PVD Magnetron Sputtering Parameters and their Effect on the Composition of AuSn Solder

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Abstract

The 80%Au20%Sn eutectic solder is frequently used for die attach due to its high strength, creep resistance, and electrical and thermal conductivities. With new applications such as LED's, there's an increasing demand for thin (several microns) physical vapor deposited (PVD) solder layers. Materion and NEXX Systems partnered to optimize the manufacturing methods for producing AuSn sputtering targets, and PVD magnetron sputtering parameters, to control the composition of the sputtered solder. Deposition power and chamber pressure are the primary process parameters that affect the composition of the deposited solder film. There is a significant composition shift between the chemistry of the AuSn sputtering target and the deposited AuSn film, due primarily to the loss of Sn during sputter deposition. Higher deposition power and lower chamber pressure result in greater Sn loss during the PVD sputtering process. In order to optimize this solder, the composition of the AuSn target has to be produced on the Sn-rich side of the eutectic, with the exact composition dependent on the processing parameters, system configuration and available Au in the final soldering system.

INTRODUCTION

Materion, a producer of precious metals sputtering targets and a leader in the development of gold base solders, and NEXX Systems a producer of semiconductor process equipment, partnered to develop a solution for producing precision AuSn solder films. With new applications in back side metallization and particularly LED's, there is an increasing demand for physical vapor deposited (PVD) solder (see Fig. 1).

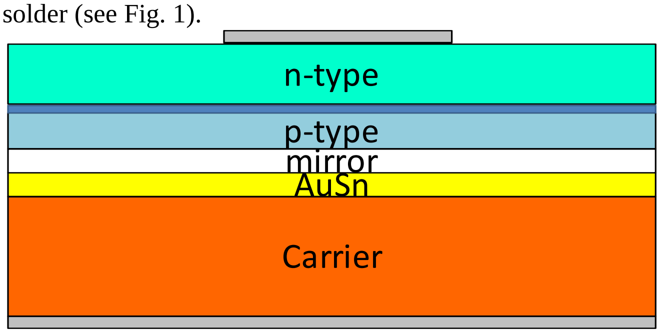

Fig. 1 Schematic of a LED structure where a AuSn solder layer is used for attachment to a carrier.

The composition of the solder is critical for proper flow, and strength, and there is a significant composition shift between the chemistry of the AuSn sputtering target and the deposited AuSn film, due primarily to the loss of Sn during sputtering. Deposition power and chamber pressure were studied to determine their relationship to the chemistry of the deposited solder film. In order to optimize this solder, the composition of the AuSn target has to be produced on the Sn-rich side of the eutectic, with the exact composition dependent on the processing parameters, system configuration and the available Au from the substrates.

SOLDER

The 80Au20Sn solder has been manufactured for semiconductor applications for more than 50 years, typically as a stamped preform or paste. This solder is always soldered to gold plated surfaces to insure proper wetting and flow characteristics. A gold coating should be deposited prior to the deposition of the solder to insure proper wetting. If the solder is directly deposited onto nickel, then tin can be leached from the solder due to the formation of the NiSn intermetallic, resulting in poor solder flow.

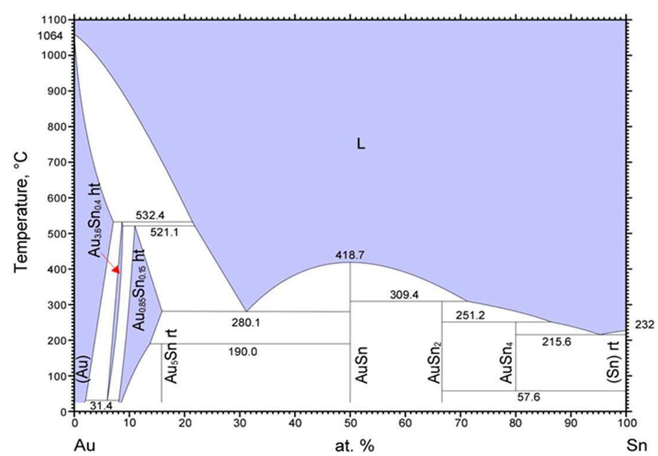

Fig. 2 AuSn phase diagram

We studied the functioning of this solder in compound semiconductor applications, considering the entire soldering system and its effect on the chemistry, wetting and strength of the solder. A careful analysis of these factors indicates an ideal deposited solder film that is slightly tin rich when deposited onto a pure gold layer. When the solder is tin rich and the adjoining surfaces are pure gold, the gold will be dissolved into the solder taking the composition from tin rich to gold rich while passing through the eutectic (80.25% Au) to insure perfect wetting. Furthermore, the liquidus slope of the hypo-eutectic (gold rich) solder is double that of the hyper-eutectic (tin rich) so gold rich solders will develop a wider melting range and a higher liquidus temperature rapidly and therefore will not solder properly (see Figs. 2 & 3). Thus is it preferable for the deposited solder layer to begin as hyper-eutectic (tin rich) before soldering and end as hypo-eutectic (gold rich) after soldering.

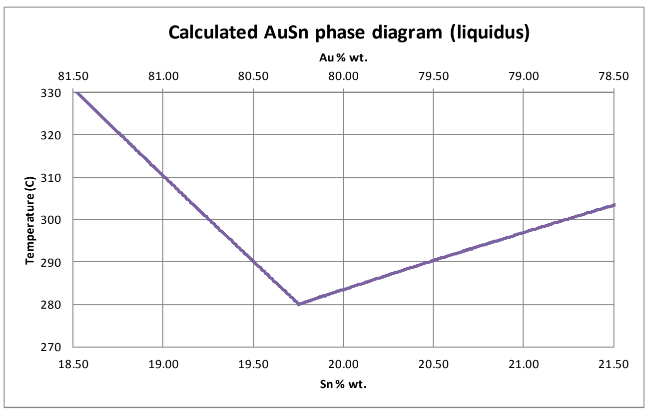

Fig. 3 AuSn phase diagram near the eutectic composition

With regard to mechanical properties, a hypo-eutectic final soldered layer is preferable for strength and stability. This is because a hyper-eutectic solder can develop large Au_1Sn_1 intermetallic spikes which are considerably weaker than the $Au_{0.85}Sn_{0.15}$ intermetallic found on the hypo-eutectic solder.

A recent solder innovation at Materion has been the invention of a three part AuSn solder containing small amounts of indium. This solder has a ternary eutectic of 306°C, providing added assurance that subsequent soldering processes will not cause it to remelt.

SOLDER TARGET MANUFACTURING

AuSn solder is known for its high strength and creep resistance, but is also quite brittle at room temperature. When this and other gold base solders are processed they are rolled at elevated temperatures where they become quite ductile. Warm rolling with reductions of greater than 90% per pass are readily accomplished, while simply flexing the thin rolled solder at room temperature will cause it to fracture.

Casting this solder typically results in large grain size (cm+) which would lead to inconsistent sputtering performance. Over a decade ago, we developed a vibration casting technology (VCT™) to generate fine grains by mechanically vibrating the solidifying casting. VCT™ has resulted in equiaxed grain structure with a typical grain size of 50 microns. Vacuum Induction Melting (VIM) and VCT™ technology are employed for large targets while VIM and warm rolling are most efficient for thinner sputtering targets.

While a chemistry range of 80% +/- 0.5% Au (melting range < 10°C) is optimum for soldering, and easily controlled in alloying and casting, a special LED grade of AuSn solder has been developed to control chemistry within 0.25% and an equiaxed grain size of less than 100 microns for optimum sputtering control.

SPUTTERING

A sputtering target with fine equiaxed grains is required for deposition of a uniform film. The solder sputtering targets in the NEXX Apollo PVD system are fairly large and are manufactured at Materion using the VIM/VCT™ technology.

Fig. 4 Nexx Apollo PVD system

When there is an abundance of solder, then a gold content of 79.5 to 80.5% is ideal for excellent flow. While this chemistry range can be easily controlled in an alloyed solder, it can be difficult to control during sputtering.

There is a general loss of tin, due to its lighter atomic mass, during the sputtering process. It is believed that this loss is due to energetic gold atoms impacting the film and preferentially ejecting some of the tin atoms.

There are several sputtering parameters that effect the composition of the deposited layer. The throw distance from target to substrate is one factor, but in the NEXX system it is fixed at 50 to 60 mm. We would expect that a greater throw distance would result in a higher tin content in the thin film because the gold atoms would have less energy on impact.

During our development trials we varied the argon pressure and also the power. Composition was determined by ICP-OES after dissolving the thin solder film in acid. Film uniformity across the 4” wafers was determined by XRF. Trials were primarily run on 6” wafers at NEXX Systems using the Apollo PVD system (see Figure 4), but also on an old MRC system located at Materion. Our optimum chemistry for the sputtered solder film is 79.5%Au +/- 0.50%. This chemistry insures that we are slightly hyper-eutectic (E @ 80.25% Au) and that we will have excellent wetting and solder flow characteristics. Ideally, we will dissolve some of the contacting pure gold, so that our solder will pass through the eutectic and wind up eutectic or slightly hypo-eutectic. It should be noted here that while compositional measurements of the deposited films are very useful for demonstrating trends there is always some risk of systematic errors. Therefore a more foolproof method of composition checking is a flow test performed at normal soldering temperatures (320 °C).

During our trials we varied the power from 2 to 6KW (Fig. 5), and the pressure from 5 to 20 mTorr (Fig. 6). We found that a power change from 2KW to 6KW increased gold by 1.0%. Raising pressure from 5mTorr to 20mTorr at 6KW power lowered the gold content by 1.6%.

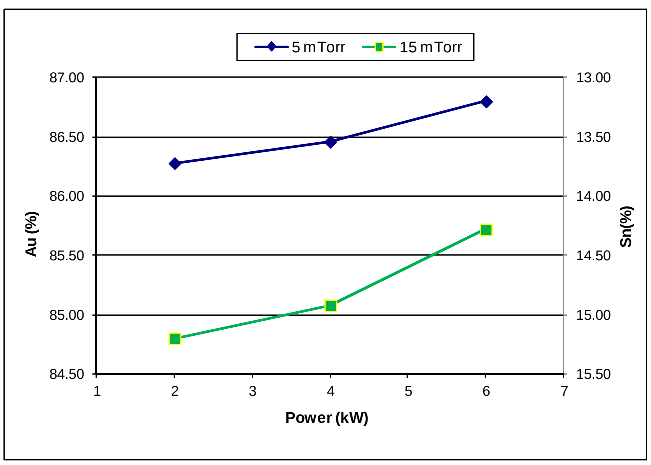

Fig. 5 Deposited AuSn composition as function of power

Raising power and lowering pressure will increase the relative gold content of the deposited film. This relationship was consistent for both systems. Depending on the sputtering system, the optimal Au content of the target to achieve the optimal on-wafer Au content may range from 72-76%.

CONCLUSIONS

In deposition of AuSn by PVD, there is a significant composition shift between the chemistry of the AuSn sputtering target and the deposited AuSn film, due primarily to the loss of Sn during sputtering.

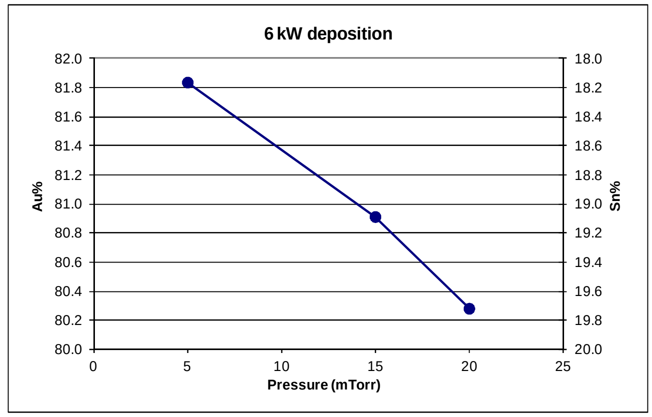

Fig. 6 Deposited AuSn composition as a function of pressure

The magnitude of this composition shift varies quite considerably for different sputtering systems. Some of the shift (1-2%) can be controlled by the process parameters of deposition power and chamber pressure. Higher deposition power and lower chamber pressure result in greater Sn loss during the PVD sputtering process. However, the majority of the shift needs to be compensated by adjusting the composition of the sputtering target. We typically use solder targets containing 72-76%Au due to the anticipated loss of tin. The aim is to deposit a film that is slightly Sn rich (79.5%Au 20.5%Sn) compared to the eutectic composition (80.25%Au 19.75%Sn) due to the existence of a gold layer on the opposing surface of the soldered assembly which will interact with the deposited AuSn layer during soldering. Thus during soldering the AuSn alloy composition will shift through the eutectic composition towards the Au-rich side of the eutectic.

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ACRONYMS

Au: Gold
AuSn: 80%Au 20%Sn by weight
E: Eutectic (single melt point)
ICP-OES: Inductive Coupled Plasma – Optical Emission Spectroscopy
MR: Melting Range
PVD: Physical Vapor Deposition
Sn: Tin
VCT™: Vibration Cast Technology
VIM: Vacuum Induction Melting
XRF: X-Ray Fluorescence