Enhancement of Fine Line Print Resolution due to Coating of Screen Fabrics

Dieter Schwanke, Jürgen Pohlner
Micro Systems Engineering GmbH
Schlegelweg 17, D-95180 Berg, Germany
Phone: +49 9293/78-174, Fax: +49 9293/78-41
E-mail: dieter.schwanke@mse-microelectronics.de
Andreas Wonisch, Torsten Kraft, Fraunhofer-Institut für Werkstoffmechanik (IWM), 79108 Freiburg, Germany ;
Jürgen Geng, Plasma Electronic GmbH, 79395 Neuenburg, Germany

Abstract

In the LTCC technology, printing is the most reliable and cost effective process for line deposition on ceramic layers. An enhancement of resolution is required to realize modules in the highest frequency range which requires small lines and distances.

The fine line print resolution is limited by two factors of processing. One is paste rheology itself including viscosity particle size and thixotropic behaviour. The other factor is the screen with limitations in mesh size, wire thickness, calendring, and angle of the screen fabric in the frame.

From the viewpoint of the screen the idea was to improve the fabric by coating. It can be shown that especially in concentric circles even with fine line screens, arrays occur, where no printing happens. These paste free areas exhibit a moiré effect and follow exactly the string angle of the screen. This is caused by the crossing of the strings of the fabric which does not allow a passing of the paste due to very narrow gaps.

To facilitate the paste passing, the idea is to coat the fabric with a “hydrophobic” surface, so that the adhesion of the paste on the fabric wires becomes drastically reduced and therefore enhance the detachment. This coating is only appropriate for the bottom side of the screen and the spaces between the meshes. On the contrary the thixotropic effect of the paste requires a good adhesion to achieve the necessary shear effect. Therefore, the topside of the screen should be coated “hydrophilic” to provide a significant paste adhesion to the screen which is necessary for this shear stress. This development is supported by numeric simulation to predict the appropriate direction for these coated screens to improve the paste rheology.

Key words: Fine Line Print, Print Resolution, Plasma Coating, Hydrophobic, Lipophobic

1.0 Introduction

Low Temperature Cofired Ceramic (LTCC) is a ceramic multilayer technology which is providing a lot of advantages in comparison to other packaging technologies. as the possibilities for embedded components, different metallization systems and the relative simple realization of cavities and windows to sink e.g. MMICs even directly to the heat sinks to provide excellent heat dissipation.

This is the reason why the use of this technology is more and more favoured in RF designs. One problem is still the print resolution because printing is still the most reliable and cost effective process for line deposition on ceramic layers. Dependant on the LTCC system the current achievable print resolution is about 50 µm for curved structures and 40 to 30 µm for straight lines. For some structures e.g. for filters, dividers or couplers (depending on the level of the used frequency) even finer structures are required. This was the driving force to start this project. For this project a consortium was built, which contains a user (MSE), a coating specialist (Plasma electronic), a print screen supplier (Koenen) and a LTCC system supplier (Heraeus). The Fraunhofer Institute IWM cares about the modelling of viscosity and rheology of the pastes to accelerate improvements.

2.0 Limitation of the Print Resolution

The fine line print resolution is limited by two factors of processing. One is paste rheology itself including viscosity and particle size and its thixotropic behaviour. The other factor is the screen with limitations in mesh size, wire thickness, calendring, and angle of the screen fabric in the frame.

In Figure 1 it is shown, that even with fine line screens, arrays occur in concentric circles or coil structures, where no printing happens. These paste free areas exhibit a kind of moiré effect. These areas follow exactly the string angle of the screen. This is caused by the crossing of the strings of the fabric which does not allow a passing of the paste due to very narrow gaps. The angle of the lining is obvious; in this case 22.5°.

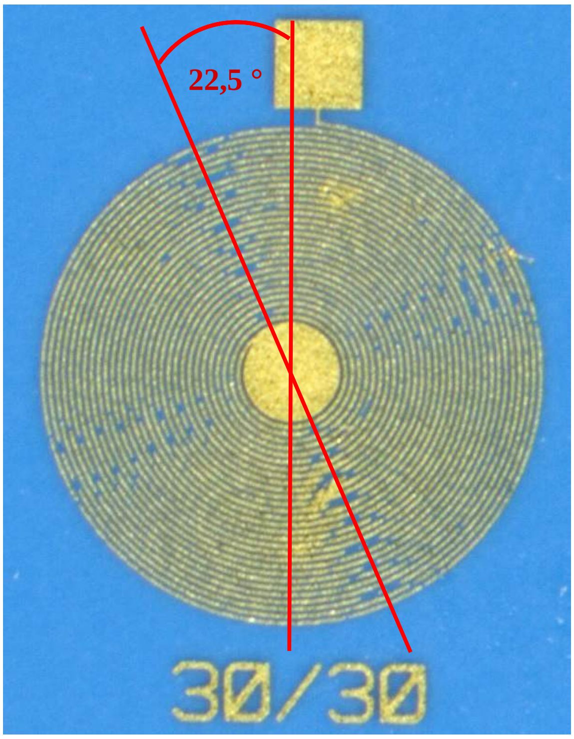

Figure 1: Moire-Effect in structures like concentric circles or coils (500mesh/18µm, cal. angle 22,5°)

Figure 2 reflects the reason of these empty areas in detail. Due to the usage of e.g. a 500mesh18 screen fabric with 18 µm wires, calendered, areas are occurring in specific angle where wire crossings are closing the small structures in the emulsion. In these areas the openings in the emulsion are blocked and the paste is not allowed to pass. Either the paste rheology is not sufficient to achieve a viscosity level which allows the paste even to pass extremely narrow gaps or the adhesion of the paste on the screen fabric is to high or both.

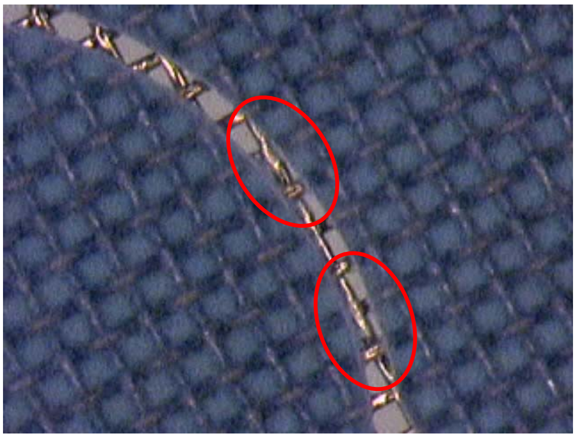

Figure 2: Wire crossings in the screen fabric avoiding the passing of pastes

This description shows that printing of straight lines is much easier and even a higher print resolution can be achieved compared with curved structures (Example Figure 3)

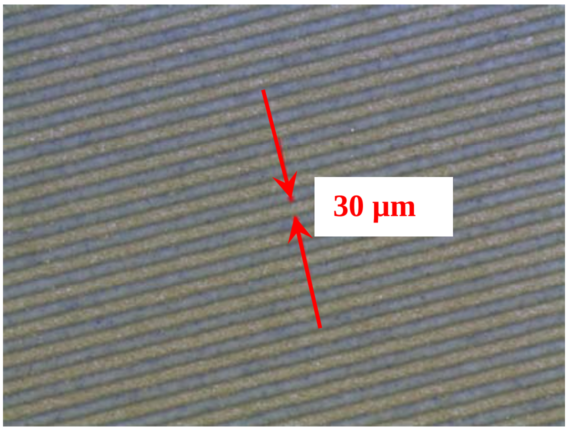

Figure 3: Printing of 30 µm straight lines and spaces

3.0 Potential to Enhance the Print Resolution

These observations led to the consideration to facilitate the passing of the paste through these gaps by coating the fabric with a “hydrophobic or lipophobic” surface, so that the adhesion of the paste on the fabric wires becomes drastically reduced and detachment is enhanced.

But further considerations led to the thought that this type of coating is only appropriate for the bottom side of the screen and the spaces between the meshes. On the contrary the thixotropic effect of the paste requires a good adhesion to achieve the necessary shear effect. Therefore, the topside of the screen should be coated “hydrophilic” to provide a significant paste adhesion to the screen which is necessary for this shear stress.

Figure 4 is showing the principle of the used coating machine for the screen fabric coating. Due to this coating the surface enhancement for improved paste depletion should be achieved

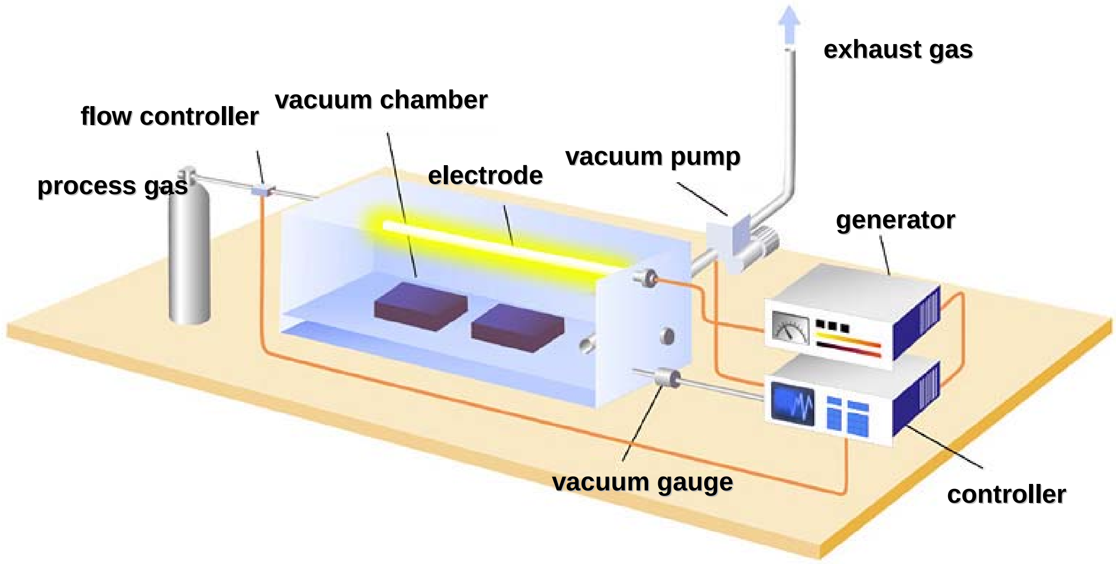

Figure 4: Machine Principle of a CVD Plasma Coating apparatus (by courtesy of Plasma electronic)

4.0 Principle of surface coating mechanism

The principle of the surface coating mechanism is as follows: The low pressure plasma is a vacuum process. Reactive gases are introduced into an evacuated chamber and ignited (ionized) by high frequency electrical power (MHz, GHz, kHz). Active species produced in the discharge react with the work piece surface to alter its characteristics (Figure 5).

By means of plasma polymerization thin layers in the µm-rage can be deposited in the gas phase. The selection of the monomers to be deposited determines the modification of the layer to certain defined properties, like being hydrophilic, hydrophobic, adhesive etc. The deposition of AQUACER©-, CARBOCER© - (Diamond-Like-Carbon = amorphous diamond-like layers) on different materials are particular applications in the field of plasma polymerization Figure 7.

There are two different types of coatings in test for the screen coating. The one is LIPOCER© and the other is CARBOCER©. Both types of coatings are registered trade marks of Plasma electronic GmbH

In the following CARBOCER© will be called DLC, LIPOCER© hydrophobic coating and AQUACER© hydrophilic coating.

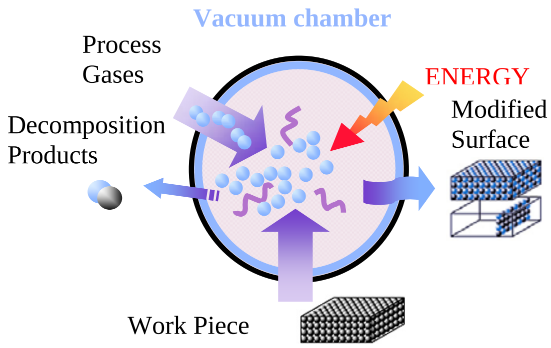

Figure 5: Principle of surface coating mechanism

LIPOCER© provides any surface with a durable hydrophobic surface for minimum wettability and adhesion. Different materials like polymers, rubber and metals can achieve water contact angles more than 110° after coating.

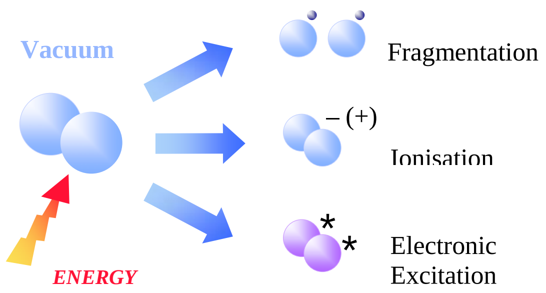

Figure 6: Elemental processes (e.g. oxygen plasma)

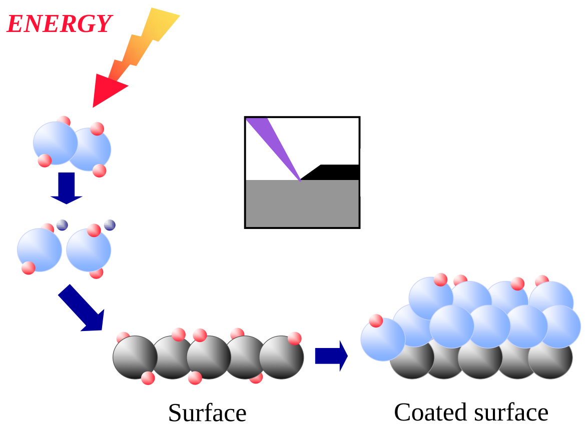

Figure 7: PECVD-coatings (plasma polymerisation)

CARBOCER© - coatings are extremely hard and show ultra low friction. On the other hand, they are flexible and corrosion resistant. Modified DLC (Diamond-Like Carbon) - coatings improve the lifetime of mechanical parts under wear significantly. In addition, some applications are only possible with the aid of such a coating. Examples are hydraulic devices, parts of injection moulding machines etc. The metal adhesion on the tool surface is minimized by the metal-free CARBOCER© - coating.
Processing below 100°C allows for the coating of temperature sensitive materials like special steels and polymers.
The coating activities have been started with the Diamond-like carbon (DLC) coating. Initially a relatively poor adhesion of the cathodic DLC-layers on the screen fabric has been detected. This problem was solved by implementing an additional cleaning step in the plasma. In addition the processing temperature was lowered in a range that simultaneously the UV curing emulsion which will be structured for the print pattern, could be coated.
At the beginning of the project it was not clear whether the DLC-Coating or the hydrophobic coating is more appropriate to the paste behaviour.
Initial tests showed that most pastes are showing a polar character so that a coating with hydrophobic characteristics like LIPOCER© is more appropriate.

For the investigation of the coating behaviour in conjunction with the reference paste and the modified surrogates a rheometer was fitted with steel plates which could be coated in different ways. With this tool the efficiency of the coating on one side and the efficiency of the paste modification on the other side could be investigated.

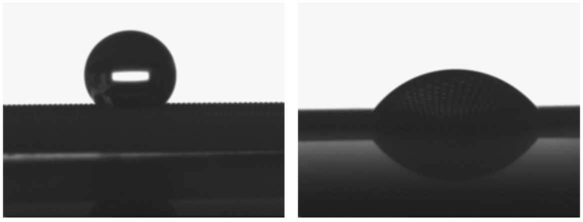

Figure 8: Wetting angles on hydrophobic coated surface (left) and uncoated surface (right)

5.0 Coating Effects on the Screen Fabrics

As mentioned, the idea behind this development project was to provide a surface on the steel wires of the screen fabrics which shows a kind of "Lotus Effect ®" for the paste.

On the bottom side of the print screen and especially on the inner side of the meshes the adhesion of the paste should be reduced whereas on the topside of the screen still an adhesion should remain to maintain a shear stress. Due to the rheology of the pastes this shear stress is necessary to lower the viscosity of the paste during shearing which is necessary to force the paste to pass the fabric, when the squeegee is sliding over the screen (thixotropy).
This effect is the basis of screen printing. The thixotropy of the paste is the cause that after passing the screen the viscosity increases in a more or less good designed time frame, which avoids, that the paste will spread out after the print process. To achieve an optimized interaction between coated surface and paste, an adaption of the paste rheology has to be done.
To keep this adhesion on the squeegee side of the screen the screen either should not be coated on this side or even better it should be coated with a hydrophilic surface e.g. with a hydrophilic coating.

The major problem of this processing is, that LIPOCER© is a PECVD vapour phase process, so that a simple covering is not sufficient to protect the opposite side of the screen. To achieve a good covering, tests are in progress, where either a polyimide adhesive tape or a blue tape as applied in the semi conductor industry will be used.
The double sided different coated screens have been tested with a wetting angle gauge. Surprisingly there was even with different measuring methods (ACA=advancing contact angle and RCA=receding contact angle) no difference was gaugeable.

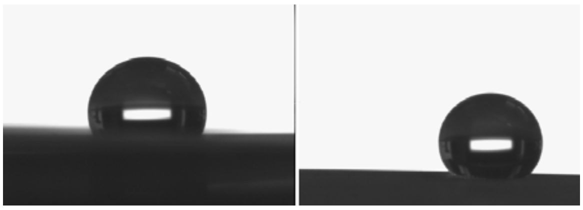

Figure 9: Wetting angles on hydrophobic/hydrophilic coated screen. LIPOCER© hydrophobic (left) and AQUACER© hydrophilic, protected with blue tape.

Nevertheless, to get an appropriate method for the detection of differences, a drop of water was put on the different surfaces. When the screen was lifted on one side, it was found that the angle until the drop starts running is significantly different. The angle of the lifted screen is for the hydrophilic coating more than two times higher than for the hydrophobic.

6.0 Initial Results of the Coating Activities

To test the practical behavior of the coated screens several small screens without any structuring have been coated. On these screens printing tests have been done to get qualitative information about the efficiency of the coating.
In Figure 10 a picture is shown of one of these experiments. The best results with the strongest improvement in the detachment of the paste from the screen fabric

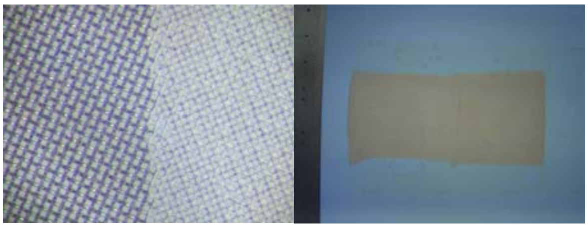

Figure 10: Simple printing test to observe the qualitative paste release from the coated screen fabric

The initial tests showed that the best paste detachment from the screen fabric was provided with a hydrophobic coating. Also the FhG IWM coated several screens but the improvement in paste release was marginal although tests of the wetting angles showed similar results as on the one from Plasma electronic. Figure 11 demonstrates how a drop of water behaves on coated screen fabrics. On an uncoated screen the water drop will seep through the fabric.

Figure 11: Drops of water on different coated screens. Left side CARBOCER©; right side FhG IWM coating No. 134640

On the right side one type of coating from FhG IWM is shown. The wetting angle on that coating is higher as on the CARBOCER© coating but it is very similar to the LIPOCER© version, although the paste release behaviour is different, as the printing tests show.

7.0 Simulation of Rheology Effects

To achieve a possibility for a faster development of the improved paste rheology the FhG IWM got the task to simulate this paste rheology.
The Fraunhofer Institute für Werkstoffmechanik (IWM) is using for its modelling activities a method called SPH (Smoothed Particle Hydro-dynamics) which is related to the DPD simulation processes (Dissipative Particle Dynamics) and comes from environment of astrophysics. It is a particle based method for the resolution of the Navier-Stokes-Equation and was already used for a variety of flow mechanic applications [1, 2]. The fluids to be simulated are divided in fluidic elements (particles) in this method.

With this method the FhG IWM will simulate the pseudoplasticity (reversible lowering of the viscosity with increasing shear stress) and the thixotropy (variation of the viscosity in a timed delay of the shear stress). The SPH method is in this way enhanced by IWM that both effects can be simulated.

The flow behaviour of the paste during the movement of the squeegee is an important factor for the screen printing process. During this movement of the squeegee a whirling of the paste happens which leads to high shear stresses. This leads to a lowering of the viscosity. With the lowered viscosity the paste is able to pass the screen meshes. Figure 12 is showing a simplified model of paste, squeegee and a support which is used to simulate the areas with the highest shear stresses.

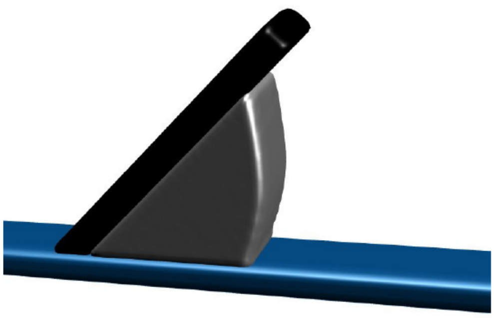

Figure 12: Model of paste**,** squeegee and support for simulating areas of the highest shear stresses

With a Newtonian model paste (viscosity 100 Pas) this simulation was started. After a short period a whirling develops as expected (Figure 13) and the area with highest shear stress is shown in Figure 14.

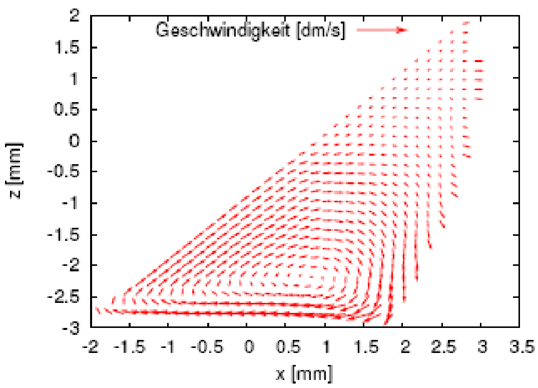

Figure 13: Steady state flow profile (velocity/height)

Simulations with the more sophisticated thixotropic paste model show that different screen surfaces impact the shear rate and thus the viscosity distribution inside the paste. Two different wetting conditions were simulated: an angle of 65° (Figure 15) and an angle of 105° (Figure 16). Here a lower structural parameter is equal to lower viscosity.

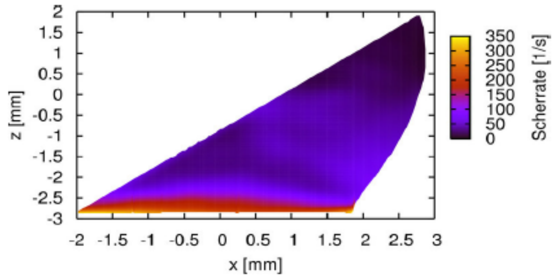

Figure 14: Shear rate distribution during squeegee movement (velocity vs. height color shear rate)

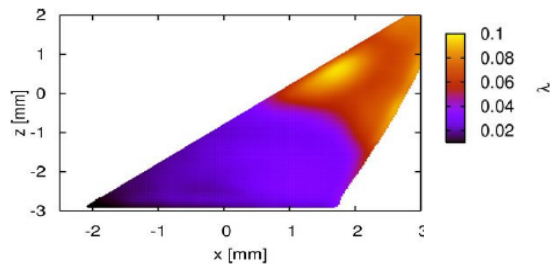

Figure 15: Steady state structural parameter λ for a screen surface with a wetting angle of δ=65°

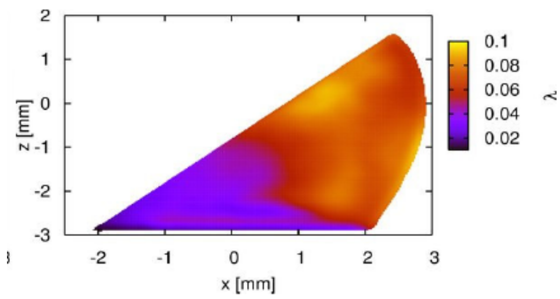

Figure 16: Steady state structural parameter λ for a screen surface with a wetting angle of δ=105°

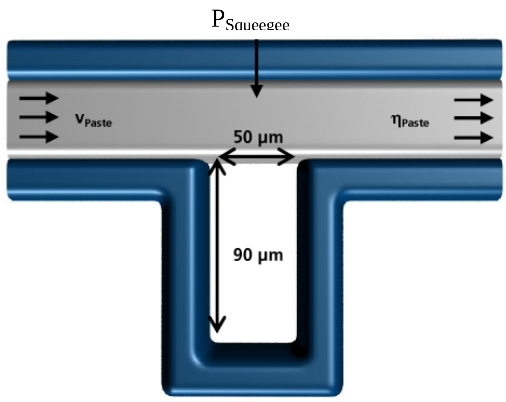

Figure 17: Chosen geometry of a screen mesh for the simulation of the filling of single meshes

So the simulation results in the both figures above are showing that the surface condition of the screen has a significant influence on the paste behaviour In the Figure 17 the geometric model of a screen mesh is shown. This is used for the simulation of the filling of single meshes. In addition to the paste movement a piston which is causing a pressure of 100 kPa is added. This should simulate the pressure of the squeegee during printing.

The paste is moving with constant velocity, taken from the simulation of the squeegee movement, over the gap in the screen (mesh opening). In addition a constant pressure of 100 kPa is applied, the viscosity is fixed with η_{Paste} = 10 Pas according to the viscosity at the lower areas in the squeegee simulation. The resolution is 5 µm.

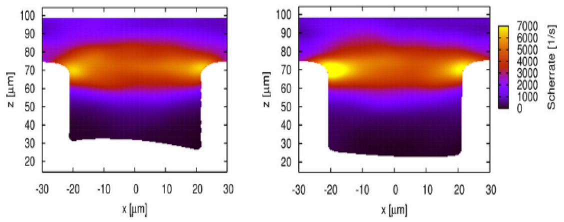

Figure 18: Distribution of the shear rates during gap filling; wetting angle left 65°, right 105°

A reduction of the paste adhesion on the screen surface accelerates the filling process. Figure 18 shows that the highest shear rates of up to 7000 1/s are achieved at the edges of the meshes.

As a further process step the detachment of the paste from the fabric was simulated by using the same parameters as before. The screen is pulled up with a constant velocity to simulate the snap-off. The screen shows different wetting angles again. Results see Figure 19.

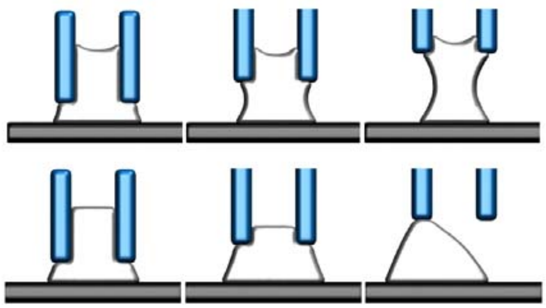

Figure 19: Paste detachment from the screen fabric with different wetting angles (upper row 50°, lower row 105°

The detachment from the fabric with the higher wetting angle is significantly improved compared to that with the lower one, but the spreading on the layer is a little bit higher. The maximum shear rate at the exit is with 300 1/s explicitly lower than at the entrance (7000 1/s)

8.0 First Printing Results

For testing the real influence of changing the wetting angle on the printing behaviour, test patterns were generated with a variety of pitches in different resolutions as lines and as curved structures (see Figure 20)

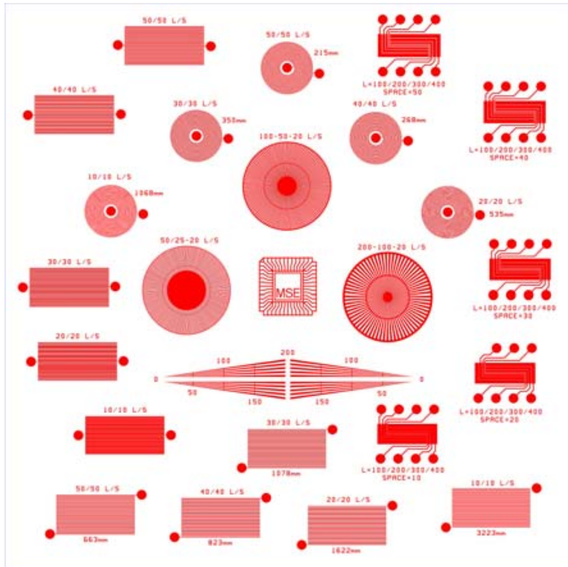

Figure 20: Testpattern designed by MSE and realized by Koenen on a screen 400mesh 18 µm wire calendered, 22,5° fabric agle, Type 10 frame, direct emulsion 13 µm hydrophobic-coated

This test layout contains straight meanders with lines and spaces 50 µm to 10 µm as well as coils with the same resolution. In addition there are structures with

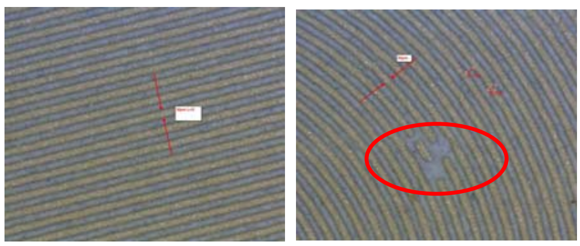

Figure 21: Printing results at 30 µm with reference paste on coated screens. Straight lines are showing good print results (left); curved structures still indicating opens (right)

broad lines and small spaces and tapered structures in a range of 200 µm to 10 µm. The printing results show that straight lines can be printed with the reference Ag paste from Heraeus down to 30 µm lines / spaces with quite smooth edges (Figure 21).
Whereas the printing of curved structures is still indicating opens at the areas of the wire crossings. Although this effect is diminished the initial goal is not reached yet.

It is expected that different coatings on both sides of the screens can improve the print resolution and also paste modification will cause improvements.

9.0 Problems and Possible Solutions

The final goal of the project (20 µm resolutions) is currently still a problem but the reason is not caused by the coating. The real cause of this effect (Figure 22) is the small size of contact points between emulsion and fabric on a 400mesh18 screen.

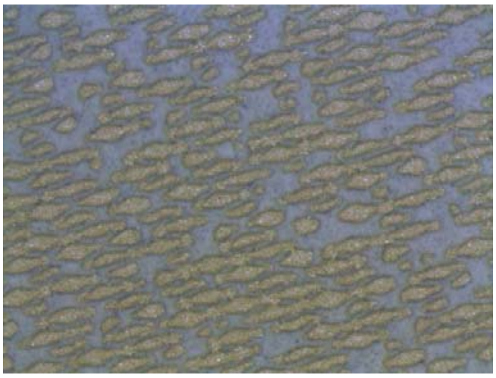

Figure 22: Print results for 20 µm lines / spaces. No homogenious printing possible due to the displacement of the structured emulsion

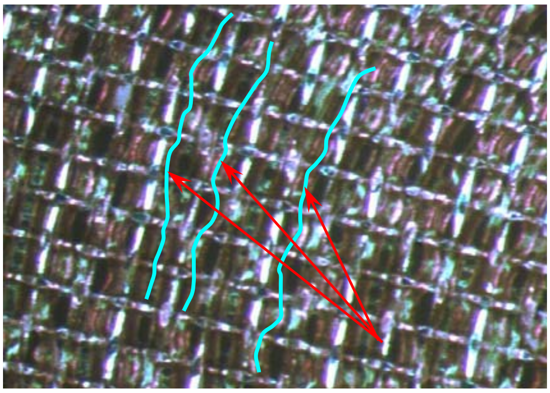

Figure 23: Dislocated emulsion of 20 µm structures

In the next runs, screens with higher number of meshes will be tested and also with thinner wires. Koenen is currently researching the market.
In Figure 23 it is obvious what causes this catastrophic print behaviour is. The arrow is pointing to the area where the 20 µm emulsion lines are displaced from the screen. Some times this is even visible before the printing process right after structuring the emulsion. Koenen is currently working on a solution which will be an activation of the wire surface and an improvement of exposure of the emulsion

10.0 Summary and Conclusions

The coating of screens is possible and also the emulsion will not be destroyed during this process. The right coating type was found and the still initial tests are showing that this coating provides a positive effect. These observations are supported by the numeric simulation results. Both the real test results and the simulation show that the consideration to use different coatings on the upper side and lower side of the screen due to the paste rheology is correct. Investigations for different coatings on both sides are ongoing. The adhesion of the emulsion has to be improved. An additional enhancement of line resolution will be provided by an enhancement of the paste rheology.

This project is in halftime now so that the probability to achieve the goal to improve the line resolution to 20 µm in screen printing on LTCC is given.

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