mAgic - Novel sintering materials for die attach on DCB

Abstract
Today the majority of DCB Modules are soldered using SnAg or SnAgCu solders. These materials have been known in the industry for years. On the other hand there are several drawbacks like the solder fatigue and limited operation temperature which also limits the power density of power electronic modules.
The trend in power electronic towards a longer life time and increased power density create the need for new die attach material with entirely different properties. This article will compare alternative die attach technology to lead free solders.

Soldered DCB Modules
The usage of SnAg and SnAgCu solders for the die attach in DCB modules is well established in the industry. Knowledge for material and process, as well as the soldering equipment is available. On the other hand solders have some limitations: thermal fatigue leads to solder joint degradation, a maximum operation temperature of 125 °C restricts the power density. Newer developments of lead free solder compositions like Innolot or the unique HT-Alloy of Heraeus allow an increase in operation temperature up to 150 °C. These alloys demonstrated their improved durability under temperature cycling in benchmark tests using DCB substrates and can be used as drop-in solutions.
A common drawback of all solder pastes are the flux residues on the DCB after soldering and the flux condensates in the reflow oven. The cleaning of flux residues and condensates creates non-negligible cleaning costs and rework efforts.

Alternative die attach solutions
Low Temperature Joining Technology
To overcome the limits of solders in terms of life time and power density, the low temperature joining technology (LTJT) was developed [1]. In comparison to soldering the LTJT technology provides a significantly higher thermally and electrically conducting die attach joint. In combination with the high melting point of silver (961 °C) and consequently a higher possible operation temperature, the LTJT technology makes it possible to have an increase of power density in the module design. Furthermore, since the operating temperature of the module is significantly lower than the melting temperature of silver, the die attach material will not show noticeable ageing.
The drawback of the LTJT technology is the relatively high process temperature of 280 °C and the special high process pressure. Detailed process know-how and very high process accuracy are mandatory to avoid a damage of the semiconductor during processing.

Nano Silver Material
Nano Silver materials help to overcome some of the issues caused by LTJT. Typical process temperatures for nano silver paste are 200-250 °C. The required process pressure varies from 1-5 MPa [2]. Similarly to LTJT, nano silver pastes result in pure silver interconnects. The high volume content of organics used in nano Ag pastes leads to long sintering profiles and limitation on bond line thickness. A processing of layers >20 µm will
create dry-out channels in the silver layer. Besides the improved compensation of thermo-mechanical stress a thicker bond line would equalize peaks of the DCB surface (Fig 1).
Due to its particle size and biocide property of Ag, health and safety hazards are of concern for nano silver materials [3].

**Diffusion Bonding**
Another alternative to conventional soldering is diffusion bonding [4]. Intermetallic phases providing high melting points are created during processing. As an example in a SnCu-Cu-system Cu3Sn (melting point of 676 °C) and Cu6Sn5 (melting point of 415 °C) are formed. Thanks to its high melting point this intermetallic die attach layer will show a lower fatigue degradation compared to solder. The reliability of such a system is proven for operation temperatures of 170°C [4]. The homologue temperature of this system at 170 °C is 65 %, for conventional lead free solder it would already be 90 %.
A proper processing of this material requires very thin solder layers (approx. 10 µm) and process pressure (≤6 MPa) [4].

**mAgic Sinter Materials**
Heraeus has developed a family of interconnect material based on micro scaled silver particles. Dedicated additives enable sintering at low temperatures and low process pressures. The Heraeus Microbond Ag Interconnect (mAgic) materials combine high performance with easy handling. The mAgic silver sinter materials are a product platform consisting of mAgic sinter pastes for medium to high power devices and mAgic sinter adhesives for low to medium power devices.
mAgic sinter pastes are mainly formulated with silver powder and solvents. Depending on the formulation and power electronics design they can be sintered with low pressure or no pressure. The resulting sintered joint consists of a porous structure of sintered silver particles without organic residues (Fig. 2, left).

**Fig 2: Comparison of mAgic Paste and Adhesive**
The metallurgical-bonded connection ensures low electrical resistivity and high thermal conductivity, as well as high adhesion strength. The high
melting point of silver (961 °C) at an operation temperature of 170 °C leads to a homologues temperature of 36 %. The high melting temperature of silver will allow a further increase in operation temperature without the risk of joint degradation.

mAgiC sinter adhesives consist of micro scaled silver powder in a polymer matrix (Fig. 2, middle) and are processed in a curing step without pressure. The pores in the resulting joint are filled with cured resin. The sintered joints provide thermal and electrical conductivities comparable to solders (Fig. 2, right). The thermal performance of packages using mAgiC adhesive is equal to soldered devices (Fig 3). The resin matrix in the sintered joint results in a higher flexibility of the sinter adhesive material when compared to mAgiC paste or solder. The temperature stability of the mAgiC sinter adhesives is significantly higher compared to solders, allowing higher operation of the packages.

mAgiC Sinter Adhesives
mAgiC adhesives provide several advantages compared to solder for the die attach on DCB. Solders are limited to operation temperatures of 125 °C – 150 °C. mAgiC adhesives like the ASA859-Series can be used up to 200 °C.

Based on the higher flexibility compared to solders mAgiC adhesives are capable to absorb more thermo mechanical stress caused by the CTE mismatch of Die and substrate. This property becomes more important for the large dies used in DCB modules.

<table>
<thead>
<tr>
<th>Solder Paste</th>
<th>Sintering Adhesive</th>
</tr>
</thead>
<tbody>
<tr>
<td>SnAg3.5-Alloy</td>
<td>ASA859-Series</td>
</tr>
<tr>
<td>Vacuum Soldering</td>
<td>0 MPa Process pressure</td>
</tr>
</tbody>
</table>

Fig 3: Thermographical Measurement of Diode in 10A DC Operation Mode

Fig 4: \( R_{th} \) measurements of DCB substrates in passive thermo-cycle test (-40/+150 °C)
Die attach with solder paste creates substantial direct and indirect process costs. Flux residues have to be cleaned after reflow to enable a reliable wire bonding process. The cleaning costs of DCB substrates are significant. Flux condensates make oven cleaning necessary and equipment downtime creates even more costs. Solder splattering during the vacuum reflow process requires 100% inspection of soldered modules. In case solder contaminates a wire bonding pad the part has to be reworked or scrapped. The inspection and the re-work of the modules are mainly done manually. mAgic adhesives are residue free materials. No substrate or equipment cleaning is required. No splatters occur during the curing of mAgic adhesives; making manual inspection and rework of the substrates obsolete. mAgic adhesives should preferably be cured in a pre-heated batch oven. Temperature or pressure profiling is not required.

For a reliable interconnect, mAgic adhesives require a NiAu or Ag interface on the die and substrate surface. Oxidation or transformation of the non-precious metal surfaces leads to an increase of the electrical resistance and a drop in the bond strength.

**mAgic Sinter Paste**

In the mAgic product family, mAgic sinter pastes have the highest thermal performance. This die attach layer provides the advantages of pure silver like high thermal, electrical conductivity and increased reliability. The melting temperature of the mAgic sinter paste layer is 961°C. To enable sintering an Ag or Au finish at the interconnect interfaces are required today. The materials are suitable for sintering in air.

The mAgic paste product group consists of several product formulations, which are tailored in performance and processing. Highest performance in terms of thermal conductivity is provided by the Ag-sinter paste ASP016-series which requires a pressure assisted sintering process. The recommended process for the ASP016-series is displayed in Fig 6.

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**Comparison of Estimated Production Costs**

SnAg Solder Paste
mAgic Adhesive

Fig 5: Comparison of estimated Production Costs

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Fig 6: Process flow for pressure-assisted sintering mAgic 016 Paste Series

Depending on the process parameters this material shows a porosity of about 15 % after sintering. The porosity of this material depends mainly on the sintering pressure applied during processing. The higher the pressure the lower the porosity of the die attach layer. Depending on the porosity adjusted in the sintering process the materials provide a thermal conductivity of $\geq 170 \text{W/m} \cdot \text{K}$ and an electrical resistivity $\leq 0.007 \text{m} \cdot \Omega \cdot \text{cm}$. Devices built with the ASP016-series demonstrated their durability by passing several hundred thousand power cycles.

To allow the usage of lower sintering pressure the ASP043-series was developed. This sinter paste can be processed according to the process given in Fig 6 and at a process pressure of 10 MPa and less. The thermal and electrical performances are similar to those of the ASP016-series. The lower process pressure will minimize potential damage of the devices caused by the process pressure. Additionally it will enable a sintering of larger areas using existing equipment simply by reducing the required pressure.

In order to simplify the sintering process for large dies further, the ASP131-series was developed. This material can be used in a no pressure sintering process (see Fig 7) for die sizes up to 100 mm².

<table>
<thead>
<tr>
<th>Items</th>
<th>Paste Application</th>
<th>Paste Drying</th>
<th>Die Placement</th>
<th>Sintering</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process</td>
<td>Stencil printing</td>
<td>Drying of printed sinter paste</td>
<td>Placement of die</td>
<td>Sintering Step</td>
</tr>
<tr>
<td>Equipment</td>
<td>convetional printing equipment</td>
<td>Conventional Box oven</td>
<td>Die placer with heated substrate holder</td>
<td>Sinter press</td>
</tr>
</tbody>
</table>
| Parameter           | • Stainless steel or PU squeegees  
• Print Speed 30-70 mm/s  
• Drying time 5-15 min  
• Drying temperature 60-120°C  
• Drying in air  
• Die Placement temperature 80-130°C  
• Die Placement force min 0.03 MPa  
• Sinter Pressure 20-40 MPa  
• Sinter Temperature 230°C-280°C  
• Sinter time 1-2 Minutes in air |
The no pressure process results in die attach layer with a porosity of 30-40% after die attach. The higher porosity of the sintering layer compared to pressure assisted assemblies, affects the thermal conductivity of the interconnect layer. The thermal conductivity of such a layer will be in the range of 70 W/m·K.

Packages manufactured in a no pressure sintering process provide an improved thermal conductivity compared to vacuum soldered modules. Comparing the different sintering processes, modules sintered by the use of pressure provide a significant higher thermal capability compared to devices sintered without pressure (Fig 8). This is due to the denser structure of the attach layers created by a pressure assisted process.

No matter which process and performance of die attach layer is selected, all mAgic materials provide improved reliability and increased thermal performance in comparison to soldered die attach layers. And they will not leave flux residues or solder splatters after processing.
Summary
Beside an increased life time, higher power density and increased operation temperature, are the ongoing trends in power electronics. Due to its low operation temperature and fatigue, lead free solders do not provide the required performance.

Diffusion soldering is a valuable alternative of die attach technology. Due to its thermo-mechanical stability it makes it possible for devices to have a long life. Special die back side metallization and pressure assisted processes are required.

Compared to diffusion soldering, sintered layers provide a higher melting temperature and consequently a lower homologues temperature. Furthermore, they are compatible with standard silver Die backside metallization.

mAgic sintering materials provide tailored properties and can be used in various processes. mAgic adhesive is easy to handle and - compared to solder has improved reliability, higher operation temperatures and lower total costs. mAgic sintering paste allow highest operation temperatures and provide an increased thermal conductivity. In combination with its ductility it ensures a long life time for power electronic devices.

The performance of the Ag interconnect in combination with the wide process window and simplified handling, compared to LTJT or nano-Ag materials enables mAgic to give a high performance for die attach material in industrial use for next generations of power electronics. (Author: Thomas Krebs, Microbond Assembly Materials, Heraeus, Hanau, Germany)

Literature

Medizinprodukte, Dentalprodukte sowie Quarzglas und Speziallichtquellen. Mit einem Produktumsatz von 4,1 Mrd. € und einem Edelmetallhandelsumsatz von 17,9 Mrd. € sowie weltweit über 12 900 Mitarbeitern in mehr als 120 Gesellschaften hat Heraeus eine führende Position auf seinen globalen Absatzmärkten.

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