Introduction

- Solder paste printing is a critical step in the SMT process
  - Solder paste
  - Printers
  - Process
  - Defects
Solder Paste Properties

- Solder particles in a thickened flux/solvent vehicle

Metal Composition - Selection

1. Materials of the substrate & surface mount components
2. Compatibility of the solder with the metallization on the substrate (Au embrittlement, Ag leaching)
3. Solder strength as a function of temperature
4. Cost (% Ag)
5. Lead free

Solder Alloys

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Range (c)</th>
<th>Difference</th>
<th>Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>75Pb/25In</td>
<td>250S-264L</td>
<td>14</td>
<td>Die gold leaching, most ductile/high Sn/Pb ratio, die attachment &amp; closures, low lead.</td>
</tr>
<tr>
<td>50Pb/50In</td>
<td>180S-209L</td>
<td>29</td>
<td>Good wettability, not recommended for gold.</td>
</tr>
<tr>
<td>25Pb/75In</td>
<td>156S-165L</td>
<td>9</td>
<td>Good wettability, not recommended for gold.</td>
</tr>
<tr>
<td>37.5Sn/37.5 Pb/25In</td>
<td>134S-181L</td>
<td>47</td>
<td>Good wettability, not recommended for gold.</td>
</tr>
<tr>
<td>80Au/20Sn</td>
<td>280E</td>
<td>0</td>
<td>Highest quality for Au surfaces: die attachment &amp; closures.</td>
</tr>
<tr>
<td>Alloy</td>
<td>Range (°C)</td>
<td>Difference</td>
<td>Properties</td>
</tr>
<tr>
<td>------------</td>
<td>------------</td>
<td>------------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>63Sn/37Pb</td>
<td>183E</td>
<td>0</td>
<td>Widely used tin-lead solders for SMT and general circuit assembly. Low cost and good bonding properties: Not recommended for Ag and Au soldering because of high leach rates.</td>
</tr>
<tr>
<td>60Sn/40Pb</td>
<td>183S-188L</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>50Sn/50Pb</td>
<td>183S-216L</td>
<td>33</td>
<td></td>
</tr>
<tr>
<td>10Sn/90Pb</td>
<td>268S-302L</td>
<td>34</td>
<td></td>
</tr>
<tr>
<td>5Sn/95Sn</td>
<td>308S-312L</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Range (°C)</th>
<th>Difference</th>
<th>Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>62Sn/36Pb/2Ag</td>
<td>179E</td>
<td>0</td>
<td>Widely used tin-lead solders containing small amounts of Ag to minimize leaching of Ag conductors and leads. Not recommended for Au. Sn/Pb/Ag (62/36/2) is strongest tin-lead solder.</td>
</tr>
<tr>
<td>10Sn/88Pb/2Ag</td>
<td>268S-290L</td>
<td>22</td>
<td></td>
</tr>
<tr>
<td>1Sn/97.5Pb/1.5Ag</td>
<td>309E</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Range (°C)</th>
<th>Difference</th>
<th>Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>96.5Sn/3.5Ag</td>
<td>221E</td>
<td>0</td>
<td>Widely used tin-silver solders providing very strong, lead-free joints. Minimizes Ag leaching. Not recommended for Au.</td>
</tr>
<tr>
<td>95Sn/5Ag</td>
<td>221S-240L</td>
<td>19</td>
<td></td>
</tr>
<tr>
<td>42Sn/58Bi</td>
<td>138E</td>
<td>0</td>
<td>Low temperature eutectic with high strength.</td>
</tr>
</tbody>
</table>
### Metal Content

<table>
<thead>
<tr>
<th>Metal Content (wt. %)</th>
<th>Wet paste thickness (in.)</th>
<th>Reflowed solder (in.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>90</td>
<td>0.009</td>
<td>0.0045</td>
</tr>
<tr>
<td>85</td>
<td>0.009</td>
<td>0.0035</td>
</tr>
<tr>
<td>80</td>
<td>0.009</td>
<td>0.0025</td>
</tr>
<tr>
<td>75</td>
<td>0.009</td>
<td>0.0020</td>
</tr>
</tbody>
</table>

### Particle Size

\[
\text{Ratio} = \frac{\text{Surface Area}}{\text{Volume}} = \frac{\pi R^2}{\frac{4}{3}\pi R^3} = \frac{3}{4R} = 1.5/D
\]

Figure 9.2: (a) Perfectly spherical and (b) unacceptable solder particles in solder paste.
Solder Paste

Type 3 Paste: 25-45µm particle size range

Paste Types

<table>
<thead>
<tr>
<th>Type</th>
<th>None Larger Than (µm)</th>
<th>Less Than 1% Larger Than (µm)</th>
<th>10% Maximum Less Than (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>160</td>
<td>150</td>
<td>150-75</td>
</tr>
<tr>
<td>2</td>
<td>80</td>
<td>75</td>
<td>75-45</td>
</tr>
<tr>
<td>3</td>
<td>50</td>
<td>45</td>
<td>45-25</td>
</tr>
<tr>
<td>4</td>
<td>40</td>
<td>38</td>
<td>38-20</td>
</tr>
<tr>
<td>5</td>
<td>30</td>
<td>25</td>
<td>25-15</td>
</tr>
<tr>
<td>6</td>
<td>20</td>
<td>15</td>
<td>15-5</td>
</tr>
</tbody>
</table>

Solder Powder Mesh Designation

<table>
<thead>
<tr>
<th>Designation J-STD-005</th>
<th>Mesh ASTM B214</th>
<th>Particle Size (µm)</th>
<th>Ave. Particle Size</th>
<th>Surface Area Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 2</td>
<td>-200/+325</td>
<td>75-45</td>
<td>60</td>
<td>1</td>
</tr>
<tr>
<td>Type 3</td>
<td>-325/+500</td>
<td>45-25</td>
<td>35</td>
<td>1.71</td>
</tr>
<tr>
<td>Type 4</td>
<td>-400/+500</td>
<td>38-20</td>
<td>31</td>
<td>1.93</td>
</tr>
<tr>
<td>Type 5</td>
<td>-500</td>
<td>25-15</td>
<td>18</td>
<td>3.33</td>
</tr>
</tbody>
</table>
### Type vs. Pitch

<table>
<thead>
<tr>
<th>Component pitch (in.)</th>
<th>Stencil aperture (in.)</th>
<th>Max. Powder size (µm)</th>
<th>Stencil Aperture/Max PS</th>
<th>Desired Paste Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.050</td>
<td>0.025</td>
<td>80</td>
<td>8</td>
<td>2</td>
</tr>
<tr>
<td>0.025</td>
<td>0.014</td>
<td>50</td>
<td>4.3 or 7</td>
<td>2 or 3</td>
</tr>
<tr>
<td>0.020</td>
<td>0.010</td>
<td>50</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>0.015</td>
<td>0.008</td>
<td>40</td>
<td>5 or 6.6</td>
<td>4 or 5</td>
</tr>
<tr>
<td>0.010</td>
<td>0.006</td>
<td>30</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

### Flux Activators and Wetting Action

- The activators in the flux promote wetting of the molten solder to the surface mount lands and component terminations by removing oxides and other surface contaminants.
- Fluxes are generally mild acids

### J-STD-004

- Rosin based
- Water soluble
- Low residue or No-clean
Rosin

- Rosin flux is primarily composed of natural resin extracted from the oleoresin of pine trees and refined.
  - Rosin (R)
  - Rosin, mildly activated (RMA)
  - Rosin activated (RA)
    - Rarely used, very high activity level

Water Soluble

- Organic acids (OA)
- Must be cleaned after soldering
- Formulated with a glycol base

No-clean

- Natural resins other than rosin types and/or synthetic resins
- Varying ‘solids’ content
  - Impacts amount of flux residue
  - Some leave no visible residue
- Residue is non-corrosive, non-conductive and can be left on the board
Void formation

- If the solvent in the paste does not evaporate before the solder melts, gas bubbles can be entrapped in the molten solder creating a void.

SOLDER BALL VOIDS
Area Array Packages

Rheology Properties

- Viscosity
- Slump
- Tackiness
- Working life
Viscosity

- Viscosity = Shear Stress/Shear Rate (Pascal-seconds)
- The internal resistance exerted by a fluid to the relative motion of its parts

Shear rate (sec\(^{-1}\)) is the rate of travel of the two parallel plates separated by fluid divided by the distance between the plates (cm/s/cm)

Viscosity as a Function of Process

<table>
<thead>
<tr>
<th>Shear Rate (sec(^{-1}))</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>10^2</td>
<td>10^2</td>
</tr>
<tr>
<td>10^3</td>
<td>10^3</td>
</tr>
<tr>
<td>10^4</td>
<td>10^4</td>
</tr>
<tr>
<td>10^5</td>
<td>10^5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Viscosity (Poise)</th>
<th>10^2</th>
<th>10^3</th>
<th>10^4</th>
<th>10^5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Through the screen</td>
<td>0.01</td>
<td>0.1</td>
<td>1</td>
<td>10</td>
</tr>
</tbody>
</table>

Fluid
Response of Fluids to Shear

- Pseudoplastic
- Thixotropic
- Newtonian
- Dilatant

Shear Rate vs. Shear Stress

**Figure 9.4** Impact of increasing shear force and temperature and particle size on solder paste viscosity with identical metal content and flux vehicle.

Viscometer

**Figure 9.5** Photograph courtesy of Intel Corp.
Spiral (Malcom) Viscometer

![Image of Spiral (Malcom) Viscometer]

Figure 9.4 Photograph of spiral (Malcom) viscometer. (Courtesy Malcom Instruments Corporation.)

Schematic of Spiral Inductor

![Schematic of Spiral Inductor]

Figure 9.7 Schematic of spiral (Malcom) viscometer.

Shear Rate

Table 9.6 Shear rates corresponding to various rotational speeds for Malcom viscometer [11].

<table>
<thead>
<tr>
<th>ROTATION SPEED (RPM)</th>
<th>SHEAR RATE (SEC⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>10</td>
<td>6</td>
</tr>
<tr>
<td>15</td>
<td>9</td>
</tr>
<tr>
<td>20</td>
<td>12</td>
</tr>
<tr>
<td>30</td>
<td>18</td>
</tr>
</tbody>
</table>
Solder Balls

1. Solder balls are formed by very fine powder particles in the solder paste.
   - They are carried away from the main solder deposit as the flux melts and flows before the solder itself melts.
   - This happens especially when the paste is deposited outside the land area either by design or misregistration
   - These smaller particles lose contact with the larger solder paste deposit and when the solder melts, each particle becomes a small solder ball at the periphery of the original paste deposit
   - A collection of small solder balls around the main solder deposit is called a ‘halo’.

Solder Balls

2. Solder balls are also formed when the oxide layer on the surface of the solder powder particles is so thick the flux and any activator in the paste are not sufficient to remove it.
   - Since the oxide cannot melt at soldering temperatures, they are pushed aside as a solder ball by the surrounding oxide-free molten solder.
   - Solder balls formed in this manner are larger than those formed by the 1st mechanism because of the presence of surface oxide which is less dense than the metal.

Solder Balls

- Improper handling
- Excessive baking/preheat prior to reflow
- Particle rubbing (Fretting corrosion)
- No-clean more likely to have solder balls
  - Less aggressive flux
Testing

- Print paste onto non-metallic substrate (ceramic, glass, FR-4)
- Reflow
- Inspect for solder balls

Solder Balls

Printability

1. Weight 5 clean dummy boards (W1) and after (W2) the paste is printed.
2. Determine the weight of paste deposited (W2-W1)
3. Measure and record the height at 4 predetermined points on each substrate
4. Perform steps 1-3 for freshly removed solder paste and solder paste exposed to the atmosphere for 4 hours.
Printability

1. The solder paste weight should not vary by more than 10% among the average measurements taken on one substrate.
2. The paste height should not vary by more than ±1 mil among the average measurements taken on one substrate.
3. The solder paste pattern should have uniform coverage, without stringing and without separation of flux and solder, and should print without forming a peak.

Printing Equipment

Figure 5.9. Laboratory model solder paste screen printer. (Photograph courtesy of Welsh International.)

Figure 5.10. An example of an automatic screen printer. (Courtesy of BER Corporation.)
Printing Equipment

Figure 9.11 An example of a semi-automatic printer. (Courtesy of Transline Automation)

Printer Selection

- Manual vs. computer control of parameter
- Stencil size
- PWB size
- Print mode
- Alignment

Print Variables

Table 9.7 solder paste printing equipment variables [15]

- Streamed
- Dwell
- Flushing
- Plastic of mechanical parts (X and movement)
- Speed
- Acceleration
- Deceleration
- Pressure (linear force)
- Stroke parallel
- Parallelism in substrate
- Down step
- Mode of operation
- Contact/Off Contact
- Bi-directional/unidirectional printing (bottom or printprint mode)
- Multiple no print
- Source holder
  - X min
  - Y min
  - Z min
  - Rotation (Tilt)
  - Rush off
  - Snap off
Stencils

- Stainless steel
- Nickel
- Brass
Stencil Forming

- Chemical Etch
  - Electropolished
  - Ni Plated
- Laser Cut
  - Electropolished
  - Ni Plated
- Ni Electroformed

Chem Etch

- As-etched
- Electropolished

Laser Cut
Laser Cut Aperture

Ni Electroformed

Comparison of Apertures to Solder Particles
1. No matter which method of application is used, be sure that the solder paste has been stored properly. A tightly sealed, unopened container of solder paste generally can be stored for 6 months at 4-29°C. Shelf life is flux dependent. It is better to use the freshest paste possible. If opened, store in a refrigerated environment.
2. Use only fresh paste every day. To accomplish this, use small jars that contain only 1 day’s worth of paste or transfer paste from large jars as needed for the day and put the rest back in the refrigerator. This helps improve paste-related yield.
Printing

3. Allow refrigerated container to reach room temperature before use. It may be advisable to take the paste out of the refrigerator the night before for the next day’s use to avoid the wait.
4. Check the solder paste for solder ball characteristics and viscosity.
5. When all solder paste printing is complete, wash the screen or stencil with the appropriate solvents.
6. Discard (hazardous material) any used paste.

Screen Printing

- Typically off-contact
- Lower viscosity for flow through wires
- Screen and PWB should be parallel within 0.002”
- Snap-off distance set to 0.030” (typical)
Stencil Print

Stencil
Solder
Metal Blade
Squeegee
PWB

Stencil Printing

Stencil Printing
Separation

Step Stencils

Step Stencil

Step 1: Selective Etching of Fine Pitch Area
- Etching aperture 4.5 mils

Step 2: Etching Apertures
- Standard SMT aperture 8.10 mils

Step 3: Printed Paste Deposit

Figure 5.28 A schematic of a multilevel stencil for dual-thickness printing.

Step Stencils

Figure 5.29 Multilevel or selective etching in a metal mask stencil for depositing different values paste thickness on the same board. (Photograph courtesy of Intel Corporation.)
Stencils vs. Screens

Table 9.9 Advantages and disadvantages of screens and stencils

<table>
<thead>
<tr>
<th>STENCILS</th>
<th>SCREENS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ADVANTAGES</strong></td>
<td><strong>DISADVANTAGES</strong></td>
</tr>
<tr>
<td>Easy to set up</td>
<td>Harder to set up</td>
</tr>
<tr>
<td>On-contact and off-contact printing</td>
<td>Off-contact printing only</td>
</tr>
<tr>
<td>Can print by hand</td>
<td>Cannot print by hand</td>
</tr>
<tr>
<td>Water usable viscosity range</td>
<td>Narrow usable viscosity range</td>
</tr>
<tr>
<td>More durable</td>
<td>Less durable</td>
</tr>
<tr>
<td>Do not plug easily</td>
<td>Plug easily</td>
</tr>
<tr>
<td>Easy to clean</td>
<td>Hard to clean</td>
</tr>
<tr>
<td>Allow multilevel printing</td>
<td>Do not allow multilevel printing</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>DISADVANTAGES</th>
<th>ADVANTAGES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Higher cost</td>
<td>Lower cost</td>
</tr>
</tbody>
</table>

Dispensing

- Low volume, slow
- Repair
- Special requirements
- Clogged needles
  - Lower viscosity

Printing Defects

Figures 8.22: Common print defects during water paste applications (a) smeared print, (b) skipped print, (c) print with ragged edges, and (d) unnatural print. (Photograph courtesy ofland Corporation.)
Solder Paste Viscosity

- Dispensing: 200,000 – 450,000 (centipoise)
- Screening: 450,000 - 800,000 cP
- Stenciling: 750,000 – 950,000 cP (50mil pitch)
- Stenciling: 900,000 – 1,200,000 cP (fine pitch)
- Temperature effects
- Paste shearing
- Moisture (water soluble paste)

Print Thickness

- Stencil thickness
- Pressure
  - Scooping
- Blade type
  - Metal
    - Stencils
  - Rubber
    - Screens & Stencils

Squeegees

Figure 5.24 Bidirectional and unidirectional rubber squeegee blade configurations.
Print Orientation

- Function of paste
- Fast print speed can cause planing of the squeegee, resulting in skips
- Slow speed generally provides better prints, but can lead to ragged edges or smearing of too slow.
- Production favors fast speeds

Stencil Aperture

Figure 9.25 Vector printing—squeegee at an angle for uniform paste printing (17).
Print Thickness

![Print Thickness Graph](image)

Figure 9.23 Recommended range of stencil thickness for various lead pitches.

---

**IPC Stencil Design Rules**

<table>
<thead>
<tr>
<th>Part Type</th>
<th>Aspect Ratio Range</th>
<th>Area Ratio Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>PLCC (50 mil pitch)</td>
<td>2.3 to 3.8</td>
<td>0.88 to 1.48</td>
</tr>
<tr>
<td>QFP (25 mil pitch)</td>
<td>1.7 to 2.0</td>
<td>0.71 to 0.83</td>
</tr>
<tr>
<td>QFP (20 mil pitch)</td>
<td>1.7 to 2.0</td>
<td>0.69 to 0.83</td>
</tr>
<tr>
<td>OFP (16 mil pitch)</td>
<td>1.6 to 2.0</td>
<td>0.68 to 0.86</td>
</tr>
<tr>
<td>QFP (12 mil pitch)</td>
<td>1.5 to 2.0</td>
<td>0.65 to 0.86</td>
</tr>
<tr>
<td>0402</td>
<td>N/A</td>
<td>0.84 to 1.00</td>
</tr>
<tr>
<td>0201</td>
<td>N/A</td>
<td>0.66 to 0.89</td>
</tr>
<tr>
<td>BGA (50 mil pitch)</td>
<td>N/A</td>
<td>0.93 to 1.25</td>
</tr>
<tr>
<td>BGA (40 mil pitch)</td>
<td>N/A</td>
<td>0.67 to 0.78</td>
</tr>
<tr>
<td>BGA (20 mil pitch)</td>
<td>N/A</td>
<td>0.69 to 0.92</td>
</tr>
</tbody>
</table>

---

**Definitions**

**Area Ratio**

\[
\text{Area Ratio} = \frac{\text{Area of Aperture Opening}}{\text{Area of Aperture Wall}}
\]

**Aspect Ratio**

\[
\text{Aspect Ratio} = \frac{\text{Width of Aperture}}{\text{Stencil Thickness}}
\]

Rule of thump:

Area Ratio > 0.66
\[ RVP = \text{Required paste volume} = 2x \pi (D_h^2 - D_l^2)x(T/4) \]

- \( D_h \) = plated through hole diameter
- \( D_l \) = lead diameter
- \( T \) = the board thickness

Hole should be 0.012" bigger than lead diameter or 0.010" bigger than the diagonal dimension of the lead.

---

**Figure 9.30** Schematic of a step stencil for printing on through-hole lands in a mixed assembly.

- **Paste in Hole**
  - Aperture larger than PWB pad
    - Printing on solder mask
  - Potential for solder balls