High Performances PPR Copper Plating for High Aspect Ratio Boards

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ABSTRACT

Multilayer boards, which are widely used in professional electronics such as sever, communication, medical and military equipments, trend to increase board thickness/layer counts (up to more than 10 mm/40 layers) and aspect ratio (up to more than 25:1). Accordingly, it becomes more and more difficult to plate copper into the through holes with an acceptable deposit. To meet these demands, a new generation of high performances PPR copper plating process has been developed, designed for use with soluble anodes and simple rectangle waveforms in vertical application. The new PPR chemistry demonstrates an excellent and stable throwing power up to a tested bath life of more than 200 AH/L. Neither a continuous carbon polish nor the frequent carbon treatment is required during operation. Meanwhile, it is easy to restart after idling with no need for a long dummy process. Effects of substrate, waveform on throwing power performance, the process capability to pattern and blind vias plating are also discussed in this article.

INTRODUCTION

The general trends in multilayer boards is towards increased circuit density by increasing board thickness/layer counts (up to more than 10 mm/40 layers) and reducing through hole diameter (as low as 0.2-0.5 mm), thus the aspect ratio (AR) will reach 25:1 or above[1,2]. Obviously, the higher aspect ratio, the more difficult it becomes to plate copper into the through holes. What is more, the complexity of multilayer boards design is also raised. Boards with mixed drilling technologies including both through holes and blind vias together with fine line imaged patterns are not new to PCB industry. For many years, end users required one plating process to plate simultaneously the through holes, the blind vias and the fine line imaged pattern of the boards with acceptable quality.

Compared to direct current (DC) process, periodic pulse reverse (PPR) process offers lots of advantages including improved throwing power (TP), reliability, surface distribution and increased throughput [3,4]. The widely use of PPR plating in acid copper, however, was hindered by disadvantages, such as expensive pulse rectifiers, short bath life and unstable TP performance, particularly for thick board with high aspect ratio. It is generally believed that the fundamental causes of short bath life and unstable TP performance lie in byproducts effect and the waveform distortion. Byproducts originated from organic additives would gradually accumulate during operation and idling, through oxidation, decomposition or interaction with copper anode Cu(0), while these byproducts could degrade the deposit quality and TP performance. In addition, the high reverse current density, typically at three times of the forward current density, would accelerate the generation of byproducts. In order to eliminate the negative effect of byproducts and keep a stable TP performance, PPR chemistry usually requires a continuous carbon polish or frequent carbon treatments during operation, and also a long dummy process after idling in the mass production. It has been experimentally confirmed that the insoluble anode system exhibits a more stable TP performance[5]. These measures, however, cannot completely solve the issues of short bath life and unstable TP. Besides, the running cost should be high if these measures were used.

Ideally, the rectangle waveform should be as square as possible with a sharp rise and drop from forward to reverse, and back again. But in fact, there are more or less overshoot and undershoot, known as waveform distortion, which may result from the pulse rectifier quality, the consistency of the resistance for each cable, the cathode contact on the long flight bar and so on. This is a physical phenomenon and will affect the plating quality of the PPR chemistry. A feasible strategy is to broaden the working window of different waveforms for PPR copper plating as possible as we can, and ultimately reduce the negative effect of the waveform distortion.

This article will introduce the new PPR chemistry performance. TP performances for a various of board thicknesses and hole diameters as a function of bath life, substrate, waveform and idling are investigated systematically. The grain structure of deposited copper is characterized by focused ion beam (FIB). The process capability to pattern and blind vias plating are also discussed.

EXPERIMENTAL

The whole PPR copper plating process started with an acid clean, micro-etch, sulfuric acid dip, PPR electroplating and finished with anti-tarnish. The experiments were carried out in a plating tank of 800 liters, using soluble anodes and simple rectangle waveforms. Neither carbon polish nor carbon treatment was conducted during operation. All organic components were analyzed by the cyclic voltammetric stripping (CVS) method. Dow designed test boards were used in this study, including 3.2mmt/0.25mmΦ, 4.0mmt/0.2mmΦ, 4.8mmt/0.3mmΦ and 8.0mmt/0.5mmΦ non-flashed (electroless Cu) or flashed (electrolytic Cu) boards with an initial copper layer of 2~3 µm.

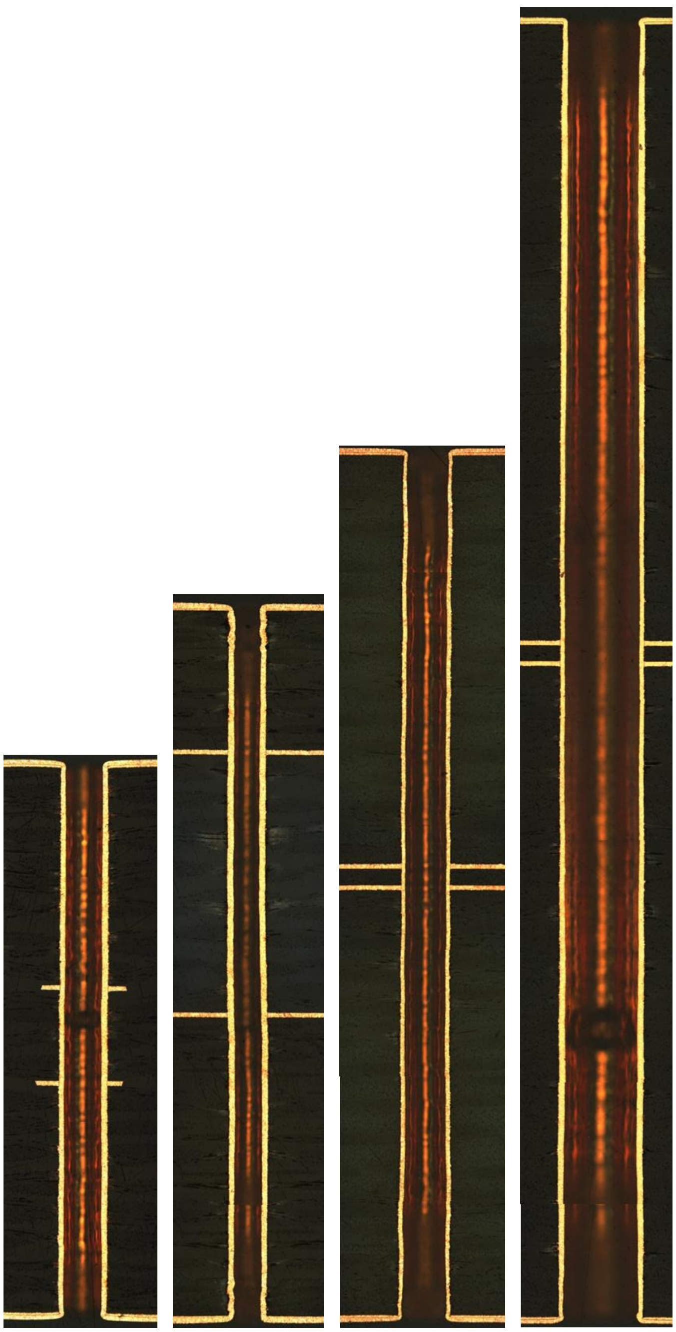
The throwing power of through holes/blind vias is calculated by dividing the average minimum hole thickness/average bottom thickness by average surface thickness.

The thermal stress test was conducted in accordance with IPC-TM-650, method 2.6.8 version E. The elongation test was performed on the basis of IPM-TM-650, method 2.4.18.1. The microstructure of deposited copper was characterized by focused ion beam (FIB).

Results and Discussion

TP Performance & Stability

Figure 1 illustrates the representative samples with different through holes diameter and boards thickness as plated using new PPR formulation. Their corresponding aspect ratio (AR), difficulty factor (DF), applied waveforms and TP performances are listed in the following table. DF is defined as the board thickness squared divided by the through hole diameter in inches, which better quantifies through hole difficulty than aspect ratio. It can be seen that the new formulation exhibits an excellent TP performance (97%~124%) for 3.2mmt /0.25mmΦ, 4.0mmt/0.2mmΦ, 4.8mmt/0.3mmΦ and 8.0mmt /0.5mmΦ no matter the substrate is flashed or non-flashed boards. The copper coating in the hole is relatively uniform and the thickness can reach 25 μm or above. A higher current density can be used in this new PPR plating formulation compared to those typical DC plating used for high aspect ratio boards, resulting in a shorter plating time and so improved production efficiency. For 8.0mmt/0.5mmΦ boards, a typical plating time utilizing DC plating at 5-8 ASF can run upwards of 12 hours or more, while the plating time using PPR plating at 20 ASF would be shorten to 3 hours with a better TP result.



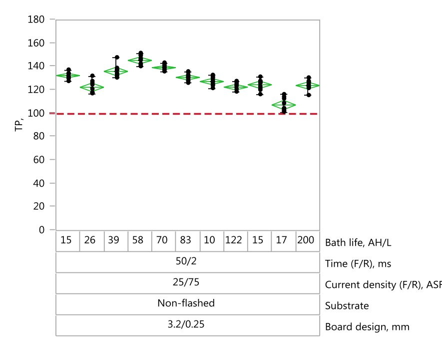
(a) (b) (c) (d)

No.	Boards	Substrate	A.R.	D.F.	Waveform (F/R)	TP
(a)	3.2mmt/0.25mmΦ	Non-flashed	12.8	1.6	25/75 ASF 50/2 ms	124%
(b)	4.0mmt/0.2mmΦ	Flashed	20	3.1	25/75 ASF 60/3 ms	98%
(c)	4.8mmt/0.3mmΦ	Non-flashed	16	3.0	25/75 ASF 60/3 ms	97%
(d)	8.0mmt/0.5mmΦ	Non-flashed	16	5.0	20/60 ASF 100/5 ms	113%

FIGURE 1. THE REPRESENTATIVE SAMPLES WITH DIFFERENT THROUGH HOLES DIAMETER AND BOARDS THICKNESS AS PLATED USING NEW PPR FORMULATION.

Another feature end users are most concerned is bath stability, which is directly related to the consistency of plated through holes quality, ease of use and the running cost. As evident from Figure 2, for both 3.2 mmt/0.25mmΦ and 8.0 mmt/0.5mmΦ boards, the newly developed formulation provides an excellent and stable throwing power performances (TP≥100%) up to the tested bath life of over 200 AH/L. In addition, it is worth mentioning that the continuous carbon polish or carbon treatment is not needed during operation. It indicates that the new PPR formulation is substantially stable during operation.

(A) 3.2 mmt/0.25mmΦ non-flashed boards



(B) 8.0 mmt/0.5mmΦ non-flashed boards

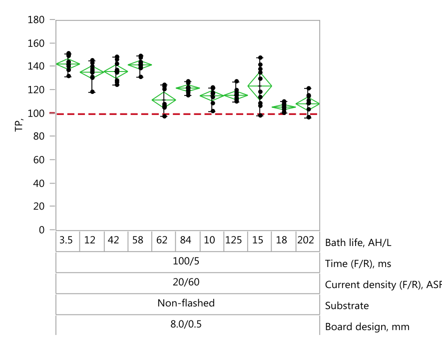


FIGURE 2. TP PERFORMANCE AT DIFFERENT BATH LIFE FOR (A) 3.2 MMT/0.25MMΦ, (B) 8.0MMT/0.5MMΦ NON FLASHED BOARDS

Effect of Substrate

Both non-flashed and flashed boards are commonly used in the mass production. In this case, the TP performances between these two kinds of substrates for 8.0mmt/0.5mmΦ boards are compared when the bath life is in the range from 79 to 125 AH/L, the results are given in Figure 3. It was found that non-flashed boards always give a throwing power 10-15% greater than that of flashed boards. Nevertheless, even for flashed boards, TP is still close to 100% or above.

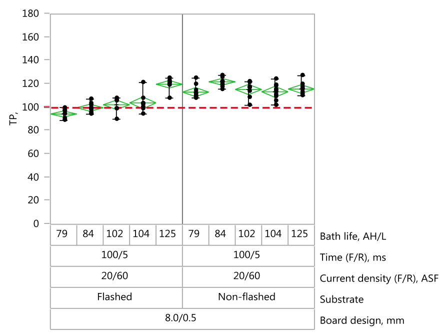
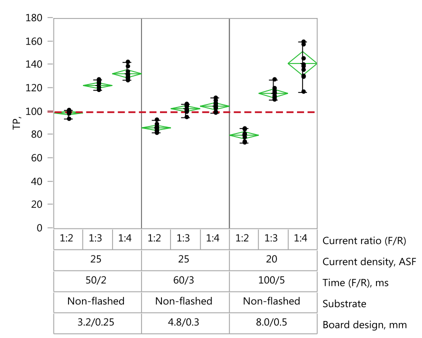


FIGURE 3. COMPARISON OF TP PERFORMANCE FOR 8.0MMT/0.5MMΦ FLASHED (LEFT) AND NON-FLASHED (RIGHT) BOARDS

(A) Effect of current ratio



(B) Effect of time ratio

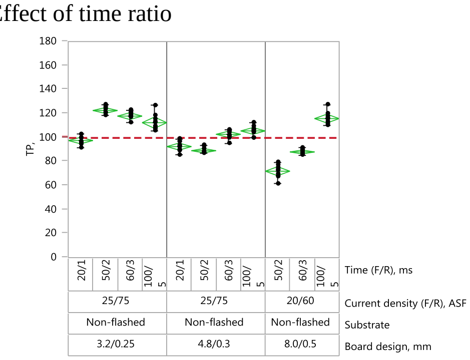


FIGURE 4. EFFECTS OF WAVEFORM ON TP PERFORMANCES FOR DIFFERENT BOARDS DESIGN, (A) EFFECT OF CURRENT RATIO; (B) EFFECT OF TIME RATIO

Waveform Study

Effects of waveform on TP performances for different boards design are presented in Figure 4. Generally, TP would increase with the increasing of reverse current and reverse time, especially for 8.0 mm boards which have a higher DF. When the current ratio (Forward/Reverse, F/R) is as low as 1:2, TP for 3.2, 4.8 and 8.0 mm boards are 99%, 86% and 80%, respectively. When the time ratio (F/R) varies in the range of 20/1 ms, 50/2 ms, 60/3 ms and 100/5 ms, TP performances for 3.2, 4.8 and 8.0 mm boards fall within the range of 97-120%, 89-106% and 72-115%, respectively. The relatively broad working window of waveform enables the new formulation to eliminate the negative effect of waveform distortion. On the other hand, it allows end users the flexibility to adjust waveforms to meet their specific needs.

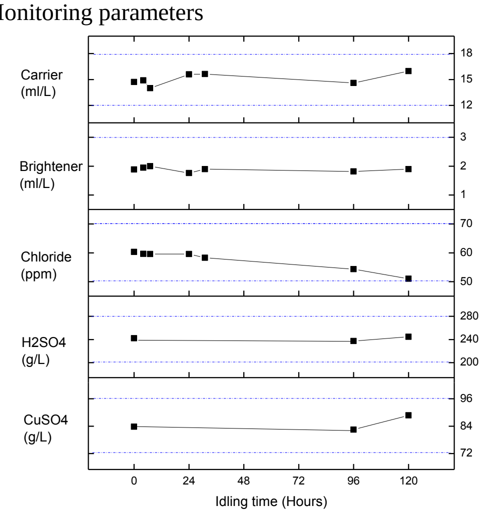
Based on the results of this study, it is suggested that the preferred waveform for the new formulation should be varied with different test boards design.

Idling Test

When bath life was around 150 AH/L, the idling test was carried out for 5 days without air agitation or filtration circulation at room temperature; meanwhile, the copper anodes were not removed. Five important parameters including copper sulfate, sulfuric acid, chloride ion, carrier and brightener were monitored and are plotted in Figure 5(A). The key bath parameters remained stable except that chloride ions decreased from 60 ppm to 50 ppm. The special design of new PPR formulation allows them to keep unchanged during the idling period, without any significant decomposition or oxidation, thus the byproducts were controlled effectively.

After 5 days idling, all bath components were replenished to the normal range, and then the 8.0mmt/0.5mmΦ non-flashed and flashed boards were directly plated without any dummy process. As expected, the TP performance could keep stable as shown in Figure 5(B). It suggests that the new formulation can withstand a long time idling, and be restarted quickly with good TP, allowing it to be an easy to use process.

(A) Monitoring parameters



(B) TP performances before and after 5 days idling

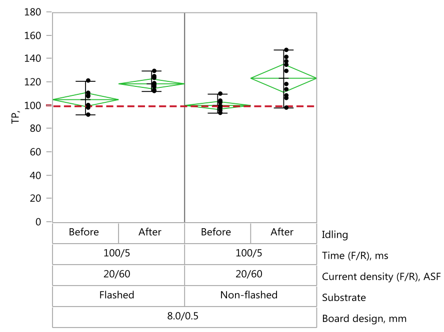


FIGURE 5. IDLING TEST RESULTS WHEN THE BATH LIFE IS 150 AH/L, (A) MONITORING PARAMETERS; (B) TP PERFORMANCES BEFORE AND AFTER 5 DAYS IDLING FOR 8.0MMT/0.5MMΦ BOARDS

Grain Structure

Figure 6 illustrates FIB cross-sectional micrographs of deposited copper on the hole center and board surface for 8.0 mmt/0.5mmΦ boards. It can be observed that the copper coating on the hole center are filled with fine, irregular equiaxed grains. In contrast, there are lots of typical twin grains on the board surface, orange arrows point to the "straight-line" twin grain boundaries. In previous studies[6,7], the twin copper structure was reported to exhibit excellent mechanical strength, which is agreement with the results of elongation test and thermal stress test in a later section of this report. It should be noted that the twin grain does not always occur on PPR copper deposits, because its formation is highly related to bath components and waveforms.

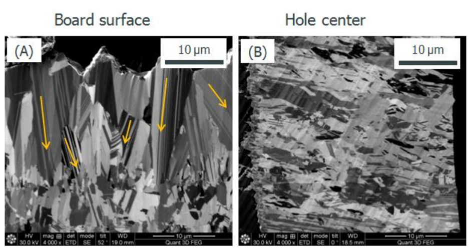


FIGURE 6. FIB CROSS-SECTIONAL MICROGRAPHS OF DEPOSITED COPPER ON BOARD SURFACE AND HOLE CENTER, 8.0 MMT/0.5MMΦ NON-FLASHED BOARDS, 20/60 ASF, 100/5 MS.

Physical Properties & Thermal Reliability

Copper deposit obtained from this PPR plating exhibits excellent physical properties and thermal reliability. Table 1 presents the consistency of elongation and tensile stress in the bath life from 0 to 200 AH/L. As shown in Figure 7, the plated through holes can withstand 9 and even 12 cycles solder float at 288 °C, 10 second.

TABLE 1. PHYSICAL PROPERTIES OF DEPOSITED COPPER

AH/L	0	50	100	160	200
Elongation, %	28.7	32.7	30.7	33.0	33.3
Tensile stress, kpsi	45.2	43.0	43.7	41.5	44.8

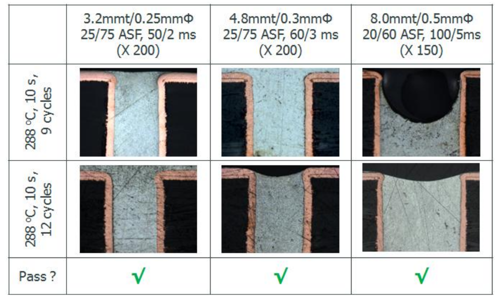


FIGURE 7. SOLDER FLOAT PERFORMANCES OF THROUGH HOLES FOR DIFFERENT BOARDS DESIGN

Pattern Plating & Blind Via Plating

Figure 8 depicts the top view and section view of inductance with 2 mil line/space. A well-shaped inductance coil was obtained with a uniform copper coating thickness for each line, without rabbit ear findings. As shown in Figure 9, conformal plating was observed in blind vias, lower current density would improve TP of blind vias. It still has room to further optimize TP of blind vias by enhancing mass transfer and adjusting the waveform.

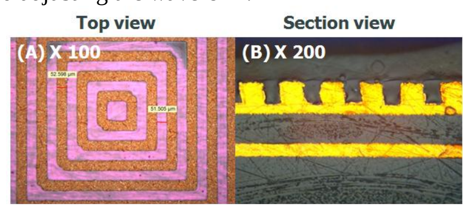


FIGURE 8. TOP VIEW (A) AND SECTION VIEW (B) OF INDUCTANCE COIL WITH 2 MIL LINE/SPACE, 20/60 ASF, 50/2 MS

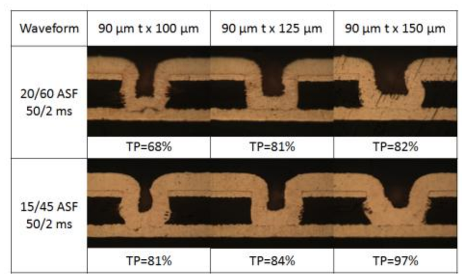


FIGURE 9. BLIND VIAS TP PERFORMANCE OVER A RANGE OF HOLE DIAMETERS AND SUBSTRATE THICKNESS

CONCLUSION

A new generation of high performances PPR copper plating process was formulated for high aspect ratio boards, using soluble anodes and simple rectangle waveform in vertical application. It provides an excellent and stable TP performance over a wide range of hole diameters, board thicknesses with different substrate types in the tested bath life of over 200 AH/L. This process is user-friendly, easy to control and low cost, namely, it does not require a continuous carbon polish or frequent carbon treatment during operation, and can be quickly restarted after 5 days idling without a long dummy process.

The broad working window of waveform not only enables this process to reduce the negative effect of waveform distortion, but also allow the customer more flexibility to adjust waveforms to their specific needs. The deposited copper has excellent physical properties and thermal reliability with a fine equiaxed gain or twin grain structures. Moreover, this process is capable of using in blind via and pattern plating modes.

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