Materials Science in Semiconductor Processing 58 (2017) 39–50

Contents lists available at ScienceDirect

Materials Science in Semiconductor Processing

journal homepage: www.elsevier.com/locate/mssp

Investigation of soldering process and interfacial microstructure evolution for the formation of full Cu_3Sn joints in electronic packaging

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ARTICLE INFO

Keywords:
Electronic packaging
Full Cu_3Sn joints
Soldering temperature
Soldering pressure
Soldering time
Interfacial microstructure evolution

ABSTRACT

Within electronic products, solder joints with common interfacial structure of Cu/IMCs/Sn-based solders/IMCs/Cu cannot be used under high temperature for relatively low melting points of Sn-based solders (200–300 °C). However, there is a trend for solder joints to service under high temperature because of the objective for achieving multi-functionality of electronic products.

With the purpose of ensuring that solder joints can service under high temperature, full Cu_3Sn solder joints with the interfacial structure of Cu/Cu_3Sn/Cu can be a substitute due to the high melting point of Cu_3Sn (676 °C). In this investigation, soldering process parameters were optimized systematically in order to obtain such joints. Further, interfacial microstructure evolution during soldering was analyzed. The soldering temperature of 260 °C, the soldering pressure of 1 N and the soldering time of 5 h were found to be the optimal parameter combination. During soldering of 260 °C and 1 N, the Cu_6Sn_5 precipitated first in a planar shape at Cu-Sn interfaces, which was followed by the appearance of planar Cu_3Sn between Cu and Cu_6Sn_5. Then, the Cu_6Sn_5 at opposite sides continued to grow with a transition from a planar shape to a scallop-like shape until residual Sn was consumed totally. Meanwhile, the Cu_3Sn grew with a round-trip shift from a planar shape to a wave-like shape until the full Cu_3Sn solder joint was eventually formed at 5 h. The detailed reasons for the shape transformation in both Cu_6Sn_5 and Cu_3Sn during soldering were given. Afterwards, a microstructure evolution model for Cu-Sn-Cu sandwich structure during soldering was proposed. Besides, it was found that no void appeared in the interfacial region during the entire soldering process, and a discuss about what led to the formation of void-free joints was conducted.

1. Introduction

Soldering involves using a molten filler metal to wet the mating surfaces of a joint, with or without the aid of flux, leading to the formation of metallurgical bonds between the filler and the respective components [1]. It is widely used in the fields of aerospace, energy power and electronic manufacturing because of advantages such as low demand for heat source, causing little stress, etc.

Recently, with the rapid development of electronic products, the application of soldering technology to electronic manufacturing industry has gained increasing attention. Particularly, to a very large extent, soldering is the only feasible joining method in this industry. Concretely, soldering is used at various levels of electronic packaging to join components, and solder joints formed mainly provide electrical and mechanical support to the components [2,3]. In other words, soldering plays an important role affecting the quality of electronic products. As Cu has high availability, favorable electrical and thermal conductivity, it has become the first choice for metallization layers within electronic products. Accordingly, lead-free Sn-based solders, such as Sn-Ag, Sn-Ag-Cu, etc, are always used with concerns of environment and health [4–7]. After soldering, the interfacial structure of Cu/Cu-Sn IMCs/Sn-based solders/Cu-Sn IMCs/Cu is formed [8–11]. Obviously, due to relatively low melting points of Sn-based solders (200–300 °C), the interfacial structure formed cannot be used under high temperature. Moreover, in the case of 3D packaging, the interfacial structure does not have sufficient capacity to keep stable when it repeatedly undergoes thermal process of soldering. Because there is a trend to realize multi-functionality for electronic products, it is very possible for solder joints within electronic products to service under high temperature. Therefore, solder joints which can be used under high temperature are of great significance for electronic manufacturing industry. According to the Cu-Sn phase diagram, it is known that Cu-Sn IMCs have relatively high melting points. For example, the melting point of Cu_3Sn is 676 °C. As a result, it is thought that solder joints with the interfacial structure of Cu/Cu_3Sn/Cu can be a substitute due to the ability of servicing under high temperature. However, the full Cu_3Sn

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http://dx.doi.org/10.1016/j.mssp.2016.11.019
Received 19 July 2016; Received in revised form 6 November 2016; Accepted 8 November 2016
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solder joints should be formed by controlling soldering process. Unfortunately, there has been no previous research systematically studying the soldering process for obtaining such joints.

In this paper, the soldering process for the formation of full Cu_3Sn joints was first investigated systematically, because an unsuitable soldering process can cause several problems in practical production of electronic products. After soldering process parameters were optimized, interfacial microstructure evolution of joints during soldering was analyzed, because it is the premise for further investigating growth kinetics of interfacial IMCs acting as the basis for studying mechanism of interfacial atomic diffusion.

2. Experimental details

2.1. Preparation of samples

High pure polycrystalline Cu foils were used as base metal, while pure Sn was used as solder to eliminate effects of alloy elements on interfacial microstructure. It is widely known that the formation of interfacial IMCs during soldering is a result of atomic diffusion and dissolution between base metal and solder. However, according to diffusion theories, boundary conditions are existed during atomic diffusion. This means the ideal thickness of Sn solder should be at micron-level for obtaining full Cu_3Sn joints. Meanwhile, in view of the miniaturization trend of electronic products, the Sn solder with a thickness of 6 μm, lower than 10 μm, was chosen in our investigation. For the interfacial reaction producing Cu_3Sn, according to the mass balance, the thickness ratio of Cu and Sn needed can be given as

$$\frac{t_{cu}}{t_{sn}} = \frac{M_{cu}}{M_{sn}} \times \frac{\rho_{sn}}{\rho_{Cu}} \tag{1}$$

where M_{cu} and M_{sn} are the weight percent of Cu and Sn in Cu_3Sn, t_{Cu} and t_{sn} are the thickness of Cu and Sn consumed in the interfacial reaction, ρ_{Cu} and ρ_{sn} are the mass density of Cu and Sn. For concrete value, M_{cu} and M_{sn} are 61.8% and 38.2% respectively, while ρ_{Cu} and ρ_{sn} are 8.92 g/cm^3 and 7.28 g/cm^3 respectively. As a result, the thickness ratio of Cu and Sn needed in the interfacial reaction are calculated to be 1.32. When the 6 μm thick Sn solder is totally consumed to form Cu_3Sn, 7.92 μm thick Cu is needed. Based on this, the Cu foil with a size of 5 mm×5 mm×1 mm was used in our investigation for ensuring Cu surplus after Sn was totally consumed to form Cu_3Sn.

The Sn solder was deposited on the surface of Cu foil using electroplating. It should be noted that a structure of double solder layers was adopted in our investigation. Concretely, the Sn layer with a thickness of 3 μm was electroplated on the surface of Cu foil. Then, two Cu foils with the electroplated Sn solder were aligned via a particular clamp to form a Cu-6μmSn-Cu sandwich structure. Fig. 1 presents the schematic illustration of Cu-6μmSn-Cu sandwich structure. For the structure of double solder layers, a liquid-liquid contact is formed in Sn contacted area during soldering. Instead, a liquid-solid contact is formed in Sn-Cu contacted area during soldering when the 6 μm thick Sn layer is directly electroplated on a Cu foil. For the liquid-solid contact, as liquid Sn reacts with solid Cu to form Cu-Sn IMCs whose melting point is beyond the soldering temperature, the solidification and the wetting happen competitively. The competition leads to insufficient wetting of liquid Sn to Cu surface. But there is no such competition for the liquid-liquid contact. This indicates the liquid-liquid contact is better for wetting effect than the liquid-solid contact. A better wetting effect during soldering contributes to improving the quality of joints. Thus, the special structure of Sn solder was chosen. Before electroplating, in order to ensure flatness and cleanness of Cu surface, the Cu surface was ground using #800, #1000, #1500, #2000 and #3000 abrasive papers, respectively. Further, polishing was conducted on the Cu surface with 0.5 μm diamond polishing paste. After electroplating, the electroplated Sn layer was cleaned by acetone and deionized water respectively. Lastly, the Sn layer was dried by an air blower.

The Cu-6μmSn-Cu sandwich structure was placed in a tube furnace to conduct soldering. The soldering process was carried out under a certain temperature and time. Meanwhile, Ar was used as protection gas. To the sandwich structure, a pressure was applied along the direction of Sn layer thickness during soldering. For one thing, the pressure makes the structure contact closely. For another, the pressure damages oxidization film on Sn surface, which improves the wettability of liquid Sn during soldering. Both aspects are good for enhancing the quality of solder joints. Fig. 2 gives the schematic illustration of applying pressure on the Cu-6μmSn-Cu sandwich structure during soldering. As shown in Fig. 2, a cylindrical weight block was vertically placed on the surface center of rectangular glass sheet. Because the pressure should be uniformly applied on the sandwich structures, two sandwich structures were symmetrically placed under the glass sheet with regarding the axis of weight block as the symmetric line. In addition, the application of different pressure was conducted by placing weight blocks with different weight.

Fig. 3 shows the schematic illustration of soldering process for the formation of full Cu_3Sn joints. After soldering, solder joints were cooled in ambient environment. To conduct interfacial microstructure characterization, metallographic cross-sections of solder joints were needed. Firstly, the solder joints were mounted in epoxy resin. The mounted samples were then successively ground with #800, #1000, #1500, #2000 and #3000 abrasive papers and finally polished using 0.5 μm diamond polishing paste.

2.2. Specific experimental methods

In this investigation, soldering temperature, soldering pressure and soldering time were included in the soldering process parameters. To obtain full Cu_3Sn joints, the soldering process parameters were optimized. Actually, the optimization was a course selecting an optimal parameter combination under given soldering process parameters.

For the soldering temperature, a high temperature can cause considerable stress in the connected materials during practical production of electronics [12]. Particularly, when the soldering temperature is higher than 270 °C, the performance of sensitive chips in packaging

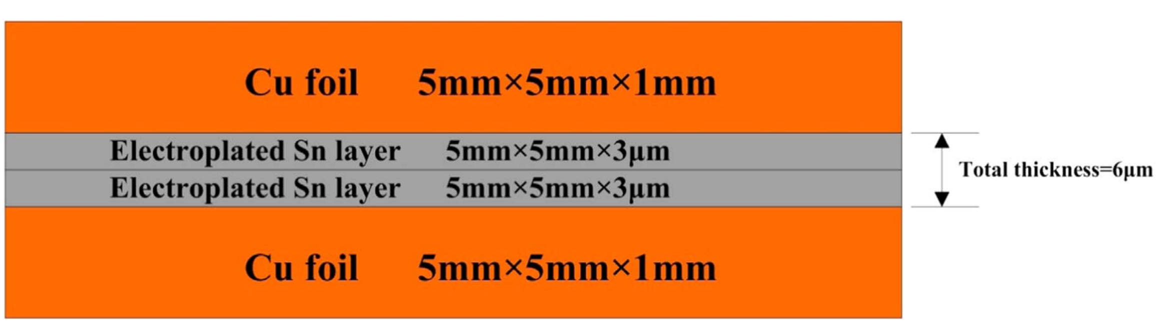

Fig. 1. Schematic illustration of Cu-6μmSn-Cu sandwich structure..

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