Features of Au(80)Sn(20) thin film solder manufacturing technology

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Abstract. This work provides the results of manufacturing technology development for Au(80)Sn(20) thin film solders produced with electron-beam evaporation coating of alternating gold and tin layers. The phase formation mechanism in the produced solders was studied to work out an evaporation procedure which enables to make a solder with the properties meeting the requirements to soldering of a laser diode onto a heatsink base surface.

1. Introduction
An Au80Sn20 alloy with a melting point of 280 °C is a eutectic in the gold tin system [1]. This alloy is one of the critical materials used to manufacture state-of-the-art optoelectronic devices. In particular, its unique properties can be applied to fabricate semiconductor lasers with high power laser diodes (LD). Foils, tapes, preforms, and soldering pastes represent today’s Russian commercial varieties of Au(80)Sn(20) [2] but for flip-chip die soldering, the best option to be used is its thin-film variety deposited directly on the components to be joined. Within the context of the semiconductor lasers production, one of the key issues was to develop an in-house manufacturing technology for an Au(80)Sn(20) solder comprising layers less than 10 μm which are deposited directly on heatsinks. For this purpose, electron-beam deposition of alternating gold and tin layers was employed. This method is intended to make micro-relief films and to control the solder stoichiometric composition to a high accuracy.

2. Electron-beam Evaporation Coating System
For vacuum evaporation of Au(80)Sn(20) solders, as well as buffer and adhesion layers, an electron-beam evaporation system was used. The system incorporates quartz measuring heads to monitor the thicknesses of alternating gold and tin layers to a high accuracy. Fig.1 shows an example of the system vacuum chamber configurations.

The heatsinks are placed and moved within the chamber by means of a rotary segmented calotte. The rotary segmented calotte design is given in Fig.2. It comprises three spherical surface segments, each of which has 8 holes to mount the heatsinks with the substrate holders.

Studies of the obtained solders allow us to state that the selected design concept of the system inner chamber provides uniform coatings having diversity in thicknesses of less than ±5%. Besides, the sequentially loaded heatsinks might amount to 4500 pieces.
Figure 1. Vacuum Chamber Configuration:
A- calotte holder, B- rotary segmented calotte (without segments), C- quartz measuring head, D – quartz heater, E - glow discharge electrode, F - shields, G - thermocouple, H - vacuum system chevron, I - shutter, J - electron beam evaporation source

Figure 2. Image of a three-segment rotary calotte with holes and substrate holders.

3. Features of Au(80)Sn(20) Solder Manufacturing

According to [4], the alloy Au(80)Sn(20) is a eutectic, comprising Au₅Sn (ξ), and AuSn (δ) phases at room temperature. The alloy microstructure incorporates ξ and ξ’ dendrites - Au₅Sn surrounded by (ξ+δ) composition matrix.

In the described solder manufacturing method used to deposit alternating gold and tin layers, the phases are being formed directly during the soldering procedure while the obtained composite is being heated. Homogeneity of ξ and δ phases’ distribution through the solder bulk will depend on the alternating layers’ thickness ratio and will control the solder behavior for the full duration of soldering.

Various evaporation procedures, including the existing ones were studied to find the best ratio of gold and tin layers [5]. The obtained solders were analyzed to determine their melting character. In the studies, the temperature range together with the solders’ heating rate were selected as relevant to the laser diode soldering with Au(80)Sn(20) solder – (280 – 340) °C.

The findings of the study, including visual, X-ray, and differential scanning calorimetric analyses enabled to formulate unambiguous criteria to select the ratio of the thicknesses for the alternating layers in the solder composition. The solder melting character in case of an unbalanced alternating gold and tin layers’ ratio can be exemplified by a 3-μm thick Au(80)Sn(20) solder obtained with one of the studied evaporation procedures.

It was noted that when passing through the eutectic-formation temperature (280 °C), the melt is being formed. It remains unchanged up to 300 °C. The temperature rise above 300°C or the exposure time of more than 5 seconds at 300°C resulted in the emergence of local crystallization areas and further rapid crystallization through the solder bulk. Figure 3 shows typical images of the sample coating surfaces produced after reflowing at 300 °C during 5 seconds. By means of X-ray spectrometry it was determined that the local crystallization areas were large crystals of δ phase. This implies deviations form the eutectic alloy microstructure.

Images of the solder cross-sections exhibit partial layering of the eutectic-forming phases through the solder bulk, and δ phase is predominantly concentrated at the solder-barrier metallization interface (Fig.4).
Figure 3. The back-scattered electron images of a 3-μm thick AuSn solder exposed at 300°C during 5 seconds show the following areas a) local crystallization areas, b) eutectic structure.

The observed inhomogeneous distribution of the phases through the eutectic structure and the visual analysis of the reflowing stages imply that the obtained solder is not homogeneously melted at the eutectic-formation temperature or above.

Figure 4. The electron back-scattered image of a 3-μm thick Au(80)Sn(20) solder exhibits inhomogeneous distribution of the eutectic-forming phases through the solder bulk.

Similar solders were used to mount the laser bars on the heatsinks. However, because of the peculiarities quoted above the laser bar metallization was only partially wet; soldering procedure, in terms of its reproducible quality, was inadequate (Fig.5).

Figure 5. Visual appearance of a solder joint with the laser bar removed. The area to the left shows that the laser bar metallization is not wet with the Au(80)Sn(20) solder, the stripes are traces of the laser bar emitters’ contact, the arbitrary shaped dark and light areas are the laser bar fragments which have remained after detachment.
The method was further developed to improve the melt stability at the soldering process due to modification of the existing evaporation procedures used for gold and tin alternating alloys. The best ratio for the solder alternating components’ thicknesses was found, and the required evaporation temperature conditions for the layers deposition [7] were identified considering the recorded data on the diffusion processes in the couple gold and tin [6]. As for the developed procedure, the thickness of the obtained Au(80)Sn(20) solder made (5.5-6) μm.

The solders were analyzed by differential scanning calorimetry to demonstrate that they start to melt at the eutectic-formation temperature (280°C) and then the melt remains steady up to 340°C (Fig. 6a). The electron microscopy was used to study the surface and cross-section of the solders after reflowing at 340°C. The analysis revealed a typical eutectic structure of the alloy AuSn at room temperature (Fig. 6b).

The techniques used to mount a laser bar on the heatsinks were worked out with this thin film solder. Studies of the obtained solder joints between the laser bar and the heatsinks convey the following: the laser bar metallization is well wet by the obtained eutectic solder and the eutectic-forming phases are homogeneously distributed in the solder (Fig. 7).

**Figure 6.** Results of analysis for 5.5-6 μm-thick Au(80)Sn(20) solders: a) – DSC-curve recorded in the temperature range (100-400) °C; b) – a typical image of a 5.5 μm thick Au(80)Sn(20) at 340 °C demonstrates a eutectic structure: ξ phase dendrites surrounded with (ξ+ δ) matrix.

**Figure 7.** Image of a solder joint between a laser bar and a heatsink with the surfaces (to be joined) properly wet by the solder.

4. Conclusions
Electron-beam evaporation coating for alternating gold and tin layers was successfully used to develop an Au(80)Sn(20) thin film solder manufacturing method. The selected design concept of the system internal chamber provided uniform deposition of solders on the heatsinks of lasers. Diversity in the thicknesses of the deposited coatings was less than 5%.

The solder evaporation procedure was developed through the studies of Au(80)Sn(20) solders deposited using various ratios of the thicknesses of alternating gold and tin layers. This procedure gave us a Au(80)Sn(20) solder with the total thickness of 5.5 μm and the composition having the eutectic structure within the gold-tin system. At the same time, distribution of the eutectic-forming phases through the bulk of the obtained solder is homogeneous for the full duration of the laser bar soldering.

The developed technology was successfully implemented to manufacture the semiconductor lasers with high power laser diodes.

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