Stencil Design Guidelines for Electronics Assembly Technologies

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REFLOW SOLDERING - MATERIAL

Solder paste is a combination of pre-alloyed spherical metal powder and flux medium.

Solder paste

Solder paste

Packing of solder pastes: jar and syringe
REFLOW SOLDERING TECHNOLOGY

The reflow soldering technology basically consists of three steps:

1. deposition of the solder paste by dispensing (topic 1.2) or by stencil printing
2. placement of the components pick&place, collect&place,
3. remelting the solder alloy in the solder paste – usually in an oven.

Surface mounted resistor
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THE STENCIL PRINTING

The **stencil** applied for depositing the solder paste is a thin, 75–200 µm thick **metal foil**, on which **apertures are formed** according to the solder pads on the printed circuit board. **Stencil printing** provides a fast, mass solder paste deposition process; relatively expensive, appropriate and recommended for mass production.
PROCESS OF STENCIL PRINTING

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1. Aligning board to the stencil
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2. Moving squeegee on the stencil – filling apertures
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3. Separating stencil from the board
BUILD-UP OF STENCILS (TERMS)

The stencil foil is tensioned and fixed to the frame by a metal mesh. The tension of stencil foil is around ~ 50 N/cm.
STENCIL MANUFACTURING TECHNOLOGIES

The main stencil manufacturing technologies are: chemical etching, laser cutting, electroforming.

Stencils are mainly characterized by the quality of the aperture wall (the roughness of the wall.)
CHEMICAL ETCHED STENCILS

- Subtractive technology, low price ~ 40 EUR; the price is determined by the size of the stencil foil
- Hour-glass shape aperture, material: brass or bronze
- Appropriate for pitch size: >0.63 mm
STEPS OF CHEMICAL ETCHING

Chemically cleaned surface

Photo sensitive coating applied to top and bottom

Developing solved photo-resist

Rinsing off photo-resist

Etching of metal

Complete etched product
CROSS-SECTION OF CHEMICAL ETCHED STENCIL APERTURES

- Single-side etching – high degree of undercutting
- Double-side etching – „hour glass” cross-section
- Single-side etching – formation of „knife-edge”
- Misalignment of phototools between the two sides
LASERCUT STENCILS

- Subtractive technology, the price is determined by the amount of apertures: ~300 EUR
- Trapezoidal aperture
- Material: nickel or stainless steel
- Appropriate for pitch size: >0.4 mm.
LASERCUT STENCILS

A trapezoidal aperture enhances the solder paste release. The aperture openings actually are cut from the contact side of the stencil. The stencil then is flipped and mounted with the squeegee side up.
ELECTROFORMED STENCILS

- Additive technology, the price is determined by the thickness of the stencil foil: ~1200 EUR
- Trapezoidal aperture
- Material: nickel
- Appropriate for pitch size up to: 0.2 mm
ELECTROFORMED STENCILS

1. Metal substrate, cleaned and degreased
2. Photo-sensitive coating applied
3. Developing and rinsing off solved photo-resist
4. Electro deposition of metal
5. Separation of stencil
6. Complete stencil
STENCIL DESIGN

Top (Cu) layer – positive

Solder mask layer – negative

Solder paste layer – negative

FR4 board with copper pads
STENCIL DESIGN

Top (Cu) layer – positive

Solder paste layer – negative

Solder mask layer – negative

Copper pads and solder mask
STENCIL DESIGN

Top (Cu) layer – positive

Solder mask layer – negative

Solder paste layer – negative

Copper pads with aligned stencil
BASIC STENCIL DESIGN GUIDELINES FOR SMD COMPONENTS

Ni/Au – 10% reduction
ImSn – no reduction
OSP – no reduction
ImAg – 10% reduction
LF HASL – 10% reduction

The possibility of aperture reduction depends on the solder alloy:
Leaded alloy: reduction is always possible
Lead-free alloy: reduction is possible only in case of PCB finishes with good wettability
ImSn – no reduction
OSP – no reduction
STENCIL DESIGN FOR PASSIVE SMD COMPONENTS

Home-plate

Inverse home-plate

Rounded inverse home-plate
STENCIL DESIGN FOR PASSIVE SMD COMPONENTS

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STENCIL DESIGN FOR PASSIVE SMD COMPONENTS

Home-plate

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Rounded inverse home-plate
EXPERIMENTAL ON SOLDER BALLING

Stencil manufacturer’s recommendation – no solder mask bridge between the solder pads

- Lower solder balling
- No decrease in joint strength
RESULTS OF THE EXPERIMENT

<table>
<thead>
<tr>
<th>Solder balls</th>
<th>Square</th>
<th>„Home-plate“</th>
<th>Inverse „home-plate“</th>
<th>Rounded inverse „home-plate“</th>
<th>No bridge on solder mask</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>60</td>
<td>31</td>
<td>20</td>
<td>30</td>
<td>50</td>
</tr>
</tbody>
</table>

O. Krammer: Stencil manufacturing and design
STENCIL DESIGN FOR FINE-PITCH COMPONENTS

- Transfer efficiency: ratio between the volume of the deposited paste and the volume of the aperture. It is determined by three main factors from the viewpoint of the stencil itself:
  - Manufacturing technology of the stencil
  - Aspect ratio (AS): length of aperture’s shorter side divided by the thickness of the foil. Should be greater than 1.5
  - Area ratio (AR): the ratio between the area and the wall surface of the aperture. Should be greater than 0.66

\[
TE = \frac{\text{Applied pastes volume}}{\text{Aperture volume}}
\]

\[
AR = \frac{\text{Pad area}}{\text{Aperture wall area}} = \frac{W \cdot L}{2 \cdot (W + L) \cdot T}
\]

\[
AS = \frac{\text{Aperture width}}{\text{Stencil foil thickness}} = \frac{W}{T}
\]
BGA PACKAGES – PBGA, CBGA

• PBGA – Plastic Ball Grid Array
  - Alloy of the solder bump is eutectic (Sn63Pb37, SAC305, SAC387)
  - Material of the package is epoxy
  - Interposer is FR4 or BT (Bismaleimide Triazin)
  - Higher CTE mismatch to silicon, lower reliability (FR4, BT CTE ~14-18 ppm/°C)

• CBGA – Ceramic Ball Grid Array
  - Alloy of the solder bump generally is non-eutectic (Sn10Pb90 – 302 °C, Sn80Au20 – 280 °C)
  - Material of the package is ceramic or alumina
  - Lower CTE mismatch, higher reliability (alumina CTE ~6 ppm/°C)
**PBGA package**
- Square aperture with side length equal to the diameter of pads
- Foil thickness considerations as below
- CSP – take care of particle diameter in paste

\[
AR = \frac{W \cdot L}{2 \cdot (W + L) \cdot T} \geq 0.66
\]

\[\Rightarrow T \leq \frac{W \cdot L}{2 \cdot (W + L) \cdot 0.66}\]

**CBGA package - overprinting**
- Min. width of bridge between apertures: \(1.2 \cdot \text{foil\_thickness}\)

<table>
<thead>
<tr>
<th>Type</th>
<th>Diameter of solder particles</th>
<th>&gt;90%</th>
<th>&lt;1% greater than</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 3</td>
<td>45 µm...25 µm</td>
<td>45 µm</td>
<td></td>
</tr>
<tr>
<td>Type 4</td>
<td>38 µm...20 µm</td>
<td>38 µm</td>
<td></td>
</tr>
<tr>
<td>Type 5</td>
<td>25 µm...15 µm</td>
<td>25 µm</td>
<td></td>
</tr>
<tr>
<td>Type 6</td>
<td>15 µm...5 µm</td>
<td>15 µm</td>
<td></td>
</tr>
</tbody>
</table>
STEPS OF THE „PIN IN PASTE” TECHNOLOGY

0. Starting

apertures for through-hole components
stencil
aperture for surface mounted components

circuit board
plated through-holes
solder resist mask
STEPS OF THE „PIN IN PASTE” TECHNOLOGY

1. Stencil printing

solder paste fills the holes in a certain extent
2. Component placement

through-hole lead

lead pushes the solder paste to the other side

surface mounted component
3. Soldering
SOLDER PASTE VOLUME NECESSARY FOR "PIN IN PASTE" TECHNOLOGY

$$S = \text{solder paste shrinkage factor, } \sim 0.5$$

$$V_{\text{solder in hole}} = V_{\text{hole}} - V_{\text{comp lead}}$$

$$= \left(\pi \cdot r_{\text{hole}}^2 - A_{\text{comp lead}}\right) \cdot h_{\text{board}}$$

$$A_{\text{men}} = 0.215 r_{\text{men}}^2$$

$$X = 0.2234 r_{\text{men}} + a$$

$$K_{\text{men}} = 2\pi X$$

$$V_p = \left(\frac{1}{S}\right) \cdot \left[\left(\pi \cdot r_{\text{hole}}^2 - A_{\text{comp lead}}\right) h_{\text{board}} + 2 \cdot (0.215 r_{\text{men}}^2 \cdot 2\pi (0.2234 r_{\text{men}} + a))\right]$$
REQUIRED DEGREE OF SOLDER PASTE HOLE-FILLING

\[ V_{\text{paste}} = \frac{1}{S}(V_{\text{hole}} - V_{\text{comp. lead}} + 2V_{\text{meniscus}}) \]

\[ V_{\text{aperture}} = w \cdot l \cdot t \]

\[ V_{pf} = V_{\text{paste}} - V_{\text{aperture}} \]

If \( \frac{d}{h} < \frac{1}{2} \), then \( V_{pf} \) can be too low.

- Overprinting…
- Step stencils…
- Two-print stencils…
- *Preform* solders…

If \( \frac{d}{h} > \frac{2}{1} \), than \( V_{pf} \) can be too high.

Boundary condition of the fusion:

\[ F_{\text{grav}} = \rho Vg \ll F_{\text{surf.tens.}} = 2\pi r \cdot \gamma_{LG} \cdot \cos \theta \]

Cross apertures
## OVERPRINTING

<table>
<thead>
<tr>
<th></th>
<th>Limits</th>
<th>Desirable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hole diameter</td>
<td>0.63…1.6 mm</td>
<td>0.75…1.25 mm</td>
</tr>
<tr>
<td>Lead diameter</td>
<td>Hole diameter</td>
<td>Hole diameter</td>
</tr>
<tr>
<td></td>
<td>minus 75 µm</td>
<td>minus 125 µm</td>
</tr>
<tr>
<td>Aperture diameter</td>
<td>Maximum 6.35 mm</td>
<td>Maximum 4 mm</td>
</tr>
<tr>
<td>Stencil thickness</td>
<td>0.125…0.635 mm</td>
<td>0.150…0.2 mm</td>
</tr>
</tbody>
</table>

- aperture for through-hole comp.
- stencil foil
- apertures for SM component
- circuit board
- plated hole
- solder resist mask
- solder pad for SM comp.
STEP STENCILS

Prepared using additive technology by electroplating, or subtractive process by chemical etching.

Design rules:

- Step height is maximum 75 µm.
- K1: distance between step and nearest aperture for SM component; should be at least 36 x step height.
- K2: should be at least 0.65 mm.
TWO-PRINT STENCILS

- **First printing** is performed by a thin stencil foil according to the fine-pitch SM components on the circuit (125…175 µm).

- **Second printing** is carried out by a thick foil according to through-hole components (400…760 µm), relief etch is formed on the contact side of the stencil at the locations of SM components to avoid solder paste smearing. Depth of relief etch should be at least 200 µm.
INVESTIGATING STENCIL DEFORMATION DURING PRINTING

Thickness of solder mask: 25 µm

Thickness of solder mask: 50 µm

O. Krammer: Stencil manufacturing and design
THE TESTBOARD

- Base thickness: contour and solder pads
- Protruding areas; thickened with electroplating
**AREA OF DEPOSITED PASTE**

Left: ID. 1 – no step nearby

Right: ID. 6 – 0.5 mm step distance

Paste area (µm²)

Aperture area (500x500 µm)

Step-pad (difference in height)

- σᵣ=2.6%
- σᵣ=5.7%
- σᵣ=8.8%
- σᵣ=12.1%
PARAMETERS OF THE FINITE ELEMENT MODELLING

- Squeegee length 30 cm
- Squeegee force 92 N
- Squeegee thickness 200 µm
- Squeegee angle 60°
- Highest level difference 90 µm
- Simulated foil thicknesses: 75…175 µm, in 25 µm steps
- Size of stencil foil 50x50 cm
NECESSARY DISTANCE FOR COMPLETE STENCIL BEND-DOWN

- Foil thickness 175 μm
- Foil thickness 150 μm
- Foil thickness 125 μm
- Foil thickness 100 μm
- Foil thickness 75 μm

Technological distance (TD) [mm]

Level difference [μm]
SUMMARY

Basic stencil design:
- For surface mounted passive components aperture reduction rules apply.
- For SM perimeter styles components (QFPs, QFNs) aperture reduction rules apply; foil thickness calculation is necessary.
- For common plastic BGA packages (pitch>1.27 mm) round aperture is recommended with reduction considerations.
- For fine-pitch plastic BGAs (pitch<1.27) square aperture recommended, aperture reduction rules do not apply.

Step stencils for Pin-in-Paste technology:
- For squeegee side steps, technological distance to the nearest surface mounted component is 36·step_thickness.
- For contact side steps, recommended technological distance to the nearest surface mounted component is 1.6·step_thickness·foil_thickness.