Cost Effects of Pulse Plating Reversal Current

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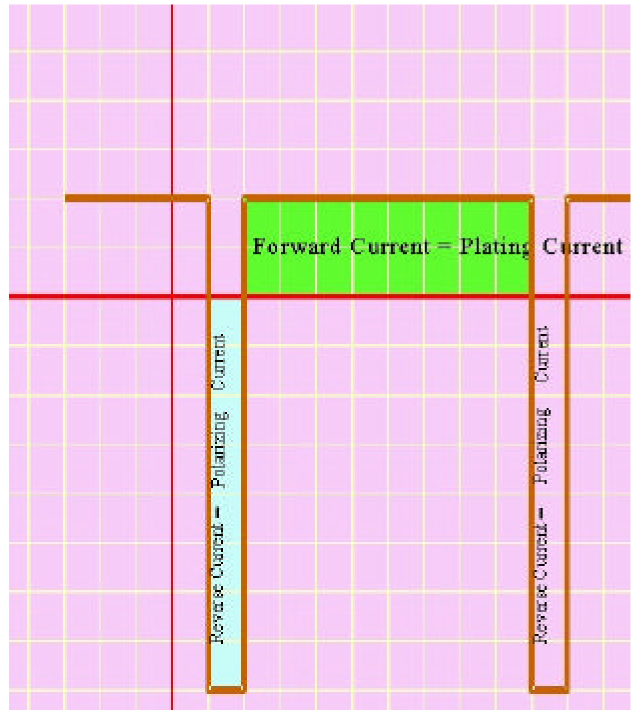
Introduction

Direct Current plating in acid copper baths containing organic supplements shows us that during electrolysis, these organic additives are attracted by the copper anode and being adsorbed on its surface. If this organic layer on the copper's surface is thick enough, it has a restraining influence on the conductivity of this electrode. The anode is becoming passive or the anode is polarized. In no small measure, polarization is dependent on the (anodic-) current density. Using the appropriate additives for the copper electrolyte and applying the right (anodic-)current density, polarization can be controlled and thus improving surface distribution of the electroplating deposition on a Printed Circuit Board.

Influence of the Reverse Current Density

The Periodic Reversal Current plating technology, makes use of the behavior that some organic molecules are attracted by positively charged electrodes to be adsorbed onto its surface and causing polarization. To grow copper on a Printed Circuit Board, the panel must be connected to the cathode, which has a negative charge. To ensure uniform copper deposition over the whole surface of the Printed Circuit Board, local high current density areas must be shielded.

Adsorption of certain chemicals must be completed within the adjusted time during the Reverse period and at the appropriate current density. To obtain the maximum Reverse pulse time, the PPR-wave has to be rectangular shaped like it is sketched in Figure 1.



Anodic Polarization
Figure 1 – Polarization Curve (Theoretical drawing)

How Pulse Plating Works

Pulse plating simply works because there are ions available in the electrolyte, which are attracted to the electrodes during electrolysis. Positive ions are moving towards the cathode while negative ions are attracted by the anode. To cause polarization or passivation, special chemicals are added to the copper bath. A well-known polarizer for acid copper baths is the chloride ion. This ion can cause severe anode passivation if its concentrate exceeds the level of 150 mg/l. Modern polarizing agents for acid copper pulse electrolyte consists of a mixture of sulfur containing organic molecules which may have a more complex electrical behavior than the chloride ion. They also form insoluble salts with copper. In high concentrations, these organic molecules can also cause anode passivation problems.

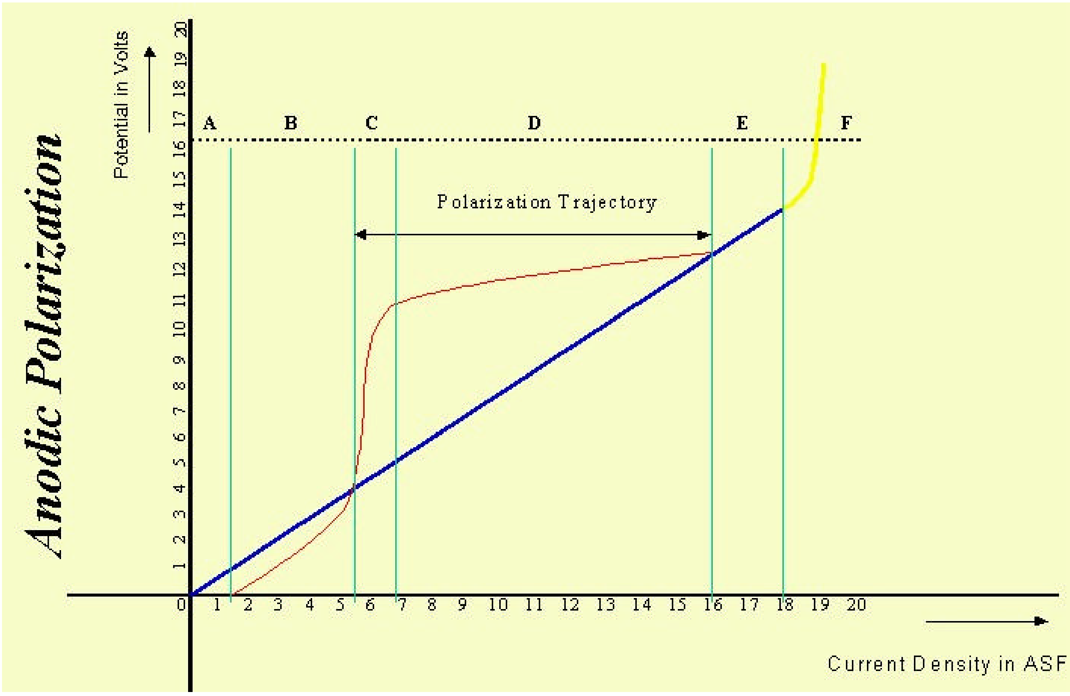


Figure 2 – Polarization Curve (Theoretical Drawing)

Explanation of the Polarization Curve:
The blue line in the curve depicts the rectilinear Ohmic relationship between Current, electrical Resistance and Potential Difference.

The red line shows the non-Ohmic behavior of the polarizing agent in relationship to Current or Voltage.

- Section A. Low current density area in where the Polarizing agent is not affected at all by the current.
- Section B. Low to Medium current density area. In this area the Polarizing agent comes under influence of the applied current, but has no shielding capacity yet.
- Section C. Medium current density. The current acts now on the polarizing agent, and the polarizer molecule will be adsorbed on the copper surface.
- Section D. Medium to High current density area. The polarizer molecule still obeys to the applied current, but its shielding effect will slowly weaken as the current density increases.
- Section E. High current density area where, due to the high potential difference, the protective (organic) layer is stripped away from the copper surface. The now unprotected copper surface can be depleted by the current.
- Section F. Very high current density areas: additional electrochemical reactions, such as Oxygen gas formation, take place alongside copper stripping.

Computing the Theoretical (Electrical) Efficiency of a Pulse Wave
In contradistinction to normal Direct Current, the Reverse Pulse Plating wave is in fact an alternating wave. There is a plating part and a deplating or polarizing part. The electroplating efficiency lies thus between two values as it is explained by the numerical example shown in Figure 3.

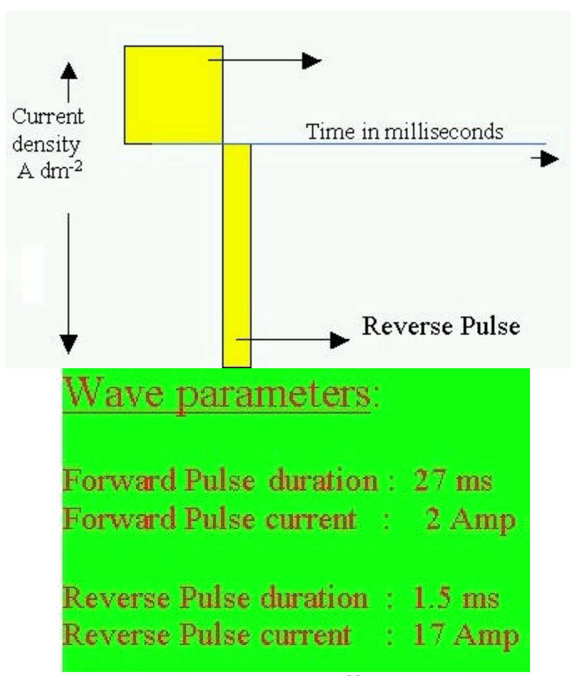


Figure 3 - Electroplating Efficiency Lies thus between Two Values as it is Explained by the Numerical Example

Calculate the charge in Coulombs (Coulomb is Ampère x second) per

Forward block	: 27 x 2	= 54.0 mC	(mC = milliCoulomb)
Reverse block	: 1.5 x 17	= 25.5 mC	
Total charge per wave is	: 54 + 25.5	= 79.5 mC	

During the Reverse pulse there are two possibilities: [1] 0% polarization or
During the Reverse pulse there are two possibilities: [2] 100% polarization

At 0% polarization, the Reverse current is used to deplete while at 100% polarization the Reverse current is used to make the copper surface passive (and no deplating activity takes place).

Nett plating charge per wave at 0% polarization	: 54 - 25.5 = 28.5 mC
Plating efficiency at 0% polarization	: (28.5 : 79.5) x 100 = 35.8%
Nett plating charge per wave at 100% polarization	: 54 - 0 = 54 mC
Plating efficiency at 100% polarization	: (54 : 79.5) x 100 = 67.9%

Or captured in a formula: 35.8% (Plating Efficiency ≤ 67.9%

The general calculation for the theoretical copper deposition in microns at 2 A dm-2 at a plating duration of 60 minutes is: 60 x 0.221 x 2 = 26.5 microns.
The expected copper thickness in a 60 minute plating sequence corresponding to the following parameters: FWD = 27 ms - 2 ASD and REV = 1.5 ms - 17 ASD will lie between Upper: 0.679 x 26.5 = 18 microns Lower: 0.358 x 26.5 = 9.5 microns

Derivation of Cu Growth per Minute <u>per dm^2</u> in <u>Grams</u> and <u>Microns</u>

Constants and Conversion Factors

- Ampere x seconds = Coulomb
- 1 Coulomb = 6,25 x 1019 eV (eV = electronVolt)
- 1 eV = elementary charge-unit = 1,6 x 10-19 Coulomb
- Avogadro's number = N = 6,02 x 1023 per mole.
- Atomic mass of copper = 63,5
- Specific density of copper = 8,96 kg dm-3.

Calculations

Coulomb charge required per Ampere per minute: 1 x 60 = 60 Coulomb.
Converting into eV: 60 x 6,25 x 1018 = 3,75 x 1020 eV.
Moles of copper = electronVolt divided by Avogadro's number and divided by the valency of copper (Note: copper valence is 2):
((3,75 x 1020) : (6,02 x 1023)) : 2 =3,11 x 10-4 moles of copper.
Amount of copper in grams per dm²: 3,11 x 10-4 x 63,5 = 0,0197675 gram
Computation of the copper volume for above mentioned quantity -mass divided by specific density- is: 0,0197675 : 8,96 = 0,0022061 ml. (1 ml = 1 cm3)
Volume = length x width x height
Height = volume : (length x width)
Height = 0,0022061 : (10 x 10) = 0,000022061 cm
Conversion factor cm into micron: 1 cm = 10.000 micron
0,000022061 x 10.000 = 0,22061 micron (round off value: 0,221(
Hence, copper growth in A-1 min-1 dm-2 stands at: 0,221(

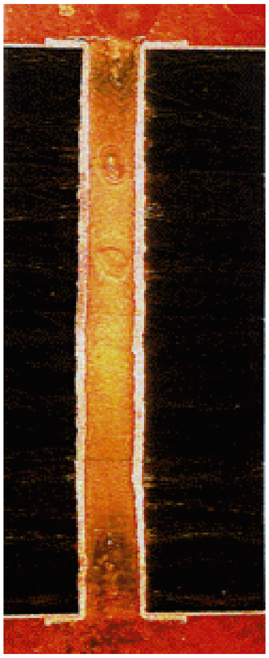
Advantages of PPR

The prices of a pulse reverse power supplies are roughly three through five times higher than direct current rectifiers of comparable output. The impact of implementation by this technology however, goes far beyond one's imagination. Direct achievements are among others:

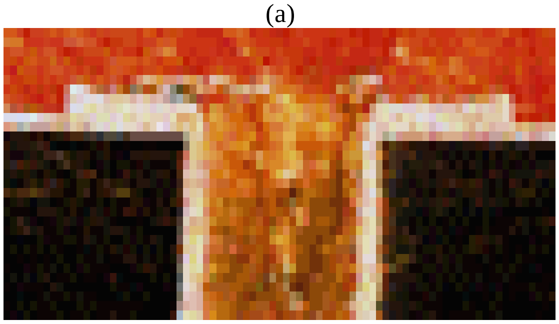
1. Less copper (-anode) consumption
2. Improved plating distribution
3. Higher throughput
4. Less soldermask consumption
5. No more panel plating required, thus longer lifespan for the etchbath.

Realize that improved plating distribution can be translated into shorter plating cycles. In preparation of numerical examples to explain the benefits of pulse plating reversal current, a visual impression of substantial improvement in Micro Throwing Power, is shown below.

Low Micro Throwing Power deposition automatically indicates that the copper layer on the surface of the board is higher than the deposition thickness in the barrel. Figures 3 and 4 shows how the micro throwing power is calculated.



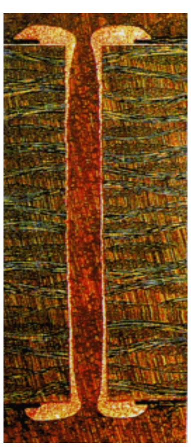
(a)



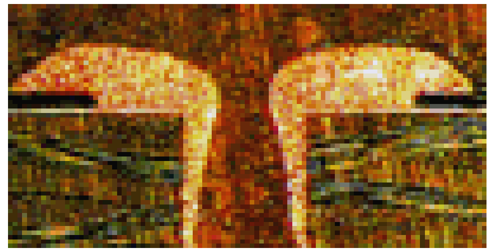
(b)

Figure 4 – PPR Patternplated board of 3.2mm Thickness and the Drilling Hole Diameter is 0.3mm

Figure1b is an enlarged detail of the hole entrance. The flatness of the copper deposition on the surface, the knee and throughout the barrel is remarkably flat as it is depicted in Figure 1a.



(a)



(b)

Figure 4 – Direct Current Patternplated Board, Same Pattern Design, Same Thickness and Same Drilling Hole Size as in Figure 3 – Aspect Ration 10.7:1

The non-uniform electroplating deposition as shown in Figure 2a and 2b is contradistinctive towards the smooth and leveled layer, which can be seen in Picture 1. Mushrooming (overplating) and dog boning is a common phenomenon in D.C. plating, especially in High Aspect ratio and isolated holes

Low Micro Throwing Power deposition automatically indicates that the copper layer on the surface of the board is higher th.

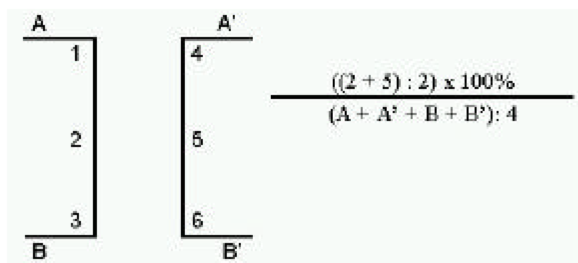


Figure 5 – Computing the Micro Throwing Power (MTP)

The micro throwing power is expressed as a percentage.

Characters in Figure 1 represent the deposed metal layers on the surface of the circuit board in Figure 1 represent the deposed metal thicknesses in the drilling hole.

According to the widely accepted standards and requirements for the quality grade of a Printed Circuit Board, the copper thickness in the middle of the hole is authoritative. The following numerical examples in Table 1 show the benefits of PPR-plating over normal D.C.-plating.

Table 1 - Benefits of PPR-Plating Over Normal D.C.-Plating

Present situation – Direct Current	Converted Line – Pulse Plating Reversal Current
Plating parameters: 2.6 ASD – 72' - 70% MTP	Plating parameters: 4 ASD - 42' – 100% MTP Gain in platingtime per cell per plating cycle is: 72 – 42 = 30 minutes.
Required charge in Amps x sec (= Coulombs) 2.6 x 72' x 60" = 11232 C per flight bar per dm².	Required charge in Amps x sec (= Coulombs) 4.0 x 42' x 60" = 10080 C per flight bar per dm². Difference in charge (absolute) is: 11232 – 10080 = 1152 Coulombs in favour of PPR In %: ((11232 – 10080)/ 11232)) x 100% = 10.3%. Also in favour of PPR.
Copper consumption per dm² per flight bar per plating cycle in grams: 72' x 2.6 x 0.0198 = 3.71 grams. The plating window is 206 dm² per side and is thus 2 x 206 dm² = 412 dm² per flight bar. Hence, copper consumption per flight bar per plating cycle is: 412 x 3.71 = 1529 grams per plating cell (Suppose 34 flightbars can be finished in 24 hours and there are 200 production days a year)	Copper consumption per dm² per flight bar per plating cycle in grams: 42' x 4.0 x 0.0198 = 3.33 grams. The plating window is 206 dm² per side and is thus 2 x 206 dm² = 412 dm² per flight bar. Hence, copper consumption per flight bar per plating cycle is: 412 x 3.33 = 1370 grams. PPR uses 1529 – 1370 = 159 grams less copper than D.C. per flight bar per plating cycle per plating cell Annual savings: 34 x 200 x 159 = 1081200 grams = 1081 kg = 1 ton of copper per plating cell
Present panel output in D.C. = 100%	Panel output in PPR is: (72/42) x 100% = 171% Output difference: 171 – 100 = 71% more than in conventional D.C.
MTP 70% implies: 25µ in hole and 25/0.7 = 35.7µ on surface	MTP 100% implies: 25µ in hole and 25/1.0 = 25µ on surface Difference in Cu thickness: 35.7 – 25 = 10.7µ Thus: 10.7µ less Cu to etch if PPR is used instead of standard Direct Current. Etching speed increment of PPR electroplated copper: ((35.7/25) – 1) x 100 = 42.8 %

Conclusion

Gain in platingtime per cell per flight bar is 30 minutes. Annual gain in time if 34 flightbars are finished each 24 hours -and in D.C. 20 flightbars could be finished each 24 hours-, while there are 200 production days a year: 30 x (34 - 20) x 200 = 84,000 minutes = 1400 hours of extra production time per cell per year. (Normal production hours per year per cell in a five-day week are: 24 x 5 x 200 = 24000 hours). If the profit per plating cell per hour is US$ 25. - then the annual extra profit for a PPR modified cell -compared to the original D.C. cell- is: 25 x 1400 = US$ 35,000:

1. Copper savings per cell per annum is: 1081 kg of copper anode material. If 1 kg of anode copper is US$ 11.- then the copper savings are: 1081 x 11 = US$ 11,891.- a year.
2. Soldermask savings per cell in one year: 211 litres. Price of 1 litre soldermask is approximately US$ 27.- So the annual savings are: 211 x 27 = US$ 5,697.-
3. The price of a standard dual output rectifier of 1200 Amps per side is between US$35,000.- and US$ 45,000.- (Depending on the supplier)
4. Labor costs for modifying one cell including replacement of the existing cables by coaxial cables: US$ 5000.
5. Total investment for modifying an existing D.C. cell into a cell which is suitable for Reverse Pulse Plating: (4 + 5) is: 45,000 + 5,000 = US$ 50,000.-, if a rectifier from the most expensive supplier is bought.

Earnings a year due to Reverse Pulse Plating: (1 + 2 + 3) = 35,000 + 11,891 + 5,697 = US$ 52,588.

Balance: 52,588.- 50,000.- = US$ 2,588.- in your advantage. Investment in Reverse Pulse rectifiers can thus be earned back within one year!