Development of reactive joining technologies for electronic packaging and assembly

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Laboratory Joining Technologies & Corrosion at Empa

Our portfolio

- Advanced Joining Technologies
  (soldering, brazing, TLP, diffusion bonding, micro- & nano-joining)
- Corrosion Management
  (investigations of corrosion failures, mechanisms and prevention strategies)
- Surface & Interface Engineering
  (of metals, alloys, oxide films and their coating systems)

Our expertise within the Swiss Photonic Packaging Laboratory

- Custom-designed solutions in the field of joining: brazing, soldering, diffusion bonding, transient liquid phase bonding, development of nanostructured filler alloys, coatings and foils,...
Laboratory Joining Technologies & Corrosion at Empa

New wetting furnace, financial support from Swiss Photonics

**Purpose**
- investigation of wettability (contact angle, spreading) under controlled conditions ($t$, $T$, atmosphere)
- generally: visual inspection of samples at high temperature under controlled atmosphere

**Specifications**
- quartz tube furnace
  - max. heating rate: ca. 20 K/min
  - max. $T$: ca. 1000 °C
- atmospheres
  - controlled flow rates: inert, reducing, oxidising
  - vacuum (HV range)
Laboratory Joining Technologies & Corrosion at Empa

New wetting furnace, financial support from Swiss Photonics

Example: Sn pearl on DCB substrate

\[ HR = 5 \text{ K/min} \]

\[ T = 18 \degree C, \quad t = 0 \text{ min} \]

\[ T = 265 \degree C, \quad t = 49 \text{ min} \]

\[ T = 295 \degree C, \quad t = 55 \text{ min} \]
Reactive nano-multilayers

Cross-sections of a nano-multilayer foil before and after reaction:
- Before reaction: nano-multilayers
- After reaction: intermetallic phase

High-speed recording of a reacting Nanofoil®, total time: 2.5 milliseconds
Reactive nano-multilayers

Key facts
- alternating layers of metals (e.g. Ni+Al)
- internal heat production by metal-metal reaction, no gas phase involved
- high reaction temperatures (>1000 °C)
- high reaction speeds (1-50 m/s)
- defined heat generation by variation of system and total thickness (10 - 250 µm)

<table>
<thead>
<tr>
<th>type</th>
<th>heat release</th>
<th>example</th>
</tr>
</thead>
<tbody>
<tr>
<td>low</td>
<td>30 - 59 kJ/mol-atom</td>
<td>Al/Ti</td>
</tr>
<tr>
<td>medium</td>
<td>60 - 89 kJ/mol-atom</td>
<td>Ni/Al</td>
</tr>
<tr>
<td>high</td>
<td>&gt; 90 kJ/mol</td>
<td>Al/Pd</td>
</tr>
</tbody>
</table>

idea: usage as internal heat source for soldering/brazing
Reactive nano-multilayers

Development

- **1960s** (esp. USSR): exothermal reactions for production of intermetallics
- **1979**, Prentice: “Heat Sources for Thermal Batteries: Exothermic Intermetallic Reactions” (US patent); **one scenario: alternating metallic layers**
- **1986**, Floro: “Propagation of explosive crystallization in thin Rh–Si multilayer films” (J. Vac. Sci. Technol. A); **preparation of nano-multilayer films**
- **1995**, Makowiecki: “Low Temperature Reactive Bonding” (patent); **films**
- **2001**, Weihs: “Method of making reactive multilayer foil and resulting product” (patent, US only); **freestanding foils**
  - **2001**, Weihs: founding of “Reactive NanoTechnologies” (now Indium Corp.); **start of commercial production of Nanofoils®**
- since then: increased usage for joining

Joining with reactive nano-multilayers

Principle

alternative approach: direct deposition of reactive nano-multilayers (e.g. on wafer)
Joining with reactive nano-multilayers

**Advantages**

**Processing**
- localised heat source: components remain “cold”
- no furnace
- no protective atmosphere
- no flux (if clean components)
- easy handling of joining components (→pick and place)
- short processing time

**Joint performance**
- microstructure refinement
- good thermal properties (heat conductivity)
- stability against high temperatures & humidity

* esp. for directly deposited RNMLs
Joining with reactive nano-multilayers

Example: joining of a nano-crystalline Al alloy (Empa, 2011)

Joining set-up

Temperature development in joining zone

successful joining of heat-sensitive materials

Benign Joining of Ultrafine Grained Aerospace Aluminum Alloys using Nanotechnology
Joining with reactive nano-multilayers

Typical problems & challenges

1. “Classical” soldering problems
   - Example: Joining of stainless steel, shear strength
     - Wang 2005: **36 MPa** (Ni-Au metallisation, AgSn solder; J. Appl. Phys. 97)
     - Sen 2016: **9 MPa** (Ni metallisation, Sn + InCuSil solder, Euro Hybrid Proceedings 2016)
   - handling, cleaning, general bonding issues...

2. Process-intrinsic problem: heat management
   - no possibility for external control of process time and temperature
     - too hot: damage of components (cf. joining of nano-Al)
     - too cold: no melting of solder
     - additionally: thermo-mechanical shockwave
   - challenge: influence of substrates and components
Joining with reactive nano-multilayers

Interreg V – Project: “Schonendes reaktives Fügen von Mikrosystemen”

Project partner:
- Hahn-Schickard, Baden-Württemberg, Germany
- R&D in micro-assembly and packaging, sensor development, ...

Project goals:
- development of *truly* benign joining processes
- characterisation of thermo-mechanical stress during joining
- design rules for reactive joining

please contact author for further information
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*Montage von Mikrosystemen mit reaktivem Nanofügen in einer Fertigungsprozesskette (ReMTeC)*
Abschlussbericht, IGF-Vorhaben-Nr. 17368 N, Axel Schumacher, Hahn-Schickard
Focus: influence of substrates/components

Design of test series

- joining components
  - materials: borosilicate glass, Si, Al$_2$O$_3$, Cu
  - bond area: 4 mm x 4 mm

- joining setup
  - reactive system: Ni-Al, commercial nanofoils®
    (60 µm + 2 x 1 µm InCuSil)
  - metallisation: Ni
  - solder: Sn foils (2 x 10 µm)

- test methods
  - non-destructive (scanning acoustic microscopy, computer tomography)
  - destructive (shear strength, cross-sections)
Focus: influence of substrates/components

Overview results

<table>
<thead>
<tr>
<th>substrate</th>
<th>heat conductivity (W · m⁻¹ · K⁻¹)</th>
<th>solderability</th>
</tr>
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<tbody>
<tr>
<td>borosilicate glass</td>
<td>1.2</td>
<td>joint formed, but extensive cracking</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>30</td>
<td>good</td>
</tr>
<tr>
<td>Si</td>
<td>129 (avrg.)</td>
<td>good</td>
</tr>
<tr>
<td>Cu</td>
<td>401</td>
<td>no joint formed</td>
</tr>
</tbody>
</table>
Focus: influence of substrates/components

Example borosilicate glass: non-destructive testing

- optical microscopy, differential interference contrast
- scanning acoustic microscopy, pore echo
- cracks, mechanical stress
- voiding in solder layer
- voiding, cracks in reactive foil
Focus: influence of substrates/components

Example borosilicate glass: process optimisation

Solution: 2 x 75 µm Sn instead of 2 x 10 µm + pressure reduction

☛ no cracks in glass (but still pores)
Focus: influence of substrates/components

Other materials: $\text{Al}_2\text{O}_3$, Si and Cu

- $\text{Al}_2\text{O}_3$ and Si: some porosity, but excellent strength
  - $\text{Al}_2\text{O}_3$: shear strength around 45 MPa
  - Si: fracture of substrates around 20 MPa

- Cu
  - thicker reactive foil (250 µm) = more heat generation: unsuccessful
  - galvanic pre-soldering of substrates: successful
Summary

Joining with RNMLs: promising new technique

- simple, fast and flexible: no furnace, no protective atmosphere, flux-free...
- benign joining possible
- hermeticity possible
- high-quality joints possible

Crucial

- good soldering practice
- tailored joining setup for heat management:
  - reactive foil vs.
  - solder vs.
  - substrate/components
Thank you for your attention!

Looking forward to your questions
...and potential cooperation projects!

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