Development and processing of an ink jettable soldermask and advantages of use in PCB manufacture
Development process for Inkjet Soldermask

- Understand Inkjet application process
- Identify Inkjet Soldermask formulation constraints
- Identify and source suitable candidate raw materials
- Meet soldermask performance requirements
- External compliance requirements
- Advantages of inkjet soldermask process
- Strategies for Print Optimization
Understand Inkjet application process

1. Types of head
   1. DOD Piezo
   2. Recirculating
   3. Non-recirculating

2. Influence of head type
   1. Droplet size
   2. Resolution
   3. Heating capability
Ink droplets
Ink droplets
Inkjet head manufacturers

KONICA MINOLTA

Dimatix

SII

XAAR

KYOCERA

TOSHIBA TEC

RICOH
Non-recirculating head

- Konica Minolta KM1024i
  - 360npi (90npi x 4 lines)
  - 6pl
  - Typical freq 50kHz
  - Max freq 60kHz
  - Width 72mm
  - Integrated heater
Recirculating head

- Fujifilm Dimatix Samba G3L
  - 2,4pl
  - 2048 nozzles/head
  - 1200dpi
  - Width 43mm

- Claimed benefits
  - More stable jetting performance
    - Prevents pigment/particle sedimentation
    - Reduces nozzle clogging
Identify Inkjet Soldermask formulation constraints

- Limited raw material suitability
  - Restricted to v.low viscosity resins and monomers
  - Pigment particle size <200nm (c.f. 5 -15μm for conventional soldermasks)

- Low or no filler content c.f “conventional soldermask)
  - Affects flammability
  - thermal shock and
  - solder resistance.
Identify Inkjet Soldermask formulation constraints

• Low viscosity, surface tension
  – Varies according to print head type
  – Constrained by laws of physics to achieve good jetting performance.
  – Results in tendency for pigment sedimentation on storage and to spreading, bleed and track edge thinning on printing.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reynolds number</td>
<td>( Re = \frac{v \rho \alpha}{\eta} )</td>
</tr>
<tr>
<td>Weber number</td>
<td>( We = \frac{v^2 \rho \alpha}{\gamma} )</td>
</tr>
<tr>
<td>Ohnesorge number</td>
<td>( Oh = \sqrt{\frac{We}{Re}} )</td>
</tr>
<tr>
<td>Fromm Z parameter</td>
<td>( Z = \frac{1}{Oh} )</td>
</tr>
<tr>
<td>Stable drop formation</td>
<td>( 10 &gt; Z &gt; 1 )</td>
</tr>
</tbody>
</table>

• Contact angle
  – Influences coating performance of subsequent layers jetted onto pin-cured layers.
Identify Inkjet Soldermask formulation constraints

- UV cure type/speed
  - Acrylate – free radical cure
  - Epoxy – cationic cure
  - Hybrid – combination epoxy/acrylate system
- Thermal final cure
Identify and source suitable candidate raw materials

- Low viscosity monomers
  - Restricted choice of monomers
  - (H&S concerns because of low viscosity)
- Suitable photoinitiators to achieve good pin/through cure
  - Prevent “wrinkling”
- Stable pigment dispersion(s)
- Flow agents/surface property modifiers/thermal curing agents . . .
Formulate test products

1. Screen formulations for basic solder mask properties
2. Modify formulations as required
3. Select formulations for jetting tests
4. Evaluate jetting performance of selected formulations
5. Evaluate cured coating performance
6. Modify formulations as required
7. Repeat 3 – 8 as required
8. Submit final formulation(s) for external compliance testing
Lab printer

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Solder mask performance requirements

• Protect copper circuitry
  – Chemically
  – Electrically
  – Physically

• from
  – High Temperatures
  – Humidity and moisture
  – Corrosives
  – Dust, dirt, contamination
Why we need soldermask!
Solder mask performance requirements

- ENIG & Immersion Sn/Imm Ag plating chemistry
- Solder dam resolution
- Pb free soldering
- Multiple solder reflow cycles
- Conformal coating compatibility
Soldermask performance requirements

• Low Ionic contamination
• Low/no Halogen content
  – <900ppm Cl or Br
  – <1500ppm total halogen to be “halogen free”
  – Green colour achieved by blending pigments other than phthalocyanine green- Cu(C_{32}N_8Cl_{14})

• Universal product
  – Rigid/flexible
  – Suitable for recirculating and non-recirculating heads
External compliance requirements

- UL 94V0
  - more difficult on thinner laminates
  - May need to incorporate flame retardants
- ROHS compliant
  - No heavy metals
- SM840E – H or T
- NASA Outgassing
  - NASA spec - SP-R-0022A/ASTM E 595
External compliance requirements

• Automotive Standards
  – Bosch -
    • TC7 – (-40/150 deg C, 1000 cycles)
    • TC8 - (-40/160 deg C, 1000 cycles)
    • TC9 - (-40/160 deg C, 2000 cycles)
  – Hella –
    • G2 - (500 cycles, -40/170 deg C)
    • G3 - (1000 cycles, -40/170 deg C)
    • (G4 - (2000 cycles, -40/170 deg C))??

• Customer specific specs
Advantages of inkjet soldermask process

- Reduction in process steps/time compared to LPISM process

**Traditional** process flow

- Pre-treat
- Coat
- Dry
- Produce artwork
- Expose
- Develop
- Cure

**Inkjet printing** process flow

- Pre-treat
- Print
- Produce artwork
- Expose
- Develop
- Cure

- Eliminates coating, artwork, exposure and development
- Elimination of drying ovens, high power UV exposure equipment
- Smaller process line footprint
- Reduction in energy costs
- Reduced WIP
Advantages of inkjet soldermask process

• Digital “artwork”
  – created straight from Gerber data or via bit-map

• Potential for high throughput
  – depends on number of heads, droplet size

• Additive process – minimal wastage

• Low/no solvent emissions
  – (150 kg/mth LPI ≡ 630kg/year solvent emitted)

• Registration compensation
  – Image stretching and offset to allow for board distortion

• Reliability
  – Repeatable process
  – 100% solids
  – No undercut at image edges
Image edge characteristics
Image edge characteristics
Inkjet soldermask Electrajet® EMJ110

EMJ110 Desired Dam shape to stop chemistry entrapment

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Inkjet soldermask Electrajet ® EMJ110

LPI screen soldermask undercut chemistry entrapment
Spoiler Alert

- Soldermask adhesion/chemical resistance and print quality very dependent on surface preparation
  - High roughness chemical clean gives best results to date.
  - Specialised surface treatments to minimize droplet spread.
Strategies for Print Optimization

• Pin cure to fix droplets in place
  – Low level UV cure for droplets in each layer

• Multilayer print profiles
  – create dams around pads and prevent thinning on track edges
  – Can be used to build thickness selectively thickness,
  – eliminate “striping” and stitch lines
  – different ink surface finishes.

• Print profiles (“recipes”) to suit different board designs
Strategies for Print Optimization

Layer 1 & 2 – dams + edges
Strategies for Print Optimization

Layer 3 – print over Au and FR4

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Strategies for Print Optimization

Layer 4 – final gloss finish
Strategies for Print Optimization

First layer - infill
Strategies for Print Optimization
Second layer – top coat
Strategies for Print Optimization

Pyramid structure – 180 microns
Strategies for Print Optimization

Pyramid structure – >200 microns
Inkjet soldermask Electrajet® EMJ110
Track coverage

2 Layers

Ink on top of track
Length: 27.76μm

Ink on track edge
Length: 9.54μm

Ink on track edge
Length: 9.37μm

Cu height
Length: 82.84μm

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Inkjet soldermask Electrajet ® EMJ110
Track coverage

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## Inkjet soldermask Electrajet® EMJ110

### Final properties

<table>
<thead>
<tr>
<th>TEST/STANDARD</th>
<th>REQUIREMENT</th>
<th>RESULT</th>
</tr>
</thead>
<tbody>
<tr>
<td>IPC SM-840 E</td>
<td>CLASS T &amp; H</td>
<td>PASS</td>
</tr>
<tr>
<td>UL94</td>
<td>V-0</td>
<td>PASS</td>
</tr>
<tr>
<td>THERMAL STORAGE DIN IEC 60068-2-14</td>
<td>TC7 1000h at 150°C</td>
<td>PASS</td>
</tr>
<tr>
<td>THERMAL SHOCK DIN IEC 60068-2-14</td>
<td>TC7 -40°C, 150°C, 1000 cycles TC8 G3</td>
<td>PASS</td>
</tr>
<tr>
<td>ADHESION TO GOLD</td>
<td>Cross-hatch &amp; tape test</td>
<td>PASS</td>
</tr>
<tr>
<td>FLEX TEST</td>
<td>180° crease – tape test</td>
<td>PASS</td>
</tr>
<tr>
<td>SOLVENT RESISTANCE</td>
<td>30 seconds methylene chloride</td>
<td>PASS</td>
</tr>
</tbody>
</table>

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<thead>
<tr>
<th>TEST/STANDARD</th>
<th>REQUIREMENT</th>
<th>RESULT</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACID RESISTANCE</td>
<td>10% HCl, 30 min dip at 20°C – tape test</td>
<td>PASS</td>
</tr>
<tr>
<td>ALKALI RESISTANCE</td>
<td>10% NaOH, 30 min dip at 20°C – tape test</td>
<td>PASS</td>
</tr>
<tr>
<td>LEAD-FREE SOLDER</td>
<td>3 x 10s at 288°C – tape test</td>
<td>PASS</td>
</tr>
<tr>
<td>ENIG RESISTANCE</td>
<td>Ni 5-10 microns, Au &lt;0.1 microns – tape test</td>
<td>PASS</td>
</tr>
<tr>
<td>PRESSURE COOKER (PCT)</td>
<td>100 min at 121°C (2 atm) – tape test</td>
<td>PASS</td>
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<tr>
<td>DIELECTRIC CONSTANT</td>
<td>Measured at 10GHz, 22°C</td>
<td>2.99</td>
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<tr>
<td>DISSIPATION FACTOR</td>
<td>Measured at 10GHz, 22°C</td>
<td>0.0228</td>
</tr>
</tbody>
</table>
# Electrajet® EMJ110

Inkjet soldermask Vs LPI screen print soldermask

<table>
<thead>
<tr>
<th>Test</th>
<th>ELECTRAJET EMJ110 SOLDERMASK</th>
<th>LPI SCREEN PRINT SOLDERMASK</th>
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</thead>
<tbody>
<tr>
<td>IPC SM840 E Class H &amp; T</td>
<td>PASS</td>
<td>PASS</td>
</tr>
<tr>
<td>UL 94 V-0</td>
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<td>PASS</td>
</tr>
<tr>
<td>THERMAL STORAGE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TC7 1000h at 150°C</td>
<td>PASS</td>
<td>PASS</td>
</tr>
<tr>
<td>TC9 2000h at 160°C</td>
<td>UNDER TEST</td>
<td>PASS</td>
</tr>
<tr>
<td>HELLA E3_{1000}</td>
<td>PASS</td>
<td>PASS</td>
</tr>
<tr>
<td>HELLA G3/4_{2000}</td>
<td>UNDER TEST</td>
<td>UNDER TEST</td>
</tr>
<tr>
<td>THERMAL SHOCK</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TC7 -40°C, 150°C, 1000 cycles</td>
<td>PASS</td>
<td>PASS</td>
</tr>
<tr>
<td>TC9 -40°C, 160°C, 2000 cycles</td>
<td>UNDER TEST</td>
<td>PASS</td>
</tr>
<tr>
<td>HELLA E3_{1000}</td>
<td>PASS</td>
<td>PASS</td>
</tr>
<tr>
<td>HELLA G3/4_{2000}</td>
<td>UNDER TEST</td>
<td>UNDER TEST</td>
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<tr>
<td>REACH &amp; RoHS</td>
<td>PASS</td>
<td>PASS</td>
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</tbody>
</table>

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Thank You!