# THE EVOLUTION OF POWER DELIVERY IN REACTIVE SILICON SPUTTERING

*By Marty Leeke, Advanced Energy Industries, Inc.*

***Architectural glass, CRTs, mirrors, eye glasses, precision optics, and food packaging barrier layers. What they have in common may be more than you think. All are products characterized by their coatings, and all are products for which consumers are demanding higher quality, more rapid production, and increased market availability–at lower and lower cost. Coaters who succeed at implementing more efficient, cost- and time-effective systems will not only help meet the demand, but help drive more industries to adapt those processes and begin to compete with–and replace–existing technologies. When the consumer can buy a better product at a lower cost, the entire design and manufacturing channel wins.***

Enter power supplies. Comprising 15-20 percent of the total cost of a vacuum coating system, the power supply is one of the highest-ticket items in the system. The power supply also is the system component directly responsible for sputtering the all-important coatings in a wide variety of industrial applications. Whether producing durable, scratch-resistant eyeglass lenses or architectural glass for a new office building, stable power is key to effective and efficient system performance and production.

**Figure 1: Until recently, glass was considered an "evil necessity" in architecture–necessary to let light in, but almost completely energy inefficient. Today, architectural glass can be a material of choice, both aesthetically pleasing and functional, with new types of coatings available.**

## SILICON SPUTTERING

Critical thin-film processes such as etching and deposition (including sputtering) take place in a vacuum chamber in the presence of a plasma. As a plasma is an electrically neutral, highly ionized gas, it is by definition an unstable load and exhibits the characteristics of many common electrical devices.

Power supplies are used to "ignite" and maintain plasmas that vary continuously. These power supplies must be capable of reacting appropriately to the plasma's changing characteristics so that power remains stable during system operation. Depending on the thin-film application, either direct current (dc) or alternating current (ac) power supplies may be used.

The economic application of high-quality dielectric layers in the fields of electronics and display technique requires progressive and powerful vacuum deposition techniques. In applications ranging from magnetic read-write thin-film heads to architectural glass and CRTs, high-rate sputtering has become the preferred method of coating due to the relatively easy scale-up for large areas and the low particle generation.

Specifically, silicon sputtering is the material of choice in more and more industrial applications because silicon-sputtered coatings are generally harder and more durable. Silicon-sputtered coatings also can be relatively cost-effective, resulting in the ability to replace more traditional (e.g., chemical spray or liquid) coatings and technologies. At the same time, silicon is an insulator with dielectic properties, which presents special challenges.

Over the past three to five years, technology has experienced an evolution in supplying power for sputtering from dc to ac to bi-polar pulsing dc. Different power sources can be more efficient and effective, and can solve many of the typical problems encountered in sputtering materials such as silicon.

## THE PROBLEM WITH ARCING

One of the primary challenges of the sputtering process is arcing. Arcing is the rapid transfer of current that occurs in low-impedance conditions, created when power is focused on a stream of ions. Arcing presents a major problem because it can actually burn a defect into the item (substrate) that is being coated. Analogous on a larger scale to a lightning strike, the current traveling rapidly from one point to another in the chamber can cause major damage.

Arcing also can cause inclusion in the substrate, another problem for coaters. When coating builds up in a non-uniform manner on the chamber walls, an arc can, in effect, serve as an antenna of sorts to protruding pieces of material. The result is that a piece of the "foreign" substance can break loose and lodge onto the substrate.

Arcing can be present as a "micro" arc or "hard" arc. Micro arcs, as their name implies, occur for only a few microseconds and warrant little concern in the sputtering process. Hard arcs, on the other hand, are more sustained, last for a half second or more, and cause substantial damage to the substrate. Since arcing is an inherent and expected condition in all plasma processing (ac-or dc-powered), the key is how to manage it most effectively. And as the demand for ultra-smooth, particulate-free films has increased, coaters have focused more attention on this source of particulates.

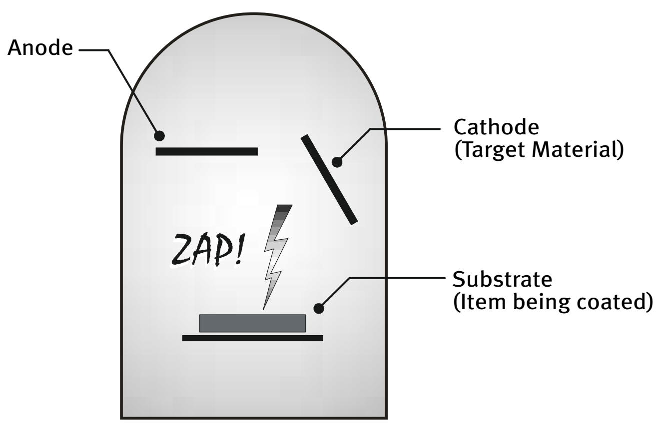


**Figure 2: Arcing in the plasma chamber**

The arc occurring between the cathode and substrate in the chamber can burn a defect into the substrate being coated, or cause inclusion in the substrate.

## CHALLENGES OF REACTIVE SPUTTERING

For today's high-end industrial coatings, reactive sputtering poses additional challenges. In reactive sputtering, a second element (often oxygen or nitrogen) is added to the sputtering mixture to obtain different coating properties (hardness, thickness). For example, sputtering a non-glare coating, such as on a CRT screen, will utilize several layers of coatings because each allows different wave lengths to pass through ($NbO_5$, niobium pentoxide, allows shorter wave lengths to pass through, while $SiO_2$ allows longer wave lengths to pass through).

In this process, the sputtering gas reacts with the target surface to form a compound, which is then sputtered. If the compound is an insulator, and the system uses dc power, careful reaction management is required. If the insulating compound is formed over the anode, it reduces the effectiveness of the sputtering process and can eventually lead to the inability of the system to sputter at all. Process engineers involved in coating are therefore looking for technologies that will allow them to sputter effectively in a reactive mode.

While silicon may be a material of choice for sputtering today's industrial coatings, it does not sputter as well as other materials. An insulator with dielectic properties, it is very temperamental, relatively unstable, and difficult to control and predict in the sputtering process. Arcing, a problem in any sputtering process, is even more of a problem in some reactive sputtering environments, such as with the silicon dioxides often used in architectural glass coatings and other coatings mentioned in this article. The need to eliminate and prevent arcing becomes greater.

## SPUTTERING WITH DC POWER

High-rate dc magnetron of sputtering silicon fails as the optimal power choice because of the high tendency of target arcing. High-frequency sputtering suffers from high power losses and high cost; however, a low-frequency application would ideally better meet the challenges presented in silicon sputtering.

With dc, the power source is constant and does not change with time. This forces the current to maintain the same value and direction at all times (batteries). With ac, the power source alternates polarity, actually causing a change in the direction of current flow. Ac produces a sinusoidal voltage waveform (sine wave) and is attached to two cathodes rather than one. By alternating polarity between the two cathodes, you prevent a polarized layer from forming. Eliminating this layer greatly reduces the potential for an arc to form.

Given the problems with arcing and dc power, users typically have used add-on arc management, or suppression, devices to manage the arcing problem. For low-power applications, these devices work well. But in high-power applications, such as reactive silicon sputtering for large-area coatings, they are indeed only "suppression" devices and therefore offer only part of the solution.

## SPUTTERING WITH AC POWER

With ac power, sputtering in a frequency range of 10 to 100 kHz produces minimal power losses. Also, advanced ac power supply designs may provide a better solution for the arcing issue, as some power supplies using ac power contain very low stored energy. But as users seek to increase throughput with the use of high-power devices, there still exists a gap in the ability to provide effective arc management. Newer technologies now are available that can help.

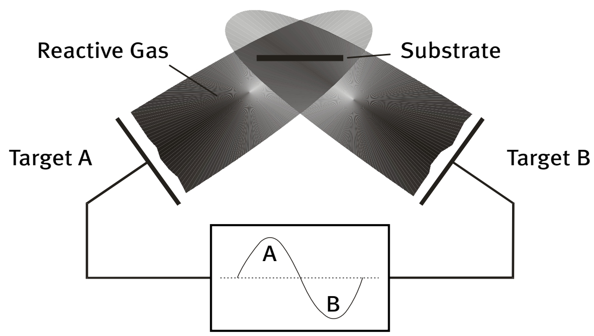


**Figure 3: Dual-magnetron, or dual-cathode, sputtering with sine wave**

In a dual-cathode process, both cathodes are connected to the power source. Polarity is reversed with each half cycle of the ac sine wave, so that cathodes alternatively serve as anode and cathode in each half of the cycle.

In a dual-cathode process (dual-magnetron sputtering), both cathodes are connected to the power source. Polarity is reversed with each half cycle of the ac sine wave, so in each half of the cycle, one cathode actually serves as the anode and the other as the cathode. In the first half of the cycle, in which the electrical field is attracting the negative ions, material is being sputtered on "Cathode A." In the second half of the sine wave, the cathode is attracting the negative ions, so material is being sputtered on "Cathode B." An easy scale-up to bigger cathodes is expected with the process, given the simple coupling of the ac power to the cathodes.

When sputtering an insulator, the anode is covered with the insulating material, creating the need to periodically remove the silicon from the anode. For dc processes and non-metallic materials, this "cleaning" process is usually achieved by shutting the entire sputtering system down to clean the chamber so it is able to conduct again. In an ac system, the polarity reverses every half cycle, effectively serving to clean itself continuously. Still, the ac-powered system does not provide the ultimate solution, because actual sputtering is occurring only during one-half of each cycle (cleaning for the other). While not a perfect solution, the ac system has proven more efficient than dc for reactive silicon sputtering.

## BI-POLAR PULSE DC TECHNOLOGY[1]: THE NEXT MILLENIUM

Solving many common problems experienced in reactive sputtering, the next generation of power supplies for reactive sputtering is being developed around adjustable asymmetrical bi-polar pulse dc technology.

Independent control of each cathode allows the user to balance the power between unlike cathodes, allowing for adjustment of both time duration and amplitude while continuing operation at the prescribed throughput. With this process, users can adjust the output power to each target to compensate for the differences in cathodes–especially critical for reactive sputtering applications using two cathodes of different sizes, or making alloys of two materials where the alloy proportion must be controlled. For shops that sputter a variety of products with various materials, the additional flexibility gained in the ability to use more cost and process-efficient compounds is a significant advantage.

Bi-polar pulse technology gives the user the ability to adjust the power delivery system. The asymmetry means that each half of the cycle can be adjusted to give more or less power to the chamber on demand. The ability to adjust each half cycle independently of the other allows the user to compensate for the variation and sputtering rates in the individual system–typical situations encountered in reactive silicon sputtering.

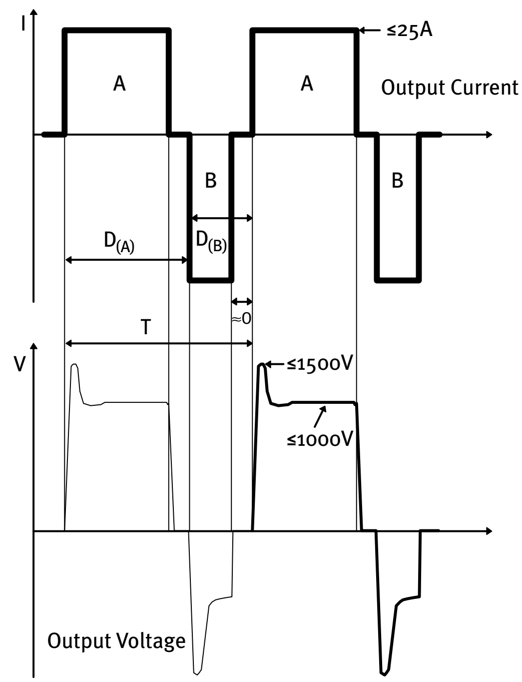


**Figure 4: The square wave associated with asymmetrical bi-polar pulse technology provides more area than the traditional sine wave, resulting in more power delivered over a longer period of time**

1 *Astral™ 120 Bi-Polar Pulsed DC power supply from Advanced Energy Industries, Inc.*

For example, in situations where one cathode sputters faster than the other, the ability to adjust each half cycle can result in longer life for the cathode. By adjusting the power downward, the user can provide a balance of the sputtering rates between the two cathodes, therefore maximizing cathode life and overall system uptime.

More space under the square wave, vs. the traditional sine wave, results in more power delivered into the chamber for a longer period of time. The number of joules each cycle delivers is more than the number of joules each sine wave can deliver. In other words, bi-polar pulse technology can deliver more power at the same power level. Studies have shown that asymmetrical bi-polar pulse products generate approximately 20 percent more deposition than ac products working at similar power levels. In addition, the technology enables coating for surfaces up to 14 feet in width, making it particularly useful for the architectural glass industry. Bi-polar pulse technology will be particularly valuable in reactive sputtering applications using $AI_2O_3$, $SiO_2$, $SnO_2$, $TiO_2$, TiN, and DLC (diamond-like carbon) to create energy-efficient optical and glass coatings.

Bi-polar pulse technology also takes the arcing problem inherent in reactive silicon sputtering to the next level, with some bi-polar pulse dc products carrying five to 25 times lower stored energy than comparable power-level ac products. Prior to the introduction of this technology, power supplies would turn themselves off when arcing conditions occurred. Asymmetrical bi-polar pulse dc power supplies provide steady power, shutting down only if a serious problem occurs.

## THE FUTURE IN DELIVERING POWER FOR REACTIVE SPUTTERING

Driven by ultimate consumer and industrial demand for higher-quality, more effective products at affordable prices, power supply developers will continue to produce products that improve efficiency and cost-effectiveness by helping to reduce arcing and to increase throughput and film quality, as well as to maximize target utilization. And when a power supply can contribute substantially to reductions of up to 70 percent in utility bills for office buildings sporting an abundance of architectural glass, the benefits are worth the research and development.

ADVANCED ENERGY®

**Advanced Energy Industries, Inc.**
**1625 Sharp Point Drive**
**Fort Collins, Colorado 80525**
**800.446.9167**
**970.221.4670**
**970.221.5583 (fax)**
**support@aei.com**
**www.advanced-energy.com**


SL-WHITE4-270-01 1M 08/00

| California | New Jersey | United Kingdom | Germany | Korea | Japan | Taiwan |
|---|---|---|---|---|---|---|
| T: 408.263.8784 | T: 856.627.6100 | T: 44.1869.320022 | T: 49.711.77927-0 | T: 82.31.705.2100 | T: 81.3.32351511 | T: 886.2.82215599 |
| F: 408.263.8992 | F: 856.627.6159 | F: 44.1869.325004 | F: 49.711.7778700 | F: 82.31.705.2766 | F: 81.3.32353580 | F: 886.2.82215050 |