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Technical Challenges of Screen Printing Deposition for Ultra-fine Patterns

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Abstract:
This paper presents a research focused on advanced screen printing technique development. In the paper it is shown that it is possible to realize structures with line width below 50 µm at the pitch below 100 µm and ultra-thin film deposition well below 1 µm by advanced screen printing technique. Screen printing quality and its resolution relate to many factors such as the type of mesh, emulsion, paste, the thickness of emulsion and squeegee speed and its hardness. These printing parameters and many others were analyzed in the presented research project.

1. INTRODUCTION

For many years expensive connecting technologies and photolithography were used as the major manufacturing processes for the fine and complicated printed circuit boards in the electronics industry. In recent years the so called advanced screen printing process has been emerged as a response to the need to reduce manufacturing costs. It also has become driver for new technical advances in the area of screen printing machines, screens, emulsions, pastes etc. The advanced screen printing process allowing ultra-thin layer deposition and ultra-fine line printing is much simpler and cheaper compared to the traditional fabrication methods of semiconductor electronics such as photolithography, vacuum deposition techniques.

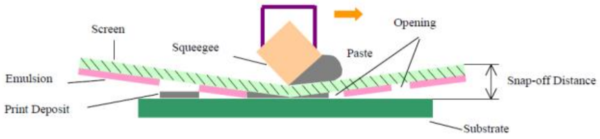

Fig. 1: Schematic diagram of the screen printing process [1].

Furthermore, the another significant advantage of screen-printing process is the fact that it is capable of building more layers including insulation materials, resistance materials, dielectric materials for capacitors and more. Screen-printing process is capable to generate electrical connection between the conductive layers without drilling and copper plating. Therefore, the screen-printing process provides great opportunities to produce low cost solutions for embedded passives with multi-layer circuits [3]. It is also possible to print on flexible or textile substrate. The basic elements of screen printing are the screen or, stencil, squeegee, paste, press bed, and substrate as shown in Fig. 1.

2. ADVANCED SCREEN PRINTING

The basic steps for advanced screen printing processes are the same as the traditional screen printing process, which may seem like a simple printing technique, but the characteristics and quality of the printed image are greatly affected by a combination of variables that can exceed to 50 what is implied in the Fig. 2. Screen printing quality parameters include thickness uniformity, mean print thickness, fine line resolution, and the number of voids. The factors that influence the screen printing quality can be grouped into 6 following categories: paste, printing process, substrate, printing machine, squeegee and screen.

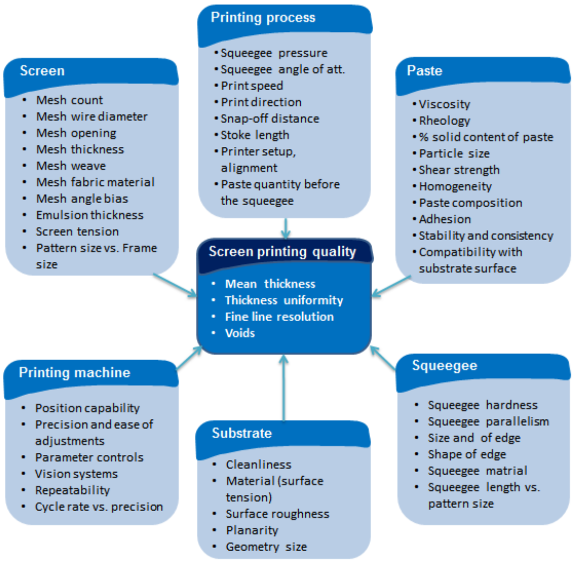

Fig. 2: Factors that influence the screen printing quality [1].

A paste material is printed on a rigid, flexible or textile substrate by screen-printing and then it is dried and fired. If necessary, supplemental screen-printing of thick film can be conducted on the conductor lines.

The key feature of the advanced process is the optimized combination of the special emulsion and paste, screen-printer and innovative screen with precision mesh. An optimized process condition generates line and space down to 50 microns or less on a thin, smooth substrate using an appropriate conductive paste. Printing machines and screen masks are already capable to screen-print down to 30 micron line and space [2].

3. RESEARCH AND ANALYSIS

This paper presents a research focused on advanced screen printing technique development for ultra-fine pitch printing, which can produce line widths below 50 µm at pitch below 100 µm and ultra-thin layer deposition well below 1 µm. In the frame of this research the effect of screen printing parameters on fine line printing was investigated in order to obtain high-resolution printing lines.

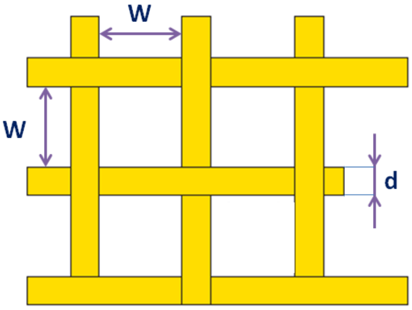

Fig. 3: Square Mesh Woven Wire Cloth.

3.1 Screens selection

For the analysis the screens with four different stainless steel wire meshes were selected as shown in the Tab. 1.

Tab.1. The overview of selected meshes.

Type of mesh	Mesh Count	Wire diameter [µm]
Square Mesh SD 45/18	400	18
Square Mesh SD 45/18 - calendered	400	18
Beta mesh 15	180 x 1400	50/20
Twilled Dutch Double Weave	325 x 2300	36/25

There were selected meshes with the thinnest wires which are commercially available. Square mesh SD 45/18, which is schematically depicted in the Fig. 3, had a mash opening (w) of 45 µm wire diameter (d) of 18 µm and an open space area (a_0) of 51%, which can be calculated according formula (1).

$$a_0 = \left(\frac{w}{w+d}\right)^2 \times 100\% \qquad (1)$$

The greater the open space area, the greater is paste passage. In order to reduce fabric thickness and create a level profile, some screens with calendered meshes were used. Calendered mesh is a product with both sides flattened at their highest point in the weave. The calendered mesh has reduced the open space area by 10 to 15 percent and its printing channel is mostly not straight. In addition to classical square mesh the filter beta mesh 15 and twilled Dutch weave meshes were selected for the analysis.

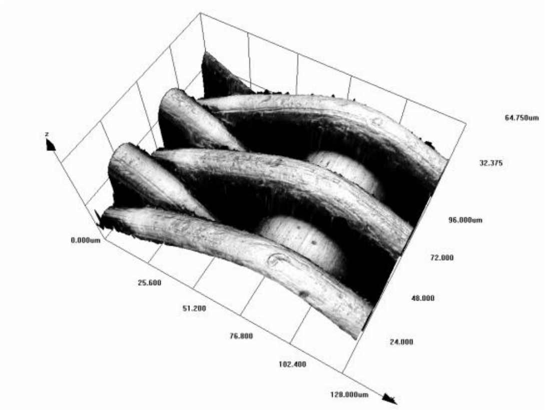

Fig. 4: Beta mesh 15 without emulsion – detailed 3D picture from the laser confocal microscope.

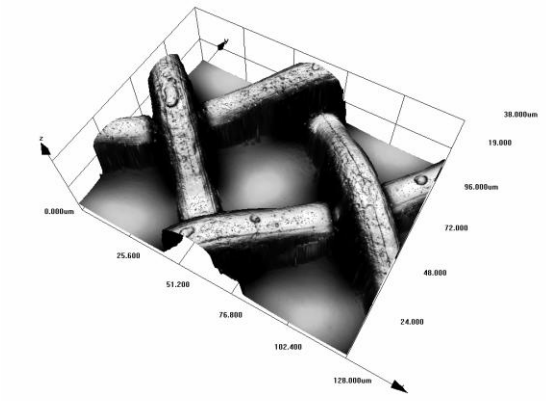

Fig. 5: Square Mesh without emulsion – detailed 3D picture from the laser confocal microscope.

3.2 Test pattern

The test pattern was design for advanced thin film and fine line screen printing experiments on ceramic and flexible substrates. The geometric and dimensional measurements, adhesion tests, electrical parameters measurement, soldering tests, bonding tests and gluing tests can be realized when the test pattern is screen printed on a sample substrate. It contains elements such as concentric circles, footprints of fine pitch SMD components, horizontal and vertical lines with 90° corners, round and square shape pads for screen printing capabilities assessment. On the top of that, the test pattern includes basic function elements such as interdigital electrodes or conductive meanders with line widths of 200, 100, 50 and 25 µm.

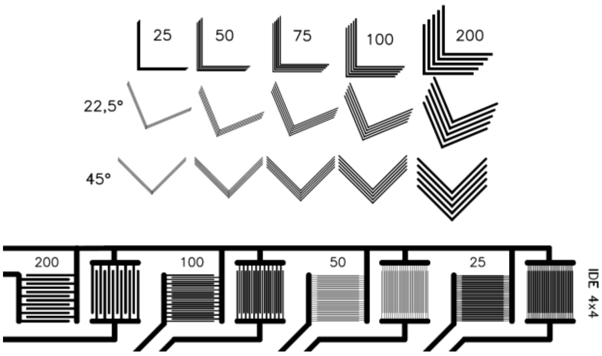

Fig. 6: Test pattern - interdigital electrodes, lines with right angle corners.

3.3 Substrate, paste and printing parameters

Many combinations of printing parameters and materials in the test vehicles have been tried to achieve high line resolution. All test samples were printed on a super-premium 96,6% Al_2O_3 alumina substrate with the dimension of 4" x 4". The alumina substrate has following parameters: warpage < 0,2 % / 100 mm length, thickness of 0,635 mm, Ra < 0,7 µm.

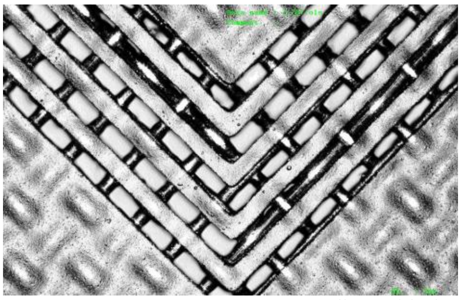

Fig. 7: Square Mesh with emulsion – 25 µm lines with sharp 90° corners, angle 45°.

The test samples were printed in a clean room either with thixotropic silver resinate or gold resinate paste with special rheological properties. The paste contained silver or gold in form of a soluble organometallic compound. The metal content was 22,5 %. The viscosity for Ag resinate paste was 20 - 40 Pas and for Au resinate paste 17 - 23 Pas. The special fine line emulsion was used. Its thickness below the screens was respectively 2 µm, 3 µm or 6 µm. The special high definition emulsion was developed with close collaboration with the KIWO company. The gold resinate paste with unique rheological properties was developed with close collaboration with HEREAUS company for this research project. The advanced screens with high precision mesh were fabricated by MCI company.

The test samples were printed on a DEK GALAXY screen printing machine with and without flooding in different printing direction. The following printing parameters e.g. squeegee pressure, squeegee hardness, printing speed, printing direction, flooding, snap off were changed during printing test in order to find optimal settings of the printer. The effect of screen printing process parameters on fine line printing were investigated through the use of statistical design of experiments (DOE).

4. RESULTS

The optimized combinations for the gold resinate paste, fine line emulsion and process conditions yielded up to 100 microns pitch traces (50 microns line/spaces) on the alumina substrates. The Fig. 8 and the Fig. 9 show examples of screen printed interdigital electrodes.

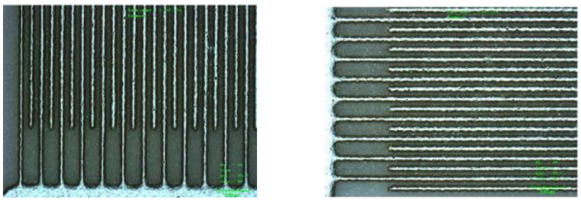

Fig. 8: Printed 50 µm horizontal IDE in horizontal and vertical direction (laser confocal microscopy - magnification 120x).

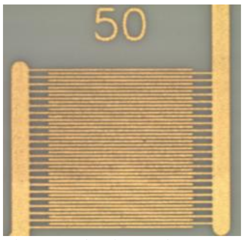

Fig. 9: Printed 50 µm horizontal IDE with gold resinate paste on alumina substrate

The average width of 50 µm lines were measured for tested samples by laser confocal microscope. The measurements were done 10 times for each sample in two horizontal lines. The average width is arithmetic mean of these values. The Tab. 2 shows very promising results of the line average widths for 50 µm lines. The majority of measured values lie inside the tolerance range.

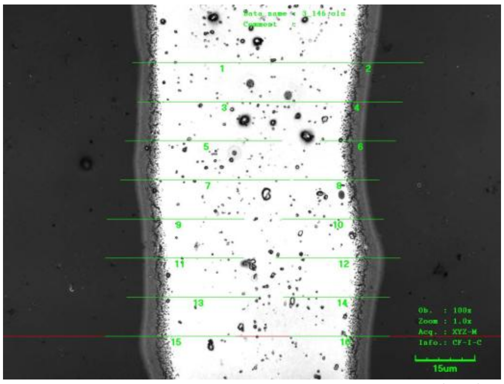

Fig. 10: Gold resinate paste thickness measurement after firing (measured by laser confocal microscopy).

Tab.2. The average width of printed 50 µm lines.

Print samples identification	Average width of 50 µm line [µm]
1T7	54,0
5T7	52,0
9T7	49,7
11T7	46,3
13T7	52,1
15T7	47,8
17T7	48,2
19T7	51,1
21T7	49,4
25T7	51,6

The thickness of gold resinate paste after printing on Al_2O_3 substrate and succesive drying, which was measured by laser confocal microscopy, was 9 µm. This thickness was achieved due to the solvents evaparation from the resinate paste and due to relatively large mesh openning in comparison to the wire diameter and the screen thickness.

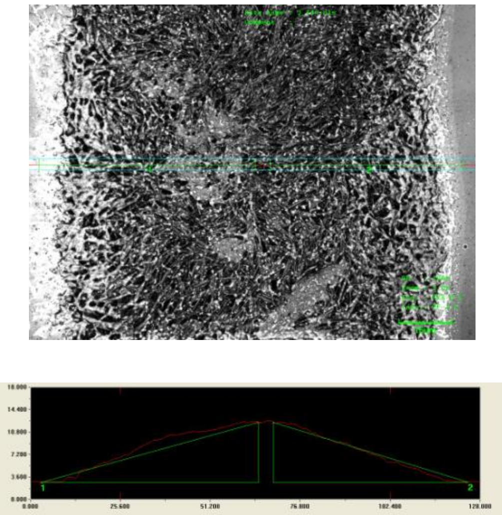

Fig. 11: Gold resinate paste thickness after printing and drying.

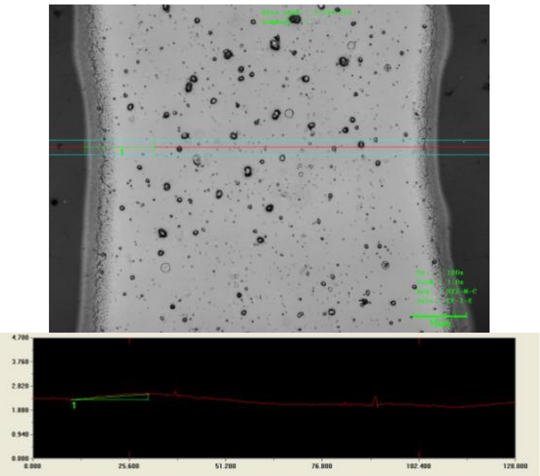

Fig. 12: Gold resinate paste thickness after firing.

Then the test sample was fired at 850 °C and after firing the average measured thickness was 0,34 µm. The thickness was measured at 16 different points as shown in the Fig. 10. The details of thickness measurement after firing are summarized in the Tab. 3. The Fig. 11 and the Fig. 12 show the detailed picture of dried and fired gold resinate paste and its thickness profile are shown in the Fig. 11 and Fig. 12 respectively.

Tab.3. The summary of gold resinate paste thickness measurement after firing.

	Fired layer thickness [µm]
Average	0,34
Max.	0,48
Min.	0,16
Range	0,32
Sigma	0,08

CONCLUSION

A goal of the presented research was to produce ultra-fine line and ultra-thin deposition by screen printing. In the printing tests it was shown, that line widths below 50 µm at 100 µm pitch and deposition thickness below 1 µm are possible to realize by the developed advanced screen printing processes.

Through several group of experiments and its statistical assessment, it was obtained a certain level of awareness to the influence factors on screen printing quality and resolution. The optimal printing settings was determined. Print samples done by screens with emulsion thickness of 6 µm showed better results. In order to find optimal emulsion thickness the printing tests with the screens with higher emulsion thickness will be carried out.
From the analysis it was found out that the filter meshes such as beta mesh 15 and twilled Dutch weave mesh are not suitable for high resolution screen printing with resinate pastes, but they can be suitable for screen printing of low viscosity inks.

The printing yield for fine lines can be improved by considering fine wire printing screen. The screens used for this work had mesh count of 400 with 18 µm wire diameter. Screen with wire diameter of less than 18 µm has bigger mesh opening and this will enable paste to go through easily. This will improve line definition and help overcome open circuits for line widths below 50 µm.

Many factors affect the quality of screen printing, which were not all involved in the presented research. Screen printing is a kind of technology involved in many fields. In order to obtain better printing quality and higher resolution, we will continue in the research and more in-depth study to be carried out.

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