Microstructure of lead-free solder bumps using laser reflow soldering

Hiroshi Nishikawa\textsuperscript{1}, Noriya Iwata\textsuperscript{2} and Shinya Kubota\textsuperscript{2}

\textsuperscript{1} Joining and Welding Research Institute, Osaka University, 11-1 Mihogaoka, Ibaraki, 567-0047, Japan
\textsuperscript{2} Graduate school of Engineering, Osaka University, 2-1 Yamadaoka, Suita, 565-0871, Japan

E-mail: nisikawa@jwri.osaka-u.ac.jp

Abstract. Compared with conventional reflow soldering using a furnace, laser reflow soldering brings advantages such as localized heating, rapid rise and fall in temperature, non-contact soldering and the fact that it is an easily automated process. In this study, to elucidate the characteristics of laser reflow soldering, we investigated the microstructures of a Sn–Ag–Cu solder bump and a Sn–Bi solder bump on a Cu pad after reflow and aging. In the as-soldered condition, we found obvious microstructural refinement and a thin intermetallic compound (IMC) layer at the interface for both the Sn–Ag–Cu solder bump and the Sn-Bi solder bump using laser reflow soldering. Also, during isothermal aging, the total thickness of the IMC layer increased, and a distinct second layer was observed at the interface between the Cu pad and the first layer, regardless of the soldering method. In particular, the growth of the IMC layer was faster in the case of the laser reflow soldering than in the case of the conventional reflow soldering.

1. Introduction

Lead-free soldering technology is commonly being used in the electronics industry all over the world. Among the various lead-free solders available, Sn–Ag–Cu solders are considered the most promising for both conventional wave and reflow soldering processes. Reflow soldering using a furnace has been widely applied in electronics packaging and assembly processes. However, with the miniaturization of electronic devices and the use of heat-sensitive electronic components, the use of the conventional reflow soldering process often gives rise to difficulties. Recently, a laser reflow soldering process was introduced in industry for practical use because of its low cost and its unique properties such as localized and non-contact heating, rapid rise and fall in temperature, and ease of automation as compared to the reflow soldering process. However, there has been limited discussion on the basic phenomena of the laser reflow soldering process and the performance of the joints soldered by this process [1-4].

Lowering the reflow temperature reduces thermal stresses on components in electronic products, and some heat-sensitive materials require low-temperature assembly. Thus, it is very important to study low-melting-temperature solders. Sn–Bi eutectic solder has been considered a promising lead-free solder for low-temperature applications due to its low melting point (138 °C). Several studies on Sn-Bi eutectic solder have been conducted to investigate the basic characteristics of the solder joint [5-10]. However, there is a lack information about laser reflow soldering for Sn–Bi eutectic solder.
The solder microstructure and the growth of an intermetallic compound (IMC) at the solder/metallization interface significantly influences solder joint reliability. So, in this study, to elucidate the characteristics of the laser reflow soldering, we investigated the effect of heating method on the solder microstructure and the growth of IMC at the interface of a Sn–Ag–Cu solder bump and a Sn–Bi solder bump on a Cu pad.

2. Experimental procedure

A Sn–3.0 mass%Ag–0.5 mass%Cu solder ball with a diameter of 1 mm and a Sn–58 mass% solder ball with a diameter of 0.76 mm were used in this study. Cu pads fabricated on an FR-4 printed circuit board were used as the substrate. Commercially available fluxes were also used. Prior to the soldering, the Cu pads were immersed in a 4 % HCl solution for 120 s. Then, the Cu pads and the solder balls were ultrasonically rinsed in an ethanol solution. After the solder balls had been dipped in the flux, they were placed on the Cu pads. Figure 1 shows a schematic illustration of a sample soldered joint being formed on a Cu pad. After being placed on the Cu pads, the solder balls were heated by laser in air using a laser soldering system (UNIX-413L2, JAPAN UNIX Co., Ltd.). This laser soldering system consisted of a high-power diode laser (\(\lambda = 940\) nm) with a 1.2 mm beam and a 120 mm focal-length objective, and it had a maximum laser power output of 50 W. As a reference, the solder balls were also heated by using reflow soldering at 523 K for the Sn–Ag–Cu solder and 443 K for the Sn–Bi solder for 60 s in a furnace under nitrogen atmosphere. Some of the soldered joints were then subjected to isothermal aging at 423 K for the Sn–Ag–Cu solder and at 353 K for the Sn–Bi solder. Then, some of these joints were cut and their cross sections were polished so that the solder/Cu pad interface and the microstructure of the solder matrix could be observed by scanning electron microscopy (SEM) and the thickness of the IMC layer at the interface measured.

3. Results and discussion

Figure 2 shows SEM micrographs of the solder matrix just after reflow soldering and after isothermal aging for 504 h. Figure 2(a) shows the Sn–Ag–Cu solder matrices and Figure 2(b) shows the Sn–Bi solder matrices. In the as-soldered condition in the case of Sn–Ag–Cu solder, the microstructures after reflow were composed of dendrites of a \(\beta\)-Sn phase, which formed as the primary phase, and a network band, which was the \(\beta\)-Sn/intermetallic compound particles eutectic phase. The size of the primary \(\beta\)-Sn phase for the laser reflow soldering was smaller than that of the conventional reflow soldering. This is because the cooling rate of the laser soldering is much faster as compared with the conventional reflow soldering. After isothermal aging of both solders for 504 h, microstructural coarsening occurred during the aging. The microstructure of the solder matrix for the laser reflow soldering was similar to that for the conventional reflow soldering. In the case of Sn–Bi solder,
the original Sn and Bi phases were finely dispersed, and the sizes of the Sn and Bi phases for the laser reflow soldering were much smaller than those of the conventional reflow soldering. These fine matrices were eventually superseded by growing islands of Sn and Bi after aging for 504 h. The Sn and Bi phases of the solder for the laser reflow soldering were somewhat smaller than those for the conventional reflow soldering. Thus, the heating method in particular affected the microstructure of the solder matrix only in the as-soldered condition.

Figure 3 shows SEM images of the interface between the solder and the Cu pad just after soldering and after isothermal aging for 504 h. Figure 3(a) shows the Sn–Ag–Cu solder interface and Figure 3(b) shows the Sn–Bi solder interface. For both solders and in the as-soldered condition, a relatively thin IMC layer was formed at the interface in the case of the laser reflow soldering. This is because the duration for which the solder was heated to a temperature greater than its melting temperature was much shorter in the case of laser reflow soldering than it was for conventional reflow soldering. After isothermal aging for 504 h, a distinct second layer was noticed at the interface between the Cu pad and the first layer, and the total thickness of the IMC layer increased, regardless of the heating method. As shown in Figure 3, it is clear that there was some effect of the heating method on the IMC layer growth at the interface, regardless of solder composition.

Figure 2. Typical SEM micrographs of the solder matrix after reflow soldering and after isothermal aging for 504 h. (a) Sn-3.0Ag-0.5Cu solder, (b) Sn-58Bi solder

Figure 3. SEM micrographs of the interface between the solder and Cu pad after reflow soldering and isothermal aging for 504 h. (a) Sn-3.0Ag-0.5Cu solder, (b) Sn-58Bi solder
Figure 4. Effect of isothermal aging on the total IMC thickness at the interface. (a) Sn-3.0Ag-0.5 Cu solder, (b) Sn-58Bi solder

Figure 4 shows the effect of aging time on the growth of the IMC layer during the isothermal aging. The total IMC thickness for the Sn–Ag–Cu solder is shown in Figure 4(a) and that of the Sn–Bi solder is shown in Figure 4(b). Regardless of solder composition and for both the laser reflow soldering and the conventional reflow soldering, the total IMC layer thickness increased with increasing aging time. The thickness is proportional to the square root of aging time. Accordingly, the growth of the IMC layer during the isothermal aging process can be considered a diffusion control process for both solders. The growth rate of the IMC layer for the laser reflow soldering was faster than that for the conventional reflow soldering.

4. Conclusions
In this study, the effect of heating method on the solder microstructure and the growth of the IMC layer at the interface of the Sn–Ag–Cu solder bump and the Sn–Bi solder bump on a Cu pad was investigated in order to elucidate the characteristics of laser reflow soldering. The main results obtained in this study are summarized as follows:
(1) The heating method affected the microstructure of the solder matrix only in the as-soldered condition, regardless of solder composition. For example, in the case of the Sn–Bi solder, Sn and Bi phases were finely dispersed, and the sizes of the Sn and Bi phases for the laser reflow soldering were smaller than those of the conventional reflow soldering.
(2) For both solders and in the as-soldered condition, a relatively thin IMC layer was formed at the interface in the case of the laser reflow soldering. Thus, the heating method had an effect on the formation and growth of the IMC layer at the interface during the isothermal aging.

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