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Pulsed Power Technology: Wave Sequencing

"The mere formulation of a problem is far more essential than its solution, which may be merely a matter of mathematical or experimental skills. To raise new questions, new possibilities, to regard old problems from a new angle requires creative imagination and marks real advances in science."

Albert Einstein

Einstein's words here, as with his theory of relativity, are timeless. It is our understanding of the "true problem" that allows us to change our thinking and arrive at a solution. Wave sequencing technology is the solution to the rephrasing of a series of problems common to electroplating. In short, wave sequencing improves capability and profitability.

The goal in any manufacturing facility is to quickly, controllably, and reliably produce a quality part or consistent result. Chemical manufacturing processes realize increased complexity, resulting from chemical requirements, such as; pH, temperature, additive levels, etc.

Wave sequencing, in a simplified explanation, replaces some of the chemical dependency with electrical signal control. Electrical signals are extremely precise, controllable and responsive. They are used extensively in a variety of products from power supplies to PCs to toys.

This column will define the basic concept and benefits of patented[8] wave sequencing technology.

What Non-DC Does

The proper use of non-DC technology (including periodic pulse, periodic pulse reverse and wave sequencing) in electrochemical deposition yields numerous capability, process control and cost benefits over DC systems.

A basic mechanism enables the non-DC waveform to assert control over the pulsating diffusion layer, primarily by the pulse width and peak amplitude parameters.

Common benefits in mature applications of non-DC technology are:

- Deposit capability that cannot be achieved with DC
- Flatter deposits (reduced dog-boning)
- Improved leveling
- Improved throwing power
- Selective deposits
- Improved plating over cathodic surfaces with difficult-to-plate geometries
- Improved process control and data monitoring
- Reduced consumption of additives
- Increased throughput
- Increased repeatability
- Increased process automation
- Decreased production cost
- Improved alloy plating
- Reduced chemical dependency during electrochemical machining
- Improved electroforming

Non-DC Limitations

Although few disadvantages apply to non-DC signals, beyond a higher initial investment in time and capital, one important limitation merits mentioning. This limitation can be best visualized with the use of an example.

Let's assume we want to plate acid copper on a printed circuit board (PCB). Most real-world surfaces consist of more than one type of geometry. Figure 1 demonstrates two difficult-to-plate geometric feature on a single PCB surface. The larger features is a plated through-hole (PTH) and the smaller are blind-vias.

Although these features can be plated with DC, the required low current density reduces throughput, making it expensive and impractical. Chemical-only processes have great difficulty properly leveling the larger PTH features, and fail to throw into the smaller blind-vias.

Successful approaches have been demonstrated at reasonable current densities, using a combination of chemical and electrical signal methods.[1] The problem arises in that the optimal waveform for the PTH features performs poorly on the blind via features. The limitation we mentioned previously is that a single waveform may not be able to properly level multiple feature types.

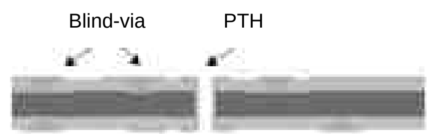

Fig. 1—Schematic example of a prined circuit board.

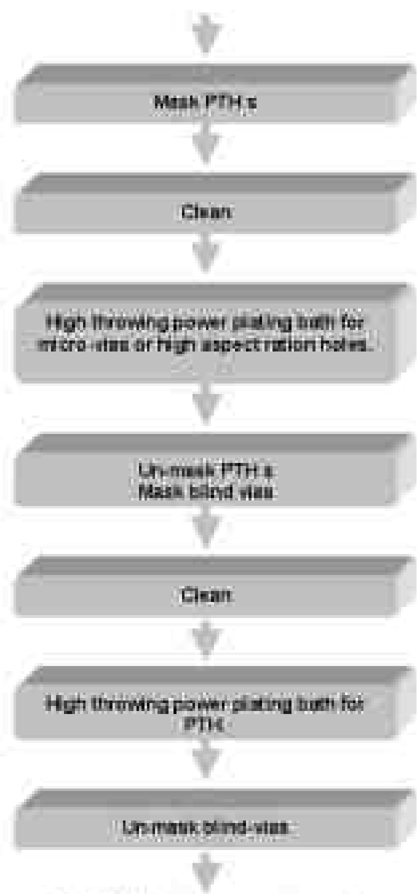

Fig. 2—Multi-step process to level two feature sizes.

Non-DC waveforms are necessarily "tuned" for specific deposition ranges, much as chemical additives are controlled for desired deposition characteristics. The larger the feature size, the more range the waveform may have. As mentioned in previous parts of this article and other reference manuals,[5] specific waveform parameters produce specific results.

A common solution to this dilemma is multiple baths, exposing only those features to be processed during each plating step. This is especially true when dealing with features both larger and smaller than the diffusion layer thickness, on a single surface. Figure 2 details an example of such a process. Clearly, this process increases cost, reduced throughput, and adds opportunity for error through its redundancy.

Wave Sequencing Solutions

Several papers have been published concerning successfully plating multiple features on a common PCB without the need for masking, multiple tanks or highly complex chemical mediation. One recent paper,[2] demonstrates this capability while increasing the plating rate to levels well above DC, utilizing a patented[8] multiple sequential waveform approach.

Wave sequencing enables proper deposition over difficult-to-plate surfaces (including those with multiple geometries) by sequentially combining a number of waveforms, such that each contributes to a specific geometry and the combined sequence of waveforms results in the proper leveling of the entire surface. In effect, we are forming a controlled plating process by applying a series of electrical signals.

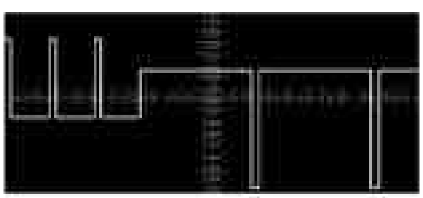

Fig. 3—Two-step wave sequence process.

The first waveform, as demonstrated in Fig. 3, deposits into the smaller 75-100 µm blind-vias. Once the blind-vias are properly leveled, the wave sequencing power supply automatically switches to a second waveform, also shown in Fig. 3, to properly level the larger 350 µm PTHs. It is important to note that the waveforms designed for smaller feature sizes should precede those designed for larger features, in order to minimize detrimental interaction. Both the waveform parameters and the order

Fig. 4—Properly leveled PTH and blind-vias in a single bath without masking. (Electrodeposition results courtesy of Faraday Technology.)

in which they are applied, are important. Results from such a process are shown in Fig. 4.

Wave sequencing provides the operator the ability to combine appropriate waveforms to complete a process. Each individual process step consists of a unique electrical waveform designed to incrementally advance the deposition process. Limiting a plating process to a single waveform is analogous to trying to drill different-sized holes with a single-sized drill bit. This simple approach, executed by a simple-to-use, self-contained power supply, yields results that cannot be achieved by DC, periodic waveforms or chemical-only means.

Wave Sequencing Equipment

The wave sequencing approach is practical only if the equipment is user-friendly in stressful production environments and affordable. Numerous design iterations have taken place, making this new technology power delivery device extremely user friendly, reliable and affordable. In many cases, it is priced at, or below, less capable periodic pulse reverse units.

A modern proprietary power supply* combines state-of-the-art power conversion technology and advanced microprocessor capability, allowing the user a single device capable of accepting a complex wave sequence and automatically executing it by time or amp-time. An example of a four-step wave sequence is shown in Fig. 5, and a power supply control panel is shown in Fig. 6. Note that that the average voltage

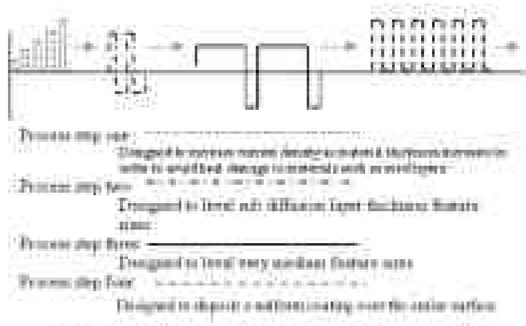

Fig. 5—Case study example of a four-step wave sequencing process.

Fig. 6—WS series power supply control panel. Unit satus 250 ADC at 4.1 VDC executing job numbers 16 process step #3. 123.64 A/hr until process step 4 begins.

and current are displayed on the top row, and the job status on the bottom row.

A powerful and practical benefit of the equipment is its ability to accept complex programming and execute a process independent of an operator being present. No PC or other expensive equipment is required. Fig. 7 details real-world benefits of the "job library" function. The 16-user-programmable "JOB Library" will accept the following parameters in each of the four process steps; Time-Forward, Time-Off-Fwd, Time-Reverse, Time-Off-Rev, Amps-Forward, Amps-Reverse, Process Step Duration, High Limit Alarm, Low Limit Alarm, and Global Counter.

Because the power supplies incorporate phase mode technology and internal microprocessor operation, they provide the advanced instrumentation discussed in the December 2001 issue of *P&SF*. By utilizing multiple controlled electrical signals, monitoring and verifying proper operation become a matter of reading meters internal to the unit. This is a significant advantage over monitoring chemical parameters. Process automation and quality metrics, including the ability to generate DPU and CPK data, are simplified in electrically based system.

Other Promising Wave Sequencing Applications

The ability to sequence waveforms in order to derive a benefit from the completed process opens many applications for consideration and potential benefit. A few examples of practical applications proven to benefit from wave sequencing are:

- True leveling of a cathodic surface using multiple waveforms. Each waveform preferentially deposits or removes material, allowing the combined sequence to achieve the desired leveling effect over the entire surface.
- Multiple DC, pulse or pulse reverse waveforms can be alternated, at varying current densities during alloy plating. This has the

*WS Series power supplies, TecNu, Inc., Highlands Ranch, CO

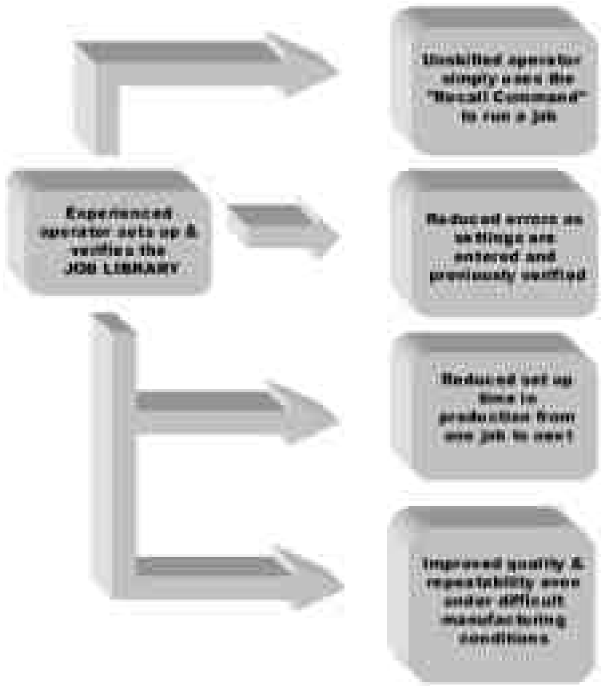

Fig. 7—Benefits of automated wave sequencing job library.

benefit of not only depositing the desired alloy, but reducing grain size and yielding a more conformal deposit, as is associated with pulse waveforms.

- Electroforming of large parts commonly involves increasing current density as a function of time or amp-time, and as the deposit builds. Wave sequencing can automate this process and improve quality, especially when a part may run for days at a time, and the next adjustment may be required at 2:00 a.m.
- Wave sequencing has been successfully applied to Electro-machining, eliminating the need for highly corrosive chemicals. Utilizing the electrical signal control element enables polishing and deburring in a simple saltwater solution[9].
- Wave sequencing is now opening many new doors and investigations into such applications as trivalent chromium, copper, silver, gold, nickel and numerous other metals. In each of these applications, improved capability, cost savings, and reduced chemical pollutants are targeted.

Affordable Technology

The metal finishing industry now has, for perhaps the first time, advanced technology products and new features at reasonable costs. Purchasing older technology to meet the needs of today's demanding customer, or to compete with a modern facility down the street, is a very risky strategy. *P&SF*

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