Advanced Arc Control for HiPIMS Power Supplies

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ABSTRACT

Excellent research has been performed in recent years to advance the field of high-power impulse magnetron sputtering (HiPIMS), and the process is being adopted into more and more industrial applications for hard and decorative coatings, optical and industrial glass, data storage, flat panel, tribological, and other applications. The possibility of arcing, however, remains a potential consequence in industrial HiPIMS processing. If uncontrolled arcs occur on HiPIMS pulses with high current, damage to the substrate is inevitable. A new energy control technology with anticipative arc management, originally developed for transparent conductive oxide (TCO) processes, has been modified and integrated into a new generation of power supplies for HiPIMS. The results are that no defects caused by arcing will appear on the substrate nor on the target. Furthermore, an energy recovery solution eliminates deposition rate losses due to arcing.

HIPIMS ADVANTAGES AND DISADVANTAGES

Compared to standard DC magnetron sputtering, HiPIMS creates a high ionization rate, which produces better film properties, including higher film density. HiPIMS power supplies also, generally, can be integrated into existing DC-MS systems, and have no (or very low) hysteresis. However, deposition rates may be lower and costs may be higher. Due to the high current/power densities in this technique, a sophisticated arc handling technology is necessary to eliminate devastating damage to the work piece.

To mitigate these drawbacks and fully realize the benefits of HiPIMS, the next-generation power supplies described in this paper possess the following capabilities:

- Advanced arc management
- All-in-one, single-box functionality
- Stable power delivery at high densities
- Easy operation
- Easy integration into existing coating systems
- Precise pulsing
- Easy synchronization and highly flexible application of bias voltage

ARC FORMATION AND ENERGY

Arc energy is the result of energy buildup on insulative regions on the target, in the plasma, on the magnetron, and in the power supply's output stage and cabling. The equation $W = ½ LI^2$ determines the amount of energy in a given arc. Energy stored in output cabling is a function of cable length and the cable's inherent inductive properties. For example, at a current of 3500A, with cable length of 10m (1uH/m), the energy stored in that cable is determined as follows:
$W = ½ 10\ \mu H \times 3500\ A^2 = 61.3\ J.$

HiPIMS applications involve highly energetic pulses. With arc current in the range of thousands of amps, the energy driving arcs is huge and can actually destroy the substrate and target. During an uncontrolled arc event, current rapidly spikes as voltage plummets. In HiPIMS processes, the resulting arc energy may be powerful enough to blast material off of the target, which causes droplets on the substrate, creating craters in the deposited film. Further, the impact of the arc can create hot spots on the cathode that result in thermionic discharge. This discharge, in turn, may form a new arc when a new pulse cycle begins. However, droplet formation and thermionic discharge can be prevented by eliminating arc energy, which reduces arc-caused target or substrate damage.

Figure 1 shows an uncontrolled, high-current arc event during HiPIMS processing that may lead to droplet formation and thermionic discharge.

ADVANCED ARC HANDLING

For truly defect-free, advanced arc management, the synergy of arc detection and arc handling, plus energy recovery play a crucial role. Power supplies must detect and handle arcs very rapidly and eliminate the stored energy in the power-delivery system that feeds the arcs.

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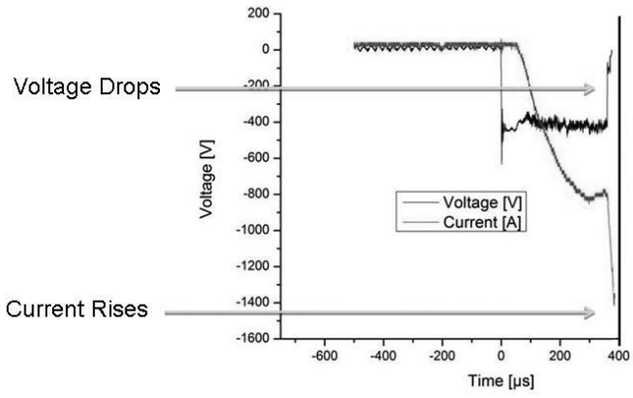

Figure 1: Uncontrolled Arc.

The ultra-fast detection and response capabilities of power supplies featuring intelligent controlled energy, ICE technology, reduce arc energy and minimize droplet formation and thermionic discharge. Competing technologies may require as long as 300 µs for arc detection and handling. However, ICE technology handles arcs in less than 4 µs at max currents. Rapid power shut down and voltage reversal remove energy from an arc once it is detected. This reversal is a powerful technique that actually removes the energy of the output cables and the cathode system, preventing that energy from contributing to cause arc damage.

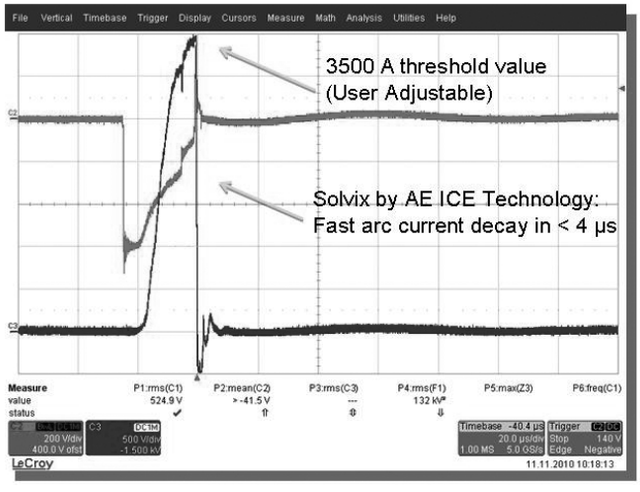

Figure 2: Fast Arc Current Decay with ICE Technology.

Advanced power supplies not only prevent stored energy from feeding arcs, but also "recover" this energy, diverting it back into the process for deposition, thus maintaining power-delivery stability, despite arc events. An energy recovery solution featured in Solvix by AE HIP[3] units maintains deposition rate by diverting the energy stored in output cables back into the process.

In Figure 3 the power supply detects an arc, and T1 is switched off. The current in the plasma and cable follow the path through the arc energy recovery system. With a voltage reversal, the energy stored in the cable (½ LI^2), is recovered into the power supply and used for deposition.

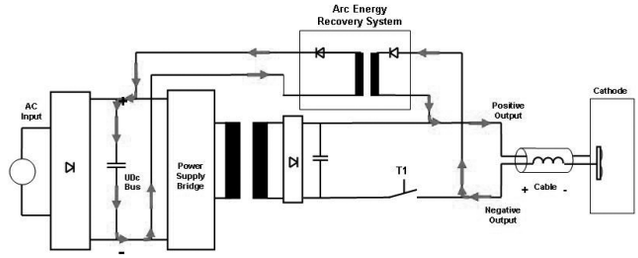

Figure 3: Simplified Diagram of ICE Technology: Arc Detection, Arc Handling, Energy Recovery, Voltage Reversal.

OTHER KEY CAPABILITIES OF NEXT-GENERATION HIPIMS POWER SUPPLIES

Sophisticated arc management is a critical feature of next-generation power supplies for HiPIMS manufacturing. However, other key capabilities enable full realization of this powerful deposition technique. This includes precise pulsing and stable power delivery, easy installation and integration into existing coating systems, easy operation, master/slave capability, and single-box functionality.

The Solvix by AE series for HiPIMS applications provides pulses that achieve peak power and maintain it throughout the discharge with no unwanted oscillations, for excellent process stability. Highly controlled pulsing, with adjustable duration and frequency, also enables unique control of layer properties.

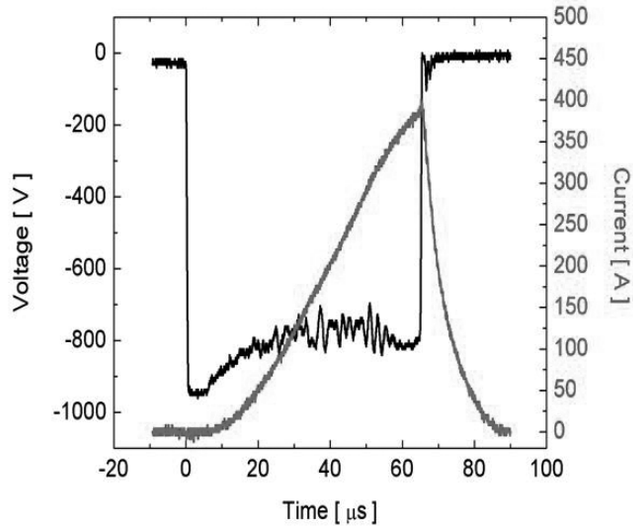

Figure 4: Precise Pulsing of a Solvix by AE HIP³ Power Supply.

The highly flexible HIP³ unit from Solvix by AE, a special design for R&D, can provide three types of functions in a single, compact package: HiPIMS mode (high-power pulsing), bias mode, and DC mode. These output options enable easy setup of custom power configurations, with fewer part numbers required.

HIPIMS-PS AND BIAS SYSTEM

Due to high power peaks, a sophisticated applied bias voltage plays a crucial role in HiPIMS technology. Dedicated bias supplies are required to handle this high peak power. Combined with the power and process control of Solvix by AE units, bias supplies enable optimization of film density and adhesion by controlling ion energy as it impacts the substrate.

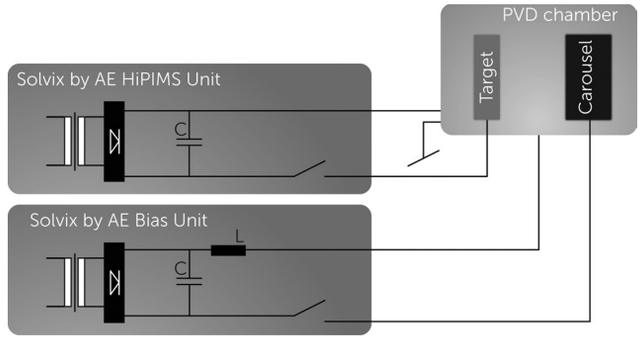

Figure 5: Solvix by AE HiPIMS-Bias System.

Process power and bias units are easily connected without additional equipment. This enables sophisticated coordination of process and bias power. A variable synchronization of the applied bias voltage may deliver power in any on/off pattern while the process power unit pulses, with multiple triggering options. For example, the bias unit may deliver constant voltage while the process power unit pulses. It may turn on and off simultaneously with process power pulsing, or, as shown in Figure 6, bias on- and off-times may be programmed at an offset from process power pulse on- and off-times.

CONCLUSION

The high currents that occur in HiPIMS manufacturing can create arcs powerful enough to destroy the substrate and target. Therefore, an arc management system that rapidly detects and distinguishes arcs and minimizes arc energy is a necessity. With the ability to detect and extinguish an arc in less than 4 µs at max current, Solvix by AE arc management is an enabling technology for advanced HiPIMS processes.

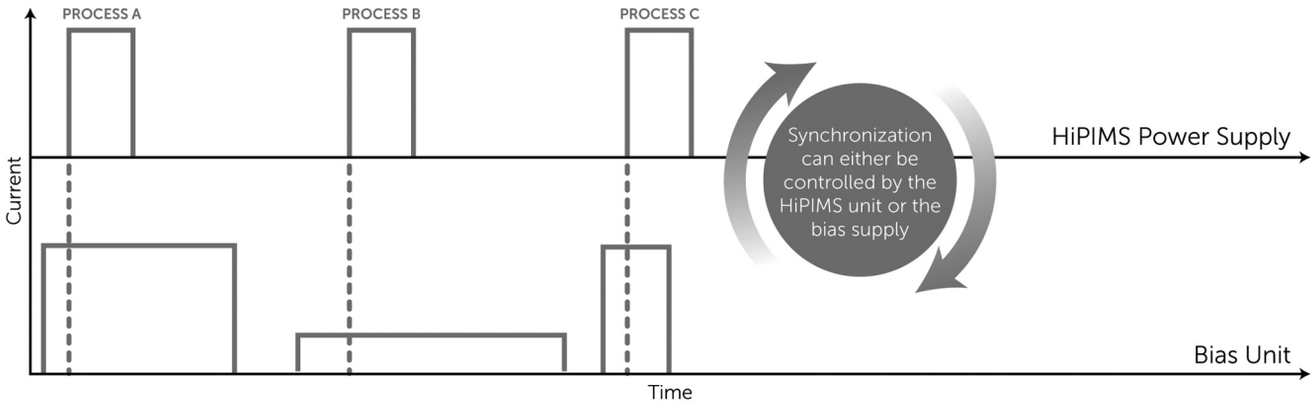

Figure 6: Sophisticated Pulse Coordination.

Solvix by AE power supplies with intelligent controlled energy, ICE technology, provide a comprehensive arc management strategy for a HiPIMS, including:

- Ultra-fast arc detection
- Ultra-fast arc handling
- Arc-energy reduction
- Arc-energy recovery

Stable power delivery at high densities, precise pulsing, easy installation and operation, single-box functionality, easy integration of bias, and coordination of bias with process-power pulsing are also key features of a successful HiPIMS power-delivery strategy. Such advanced power supplies create dense, stable plasmas for remarkably hard, dense, homogenous coatings with excellent adhesion.