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Characteristics of Interfacial Microstructure of PBGA Solder Bump During Multi-Reflow and Aging Processes

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ABSTRACT
Characteristics of intermetallic compounds at interface of PBGA solder ball and Au/Ni/Cu metallization on BT substrate during multi-reflow and aging processes was presented. The eutectic Sn/Pb solder bump was formed by laser reflow first, then followed by the secondary infrared reflow process to form solder joint, and then the solder joint was aged at 160°C for different days. Finally, the aged solder joint was reflowed once again. During first laser reflow, the morphology and distribution of AuSn, IMC were strongly dependent on the laser reflow power and heating time applied, and both changed after the secondary infrared reflow process. The AuSn, layer formed at the interface in the first laser reflow process dissolved partially after the secondary infrared reflow process, and AuSn, particles precipitated out at the eutectic cell boundary of the solder. After aging process, AuSn, IMC converted into Au-Ni-Sn ternary compounds, and continuous Ni5Sn3 layer grow out under the Au-Ni-Sn IMC layer. The thickness of Au-Ni-Sn and Ni5Sn3 IMC layer increased as the aging time increasing. When the aged solder joint was reflowed again, the Au-Ni-Sn IMC disappeared at the interface, and continuous Ni5Sn3 IMC transformed to scallop-type morphology.

KEYWORDS
Intermetallic compounds, PBGA solder ball, laser reflow, infrared reflow, aging

1. INTRODUCTION
Plastic Ball Grid Array (PBGA) packages have been widely used in large scale integrated circuit due to their high density, high reliability and excellent electric performance [1]. During packaging and assembly of PBGA devices, eutectic solder balls are heated and metallurgically joined with pads to form solder bumps, which then are subjected to the second reflow soldering for formation of solder joints. Fig. 1 shows the illustrations of solder bump and solder joint of PBGA.

Currently, hot air reflow and infrared reflow soldering methods were widely used in industry. Laser reflow soldering, as a new and unique reflow process has shown its advantages over the conventional processes due to its high energy input and local heating capability, especially for solder bumping in ball grid array electronic packages [2, 3]. Reliability of the solder joints using laser reflow soldering is the major concern. One of the key factors affecting the reliability of laser reflow is the bump’s microstructure. During the reflow process, solder and pad will react with each other to form intermetallic compounds. Most intermetallic compounds are brittle, excessive intermetallic compounds at the solder joints will deteriorate the mechanical integrity of the solder joint. Interfacial reactions between solder balls and Au/Ni/Cu metallization in PBGA packages by traditional reflow methods have been extensively studied [4-8]. However, the reaction kinetics between Au/Ni/Cu pads and solder bumps by laser reflow has little been reported yet. The objectives of the present study include 1) study laser reflow bumping of PBGA solder ball, and 2) how these variables affect the interfacial microstructure after the first laser reflow process, 3) how the intermetallic compounds change within the solder joints when subject to the second infrared reflow and aging processes.

2. Experimental Procedures
Solder balls (dia. of 0.76 mm) of 63Sn37Pb eutectic alloy and BT substrates (0.5 mm thick) were used in this study. The pad used in this study is BT/Cu metallization consisted of an electroplated Ni layer (7 um thick) and a thin top Au layer (2 um thick). The BT substrates were ultrasonically cleaned. Solder balls were dipped into a soluble flux and were placed on the pads manually. The laser device in this study was a continuous wave type Nd:YAG laser with a beam diameter 0.6mm. Laser heating time and laser power output were computer controlled. The BT substrate with planted solder balls was then placed on a computer controlled x-y platform. After laser reflow soldering, several solder bumps were chosen to undergo a second infrared reflow soldering. The infrared reflow temperature is 225°C, reflow time is 60s. Some second reflowed solder joints were aged at 160°C for...
3. Results and Discussion

3.1 Formation of AuSn₄ Compound at LR Bump Interface during Laser Reflow

Fig. 2 showed the SEM images of the solder/Au/Ni/Cu metallization interface reflowed by different laser input energy.

When using a 15 W laser power heating for 0.1s, a continuous intermetallic compound layer (a few μm thick) and needle-like intermetallics formed at the solder joint. Some remained Au was found at the solder/pad interface (Fig. 2a). The needle-like phases grew sideways from the continuous intermetallic layer at the solder/pad interface into the solder, and then spread out to the entire interface region. EDX analysis on the continuous intermetallic layer and needle-shape intermetallics indicate that the intermetallics were AuSn₄. When the eutectic solder ball was melted by the laser and contacted with the Au/Ni/Cu pad, the Sn in the molten solder reacted with Au to form a continuous AuSn₄ layer at the interface and then the needle-like AuSn₄ formed above the layer. The formation of this needle-like compound was due to rapid cooling rate by the laser heating nature, and its preferred growth direction of AuSn₄ was greatly controlled by the fast cooling rate.

In Fig. 2a, it could also be found that at least a 3 μm thick layer of AuSn₄ was formed within 0.1s laser heating time. When the laser power increased to 20W and laser heating time remained for 0.1s, the AuSn₄ layer became thinner, and most needle-like AuSn₄ intermetallics broke off at the solder/pad interface, as shown in Fig. 2b. Under a 15 W laser heating for 0.4s, AuSn₄ intermetallics disappeared completely both at the interface and within the solder matrix as shown in Fig. 2c. The AuSn₄ intermetallics formed at the interface during the initial stage seemed to be dissolved into the melt solder. The melt solder balls might exist for a longer time under the higher laser power and longer heating time.

Based on the above observations, a series of interfacial reactions might occur within a short laser heating time. Firstly, Sn in the molten solder could react with Au to form a continuous AuSn₄ layer, and needle-like AuSn₄ would initiate and grow on the continuous intermetallic layer due to high temperature gradient. Secondly, needle-like AuSn₄ intermetallics might break off from the interface during the solidification of the molten solder. With an increase of the laser input energy, the needle-like AuSn₄ phase could break off into the solder bulk, forming random distribution of AuSn₄ rods within the whole solder bump. Finally, AuSn₄ rods would dissolve into the solder matrix.

3.2 Change of AuSn₄ at LI Joint Interface after the Second Hot Air Reflow

SEM images of solder/AuNi/Cu pad interface after laser heating and the second hot air reflow were shown in Fig. 3. The solder bump was reflowed by a 15 W laser for 0.1s, followed by the second infrared reflow at 225°C for 60s. Comparing with Fig. 2a, it could be noted that after the secondary infrared reflow (207°C for 53 s), the remaining Au and at solder/pad interface were absent, the continuous AuSn₄ layer dissolved partially, and the needle-like AuSn₄ disconnected with the solder/pad interface and spread inside the solder bulk as rod shape as shown in Fig. 3a. The formation of the AuSn₄ rods could be explained as followed: (1) needle-like AuSn₄ broke off from the interface and fell into the solder since they were brittle and stressed by higher flowing rates of the molten solder; (2) then they could further dissolve into solder because of the high solubility of Au in the molten solder; and (3) because of the longer secondary reflow time (53 s), the needle-like AuSn₄ would change into rod-shape under a slow solidification rate. Fig. 3b showed...
and the same second infrared reflow, the total amount of AuSn₄ was dramatically reduced as shown in Fig. 3b. The continuous AuSn₄ layer became thinner and discontinuous. Some AuSn₄ rods were distributed near the solder/pad interface, indicating that AuSn₄ has the tendency of dissolution after a long time reflow. When using the same laser heating time (0.1 second), but applying different powers, and followed by the same infrared reflow (53s at 207 °C) process, the solder matrix structure changed from rod eutectic (Fig. 3a) to lamellate structure (Fig. 3b), since the larger laser power (20W) was used in the later case, and therefore, the lamellate structure would be expected under a slow cooling/solidification rate.

Fig. 3 shows SEM images of solder/pad interface by laser and the second infrared reflow. (a) laser reflow(15W,0.1s) and infrared reflow(207°C,53s), (b) laser reflow(20W,0.1s) and infrared reflow(207°C,53s), (c) laser reflow(15W,0.4s) and infrared reflow(207°C,53s).

3.3 Growth of Au-NiSn and Ni-Sn Intermetallics at LIA Joint after Aging

Fig. 4 shows the SEM images of non-aged LIA joint interface and LIA joint interface for different aging time. The LIA joint in Fig. 4a was reflowed by a 12 W laser for 0.5 s, followed by the secondary infrared reflow at 207°C for 53s.
At the interface of LI joint, a thin layer of Ni$_3$Sn$_4$ was found. AuSn$_4$ particles dispersed randomly within the bulk solder. After aging, Ni$_3$Sn$_4$ layer became thicker, and ternary Au-Ni-Sn compound and Pb-rich layer were found over the Ni$_3$Sn$_4$ layer. With the aging time increasing, the thickness of ternary Au-Ni-Sn compound, Ni$_3$Sn$_4$, intermetallics and Pb-rich layer increased, as shown in Fig.4 b and Fig.4c.

![Fig.4](image1)

![Fig.4](image2)

![Fig.4](image3)

Fig.4 Microstructure of solder/Au/Ni/Cu metallization interface for different aging time at 160°C (a) Non-aged, (b) Aged for 9 days (c) Aged for 25 days

3.4 Evolution of Ni$_3$Sn$_4$ Intermetallic at LI Joint after Infrared Reflow Progress

Fig.5 shows the SEM image of LIAl joint interface. When the aged solder joint was reflowed again, the ternary Au-Ni-Sn compound disappeared, and the morphology of Ni$_3$Sn$_4$ compound changed from continuous layer to scallop shape. The scallop-type grains is favorable to high shear strength of solder joint. The reason that Ni$_3$Sn$_4$ in solid state aging does not keep the scallop-type morphology is scallops have a larger surface area than a flat surface. The scallop-type morphology is unfavorable because of the high interfacial energy between solid solder and Ni$_3$Sn$_4$. However, in the wetting reaction during infrared reflow, the rapid gain in compound formation energy may compensate the surface energy spent in growing the scallops.

![Fig.5](image4)

Fig.5 SEM images of solder/Au/Ni/Cu interface of LIAl joint (aged for 25 days followed by infrared reflow)

4. Conclusions

1. In first laser reflow of PBGA solder ball, Au-Sn intermetallic compound morphology at interface of solder bump was strongly influenced by laser input energy and heating time. With increasing laser input energy, AuSn$_4$ IMC changed from a continuous layer into needle-like phases and then to fine particles.

2. The morphology and distribution of AuSn$_4$ compounds at LI solder joint interface was also dependent on the first laser reflow parameter, and inherit the characteristic of interfacial microstructure of LR bump. So it is important to consider the laser reflow parameters during packaging process when the reliability of solder joint was analyzed.

3. The continuous ternary Au-Ni-Sn intermetallic and Ni$_3$Sn$_4$ intermetallics appear at the interface of solder joint after aging, and become thicker as the aging time increase. When the aged solder joint was reflowed once again, the continuous Ni$_3$Sn$_4$ converted to scallop-type, and the scallop-type morphology could strengthen the aged solder joint.

REFERENCES


