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Solder wetting behavior enhancement via laser-textured surface microcosmic topography

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A B S T R A C T

In order to reduce or even replace the use of Sn-Pb solder in electronics industry, the laser-textured surface microstructures were used to enhance the wetting behavior of lead free solder during soldering. According to wetting theory and Sn-Ag-Cu lead free solder performance, we calculated and designed four microcosmic structures with the similar shape and different sizes to control the wetting behavior of lead free solder. The micro-structured surfaces with different dimensions were processed on copper plates by fiber femtosecond laser, and the effect of microstructures on wetting behavior was verified experimentally. The results showed that the wetting angle of Sn-Ag-Cu solder on the copper plate with microstructures decreased effectively compared with that on the smooth copper plate. The wetting angles had a sound fit with the theoretical values calculated by wetting model. The novel method provided a feasible route for adjusting the wetting behavior of solders and optimizing solders system.

1. Introduction

Electronic packaging technology is the indispensable foundation for the development of electronic information industry and other high-tech industries [1,2]. Soldering is the most common method used in electronic packaging field [3–5], and the package quality is determined by the wetting behavior of solders during soldering. Over the past few decades, the most popular solder used in electronic packaging is Sn-Pb solder [6,7]. However, faced with the increasingly severe environmental pressure and requirements of microelectronic device performance [8–10], the traditional Sn-Pb solder has been difficult to adapt to the market demand. Therefore, it's urgent to use an environment-friendly solder with high-reliability.

Sn-Pb solder was widely used in electric industry due to its excellent properties, such as superior electrical conductivity [11] and excellent wettability [12]. However, the widely use of Sn-Pb solder causes Pb pollution, which is harmful to the environment and human's health [13]. In addition, the Sn-Pb solder joint will fail soon owing to the low shear strength and the poor resistance to creep and thermal fatigue [14,15]. The shortcomings of Sn-Pb solder become more evident, especially used in the surface mounting structure. Compared with perforation soldering, the surface mount soldering withstand the stress generated between the device and the printed circuit board directly when the temperature changes. In order to overcome these shortcomings of Sn-Pb solder, many lead free solders have been developed and applied [16,17]. As the most promising alternatives, the alternative performance of Sn-based lead free solder should have a further research, especially for the improvement of the wettability [18–20]. It means that although Sn-based lead free solder can avoid these problems Sn-Pb solder faces, the poor wettability blocks the application and popularity of Sn-based lead free solder. At present, the wettability of Sn-based lead free solder is worse than that of Sn-Pb solder. Generally, a small wetting angle is essential for obtaining a sound soldering joint. In theory, the wetting angle of solder is related to not only the performance of solders but also the compositions and surface condition of the materials to be soldered [21,22]. To deal with the wettability of Sn-based lead free solders, it is feasible by adding surface enriched elements and active elements into the solders or changing the surface condition of the materials to be soldered. There are many reports about improving the wettability of solders by adding active elements or surface enriched elements into solder until now. Nai and Lin [23] found that the wettability of Sn–Ag alloy systems on Cu can be improved effectively by increasing Ga content. But adding the active element tends to form lots of brittle compounds

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in the joints, decreasing the mechanical properties and reliability of joints. Moreover, most of the active elements are expensive and harmful to environment, which will increase the cost of packaging processing and cause the environmental pollution.

Another potential method available for improving the wettability of lead free solders is the use of surface microstructure. This method utilizes the capillary action of surface microstructure to affect the wetting behavior of liquids, which has a widely application in the field of the hydrophobic and hydrophilic materials [24–26]. Bathlott and Neinhuis [27] surveyed the “lotus effect”, and the results showed that the wettability of water on a surface is related to the roughness of the surface. Son et al. [28] prepared cylindrical convex on glass by ICP-RIE, and made a series of super-hydrophilic surfaces on which the minimum contact angle of water was 3°, the glass after such surface-treated has a certain of fog function. Currently, the method of controlling wetting behavior by surface microstructure is relatively mature in the field of waterproof materials. However, there are few reports on the effects of surface conditions on the wettability in the field of brazing and soldering. Moreover, the study of surface conditions mainly focuses on surface roughness [29,30] rather than surface specific regular microstructure. At present, the different surface roughness can be obtained by many technologies, such as ball spray treatment, sanding and so on [31,32]. However, these methods are difficult to use in the preparation of surface specific regular microstructure. Based on the high precision of laser, many researches showed that the surface microstructures can be manufactured by fiber femtosecond laser machining [33–35].

According to wetting theory and the effects of microstructure on wetting behavior of water, it can be inferred that the surface microstructure will also have a significant influence on the wetting behavior of the high-temperature liquid solders. However, there are several differences on wetting behaviors between water and high-temperature liquid solders. First, the wetting mechanisms of water and high-temperature liquid solders on the substrate materials are different. Water usually has no chemical reaction with the substrate materials during the wetting, while high-temperature liquid solders generally reacts with the substrate materials. And chemical reactions can cause the loss of surface microstructure and affect the capillary action. Second, the surface tension of water and high-temperature liquid solders is different, thus the most effective shapes and sizes of surface microstructure that improve the wetting behavior of water and high-temperature liquid solders are different. Using the surface microstructure which can improve the wettability of liquid lead free solders, the wetting angle and even soldering temperature can be reduced. Thus this study has important implications for improving the soldering quality and promoting the application of lead-free solders.

In this study, the wetting model of high-temperature liquid solder was established. For Sn-Ag-Cu solder, four types of surface microstructure with similar shape and different sizes were calculated, designed and processed. Subsequently, the wetting experiments of Sn-Ag-Cu solder on Cu plates were carried out, and the wetting angles were measured by wetting angle measuring system. In order to investigate the corrosion of surface microstructure during soldering, the interfacial microstructure of soldered joints was surveyed.

2. Experimental

In the study, the copper plate with a purity of 99.9 wt.% was used as the substrate material during the wetting. The copper plate was cut into blocks with the size of 10 mm × 10 mm × 2 mm by electrical discharge machining. All copper specimens were polished by SiC papers up to grit 3000 and degreased with acetone prior to using. 96.5Sn-3.0Ag-0.5Cu (wt.%) solder ball about 0.6 mm in diameter was chosen as the representative of lead free solders. According to the physical parameters of Sn-Ag-Cu solder and theoretical calculations, the shape and size of surface microstructure were be determined. The surface microstructure was processed on copper specimens by HSGQ-2W fiber femtosecond laser machining.

The wetting experiments were carried out by O_2C wetting angle measuring system. First, the Sn-Ag-Cu solder balls were degreased with acetone for 10 min. Second, the solder balls were placed on the surface of copper specimens with and without surface microstructure, respectively. Then the specimens were heated with a rate of 50 °C/min to 320 °C in vacuum (<1.8×10^{-3} Pa) and incubated for 5 min. The wetting angles were measured and recorded by optical photography and data acquisition system. Finally, the specimens were cooled down spontaneously to room temperature. The interfacial microstructure was characterized employing GX71 OLYMPUS optical microscope and X-max20/INCA250 scanning electron microscopy (SEM). Componential analysis of interfacial microstructure was carried out using an energy dispersive spectrometer (EDS) with the operation voltage of 15 kV.

3. Results and discussion

3.1. Design and calculation of surface microstructure

In past years, the effects of surface conditions during soldering or brazing were always achieved by sand-papering or surface peening technology [36]. However, it is difficult to obtain the regular microstructure on the surface by these surface treatment technologies. Considering the easy processing, an alternant microstructure with the convex platform and groove was set as the shape of surface microstructure. Moreover, the shape of the convex platform was assumed to be a trapezoid platform, and the included angle at the bottom of convex platform was α, which can change from 0 to π. Gao and McCarthy [37] found that the contact angle behavior (advancing, receding, and hysteresis) is determined by interactions of the liquid and the solid at the three-phase contact line alone. It means that the wetting behavior of droplets on the rough surface is only subjected to Young’s equation:

$$\gamma_{sv} - \gamma_{ls} = \gamma_{lv} \cdot \cos\,\theta \tag{1}$$

where γ_{sv}, γ_{ls} and γ_{lv} are the surface tensions of solid–vapor, solid–liquid and liquid–vapor contacts, respectively. Young’s equation gives the equilibrium contact angle in terms of interfacial tensions at the three-phase contact line. According to the derivation process of Young’s equation, the equation is made under the assumptions of wetting of non-reactive liquid on an ideal solid (smooth, homogeneous and rigid, physically and chemically inert). Actually, few practical situations is met the precondition of Young’s equation. However, Young’s equation is the most fundamental starting point for understanding of wetting. Both for ideal system and for practical system, Young’s equation has a guiding significance to understand the spreading trend. For the initial wetting process of solder on copper plate, the spreading stage is similar to the ideal situation and can be explained by Young’s equation. Although no theoretical models are developed to describe the complete practical reactive wetting process, the wetting trend of solder on copper plate can be obtained by the calculated results according to Young’s equation. Based on Young’s equation, the optimal sizes of the convex platform and groove were calculated. Fig. 1 shows the longitudinal impedance profile of solder droplet on microstructure surface. There are two types of solder filling modes when solder spreads on microstructure surface during soldering. One is liquid solder flowing along the grooves from the bottom to the top as shown in Fig. 1(a), which is defined as “spreading flow”. The other