NEW SOLDERING PASTES FOR DIFFUSION BASED JOINING TECHNOLOGIES

Chemnitz, 12.06.2018, S.Käss, S.Fritzsche, J.Strueben, J.Trodler
1. Introduction of Heraeus Electronics

2. Introduction for New soldering pastes for diffusion based joining technology
   2.1 Target and Motivation of Hot Power Connection
   2.2 Solder Materials and Process
   2.3 Selection of solder materials
   2.4 Paste application
   2.5 Infiltration and intermetallic forming
   2.6 Solder joint analysis
   2.7 Comparison with solder process and sintering
   2.8 Paste requirements
   2.9 Reliability of diffusion soldering

3. Conclusion and outlook
WHERE IT ALL STARTED

In 1851 Chemist Wilhelm Carl Heraeus takes over his father’s pharmacy. Five years later he melts two kilograms of platinum in oxyhydrogen gas flames for the first time, rendering the precious metal fit for industrial processing. This builds the nucleus for nowadays’ global industrial usage of precious metals.
HERAeus BUSINESS SEGMENTS

9 Global Business Units (GBU)

**Heraeus Emerging Businesses (HEB)**
- Sensor Technologies and Electronic Chemicals

**Heraeus Medical (HME)**
- Medical products for orthopaedic surgery and traumatology

**Heraeus Precious Metals (HPM)**
- Leading provider of precious metal services and products – from trading to recycling

**Heraeus Electro-Nite (HEN)**
- World market leader in sensor and measurement systems (e.g. for steel)

**Heraeus Medical Components (HMC)**
- Components and solutions for the medial technology industry

**Heraeus Photovoltaics (HPT)**
- Focus on global photovoltaic industry based on silicon wafer technology

**Heraeus Electronics (HET)**
- Matched materials solutions for the electronics packaging and component industry

**Heraeus Noblelight (HNG)**
- Special lamps with wavelengths from ultraviolet to infrared

**Heraeus Quarzglas (HQS)**
- Technology leader for manufacture and processing of high-purity quartz glass

**Incubator New Businesses (INB)** for start-ups
- to foster new business ideas outside of a GBU structure

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WE ARE HERAEUS ELECTRONICS.

10 production sites in 7 countries worldwide

1,400 employees worldwide

50+ countries where our products are sold

WE ARE FOCUSED on providing innovative materials and matched materials solutions for the electronics packaging and component industry.

CLOSE to your development centers and factories we have experts located in Asia, US and Europe to grant fast reaction and easy access without language barriers.

TRUST & RELIABILITY have been the basis of our cooperation for more than 160 years, founded on leading compliance and environmental standards, transparency, and our financial stability.
PROVIDING SOLUTIONS FOR THE ELECTRONICS INDUSTRY

- Consumer Electronics & Computing
- Automotive
- Industrial
- Communications
- Power Electronics
- IGBT modules
- RF Amplification systems
- LED
- High-Power LED
- Automotive headlamps
- System in Package (SiP)
- SMT; Advanced packaging
- Metal Ceramic Substrates
- Thick Film Pastes
- Metal Substrates
- Sinter Materials
- Bonding Wires
- Solder Materials
- Adhesives

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NEW REFLOW SOLDER TECHNOLOGY FOR ELECTRONIC ASSEMBLIES UNTIL 300°C

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Klaus Wilke, Jörg Strogies, Hans-Jürgen Albrecht, Siemens AG, Berlin
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Andreas Reinhardt, Volker Liedke, Sonja Wege, Rolf Diehm, Seho Systems GmbH, Kreuzwertheim
Thomas Zerna, Alexander Klemm, Technische Universität Dresden, Dresden
Uwe Pape, Christian Mertens, Volkswagen AG, Wolfsburg
Jürgen Freytag, Ralf Ghetto, Daimler AG, Sindelfingen
DEVELOPMENT OF JUNCTION TEMPERATURE OF IGBTs OVER THE YEARS

* Chart made for a device with 1200V breakdown voltage.
OVERVIEW OF EXISTING SOLDERING MATERIALS
MOTIVATIONS FOR „HOT-POWER-CONNECTION“

Reduction of costs
› Material costs (solder vs. Silver sintering)
  › 1g Ag ~ 0,45 €
  › 1g Sn ~ 0,017 €
› Production costs
› System costs

Enable for
› miniaturization of performance assembly
› Integration of sensors
› Ability for reflow processes

Reliability
› Operating temperature for conventional lead free solder limited
› No hard solder for low temperature available

Laws
› Prohibition of PbSn5
Combination of thermal solidification and isothermal solidification could be the basis for a new quality of interconnection

Phase diagram of a two element system

- Structure design through high melting intermetallic by using soft solder alloys based on solder paste
- Soft solder alloy will be used based on Sn with a high metal concentration and additives
- Isothermal solidification at low/standard solder temperatures
### Possible Elements for Isothermal Soldification

<table>
<thead>
<tr>
<th>Hauptgruppen</th>
<th>Nebengruppen</th>
<th>gruppen</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Sc, Ti, V</td>
<td>II</td>
</tr>
<tr>
<td>II</td>
<td>Cr, Mn, Fe, Co, Ni, Cu</td>
<td>III</td>
</tr>
<tr>
<td></td>
<td></td>
<td>IV</td>
</tr>
<tr>
<td></td>
<td></td>
<td>V</td>
</tr>
<tr>
<td></td>
<td></td>
<td>VI</td>
</tr>
<tr>
<td></td>
<td></td>
<td>VII</td>
</tr>
<tr>
<td></td>
<td></td>
<td>VIII</td>
</tr>
</tbody>
</table>

- **Metallurgical Unsuitable**
- €Too Expensive
- Nuclear
- Non Metal
- Toxic

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MATERIAL SELECTION – THERMAL ASPECTS

![Graph showing material selection based on thermal aspects and temperature]

- SnPb37
- SnAg3Cu0.5
- AuSn20
- SnSb5
- PbSn5
- AuSi3
- Cu6Sn5
- AuGe12
- BiSn42
- PbIn20
- Cu3Sn...

Thermal conductivity W/mK

Reference

Forbidden zone

Target area

Junction temperature referred to $T_h = 0.8$
ALLOY SYSTEM OF CHOICE (SN-CU)

\[ \beta, \gamma, \delta, \epsilon, \zeta, \eta = \text{intermetallic phases} \]

**Weight Percent Tin**

**Temperature °C**

**Cu** | **Atomic Percent Tin**
--- | ---
100 | 0
50 | 20
25 | 40
--- | ---
**Sn**

**Isothermic solidification = \eta Phase Cu₆Sn₅**

**Thermic solidification**

Initial point \( T > T_m \)

**Alloy system with partially solubility**
Construction of an mechanical stable Cu + IMC and due to shrinking of SnCu paste by app. 50% creates 3D failures by using high Cu content (>20 w%)
NEW CONCEPTS OF PASTE APPLICATIONS

- Vertical infiltration: so far not successful, separating layer
- Lateral infiltration: successful, continuous attachment of the joining partners
MECHANISM OF THE INFILTRATION

Printing Cu and Solder paste

Melting solder paste

Infiltration of solder paste

Forming of intermetallics

Cross section: Detail with light optical microscope.

SEM analyses with pcb/pcb sandwich
ACTIVATION OF THE SOLDER JOINT

Activation with F645

"swelling" of the copper depots and lack of contour stability

Activation with reducing gas

Contour stability of the copper depots during activation
CU PASTE DEPENDENCY OF THE INFILTRATION DEPTH AS FUNCTION OF TIME
DEPENDENCY OF INFILTRATION ON ACTIVATION

Flux with Resin

Flux without Resin

Cu T4, 1% Polyimide, 15% SnAgCu T6
Cu T4, 15% SnAgCu T6
Cu T4 Heraeus, 15% SnAgCu T6
Cu T4 Heraeus, 15% SnAgCu T6
Cu T3, 15% SnAgCu T6
Cu T3, 15% SnAgCu T6
Cu T4, 15% SnAgCu T6
Cu T4, 15% SnAgCu T6
SOLDER JOINT ANALYSIS

<table>
<thead>
<tr>
<th>Spot #1 (Cu-Phase)</th>
<th>Element</th>
<th>Atomic %</th>
<th>Weight %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cu</td>
<td>91.5</td>
<td>85.2</td>
<td></td>
</tr>
<tr>
<td>Sn</td>
<td>8.2</td>
<td>14.3</td>
<td></td>
</tr>
<tr>
<td>Ag</td>
<td>0.4</td>
<td>0.6</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Spot #2 (Cu$_2$Sn)</th>
<th>Element</th>
<th>Atomic %</th>
<th>Weight %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cu</td>
<td>72.9</td>
<td>59.1</td>
<td></td>
</tr>
<tr>
<td>Sn</td>
<td>26.3</td>
<td>39.8</td>
<td></td>
</tr>
<tr>
<td>Ag</td>
<td>0.8</td>
<td>1.1</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Spot #3 (Cu$_2$Sn$_3$)</th>
<th>Element</th>
<th>Atomic %</th>
<th>Weight %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cu</td>
<td>54.1</td>
<td>39.8</td>
<td></td>
</tr>
<tr>
<td>Sn</td>
<td>43.9</td>
<td>58.8</td>
<td></td>
</tr>
<tr>
<td>Ag</td>
<td>2.0</td>
<td>2.5</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Spot #4 (residual solder)</th>
<th>Element</th>
<th>Atomic %</th>
<th>Weight %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cu</td>
<td>20.5</td>
<td>12.2</td>
<td></td>
</tr>
<tr>
<td>Sn</td>
<td>79.0</td>
<td>87.4</td>
<td></td>
</tr>
<tr>
<td>Ag</td>
<td>0.5</td>
<td>0.5</td>
<td></td>
</tr>
</tbody>
</table>

SOLDER JOINT ANALYSIS OF DIFFERENT CU-POWders

- samples without vehicle
- Powder with additional 15 % SAC 305 type 6
- Solder joint analysis after soldering

<table>
<thead>
<tr>
<th>Phase proportion [%Vol]</th>
<th>Cu T3</th>
<th>Cu T4</th>
<th>Cu T6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cu-Phase</td>
<td>41</td>
<td>31</td>
<td>15</td>
</tr>
<tr>
<td>IMC</td>
<td>25</td>
<td>47</td>
<td>63</td>
</tr>
<tr>
<td>Residual solder</td>
<td>33</td>
<td>16</td>
<td>18</td>
</tr>
</tbody>
</table>
# PASTE REQUIREMENTS

<table>
<thead>
<tr>
<th></th>
<th>Cu-Paste</th>
<th>Solder paste</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Application</strong></td>
<td>Stencil printing / Screen printing</td>
<td>stencil printing/dispensing</td>
</tr>
<tr>
<td><strong>Printability/dispense ability</strong></td>
<td>Like available solder pastes</td>
<td>Like available solder pastes</td>
</tr>
<tr>
<td><strong>Hot slump</strong></td>
<td>0,2-0,4 (acc. IPC )</td>
<td>0,2-0,4 (acc. IPC )</td>
</tr>
<tr>
<td><strong>Powder size</strong></td>
<td>Type 4</td>
<td>tbd</td>
</tr>
<tr>
<td><strong>Infiltration</strong></td>
<td>$&gt; = 100$ mm</td>
<td>$&gt; = 100$ mm</td>
</tr>
<tr>
<td><strong>Tackiness</strong></td>
<td>High enough to fix die/component</td>
<td>High enough to fix die/component</td>
</tr>
<tr>
<td><strong>Process</strong></td>
<td>Vacuum soldering with reducing gas</td>
<td>Vacuum soldering with reducing gas</td>
</tr>
</tbody>
</table>
COMPARISON DIFFUSION SOLDERING WITH OTHER DIE ATTACH PROCESSES

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Performance – Power cycling results

- Solder materials failure around 25 k cycles
  - $R_{th}$ drift due to solder degradation
  - No significant improvement with SnSb5-solder

- Ag-Sintering and HotPowCon
  - 10 fold lifetime increase towards soldering
  - No failure in die attach materials (Bond failure)
  - Significant deviation between Ag-sintering and HPC

- Starting Conditions
  - Higher system $R_{th}$ of Ag-Sinter samples
  - Lower currents due to temperature controlled testing

<table>
<thead>
<tr>
<th>Die-attach</th>
<th>avg. cycles till failure</th>
<th>Failure mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>SnAgCu305</td>
<td>25 k</td>
<td>Die-attach failure</td>
</tr>
<tr>
<td>SnSb5</td>
<td>26 k</td>
<td>Die-attach failure</td>
</tr>
<tr>
<td>Sinter-Ag</td>
<td>364 k</td>
<td>Bond failure</td>
</tr>
<tr>
<td>HotPowCon</td>
<td>273 k</td>
<td>Bond failure</td>
</tr>
</tbody>
</table>
CONCLUSION

- For the future IGBT technology with higher junction temperature new joining materials are needed.
- A possibility of such a material is the forming of a IMC of Cu Sn Alloys ($\text{Cu}_6\text{Sn}_5$, $\text{Cu}_3\text{Sn}$) which are formed by isothermal soldification.
- Lateral infiltration of a Cu Pastes and Sn Pastes are needed to produce these joints.
- The formation of the IMCs in the joint are dependent on the Cu-Paste system (PSD of the Cu-Powder).
- It is possible to infiltrate a area until 100 mm$^2$ this is also dependent on the Cu-Paste system.
- The process of the diffusion soldering is in comparison to the solder process and sinter process more complex but can be done with existing machines.
- The reliability of the Hot Pow Con layer is comparable to Ag-sintering and is much higher than soldering.
OUTLOOK

• Diffusion soldering have high potential to be a material for IGBTs and Cu-baseplates with high joining temperature as joining material
• The diffusion solder process can be used as material to solder bigger areas instead of more expensive silver sintering
• First experience have to be collected for joining base plates
• The process is not fixed yet further improvements are in evaluation
• The vehicle system have to be improved to full fill all paste requirements
THANK YOU FOR YOUR ATTENTION