Presented in the ECWC 10 Conference at IPC Printed
Circuits Expo®, SMEMA Council APEX® and
Designers Summit 05

The Property Research and Applications of Vertical Pulse Copper Plating

Su Peitao, Su Zhangsi
China Circuit Technology (Shantou) Corporation
Shantou, China

Abstract
Horizontal and vertical pulse plating have been widely used for panel plating in PCB industry, but rarely used for pattern plating. This article analyzes and reviews the crystal structure, throwing power, surface distribution, elongation, appearance, thermal shock, temperature cycling and IST test of copper plating after pattern plating. The article also describes some problems and their resolution in production.

Preface

At present, DC and Pulse plating are very common in the PWB field, however, the most remarkable point of pulse plating is that the periodic current can alter the condition of ionic discharge on the current interface and improve the structure of copper plating through plating and stripping a very thin copper layer in a cyclic manner. Meanwhile the surface distribution and the range of applied current can be subject to further improvement.. As currently employed, the plating rate, the density of copper, the distribution and throwing power of this method are all superior to DC plating. . At present, pulse plating has been gaining popularity in wide applications for the panel plating of PWBs. However; its disadvantage is obvious to the thick project. Other than panel plating, because of the status and influence of DC plating, pulse plating is rarely applied to pattern plating. This article will discuss and review the application of pulse plating for pattern plating and provide details of that application with test results.

Test Process

Test Conditions and Chosen Variables

Using the Design of Experiment process (DOE) we have chosen the parameters for pulse plating as I_d, $I_r : I_f$, $T_r : t_f$ and Brightener. The values are shown in Table 1.

Table 1 - Experimental Variables

No.	Correlative factor	Level 1	Level 2	Level 3
A	I_d (A/dm^2)	2.0	2.5	3.0
B	I_r:I_f	1:2	1:2.5	1:3
C	T_r:t_f	10:0.5	20:1	30:1.5
D	Brightener (ml/L)	0.5	1.0	1.5

Test Process

Based on the DOE with 4 variables and 3 levels gave a total of 9 test groups.

The test vehicle size was 559 mm X 406 mm with a thickness of 2.4 mm, with a minimum hole diameter of 0.3 mm. After chemical plating of the through holes, panel plating and outer layer D/F, pulse plating was applied. The plating time was 45 minutes and the distribution and throwing power as follows in Table 2.

Table 2 - Variable Settings for Test Cells

Test No	I_d	I_r:I_f	T_r:t_f	Brightener	TP%	Distribution
1	2.0	1:2	10:0.5	0.5	94.4	86.3
2	2.0	1:2.5	20:1	1.0	97.2	87.5
3	2.0	1:3	30:1.5	1.5	120.0	85.8
4	2.5	1:2	20:1	1.5	103.0	88.2
5	2.5	1:2.5	30:1.5	0.5	110.0	85.9
6	2.5	1:3	10:0.5	1.0	105.2	85.8
7	3.0	1:2	30:1.5	1.0	98.0	86.2
8	3.0	1:2.5	10:0.5	1.5	99.5	88.9
9	3.0	1:3	20:1	0.5	108.0	87.1

Test Results and Discussion
Were analyzed using the Minitab statistical software. Results are displayed in Figure 1.

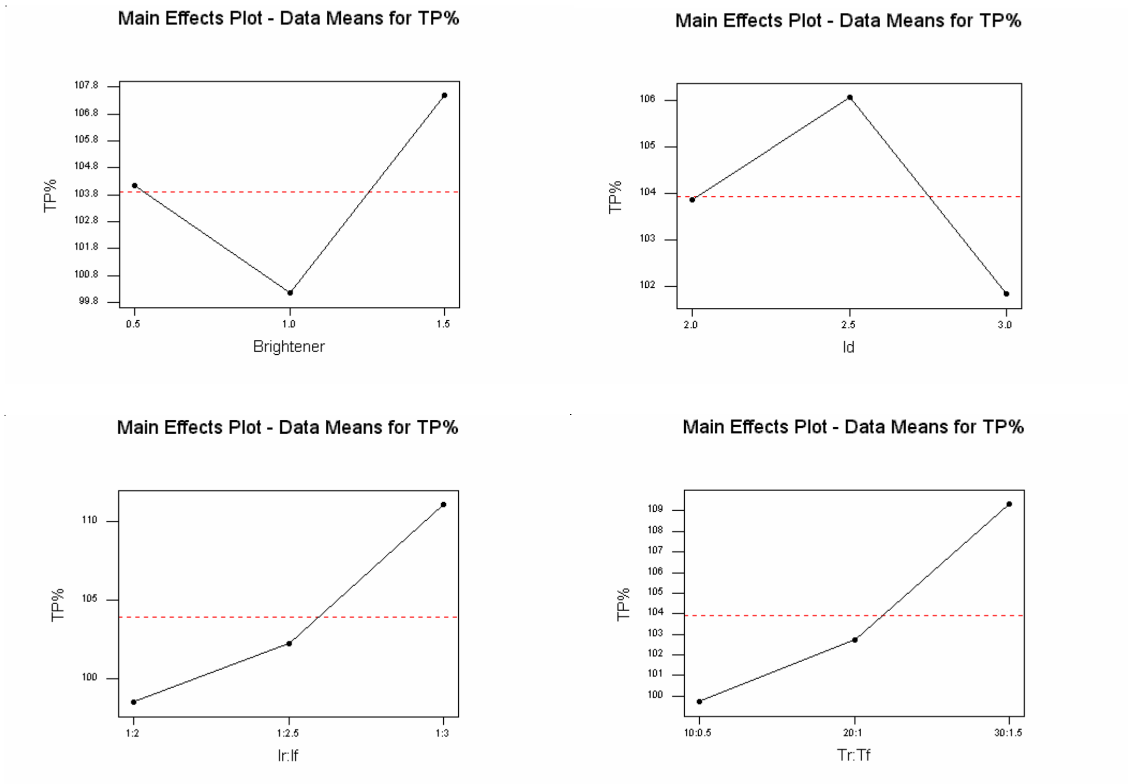

Figure 1 - Software Statistical of Main Effects

The ratio between forward current and reverse current and pulse plating time all are affected directly by the throwing power. Meanwhile increases in current ratio and the reverse plating time both improve the throwing power. However, the brightener concentration and current density are not significant factors. The throwing power for all test cells was excellent. Pulse plating can always improve the throwing power and decrease the discrepancy between the surface and hole plating. DC plating is not able to provide the same results. As an example Figure 2 and Figure 3 are micro sections of the test cells 2 and 3. The distribution of all tests in the project is above 85 percent and there is no one distinct factor about it. Pulse plating cannot change the geometry distribution of the current but can change the distribution of quadratic current when integrating with polarization. The peak value of the current is close to the limiting current and has a large polarization with differences in concentration, so the distribution of plating within the project is more uniform.. Relative to the project, pulse plating is better than DC plating.

The concentration of brightener does little to influence the throwing power, however, the tests indicate when the concentration of brightener is high, and the surface color of the test vehicle is uniformly matte. In contrast, the surface color of the test vehicle is non-uniform and/or shiny on the edge of hole and or red on portions of the surface plating.

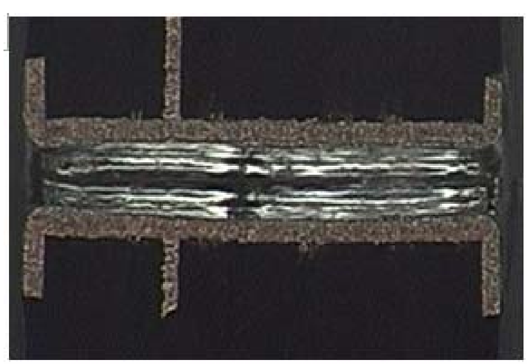

Figure 2 - Cross Section of Test Cell 2

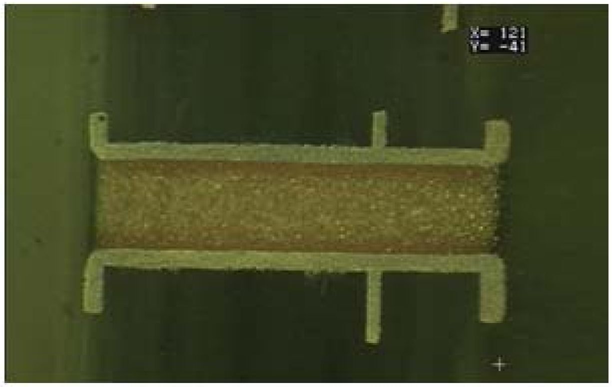

Figure 3 - Cross Section of Test Cell 3

The Performance Evaluation of Plating

Ductility Test

Plating Parameters: current density: 2.5A/dm^2, forward time: 10 ms, reverse time: 0.5ms
Current Ratio: 2.5: 1, full plating time: 120minutes, leveler concentration: 30ml/l
The tested results are shown in Table 3.

Table 3 - Plating Ductility Results

Spec. No.	Brightener concentration. (ml/L)	Temp (□).	Copper thickness (35-80um)	Ductility (15-25%)	Tensile strength (28-35kn/cm2)
1	0.5	35	67	20.3	29.2
			60	19.7	30.9
2	1.0	35	58	25.0	32.4
			63	22.1	30.2
3	1.5	35	57	19.0	30.7
			64	20.1	30.8

Crystal Structure of Copper Plating

The prominent characteristic of pulse plating is that it can change the microstructure of copper plating through a physical mode. In fact, pulse plating is periodic direct current electroplate. In the course of plating, when current is present, the peak value of current is several times or more than the current seen with general DC. Instantaneous high current density can cause the metal ions to be deoxidized at high potential that yields the fine crystal structure of copper. When current power is off, the concentration of metal ions near to the cathode will come back to the initial concentration, the difference of concentration is eliminated and so it is made ready for the next applied high current density. At the same time, the helpful phenomenon of both refining the crystal and absorption or breakaway usually occurs. As seen in the SEM photographs, the copper crystal is not ordered and the crystals range in size of 2-5 microns. (See Figures 4 and 5)

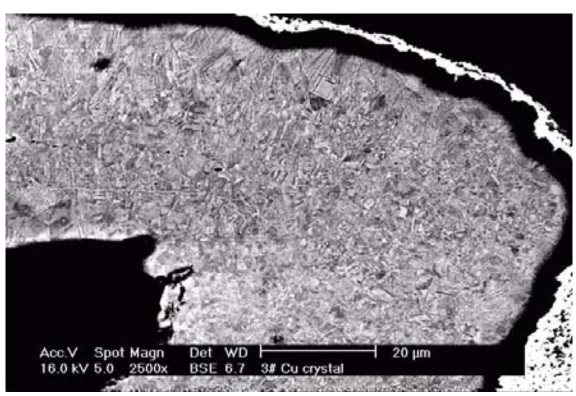

Figure 4 - SEM of Copper Crystals

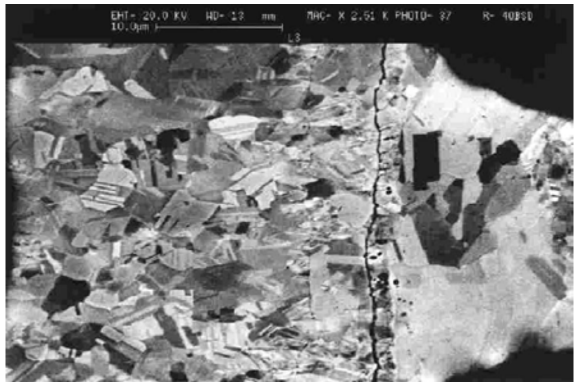

Figure 5 - SEM of Copper Crystals

Physical Performance Test

Table 4 shows the thermal stress (hot oil testing),

Table 4 - Thermal Stress (Hot Oil Testing)

Test condition: 260℃ (10sec.) To 20℃ (20sec.), achieved 100 cycles.			
Estimate standard: Measure the change of resistance value for plated hole Required the range of resistance values to change less than 10 percent			
Test result：PASS	Speci.1	Speci. 2	Speci.3
Initial resistance（Ω）	6.5	6.5	6.4
The resistance after 100 cycles（Ω）	6.7	6.6	6.6
The changed value (%)	3.08%	1.54%	3.13%

Based on the results in Table 4 of thermal stress met the requirement of project in Table 5.

Table 5 - Thermal Shock

Test condition: -25℃ (15minutes) to +125℃ (15minutes) as one cycle [300 cycles achieved]			
Estimate standard: measure the change of resistance value for plated hole Required the resistance values to change less than 10 percent			
Test result：PASS	Speci.1	Speci.2	Speci.3
Initial resistance（Ω）	6.3	6.3	6.2
Resistance value after 300 cycles（Ω）	6.5	6.4	6.4
The changed value (%)	3.17%	1.59%	3.22%

Base on the result in Table 5 of thermal shock meet the requirement of project.

IST Test

The results of testing six samples are shown in Figure 6. Copper hole wall fracturing occurred after 170-180 IST cycles, as seen via micro sectioning. As observed in the micro sections, hole wall roughness was present whenever copper fracturing occurred. However, other test vehicles did pass 250 IST cycles successfully. (See Figure 7)

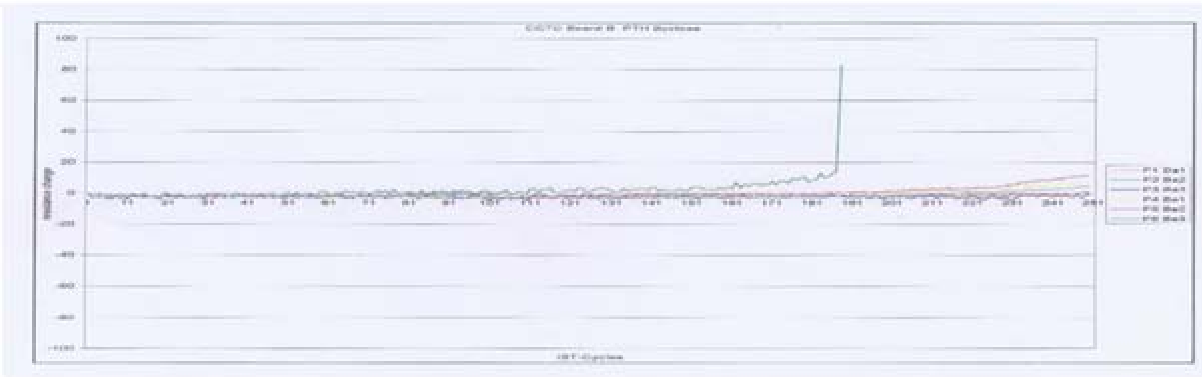

Figure 6 – 1st Cycles

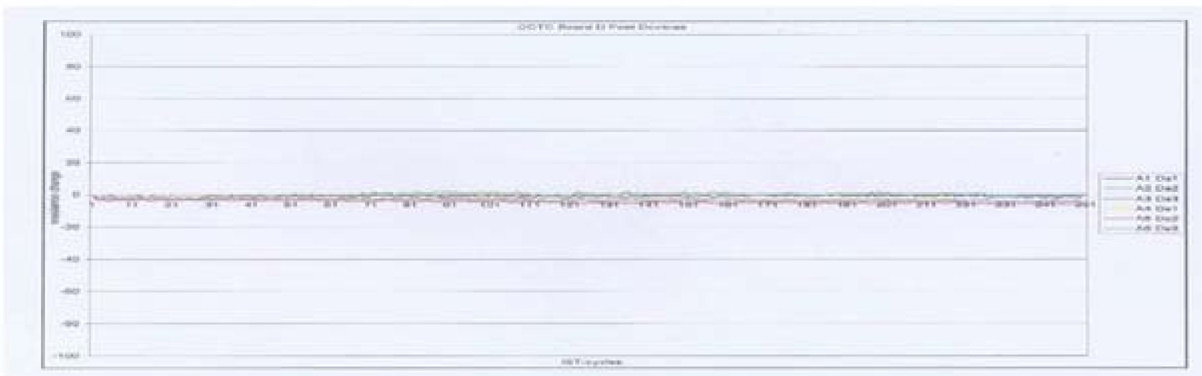

Figure 7 – 1st Cycles

Discussing the Issues about Vertical Pulse Copper Plating

Due to the high concentration of leveler in the system, a familiar problem occurs in that the dry film cannot be stripped where it defines isolated line or pad features (see Figure 8). The micro section, as seen in Figure 9, shows a plated copper mushroom shape, although a low current density and extended plating time were used. The problems with photo resist stripping of isolated feature lines can be found when line spacing is less than 4 mils. Keeping the concentration of leveler to a lower value can improve this problem but will not absolutely prevent it from happening.

If the process parameters are not controlled, non-uniform surface plating color can frequently result. Shiny plating on the edge of a hole (see Figure 10) and/or blotches on portions of the surface plating (see Figure 11) are examples that can lead to processing difficulties in the next stages.

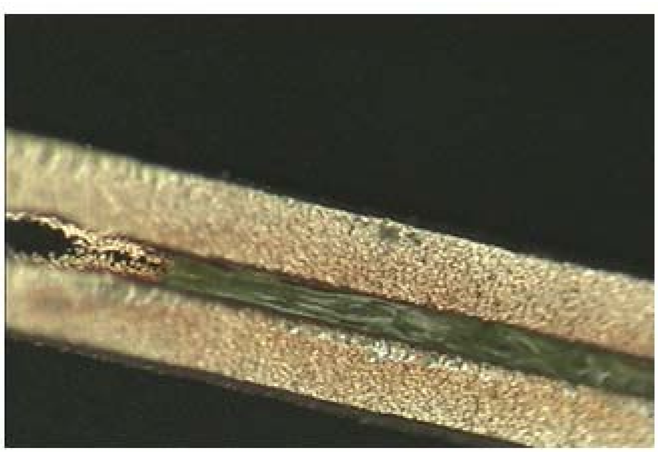

Figure 8 - Lack of Dry Film Stripping

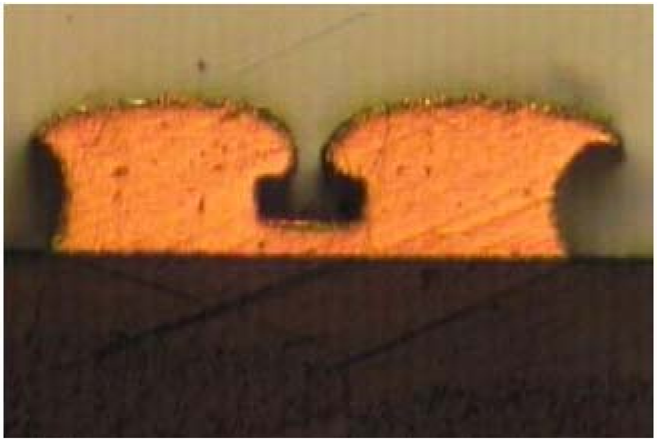

Figure 9 - Micro Section of a “Mushroom” Pad

Figure 10 - Shiny Hole Edge Plating

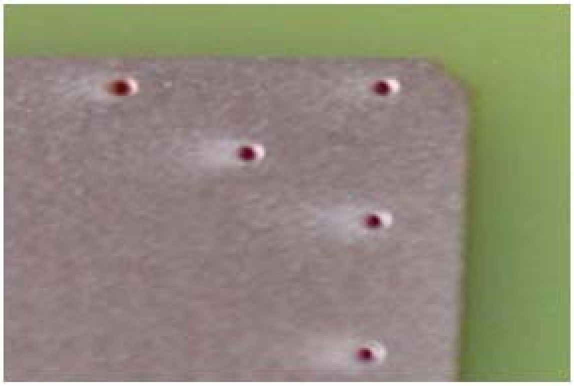

Figure 11 - Surface Blotches

Because high plating bath temperatures and high current densities can exacerbate attack on the dry film by the plating solution. This, in turn, can severely affect the adhesion of the dry film and directly lead to poor general quality.

Equipment maintenance is much stricter than with direct current plating because high plating equipment resistance will interfere with the normal curve of pulse plating (see Figure 12). The abnormal curve seen in Figure 13 will lead to poorer plating performance, in that the high resistance encountered in the changeover between forward and reverse currents. Regular curve measurements are therefore necessary to monitor the current changeovers.

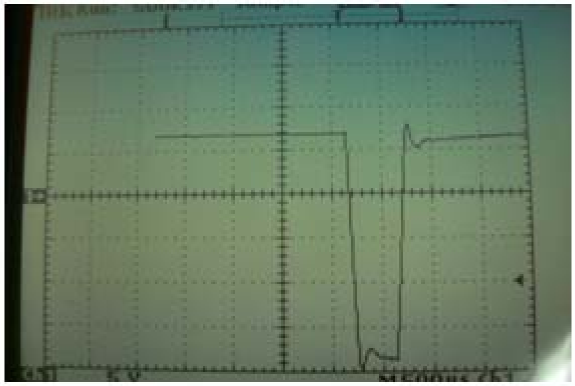

Figure 12 - Normal Pulse Plating Curve

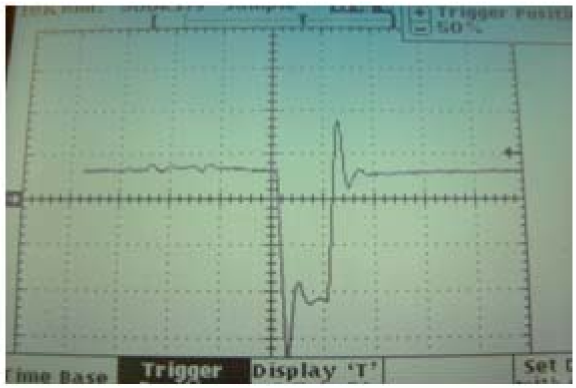

Figure 13 - Abnormal Pulse Plating Curve

Due to a higher reverse current of approximately 2-3 times the forward current, a very few impurities can interfere with the crystal structure of the deposited copper. For example, the normal crystal structure of copper as seen in Figure 14 was developed under normal working parameters, whereas the abnormal crystal structure of copper as shown in Figure 15 was caused by higher organic contamination. The black impurities are the obvious evidence of these organics that have embedded into the crystal structure of the copper. Pulse plating is hypersensitive to organic contamination, so periodic carbon filtration to remove these organics is very important. TOC (total organic carbon) value is one of the important measures of organic contamination. When the TOC value is more than 2000 units, the plating solution should be carbon treated or outright replaced. In addition, because the Hull cell cannot be used with pulse plating, CVS becomes the only effective measure or control mechanism. Never the less, measuring and controlling the concentration of brighteners and levelers, are also very necessary.

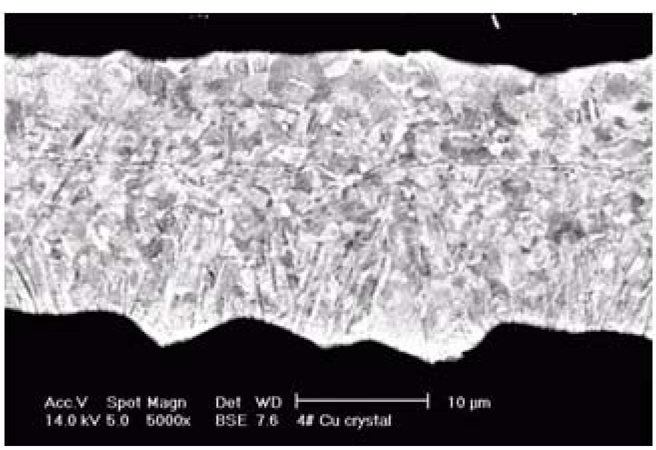

Figure 14 - Normal Copper Crystal Structure

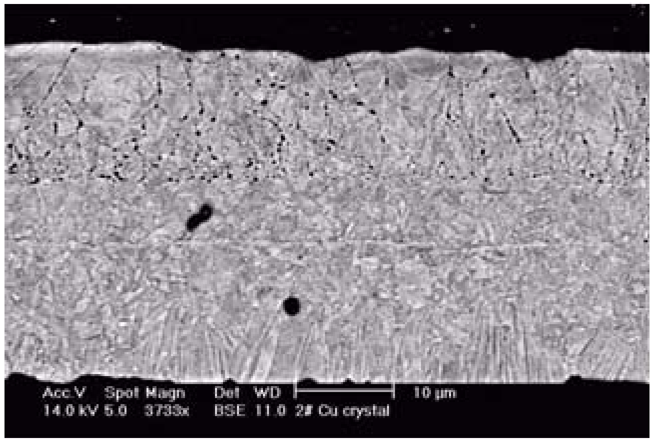

Figure 15 - Abnormal Copper Crystal Structure

Conclusions

Vertical pulse plating is an advanced type of plating because it not only exhibits excellent throwing power and surface distribution but also can further enhance productivity with plating very thick back panels or motherboards. However, the requirements are very strict with the maintenance of both plating solution chemistry and control parameters and the plating equipment. This is especially true for pattern plating using a dry film process. If the process control is lost, remnants of scum resulting from the photo resist stripping process will cause non-uniform color of the copper surface, abnormal current curves, plating solution contamination, etc. So, when pulse plating is applied to copper pattern plating, higher levels and stricter means of process control are required than when using general direct current plating, in order to achieve excellent plating quality.

Reference

1. Karl Dietz. Organic Additives in Copper Plating Baths