Conductive Fusion Technology
Advanced Die Attach Materials for High Power Applications

Nicholas Krasco¹, Maciej Patelka¹, Steve Anagnostopoulos¹, Sho Ikeda¹, Frank Letizia¹, Toshiyuki Sato², Satomi Kawamoto², Miguel Goni³, Elbara Ziade³ and Aaron J. Schmidt³

¹ NAMICS North American R&D Center, Diemat, Inc., Byfield, MA, USA
² NAMICS Techno Core, Niigata, Japan
³ BOSTON UNIVERSITY, Department of Mechanical Engineering, Boston, MA, USA
Overview

• Background
• Concept
• Summary of Invention
• Properties and Reliability
• Conclusion
Background

Expanding the power electronics market

Increase in demand for products that are energy saving and reduce environmental footprint

Increase our attention to power electronics

2006-2020 Power device market size

Growing market size

Source: Yole’s report “Status of Power Electronics Industry 2015"
### Background

Constantly developing Wide Band Gap (WBG) power devices require:

- Save space and weight
- Lower switching losses
- Operation at higher switching frequencies

#### Solution

**SiC and GaN**

On another front...

**Emerging issue**

<table>
<thead>
<tr>
<th></th>
<th>Si</th>
<th>SiC</th>
<th>GaN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bandgap (eV)</td>
<td>1.1</td>
<td>3.3</td>
<td>3.4</td>
</tr>
<tr>
<td>Electronic mobility (cm²/V.s)</td>
<td>1350</td>
<td>700</td>
<td>1500</td>
</tr>
<tr>
<td>C.T.E. (10E-6/k)</td>
<td>2.4</td>
<td>4.4</td>
<td>3.2</td>
</tr>
<tr>
<td>Thermal conductivity (W/m.K)</td>
<td>1.3</td>
<td>4.9</td>
<td>1.3</td>
</tr>
<tr>
<td>Tj max (deg. C)</td>
<td>150</td>
<td>250</td>
<td>300</td>
</tr>
</tbody>
</table>

*The material with higher thermostability is needed for SiC and GaN*

Increase in functional temperature
Background

The issue of conventional die attach materials

- Contain organic additives: Epoxy resin, polymer powder, etc.
- Modify CTE, modulus, thermal conductivity (k), DSS, etc.
- Why?
- Thermal conductivity degradation
- Bleeding issue
- Limitations of the solvent incompatibility
- Polymer decomposition at high temp.

Potential problems

- High temperature solders
- Ag-glass adhesives
  - Do not exhibit low stress die attach properties, and have high temperature processing requirements

New die attaching material is needed.

The Solution: Low stress die attach adhesives with Soft Modifier
Ag Die Attach Adhesives

<table>
<thead>
<tr>
<th>Adhesive</th>
<th>Thermal Conductivity (W/m-K)</th>
<th>Modulus (GPa)</th>
<th>Processing Temp.</th>
<th>Use Temp.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ag-Epoxy</td>
<td>Low modulus, but low k</td>
<td></td>
<td>150°C – 200°C</td>
<td>&lt; 200°C</td>
</tr>
<tr>
<td>Ag-Glass</td>
<td>High k, but high modulus</td>
<td></td>
<td>370°C</td>
<td>300°C</td>
</tr>
<tr>
<td>Sintered Silver</td>
<td>High k, but high modulus</td>
<td></td>
<td>200°C</td>
<td>200°C</td>
</tr>
<tr>
<td>Conductive Fusion</td>
<td>High k with a controlled modulus</td>
<td></td>
<td>175-200°C</td>
<td>&gt; 250°C</td>
</tr>
</tbody>
</table>
### Standard Solder, Ag-Epoxy/Thermoplastic vs. Conductive Fusion Technology

<table>
<thead>
<tr>
<th>Data Comparison</th>
<th>PbSnAg Solder</th>
<th>AuSn Solder</th>
<th>Ag-Epoxy, Thermoplastic</th>
<th>Conductive Fusion</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Bulk Adhesive</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thermal Conductivity (1-layer k, bulk)</td>
<td>40-60 W/m-K</td>
<td>57 W/m-K</td>
<td>50 W/m-K</td>
<td><strong>100 W/m-K</strong></td>
</tr>
<tr>
<td>Storage Modulus (GPa)</td>
<td>14</td>
<td>59</td>
<td>12</td>
<td>11</td>
</tr>
<tr>
<td>Density (g/cc)</td>
<td>9</td>
<td>14.7</td>
<td>3-5</td>
<td>5</td>
</tr>
<tr>
<td><strong>Die Attach Process</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DA Temperature</td>
<td>&gt;300°C</td>
<td>&gt;300°C</td>
<td>175-200°C</td>
<td><strong>175-200°C</strong></td>
</tr>
<tr>
<td>DA Process Atmosphere</td>
<td>Reducing or Flux</td>
<td>Reducing or Flux</td>
<td>Air, or Inert</td>
<td>Air, or Inert</td>
</tr>
<tr>
<td><strong>Die Attach Properties</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shear Strength (MPa)</td>
<td>15</td>
<td>TBD</td>
<td>20</td>
<td>30</td>
</tr>
<tr>
<td>Interfacial Resistance (Rth)</td>
<td>TBD</td>
<td>TBD</td>
<td>~0.06 K/W</td>
<td><strong>0.007 K/W</strong></td>
</tr>
<tr>
<td>Effective Thermal Conductivity - keff (3-layer k)</td>
<td>TBD</td>
<td>TBD</td>
<td>7 W/m-K</td>
<td><strong>75 W/m-K</strong></td>
</tr>
</tbody>
</table>

- **100% increase**
- **Controlled modulus**
- **Low DA temperature, no pressure or vacuum needed**
- **Very good thermal interfaces, great for heat dissipation.**
What is Conductive Fusion Technology?

- Sintered conductive component (silver or copper) plus a “soft modifier” stress reliever
  - Sintered system = high thermal conductivity
  - Soft Modifier = acts as CTE buffer, without disrupting heat flow
- Uses: high-power semiconductor applications
- Focus: pressure-less, low temperature sintering technology
- **Goal**: great and dependable material for high temperature applications (250°C)
Concept

The key factor for new die attach material

- The die attach material acts as a buffer between die and substrate
  - CTE and modulus = very important
  - Low modulus die attach material can relieve stress and improve reliability

<table>
<thead>
<tr>
<th>CTE (ppm/°C)</th>
<th>Young's Modulus (GPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>220</td>
</tr>
<tr>
<td>17</td>
<td>83</td>
</tr>
<tr>
<td>7.2</td>
<td>413</td>
</tr>
</tbody>
</table>

Main Goal: Develop a material that exhibits both high thermal conductivity and reliable stress control.
Simulation Test
With Soft Modifier vs. Without Soft Modifier

Simulation model

- **With Soft Modifier**
  - Stress: 70 MPa

- **Without Soft Modifier**
  - Stress: 140 MPa
Thermal Properties Analysis

• Nano-Heat Transfer Lab – Department of Mechanical Engineering of Boston University
  – Fundamental physics of thermal energy at the nanoscale, ultrafast laser measurement techniques, and laser-material interaction

• Thermal Property Imaging – Frequency Domain Thermoreflectance (FDTR)
  – Create quantitative, sub-micron maps of a sample's properties such as the thermal conductivity and specific heat

Images courtesy of Boston University
Thermal Conductivity Map of the Bond Line via FDTR

Thermal conductivity of cross-sectioned Conductive Fusion die attach sample via FDTR (Frequency Domain Thermoreflectance)

Excellent thermal path – average values above 100W/m-K

*Analysis imaging provided by the Nano-Heat Transfer Lab, part of the Mechanical Engineering Department of Boston University
Impact on the Storage Modulus vs. Soft Modifier

- Soft Modifier significantly decreases the modulus as the concentration increases.

Approximate curve
Impact on the Thermal Conductivity vs. Soft Modifier

Thermal conductivity is greatly affected as the concentration of soft modifier increases.
Impact on the Thermal Resistance vs. Soft Modifier

Thermal resistance values increase due to obstructed heat flow path through the bond line.
**Impact on Die Shear Strength (DSS) vs. Soft Modifier**

An increase in soft modifier leads to a decrease in DSS, as expected.

Approximate curve

- 3 mm Si die (Au plated)
- Die attach material
- TO-220 (Ag plated CuLF)

Impact on Die Shear Strength (DSS) vs. Soft Modifier
To select amount of stress modifier, all properties must be observed. Need a well-balanced feature between the modulus, thermal, and mechanical properties, which are in a trade-off relationship.

- 5-8% is conducted as reasonable range for amount of soft modifier.
Reliability
High Demand for Reliability at Adverse Conditions

- Hot Die Shear Adhesion Test
  - 200, 260 and 300°C

- Temperature, Humidity Test (THT)
  - 85°C/85% RH for 1000 Hours

- High Temperature Storage (HTS)
  - 250°C for 1000 Hours

- Temperature Cycling Test (TCT)
  - -55°C/200°C for 1000 Cycles
Hot Die Shear Adhesion

Overall strengths remain rather impressive (above 10 MPa at 300°C)
Temperature, Humidity Test - (85%RH, 85°C)

High humidity environment does not promote any degradation after 1000 hours.

Humidity Chamber Test - 85°C/85%RH
10x10mm AuSi on Laser Services AuAl₂O₃ - Cured at 200°C/1HR

DSS (MPa)

0.0  2.0  4.0  6.0  8.0  10.0  12.0  14.0  16.0  18.0  20.0

0 Hours  1000 Hours

Reliability Storage Time
High Temperature Storage at 250°C

**HTS results show no degradation after 1000 hours exposure to elevated temperatures.**

High Temperature Storage Results - 250°C

10x10mm AuSi die on AuAl₂O₃ - Cured at 200°C/1HR

![Graph showing no degradation over 1000 hours at 250°C](image)
Temperature Cycling Data from -55°C/+200°C

TC results show no degradation after 1000 cycles of exposure to wide range of temperatures.
Summary of Conductive Fusion

• Sintered silver adhesive with soft modifier shows:
  – Modulus controlled by adding soft filler, better stress management
  – DSS = > 30MPa
  – HDSS (300°C) = > 10MPa

• Low cure with high use and operating temperature.

• Reliability:
  – THT (85°C/85% RH) – results show stable DSS results after 1000 hours
  – HTS (250°C) – results show stable DSS results (roughly at or above 8MPa) after 1000 hours
  – TCT (-55°C/200°C) – large area die results show stable DSS values after 1000 cycles.
Acknowledgements

Boston University Nano-Heat Transfer Lab
Mechanical Engineering Department
for thermal analysis using FDTR (Frequency Domain Thermoreflectance)
Thank you
for your attention

Nick Krasco
Chemist
NAMICS North American R&D Center
N-Krasco@Diemat.com