Design of Filled One Step Chip Attach Materials (OSCA) for Conventional Mass Reflow Processing: Rheology Considerations for Jet Dispensing and Die Placement

Daniel Duffy, Hemal Bhavsar, Lin Xin, Jean Liu, Bruno Tolla
Kester Inc., Itasca IL
Outline

Introduction

- Conventional Flip Chip Assembly Process
- One Step Chip Attach Process & Materials (OSCA)

OSCA Materials for Reflow Processing (OSCA-R)

- Design for Dispensing & Die Placement - Fillers
- Copper Pillar Test Vehicle
- Reflow Processing
- Assembly by Conventional Reflow

Summary & Conclusions

Acknowledgements
Conventional Flip Chip Assembly Process

- Flux / Chip Place
- Reflow
- De-flux
- Underfill
- Post Cure

New and Improved Process Flow

- Flux & Die Placement
- Underfill
- Cleaning
- Post Cure Underfill

Confidential
Advantages of OSCA Materials & Process

Process Simplification + Throughput

Dispense OSCA-R  Place Die

Flux / Chip Place  Reflow  De-flux  Underfill  Post Cure

Next Process Step

Dispense OSCA-R  Die Placement  Conventional Reflow Processing
Assembly Using OSCA-R Materials

Reduced complexity and increase throughput

Die on Carrier → Pick & Place Die → Dispensing → Substrate → Mass Reflow → Assembled Devices
Assembly Using OSCA-R

- Die on Carrier
- OSCA Dispensed on Wafer
- Die Placement
- Wafer Dicing - Assembled Devices
- Mass Reflow
- Additional Wafer Level Assembly Steps
- Functional Wafer, Glass or Ceramic
- Multi-Die Assembly 3D Integration Die Stacking
- Multi-Die Assembly
Multi-Die Assemblies Using OSCA-R

- Dense Die Placement
- No Need to Leave Room for Dispensing Needles (cap fill)
- Wafer or Multi-Die Substrate
- OSCA-R
- Die Placement
- Jet Dispense
- Interconnected Multi-Die Assembly
- Reflow
- Dicing or Additional Assembly Steps
- OSCA-R Amenable to Various Cu Pillar Configurations or Micro-Bump Geometries
Die Stack Assembly Using OSCA-R
One Step Chip Attach Process & Materials

1/ Rheological Profile designed for Assembly
   - Dispensing
   - Controlled Flow & Wetting
   - Die Placement
   - Filet Formation

2/ Fluxing & Cure Kinetics balanced for appropriate sequencing
   - Assembled Device
   - OSCA Curing
   - Solder Wetting & Interconnection
   - Fluxing
   - Reflow Processing

Key formulation design considerations for OSCA-R materials
- Rheology/flow for dispensing and die placement
- Balance of fluxing & cure chemistry during reflow processing
- Final cured properties, interconnection and reliability
OSCA-R Material Design

- OSCA-R is a multi-functional reactive mixture that fluxes and then thermally cures to a high performance thermoset polymer composite during reflow processing.
OSCA-R Design – Flow Fluxing & Cure

- Particle effects on flow and cure
  - Understand chemical and physical interactions
  - Anticipate and take advantage of for material design

Interfacial Chemical Effects

Confinement & Diffusion Effects

Balance of Inter-particle Forces in a Reactive System
OSCA-R Flow – Filler Loading

- First step in filled system design – understand loading response

![Graph showing relative viscosity at 25°C versus filler volume fraction with the equation $y = 0.95e^{4.08x}$ and $R^2 = 0.99$.]

Use semi-empirical modeling to help design and select fillers and resins for best flow response.
OSCA-R Flow – Filler Size

- Second step in filled system design – understand filler size response
  - Sub micron fillers required for fine pitch assemblies
OSCA-R Flow – Filler Interface Design

- Final step for filled system design – particle interface and interactions with resin
Dispensing

OSCA-R materials designed for use with different dispense technologies

- **Time-Pressure**
  - PDP - Auger
- **Auger**
- **Jet**
  - SmartStream™
  - NanoShot™

Dispensing → Controlled Flow & Wetting
OSCA-R Flow – Shear Rate Response

- Design a non-Newtonian rheology response for dispensing and placement

![Graph showing shear rate response with labels for low shear yield stress, shear thinning, recovery, and high shear.](image-url)
OSCA-R Flow – Under Compression and Extension

- Flow under compression and tension → Placement and dispense
OSCA-R Design for Dispense

- Filled system design – avoid “stringing” and enable clean release during jet dispensing
OSCA-R Flow - Dispensing

Fluids with shear thinning / yield stress behavior meet patterning & flow control CTQs

- Formation of Stable Droplets
- Wetting & Flow Control During dispense No Stringing
- Controlled Flow Pattern & Shape Retention

Viscosity (Pa-s) at 25°C vs. Shear Rate (Hz)
OSCA-R Flow - Dispensing

OSCA-R materials have good jet dispensing characteristics and pattern retention. Controlled flow keeps materials out of “no-go” zones and avoids bleed out.

![Viscosity vs Shear Rate Graph]

OSCA-R Dispensed on Test Vehicle
OSCA-R Flow - Die Placement

OSCA-R materials designed to overcome key placement challenges

- Flow properties enable dispense pattern and void elimination

- Flow behavior during die placement under compression can complicate accurate die placement
OSCA-R Flow - Die Placement

OSCA-R materials designed to overcome key placement challenges and to be compatible with common placement technologies.

- R&D Bonder
- Board Level Assembly
- Flip Chip Assembly
- Thermo Compression Bonding
OSCA-R Flow - Die Placement

Finetech die bonder system

- Multi step placement procedure ensures die contact, and flow

- Approach Step 1
- Approach Step 2
- Apply Force
- Hold
- Retract Placement Tool

- High Speed
- Low Speed
- Change Over Distance 0.5 to 2 mm
- Force 1 to 15 Nt (10x10 mm die)
- Dwell 0.05 to 0.2 Sec

- Depends on Deposit Profile & Die Size / Shape

Make Contact with Substrate Drive to Target z-position

Confidential
OSCA-R Reflow Processing

Timing kinetics of fluxing, solder melting, interconnection and cure
Cu pillar test vehicle used for OSCA-R evaluations

Wafer thickness = 0.75mm
Die size = 6.35x 6.35mm.
Two daisy chained arrays
Central Array  20x 20 bumps (400)
Perimeter Array is 5x 70 bumps per side (1300)
128 interstitial bumps

Pitch = 80 microns
Cu Pillar Height = Diameter = 40 micron
10 micron SnAg cap on pillars
Cu Pad Diameter = 40 microns
Cu Pad Height = 10 micron
Examples of reflow profiles used to assemble devices with OSCA-R materials

- Range of profiles for different assembly applications
Illustration of relationship between placement voids and ORCA-R rheology design
OSCA-R Assembled Devices

Successful assembly of devices with copper pillar features using conventional reflow processing and OSCA-R materials
Summary & Conclusions

One Step Chip Attach (OSCA-R) materials can be used to assemble devices with copper pillar features using convection or conduction mass reflow

- Single die devices assembled in this work
- Can be extended to wafer level
- Can be used for 3D assembly
- Device density increase, close placement
- Approach reduces complexity of manufacturing with respect to conventional processing
- Higher throughput with use existing processing equipment
Summary & Conclusions

Approaches to overcoming the key technical challenges presented

- Systematic studies of soldering, rheology cure kinetics and used to design OSCA-R materials for dispensing and successful assembly
- Die and substrate size, configuration and type are integral considerations for OSCA-R materials and processing

Process integration is key to enabling OSCA-R materials

- Chemistry matched to desired reflow processing
- Rheology adjusted for dispensing and die placement process
Thank You for Your Attention

Questions?

Acknowledgements:

Kester Inc. → David Eichstadt, Maulik Shah, Chris Klimaszewski, Jim Lowe, Kal Chokshi

ITW Innovation Center → Marina Litvinsky

Research Triangle Institute, NC. → Chris Gregory, Alan Huffman

TA-Instruments → Gregory Kamykowski PhD, Kushal Modi

Finetech → Neil O’Brian, Adrienne Gerard, Wade Gay

Sonoscan → Michelle Forbes
OSCA-R Material Properties

- Rheology, viscosity, flow properties tunable for target dispensing/flow during die placement, cure kinetics and thermomechanical properties

<table>
<thead>
<tr>
<th>Property (method)</th>
<th>Units</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Filler %</td>
<td>Wt%</td>
<td>40</td>
<td>55</td>
<td>0</td>
<td>40</td>
</tr>
<tr>
<td>Filler Size</td>
<td>micron</td>
<td>0.5</td>
<td>0.5</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Tg (a)</td>
<td>°C</td>
<td>159</td>
<td>125</td>
<td>116</td>
<td>125</td>
</tr>
<tr>
<td>CTE-1 (a)</td>
<td>ppm/K</td>
<td>46</td>
<td>36</td>
<td>68</td>
<td>49</td>
</tr>
<tr>
<td>CTE-2 (a)</td>
<td>ppm/K</td>
<td>138</td>
<td>117</td>
<td>212</td>
<td>163</td>
</tr>
<tr>
<td>ΔH (b)</td>
<td>J/g</td>
<td>235</td>
<td>165</td>
<td>348</td>
<td>212</td>
</tr>
<tr>
<td>T-onset (b)</td>
<td>°C</td>
<td>129</td>
<td>118</td>
<td>160</td>
<td>157</td>
</tr>
<tr>
<td>T-peak (b)</td>
<td>°C</td>
<td>197</td>
<td>162</td>
<td>204</td>
<td>203</td>
</tr>
<tr>
<td>Viscosity (c)</td>
<td>Pa-s</td>
<td>49</td>
<td>26</td>
<td>2.6</td>
<td>6.8</td>
</tr>
<tr>
<td>Viscosity (d)</td>
<td>Pa-s</td>
<td>14</td>
<td>40</td>
<td>2.6</td>
<td>6.7</td>
</tr>
<tr>
<td>STI (e)</td>
<td>Ratio</td>
<td>3.5</td>
<td>0.5</td>
<td>1.0</td>
<td>1.1</td>
</tr>
<tr>
<td>Yield Stress (f)</td>
<td>Pa</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Temperature Thinning (g)</td>
<td>Kelvin</td>
<td>2200</td>
<td>7300</td>
<td>5000</td>
<td>6900</td>
</tr>
</tbody>
</table>

Thermo. Cure

Flow