Solder Flux Evolution for Heterogeneous Integration

Evan Griffith
Indium Corporation
IMAPS DPC
Outline

• Introduction
• Flip Chip Flux
• Ball-Attach Flux
• Flux-Free Processes and Materials
• Summary
Introduction

Advanced Packaging Needs

- Higher functional performance
- Smaller form factor / higher density
- Higher frequency

Challenges:

- Tighter pitch & smaller joints
- Thin/coreless substrate, thin/large die

- Flux residue cleaning effectiveness
- Warpage induced open joints
## Characteristics of Flux

<table>
<thead>
<tr>
<th></th>
<th>Regular NC Flux</th>
<th>NC-ULR Flux</th>
<th>WW Flux</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cleaning Equipment</strong></td>
<td>Typically Not Needed</td>
<td>Not Necessary</td>
<td>Required</td>
</tr>
<tr>
<td><strong>Cleaning Solution</strong></td>
<td>Typically Not Needed</td>
<td>Not Necessary</td>
<td>Required</td>
</tr>
<tr>
<td><strong>Typical Residual Amount</strong></td>
<td>20~60%</td>
<td>0~10%</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Compatibility with Underfill</strong></td>
<td>Typically Low</td>
<td>Good</td>
<td>Good (After Clean)</td>
</tr>
<tr>
<td><strong>Wetting Power</strong></td>
<td>Strong</td>
<td>Good</td>
<td>Strong</td>
</tr>
<tr>
<td><strong>Formulation Aspect</strong></td>
<td>Hydrophobic Ingredients</td>
<td>Hydrophobic and Minimum of High Molecular Weight Ingredients</td>
<td>Hydrophilic Ingredients</td>
</tr>
<tr>
<td><strong>Post Heat Treatment (TCB/LCB)</strong></td>
<td>150°C (or 180°C) for an hour for TCB</td>
<td>150°C (or 180°C) for an hour for TCB</td>
<td>150°C (or 180°C) for an hour for TCB</td>
</tr>
</tbody>
</table>
Flip-Chip Challenges

• Package Design Changes
  – < 100um pitch
  – < 60um die clearance
  – Thin substrates (<20um) suspect to warpage

• Resulting Cleaning Challenges
  – Pitch reduction limits ability to completely remove water soluble flux residues:
    • Corrosive residues left behind
    • Block flow of CUF and MUF leading to underfill voiding
    • Interfere with CUF and MUF adhesion causing delamination
  – Cleaning process:
    • Increases substrate warpage after reflow and before underfill
      – Die damage
      – Cracked solder joints
    • Adds costs
Flip Chip Die Attach Challenges

Warpage

- Thinner Substrates
- Larger and thinner die
- Asymmetrical bump design

Open joints

Possible solutions

- Flux with better wetting or higher tack to hold die in place - even with warpage
- Mass reflow → TCB/LAB
Flip Chip Die Attach Challenges
Mass reflow + Water Washable Flux

- Shrinking pitch, tighter die-substrate clearance
- Flux residue cleaning challenges

Dendrite
Conductive residue
Underfill void & delamination

- Possible solutions
  - No clean process using ultra-low residue (ULR) flux
  - Fluxless process
Assembly Process Flow

Mass Reflow

- Flip-chip flux Dipping
- Die attach on substrate/wafer
- Reflow (Typical 4-6mins)
- Flux Cleaning

Formic Acid Reflow

- Flip-chip Tacky/Adhesive Dipping
- Die attach on substrate/wafer
- Formic Acid Reflow
- Adhesive solution fully burnt off
- No cleaning needed

Thermo-compression (TCB) or Laser-Assisted Bonding (LAB)

- Flip-chip flux Dipping
- Die attach on substrate/wafer
- TCB or LAB (Typical <10sec)
- Flux Cleaning

Pedestal at 100-150°C

Not needed for ULR-NC fluxes, though post bake required to reduce flux residue

Not needed for ULR-NC fluxes, though post bake required to reduce flux residue
# TCB / LAB Reflow

Less and shorter heat exposure reduces warpage

<table>
<thead>
<tr>
<th></th>
<th>Mass Reflow</th>
<th>TCB</th>
<th>LAB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal Stress on ELK</td>
<td>5x</td>
<td>1x</td>
<td>2x</td>
</tr>
<tr>
<td>Warpage</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>UPH / Productivity</td>
<td>Fast</td>
<td>Slow/Moderate</td>
<td>Fast</td>
</tr>
<tr>
<td>Selective soldering</td>
<td>No</td>
<td>Die only</td>
<td>Yes</td>
</tr>
<tr>
<td>Multidie &amp; components</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Selfalignment</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Fine pitch capability</td>
<td>Challenging</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

LAB: no z-axis compressive forces
TCB / LAB Reflow

Short “pulse” profiles for TCB and LAB necessitate post-reflow heat treatment for ULR Fluxes
TCB / LAB Reflow

Heated pedestal (typically around 100-150°C) holds the substrate or wafer for the whole duration of TCB process (1-2hrs or longer)

- If standard water washable or no-clean flux is used, excessive “baking” at 100-150°C may hardened flux residue further, making it difficult to be cleaned off
- For fine pitch micro bump/Cu pillar, flux induced corrosion may happen at such temperature for prolong hours
Flip Chip Flux
Residue levels from TGA

* Residue level was measured by gravimetric method before and after reflow using typical lead free SAC profile with convection oven.

**Thermogravimetric analysis**

<table>
<thead>
<tr>
<th>Flux Type</th>
<th>Viscosity (kcs)</th>
<th>Residue Level*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flip Chip Flux NC 026S</td>
<td>20</td>
<td>7~8%</td>
</tr>
<tr>
<td>Flip Chip Flux NC 26A</td>
<td>4</td>
<td>~4%</td>
</tr>
<tr>
<td>Flip Chip Flux NC 699</td>
<td>1.5</td>
<td>&lt;1%</td>
</tr>
</tbody>
</table>

Standard reflow peak maximum
ULR Flux
Compatibility with Molded Underfills

HT: steam autoclave treatment at 108.4°C / 135kPa steam pressure
Residue/CUF Compatibility

NC-26-A has good compatibility and no delamination.

Before thermal cycle:
- No baking
- Bake 180°C 1hr
- Bake 180°C 3hr

After thermal cycle:
- No baking
- Bake 180°C 1hr
- Bake 180°C 3hr

Flip-Chip Flux NC-26S
Flip-Chip Flux NC-26A
Competitor NC Flip-Chip Flux

Cut here
Formic Acid Reflow

- Formic acid (HCOOH) vapor reacts with metal oxides
  - Resulting formates are further decomposed and removed through a vacuum system
- Eliminates need for pre-reflow fluxing and post-reflow flux removal
- Need a tacky adhesive solution to be compatible with this reflow process

Metal Oxide + HCOOH -> Metal + CO₂ + H₂O

Typical formic acid reflow profile
Adhesive Solution
Near-Zero Residue & Tacky

No measurable adhesive residues present post reflow

Maintains high tack strength over time to hold chip in place
Soldering Performance

Adhesive

Typical Product
Challenges of ball attach process

– Warpage
– Compatibility of flux with passivation material
– Cleanability of flux after ball attach process
Ball-Attach Process

**Substrate Treatment**

- Pre-bake at 170°C for 2 hours
- Apply flux; Reflow at 240°C for 90 seconds; wash with cleaning chemistry at 96°C; dry for 2 hours at 130°C
- CUF: cure CUF for 2 hours at 130°C. Transfer mold EMC and post-mold cure at 130°C for 2 hours
- Laser ablate overmolding compound
- Plasma desmear

Bottom pads now poor solderability: need flux pretreatment
Challenges of ball attach process

Flux requirements

Printing
No (or low) flux smear with long stencil life

Tackiness sufficient to hold sphere in place during reflow, even with slight warpage
Challenges of FOWLP ball attach process

Flux requirements

- Compatible with passivation material
- No reaction (swelling) with various polymers; does not cause “volcano” effect
- No reaction with RDL/copper, does not cause delamination
- No residue after cleaning

“halo” ring of stain around the solder bump after cleaning

Good

Delamination and discoloration observed after reflow
Wetting Comparison: One-Step Process

![Average Spreading Ratio Graph]

- GOOD
- BAD

- Fresh Cu
- Oxidized Cu 150C 30min
- Oxidized Cu 150C 1hr
- Oxidized Cu 150C 2hr

WS575-C, WS-446-HF, Other
Cleaning Efficiency: One-Step Process

One-Step Flux

Non-One Step

OSP residue
Summary

- Proper selection and application of interconnect materials for the various assembly processes is crucial to ensuring high production yield for the assembly process for reliable packages.
  - ULR flux for TCB/LAB
  - Adhesives for Formic Acid Reflow (fluxless)
  - Flux for ball attach

- Indium Corporation is directly engaged with customers and equipment partners to bring innovations into advance packaging
Acknowledgement

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Thank You!

egriffith@indium.com