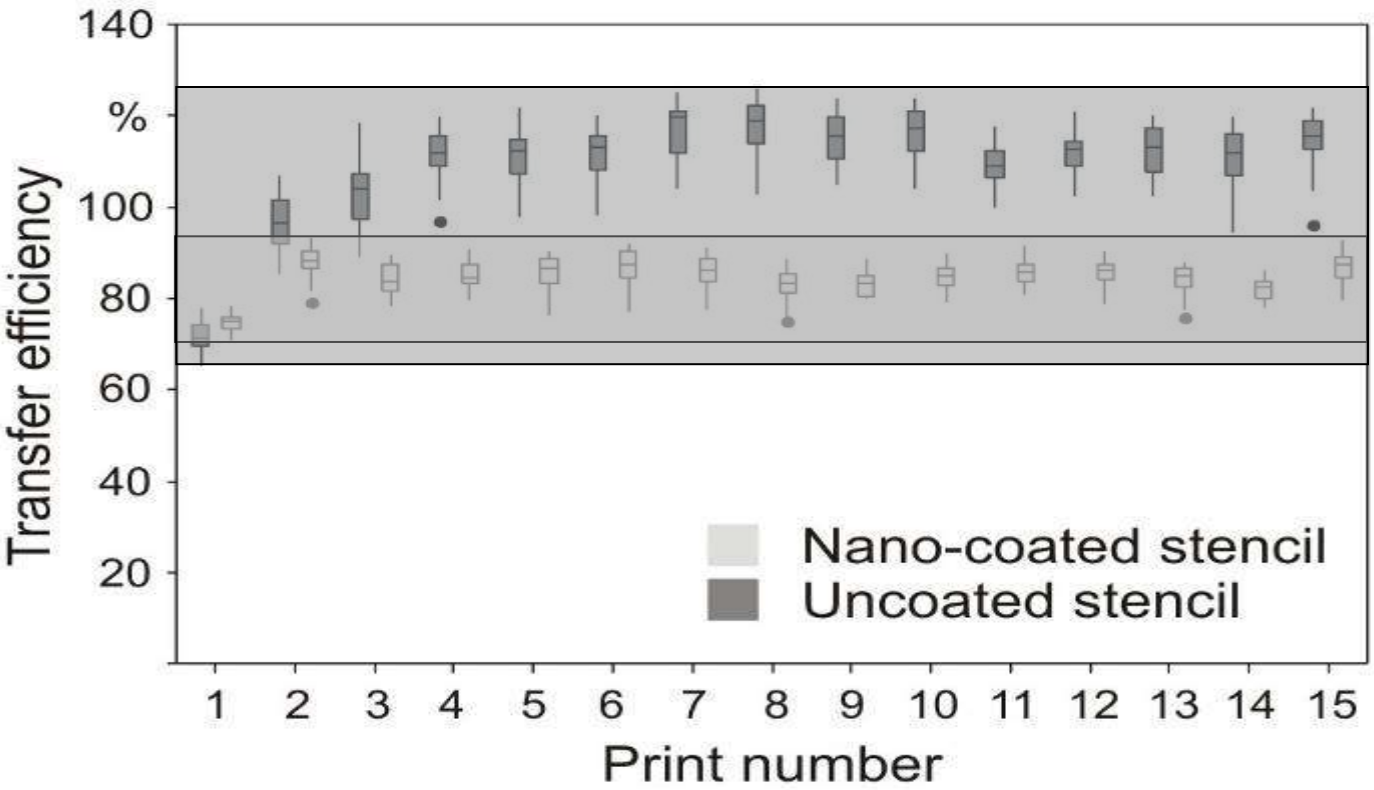


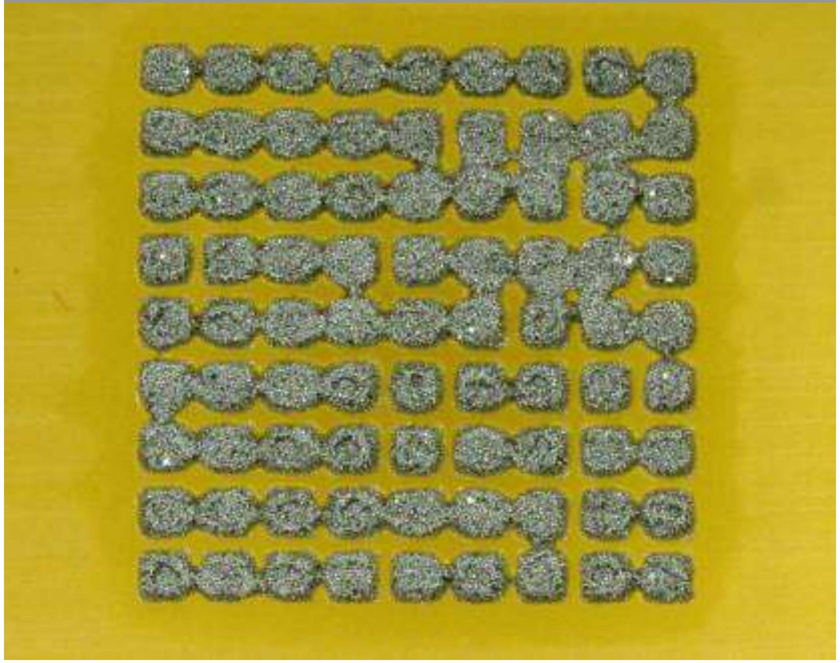
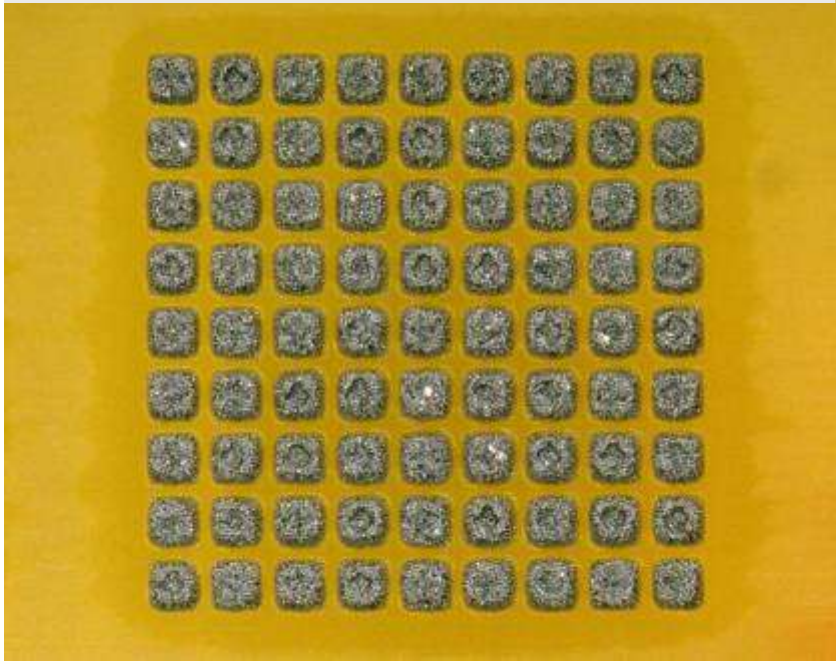
# Printing Performance of QFP0.5 (Area 1)



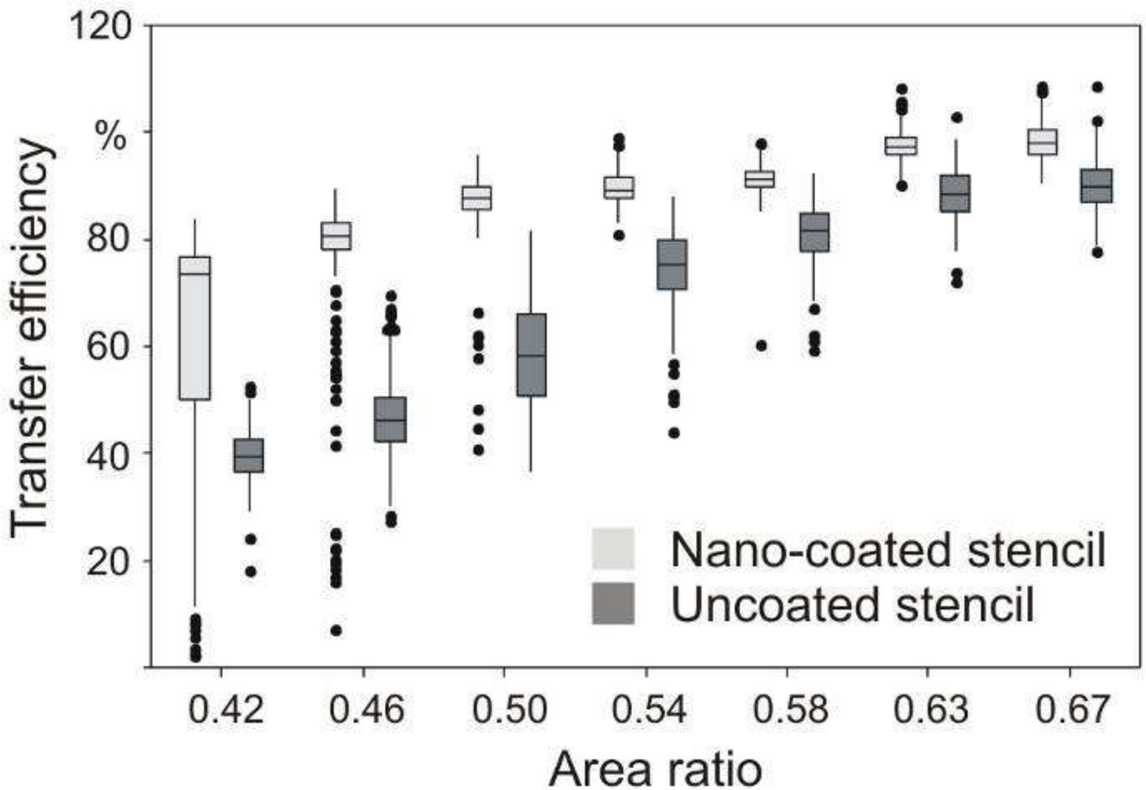
# Printing Performance of QFP0.4 (Area 1)



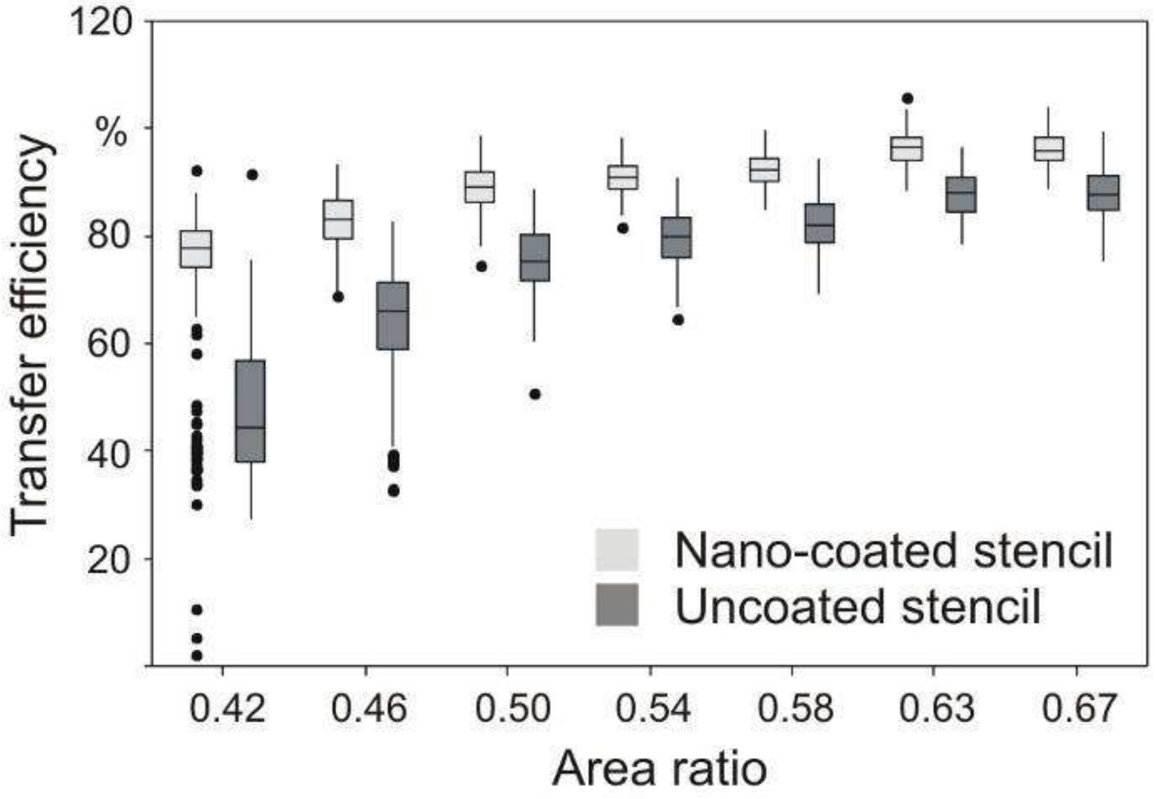
# Print Results of 400 µm Squares (pitch: 500 µm) after the 5th print (Area 3)

| Uncoated stencil | Nano-coated stencil |
|---|---|
|  |  |

# Printing Performance of Circular Apertures (Paste Type 3) – (Area 2)



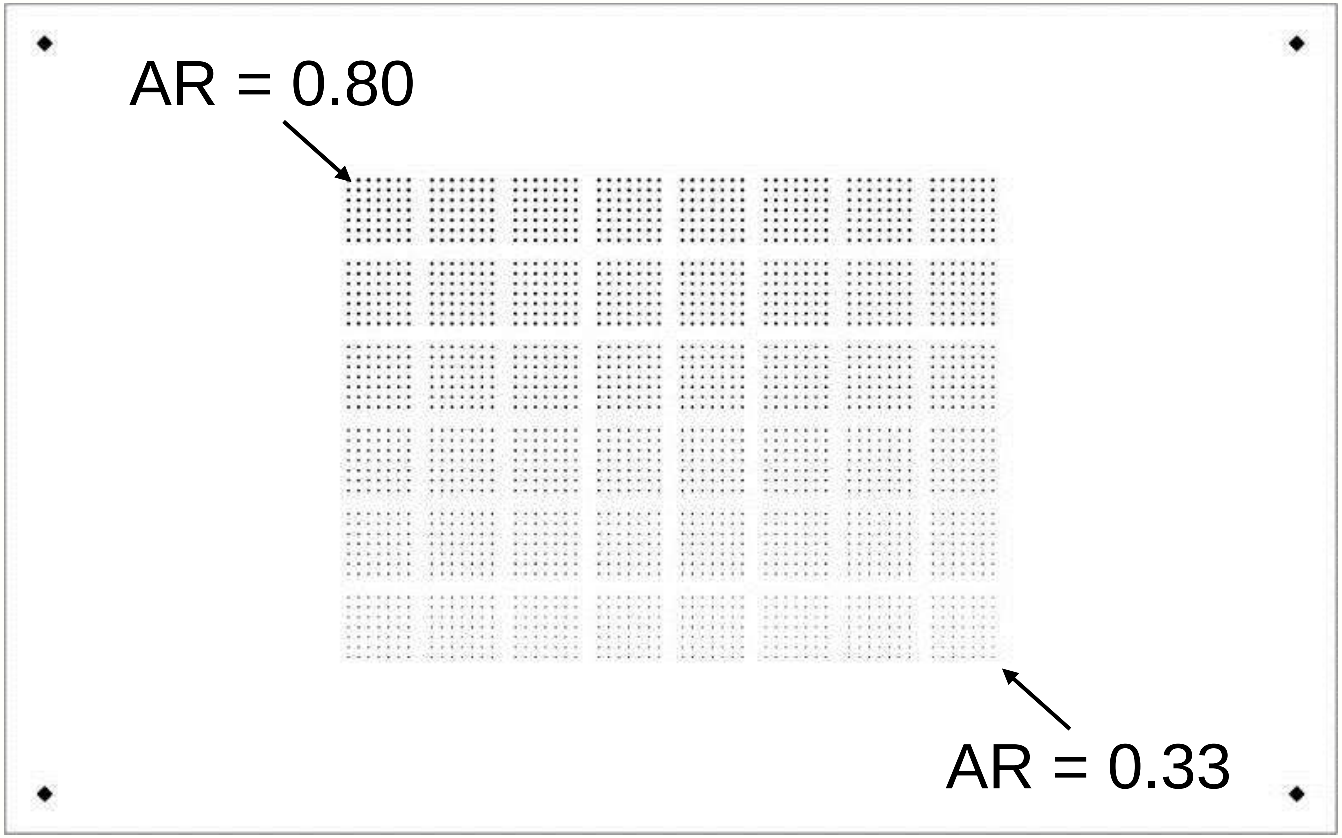
# Printing Performance of Circular Apertures (Paste Type 4) – (Area 2)



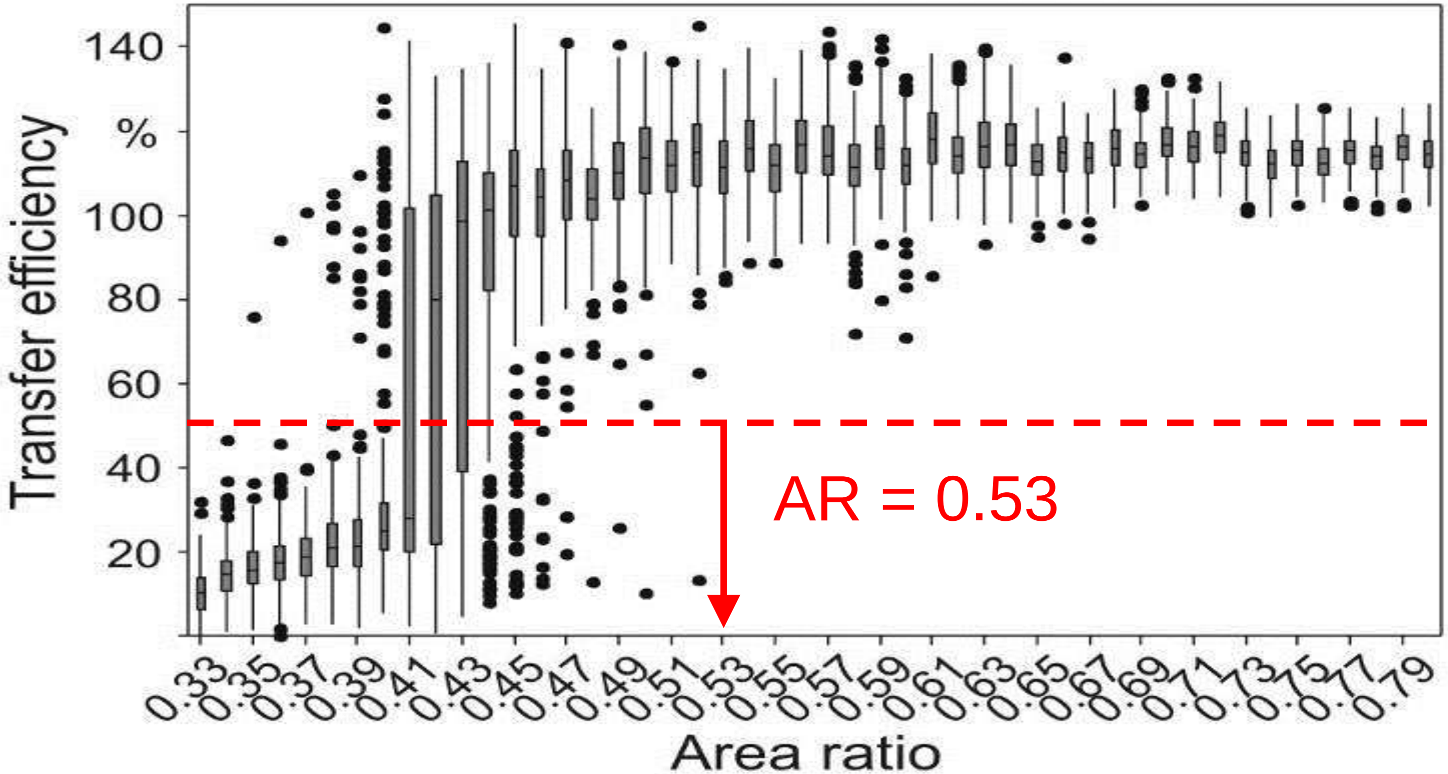
# Test Series 2

- 1 uncoated and 1 nano-coated stencil (stencil thickness 150 µm, stainless steel, laser cutting), stencil layout 2
- Solder Paste Type 4 (particle size: 20 µm to 38 µm)
- Process parameters: 3.5 N/cm squeegee force, 10 mm/s squeegee speed, 45° squeegee angle
- 8 boards printed with cleaning of the pcb side of the stencil after each print

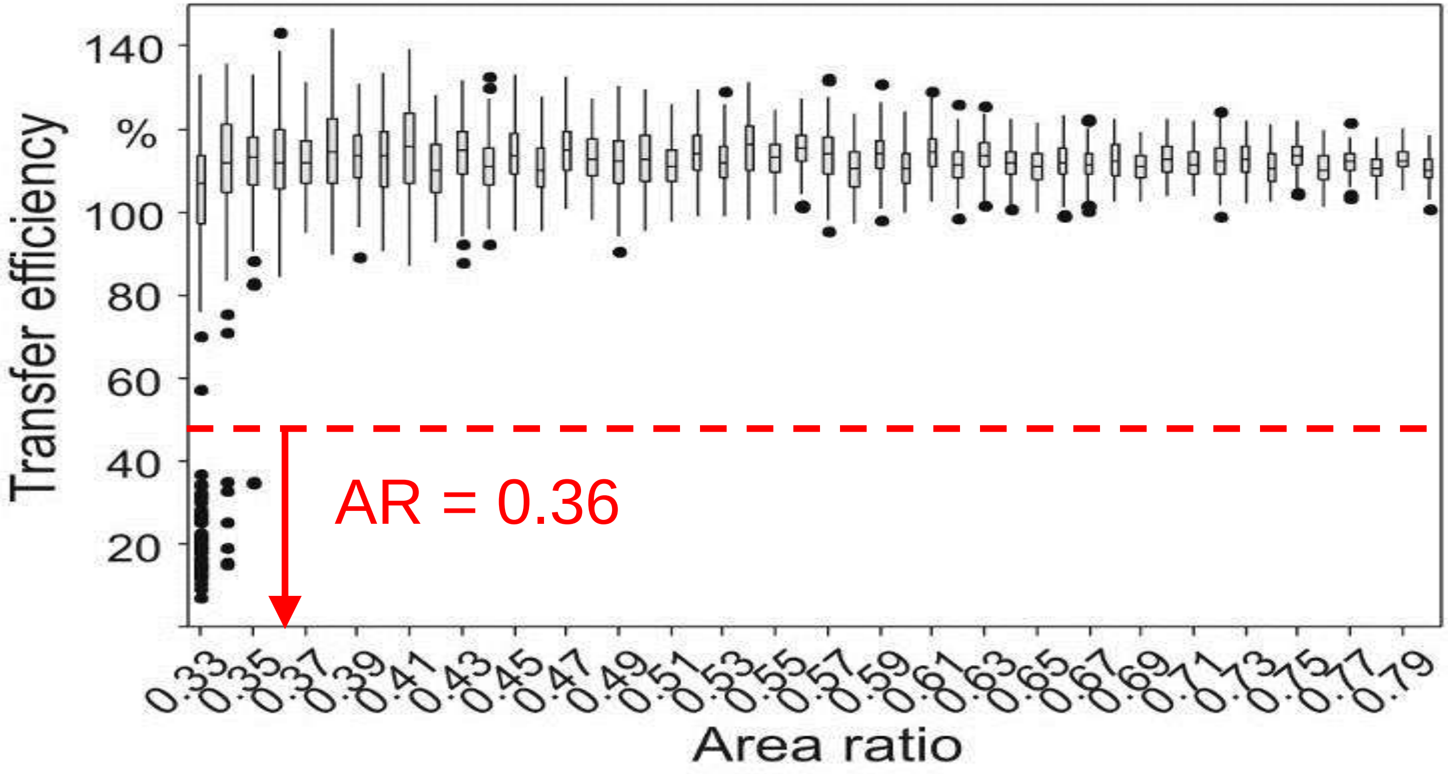
# Stencil Layout 2



# Transfer Efficiency of the Uncoated Stencil Using Solder Paste Type 4

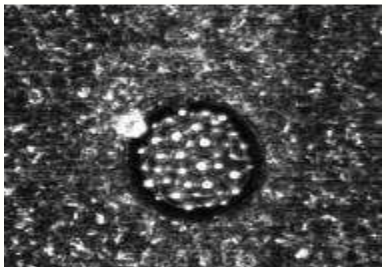


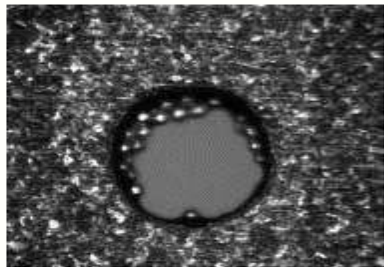
# Transfer Efficiency of the Nano-Coated Stencil Using Solder Paste Type 4

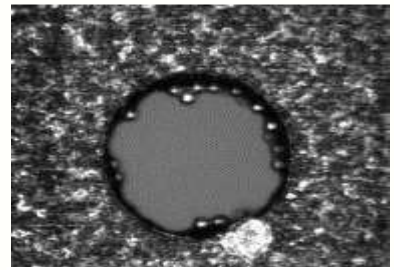


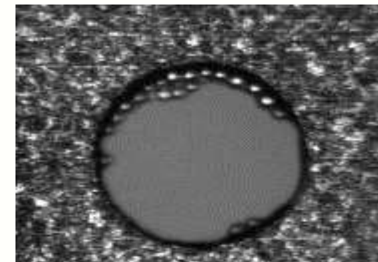
# Optical Inspection of the Stencil Apertures After the Print

## Uncoated stencil

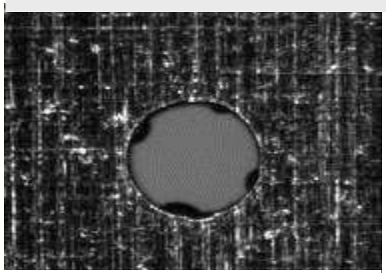

AR = 0.40

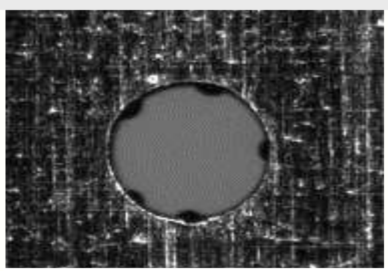

AR = 0.48

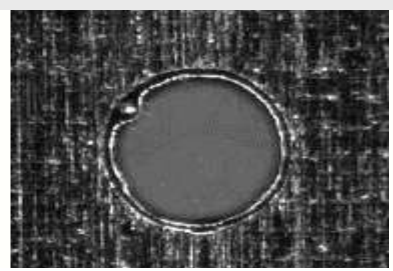

AR = 0.56

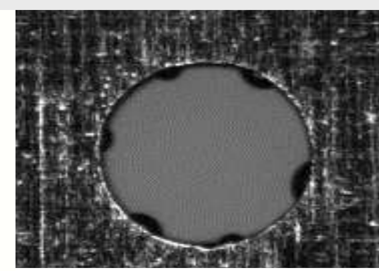

AR = 0.64

## Nano-coated stencil


AR = 0.40

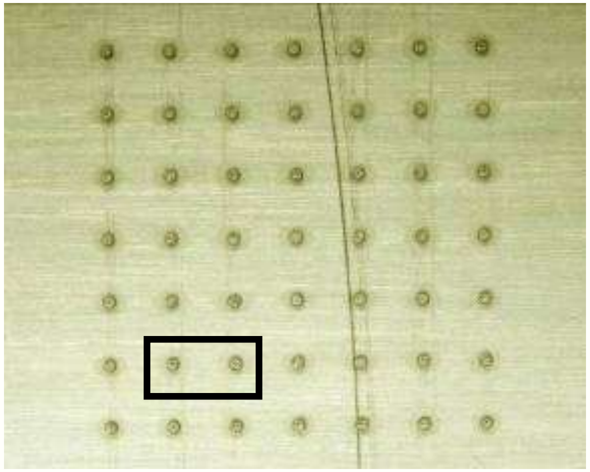

AR = 0.48


AR = 0.56


AR = 0.64

# Solder Paste Deposits Printed with a Nano-Coated Stencil

- Solder paste type 4
- Stencil thickness of 150 µm
- Area ratio of 0.36



# Conclusion

- The nano-coating of stencils improves the printing performances and sets a milestone in stencil technology
- Area ratios of 0.40 are printable due to the reduced adhesion between solder paste and stencil surface
- The cleaning frequency of the pcb side of the stencil can be reduced dramatically
- The risk of solder paste bridges at QFP structures is reduced significantly
- Solder paste deposits printed with a nano-coated stencil are more uniform