Screen Printing Imaging Technologies for Fine Features in Printed Electronics Applications

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Abstract

This paper investigated the commercially available imaging technologies for screen printing to produce fine feature size less than 50 microns. The technologies discussed include emulsions such as direct emulsion, capillary film, and mesh alternative such as metal plating. The mesh quality affects the feature size. There were three types meshes examined, which include calendered stainless steel mesh, electroformed mesh, and stencil. The results showed that the mesh structure affects the size of fine feature greatly. Another factor is the type of emulsion being applied. The emulsion with smaller particle sizes are able to hold smaller features. The orientation of the feature to the mesh also plays important role. To achieve uniform feature width, the features cannot be placed with the same angle to the mesh. The results suggested that woven structure impacts the ink flow after the ink is pushed through the mesh. Electroformed mesh can produce features with better edge definition than woven mesh.

Introduction

Screen-printing is one of the most versatile printing processes for transferring inks and functional coatings on large variety of substrates. The applications of screen-printing range from artistic applications to large-scale industrial sector; from extremely small components to very large panels (Kipphan, 2001).

Besides the common applications, such as printing on textiles and rigid substrates with graphics, screen-printing is widely used in the semiconductor industry as the process for manufacturing solder bumping, die attachment, and other applications.

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Screen-printing is also used widely in manufacturing membrane switches for polymer thick film conductors and dielectrics. With the developments in mesh and emulsion technologies, screen-printing has demonstrated the advantages over other conventional processes employed in the semiconductor industry in terms of reducing cost and improving productivity. The new technologies allow screen-printing to be a production process with high throughput, high accuracy, and high repeatability.

Screen-printing has been identified as one of the vital printing processes for printed electronics. The material development has brought new challenges for screen-printing. Screen-printing as a versatile printing process can be utilized for applying functional inks with wide range of viscosities, for delivering ink film with wide range of thicknesses, and for outputting features with wide ranges of width and spacing requirements.

With most applications developed for screen-printing, the main characteristics are typically associated with low resolution and thick ink films. Although screen printing is versatile enough for many applications, the nature of screen-printing, such as using a woven mesh and squeegee, makes screen printing one of most complicated printing processes.

Many new applications, such as, touch screens require fine printed conductive traces which can reduce the size of the screen border and produce bigger display area. For such application, less than 50 microns width of conductive traces are desired. Traditionally, screen printing is not the best option to print such small features.

To print small features, mesh is not the only obstacle, there are more than fifty variables involved during mesh and frame manufacturing, imaging, and printing (Hoff, 1998). To optimize printing quality for functional materials, there are many factors to be taken into consideration, which include mesh/emulation characters, printing conditions, and ink rheological properties.

This research work focused on possible imaging technologies including mesh options, emulsion choices, and mesh alternatives, which may impact the production of smaller features when printing with commercially available conductive inks.

Experiments

Mesh options

To print thin ink films and fine features require the screen mesh has the following features: 1) thin mesh threads so that the woven mesh has low mesh thickness; 2) thin emulsion thickness so that it delivers low wet ink film thickness; 3) high resolution emulsion for holding fine features.

The meshes chosen for this project were from Dynamesh (http://www. dynamesh. com). The suggested meshes and the characteristics of the meshes are listed in the following table (**Table 1**).

Mesh Type	Calendered	Mesh Count	Thread Diameter (μm)	Mesh Thickness (μm)	Open Area (%)
Stainless Steel HS-380	Yes	380	14	14	62%
Stainless Steel MS-640	Yes	640	15	17	39%

Table 1: *Mesh choices with different mesh counts, thread diameters, mesh thicknesses, and open areas.*

These two meshes have very thin threads. In theory, the mesh thickness is twice as thick as the thread diameter. After calendaring, the thickness of the mesh is greatly reduced. This helps to reduce the wet ink film thickness after the ink is pushed through the mesh.

The HS-360 mesh has bigger open area then the MS-640 mesh. The contact area of thread-to-thread is smaller for the mesh with bigger open area. This may potentially reduce the interference with the threads for producing finer features.

Emulsion options

Another factor of achieving low ink film thickness is to lay down thin emulsion over the mesh. However, if the emulsion is too thin, after the emulsion is dried, it may leave a relatively rough surface on print side for contacting the substrate. The negative impact of rough emulsion surface is that it will produce features with poor edge definition. The emulsion options are listed in the following table (**Table 2**).

Emulsion Type	Direct Emulsion AE-1 (Prototype)	Capillary Film CV1
Thickness (EOM) (μm)	5-35	2,8,13,18,23
Minimum Line Feature (μm)	20	50
Advantage	Good gasket, sharp edges	Good paste transfer
Disadvantage	N/A	Durability is low

Table 2: *Emulsion options include direct emulsion and capillary film.*

To benefit from low particle size, the prototype product AE-1 direct emulsion can hold line width around 20 µm after exposure. At the same time, AE-1 emulsion can be applied at various thickness to achieve better smoothness needed for better edge definition. The capillary film has consistent thickness. In many cases, capillary film could produce smoother emulsion then direct emulsion. The meshes for the experiments were coated with both emulsions with controlled emulsion thickness of 8 µm.

Another factor of mesh structure is the angle of mesh to the frame. The common setting is to set the mesh with 22.5 degree of bias to the frame for better ink release. For this study, meshes were also being place with 90 degree (without bias) to the frame to understand the impact of mesh bias to imaging quality.

A test form (**Figure 1**) was developed to expose the selected mesh and emulsion. In this form, there are positive traces, negative traces, and traces at different angles. These traces were measured later to learn the imaging quality.

From the choice of meshes, emulsions, and biases, several comparisons can be drawn: 1) the emulsion technologies on the meshes with different open areas, how the emulsion technologies affect the smoothness of emulsion on the print side, how the emulsion technologies affect the minimum feature width held on the screen; 2) the impact of mesh bias to feature print quality; 3) the interference of threads to the feature print quality.

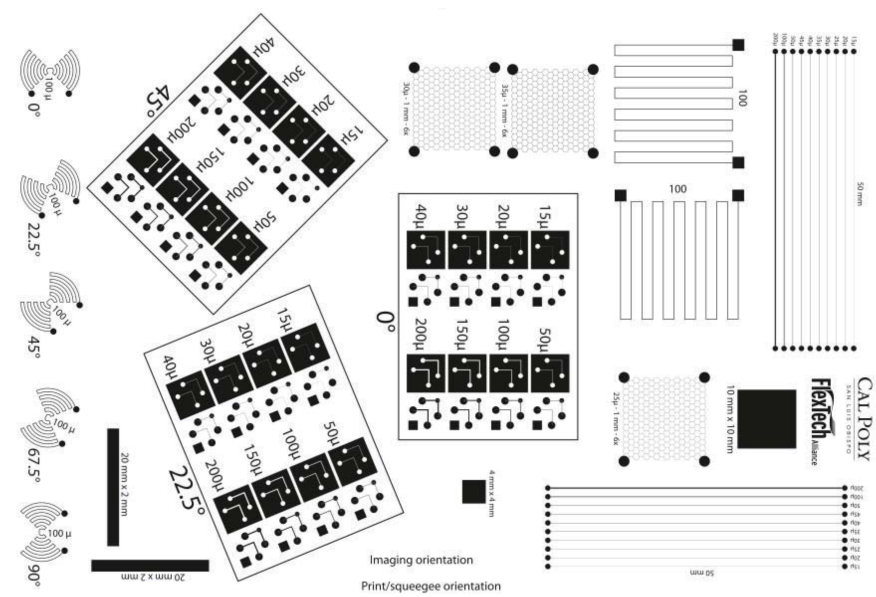

Figure 1: *Test form used for this study.*

Results and Discussions

Film positive

Screen printing commonly use film positive to exposure the emulsion to produce the patterns need to be printed. The accuracy of film positive greatly impact the dimension of the features imaged on the emulsion. The horizontal and vertical traces (in relation to print direction) of positive and negative forms were examined. The results are shown in the **Figure 2** and **3**.

The accuracy of the traces imaged on film positive is strongly related to the imaging device. For this study, the results suggested that the features were imaged more accurately for the positive traces than the negative traces. The negative traces are considered as the gaps in printed electronics application. This may compensate the spreading of ink film after printing to maintain more precise gaps as needed.

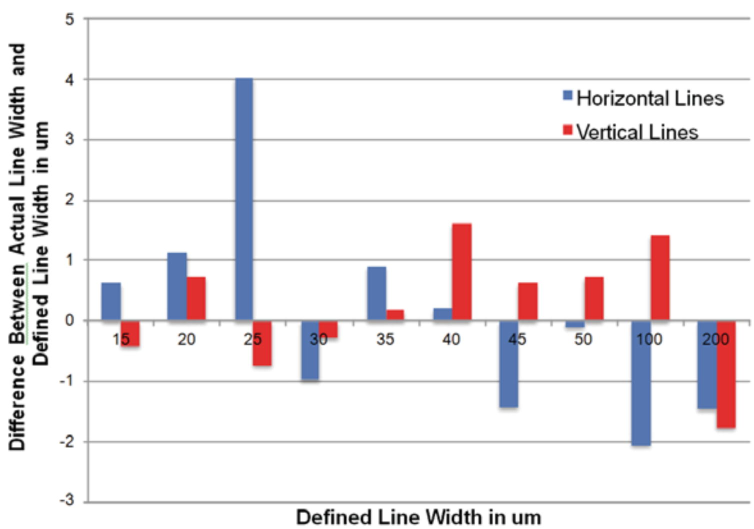

Figure 2: *Line width of positive traces at horizontal (perpendicular to print direction) and vertical direction (along print direction) which were imaged on film positive compared to the positive line width defined in AutoCAD file.*

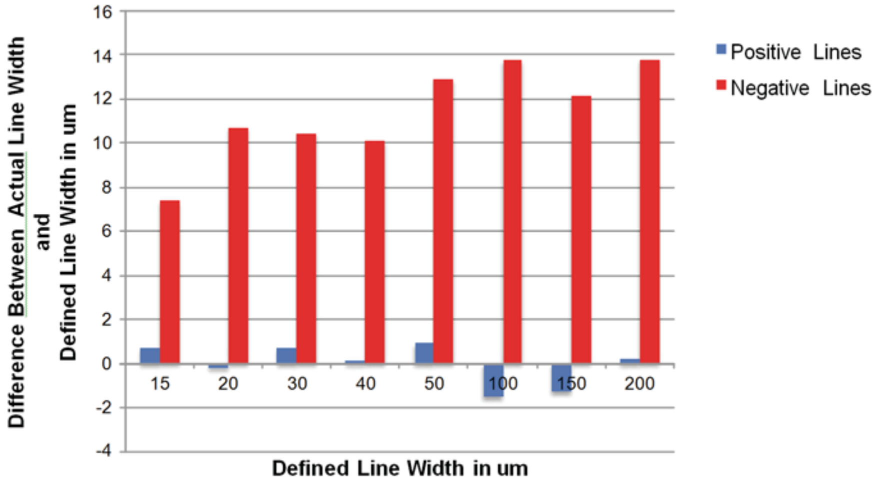

Figure 3: *Line width of negative traces at vertical direction (along print direction) which were imaged on film positive compared to the negative line width (gap) defined in AutoCAD file.*

There is no significant difference between the traces imaged in horizontal direction (perpendicular to print direction) verses vertical direction (along print direction).

Impact of emulsion type to imaging accuracy

Two types of emulsion tested have different resolutions. The resolution of the emulsion has great impact to the image quality on the mesh. The direction emulsion labeled as DE and the capillary film labeled as AE-1 were applied on the HS-380 and MS-640 meshes. For this experiment, the meshes were mounted with 22.5 degree bias to the frame.

The line width of positive and negative traces are shown in **Figure 4**. The line width of the traces being imaged on the meshes at horizontal and vertical directions are shown in **Figure 5**.

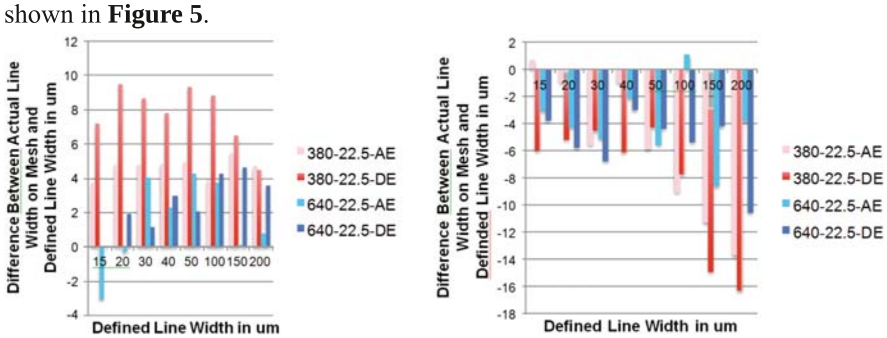

Figure 4: *Line width of positive traces (left) and negative traces (right) which were imaged on the meshes with different emulsions compared to the line width defined in AutoCAD file.*

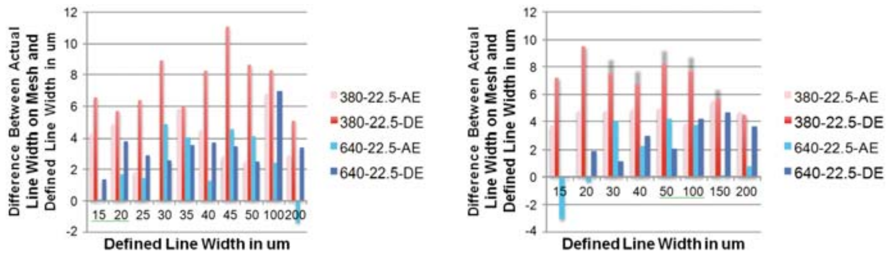

Figure 5: Line width of positive traces which were imaged on the meshes on horizontal direction (left) and on vertical direction (right) with different emulsions compared to the line width defined in AutoCAD file.

The results showed that the mesh with lower mesh count appeared to have more errors in terms of feature dimension no matter what type of the emulsion was exposed. This may be due to the larger open area of the lower mesh count mesh. The support from the threads to the emulsion is limited because of the larger open area. On the opposite side, the mesh with higher mesh count has better support to the emulsion, which resulted in less deformation of the features imaged. There is no significant difference between the traces imaged on horizontal direction (perpendicular to print direction) and vertical direction (along with the print direction).

Emulsion roughness

The roughness of emulsion is strongly related to image quality after the features are printed. The mesh with smoother emulsion can provide good gasket and produce features with smoother edges.

The roughness of the emulsion was measured as Rz (Mean Roughness Depth). The thickness of the emulsion was measured as EOM (Emulsion Over Mesh). The results of all the meshes mounted with and without bias, and coated with different emulsions are shown in the following figure (**Figure 6**).

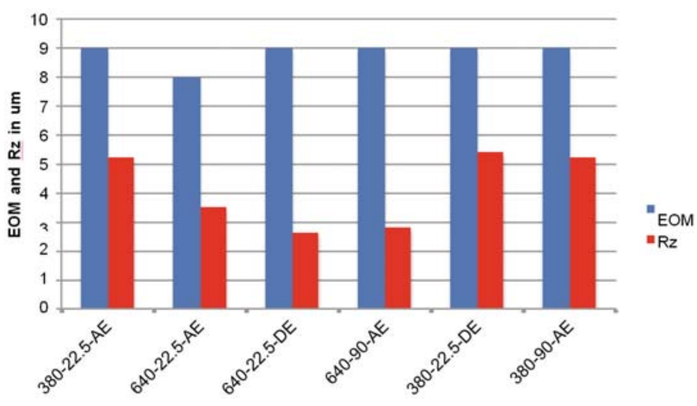

Figure 6: *Emulsion roughness of mesh mounted at different biases and coated with different types of emulsion.*

The results indicated that with the same amount of emulsion applied, the meshes with higher mesh count (MS-640) had smoother surface on the emulsion. This is due to the open area difference between the higher and lower mesh count meshes. The mesh with larger open area has less support to the emulsion, which contributes the roughness. There is very small difference in smoothness between capillary film and direct emulsion.

Mesh bias to image quality

Meshes were mounted at different directions in relation to the frame. Commonly, 22.5 degree of bias is used for most industrial applications for better ink release from the mesh.

Due the high cost of stainless steel mesh, many stainless steel meshes are now mounted on a polyester mesh. The stainless steel mesh is in the middle and mounted onto the polyester mesh, the polyester mesh is at the outside to connect to the frame. This type of mesh is called “trampoline“ mesh.

There are options of how to place the stainless mesh in relation to the polyester mesh. For this study, the polyester mesh was mounted with no bias to the frame, which means the threads of the polyester mesh are at the same direction as the frame. The stainless steel meshes were mounted two different ways, one was at 22.5 degree to the frame and one was mounted with no bias (the same direction as the frame). The mounting angle differences between the polyester mesh and the stainless steel mesh can cause deformation of the stainless steel mesh. The deformation of stainless steel mesh is more significant to the lower mesh count mesh.

The following images (**Figure 7**) showed the difference between the lower and higher mesh count meshes when mounted with 22.5 degree bias to the frame. It is clear that the threads on the lower mesh count mesh were not at exact 90 degree.

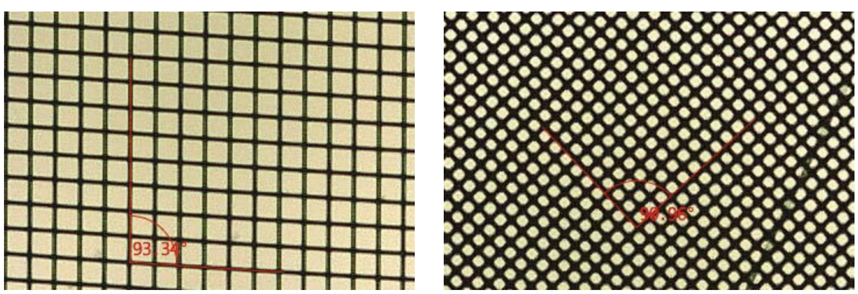

Figure 7: *The deformation of mesh when mounted at 22.5 bias to the frame on a “trampoline“ mesh. The lower mesh count mesh (left) showed more deformation compared to higher mesh count mesh (right).*

Alternative meshes

Woven mesh with threads always show thread interfere no matter how much calendering is applied. **Figure 8** showed the mesh and emulsion wall of a woven mesh. It is clear that the emulsion wall is rough and the rough structure of woven threads. The roughness of the emulsion wall and woven threads can cause different shear force to the inks that being pushed through the mesh, thus affect the print quality of the features.

In Figure 8, the electroformed meshes showed smoother walls at the open areas. The smoother walls can produce more uniform shear when the inks are pushed through. The smoothness of the surface of the electroformed mesh may also contributes to lower emulsion roughness.

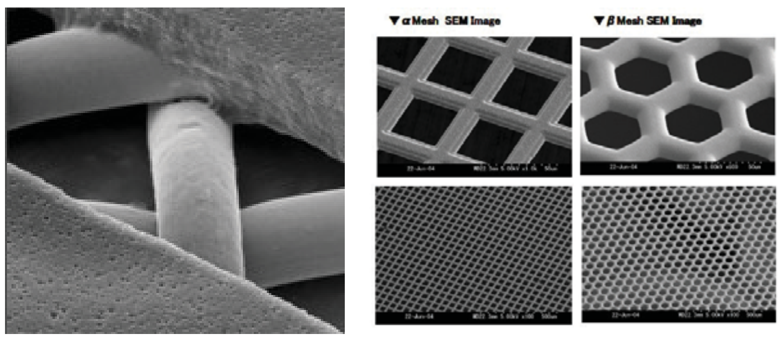

Figure 8: *Woven mesh (left) and electroformed mesh (right) showed different structures at the open areas which are for ink to transfer through.*

However, due to the limited resource, the exposure time was not optimized for this type of mesh and emulsion combination. The features smaller than 50 microns were not imaged correctly. Given the time and resource to optimize the exposure time, it is possible to produce good quality images and small features on the electroformed meshes.

Stencils can also be used for printing. The limitation of stencil is that only simple straight traces can be imaged. The traces with right angles or the traces with complicated forms can not be imaged. **Figure 9** showed the features can be imaged on a stencil. The technologies for making stencils have improved in the past years. The smallest features can be imaged on a stencil can be as small as 3 microns. However, it is challenge to print such small features.

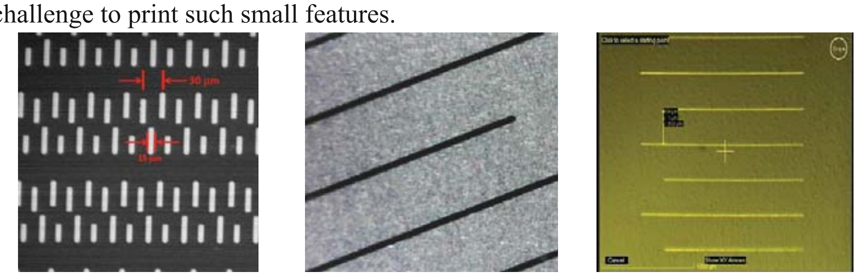

Figure 9: *Stencils can be used for printing. Only simple shape of features can be imaged.*

Conclusions

In order to print small features by screen printing, the image quality on the mesh is one of the most important factors. This study examined the image quality on positive film, on meshes with different mesh counts, on the meshes with different emulsions, and on the meshes with different biases. The alternatives of woven mesh were also discussed.

The results of this study suggested that in order to image small features (less than 50 microns) accurately, meshes with higher mesh count can produce smaller features (around 15 microns) more accurately than lower mesh count meshes. Negative traces (gaps) are more problematic than the positive traces. Negative traces are much larger in width on the mesh compared to what the negative traces were designed to be. However, this is beneficial to compensate ink spread during printing. The spreading of the inks during printing will reduce the width of the negative traces, thus to approach desired gap width after printing.

The alternative to woven meshes showed potential of good imaging quality. However, further research is needed to optimize the exposure condition to produce smaller features on the non-woven mesh. Stencils are good for imaging straight lines. The limitations of stencils are the limited patterns can be imaged and possible printing problems due to limited or no tension of the stencil.

Printed electronics industry is interested in imaging and printing small features by screen printing. The investment in screen printing presses and knowledge carried over from semiconductor industry make screen printing as a good choice of production method for printed electronics. Further research in imaging technologies and imaging materials can broaden the capability of screen printing to be a production method for both large and small features, thin and thick features.

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References

Kipphan, H.
2001 “Handbook of Print Media”, , Springer

Hoff, S.
1998 “The 53 Variables of Screen Printing Process”, SGIA Journal