Au/Sn Solder Alloy and Its Applications in Electronics Packaging

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1. Introduction

Soldering is an important technique in the assembly of electronic products. To make a sound solder joint, the choice of solder materials is very important. Solderability, melting point, strength and Young's modulus, thermal expansion coefficient, thermal fatigue and creep properties and creep resistance will all affect the quality of a solder joint.

The eutectic Au80Sn20 solder alloy (melting point ≈ 280 °C) has been applied in semiconductor and other industries for years. Due to some superior physical properties, Au/Sn alloy gradually becomes one of the best materials for soldering in optoelectronic devices and components packaging.

2. Physical Properties

Some principal physical properties of Au80Sn20 are in table 1, by which the advantages of Au/Sn solder could be identified as follows:

Properties	
Density	14.7 $g \cdot cm^{-3}$
Coefficient of thermal expansion*	16×10^{-6} /°C
Thermal conductivity	57 $W \cdot m^{-1} \cdot K^{-1}$
Tensile strength	275 MPa
Young's modulus	68 GPa
Shear modulus	25 GPa
Poisson's ration	0.405
Electrical resistivity	16.4×10^{-8} $\Omega \cdot m$
Elongation	2 %

Table 1: Some physical properties of Au/Sn 20 wt. % at 20 °C.
* temperature range 20 to 250 °C.

- Soldering temperature;

The soldering temperature is only 20-30 °C above its melting point (about 300 ~ 310 °C). Because the alloy is eutectic, minimal superheat is needed for the wetting and flowing in the soldering process. It also freezes quickly resulting in a shorter soldering cycle. This temperature range is suitable for high-reliability component packaging. The components could also be safe for subsequent assembly with a Pb-free assembly solder. These solders typically require an assembly temperature up to 260 °C.

- High strength;

The alloy has high yield strength at ambient temperature, and even at assembly temperatures of 250-260 °C, it is still strong enough to maintain hermeticity. Material strength is comparable to that of high temperature brazing materials, but with the benefit of much lower processing temperatures.

- Fluxless;

The alloy allows for fluxless soldering due to the minimal surface oxidation of the high content of Au (80 wt. %). If used in a vacuum or under a forming gas (N_2/H_2-mixture), soldering can be achieved without the use of a chemical flux.

- Good wettability; meanwhile, due to similar compositions, Au/Sn solder has a good compatibility with Au metallization due to low leaching rate to thin Au coatings; no migration problems like Ag; etc.

- Low viscosity; the alloy has low enough viscosity in liquid form that it can fill large gaps.

In addition, Au80Sn20 solder has high corrosion and creep resistances and good thermal and electrical conductivities. The disadvantages of Au80Sn20 solder include high cost, brittleness, low elongation and difficult to process.

3. Thermodynamic Properties

The superior properties of Au/Sn result from its thermodynamic properties. The Au/Sn alloy system forms a eutectic alloy at the composition of 80 wt. % (or 71at. %) Au and 20 wt. % (or 29 at. %) Sn as shown in Figure 1.

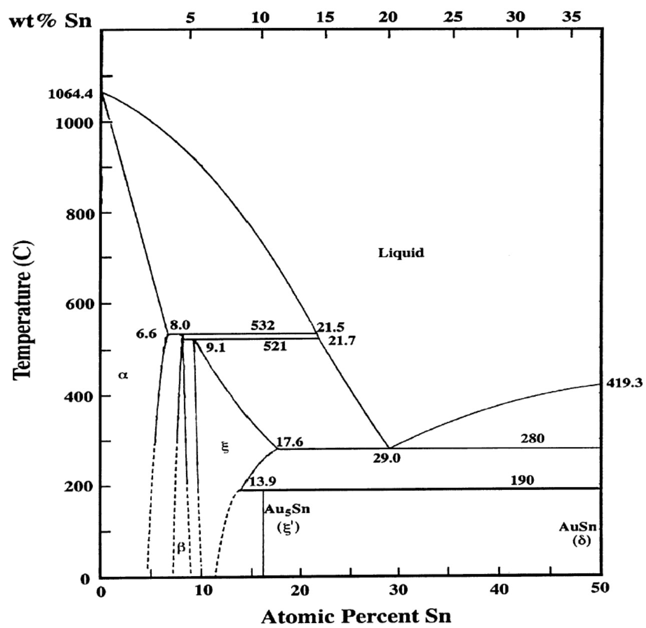

Figure 1: Au-Sn binary phase diagram (Au-rich side) [1].

The reaction L ↔ ζ + δ at 280 °C provides the basis of the eutectic solder. The interesting phases for Au-Sn solder include; ζ' (Au_5Sn), ζ and δ (AuSn). The ζ' phase has a composition of 10.7 wt. % Sn and exists up to 190 °C. It has a hexagonal structure. The ζ phase exists from the peritectic β + L ↔ ζ at 5.7 wt. % Sn at 521 °C to 11.3 wt. % Sn at 280 °C, and to 8.8 wt. % Sn at 190 °C. This phase has a Mg-type close packed hexagonal structure. The δ phase is an intermetallic compound with a melting point of 419.3 °C and a NiAs-type hexagonal structure. It is a non-stoichiometric compound with a Sn composition of 50.0 to 50.5 at. % (or 37.5 to 37.9 wt. %).

4. Preforms

The solders used in microelectronics packaging are typically available in a variety of forms. The most predominant forms are wire, strip, paste and preforms. Because of the brittle nature of Au/Sn, wire and strip will be difficult to form and shape into usable configurations, resulting in excessive scrap, high labor costs, and inconsistent joint quality. Of these forms paste is the preferred form for electronics assembly. A constituent of paste is flux, which for many applications is prohibited. Even if allowed, the assembled parts need to be cleaned to remove all flux residues. The preferred form for high reliability applications like component manufacturing and/or packaging, where the use of flux is unwanted, is stamped preforms. The preforms allow exact placement of a precise amount of solder to achieve the highest quality joint at the lowest total cost. Preforms were first used for component manufacturing in the 1960s for metal encapsulated tantalum capacitors. They are now the most widely used means for passive components manufacturing and packaging.

The advantages of preforms are:

- Accurately controlled solder volume, composition, and surface condition, enabling a wide soldering-process window and optimal finished assembly quality, resulting in a high-reliability of consistent solder joints, which are required by the high Cpk-demands by the industry, while assuring lower, bottom-line, quality assurance cost.
- Preforms used in a controlled atmosphere eliminate the need for the messy and uncontrolled use of flux. A proper control over the soldering conditions eliminates the need for a costly, post-soldering cleaning.
- Preforms are often the best solution for high-reliability and excellent heat transfer to meet the ever-increasing demand for making challenging joints.
- On the requirements of the change of substrate materials for their specific properties and/or their environmentally friendly behavior, there is almost no limit for AuSn preforms.
- When correctly designed and applied, preforms can have a high ratio of performance to cost, creating extremely high yields of sound and electrically reliable soldered joints.

5. Applications of Au/Sn Preforms

Since eutectic Au/Sn has a much higher melting point than Sn96.5Ag3.5 solder (280 °C versus 221 °C), it is incompatible with the organic materials widely used with electronic packaging. However, many high-reliability solder applications exist where the unique combination of mechanical and thermal requirements make eutectic Au/Sn the optimal choice. These applications include, but are by no means limited to, lid sealing, RF and DC feed-through attach on optoelectronic packaging, and laser diode die attach.

Certain market segments of hermetic electronic packages require joining to ceramic components. In those cases the ceramic's physical properties of low CTE and high insulation and strength are preferred over their metallic counterparts. One such application is attaching an active electronic component to a package, where the CTE of both the component and package need to be low (see Figure 2). A 25µm thin stamped AuSn preform is the preferred material option. Another application with ceramics is lid sealing, where a metal or glass lid is hermetically sealed to a ceramic package (see Figure 2). In this case, a 25µm stamped Au/Sn preform, in the shape of an open frame, is the preferred material. For lid sealing, a seam seal machine will be used which produces only localized heat on the joint, so any components inside the package soldered with Au/Sn will be unaffected by the final process. A third market application of ceramic is in feed-through attach, see Figure 3. In this case ceramic is used instead of glass as the electrical insulator because of ceramic's high strength. The requirements for the solder include good wettability, good corrosion resistance and high Young's modulus. The high Young's Modulus allows the material to be produced very thin and maintain flatness over a large area. Thanks to its clean, non-oxidized preform surface, AuSn allows fluxless soldering. Even in situations where the substrate is slightly oxidized, the application of a N2H2-mixture usually can deoxidize and clean most substrate materials before the AuSn preform will melt and start the joining process. This deoxidation reaction becomes effective at a temperature well over 235 °C. Lower melting solders will cover oxidized substrates and cause bad joints, before the N2/H2-mixture becomes effective. With applications of Au/Sn solder, the components will be in a safe place even after a prolonged thermal stressing cycling

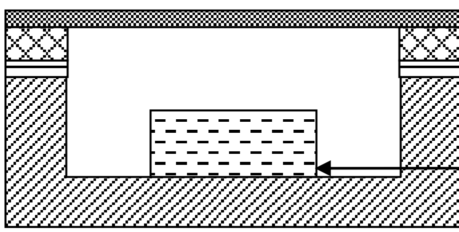

Figure 2: The application of Au/Sn preforms in final closure of lid hermetic sealing.

Au/Sn-washer preform is the best choice for optoelectronic feed-through attach in packaging used for transmitters, receivers, amplifiers and so on (seen in Figure 3). During the soldering process, the Au/Sn washer will melt and by capillary action fill the gap between the feed-through body and package body which are both maybe made of Kovar® and coated with Ni/Au metallization. Since the air gap between the pin and package body is very small, any excessive solder will bridge the two, making a short circuit. As one of the advantages of preforms, an exact amount of Au/Sn solder can be applied to the joint, which prevents bridging.

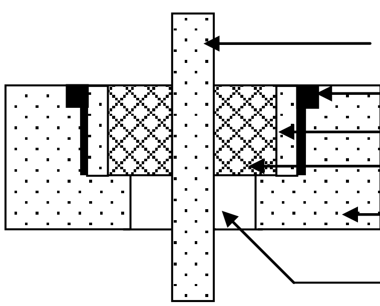

Figure 3: The application of Au/Sn preforms in optoelectronic packaging.

Au/Sn-preforms die-attach application is becoming the preferred method for the assembly of high power laser diodes (LD) as seen in Figure 4. The LD chips are bonded by Au/Sn preforms onto heat sinks, which are usually made of copper. Since the efficiency of a LD will drop dramatically with increasing temperature, conducting heat away from the LD is critical. The good thermal conductivity of Au/Sn is very helpful to solve this problem and gives LDs their best performance. Thanks to its high Young's modulus, the Au/Sn can be made very thin (5-25 µ), while maintaining flatness and resisting bending. As a consequence the risk of air/gas inclusion during the soldering process is minimal. As a result the thermal-conductivity of the joint gives the best reliability for LDs.

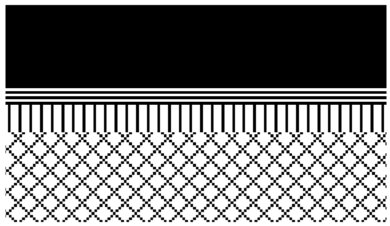

Figure 4: The application of Au/Sn preforms in the assembly of a laser diode.

As a hard solder alloy, the alloy also becomes very attractive to flip-chip bonding where the active area of the device is next to submount. In this case, a solder alloy like Au/Sn with good thermal and electrical conductivities is particularly needed. Au/Sn preforms also have applications in microwave systems assembly and other fields. With the superior properties of Au/Sn and the advantages of using preforms, Au/Sn will become more popular and even necessary in packaging applications.

6. Notes for Au/Sn Applications

Au/Sn solder must be applied properly to get good joining results. The main effects to the joints' quality include: Au/Sn solder composition, surface quality of work pieces and preforms (for instance, oxides, contamination and flatness, etc.), processing conditions (like furnace temperature profile, peak temperature, forming gas and tools) [2]. From Figure 1, the melting point of Au/Sn is very sensitive to the composition close to eutectic temperature. When the gold content is over 80%, the melting point of Au/Sn will increase dramatically. However, the work pieces needed to be joined usually have a Au metallization layer and the Au element will diffuse into the solder during joining process. Under some circumstances like as a very thick Au metallization layer, a very thin preform and a long soldering time, the Au contents in the solder will increase and result in a higher melting point of the solder. So, all the soldering conditions need to be optimized [2]. In general, the peak temperature is often at 310 to 340 °C, the holding time is about 2-4 minutes.

7. Conclusions

Au80Sn20 eutectic alloy has a melting temperature at 280 °C, high strength, fluxless, high thermal and electrical conductivity, good wettability, low viscosity, good solderability, high corrosion and creep resistance. It has been widely used in the applications in lid sealing and component attachment of ceramic packaging for microelectronic and optoelectronic components, feed-through attach in optoelectronic packaging and die-attach for high power laser diodes. AuSn can dramatically increase the reliability and thermal/electrical conductivity for the packaging of these components.

Reference

1. J. Ciulik, M. R. Notis, J. Alloys Compounds, 191 (1993), p71.

2. R.R.Tummala 等编著，贾松良等译，微电子封装手册（第二版），中译本，电子工业出版社，2001 年，p941～942。