VIDEO ANALYSIS OF SOLDER PASTE RELEASE FROM STENCILS

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Agenda

- Why smaller Area Ratios influence paste release?
- Background and previous work
- Experimental Methods
  - Side View Videos
  - Top View Videos
- Inferences from Data Findings
- Conclusions
WHY DO SMALL AREA RATIOS INFLUENCE SOLDER PASTE RELEASE?
Solder Paste Release

- Factors influencing solder paste release
  - Stencil aperture area ratio
  - Solder paste formulation
  - Solder powder particle size
  - Stencil cleanliness
  - Flux-repelling nanocoatings

- Other factors include
  - Aperture cut quality
  - Print parameters
  - Separation speed
  - PCB design
  - Tooling setup
  - Environmental factors

- This study focuses on the first listing of factors
Transfer Efficiency - TE

- Percentage of paste that is released from the aperture
- Historically characterized using automated solder paste inspection (SPI)
- SPI generates numerical data regarding deposit characteristics
  - Deposit volumes, areas and heights
  - Enables us to quantify the end results of the print process
  - **However** - Visual information on the mechanics of paste release is extremely limited

- The purpose of this study is to
  - Produce visual data
  - Gain a better understanding of solder paste release
Aperture Size

- Most influential factor in solder paste release
  - Drives Area Ratio (AR)
- During separation, solder paste sticks to
  - PCB pad
  - Stencil wall
- The adhesive forces between the solder paste and pad must
  - Overcome the adhesive forces between the solder paste and aperture wall
  - The adhesive forces are proportional to contact areas
  - The ratio of the areas indicates the amount of solder paste that will be released
    - The lower the AR, the lower the TE
    - The higher the AR, the higher the TE
Basic Metrics in Stencil Printing

**Area Ratio, AR**

\[
AR = \frac{\text{Area of circuit side opening}}{\text{Area of aperture walls}}
\]

**Transfer Efficiency, TE**

\[
% \text{TE} = \left( \frac{\text{Volume of paste deposited}}{\text{Volume of stencil aperture}} \right) \times 100
\]

- As electronics become more miniaturized:
  - Interconnections become smaller
  - Area Ratios are lower
  - Transfer Efficiencies drop and variability increases
- Lower ARs (0.66) present substantial challenges to High-yield solder paste printing
Solder Paste Release from Stencil

After the aperture is filled, the solder paste sets up and sticks to both the stencil walls and the pads.

At separation, the forces holding the deposit to the pad must overcome the forces holding the deposit to the stencil walls.

Depending on area ratio, a portion of the paste will release to the PWB, while some will stay in the aperture. Some paste may also stick to the bottom of the stencil due to stringing, bad gasketing or pump out.

The smaller the AR, the lower the TE
Background

- Began project last year, presented results at SMTAI 2014

**2014 Top-Down Video**
- Square apertures, AR 0.71
- Look for time to clear and residual paste

**2015 Top-Down Video**
- Round and square apertures, AR range from 0.45 to 0.70
- Look for snap back and size of apertures that clear
Background

- Began project last year, presented results at SMTAI 2014

2014 Side-View Video
- Square apertures, AR 0.71
- Lower mag, higher focal distance, lower resolution

2015 Side-View Video
- Round apertures, AR’s of:
  - 0.60, 0.65, 0.70
  - 0.45, 0.55, 0.65
- Higher mag, closer focus, higher resolution
Aperture Walls

- Aperture wall quality further exacerbates low AR print challenges
  - More friction and resistance to fluid flow, fissures to trap paste powder spheres, higher contact area for adhesion

- Smooth walls are needed
  - Not easy to achieve, depends heavily on laser cutter and stainless steel alloy
Nano-Coated Walls

- The polymer nanocoating used in this test
  - Fills the valleys in the cut and smoothes the walls
  - Repels solder paste
  - Improve Transfer Efficiency:
    - Less adhesion between paste and wall
    - Less surface area of wall
SMT Stencil Nanocoatings

- Nano-coating covers walls and stencil’s PCB contact surface, but *not* the solder paste side

- Polymer coatings:
  - Fill the peaks and valleys created by the laser cutting process
  - Lower aperture wall and PCB contact side adhesion properties

- Thinner, non-polymeric (SAMP) nanocoatings:
  - Do not smooth the peaks and valleys in the same way as polymeric coatings
  - Do lower the adhesion properties
  - Reduce the surface energy of the stencil

- Nanocoatings helps repel flux
  - Prevents wicking
  - Helps ameliorate gasketing issues
  - Less smearing during under wipe
EXPERIMENTAL METHODS
Methodology

- To visualize solder paste release mechanics
  - Tests were devised to capture videos during the separation of the PCB from the stencil

- Two angles were videoed
  - Side release
  - Top down
Videos

- Both video setups incorporated multiple ARs in each field of view
- The side view image a single row of the 0.5mm BGA 36
  - Eliminated background noise seen in last year’s videos
  - Two sets of ARs were incorporated:
    - 0.60, 0.65 & 0.70 to represent generally accepted stencil design practices for Type 3 & 4 solder pastes
    - 0.45, 0.55 & 0.65 to demonstrate the challenges associated with miniaturization
- The top-down videos image a 0.5mm BGA 36
  - ARs ranging from 0.45 to 0.70 in 0.05 increments
  - Both circular and square apertures ranged in size from 180-280µms (7-11mils) on a 100µm (4mil foil)
## Side View Aperture Sizes

### 100µm/4mil foil

<table>
<thead>
<tr>
<th>Area Ratio:</th>
<th>Hole Size, µm:</th>
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<tr>
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<table>
<thead>
<tr>
<th>Area Ratio:</th>
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<td>0.65</td>
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</table>
Top View Aperture Sizes

100µm/4mil foil

Area Ratio:

Hole Size, µm:

180 200 220 240 260 280

Hole Size, mil:

7.1 7.9 8.7 9.5 10.2 11.0
Stencil Manufacturers

- Stencil #1 – US
  - Laser cut
    - 100µ (4mil)
    - Fine Grain foil
    - No Nanocoating

- Stencils # 2 & 3 - EU
  - Laser cut
    - 100µ (4mil)
    - Fine Grain foil
    - One stencil was nanocoated with a Polymer nanocoating
    - One stencil was not nanocoated
    - Stencils 2 & 3 came from same manufacturer
    - SEM of walls shown

- Wiping effects
  - Dry Vac / Dry Vac
  - Solvent Vac / Dry Vac
Solder Pastes Tested

- **No-Clean A**
  - Type 4.5
  - New formulation introduced in 2014

- **No-Clean B**
  - Type 4
  - New Formulation introduced in 2015

- **No-Clean C**
  - Type 4
  - New Formulation introduced in 2015

<table>
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<tr>
<th>Type Designation</th>
<th>Mesh Size (lines per inch)</th>
<th>Particle Size, um (at least 80% in range)*</th>
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Print Sequence

- Start with squeegee in back
- Print 2 boards
- Video top-down release of BGA on bd #2
- Print 2 boards
- Video side-view release of BGA on bd#4 (no wipe)
- Print one board
- Wipe – 5th print
- Video top-down view of wipe
- Print one board
- Video side-view of BGA on board #6 (after wipe)
Print Process

**Print Parameters**
- Squeegee speed: 63mm/sec (2.5 in/sec)
- Squeegee pressure: 0.2 kg/cm (1.1 lb/in)
- Separation speed: 0.05mm/s (0.02in/sec)
  - Note that this is slower than typical but enables better video

**Run Order**
- 0.60 – 0.70 ARs and square BGA apertures
- 0.45 – 0.65 ARs and circular apertures
  - Two replicates of each run in first phase of experiment
  - One replicate in second, third phases
Phase 1 – Uncoated stencil

- Side view release

<table>
<thead>
<tr>
<th>Solder Paste</th>
<th>Side View ARs</th>
<th>Top View Aperture Shape</th>
<th>Wipe</th>
<th>Prints</th>
<th>Clean</th>
<th>Video #</th>
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<tbody>
<tr>
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Phase 1 Side View Findings

- Paste A did not release well – at all
  - Not typical for this product
  - Was within date code but not sure of refrigeration/handling history
  - Partially discounting results due to poor printing, but results did trend consistently with B & C

- Pastes B and C printed very well
  - Conclusions based primarily on behavior of pastes B & C
  - Within date code and handling history known
  - Fantastic illustrators of effects of clean/unclean and nanocoated/not coated
Dirty vs. Clean – Uncoated Stencil

- **“Dirty”** condition is 4th print without wipe
  - Not an exceptionally long wipe interval
- **“Clean”** condition is 1st print after solvent wipe
  - 5 prints before wipe to get squeegee in right position
Top View Release Videos

- Videos show the paste getting pulled from the apertures, stretching and snapping back into the apertures
- From top, many apertures appear fully blocked, but they did transfer paste to the PCB:
Square vs. Circle

What releases better?

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<th>ARs:</th>
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<td>10.2</td>
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Uncoated stencil, Paste C
# Phase 2 – Nanocoated Stencils

## Side view release

Polymer nanocoating

<table>
<thead>
<tr>
<th>Solder Paste</th>
<th>Side View ARs</th>
<th>Top View Aperture Shape</th>
<th>Wipe</th>
<th>Prints</th>
<th>Clean</th>
<th>Video #</th>
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<tbody>
<tr>
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<td>36</td>
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</table>
Dirty vs. Clean – Nanocoated Stencil

- Lower ARs
- No discernable difference in release in this comparison
Dirty vs. Clean – Nanocoated Stencil

- Higher ARs
- Clean stencil appears to have slightly flatter tops
- Clean stencil shows slightly less sticking
Is solvent needed with Nanocoating?

- Visual indicators showed similar release with both dirty and clean stencils
  - “Dirty” was defined as 4 prints without wipe, in an ideal environment with good board support, alignment, and gasketing (due to larger pads, smaller apertures) and no pause time to let the paste dry
  - Real-life production results may differ 😐

- Previous tests showed that flux smeared across bottom of nanocoated stencil using dry wipe only
  - Flux can redeposit on PCB between conductors, get baked on, be resistant to cleaning, and create signal integrity issues
  - The sticky film contacting the PCB makes stencil-PCB separation more difficult
Solvent vs Dry Wipe on Nanocoated Stencil

Solvent Wipe

Dry Wipe

Tests were performed using wipe-on (SAMP) nanocoating with solder paste treated with UV tracer dye and a black light to show the flux smearing.

What about the Bottom View?

Good

Bad
Nanocoating vs. No Nanocoating

- Nanocoating is always better. **ALWAYS**
- Videos at low ARs

![Nanocoated](image1)
![Not Nanocoated](image2)
Phase 3 – Wipe Effectiveness

- Top View
- Non-coated stencil #1
- 2-pass wipe
  - Wet with vacuum, Dry with vacuum (W-D)
  - Dry with vacuum, dry with vacuum (D-D)
## Dry Vac / Dry Vac

<table>
<thead>
<tr>
<th>Solder Paste</th>
<th>Square Apertures</th>
<th>Circular Apertures</th>
</tr>
</thead>
</table>

- **A Round Apertures**

[Image of dry vacs with square and circular apertures]
<table>
<thead>
<tr>
<th>Solder Paste</th>
<th>Square Apertures</th>
<th>Circular Apertures</th>
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## Solder Paste

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<td>![Square Apertures Image]</td>
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**Dry Vac / Dry Vac**

- **Round Apertures**
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<td>Paste C</td>
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## Wet Vac / Dry Vac

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</thead>
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<td>Paste C</td>
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Dry or Wet Wipe?

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<tr>
<td>Paste C</td>
<td><img src="image1" alt="Dry Apertures" /></td>
<td><img src="image2" alt="Wet Apertures" /></td>
</tr>
</tbody>
</table>
## Dry or Wet Wipe?

<table>
<thead>
<tr>
<th>Solder Paste</th>
<th>Circular Apertures (Dry)</th>
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INFERENCES FROM DATA FINDINGS
Side View Videos

- Side view lighting
  - Critical to see the solder paste snap-off resolution
  - Slow separation speed (0.05mm/sec) was used to aid in capturing
    the video may influence release

- Phase 1 Side-view videos show differences in release properties between
  - Solder paste formulations
  - Stencil cleanliness conditions
  - Solder paste A videos showed poorer release performance than pastes B or C
  - Pastes B and C showed better release from a clean stencil than a dirty one
Phase 1 Non-Nanocoated Stencil

- Smaller apertures substantially impacted transfer efficiency
- The Understencil Wipe before a print appeared to improve transfer efficiency on non-nanocoated stencils
- Square apertures appeared to release better than circular ones
  - 0.55 AR is where most circular apertures showed residual paste across the span of the aperture
  - Squares apertures were still partially open at the 0.55 and 0.50 ARs
Phase 2: Nano-coated vs. Non-Nanocoated

- Transfer Efficiency was far superior using nanocoated stencil as compared to the non-nanocoated stencil
  - Both stencils from same supplier

- Transfer efficiency before and after understencil wipe
  - On Nanocoated stencil, little difference in transfer efficiency for dirty vs clean wipe
  - Nanocoating keeps the stencil contact surface cleaner by repelling the flux

- All three solder pastes tested performed better when using the nanocoated stencil
  - Some were very impressive at the 0.45 AR!

- The smaller the aperture, the greater the effect of the nanocoating on TE
Phase 3: Wet vs. Dry Wipe

- Difference between the wet and dry
  - Similar results
  - Small sample sizes are not enough to conclusively state that wet wiping is more effective at clearing small, non-nanocoated apertures

- Previous testing conclusively showed that
  - Wet wiping removes flux residues from the PCB contact surface of the stencil
  - Important factor in clean separation
  - Redeposition of flux or bottom side of stencil
CONCLUSIONS
Miniaturization

- Exhibits considerable implications on
  - Assembly process
  - Overall output quality
  - Long-term product reliability

- Small feature sizes that drive ARs below 0.65
  - Demonstrate a considerable decline in TE
  - Substantial increase in variability, even with some of the newest, highest performing solder pastes currently on the market

- Nanocoatings and solvent wipes combine to form a best-in-class SMT print process

The basic stencil printing process can no longer support small feature sizes without (sometimes) disruptive changes to the materials and process
Key Findings

- Stencil nanocoating
  - Enabling technology
  - Increases solder paste transfer rates
  - Reduces variability in transfer rates (prior studies)

- Under stencil wiping also improves
  - Print quality, especially on non-nanocoated stencils

- Nanocoated stencils
  - Not as dependent on wiping as non-nanocoated stencils

- The use of solvents in under stencil wiping
  - Removing solder paste from apertures
  - Flux on the PCB contact side of the stencil
Video and Still Images

- Visual images
  - Illustrate the relationship between AR and TE
  - Associated variability
  - Adds a visible dimension to the challenges faced on the assembly line, and the nuances left uncaptured by standard SPI
End-Use Reliability

- The more miniaturized and variable the joint formation
  - The lower the overall reliability of the product
- ARs of 0.55 or lower, or on devices with low standoff interconnects like LGAs, BTCs, or 0201 or smaller chips
  - Nanocoated stencils improve TE
  - Wet Wipe improves
    - Solder paste release from apertures
    - Presents flux from smearing onto the PCB stencil side
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