Effect of isothermal aging on Sn-Ag-Cu solder joints on electroless Ni-P/Au plating by laser reflow soldering

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Abstract

With the miniaturization of electronic productions and the use of heat sensitive electronic components, the traditional reflow soldering process often has difficulties. As an alternative soldering process, the laser reflow soldering has been recently proposed. To clarify joint properties of the joint soldered by the laser reflow soldering, we investigated the effect of isothermal aging on Sn-Ag-Cu solder joints on electroless Ni-P/Au plating by the laser reflow soldering. Especially, the microstructure at the interface between Sn-Ag-Cu solder and Ni-P/Au plating and joint properties of solder joints were studied.

Introduction

Lead-free soldering is showing a global trend and conventional reflow soldering process has been widely used in the electronic industry. Recently the laser have been utilized as an alternative heat source for the soldering process because of its unique properties such as localized heating, rapid rise and fall in temperature, non-contact heating and easily automated process [1-3]. In addition, the laser reflow soldering process enables mounting of individual components and customized modifications of PCB assemblies. However, there is limited discussion of the laser reflow soldering process and a lack of information exists about the performance of the resultant joints.

As one of basic characteristics of lead-free solders, the high reaction rate of metals in molten lead-free solders; that is, the high dissolution rate of metals, is pointed out compared with Sn-Pb eutectic solder. Then, during heating, an intermetallic compound (IMC) layer is easily formed at the interface between the lead-free solder and the metal pad. It is well known that the IMC thickness of the interface is very important for the reliability of the solder joint. So, Cu dissolution from the Cu pad must be strictly controlled in industrial production to prevent the formation of the thick IMC layer at the interface. Usually, nickel in lead-free finishes is used as a solderable diffusion barrier to control the rapid reaction between the solder and the Cu pad. However, for the laser reflow soldering process, there is limited information of the effectiveness of Ni-P/Au plating to form the IMC layer at the interface and to concern the joint properties of the solder joint.

In this study, to clarify joint properties in the laser reflow soldering, the effect of isothermal aging on Sn-Ag-Cu solder joints on the electroless Ni-P/Au plating in laser reflow soldering was investigated compared to Sn-Ag-Cu solder joints on a Cu pad. Especially, the microstructure at the interface between Sn-Ag-Cu solder and Ni-P/Au plating and joint properties of solder joints were studied.

Experimental procedures

Sn-3.0 mass%Ag-0.5 mass%Cu solder ball with a 1 mm diameter was used in this study. Figure 1 shows the schematic diagram of the test board. The pads on the substrates were classified into two types of metallization layers, i.e., bare Cu pad and electroless Ni-P (5 μm)/immersion Au over an underlying Cu pad. Cu pad with 800 μm diameter and 35 μm thickness on an FR-4 printed circuit board was formed. The commercial rosin mildly activated (RMA) flux was used. Before soldering, the pads were immersed in a 4 % HCl
solution for 120 s and then the pads and the solder balls were ultrasonically rinsed in an ethanol solution. After the solder balls were dipped in the flux, they were placed on the pads. The solder balls on Cu pads were heated by the laser irradiation in air using a laser soldering system (UNIX-413L2, JAPAN UNIX Co., Ltd.). The laser used in this system is a high-power diode laser (λ = 940 nm) with a 1.2 mm beam diameter on a focal plane. Laser irradiation conditions were controlled by laser power and heating time listed in Table 1. As a reference, conventional reflow soldering was performed at 523 K for 60 s in a nitrogen atmosphere. After soldering, the specimens were ultrasonically cleaned in an ethanol solution to remove residual flux from the solder joints. Some solder joints were then subjected to isothermal aging at 423 K for 168 h and 504 h.

To evaluate the joint properties, an impact test [4-6] was performed using a micro-impact tester (MI-S, YONEKURA Mfg. Co., Ltd.). The test conditions were as follows: an impact height of 100 μm and an impact speed of 1 m/s. In this study, the maximum load and total energy of the load-displacement curve obtained from the micro-impact tester were investigated. An average value based on 10 measurements for each soldering condition was adopted.

Some specimens before the impact test were cut and their cross-sections were polished to observe the solder/Cu pad interface and the solder microstructure by scanning electron microscopy (SEM).

### Results and Discussion

Fig. 2 and Fig. 3 show the SEM images of the joint interface formed on the Cu pad and on the Ni-P/Au plating, which were respectively subjected to the laser reflow soldering and the conventional reflow soldering. For both cases, the laser conditions are at 20 W for 40 s and at 40 W for 1 s. Fig. 2 shows the interface between the solder and the Cu pad in as-soldered condition. The formation of intermetallic compound (IMC) layer at the interface soldered by the laser process is different from that soldered by the conventional process. The IMC thickness formed by the laser process was clearly less than 1 μm. On the other hand, a scallop-like IMC layer with the thickness of 3.5μm was formed at the solder/Cu interface by the conventional process. Fig. 3 shows the interface between the solder and the Ni-P layer in as-soldered condition. For the Ni-P layer, there is little difference in the IMC formation between the laser process and the conventional process. For both cases, the IMC thickness formed was very thin.

The influence of the heating parameters of the laser process on the joint properties in as-soldered condition was investigated. The relationship between the maximum load obtained from the impact test and the heating parameters for the Cu pad is shown in Fig. 4. For the Ni-P/Au plating, the relationship between the maximum load and heating parameters is shown in Fig. 5. For both cases, if the laser input energy was too low, the wetting behavior of the molten solder by the laser process could not be found on the pads. As shown in Fig. 4, for the Cu pad, maximum loads at 20 W increase with the increase of heating time. The maximum load at 20 W is the largest for 40 s. In the case of the laser power at 40 W, there is little difference in maximum load. For the Ni-P plating shown in Fig. 5, there is little difference in maximum load among same laser power.
Fig. 5 Effect of heating parameters of laser process on maximum load for Ni-P/Au plating obtained by impact test.

Then, the maximum loads at 20 W are larger than those at 40 W. Comparing the maximum load between on the Cu pad and on the Ni-P plating, the maximum load for the Cu pad is larger than that for the Ni-P plating regardless of the laser power. Two laser irradiation conditions to examine in detail were chosen: at 20W for 40 s and at 40 W for 1 s.

The effect of isothermal aging on the joint properties on the Cu pad and on the Ni-P/Au plating was investigated in the laser reflow process compared to the conventional reflow process. Figure 6 shows the effect of aging time on the joint properties such as maximum load and total energy on the Cu pad. The effect for maximum load is shown in Fig. 6(a), and the effect for total energy is shown in Fig. 6(b). In the as-soldered condition, both the maximum load and total energy of the joints soldered by the laser process were higher than those soldered by the reflow process. After aging for 168 h, the maximum load gradually decreased. In contrast, the total energy increased in all solder joints. After aging for 504 h, the maximum load and total energy of the joints soldered by the laser process at 20 W for 40 s and by the reflow process were maintained. However, in the case of soldering at 40 W for 1 s by the laser process, the maximum load and total energy were lower than those of the joints soldered by the reflow process.

Figure 7 shows the effect of aging time on the joint properties such as maximum load and total energy on the Ni-P/Au plating. The effect for maximum load is shown in Fig. 7(a), and the effect for total energy is shown in Fig. 7(b). In the as-soldered condition and after aging for 168 h and 504 h, the maximum load of the joints soldered by the laser process at 20 W for 40 s was higher than those soldered by the reflow process. And the total energy of the joints soldered by the laser process at 20 W for 40 s was almost similar with those soldered by the reflow process. In contrast, both the maximum load and total energy of the joints soldered by the laser process at 40 W for 1 s were almost similar with or lower than those soldered by the reflow process.
soldered by the reflow process regardless of aging time. So there is not much difference in the joint properties on the Ni-P/Au plating between the joint soldered by the laser process at 20 W for 40 s and the joint soldered by the reflow process. As a result, regardless of pad material, the joint properties of the joints soldered by the laser process at 20 W for 40 s were superior to those of joints soldered by the conventional reflow process.

Conclusions

The microstructure at the joint interface and the joint properties of the joints soldered by the laser reflow soldering process were studied. The results obtained are summarized as follows.

(1) For the Ni-P/Au plating, there is little difference in the IMC formation between the laser process and the conventional process. For both cases, the IMC thickness formed was very thin in as-soldered condition.

(2) Regardless of a pad material, the joint properties of the joints soldered by the laser process at 20 W for 40 s were superior to those of joints soldered by the conventional reflow process.

References