

Beyond Periodic Pulse Reverse

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Introduction

According to Michael Shermer of Scientific American (Jan. 2002) technology has advanced more in the past one century than in the previous one hundred centuries. Yet it seems from a technical perspective that many of these advances yield distinct paths and isolationist positions, where each “technology island” meets only a part of our needs. Not until a technology is fully evolved, can we apply it to our entire spectrum of problems.

Some practical examples may help define “technology islands”. As the electronic typewriter evolved into a PC application such as MS Word, those who needed to utilize data adopted data base programs such as Excel, others who dealt primarily with presentations standardized on Power Point. Users were grouped or isolated into different applications based on their primary need. Yet each category of users did not have 100% of their needs met by their one primary application. Using two or three applications still limited them or at best reduced productivity. The evolution of this technology led to the Microsoft Office application allowing the seamless use of all three programs. This can be viewed as less choice; one program vs. three but yielding improved capability.

“The evolution of technology is not about increasing choices, but about it’s ability to meet our spectrum of needs effectively”.

Other examples include the DVD race. Currently there are three formats; one which is common and low cost, a second which is feature rich and a third which holds more data but is expensive. The evolution of this technology will be an affordable feature rich product that holds large amounts of video data.

Most of us have a home telephone number, a cellular telephone number, an e-mail address and some of us also have a personal pager number. Many choices, but not the most effective means of tracking a person down. This technology will eventually evolve to optimally meet our needs when a single personal identifier serves for all our voice and data communication, independent of our location.

Yet another technological advancement, which has led us into “technology islands” is the use of plating waveforms; Direct Current (DC), Periodic Pulse (PP) and Periodic Pulse Reverse (PR). Each provides unique capability but is exclusive and limits us to that specific

benefit. This paper will deal with these waveforms and introduce a bridge between today’s single waveform choice and tomorrow’s evolved product, introducing a practical method (tool) for increasing quality, capability and profitability for electroplating advanced electronic devices such as PWBs, wafers and semiconductors packaging.

How is it we evolved into “electroplating technology islands”: DC, PP & PR? The short answer is that unique technologies evolve as a result of multiple companies independently advancing technology. The historic lack of cooperative effort between system integrators, chemical and power supply manufactures creates independent standards (plating methods), each driven by that individual company’s desire and competency to generate revenue.

DC Power

Direct Current (DC) is the traditional and most widely used electroplating waveform. DC shown in Figure 1 is characterized by a non-varying amplitude as a function of time.

DC power supplies and processes represent proven mature products that electroplaters and line operators are accustomed to using. Furthermore, most electroplating chemicals have been developed using DC.

DC represents minimal electrochemical control; the potential remains constant allowing chemical additives to control the process. Numerous limitations exist for DC, but as applicable to PWB’s, wafers and other advanced electronic components, two are prevalent (Figure 2).

The second critical limitation, is that DC by virtue of it’s constant potential creates a stationary diffusion layer at the cathode-solution interface. The theoretical diffusion layer is approximated at 75 microns. As a result features with openings near or below 150 micron (2X the diffusion layer thickness) become inaccessible to DC processes, without the use of complex chemical mediation. We can visualize this with the help of Figure 3; it is reinforced by the fact that most successful Plated Through Holes plating (300-400 microns or 4-5 X the diffusion layer thickness) is done with pulse reverse¹, not DC.

Today’s technological advancement is marked by miniaturization, DC can help with many deposit properties but is limited in its ability to process today’s smaller PWB and wafer features. It should be noted that

DC has been successfully used to plate small features, but the plating rates are so low as to make this approach impractical. Table 1 summarizes DC benefits and disadvantages.

Periodic Pulse Power

Periodic Pulse (PP) has a long tradition in the electroplating of precious metals. PP shown in Figure 4 is characterized by an interrupted current as a function of time.

PP power supplies and processes represent a step up in complexity over DC. PP equipment has an increased number of adjustments over DC, but remains user friendly for electroplaters and line operators. It is important to note that because the PP waveform is unipolar (positive only polarity), it has minimal negative interaction to most additives. PP can reduce the need for or dependency on such additives as grain refiners.

PP represents increased electrochemical control over DC. The changing potential created by T_{ON} and T_{OFF} ,

creates a second diffusion layer termed the *pulsating diffusion layer*, see Figure 5.

Common application of PP involves using the pulsating diffusion layer (not present in DC) to reduce grain size and increase nucleation sites. For PP waveforms it has been demonstrated that T_{ON} and I_{PK} are primary control parameters². The T_{ON} is proportional to the pulsating diffusion layer thickness allowing for control over grain size. The nucleation sites are increased with increasing I_{PK} . The I_{PK} can be increased without exceeding the maximum DC current limit (plating rate limit), by reducing the duty cycle, where the duty cycle = $[T_{ON} / (T_{ON} + T_{OFF})]$. A low duty cycle pulse with increased peak current can decrease grain size and increase number of sites where crystals begin to grow to yield a flatter deposit, see Figures 6 & 7. It is important to understand that increased output voltage may be required with increased I_{PK} in accordance to Ohm's law; V (volts) = I (amps) x R (ohms).



Figure 1– Direct Current Waveform (DC)

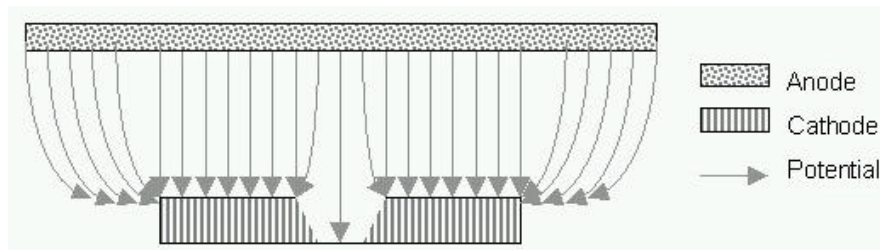


Figure 2– Uneven Deposit is caused by Anode/Cathode Geometry

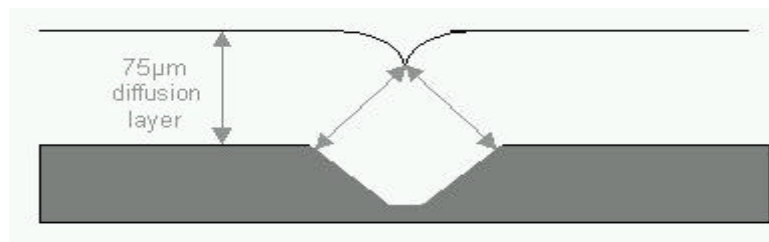


Figure 3– DC Creates a Stationary Diffusion Layer Limiting Accessibility to Small Features

Table 1 - DC Waveform

Pro's	Con's
Low cost equipment	Very slow plating to level small features
Considerable history and application material	Chemical cost & complexity increases with cathode surface complexity
Most chemicals developed with DC	Inability to access smaller features
Strong comfort level by operators	Inherently uneven deposition

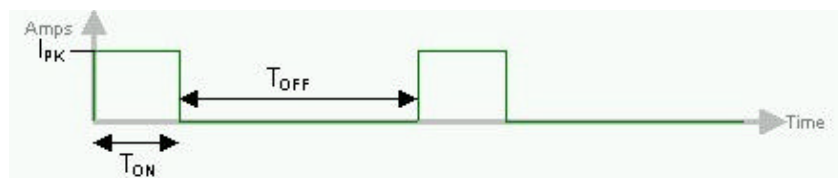


Figure 4– Periodic Pulse Waveform (PP)

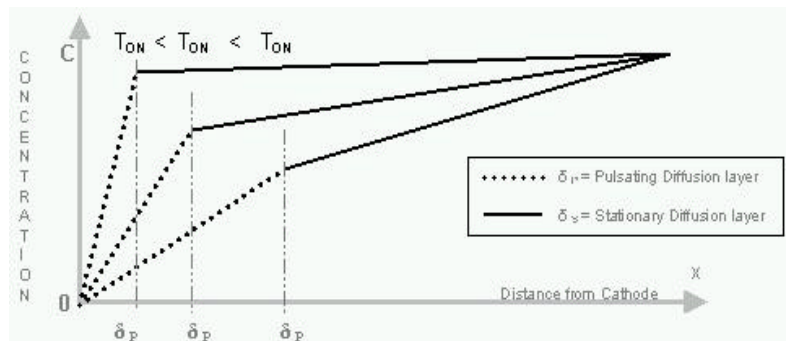


Figure 5– PP Creates a 2nd “Pulsating Diffusion Layer”

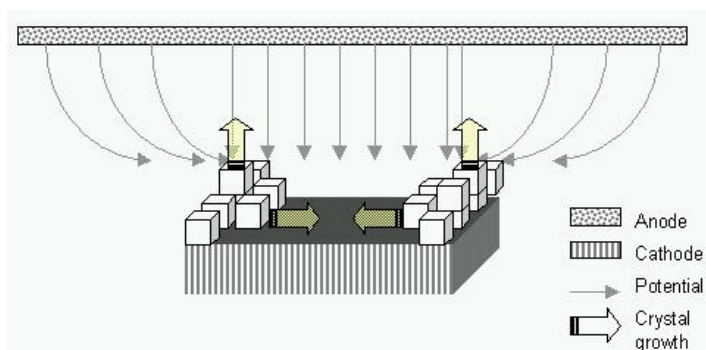


Figure 6– DC Deposits Larger Grains and Tends to Build up Existing Crystals at High Current Density Regions, Creating a Dog Bone Effect

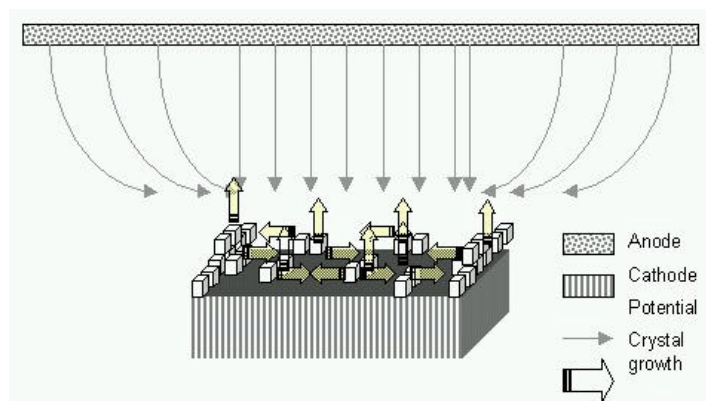


Figure 7– PP can Reduce Grain Size and Increase Nucleation Sites, Yielding a Flatter Deposit

PP waveform parameters (T_{ON} , T_{OFF} , I_{PK}) are determined based on cathodic geometry, desired deposit characteristics, cell design, chemistry and additives.

The most prevalent limitations to PP are the inability to redistribute material along the cathodic surface. Although PP allows for the reduction of the diffusion layer thickness, some dog boning will inevitably occur. Over time small features such as PCB via's will become

blocked before they can be properly filled. PP produces a flatter deposit over larger surfaces (as compared to the diffusion layer) but has limited throwing power into small features.

As with DC, PP can help with many surface properties but is limited in its ability to process today's smaller PWB and wafer features. Table 2 summarizes PP benefits and disadvantages.

Periodic Pulse Reverse Power

Periodic Pulse Reverse (PR) is a relatively recent successful means of electroplating such difficult geometries as plated through holes (PTH). PR is characterized by a bipolar current as a function of time, shown in Figure 8.

PR power supplies and processes represent a step up in complexity over PP plating. PR equipment has an increased number of adjustments over PP, and vary in level of user friendliness for electroplaters and line operators. It is important to note that because the waveform is bi-polar (positive & negative polarity), PR may be incompatible with certain additives. Some chemical vendors are now providing PR chemicals & additives.

PR represents increased electrochemical control over DC and PP. PR benefits include the ability to modulate the pulsating diffusion layer and redistribute material over a cathodic surface. The cathodic current (I_{FWD}) selectively deposits metal and the anodic current (I_{REV}) selectively removes metal, resulting in redistributing the deposit over the surface for proper leveling.

Common application of PR is to improved throwing power. The T_{FWD} & T_{REV} remain proportional to the pulsating diffusion layer thickness allowing for control over grain size. The nucleation sites continue to increase with increasing peak-amplitude. The forward / reverse polarities are used to redistribute metal over the cathodic surface, as shown in Figure 9.

Pulse waveform parameters; T_{FWD} , T_{REV} , T_{OFF} , I_{FWD} & I_{REV} , are determined based on cathodic geometry, required throwing power, cell design and chemistry + additives. Prevalent PR limitations include; limited range of effectiveness and incompatibility with many common chemical additives.

The T_{FWD} , T_{REV} , T_{OFF} , I_{FWD} & I_{REV} settings demonstrated to properly level a 350 μ M PTH will not properly level a blind 100 μ M via.^{3,4} A specific set of waveform parameters, yield desired leveling for a given feature type +/- a limited range. As PR waveforms are periodic (continuous & repetitive), and can only address a single feature type or deposit requirement. This can be overcome by multiple baths and masking, but this approach is not practical as it reduces throughput, increases cost and opportunities for error.

Secondly, PR anodic current (I_{REV}) can interacts negatively with many common additives, such as brighteners and levelers. These selectively attach themselves to high current density areas to inhibit growth, the I_{REV} then attempts to remove them. It's an electrochemical tug of war, which complicates the plating process.

PR has excellent throwing power but is limited in its ability to process multi-feature PWBs or wafers. Table 3 summarizes PR benefits and disadvantages.

Table 2 - PP Waveform

Pro's	Con's
Mid cost equipment	Increased complexity over DC
Application material available	Empirical data may be required to implement
Yields flat deposits & reduced grain size	Inability to access small features
Compatible with most DC chemicals	Produces an inherently matte finish

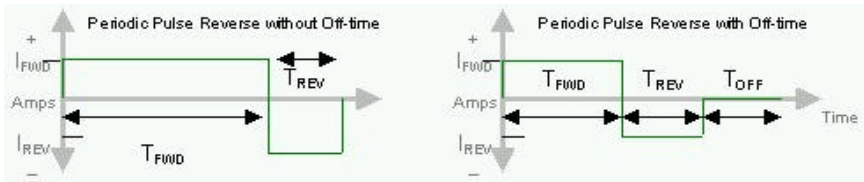


Figure 8– Periodic Pulse Reverse Waveforms (PR) with and without Off-time

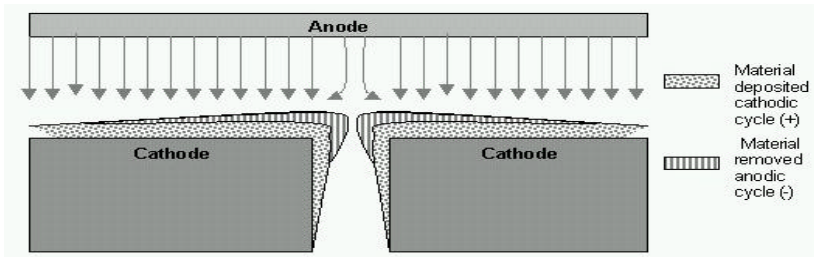


Figure 9– PR Deposits During the Forward Cycle (+ cathodic) and Removes Material from High Current Density Regions during the Reverse Cycle (-anodic)

Table 3 - PR Waveform

Pro's	Con's
Excellent throwing power	Specific to a feature type +/- limited range)
Ability to selectively deposit metal	High cost equipment & increased complexity (including inductance)
Proven to work well on PTHs	Limited application information & considerable empirical analysis may be required
	Incompatible with many DC chemicals
	Inherently produces a matte finish

Choosing a Waveform

Understanding the general capability of each waveform; DC, PP and PR- the obvious question is, "Which waveform is right for my application?"

If we consider chemical additives important, the right choice may be DC.

If we consider flat deposit and small grains important, the right choice may be PP.

If we consider the ability to throw into small features and high aspect ratio holes important, the right choice may be PR.

We have a dilemma, similar to the WORD, EXCEL, POWER POINT scenario described in the introduction, these waveforms are inherently exclusive in the benefit they provide, see Figure 10. Give serious thought to your PWB or wafer geometries, and it becomes clear that all three waveforms are required- i.e. MS OFFICE. If all three waveforms are not required, at least two of the three will be each time you plate, and we have no way to know which two therefore we need to count on all three.

Technology is advancing at an unprecedented pace; PWBs remain the backbone of electronic products and wafers for integrated circuits. They continue not only to miniaturize but to increase in complexity by combining multiple feature types on each PWB; PTH, blind vias,

high aspect ratio holes, thin line traces, minimal line spacing, etc.

As previously stated, waveform parameters yield optimal plating for a limited range surrounding a specific feature type. Periodic waveforms are therefore limited in their ability to properly level PCB's with widely varying features such as PTHs and blind vias. Rehrig & Mandich suggest that "simple electronic manipulation of the pulse waveform" could be used to "tune" the electro-deposition process and replace chemical additives.⁷ E.J. Taylor, J.J. Sun, M.E. Inman and L. Zhang have published numerous papers successfully achieving this result.^{3,6}

Which waveform? – In practice we cannot predict our next part geometry, therefore we need the ability to use any or all three waveforms for any given job. Additionally, in considering equipment needs, we need to go beyond the cathodic surface geometry and consider the manufacturing process, quality, cost and throughput.

Real world answers are rarely black and white. After a detailed review of numerous plating / fabrication shops the list of requirements, looks something like this:

- DC for its compatibility with chemical additives, such as brighteners.
- PP for its ability to provide flatter deposits over large surfaces.

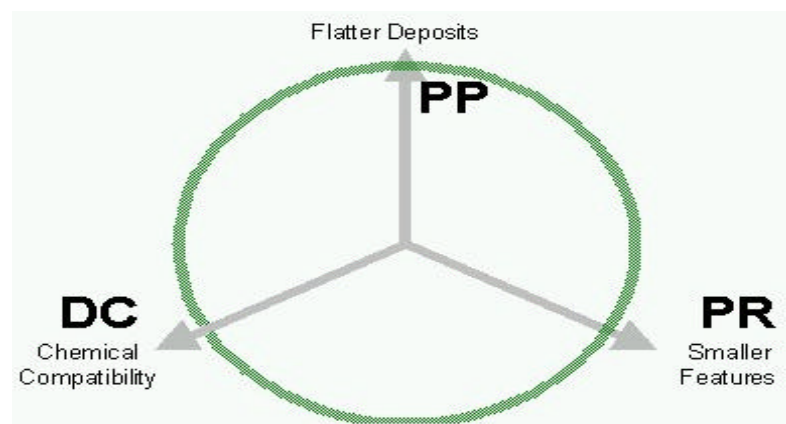


Figure 10 – Individual Waveforms Provide a Specific Plating Capability, Today's Electronic Components Require We Combine all these Capabilities for Every Job, shown in Green Circle

- PR for throwing power and material redistribution ability.
- User-friendly equipment for low skilled operators and to minimize scrap.
- Clear application data and the ability to break the process down into manageable size steps.
- Reliable equipment for reduced down time, critical in fast turn shops.
- Ability to plate at high current densities for increased throughput
- Reasonable equipment costs to justify investment.
- Advanced internal instrumentation to monitor quality metrics.
- Automation to reduce labor cost and operator error. Especially for shops that run two or three shifts, as key personnel are not always available.

The above list may seem a bit overwhelming, perhaps even unrealistic. Common sense dictates that unless we purchase flexible systems, which meets or exceeds our needs, we will find ourselves re-investing in capitol equipment much sooner than anticipated.

The good news is, a few advanced technology equipment manufactures have products that comply with this list of requirements. These products are based on a sequential waveform approach, combining advanced power conversion electronics with embedded microprocessor control. Table 4 provides additional detail regarding these requirements.

Wave Sequencing-Beyond Pulse Reverse

Wave Sequencing⁸ (WS) is a device / process, capable of sequentially combining two or more waveforms as a function of time, into a single electrochemical process. Sequential waveforms go beyond Periodic Pulse Reverse allowing the operator to generate multiple waveforms

(DC, PP, PR) and combine these waveforms in a common process, see Figure 11. This includes the ability to combine multiple PR waveforms to address multiple feature sizes on a common cathodic surface. The duration of each waveform is variable and there need be no relationship from one waveform and the next.

The sequential combination of multiple waveforms affects the cathodic surface as a multi-step electrochemical process. Each waveform is selected or specified for a specific deposit characteristic or leveling capability by feature sizes. The WS net result, after completion of its N individual process steps, is the desired surface deposit characteristics and proper leveling of the entire cathodic surface.

WS is a relatively new area of power conversion, developed to over come the limitations of today's electronics plating industry. It can be viewed as a bridge between the "Plating Waveform Islands" of today (DC, PP & PR) and tomorrows more advanced electrochemical process solutions. WS simply segments a plating job into a number of manageable steps. Each step can be programmed with the best waveform to achieve a partial deposit result. The sum of the partial results, or process steps, yields a finished part.

WS power supplies typically consist of an input stage, power stage, rectification, output stage, control system and user interface, illustrated in Figure 12. WS Equipment has greater sophistication in the User Control section than DC, PP or PR units. This additional capability enables the unit to generate numerous waveforms and provides improved user ergonomics to reduce process errors.

Table 4 - Equipment Requirements

MINIMAL REQUIREMENT	INCREASED TECHNICAL DETAIL
DC for compatibility with certain chemical additive such as brighteners	Current control, low ripple DC, line & load regulation & increased operating range
PP for flatter deposits	Control of T_{ON} , T_{OFF} & I_{PK}
PR for throwing power	Control of T_{FWD} , T_{REV} , T_{OFF} , I_{FWD} , I_{FWD}
User friendly equipment for low skilled operators and to minimize scrap	Programmable by a friendly menu system including nonvolatile memory for storing job recipes
Clear application data & ability to break the process down into manageable steps	Sequential waveforms combine individual waveforms and utilize available application data
Reliable equipment for reduced down time, critical in fast turn shops.	Small environmentally sealed enclosure to place near the tank reducing inductance
Ability to plate at high current densities	Ability to generate a wide variety of PR waveforms including non 1:1 forward to reverse ratios and .1 – 100ms pulse widths for anodic and cathodic pulses
Reasonable equipment costs	Pricing varies by supplier, but advanced technologies are more cost effective.
Advanced internal instrumentation to monitor quality metrics	Internal micro-P and software provide advanced and accurate instrumentation
Advanced automation to reduce labor cost and decrease operator error	Bi-digital control interface & software compatible with PCs and PLCs

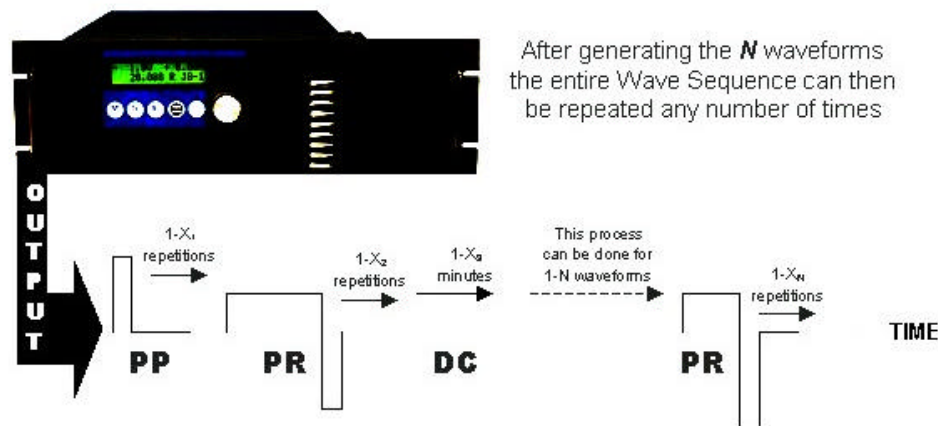


Figure 11 – WS Combines N Multiple Independent Waveforms, into an Electrochemical Process

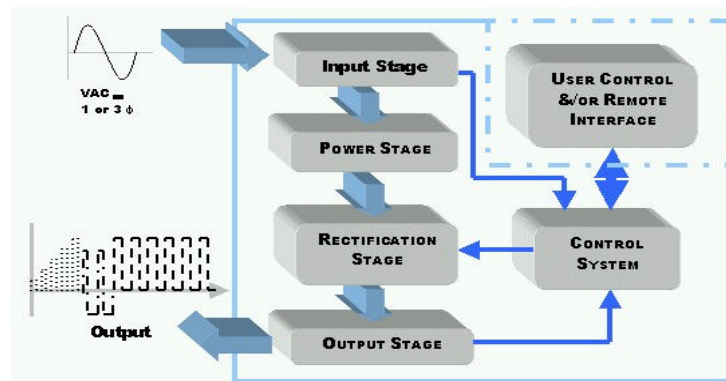


Figure 12 – Block Diagram of a Basic WS Power Supply

Critical in today's fast paced fabrication shops is it's simple equipment operation and advanced features. DVD players today are more powerful and simpler to operate then the early VCR's. This is due to the incorporation of On-Screen Menu Driven Control. Similarly WS equipment incorporate Menu Driven Controls and non-volatile memory to simplify data entry, store vital setting, reducing task duplication and insure user-friendly operation.

Much of the user ergonomics is accomplished through the introduction of a *JOB LIBRARY*. The Job Library is a menu driven software tool within the unit that allows the operator to store and recall "job recipes". Data entry is done in multiple steps making programming very manageable. Menu Driven systems are used in storing/recalling numbers in cellular phones. Numerous other advanced features can be combined with the WS equipment to yield further process capability, these will be discussed in section 9.

Figure 13 is an example of the data entry of a four process-step wave sequence. Note that the defining waveform parameters, for each sequential waveform, are independent. This is critical in order to insure the ability to generate the exact waveform required to process a specific cathodic surface geometry. As an example, some WS systems require a forward to reverse ratio of 1:1,

thereby severely limiting the waveform capability and compatibility to many chemistries. Other systems require a longer T_{FWD} than T_{REV} , limiting the ability to generate waveforms which process sub-diffusion layer thickness features like micro-vias and semiconductor trenches.

The benefit of Sequential waveforms over traditional periodic waveforms is it's ability to process geometries with multiple feature types. These complex geometries are basic to the electronics industry and describe a wide range of parts from PWBs to wafers from Chip Scale Packages to lead frames and Connectors to Microwave Cavities.

One of the concepts basic to WS is accessibility. Accessibility to sub diffusion layer thickness features and to multiple feature types on a single surface. The prior governs the waveform parameters and the later governs the order or progression of the waveforms.

Waveforms for small features (require less material) must necessarily precede those of larger features (require large material). Reversing the order would cause the small features to be plated over and become inaccessible to remaining waveforms, as show in Figure 14.

Case study examples may help further the understanding of WS technology.

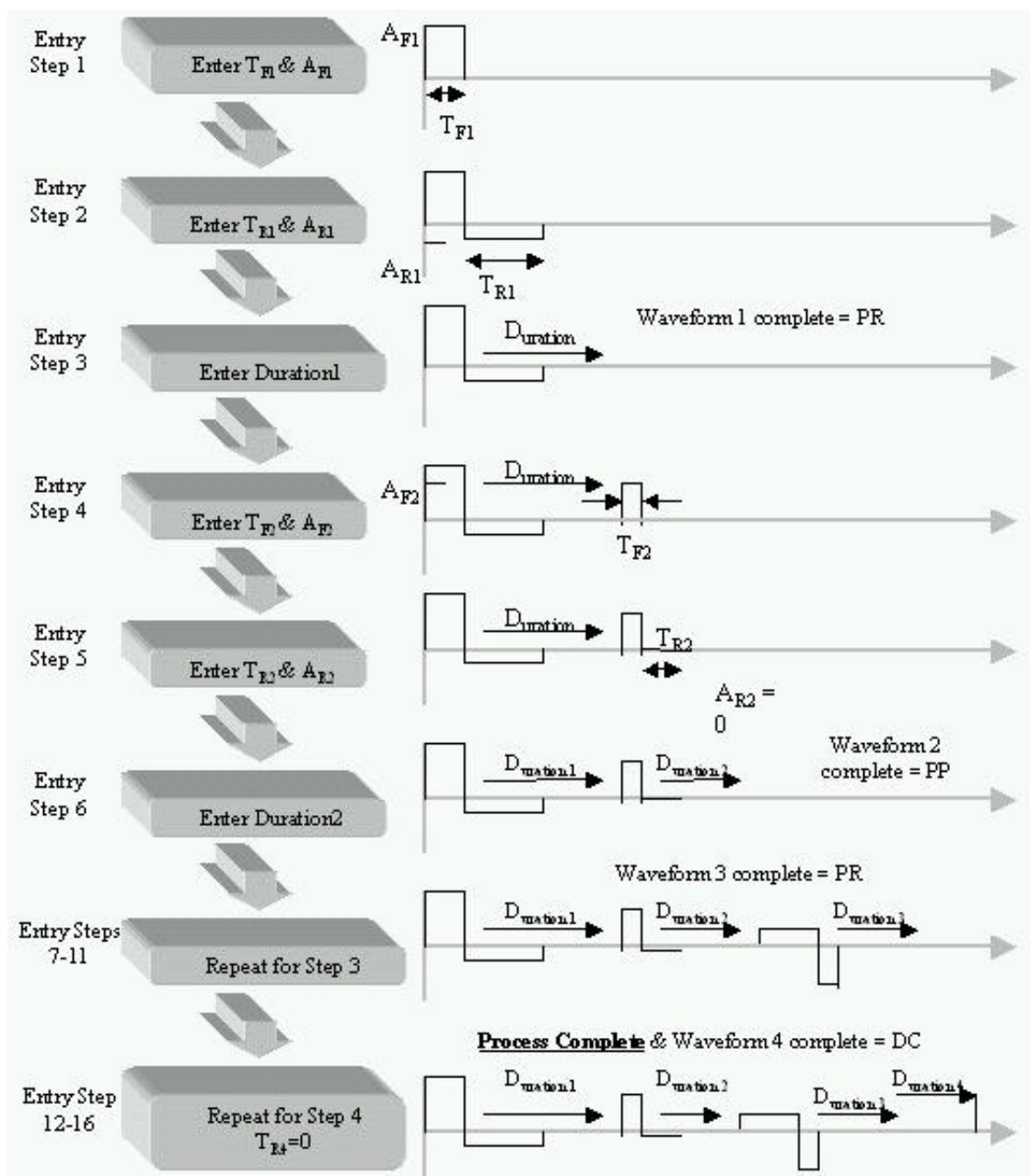


Figure 13 – Example of Data Entry for a Four-Step Wave Sequence Electroplating

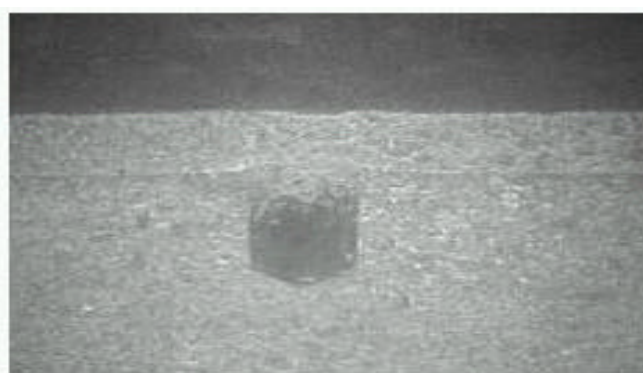


Figure 14 – Incorrect Waveform Parameters or the Incorrect Sequence of Waveforms can Block Access to Smaller Features

PCB Case Study Example

Cathodic Surface — Two sided PCB with PTHs & blind micro-vias as seen in Figure 15.

PCB Feature Details — 325 μM Plated Through Holes
75 – 100 μM blind vias

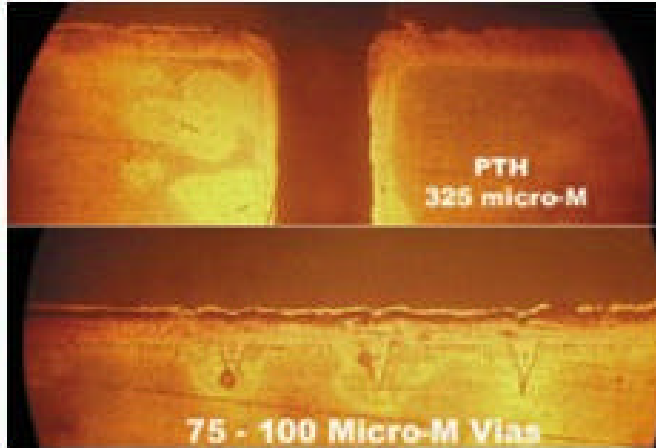


Figure 15 – Two-Sided PCB with PTH and Blind Via Features

Requirement — Leveling of surface including bright finish

Brief Feature Analysis

Blind via - Smallest feature and therefore requires the least amount of material. This feature is well below the diffusion layer thickness and is inaccessible using traditional DC at production current densities.

PTH - Next smallest feature and material requirement. This feature is about 4X the diffusion layer thickness.

Traces - Require even deposit across the entire panel area.

Bright Finish - Customers appreciate the aesthetics a bright finish.

Waveforms Analysis

Blind via - First waveform in sequence to access the smallest features before they are rendered inaccessible by the other waveforms.

Will require a short T_{FWD} of high I_{FWD} to reduce the diffusion layer thickness and to increase nucleation sites in this low current density region.

Will require a long T_{REV} low amplitude I_{REV} pulse to remove material in a “DC like” fashion

PTH - Second waveform in sequence to access the next smallest features before they are rendered inaccessible by the other waveforms.

Will require a long T_{FWD} of low to mid-amplitude as the feature openings are over four times the diffusion layer thickness and open on both sides.

Will require a short T_{REV} high amplitude I_{REV} to remove material in a from the opening to this feature.

Traces - Based on the traces and surface, a PP waveform will be required to uniformly coat the entire surface, especially if multiple panels are placed in the same bath.

Bright Finish - If additives are present a DC signal may be applied for a short time to over come the inherent matte finish associated with many pulse-plating processes .

Duo Sided PCB

Typical PCB's have different trace patterns on each side requiring different current densities based on the surface area. This means two power supply outputs with independent amplitudes are required.

Additionally, in order to minimize negative interaction between the two power supply outputs in the common bath, both signals are required to be synchronized in time. Both will need to have the same waveform envelope (although amplitude may vary) and have similar polarity as a function of time.

Assumptions

Plating system is optimized for DC plating including; cell geometry, agitation, anode spacing and other critical factors that affect mass transport.

Wave Sequence

Results – Sequential waveforms has been demonstrated to properly plate multiple feature sizes in a common bath without the need for masking³. Further E.J Taylor and team have demonstrated successful implementation without the need for chemical additives such as levelers or brighteners (Figure 16).

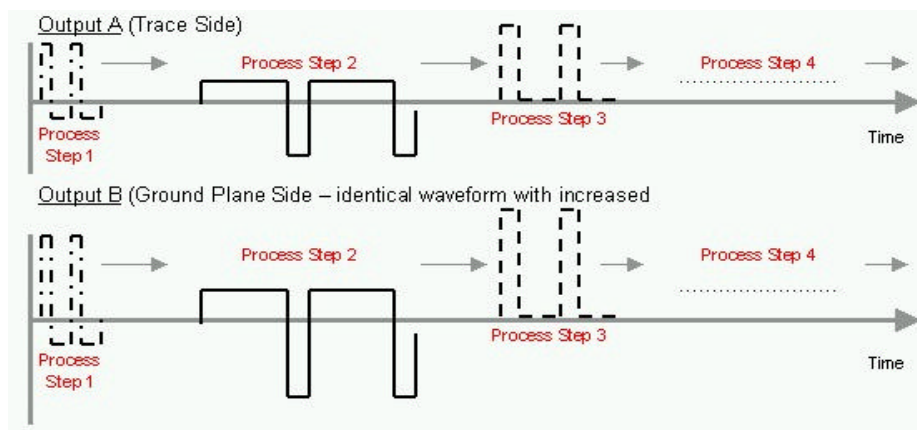


Figure 16 – Duo Synchronized WS Output for a Two Sided PCB with PTH's and Blind Vias

Process Step 1 – PR Waveform Levels Blind Vias
Process Step 2 – PR Waveform Deposits into PTH
Process Step 3 – PP Waveform Deposits over Surface
Process Step 4 – DC helps Achieve Bright Finish

Wafer Case Study Example

Cathodic Surface

Semiconductor wafer with 100-micron trenches as seen in Figure 17.



Figure 17 – 100mM Feature

PCB Feature Details

100- μ M feature

Requirement

Leveling of surface with minimal over-plate

Brief Feature Analysis

Trench - Smallest feature and therefore requires the least amount of material. This feature is well below the diffusion layer thickness and is inaccessible using traditional DC at production current densities.

Surface - Considerable process savings can be realized if the final surface requires minimal machining.

Waveforms Analysis

Seed Layer - First waveform should produce a thin conformal coat to help with heat dissipation enabling faster plating.

Trench - Second waveform in sequence to access the smallest features before they are rendered inaccessible by the other waveforms.

Will require a short I_{FWD} pulse of high amplitude to reduce the diffusion layer thickness for accessibility and to increase nucleation sites in this low current density region.

Will require a long low amplitude anodic pulse to remove material in a “DC like” fashion.

Overplate - PR waveform, which simultaneously deposits over the surface and levels the high current density regions.

Assumption

Plating system is optimized for DC plating including; cell geometry, agitation, anode spacing and other critical factors. Including mass transport.

Wave Sequence (Figure 18)

Process Step 1 PP waveform to cover seed layer
Process Step 2 PR waveform deposits into trench
Process Step 3 PP waveform to level the surface with minimal over-plate

Results – Sequential waveforms has been demonstrated to properly level or conformably coat small features with minimal over-plate. Further E.J Taylor and team have demonstrated successful implementation with out the need for chemical additives such as levelers or brighteners (Figures 19, 20 and 21).

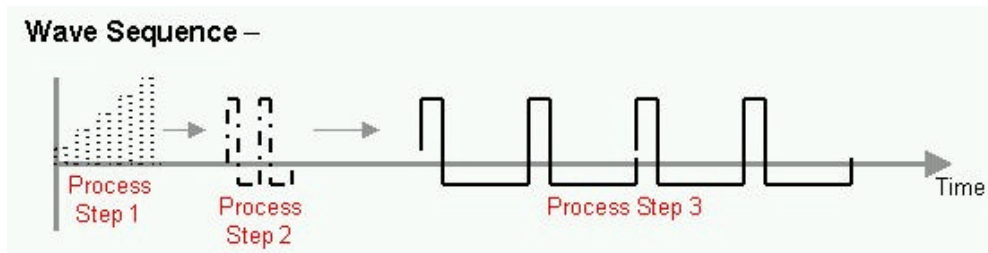


Figure 18 – WS Waveform

Process Step 1 – PP Waveform to Cover Seed Layer

Process Step 2 – PR Waveform Deposits into Trench

Process Step 3 – PP Waveform to Level the Surface with Minimal Over-plate



Figure 19 – 100 Micron Conformal

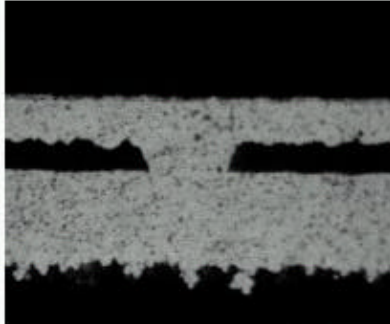


Figure 20 – 30 Micron Filled

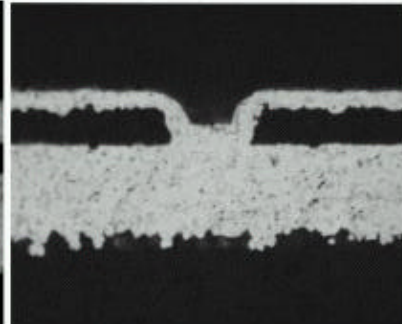


Figure 21 – 30 Micron Conformal

Additional Critical non-DC Power Supply Requirements

As mentioned previously the ability to properly level micron size features is not enough for today's fast paced ISO 9000 highly automated, cost and quality conscious manufacturing facilities. The following section will touch on a few other important WS Equipment characteristics and specifications.

Section 9 also provides limited details regarding non-DC power supply characteristics. Detailed technical explanations available from the authors past papers.^{9,10}

Variable Forward to Reverse Amplitude Ratio

Certain PCB plating equipment which utilize multiple waveforms limit the forward and reverse amplitude to a common value, see Figure 22.

A unit which forces a output current for forward and reverse seriously limits the pulse waveforms which can be generated. This creates various undesirable results. Chemical solutions react differently during forward and reverse currents requiring different forward and reverse amplitudes, common examples include the commonly used 1:3 (fwd:rev) amplitude waveform. Secondly, a fixed output amplitude slows the plating process by reducing the plating rate for low duty cycle waveforms.

Long Cathodic / Short Anodic Pulse Reverse Capability

It is very important that advanced PCB plating equipment be able to generate not only pulse trains as demonstrated in Figure 22 but also pulse reverse waveforms as shown in Figure 23.

Pulse reverse waveforms can more effectively redistribute material over the cathodic surface and therefore improve throwing power. Most PCB power supplies are able to generate pulse reverse waveforms with long cathodic and short anodic times, as shown in Process Step 2 of Figure 23. These are commonly used with low aspect ratio plated through holes.

Long Anodic / Short Cathodic Pulse Reverse Capability

Additionally your PCB power supplies should be capable of generating pulse reverse waveforms with long anodic and short cathodic times, as shown in Process Step 1 of Figure 23. These waveforms have been demonstrated more effective with smaller features and higher aspect ratio plated through holes.^{3,4,11}

Fast Transition Times

Significant improvements have been made to improve waveforms transition times. Slow rise or fall times can significantly distort the wave shape. Numerous detrimental effects result from this distortion, including slower plating. Typical rise times for pulse power supplies range from 10 - 50 microsecond, enabling .1 millisecond pulses width.

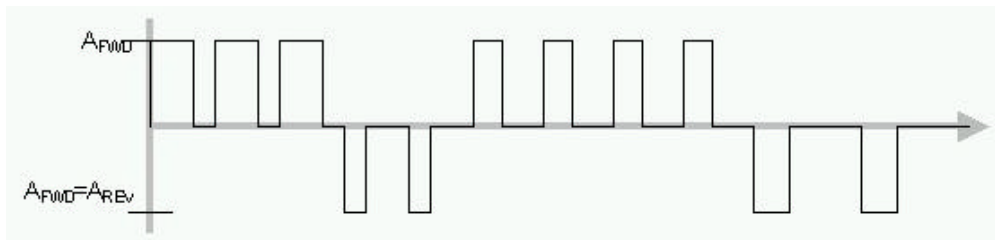


Figure 22 – WS Waveform Limited to a 1:1 Forward to Reverse Ratio

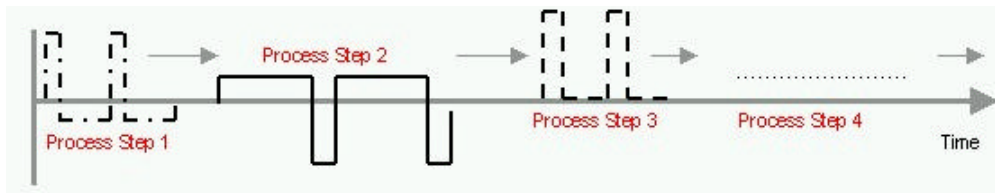


Figure 23 – Pulse Reverse WS Output

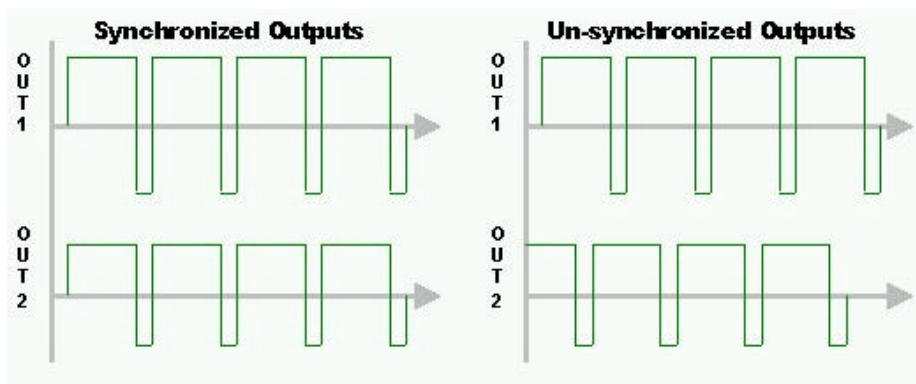


Figure 24 – The Drawing on the Left Demonstrates Synchronized and the Right Un-synchronized Waveforms

Multi-output Pulse Synchronization

For two sided PCB's or multiple wafers in a common bath, a power supply with multiple outputs or multiple power supplies may be required. Unlike DC power supplies, reversing polarity power supplies must be synchronized in time to minimize detrimental interaction between them.

Figure 22 helps visualize synchronized and un-synchronized outputs. Synchronized outputs means a common frequency, duty cycle and the pulse transitions occur simultaneously. Un-synchronized means that pulse transitions do not occur simultaneously. Note that the amplitudes of the various synchronized waveforms need not be the same. The problem with un-synchronized pulse outputs is that one power supply may have a positive polarity while the other has a negative causing the current to flow out of one power supply and into the other, adversely affecting the plating bath. This is analogous to having a second cathode and sharing the current between both. Negative interaction is minimized for synchronized power supplies.

Reduced Cable Inductance

Inductance can be thought of as the magnetic resistance to the change in current in a conductor. Pulse waveforms by definition continually change current level with each

pulse transition. Inductance therefore degrades pulse performance and is a critical factor in non-DC plating. Inductance degrades pulse performance by decreasing rise and fall times.

Plating power supply rise and fall times are typically rated at the output of the power supply and can be substantially different in the plating bath if no care is taken to reduce inductance.

In general the following guidelines should be followed to reduce inductance.

- Place the power supply as close to the tank as possible to reduce the cable or bus bar length.
- Use large diameter cables or large flat bus bars to increase surface area.
- Keep the distance between the conductors as short as possible. This is more feasible by using cables with thin insulation and twisting them together over the length of the run from the power supply to the tank (twisted pair). For bus bars run them in parallel with minimal separation, as required for safe operation.
- Additional gains can be achieved by running multiple twisted pair cables dividing the current between them.

Small Size and Weight

Newer technology plating power supplies offer significant reduction in both the size and weight as compared to SCR or linear units. Higher frequency electronics result in a reduction in the size and weight of the power stage and related circuitry. As a result several advantages are realized:

- Smaller units are able to be placed near the plating tank, reducing inductance. If the unit cannot be placed near the tank, low inductance cabling cost can exceed the cost of the power supply.
- Smaller units require less floor space
- Lower weight units enable cost savings related to shipping freight.
- Lower weight units enable flexibility to move them from one location to another without the requirement of a forklift for the purpose of routine maintenance, calibration, line changes and process modifications.

Reliability and Proper Environmental Construction

Power supply construction is critical to new technology power supplies. The primary reason is that industry standard components, printed circuit boards and assemblies are very susceptible to the corrosive environments found in most plating shops. This is especially true when companies take power supplies developed for the communications or medical industries and attempt to operate them in a plating environment. Unreliable power supplies mean production down time and loss of revenue.

The initial effort to compensate for the susceptibility to the corrosive environment, was to place the power supplies susceptible to the environment in sealed air-conditioned environmental rack enclosures. This has several serious limitations;

- Racks force power supplies to be distanced from the tanks increasing cable inductance.
- Racks are very expensive.
- Racks are large and requiring additional floor space
- The rack seal is broken each time the enclosure door is opened to make adjustments or during routine maintenance.

WS power supplies should be housed in self contained, environmentally sealed enclosures. This enables the standard lower cost circuitry to function reliably in the plating environment. Additionally the units are able to be placed near the tank to reduce inductance and the operator access to the unit while standing next to plating tank.

Programmability and User Ergonomics

The proper integration of microprocessor circuitry into a pulse plating power supply can simplify user operation, increase functionality, reduce errors and improve process efficiency and system integration.

An analogy would be the use of microprocessor circuitry in hand-held video camera operation. The complex and numerous controls have been replaced by soft key, menu driven controls and new features, such as titles, have been added without overwhelming the user. Similarly WS power supplies with multiple adjustments can significantly benefit from the improved user ergonomics, microprocessor circuitry enables.

Along with the integration of microprocessor circuitry, new technology power supplies incorporate non-volatile memory in order to store vital information associated with power supply operation, communication, job recipes, waveform libraries and / or a number of other process and performance related benefits. Memory and programmability benefit plating shops to reduce errors, improve quality and increase efficiency, as well as reduced set-up time between jobs.

Advanced Instrumentation and Measurement

Internal microprocessors enable the software flexibility to create custom internal instrumentation. An example is an internal amp-hour meter for a WS power supply such that:

$Total\ A \cdot H = \{[Positive\ A \cdot H] - K * [Negative\ A \cdot H]\}$ where K is a multiplier.

This enables the power supply to recognize that deposition and removal of metal from the cathodic surface does not necessarily occur at the same rate. In the case where the rate of deposition and removal are equal K may be set to 1. Considerable other instrumentation benefits are present in today's advanced WS power supplies

Digital Control

Production facilities, driven by rising labor rates, a decreased labor pool, increasing competition and increased quality requirements by customers, are continually forced to find process and cost improvements.

The proper implementation of digital remote operation enables decreased process cost and increased process efficiency. Process parameters or "recipes" can be stored in a central controller and downloaded to each production location, critical factors such as chemistry, temperature, amp-hours, power supply status and system alarms can be monitored for quality control and to avoid time and material loss due to manufacturing or process error. Quality logs can also be made available for customers tracking each production lot.

Concluding Remarks

Electroplating techniques and capability for PWBs and wafers remains at an early stage of development. Today's periodic pulse reverse equipment and

techniques represent at best, a limited initial approach. It is a good first step.

Sequential waveforms go well beyond periodic pulse reverse, by sequentially combining appropriate waveforms to level real world electronic component surfaces. WS equipment also incorporates advanced microprocessor hardware and software to create advanced internal instrumentation and process integration capability.

Currently WS Equipment is the most viable and flexible means of properly leveling difficult to plate surfaces. WS is compatible with existing pulse plating recipes and can also generate low ripple DC for example. This makes WS a safe investment and not a technology fad.

Caution is recommended to insure any new equipment purchase, at a minimum, allows for:

- Variable forward to reverse amplitude ratio, not limited to 1:1
- Variable pulse width such that $T_{FWD} > T_{REV}$, $T_{FWD} < T_{REV}$ or $T_{FWD} = T_{REV}$
- Dual synchronization outputs for two sided PCB's
- Sealed & self contained unit enclosure to reduce inductance & floor space
- Simple user-friendly operation to reduce error and scrap

This author considers, WS equipment a bridge between the "waveform technology islands" of today, and tomorrow's advanced electrochemical solutions leveraging both chemical and electrical signal mediation.

The future, independent of additive content will bring additional intelligent electrical signal control and increased computational capability to continue to improve metallization in the electronics industry.

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