ADVANCED ENERGY®

WHITEPAPER

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HOW ADVANCED ENERGY, MDX™ PRODUCTS MANAGE ARCS

All MDX products have been engineered not only to survive the severe environment of vacuum arcs, but also to provide a high level of arc control for the purpose of minimizing arc-related damage. Arc-related damage can be divided into three categories:

- *Damage to deposition targets, which is generally heat related*
- *Contamination of the film resulting from foreign particles or target material particulates contacting the film and being included in it*
- *Damage to growing films, caused by arcs striking or moving across the film surface*

Although the use of an MDX power supply can greatly reduce the possibility of vacuum chamber arcing, two specific electronic circuits in the MDX are designed to minimize the destructive effects of arcs that do occur. These trademarked circuits are ARC-OUT™ and ARC-CHECK™.

ARC-OUT™

ARC-OUT consists of a passive and an active circuit. The passive circuit is designed to control the energy level and the duration of small arcs. The active circuit comes into play when the arc is too large to extinguish with the passive circuit. This active part of ARC-OUT also protects the power supply from destructive high current levels resulting from short circuits.

The passive part of ARC-OUT that controls small arcs consists primarily of an inductor and capacitor that form a resonant circuit. When an arc occurs in the chamber, the resulting lowered impedance across the output of the power supply permits the energy in the capacitor to be transferred to the inductor and then back again to the capacitor. The resulting oscillatory (ringing) waveform of current can cause the plasma current to actually reverse in polarity momentarily. This means that instead of supplying current to the load (and the arc), the MDX will temporarily draw current (electrons) from the load (Figure 1). This reversal will occur if the process voltage is above a certain minimum, the process current does not exceed a certain maximum, and the impedance of the arc is low enough. For most processes and arcs these conditions are met and the current will reverse.

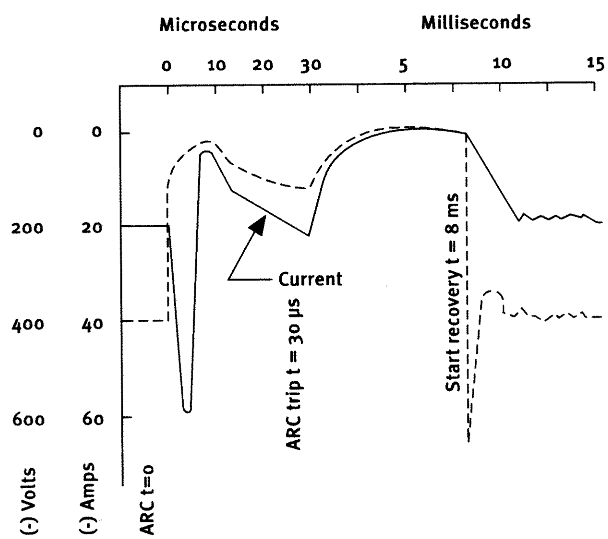

Figure 1. The passive circuit of ARC-OUT attempts unsuccessfully to quench a chamber arc. The active circuit of ARC-OUT intervenes to successfully quench the arc.

If the resonant circuit is able to reverse the current direction, the voltage of the load will go to zero (or even reverse slightly to positive) and the arc will be extinguished. This will happen in about 10 µs, and the process will continue without further interruption. It is important to note that the plasma in the chamber will not be extinguished, even though the voltage goes briefly to zero. Because the change happens so quickly, the ions do not have time to diffuse to the chamber walls, and the plasma does not need to be reignited. Because the arc is limited in both current and duration, any resultant damage is kept to a low level. Well over 95% of the arcs normally encountered in plasma processing are extinguished by this ringing circuit, and it is important to note that very little (well under 10%) of the energy stored in the power supply's output circuits is delivered to the arc in this case.

If the conditions for current reversal are not met, the load voltage will not reverse, and the arc will not be extinguished. In this case, the output circuits of the power supply will continue to drive current into the arc, and the second part of the ARC-OUT circuit must be activated.

The arc represents a low impedance across the power supply. If the ringing circuit described above is not successful, the arc will draw more and more current from the MDX. The active ARC-OUT circuit senses this rapid increase in current and turns off the switching transistors in the MDX. This happens in a few tens of microseconds. Once the MDX is shut off in this way, the output filter components can bleed off their stored energy, and the output voltage can go to zero. When this happens, both the arc and the plasma will be extinguished. This happens in about 5 ms. The logic in ARC-OUT will keep the output off for an additional 3–5 ms to allow for cooling of the arc site, reducing the chances of another arc at startup. In 8–10 ms after the shut down, the output will be enabled and the process will resume. This rapid shutdown, in addition to the use of small filter components in the output section (lowering stored energy), reduces the damaging effects of the arc.

An improved version of the ARC-OUT circuit is available on the MDX domestic and international voltage units as an option. This option is referred to as the enhanced version of ARC-OUT. In the enhanced version, the passive circuit has been changed so that the latitude for output current reversal is wider. This means that fewer arcs will result in a power supply turnoff.

ARC-CHECK™

ARC-CHECK is an active circuit in the MDX that is useful in establishing a bias voltage in cathodic arc processes and in burning away target flakes that create cathode-to-anode shorts in magnetrons. ARC-CHECK is available as an option on the MDX domestic voltage, international voltage, and MDXII products.

In cathodic arc deposition processes, current supplies drive an arc discharge on a metal cathode target to vaporize the target material. This vaporized target material is deposited on a substrate as a hard or decorative coating. Vaporized metal atoms are ionized (+) in the arc discharge upon leaving the cathode by removal of one or two electrons. An MDX supply can be used to create a negative voltage (bias) on the substrates to be coated. This bias voltage (-) will attract the metal ions (+) to speed up film growth and enable coatings in non-line-of-sight locations (Figure 2).

If arc supplies are permitted to run while the bias supply is off, such as when ARC-OUT has shut off the output of the MDX for 8–10 ms to extinguish a chamber arc, the chamber can become saturated with ions. This produces a very low impedance load for the MDX that, like an arc, causes high enough current levels to trip the active ARC-OUT circuit again. This cycle can continue, disabling the process (Figure 3).

ARC-CHECK will sense this cycle and intervene. The MDX will temporarily be changed from voltage regulation mode to

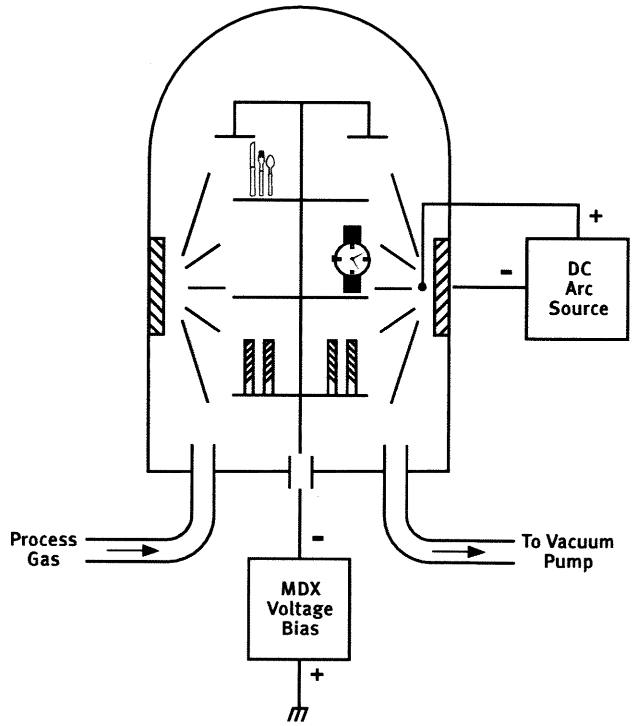

Figure 2. A vacuum system for executing cathodic arc depositions

current regulation mode, and the output will be ramped up to the programmed level, starting at 0 A. As the current is increased, ions are drawn to the substrate, and an unsaturated condition is restored in the chamber. Once the desired substrate voltage is achieved in current regulation mode, ARC-CHECK restores the MDX to voltage regulation mode and the process continues.

A similar cycle can result in a sputtering process when a flake of target material becomes lodged between the cathode and anode of the magnetron. The shorting flake cannot be melted away because of the fast reaction time of the active ARC-OUT circuit and the small amount of energy stored in the MDX output. Again ARC-CHECK can intervene to temporarily change the MDX to current regulation mode and ramp the current up until the flake is melted away and the normal power level restored. Advanced Energy Industries, Inc., holds design and process patents on ARC-CHECK.

SPARC-LE®

Small Package Arc Repression Circuit-Low Energy is the name of an accessory product that offers new ways to manage chamber arcs. Sparc-le is designed for use with any MDX unit with 2.5 kW to 10 kW output, with a maximum of 25 A. A larger version, Sparc, is designed for use on MDX units from 10 kW to 30 kW, with a maximum process current of 100 A (Figure 4).

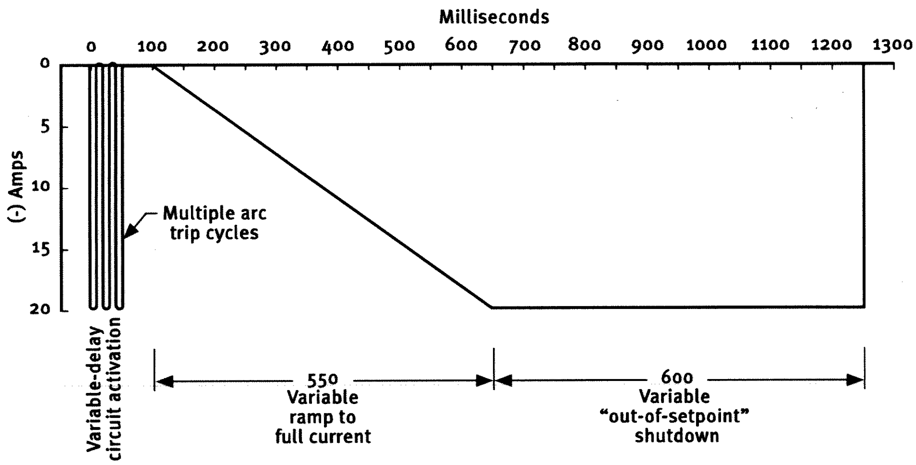

Figure 3. ARC-CHECK circuits will drive high current levels into the load to increase the load impedance or melt cathode-to-anode flake shorts.

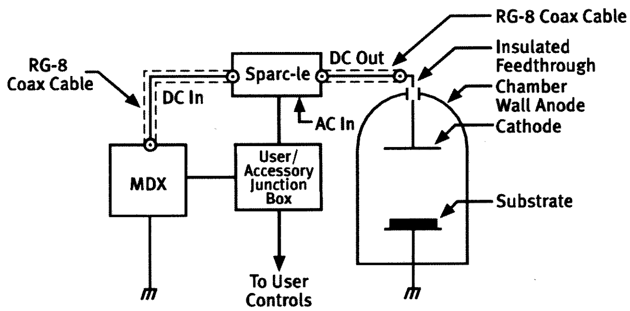

Figure 4. Sparc-le unit located between an MDX and the vacuum chamber

These accessories are installed between the MDX and the chamber. All of the output power is run through the Sparc-le. There are three different modes in which the Sparc-le can be operated: one passive mode, called ARC-OUT enhancement, and two active modes, active arc-handling and self-run.

ARC-OUT ENHANCEMENT MODE

Often, new sputtering targets contain many microscopic burrs, souvenirs of the machining and manufacturing process. During target conditioning, these burrs can act as electron field emission points that produce target arcs. If enough energy is delivered into the arc, the burrs will be burned away (melted) during the target-conditioning process.

Ironically, the active modes of Sparc-le and Sparc are so effective in reducing the energy delivered during target arcing that conditioning such a target can take an inordinately long time. For this reason, a passive circuit similar to the enhanced version of ARC-OUT has been included in Sparc-le and Sparc. This ARC-OUT enhancement mode will deliver sufficient energy to burn away burrs but not enough energy to damage targets. Since this mode of operation does not interrupt the conditioning process or extinguish the plasma, target conditioning time is reduced.

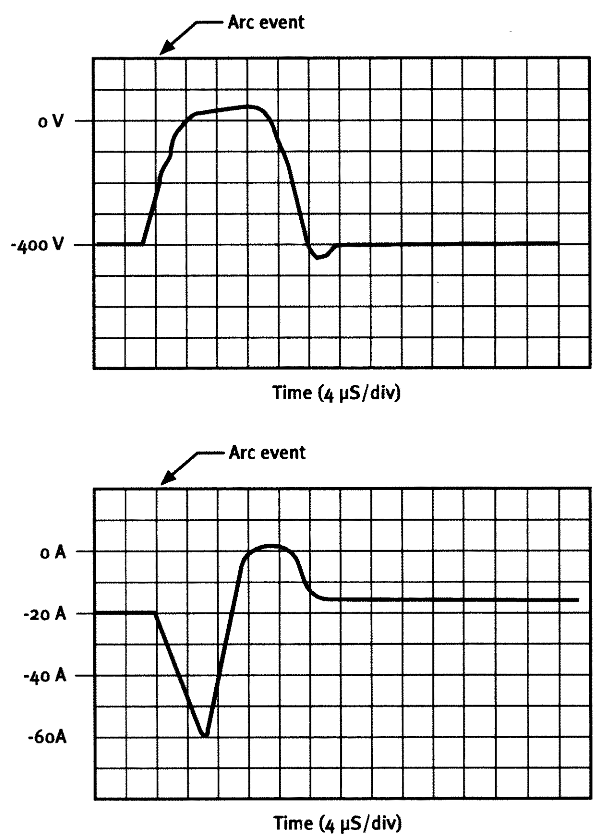

Figure 5. The voltage and current waveform of Sparc-le quenching an arc in ARC-OUT enhancement mode

Since this circuit has been further improved from the optional enhanced version available internally in the MDX series, it can be thought of as an "improved enhanced" version of ARC-OUT. This version of ARC-OUT, in Sparc-le, can extinguish arcs with even wider latitude (Figure 5).

ACTIVE ARC-HANDLING MODE

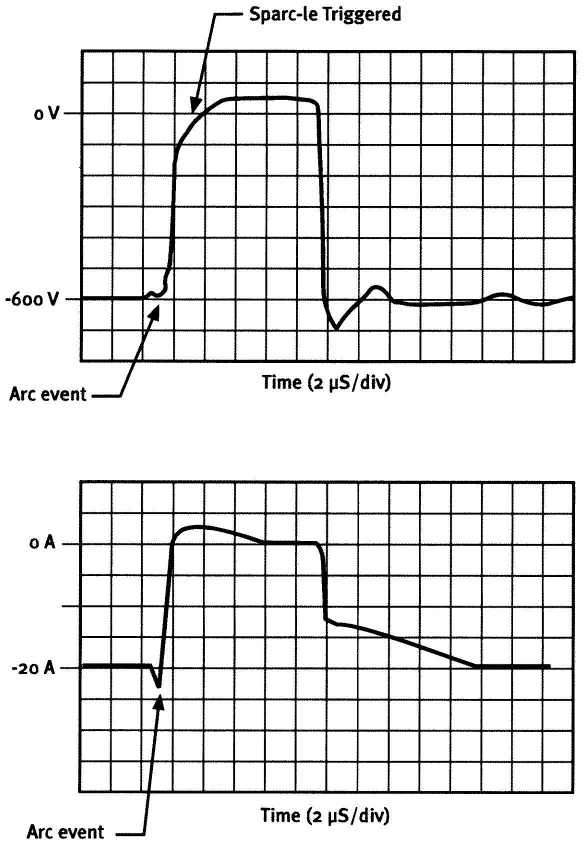

Figure 6. Sparc-le, in active arc-handling mode, reacts quickly to stop the formation of chamber arcs.

The active arc-handling mode is designed to respond to chamber conditions that signal the beginning of an arc. Before an arc forms, the chamber voltage drops rapidly. The active circuit of Sparc-le detects this condition and activates an electronic switch. This switch does two important things. 1) It diverts the MDX current away from the chamber (and the potential arc), and 2) It acts to temporarily reverse the voltage on the target, drawing electrons from the load and killing the arc in the prenatal stage. This circuit function is extremely fast—the reaction time is 1 µs, and the total interruption of the process is only about 10 µs. In this mode, Sparc-le can respond to up to 2000 arcs per second. This fast response can reduce the amount of energy dissipated in an arc (or potential arc) to one one-hundredth of the energy dissipated in the active mode of ARC-OUT (Figure 6), and about one one-thousandth of the energy stored in the power supply's output circuits.

SELF-RUN MODE

The second active mode of Sparc-le, the self-run mode, can be thought of as an "arc-prevention" mode. The self-run mode is especially valuable in reactive dc sputtering processes that yield electrically insulative films. In this process, insulative layers can build up on conductive targets. These insulative areas cannot be sputtered away because the arriving ions eventually charge the surface to a positive potential, repelling further ions. The charged surface cannot be discharged because the insulator prevents electrons from the power supply from reaching the ions and neutralizing them. The resulting positive voltage on the front surface of the insulative layer creates a large voltage difference across the insulative layer because the back side of the layer is in direct contact with the high negative voltage of the target. If this voltage difference between the front and back sides of the insulative layer exceeds the dielectric strength of the layer, a voltage breakdown will result; this breakdown can frequently initiate an arc.

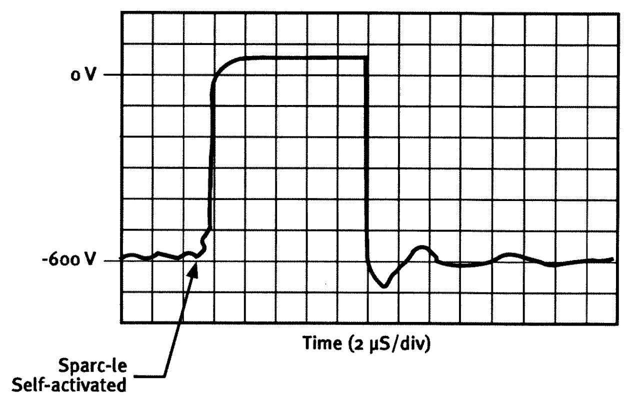

Figure 7. Sparc-le, in self-run mode, reverses the chamber voltage 2000 times per second to prevent arc-forming high voltage buildup.

In the self-run mode, the electronic switch that reverses the target voltage is activated automatically (i.e., even in the absence of an arc), at a rate of 2000 times per second (Figure 7). This reversal of the voltage on the target will attract electrons from the plasma to the front surface of the insulative layer on the target. The arriving electrons neutralize the ions, restoring them to neutral gas atoms. This "discharges" the insulative layer, reducing the voltage difference between the front and back sides, which greatly reduces the probability of voltage breakdown and arc occurrence. In addition to preventing charge buildup, discharge of the insulative surface lowers the surface potential to the negative power supply voltage, which attracts positive ions from the plasma during the normal negative voltage period. This will sputter away the insulative layer, or keep it so thin that it does not create an arcing hazard. It is important to note that if an arc does begin to form, between discharging pulses of the self-run mode, Sparc-le will respond to the falling voltage, as in the normal active arc-handling mode, to suppress the arc (Figure 8).

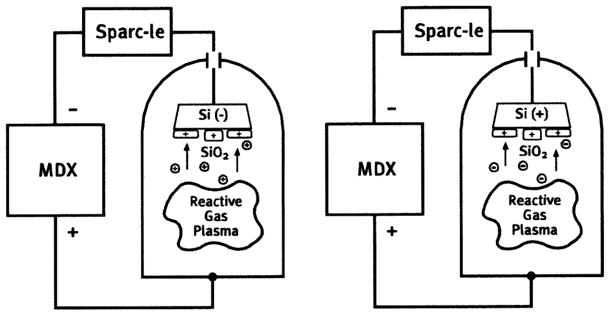

Figure 8. Insulative SiO_2 builds up on target surface. Sparc-le momentarily reverses target voltage to discharge the insulative layer SiO_2.

Sometimes, problems encountered during the conditioning of new targets are related to arcing that results from contamination and oxides on the target surface, rather than from the microscopic burrs discussed earlier. The self-run mode can also be used to "clean" insulative contamination or oxide layers from the target prior to use in normal (nonreactive) dc sputtering processes. The insulative film will be sputtered away by the mechanism outlined above.

An added feature of Sparc-le is the activation port. This BNC connector allows the user to observe the operation of Sparc-le. Every time an arc is repressed in the active arc-handling mode, or every time the target voltage is discharged in the self-run mode, a 5 V, 10 ms signal is produced at the activation port. This signal can be monitored with an oscilloscope or frequency counter to track Sparc-le's operation.

APPLICATIONS

The ARC-OUT circuit in the MDX and Sparc-le will enhance any vacuum process in which arc energy is a problem (not all processes are sensitive to arc energy). The ARC-CHECK circuit is essential for cathodic arc deposition processes. It also brings significant value to sputtering processes that use magnetron cathodes with anodes that are close to cathodes and are therefore prone to target flake shorts. This is especially true in applications where sputtering is conducted in either a "side" or "up" sputtering configuration, where gravity can exacerbate a target flake short problem.

Sparc-le's most significant contribution to the vacuum processing industry comes in the area of reactive dc sputtering of electrically conductive or semiconductive targets in reactive gas environments, particularly where the reaction between gas and target produces an electrically insulative material. This revolutionary product permits the low cost and high sputter rates of dc to be used effectively for sputtering these troublesome films. It should be pointed out that even though Sparc-le has been shown to be very effective in sputtering insulative films formed reactively from conductive targets, Sparc-le will not work to permit dc to sputter thick, truly insulative targets. This is true because thick targets charge up so rapidly that much higher frequencies than Sparc-le can produce are required to maintain sputtering action. Generally, the ISM (industrial, scientific, and medical) frequency of 13.56 MHz is used for RF sputtering of electrically insulative targets. Advanced Energy Industries, Inc., has a complete 13.56 MHz product line suitable for this purpose.

The ARC-OUT enhancement mode of Sparc-le will improve voltage bias supply performance in cathodic arc and ion-plating deposition processes by reducing the energy dissipated in arcs. Likewise, Sparc-le operating in the active arc-handling mode will further reduce arc-related damage in these processes.

Our experience in using Sparc-le, in all modes, in processes that incorporate RF bias on substrates being coated, is excellent. We have not detected any interaction between Sparc-le and the RF bias source, and the function of Sparc-le is unaffected.

This paper was written to clarify the numerous and complex arc-managing schemes and designs incorporated in dc products engineered and manufactured by Advanced Energy Industries, Inc. If you have any questions, or desire further information on a higher technical level regarding any of these designs or processes, please contact the technical support or technical education department of Advanced Energy Industries, Inc.

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