Investigation into the buffer-layer effect on the phase formation in Au80Sn20 thin film solder obtained by electron-beam deposition technique

E M Filonenko, A V Fomin, O V Titova and I V Chemagina

E.I. Zababakhin All-Russia Research Institute of Technical Physics-Russian Federal Nuclear Center, 456770, Snezhinsk, Russia

E-mail: dep5@vniitf.ru

Abstract. In this work, differential scanning calorimetry (DSC) and X-ray microanalysis are used to investigate Ti and Ti/Pt buffer-layer effect on the eutectic formation in 1μm Au80Sn20 thin film solder obtained by electron-beam deposition of gold tin alternating layers.

1. Introduction

An Au80Sn20 alloy with a melting point of 280 °C is a eutectic in the gold tin system [1]. It is a widely used alloy intended to manufacture state-of-the-art optoelectronic devices. Designers of laser emitters based on high-power semiconductor laser diodes show considerable interest in its unique properties. For flip-chip assembly of a semiconductor laser crystal, Au80Sn20 films less than 10µm are directly deposited on the components to be joined on a pre-deposited buffer layer.

Gold and tin layers are deposited in vacuum to obtain an Au80Sn20 solder [2]. With this technique, a eutectic melt is immediately formed during the soldering process while a thin film solder made of alternating alloys is being heated. At the same time, melting homogeneity depends on a number of factors, including the level of the buffer-layer components’ effect on the eutectic formation in the obtained solders. In case intermetallic compounds of the solder and buffer layer components are being formed, deviations from the eutectic composition are possible and the solder melting point can be subsequently shifted to a high-temperature range. As a result, the required properties, inherent to Au80Sn20, will be deteriorated. For 5–10 µm AuSn thin film solders, Ti/Pt-type buffer layers are traditionally used including Ti as an adhesion layer and Pt as a barrier layer. Typically, the thickness of these layers is less than 200 nm [3]. The purpose of this work was to study the level of the buffer-layer effect on the eutectic formed in the gold tin system when the obtained solder is less than 1µm thick.

2. Experimental details

Two groups of 1µm Au80Sn20 thin films different in their buffer-layer compositions (table 1) were fabricated. Vacuum e-beam deposition system was used for buffer layers and solder on the Al2O3 ceramic substrates.

To identify the phase transition temperatures in the soldering temperature range from 280 to 340°C, the samples were studied in inert gas at the heating rates of 10 K/min and 20 K/min, respectively, using differential scanning calorimetry (DSC).
X-ray spectrometry microanalysis was used to study the solder phase composition. The samples in both groups were heated up to 340 °C in vacuum and held at this temperature for 40 seconds. The phase composition of the heat-treated solders was analyzed on their surface and cross section at room temperature using a scanning electron microscope with an energy dispersive spectrometer.

### Table 1. Solder groups.

| Solder thickness, μm | Adhesion layer, nm | Barrier layer, nm |
|----------------------|-------------------|------------------|
| 1                    | Ti, 100 nm        | –                |
| 2                    | Ti, 100 nm        | Pt, 200 nm       |

### 3. Results and discussion

DSC analysis of samples in group 1 at temperatures ranging from 215 to 340 °C shows the endothermic reaction peak at ~279 °C while in heating and the exothermic reaction peak at ~274 °C while in subsequent cooling. The recorded peak areas are roughly equal (figure 1(a)). Hence, the eutectic melt is formed at ~279 °C and its total volume is crystallized while in the reverse cooling process at ~274°C. DSC curves of the reheating and recooling processes demonstrate reversibility of melting for the samples in group 1 (figure 1(a)).

The backscattered electron images of the heat-treated samples in Group 1 demonstrate two phases (figure 1(b)). The X-ray spectroscopy microanalysis data indicates that the light-grey phase contains (86–89) wt.% Au and (11–14) wt.% Sn, the light-grey phase – (68–72) wt.% Au, and (28–32) wt.% Sn. As per phase diagrams of gold tin alloys, composition of these phases corresponds to Au5Sn (ξ) and AuSn (δ) phases forming a eutectic [1]. It should be noted that δ- and ξ-phases are uniformly distributed over the total volume: the linear size of each phase area is less than 1 μm.

To analyze lasting stability of the properties, the samples in Group 1 were studied 6 months after their fabrication. DSC analysis revealed a significant shift of the crystallization temperature as a result of the reheating/recooling cycle in the studied temperature range. This probably implies deviations from the eutectic composition (figure 2(a)).

In this case, X-ray spectroscopy microanalysis of the samples in Group 1 reveals ξ- and δ- phases forming the eutectic, as well as an extra phase in the volume and on the surface of the sample (item 3 in figure 2(b)). At this point, uniformly-distributed ξ and δ-phases are not observed over the total volume.

Linear size of the solder ξ-phase areas exceeds 3 microns (Item 1 in figure 2(b)). Based on the linear distribution of characteristic X-radiation of chemical elements from the surface of the samples in group 1, it follows that the extra phase aside to Au and Sn contains Ti and O (figure 3). In this case, presence of Ti on the surface and in the volume of the solder is due to its diffusion from the adhesion layer while in storage and formation of Au,Sn,Ti intermetallic compounds.
Figure 2. DSC curves at temperatures ranging from 215 to 340 °C for 1μm Ti/Au80Sn20 solder 6 months after fabrication (a); backscattered electron image of the solder cross section after heat treatment at 340°C during 40 seconds (b): 1 – area of the alloy microinhomogeneity, 2 – area of the uniformly-distributed phases, 3 – area of an extra phase.

Figure 3. Backscattered electron image and linear distribution of characteristic X-radiation of chemical elements from 1μm Ti/Au80Sn20 solder after heat treatment at 340°C during 40 seconds 6 months after fabrication.

A 200-nm Pt barrier layer was added to the deposition pattern to obtain solders of group 2. DSC analysis of the samples in group 2 at temperatures ranging from 180 to 390 °C did not reveal peaks of exothermal and endothermal reactions (figure 4(a)).

Figure 4. DSC curve at temperatures ranging from 180 to 390 °C for 1μm Ti/Pt/Au80Sn20 solder (a) and backscattered electron image of the solder cross section after heat treatment at 340°C during 40 seconds (b).
Images of the solder cross sections from Group 2 demonstrate two phases. The light-grey phase, as was the case for the samples in Group 1, contains 86-89 wt.% Au and corresponds to ξ-phase composition, while the light-grey δ-phase aside to gold and tin contains Pt (up to 5 wt.%). In contrast to group 1, these samples show that the phases are decomposed in the solder volume and δ-phase is concentrated at the Pt–AuSn interface (figure 4(b)). The above-mentioned peculiarities are indicative of the reaction with the Au₄Sn₅Pt intermetallic compounds being formed at the barrier layer-solder interface.

4. Conclusions
The phase formation dependence in 1μm Au80Sn20 solders was established for two types of Ti- and Ti/Pt buffer layer. It is demonstrated that ξ- и δ-phases are uniformly distributed in the heat-treated solders containing a Ti layer. In this case, the melting temperature corresponds to the eutectic formation temperature in the Au-Sn system. However, it was identified that Ti diffuses in time with the Au₄Sn₅Ti intermetallic compounds being formed. This results in non-uniformly distributed ξ- and δ-phases at the solder melting and structural microinhomogeneities in the alloy Au80Sn20. For the solders with Ti/Pt layers, decomposition of ξ- and δ-phases, as well as lack of melting at a eutectic-formation or higher temperatures are identified.

References
[1] Lyakishev N P 1997 State Diagrams of Binary Metal (Moscow: Mashinostroenie) 400
[2] Katz A et al. 1992 Materials Chemistry and Physics 33 281–8
[3] Kondratyuk R 2015 Electronics: science, technology, and business 10 154–160