Die-attach Materials and Processes
A Lead-free Solution for Power and High-power Applications

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The die-attach layer has two main functions: mechanical fixation of the die on its substrate, and dissipation of heat generated in the die. Especially in power and high-power applications, generated heat density is high. Therefore, conventional die-attach adhesives or eutectic solder alloys are not suitable as die-attach materials. For these applications, high-melting solder alloys are used, which contain more than 85% lead by weight, and do not satisfy the requirements of RoHS. Since there is no established lead-free substitute on the market, high-lead alloys are included on the exemption list of RoHS for these applications. However, die-attach materials that satisfy the requirements of RoHS do exist.

Requirements for Die-attach Materials
High heat dissipation throughout package life: To achieve this, the solder alloy needs to cover completely the surface between leadframe and die for good solder wetting on leadframe and die metallization, and low void rate on the die-attach layer. Typically, for power and high-power applications, maximum void rate allowed is 5%.

Resistance against thermal fatigue: During package life, the joint is subjected to cyclic heating and cooling. The mismatch in coefficient of thermal expansion (CTE) between the die and the leadframe induces shear stress, which leads to so-called thermal fatigue in the joint. The die-attach layer needs to withstand thermal fatigue to ensure joint reliability.

Typical die-attach materials are PbSn, PbSnAg or PbInAg alloys (Table 1). These alloys wet conventional substrates and die metallizations due to the formation of intermetallic compounds, which build an adhesion layer between substrate or die metallization and bulk solder. To achieve the best wetting and lowest void rate, the solder material should contain the lowest possible oxide content.

High-lead alloys withstand thermal fatigue stress because they are soft, have a wide elastic deformation range, and can survive plastic deformation. This allows them to compensate the shear stress induced in the die-attach layer. Additionally, the finer the alloy micro-structure directly after reflow and during the package lifetime, the slower fatigue crack propagation, and the more reliable the die-attach joint. Unfortunately, alloys with the finest micro-structures are more prone to oxidation, and therefore more difficult to handle and process to achieve good wetting and low void rate. Thus, the best solder alloy for a given application is always the best compromise between reliability requirements and processing requirements.

High-lead solder alloys are available on the market as wire or paste. Solder wires are typically produced by an alloyed billet via extrusion, a drawing process, or continuous casting. Because solder wires are used in a flux-free die-attach process, the alloy needs to have high purity and no surface contamination. Therefore, lubricant is not allowed during production.

High-lead solder pastes are a mixture of alloyed solder powder and a binder, or flux, and are produced by mixing the solder powder and the binder before subjecting the paste to special treatments to adjust rheological properties such as viscosity, slump, and tackiness. These pastes are either no-clean (NC) — or rosin mildly activated (RM) — or water soluble (WS). With NC, after reflow, flux residues are non-corrosive, and do not need to be washed away. Nevertheless, most users prefer to wash the residues using organic solvents. With WS pastes, which are corrosive, the flux residues need to be washed with warm water after reflow.

Conventional Die-attach Processes
Solder wire die-attach involves a wire dispensing process (Figure 1a) on automated equipment, and is mainly used when followed by wire bonding. The wire is fed into a crucible and pressed onto the hot leadframe, which heats the tip of the wire and lets it melt. The solder wire is then removed and a solder droplet remains on the leadframe. The leadframe is heated from the bottom to keep the solder droplet liquid. Next, the droplet is spread to the area of the die with a rectangular spanker. Upon lift-off of the spanker tip, the solder will flow back to form a droplet with a rectangular footprint. Then the die is pressed in the molten solder, leading to an overflow of solder around the die, which is controlled by another tool. When the pressure on the die is released, the surface tension of the molten solder leads to solder flow back beneath the die. Finally, the leadframe goes through a cooling section and the die-attach layer solidifies. This flux-free process does not require any cleaning steps. To prevent solder oxidation, die attachment is performed under protective or reducing atmosphere. The wire itself needs to be free from oxide and organic contamination to ensure good wetting and low void rate in the die-attach layer.

Using solder paste leads to an additional cleaning step. Using a paste allows for all the parts, which are loosely fixed before reflow due to paste tackiness, and all solder joints — die and clip attach, one level or stacked.
they need to be adjusted for each combination of application, equipment, and solder product. Therefore, cooperation between equipment, solder supplier, and assembly company is essential.

A suitable substitute for high-lead solder alloys requires: material processing at temperatures below 400°C; no re-melt until a temperature of at least 260°C is reached; good adhesion on conventional part surfaces; good resistance against thermal fatigue; and of course, no lead in the composition.

In the past, two potential lead-free substitutes had been reported: eutectic gold/tin and bismuth/silver alloys. Eutectic gold/tin (AuSn) contains 80% gold (Au) and 20% tin (Sn) by weight.

## Table 1. Conventional die-attach alloys and their properties.

<table>
<thead>
<tr>
<th>Alloy</th>
<th>CTE in 10&lt;sup&gt;-6&lt;/sup&gt; K&lt;sup&gt;-1&lt;/sup&gt;</th>
<th>Thermal conductivity in W/m.K</th>
<th>Electrical conductivity in % IACS</th>
<th>Elongation to rupture in %</th>
<th>Young’s modulus in GPa</th>
<th>Tensile strength in MPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>PbSn10</td>
<td>29.9</td>
<td>46</td>
<td>9.0</td>
<td>25-35</td>
<td>19</td>
<td>28-32</td>
</tr>
<tr>
<td>PbSn5</td>
<td>29.0</td>
<td>34.7</td>
<td>6.6</td>
<td>27-32</td>
<td>14</td>
<td>22-23</td>
</tr>
<tr>
<td>PbSn10Ag2</td>
<td>27.0</td>
<td>55</td>
<td>8.4</td>
<td>20-25</td>
<td>16</td>
<td>30-35</td>
</tr>
<tr>
<td>PbSn5Ag2.5</td>
<td>29.0</td>
<td>44</td>
<td>8.3</td>
<td>20-30</td>
<td>14</td>
<td>25-35</td>
</tr>
<tr>
<td>PbSn2Ag2.5</td>
<td>28.8</td>
<td>53</td>
<td>9.5</td>
<td>40-45</td>
<td>20</td>
<td>27-30</td>
</tr>
<tr>
<td>PbSn1Ag1.5</td>
<td>30.0</td>
<td>44</td>
<td>8.1</td>
<td>30-40</td>
<td>15</td>
<td>36-39</td>
</tr>
<tr>
<td>Pbn5Ag5</td>
<td>27.0</td>
<td>25</td>
<td>6.0</td>
<td>20-25</td>
<td>21</td>
<td>35-37</td>
</tr>
</tbody>
</table>

The alloy is very expensive and unsuitable for mass production. It has a melting temperature of 280°C, high mechanical strength, and resistance against thermal fatigue. Unfortunately, AuSn is brittle, which makes it difficult to produce and process. Due to low ductility and high mechanical strength, AuSn die-attach layers tend to transmit thermo-mechanical stress to the die.

Bismuth/silver (BiAg) alloys seemed to be a drop-in solution for replacement of high-lead solders. Alloys containing between 2 and 12% silver (Ag) satisfy the requirements of melting temperature. Unfortunately, the wetting on copper (Cu), which is a popular metallization type, is very limited. Also, the low thermal conductivity of the alloy may lead to die overheating and damage. The manufacturing conditions of the alloy are problematic, because a high deformation speed leads to a brittle response. For these reasons, BiAg alloys did not match the requirements for substituting high-lead-containing solders.

A newcomer to the market is an adhesive filled with copper, which is currently in test phase at assembly companies. It can be processed like conventional high-lead solder pastes via dispensing or printing, followed by thermal curing, making it a drop-in replacement for solder paste. Unlike solder paste, no cleaning is required after curing. A micro-section of the formed die-attach joint is shown in Figure 2. The adhesive layer shows a composite structure, composed of copper powder particles, homogeneously distributed in a polymer matrix. In comparison to joints made of solder pastes, the adhesive paste exhibits: a void rate near zero, rather than 5%; high adhesion on conventional part metallizations (copper, nickel, gold, silver, bare silicon); high mechanical strength; and high interface quality to chip and substrate.

With solder paste, the interface between solder and die or substrate is made of an intermetallic compound, which is barrier for heat dissipation. With the adhesive joint, no intermetallic compounds are formed; positively influencing heat dissipation through the joint. These advantages compensate inherent weaknesses of the adhesive like low bulk thermal conductivity, or poorer deformation capability, leading to similar heat dissipation through the adhesive die-attach joint and through a solder joint (Figure 3). Therefore, high thermal fatigue resistance and high package reliability is achievable. This product shows promise as a substitute for high-lead solderers in power and high-power packages.

## Conclusion

For power and high-power applications, die-attach products are made of high-lead solder alloys, which fulfill the requirements of high melting temperature and adequate thermo-mechanical properties, to ensure lifetime package reliability. However, die-attach processes parameters must be adapted for each application to achieve optimal results. There have been several unsuccessful trials to switch to lead-free products for these applications. A new copper-filled adhesive, which is in test phase at assembly companies, may replace high-lead solder pastes in the near future.

* MicroBondGecko

## REFERENCES

Contact the author for a complete list of references.

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