



Stencil Printing Basics

Equipment, Material and Process Considerations

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Optimizing fine-pitch electronics assembly requires a careful review of the complete process. Each variation of device, lead spacing, substrate, material and build rate schedule requires specific parameters to ensure high yields. Using the correct combination of materials, equipment and data analysis systems can greatly reduce development time and costs.

For stencil printing, defects are typically caused by one or more of the following: poor alignment between the substrate and stencil, incorrect paste chemistry, or variations in the amount of paste deposited. To eliminate defects, the capabilities of the printer and the materials selected (substrate, paste type and stencil design) should be examined closely.

Process Considerations

It is no longer reasonable to define the high yield PCB production process by trial and error. Many aspects of designing and optimizing the process require efficient, accurate experimentation. Statistically designed experimentation is used to obtain maximum information at a minimum cost in time and resources. Conclusions drawn from experiments determine the best course of action in establishing the process. In this way, the controllable variables of the process can be set at optimum levels in an objective manner supported by data to produce the desired outcome.

Some commonly used methods of designed experiments for process development are Taguchi, Factorial DOE and Shianian. Both Taguchi and Factorial DOE are difficult to use and require a large number of experiments. Shianian's methods should be investigated as the number of experiments can be easily cut in half and the results easily interpreted.

For fine-pitch, printing parameters must be individually tailored to each application. However, it is possible to offer some general guidance as a starting point for experimentation and process development.

Material Considerations

Circuit Board Design

The printed circuit board design and the many materials of fabrication and methods used in circuit board construction should be examined first and can be broken down into three critical elements that directly affect the printing process: pad size, pad plating or finish, and solder mask type. Identifying these parameters will dictate the materials and equipment selected to complete the process.

Stencil Design

Four main elements define the typical stencil design: material, thickness, image pattern and aperture size. There is no single combination of these elements that can be recommended as the best choice for fine-pitch printing. Instead, the various options available must be considered in the context of the overall assembly process (Table 1).

TABLE 1

Recommended Sizes: Pad Width and Tolerance

Pitch*	Pad Size*	Aperture*	Stencil Thickness*	Aspect Ratio
25	15	12	6	2.0
20	12	9-10	5-6	1.7
15	10	8	5	1.6
12	8	6	4	1.5

*in mils



Paste Selection

The factors that affect paste are its rheology and particle size and shape. Type 4 solder paste, for example, is required for pitches under 0.4mm, based on experimentation that has shown that four or more solder particles are needed to span the stencil aperture to achieve consistently good solder paste deposition. Similarly, with 0.3 to 0.4mm pitch, the stencil openings should be between 0.005" and 0.008" wide. Since Type 4 paste has solder particles <0.0014", this criterion is statistically met. Recommended paste particle sizes, based on lead pitch, are provided in Table 2.

TABLE 2

Paste Selection

Lead Pitch	Mesh Type	Particle Size
0.025"	3	-325/+400 to 500
0.020"	3	-325/+500
0.016"	4, 3	-400/+500
0.012"	4	-400/+625

Adhesives

A successful adhesive printing process is comprised of several components: a stencil printer capable of vertical separation of board and stencil (preferably at a controlled speed) for on contact printing and a programmable snap-off distance for off contact printing, an appropriately designed stencil and an adhesive suitable for printing.

In terms of equipment, any stencil printer capable of printing solder paste for fine-pitch SMT assembly can be used for adhesive printing. In fact, adhesive printing does not require any special features from the stencil printer and, in some cases, semi-automatic equipment is adequate. The most important aspect of the printer is its ability to form a programmable "snap-off" or "printing gap" between board and stencil. The printer should also have a programmable, controlled separation of stencil and substrate.

Where adhesive printing and solder paste printing differ is in the materials (paste and stencil) used. Adhesives must possess several

characteristics to produce reliable depositions. Most important, printable adhesives must be suitable for long term exposure to ambient humidity. Most adhesives designed for dispensing are hygroscopic and may have problems with moisture from the atmosphere when applied by stencil printing. To be suitable for printing, an adhesive should be capable of being left on (printed onto a stencil)for 3-5 days with no adverse effects. Printable adhesives must also be thixotropic so that material will flow freely into apertures when sheared in the squeegeeing process and then recover quickly to resist slump after printing. Finally, whether dispensed or printed, adhesives must have sufficient green, or "wet", strength to hold components during the placement process, as well as a yield point high enough to avoid slump and give appropriate dot profiles.

The phenomenon of a single thickness stencil producing various dot heights is the key to successful adhesive printing. This occurs because adhesives do not behave like solder paste when released from stencil apertures. Adhesives do not release completely from apertures and, in most cases, more is left in the apertures than is deposited on the substrate. As a rule, the thickness of the stencil is determined by the highest dot height required. In most cases, dot heights should be about 1.5-2 times the component standoff height. For high yield point, printable adhesives, a stencil thickness of 6-8mils is recommended, while 10-12mil thicknesses are suggested for SOIC's.

Squeegee Blades

Metal squeegee blades enable a more controlled and consistent print height across the entire board area, however, good results can be obtained with urethane squeegee blades if there are few large pads on the board. Using a harder urethane or high-density, polyethylene blade minimizes the potential for "scooping" on all but very large pads. Durometer hardnesses range from 60 to 120, however 90 to 110 durometer blades provide excellent results.

Equipment Considerations

After the design of the PCB has been determined and the materials have been



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selected, the next step is to review and select the appropriate equipment and it is important to consider future production when evaluating systems for your line. There are several, key criteria that a stencil printer should meet:

Adequate Positioning Capability

The printer must align the stencil to the substrate with precision and repeatability. Because of the dimensions inherent in fine-pitch processing, positioning capability is the most important factor in printer selection and is essential for high-throughput.

For a 0.020" pitch device, the typical designed pad size is 0.012" to 0.013" wide, while that for a 0.012" pitch device is 0.007" to 0.008" wide. The stencil opening should be designed 0.001" to 0.002" less than the pad width to ensure good gasketing during the paste deposition process. These dimensions allow only 0.001" to 0.002" between either side of the opening and the edge of the pad. If the printer alignment system is incapable of maintaining this relationship and paste is deposited beyond the edge of the pad, there is a possibility of bridging to an adjacent pad and producing a solder short.

In volume production, the printer must reproduce this precise alignment at production speeds. To ensure it can meet the requirements of the application, the alignment process must be capable of greater precision than is required to meet the physical alignment specifications. The most efficient and reliable alignment system will incorporate discrete motion control for each axis. Ideally, the alignment process should be controlled by a closed-loop vision system that has the capability to view multiple fiducial points on the stencil or substrate.

Mechanical Stability

The ability of the printer to provide the necessary placement accuracy and repeatability requires a robust design. Structurally, the machine must be rigid enough to prevent relative motion between any axis of motion and the rest of the machine, which can cause variations in the system's response resulting in assembly defects. Rigidity is also required to ensure that all movement of the stencil in

relation to the board is accomplished in planes that are parallel within narrow limits.

Squeegee Pressure, Speed & Downstop Level

Squeegee pressure is based on the length of blade and material. For urethane or polyethylene blades, the starting pressure should be around 1.6 to 3.01 lb./in. of squeegee. When using metal blades, the starting pressure should be 1 lb./in. of squeegee. Based on the quality of the print, the pressure should then be adjusted to give complete fills of the apertures and clean wipes of the stencil surface.

Squeegee speed is determined primarily by the solder paste being printed. A range of 0.500" to 2.000"/sec. is typical with higher viscosity levels requiring slower speeds to allow the paste to flow into the stencil openings. When printing ultra-fine-pitch, a range of 0.500" to 1.000"/sec. has been found to yield good results.

Both pressure and speed can be used to control print viscosity, with pressure contributing 80% and speed 20%, to take advantage of the shear-thin properties of the paste.

Maintaining consistent print pressure across the board during the entire print stroke, despite board topography, is an absolutely essential task performed by the printhead. Real-time control of downward printhead pressure with precise stencil and PCB relative positioning prevents process variations. Sophisticated programmable printheads with balanced pressure points, located at each end of the blade, offer significant advantages. Left and right pressures, print speeds, blade attack angles and squeegee downstop are independently controlled at the pre-programmed levels to match the stencil, paste and board variables, resulting in controlled compliance with PCB topography. Consistent squeegee pressure is impossible to achieve without sufficient board support.

Downstop Level is dependent on machine type with the major consideration being the design of the printhead. Downstop controls the distance the print head travels beyond the substrate when the blades are not over the substrate. It



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prevents coining of the stencil. In general, the downstop should be set to a level that enables the squeegee to wipe the stencil clean and not over-deflect the stencil as the blades go beyond the substrate. For trailing-edge blades, a typical setting is 0.085”.

Sufficient Board Support

Proper board support is essential to ensure consistent print results and higher yields. Without proper board support, the force applied to the board, across the entire width of the PCB, will vary and proper gasketing between the stencil and the board will not be achieved. Blade angle can also be affected and cause paste to be left on the stencil. Board supports should be distributed evenly across the width of the board, particularly with BGA and fine-pitch components, to prevent bridging (sagging) and inconsistent paste deposition. In addition, board supports should be kept clean to ensure flatness and eliminate the potential for paste deposits on the underside of the board.

Optimal Stencil/PCB Separation

The critical factors in stencil/board separation are speed and distance. If the board is separated from the stencil too quickly, “bounce back” (fast, repeated contact between the stencil and PCB during board separation) will occur and the board will need to be cleaned and reprinted. Paste will remain on the bottom of the stencil, causing problems during the next print cycle unless thoroughly cleaned. Lifting, or paste retention in the apertures, can also occur if separation is performed too quickly, causing insufficiencies and bridging, and the stencil will have to be cleaned prior to successive prints.

Snap-off distance is the measurement from the top of the board to the bottom of the stencil and applies only to contact printing. Lift height is the distance that the squeegee blade is raised from the stencil after the conclusion of the print. Both are application-dependent and it is recommended that material and equipment suppliers be consulted for optimal settings.

Inspection/SPC Data Collection

To have a reasonable grasp on true production fluctuations, inspection tools must be combined with active Statistical Process Control features

(SPC). A good inspection system must be able to feed data back to enable process adjustments in real time so that the process engineer can take action to correct the situation before it becomes a true problem where defective product is made.

2D inspection systems measure the amount of paste that is covering the target pad and compare that against the required coverage. For automated systems, the operator can elect to allow the printer to automatically initiate corrective action. Verifying the results of a freshly printed board is the optimal way to determine that the print process is in control and that acceptable boards are being produced. Inspecting a PCB immediately after printing verifies the printing operation itself to characterize the process. Correcting problems at this stage requires merely cleaning and reprinting the board, considerably less expensive than repair downstream.

The best in-line 2D/SPC inspection equipment will offer an array of tools that will streamline the inspection and data gathering process and allow the engineer to customize inspection patterns and timing to best meet the needs of the production line. For an SPC program to be effective, it must be receiving data from the line at the stages when this is most important.

Minimal Operator Intervention

Automated operations minimize the need for operator intervention, making set-up easier and ensuring a consistent and repeatable process. Some advanced stencil printers have features, such as a programmable printhead, which permits the operator to program squeegee pressure and downstop and to automatically level the blades before printing. Automatic paste dispensing systems add preprogrammed amounts of paste at preselected intervals, eliminating solder paste from being on the stencil for extended periods and constantly refreshing paste supply. Automatic stencil wiping provides unassisted cleaning of the stencil, while a vacuum system cleans paste from clogged apertures.



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Wafer Bump Printing

Stencil printing solder bumps onto semiconductor wafers brings promise of high yield and throughput, low tooling costs and full automation to the table. Including wafer handling and printing, a production rate in excess of 40 wafers/hour is easily achieved. Adaptable for a variety of solder paste compositions, there is no penalty for wafer size evolution and print speed is independent of pattern density and bump size. However, process integration for wafer printing calls for more than just scaling down the stencil dimensions. The typical aperture size of roughly 125 microns violates the aspect ratio rule for stencils thicker than 85 microns. High-density patterns, needed to make larger bumps, require large, closely spaced apertures in thick foils. This requirement to meet the aspect ratio rule puts increased demands on the paste release and stencil wipe processes and frequency. In addition, the stencil represents a critical limiting factor in the quality of the printed wafer. With a required aperture aspect ratio in excess of 1.5 for good paste release, the thickness of the stencil must be minimized to achieve consistent paste height and fabricators must inspect 100% of the apertures for location and size. Several vendors have implemented machine vision and precision micro-manipulation to accomplish this, but the equipment and procedures are expensive, difficult for an industry familiar with lower-cost stencils.

Also of concern is the paste type. Because wafer printing stencils are typically 75-125 microns thick, a Type 5 paste PSD centering on 22 microns will give a typical printed brick only about 3-5 beads in height. A variation in paste volume of +/- one layer of beads for this paste results in a variation of +/- 25% of bump volume.

Although the actual printing, aligning and passing the squeegee across the wafer takes less than a minute to deposit hundreds of thousands of bumps, none of the material and equipment operating parameters is completely independent of the other. The integration of printing equipment technology, solder paste development and stencil manufacture improvements is required to take full advantage of this lucrative process.

Conclusion

To develop the optimal PCB production process, it is essential to consider all aspects of the process. The design of the board to be produced, the components to be placed, the materials used and the equipment selected to perform the process must all work in harmony with one another. More so than ever before, suppliers are realizing that they must work together to develop recommended process parameters in order to satisfy the requirements their customers demand.

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