Tutorial: How to Select the Best Stencil for SMT and Advanced IC Package Printing

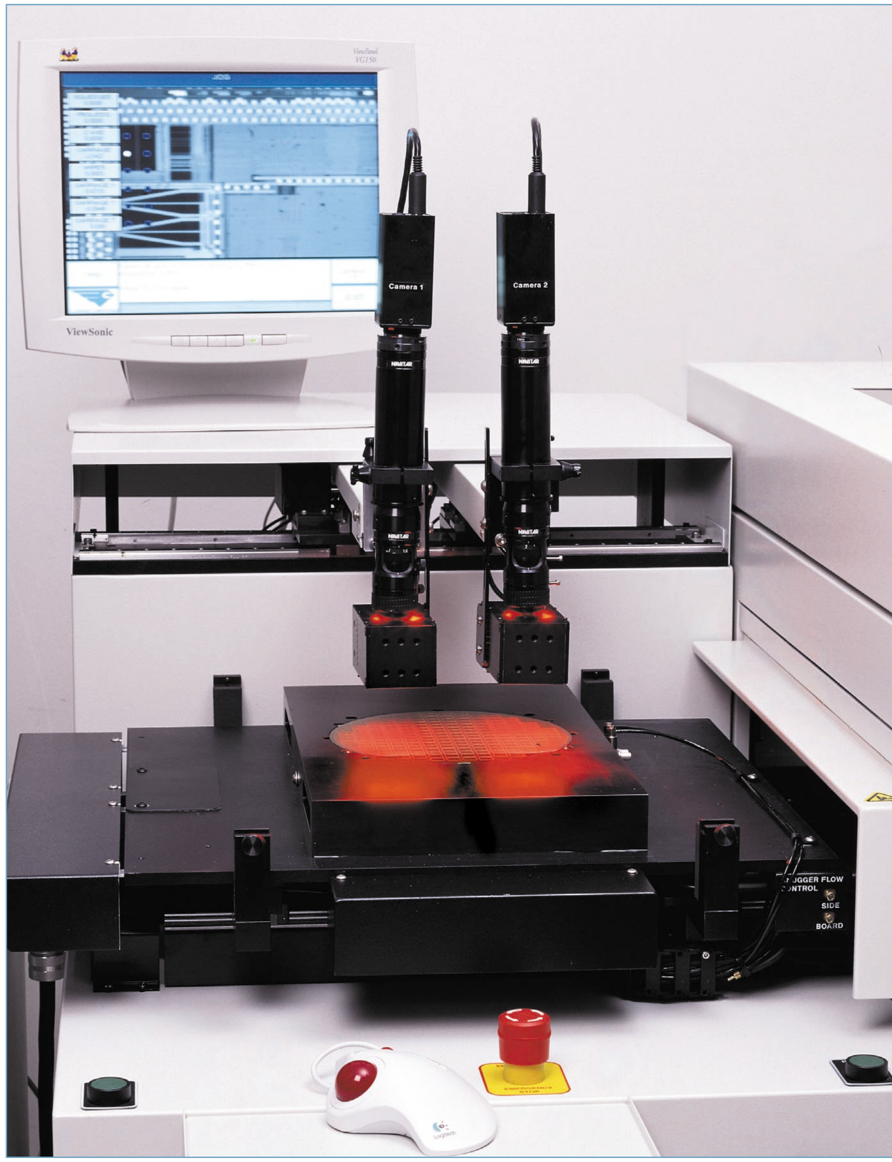
The stencil selection process can be confusing, particularly when creating a stencil for a new application. This tutorial, which covers stencils for SMT and advanced IC packaging applications, offers guidelines to assist users in stencil selection and print optimization.

By Alden Johnson, Cookson Electronics Equipment, Franklin, Mass.

This article discusses three basic stencil manufacturing techniques, explains the benefits of each type and details the effect of aperture shape and size with regard to paste release. How squeegee material choices and general paste-printing parameters affect the process are also reviewed.

Although the general principles are the same for printing a fine-pitch PWB and ultra-fine-pitch wafer bumping, subtle differences can mean the difference between a successful result versus a struggle to achieve desired yields.

There are three basic methods of manufacturing stencils. Although all three work well for most SMT or paste-printing applications, the production of ultra-fine-pitch devices on wafers can be a bit more challenging. Cost, additionally, is a contributing factor in the stencil selection and design process.



Lead photo — no caption supplied.

Stencil Manufacturing

Common stencil manufacturing methods include chemical etching, laser cutting and electroforming.

Chemically Etched stencils are created by passing thin, photo-imaged stainless steel plates though an FeCl bath to etch unprotected stainless steel material from both sides of the stencil (Figure 1). This method creates an hourglass-shaped aperture that, in fine-pitch applications, may cause problems with paste release, even though the aperture walls are smooth.

Laser Cut stencils are created by using a laser to cut through the metal. The laser creates apertures, one at a time,

Figure 1. Example of a chemically etched stencil

Figure 2. Illustration of a laser-cut stencil

Figure 3. An electroformed stencil is best suited to ultra-fine-pitch applications and wafer printing.

with trapezoidal walls (the degree of taper may vary, if desired). These stencils are generally more expensive to manufacture than a chemically etched stencil (based on aperture counts). The inner walls of the aperture can be electropolished to achieve a smooth finish.

Remember, if you are creating a stencil with 200,000 apertures (for a wafer application) you might see an increase in stencil cost, since most stencil manufacturers charge by the aperture. The paste release characteristics with this method are very good for both SMT applications and wafer printing. (Figure 2 illustrates a laser-cut stencil.)

Electroformed stencils are best suited for ultra-fine-pitch applications and wafer printing. The process consists of growing Ni plating around a photoresist of the desired stencil image.

The photoresist is removed when the desired thickness is reached and a thickness of 25µm is possible. An electroformed stencil for a typical wafer application can cost 5-10X less than a laser-cut stencil with the same number of apertures (Figure 3).

Stencil Design

The most common way to characterize an aperture's ability to print well is its *Aspect Ratio*. This is the ratio between the width of the aperture compared to the thickness of the stencil. This ratio, however, is not an accurate way to determine how well a BGA or CSP aperture will release paste.

In this situation, the aperture has an equal length and width (usually a circular aperture). When this aperture style is employed, *Area Ratio* measurement should be employed. This method uses the ratio between the contact area of the board, the area of the aperture opening, and the surface area of the aperture (inner wall area). Assuming a circular aperture, the equation is:

$$\text{Area Ratio} = \frac{\pi r^2}{2 \pi r t} = \frac{r}{2t}$$

Where: r = Radius of the aperture
t = Stencil thickness

Area Ratio calculation for a square or rectangular aperture:

$$\text{Area Ratio} = \frac{\text{Length} \times \text{Width}}{2(\text{Length} \times t) + 2(\text{Width} \times t)}$$

Where: t = Stencil thickness

Aperture size calculation for a square aperture:

$$\text{Aperture size} = \sqrt{\frac{p}{t}}$$

Where: p = Paste volume
t = Stencil thickness

The user should try to maintain a minimum value for the Area Ratio to be 0.66.

Another factor to consider when printing SMT devices is the solder paste mesh size. For all apertures, the user should try to maintain a 4:5 solder-particle width minimum aperture (shown in Figure 4).

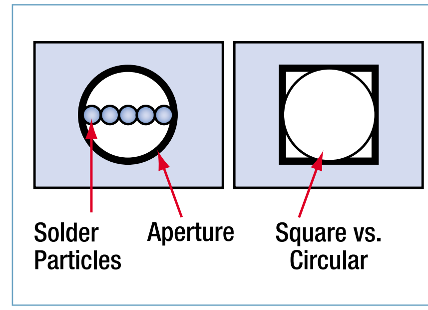


Figure 4. Solder particle width recommendations for round and square apertures

Paste Selection

A Type 3 solder paste (-325 +500 mesh) is typically used for most fine-pitch SMT applications. This paste should be able to adequately print down to 0.020" pitch standard devices (0.010" x 0.065" apertures). The maximum size solder particle in this paste is 0.0017" in diameter, therefore, the minimum aperture width should be 0.0085".

However, printing a circular or square aperture of this size requires a stencil thickness of 0.003" (see table). On occasion, this will only be two solder particles high. Therefore, to obtain the best and most repeatable volume of solder paste in a wafer bumping application, the particles need to be more tightly packed, which requires a smaller mesh paste (Type 5 or Type 6). The user should try to maintain a 5:6 solder particle height deposit.

Recommendations for Fine-Pitch Technology

Lead Pitch	Mesh	Particle Size
> .025	Type 3	-325/+400
.025	Type 3	-325/+400 to 500
.020	Type 3	-325/+500
.016	Type 4,3	-400/+500
.012	Type 4	-400/+525
< .012	Type 5	-500/+635

Figure 5. Photo shows an "as-printed" solder paste deposit

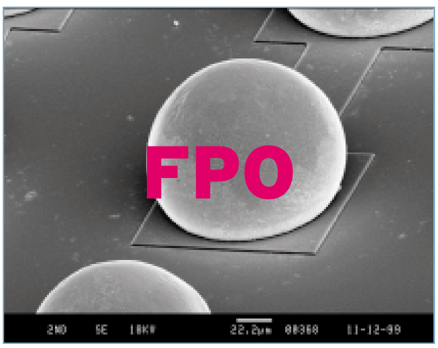


Figure 6. This graphic illustrates a typical bump after the reflow process

When creating stencils for wafer-printing applications, a square aperture will yield better volumes than a round aperture (about 80-85% release). Also, there is a benefit to having enough mesh between the apertures to maximize both volume and spacing between the apertures.

In an SMT process, it is typical to underprint (create the stencil aperture slightly smaller than the pad being printed). Underprinting aids in gasketing and reduces bridging.

However, when printing paste onto wafers, it is often necessary to overprint the pad. During reflow, solder shrinks about 50 percent, so overprinting the pad will not generally cause a problem with bridging.

Typical bumps using Type 5 paste are shown in Figure 5, before reflow, and in Figure 6, after reflow at 220°C.

A 125mm wafer contained a total of 344 die measuring 200 mils by 200 mils. Each die has a total of 317 bumps arranged in a "full array" pattern of 10 mil pitch. The bump pads (UBM) are electroless Ni/Au construction on Al metallization with $SiNi_3$ passivation. The pads are 4 mils in diameter.

Squeegee Blade Types

Typically, in a standard PWB paste-printing application, a metal squeegee blade is used. Tests have shown that when printing a standard, fine-pitch application with device pitch down to as low as .012 and aperture sizes of .008, a metal squeegee blade is perfect.

However, when printing wafers, with the pitch of the device as low as 150µm and aperture sizes as small as 80µm, a polypropylene 90 durometer, trailing edge squeegee blade is used.

With such a fine mesh, there is potential to damage the stencil with a metal squeegee. There is no measurable scavenging or scooping of the apertures when using a polypropylene blade. This type of squeegee yields the best results in this application when optimized.

Print pressure should be optimized to clean the stencil without overfilling or scavenging the apertures.

Too much print pressure may cause bleed-out of paste under the stencil causing bridging. Insufficient pressure may actually cause volumes to be higher than desired.

Typical squeegee pressure for printing wafers ranges anywhere from 2-2.5 lbs. per linear inch of blade, as opposed to 1-1.5 lbs. per linear inch when printing SMT devices. This pressure increase on wafer printing is due, in part, to the need for "off contact printing" or "snapoff" printing.

Print pressure and speed, when printing with a snapoff (defined as the distance between the top of the substrate being printed and the bottom of the stencil at rest), will dictate how the substrate is separated from the stencil.

Snapoff

The speed at which the board separates from the stencil is especially crucial in SMT, CSP and fine-pitch applications.

Space for pullout.

Optimizing Printing

In an ultra-fine-pitch application, it is often necessary to sacrifice a few seconds of cycle time to ensure proper aperture fill. Print speed is dependent upon the thixotropic characteristics, or shear properties, and paste viscosity.

Squeegee speeds for printing wafers may range from 0.4 inches per second (ips) up to 1.0 ips, as opposed to SMT squeegee speeds that vary from 0.5 ips up to as fast as 8 ips. Squeegee pressure and speed are dependent on blade-to-board contact and the type of paste.

Available high-speed pastes can be employed for most SMT printing applications with a device pitch of .020" or greater and a minimum aperture size of .012". The separation speed should allow the paste to release from aperture walls without leaving much residue in the aperture or damaging/distorting the paste deposit.

When adjusting print parameters for SMT devices, it is necessary to fine-tune board separation speeds and profiles to match the thixotropic characteristics of the paste. This method is typical in an SMT and CSP process.

However, when printing wafers, "contact printing" is difficult to achieve because the separation is usually too fast and damages the paste deposits. The difference in adhesion characteristics between the substrate and the paste are responsible for most difficulties.

A snapoff print will usually solve the adhesion problem. Snapoff printing

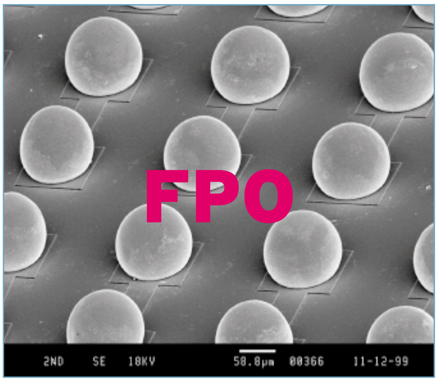


Figure 7. Printed solder bumps after reflow and cleaning

utilizes a space between the top of the substrate and the bottom of the stencil. This gap, in conjunction with optimum print speed and squeegee pressure, will allow the squeegee to press the stencil to the substrate as the force is applied and the squeegee traverses the stencil.

While the squeegee passes across the stencil, depositing paste through the apertures, the tension in the stencil allows it to peel away from the substrate at the rate of the squeegee speed, leaving a uniform deposit. The snapoff may be as much as 0.100". A 0.070" snapoff is typical for most applications.

Stencil Cleaning

Most automatic stencil printers employ a fully programmable stencil cleaner that uses a vacuum and solvents in order to clean the bottom of the stencil. This is necessary to obtain the desired volume of paste. Adjust wipe frequency, speed, vacuum speed and solvent to match the application. Wiping after every print is not uncommon.

Summary

Due to space constraints, this article barely touched on the many intricacies involved in the preparation of stencils for SMT and wafer bumping applications. The basic manufacturing techniques are chemical etching, laser cutting and electroforming. SMT paste printing, now a mature process, is typically less difficult than stencil preparation for wafer bumping.

Mr. Johnson is a senior process development engineer for Cookson Electronics Equipment with more than 25 years experience in assembly, defect reduction, materials and process optimization. He earned a bachelor's degree in industrial technology from Northeastern University, Boston. [ajohnson@cooksonelectronics.com]