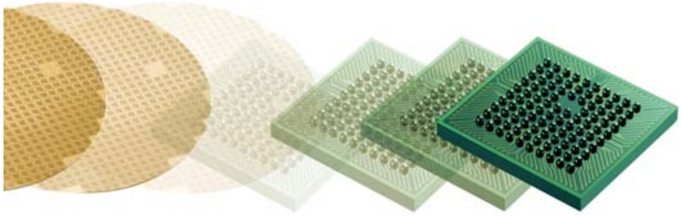

Tough Thermal Apps Drive
AuSn Die Attach

You can match the appropriate deposition technique with the die attach requirements of a given application.

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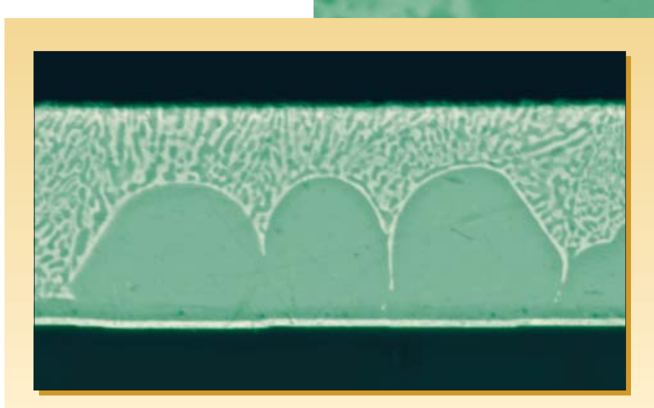
Gold-tin (AuSn) solder is widely used as a die attach material for high thermal demand applications, such as microwave devices, laser diodes and RF power amplifiers. AuSn is an excellent choice for these applications because it has high thermal conductivity and is usually fluxless and lead-free. During the past few years, new technology has been developed that makes electrolytic plating of AuSn material a commercial option. Plating is added to a list of other AuSn deposition alternatives that include evaporation, thick-film printing and pre-form placement. In this article, the basic attributes of AuSn die attach will be reviewed and these various deposition approaches will be described and compared with the goal of determining which deposition techniques fit specific die attach requirements.

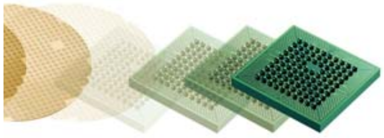
Key benefits, applications



AuSn solder has a combination of properties that make it the most appropriate die attach option for a number of high thermal demand applications. Key characteristics of AuSn solder relevant for die attach include:

- Thermal conductivity of 57 W/m-K
- Die attach temperature below 320°C
- Fluxless (in most situations)
- Lead-free
- A temperature hierarchy with lower melting solders

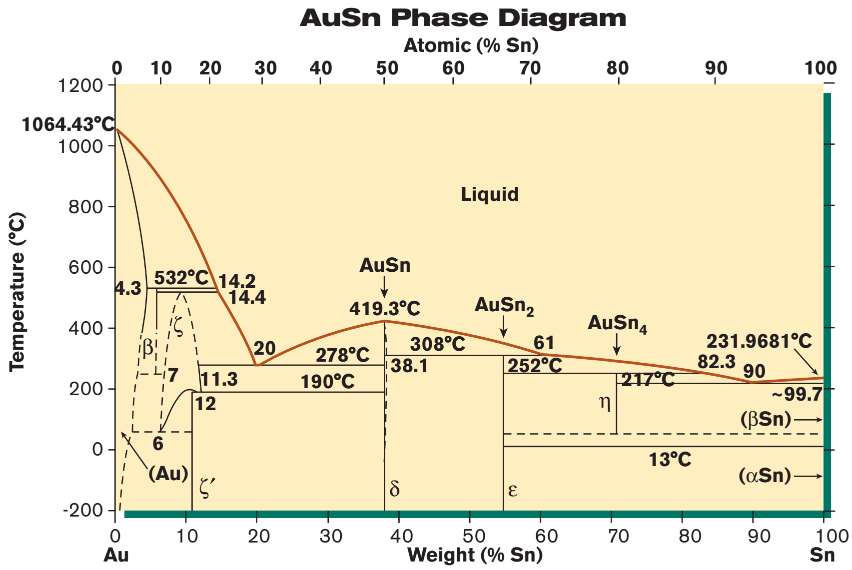
This combination of properties makes AuSn a good solution for many power electronics applications where heat must be transported from the die through the die attach into the package for effective dissipation. Such applications include RF power amplifiers for wireless infrastructure, laser diodes for fiberoptic telecommunications and high-frequency devices used in radar and microwave communication applications.



Of course, one of the drawbacks of AuSn is its high cost (80 wt% gold). With material costs of ~$17/g, AuSn will only be used in applications where its benefits are enabling, and must be applied only where it is required. In addition, AuSn can only be used in situations where the die is able to withstand a temperature above 300°C for a short duration.

AuSn materials science

Eutectic compositions are defined as the point on a phase diagram where a two-phase solid freezes from a single-phase liquid. Unlike other common eutectics used in electronic applications, such as lead-tin (PbSn) and gold-silicon (AuSi), the two solid phases in the AuSn system are both intermetallic compounds vs. elemental metals. For example, in the AuSi system, the melt at the eutectic composition solidifies to a combination of elemental gold and elemental silicon. For AuSn, in contrast, the eutectic melt solidifies into a combination of δ-phase AuSn and ζ'-phase Au_5Sn.



1. This AuSn phase diagram illustrates the eutectic at $Au_{80}Sn_{20}$. *(Source: ASM International)*

This characteristic of the AuSn phase diagram (Fig. 1) at the eutectic composition has a number of implications for technologically relevant properties. For example, gold has a thermal conductivity of 320 W/m-K and tin has a thermal conductivity of 67 W/m-K, yet the $Au_{80}Sn_{20}$ wt% combination only has a thermal conductivity of 58 W/m-K. This is because the thermal conductivity of intermetallic compounds is much lower than pure elements. $Au_{80}Si_{20}$, in contrast, has a thermal conductivity of 190 W/m-K.

This combination of intermetallic compounds also affects AuSn electrical, mechanical and chemical properties. In designing reliable metallization systems to work in combination with AuSn, it is very important to take these material characteristics into account.

AuSn deposition techniques

Because of the utility of AuSn, a number of different deposition technologies have been developed, each with its own unique strengths and weaknesses. The deposition techniques that will be discussed are:

1. Electron beam (e-beam) evaporation of gold and tin to form Au/Sn layered structures
2. Electroplating of the AuSn eutectic alloy
3. Electroplating of gold and tin to form Au/Sn layers
4. Application of AuSn pastes using either screen printing or dispensing technology

In evaluating various deposition options, two key parameters must be considered: the cost of the deposition process (deposition rate, tool cost) and the ability to efficiently use AuSn with minimal waste (ability to apply AuSn only where it is required for the application and with the minimum layer thickness required). Other considerations include tolerance

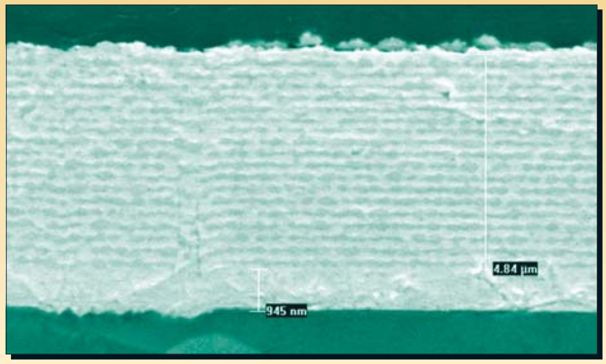
AuSn Deposition Technology Comparison

Key properties	Evaporation	Plating alloy	Plating layers	Screen print/ dispense paste	Pre-form
Minimum thickness	0.01 μm	0.25 μm	2.5 μm	12 μm	25 μm
Contamination	High purity	Good purity (organics)	Good purity (organics)	Low purity, organic binders, flux	High purity
Deposition equipment	Evaporation chamber	Plating line	Plating line	Screen printer, dispenser	Pick-and-place or manual place
Strengths	High deposition rate; high purity; low-cost tool; thin to thick layers	Good purity; targeted deposition on conducting surfaces	Good purity; targeted deposition on conducting surfaces	Very low-cost tool; very rapid deposition	High purity; manual or automated application; targeted deposition based on pre-form shape
Weaknesses	Wide area deposition (poor material utilization for many applications); requires diffusion step	Expensive tools; difficult to control; low deposition rates	Expensive tools; difficult to control; low deposition rates; requires diffusion step	High level of impurities; thick layers only possible; requires diffusion and cleaning steps	Thick layer only possible; high cost for automated tools; placement can be difficult

Source information TableSource

to impurities, the thickness uniformity specification and patterning requirements.

1. Evaporation of AuSn — In the evaporation process, a crucible containing the deposition material is vaporized by exposure to an e-beam in a high-vacuum chamber. The vaporized metal then deposits on a substrate that is suspended above the crucible. Since the vaporization process is not highly directional, deposition also occurs on the chamber walls. Layers of different materials can be deposited in the same deposition run by sequentially rotating multiple crucibles under the e-beam.



2. SEM shows an evaporated multilayer Au/Sn structure. (Sample prepared by Stellar Industries.)

A key advantage of evaporation is the high rate of deposition. Gold deposition rates of 10 µm/sec are typical. This makes evaporation ideal for full-face metallization of large substrates, where the high deposition rate is an advantage and deposition is not targeted in specific areas. In addition, the substrate is typically rotated during the deposition process, enabling thickness uniformity with variation <1% across a 200 mm wafer.

For AuSn evaporation, the most common approach is to deposit alternating layers of gold and tin with an overall composition near $Au_{80}Sn_{20}$ (Fig. 2). After deposition, the layer is heat-treated between 200° and 250°C to interdiffuse the gold and tin. This results in a highly uniform and dense microstructure prior to die bonding, which produces more uniform melting during the eutectic bonding process.

2. Plating Au/Sn multilayer structures — An alternative to evaporation of Au/Sn multilayer structures is to deposit the elemental layers using electroplating. To achieve this type of structure, the substrate is shuttled between a gold plating bath and a tin plating bath. After the deposition step, the layers are typically annealed well below the eutectic melting temperature (200-250°C) to intermix the two layers.

One advantage of electroplating is the ability to deposit the layer only on electrically conducting materials or through a patterned photomask. This allows very efficient use of the expensive AuSn material in applications where a patterned layer is required.

Plating, however, is typically only able to provide thickness uniformity in the ±10% range for rack plating, and ±5% for fountain plating technology; it is very difficult to target exact layer thickness values. This can result in variations of the film composition off the eutectic value, which can degrade bonding characteristics. This problem can be minimized by targeting a more tin-rich composition than the 80/20 eutectic. Because the change in melting temperature with composition is much more gradual on the tin-rich side of the eutectic, small variations in composition in this region have less of an impact than they do on the gold-rich side (Fig. 1).

When selecting gold and tin baths for this application, it is very important to choose baths with low organic content. Many tin baths extensively use organic additives as grain refiners and brighteners. When these organics are co-deposited in the tin layer, they will disrupt die attach.

3. Plating $Au_{80}Sn_{20}$ from a single alloy plating bath — At present, only one plating bath supplier manufactures a bath designed to plate $Au_{80}Sn_{20}$ directly. One potential advantage of an alloy bath is that it eliminates the difficult task of controlling the relative thickness of both the gold and tin multilayers to achieve the correct composition. A complication of this bath, however, is that very tight controls on bath parameters must be made to keep the composition of the deposit on eutectic. Research has shown the composition shifted 1-2 wt% for each degree in temperature change and 4 wt% for each mA/cm^2 fluctuation in current density.[1] In addition, the gold concentration needed to be controlled to ±0.15 g/L.

4. Solder paste — For many applications, the most cost-effective method for depositing AuSn eutectic solder is to use an AuSn solder paste. The components of an AuSn paste include the metallic elements in the form of very fine powders, binders to give the paste mechanical integrity during application, and also a flux component that reduces the SnO_2 on the tin powder surface. Without an effective flux, this oxide layer would prevent uniform reaction of the gold and tin powders.

The main drawback of AuSn paste for electronic applications is the presence of impurities in and around the AuSn layer formed from flux residue and decomposition products from the binders. Flux, which vaporizes during die bonding, can also contaminate components surrounding the die attach site.

Conclusion

AuSn is widely used as a high-temperature die attach material in high thermal demand applications. The Table provides a summary of the strengths and weaknesses of various AuSn deposition options. **SI**

Reference

1. G. Hradil, "A Practical Electrolyte for the Electro-Deposition of Eutectic Gold/Tin Alloy," *IEEE Advanced Packaging Materials: Processes, Properties and Interface International Symposium*, 2006.

Jonathan Harris is CMC Interconnect Technologies' president. He has played a leadership role in the advanced ceramics and electronics packaging industry over the past 20 years. Harris received his Ph.D. in solid-state physics from Brown University in 1983.

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