

Fabrication and characterization of micro-sized copper bump of multi-layer PCB by pulse-reverse electroplating

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ARTICLE INFO

Article history:

Received 27 August 2010

Received in revised form

23 November 2010

Accepted 26 November 2010

Available online 4 December 2010

Keywords:

Copper bump

Multi-layered PCB

Pulse-reverse

Electroplating

ABSTRACT

In this research, micro-sized copper bump for multi-layered printed circuit board (PCB) was successfully developed using pulse-reverse electroplating method. The electroplating parameters of current density, pulse-reverse ratio and brightener content were optimized for fabrication of suitable micro-bumps. The pulse-reverse electroplated micro-bumps were characterized using various analytical tools and techniques such as optical microscopy, scanning electron microscopy, atomic force microscopy and hydraulic bulge testing. Optical microscope and scanning electron microscope analysis results indicated good electroplating uniformity in the current density range of 1.4–3.0 A/dm², pulse-reverse ratio of 1:1, and brightener concentration of 600 ppm.

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1. Introduction

Printed circuit board (PCB) is widely used not only in the conventional electronics such as television sets and video tape recorders but also in computers, mobile phones, displays and communication networks. Amongst various kinds of PCBs, those made by build-up method are preferred for more compact electronics. Build-up method comprises alternate layering of conductors and insulators and it builds via-hole layers for the both-sided boards. As the rapid transmission of signal is possible through via-holes, it is suitable for large-scale integrated electronics. However, new technology had to be developed for multi-layering back panel and diminishing scale of circuits [1–3].

Pulse-reverse electroplating is regarded as a promising method to fabricate high quality build-up PCBs by suitably combining conventional plating with regular and reverse electric currents. Development of proper plating solution and electroplating process is essential to enhancing quality and productivity of multi-layered PCBs. The pulse-reverse plating is one of the cyclic-plating methods that uses alternate electrical waveforms and creates minute crystalloids, which reduces internal stress and number of cracks,

increases hardness and flexibility, and thus improves contact strength of electroplated layer [4–6].

Copper sulfate plating solution has been suitably adapted for pulse-reverse plating process, as it is more convenient for process management and waste treatment. However, an increase in integration of PCBs and decrease in via-hole size prompted researchers to seek further on for the state of the art electroplating technology for PCBs [7]. In the present research, conditions for electroplating of copper have been intensively studied as a means to improve overall quality of multi-layered build-up PCBs and micro-sized copper bumps, more specifically by investigating into the effects of current density, pulse-reverse ratio and brightener contents.

2. Experiment

The 30-L capacity plating system used in this experiment consisted of the rectifier, filter, and plating reservoir. Plating reservoir contained stirrer, clamping equipment, and heater for balanced mixing of plating solution, for holding copper balls and controlling temperature, respectively.

Oscillation device for mechanical stirring of cathode has also been designed. The distance between the ends of the plating system was 120 mm and the oscillation distance of cathode was 60 mm. Plating experiment was carried out at the rate of 8–10 times per minute. The rectifier (DRPP/30 model) controlled time

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duration for forward and reverse currents. The capacities for forward and reverse currents were 30 and 90 A, respectively. The allowed potential window ranged from 0 to 6.5 V.

Magnetic pump with maximum capacity of 30 L/min was used for filtering and the pump capacity of 10 L/min was used for actual electroplating. Actual PCBs of $120 \times 200 \text{ mm}^2$ was used as cathode. The pulse-reverse electroplating system and actually tested PCB samples are schematically shown in Fig. 1(a) and (b), respectively.

The source of copper electroplating on the PCB was the CCL (copper clad laminates) board. The cathode was pre-treated by acid degreasing at room temperature for 5 min, and then further treated by immersing in 10% sulfuric acid for 1 min to remove oxidized surface products. Current density for electroplating varied from 1.4 to 3 A/dm² and it was applied for 25 min at 25 °C.

The main components of the residual plating solution consisted of sulfuric acid, copper ions and supplementary chlorine ions. The sulfuric acid, CuSO₄·5H₂O and chlorine ions were controlled at 180 g/L, 18 g/L, and 60 mg/L, respectively. 2 g/L of PEG-8000 and mercapto-propane sulfonic (MPS) acid was used as a carrier [8] and brightener, respectively.

3. Results and discussion

3.1. Effect of current density change on electroplating

Fig. 2(a)–(c) represents cross-sectional morphologies of the bumps, showing the effect of current density which was varied from 1.4 to 3.0 A/dm². The cross-sectional contour of the electroplated bumps was apparently similar to each other. The electroplating current density and time were optimized to form bumps without formation of cracks or pores as depicted in Fig. 2(a)–(c). The bump thickness of 68, 88, and 79 μm were obtained with respect to required plating time of 100, 60, and 45 min, respectively.

Fig. 2(d) shows the tensile strength variation of electroplated copper bump with varying current density. Although there was no straightforward correlation between measured tensile strength and current density, the current density of 3 A/dm² turned out to have synergistic effect on both electroplating uniformity and efficiency. Therefore, electroplating characteristics were investigated at 3 A/dm² only with varying pulse-reverse ratio and brightener composition of

electroplating solution. Similar selection criteria were also used by other researchers [8] who chose optimum current density for maximum micro-hardness of coatings obtained by pulse electro-deposition.

3.2. Effect of pulse-reverse current ratio change

Pulse-reverse plating is characterized by intermittently applied forward and reverse currents at regular intervals. Fig. 3 shows the morphological and mechanical properties of electroplated bumps with forward and reverse current ratios of 1:1, 1:2, and 1:3 at an applied constant current of 3 A/dm². All in all, with the increasing current density ratio, the surface roughness and particle size increased, while the hardness decreased. In general, the increased reverse current ratio enlarged copper particle size and its surface roughness, which in turn decreased the density and hardness of the electroplated copper particles. Similar phenomena were also observed by Shahrabi and Lajevardi [9].

In view of these results, current density ratio of 1:1 was selected and it was expected to lead to formation of fine, dense copper particles for generation of better bumps. Fig. 3(d) shows XRD result of the bumps electroplated at current density of 3 A/dm² and pulse-reverse ratio of 1:1. It was quite evident that metallic copper particles formed for all current density ratios. An increase in reverse current density caused extensive crystallization of Cu along (111) and (220) planes. It is highly probable that the current density change affected the electro-deposition speed and consequent texture of the electroplated copper particles.

3.3. Effect of brightener concentration

Surface quality of copper plating largely depended on the organic additives such as brightener, which is quite crucial in forming glossy and smooth electroplated surface. Brightener usually refined metal grains and prevented dendrite formation. Excessive amount of brightener, however, degrades surface quality [10]. Fig. 3 illustrates the effect of brightener concentration on the hardness of electroplated copper, where forward and reverse current density of 2 and 4 A/dm² were applied with appropriately chosen forward and reverse voltages of 10 and 0.5 mV, respectively,

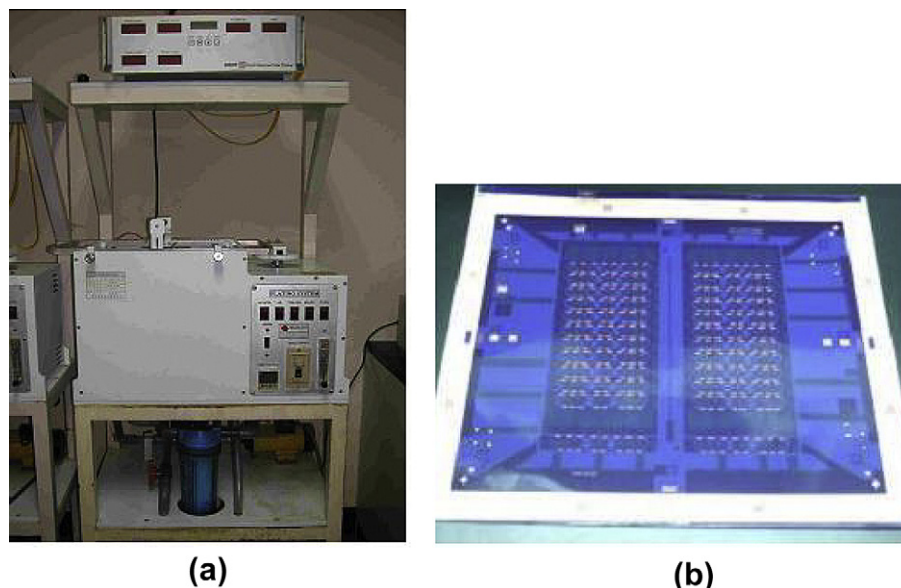


Fig. 1. Pulse-reverse electroplating system, (a); actually tested PCB sample, (b).

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