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Screen Making for Functional Printing Applications

Technical printing requires precision screen making to achieve the right print.

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In functional screen-printing applications, it is best to recognize the use of the screen as a "deposition process" rather than a printing method. Functional inks are deposited onto various substrate materials with the length, width, and height (volume) of the printed ink geometries critical to achieving the intended functional properties such as conductivity, resistance, or dielectric strength.

When screen making for functional printing, harmonizing screen parameters such as mesh, emulsion type, and screen stencil characteristics to the ink and artwork design is critical to achieving the correct ink film deposit. Printed functional ink becomes a component of the final end product and must satisfy the requirements of the application.

Dimensional Support

Nonglamorous and easy to overlook, screen frames need to fulfill a few important requirements: be dimensionally and structurally stable, and be the appropriate size for the intended print area.

If using static extruded aluminum screen frames, be sure to pay attention to the wall thickness of the extrusion. A heavier extrusion wall thickness increases a frame's dimensional stability under the stress of mesh tension and squeegee deflection to maintain greater registration accuracy. Considering the total cost of mesh bonded to a screen frame over the course of a frame's working lifetime, it is a better investment to use the heaviest wall thickness available for the size of the frame profile (typically 0.125"). ▸

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With respect to size, the minimum inside dimension of any screen frame should be approximately 1.5 times larger than the intended squeegee path to provide sufficient margin for proper mesh deflection. Appropriate screen margin helps minimize screen stretch and image distortion when off-contact printing.

Separation is Key

In contact printing processes, ink transfers from a printing plate to a substrate at the moment the printing plate separates from the substrate. Contact printing processes, such as offset and gravure, have a natural, built-in separation that occurs when the cylindrical printing plates utilized in those methods rotate away from the substrate surface.

While some screen-printing methods take advantage of cylinders (such as rotary and cylindrical screen printing), the vast majority of screen-printing applications utilize a flat screen, printing on a flat substrate. Successful flatbed screen printing also requires a timely separation of the screen from substrate for proper ink transfer. However, this necessary separation must be artificially generated, as it will not occur naturally when no rotating cylinders are involved.

In screen printing, mesh is integral to getting ink to transfer from the screen onto the substrate. When a tensioned screen is deflected downward by squeegee force in an off-contact printing setup, the mesh component utilizes its elastic properties to lift the screen up from the substrate behind the moving squeegee ("screen peel"). This creates the separation needed to lift the screen out of the wet ink film deposited on the substrate.

Proper mesh tension provides the counterforce needed to overcome any tackdown of the screen generated by the wet ink film. The higher the mesh tension level, the greater the counterforce the screen has to peel up from the wet ink film during the print cycle (thus the benefit of using thicker-walled screen frames to maintain higher tension).

Mesh Controls Print

In any printing application, screen mesh must satisfy three requirements:

- be capable of printing the smallest feature size contained in the artwork.
- meter the wet ink film and deposit the ink thickness required for the intended application.
- openings should be four times greater than the largest solid particles contained in the ink to avoid sifting.

When setting up screen specifications for printing functional applications, the diameter of the mesh filaments plays a critical role. Diameter has commanding influence on the overall mesh weave thickness, and in conjunction with mesh count diameter, controls the opening size and sets the resulting open area percentage. The greater material strength of stainless-steel mesh results in smaller filament diameters, larger mesh openings, and greater open area than its polyester fabric counterparts.

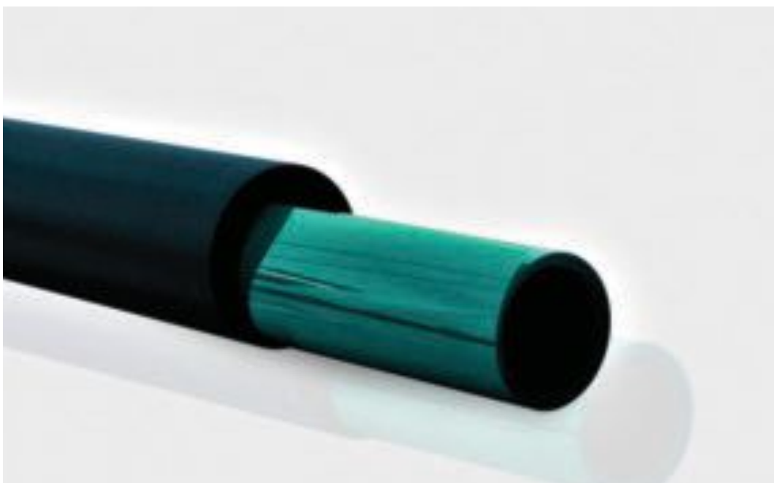
When printing fine features or circuitry, select a screen mesh that contains low obstruction to ink flow. Use a mesh with a wire or thread diameter no greater than 25%-30% of the width of the smallest image size contained in the artwork (see Figure 1).

Many mesh types incorporating smaller diameter filaments may comprise a higher tensile strength alloy or higher modulus polymers to increase tension capability. This increased tension capability assists in generating a screen's necessary uplifting counterforce without choking mesh opening size or closing open area percentage. ▸

Figure 1: Recommended Screen Mesh by Minimum Artwork Size for Functional Printing Applications

Min Feature Size	Mesh Type
200μ	325/28μ
150μ	325/23μ
100μ	400/18μ
≤ 50μ	≥ 500/16μ

Screen stencils are commonly created using a photosensitive coating applied directly to the tensioned screen mesh. The liquid version is called direct emulsion. Courtesy of Chromaline Screen Print Products.



The dry film form of screen emulsion is capillary film, which is applied to the substrate side of a tensioned screen by wetting the film to soften it. Courtesy of Chromaline Screen Print Products.

The Screen Stencil

The "X & Y" of the print pattern geometries is reproduced and controlled by the stencil component of a printing screen. The screen stencil is commonly created using a photosensitive coating applied directly to the tensioned screen mesh. This is in either a liquid or dry film format. The liquid version, called "direct emulsion," is coated in wet layers onto the screen mesh.

This can be performed manually or with automatic screen-coating equipment. Additional wet-on-dry layers can be applied to increase the coating's thickness and smoothness.

The dry film form of screen emulsion is capillary film (cap film). Cap film is manufactured as a coated film layer of a specific thickness on a backing sheet. It is applied to the substrate side of a tensioned screen by wetting the film to soften it, permitting the screen mesh to embed into the softened coating.

Stencil Chemistry

Attention should be focused on the type of emulsion used for creating the screen stencil. Emulsions and cap films are often categorized by their internal photochemistry, loosely describing its crosslinking component, or combination thereof:

- Diazo
- SBQ photopolymer
- Hybrid photopolymer
- Dual-cure

The emulsion base used in these formulations is primarily a combination of polyvinyl acetate (PVAc) and polyvinyl alcohol (PVOH).

Diazo-sensitized emulsions require the photochemistry to be added to the emulsion base. A diazo photoinitiator is mixed into the base material before use. Diazo emulsions typically exhibit good resistance levels but are slow exposing.

Photopolymer emulsions contain SBQ-PVA (stilbazolium quaternary polyvinyl alcohol) photoinitiators, and in the case of hybrid photopolymer, additional UV-curable resins are added for enhanced properties. These emulsion types are delivered to the end user as ready-to-use products. SBQ-based emulsions expose very quickly and exhibit lesser solvent tolerance than their diazo-sensitized emulsion counterparts.

Dual-cure emulsion formulations combine diazo and UV photopolymer blends (monomers, polymers, and photoinitiators) and SBQ photochemistries at specific ratios. The photopolymer blend, SBQ, and/or radiation-curable photoinitiators are ▸

mixed into the base emulsion material before packaging. A specific amount of diazo compound is then added into a dual-cure emulsion base prior to use. The combination of these materials yields greater solvent resistance, resolution, and image quality than either diazo or photopolymer SBQ-based stencils display individually.

Dual-cure emulsion formulations exhibit many characteristics preferred for use in stencil making for functional screen-printing applications.

Stencil Thickness

The thickness of a stencil coating measurable above the tensioned mesh plane is referenced as "emulsion-over-mesh" (EOM). While screen mesh is the dominant contributor to printed ink film thickness, in many instances stencil EOM thickness adds to the wet ink deposit thickness that the mesh component can deliver on its own.

It is common in decorative screen printing to use a stencil thickness that is based on a percentage (traditionally 12%-20%) of the tensioned screen mesh thickness. In screen making for functional printing applications, it is preferred to coat the screen stencil to a specific, predetermined EOM value that assists the screen mesh in depositing the required wet ink film thickness for the application. The EOM needed can be determined using the following calculation:

WIFT = (Mt x OA) + EOM
WIFT = wet ink film thickness
Mt = mesh thickness under tension
OA = mesh open area %

Note that EOM is rendered less influencing on WIFT when artwork features are 2mm or greater in size. Mesh is semi-rigid while under tension but remains "deflectable" so the squeegee can push the screen down to touch the substrate in the off-contact position. Once image features exceed 2mm, the mesh will begin to yield under squeegee force and begin deflecting down into the larger individual artwork features, resulting in ink deposits with "dish-like" profiles as a result.

Artwork Reproduction

When imaging screen stencils for high-tech applications, absolute care must be taken to reproduce the image sizes within the tolerance permitted for the application, while still sufficiently photocuring the stencil. Stencil materials are water-soluble, but reach some degree of their intended resistance to solvents, water, and abrasion after being crosslinked by specific wavelengths of UV energy. The areas where operators wish to deposit ink or paste

Figure 2: Suggested Stencil Thickness (EOM) by Mesh Count for Functional Printing Applications

Mesh Count	EOM
280	10-13µ
325	8-10µ
400	8µ
≥ 500	6-7µ

Chromaline Screen Print Products uses this mirrored UV system to simulate collimated UV energy as it is redirected to the exposure plane. Courtesy of Chromaline Screen Print Products.

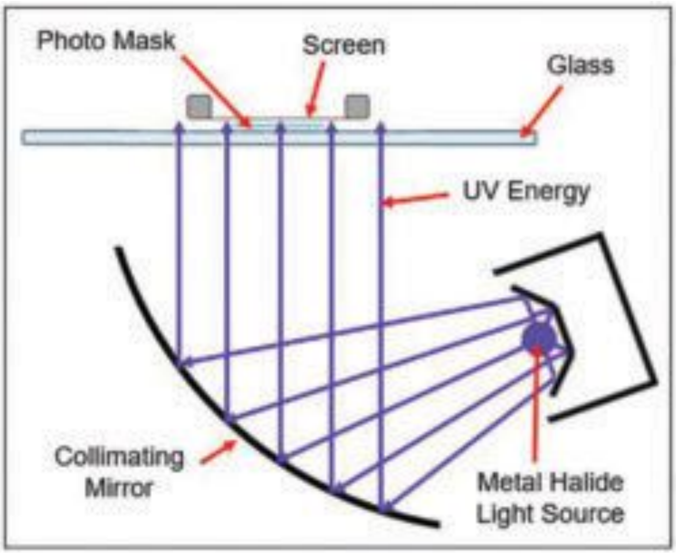


Figure 3: Stencil Masking Methods and Their Image Size Capabilities

Type	Method	Screen Stencil Exposure Method	Max Resolution	Smallest Imageable Feature
Computer-to-Screen	Opaque Ink Photomask	Internally Contained UV LEDs	750 DPI	90µ
Computer-to-Screen	Opaque Wax Photomask	External UV System	1,000 DPI	85µ
Direct-to-Screen	UV Light Direct to Stencil	Internal UV Laser	2,540 to 10,160 DPI	75µ to 30µ
Photomask	Light to Photographic Film	External UV System	Up to 50,000 DPI	7µ

are masked from the UV radiation during exposure so they remain water-soluble, and operators conversely allow the UV energy to reach and harden the areas of the stencil where they do not want composition to deposit.

There are different methods of controlling the selected locations of photocure of a screen stencil. The traditional method is using a photomask. Photomasks can be generated by inkjet printing the artwork onto clear polyester film using opaque ink. Photomasks commonly used in functional printing applications are traditionally created using photographic imaging of industrial photo film.

An alternative to film photo tools is dispensing opaque ink or wax directly onto the surface of the screen stencil, eliminating the use of a film sheet. This type of dispensed ink or wax is water-soluble and is removed during the stencil development process following exposure.

A more recent methodology is the direct-to-screen (DTS) process, in which artwork file data is fed into DTS equipment, which then projects focused UV energy directly onto the stencil of the screen specifically where the artwork file designates. The UV only strikes the screen surface where no ink deposit is to occur, crosslinking the stencil only where it should.

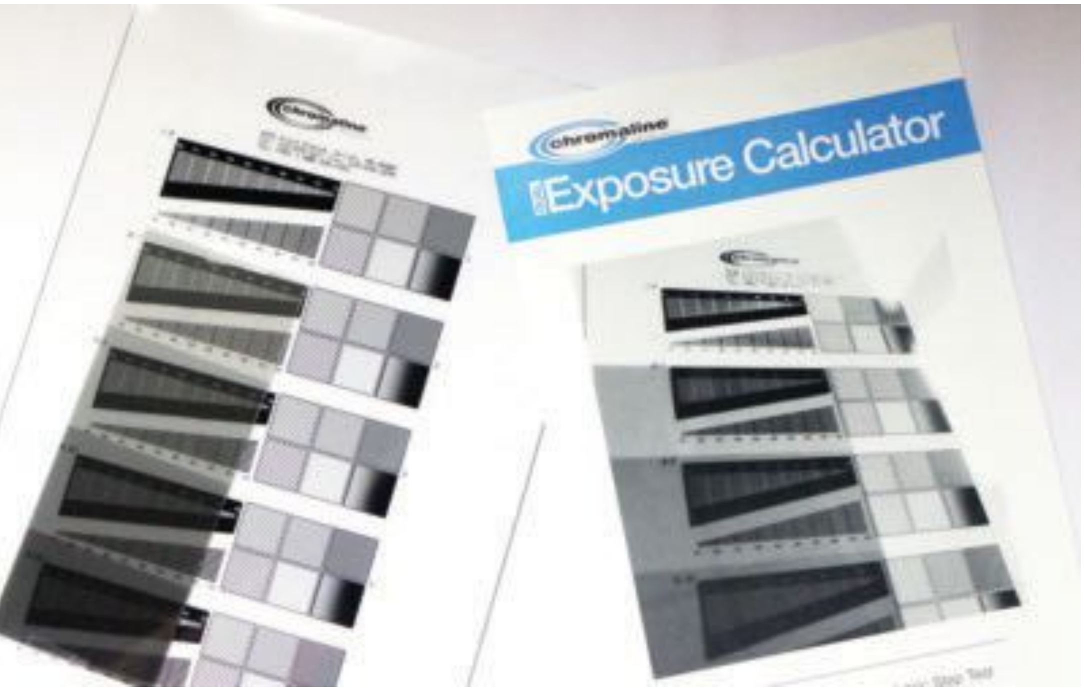
Which UV masking method is best suited to a given functional printing application can depend on a number of factors, one of which is minimum artwork feature size. These various photo-masking methods have limitations relating to the smallest artwork feature size that can be reproduced.

Thorough crosslinking of a stencil can be readily achieved, but this can choke resulting image sizes in the stencil due to light undercutting the images on a photomask during the UV exposure cycle.

One method for reducing or eliminating light undercutting is using collimated light energy. One method of collimating UV light is through the use of a specially curved mirror positioned at the focal point between the lamp and the exposure plane to create simulated collimation of the light emitting from the UV lamp system.

Other methods include photo tool compensation by spreading artwork feature sizes to allow any anticipated undercutting light to expose the image back down to intended size.

When using photographic film positives to image screens, all high-resolution and critical registration artwork should be photoplotted onto stable, industrial photo film using a laser photoplotting system set to 25,000 lpi or higher. The selected UV exposure system needs to have a properly functioning method (traditionally vacuum) of maintaining intimate contact between ▸



Exposure calculators simulate a series of exposure dosages with a single exposure, using staged levels of filtration.
Courtesy of Chromaline Screen Print Products.

the film photomask and the surface of the screen stencil to minimize light undercutting.

Getting Image Ready

The earlier recommendation of dual-cure emulsion as the stencil component of choice for functional screen-printing applications requires diazo photochemistry be added to the emulsion before use. It is extremely important that all coated screens be completely dry prior to exposure. Emulsions are hydroscopic, and will reabsorb moisture directly from the ambient room air. Diazo can be inhibited from crosslinking with the PHOH by any water molecules still present in a stencil during exposure, resulting in a screen with inferior resistance levels. Exposure and screen storage areas should be kept at less than or equal to 35% relative humidity, and previously dried screens staged for imaging should be placed in a dry box or low-temperature oven to prepare them to actively react with UV energy during exposure by minimizing internal moisture.

Proper exposure dosage is mandatory to achieve a crosslinked stencil with accurate image reproduction. This should be determined using designated exposure tools such as an exposure calculator and/or a multi-step “Stouffer Scale.”

An exposure calculator simulates a series of exposure dosages with a single exposure, using staged levels of filtration.

A Stouffer Scale provides visual feedback relating to the level of crosslink the screen stencil achieved after exposure. The higher numbered segments have greater levels of light filtration, and it is commonly agreed that at proper exposure, the more filtered segments will dissolve during development until a position seven (and lower) remains intact.

Screen making for technical printing applications requires precisely followed process steps and well-selected, high-end materials and processing equipment. Applications such as medical implant manufacturing, under-the-hood automotive circuitry, and military/aerospace equipment lean toward exceptionally tight tolerances for printed materials. This is to ensure the resulting function of the screen-deposited material meets the design’s requirements. ■

Art Dobie is Northeast region technical representative for Chromaline Screen Print Products in Duluth, Minn. A 40-year screen printing industry veteran, he received his B.S. in Graphic Communications specializing in Screen Printing Technology in 1980 from California University of Pennsylvania. He is a Life Member and Fellow of the Society of the International Microelectronics and Packaging Society, and was the 2006 recipient of the IMAPS John A. Wagnon Technical Achievement Award for outstanding technical contributions to screen printing technology as related to microelectronics. Dobie was inducted into PRINTING United Alliance’s Academy of Screen Printing Technology in 1998, and was the recipient of the Alliance’s 2010 and 2019 David Swormstedt, Sr. Memorial Award, recognizing the best published article or technical paper written for any aspect of the screen printing industry.

The Stouffer Scale provides visual feedback relating to the level of crosslink the screen stencil achieved after exposure.
Courtesy of Chromaline Screen Print Products.