POWER SUPPLY TOPOLOGIES

A closer look at the Crystal® platform's LCC resonant circuit design optimized for low–frequency, sinusoidal, process plasma power

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As a result of its circuit topology—designed specifically to work with process plasma—the Crystal® power supply is more stable and develops less arc energy than alternate solutions. This paper compares the LCC resonant circuit used with Advanced Energy's Crystal power supply to the parallel resonant circuit used in competing solutions.

As the only AC high power supply designed from the ground up to power plasma environments, Advanced Energy's (AE) Crystal platform is inherently more stable and provides significantly lower arc energy than competing solutions. Optimized for process plasma applications, the Crystal power supply offers higher yields, fewer substrate defects, and superior film quality.

By contrast, other manufacturers have adapted existing power supplies to work with plasma. Often the setup of such equipment is specific to a given process, limiting flexibility.

Power Control in a Plasma Environment

A fundamental advantage of the Crystal power supply is how it manages delivered power to a plasma load. Power supplies that drive high-power, dual-magnetron sputtering applications are typically of the resonant type. These designs are better able to adjust to plasma variations and can deliver full power over a wide range of plasma loads. While resonant circuits attempt to deliver waveforms that are rounded and as close to sinusoidal as possible under load, some distortion occurs. Moreover, when driving a non-linear source like plasma, waveforms are even more likely to experience distortions. Predictably, a power supply designed to minimize waveform distortion and more precisely control plasma conditions will provide the best solution for dual-magnetron sputtering applications, such as large-area glass coating.

There are two basic types of resonant circuit approaches when driving plasma: the LCC resonant circuit and the parallel resonant circuit. Each contains a different circuit topology, or arrangement of circuit elements within the power supply, and each will interact with plasma differently.

Crystal power supplies use a LCC resonant circuit with the inductor and capacitor arranged in series. As a result, the power supply orients its current output to match a sine waveform as closely as possible. Thus, to the non-linear plasma environment, the Crystal power supply appears as a current source. Competing power supplies use a parallel resonant circuit with the inductor and capacitor arranged in parallel, an arrangement most suitable for induction heating applications (for which their supplies were originally designed). Delivering a voltage output to match a linear waveform as closely as possible, these power supplies act as a voltage source within a plasma environment.

Power Supply Stability

Given how plasma reacts to current versus how it reacts to voltage, a LCC resonant circuit is always more stable in powering plasma than a parallel resonant circuit. As power is increased, voltage will exhibit less change in a plasma environment than current—in other words, the incremental impedance, dV/dI, drops as the current is increased.

Thus, if a plasma environment is driven by a voltage source, the current will fluctuate widely even if the voltage is held relatively constant. On the other hand, driving plasma with a current source will hold the voltage within a predictable, narrow range. In other words, plasma conditions are more precisely controlled by putting a steady current into the process chamber rather than by putting a steady voltage across it. So even in the simple case of sputtering in a non-reactive gas environment, the plasma will be more stably driven by a current source than by a voltage source.

When a reactive gas is added to a plasma environment, there is an even wider difference in how the two circuit topologies will effectively drive the plasma. In the case of reactive sputtering silicon in a partial pressure of oxygen, the voltage at a given current will significantly drop as the target is oxidized. Since the range of currents drawn by the plasma at a given voltage will vary substantially, a voltage-based power source will have great difficulty in keeping the plasma stable. Especially when operating at high power, the variance between the voltage-source power system and the plasma may cause the system to become unstable and oscillate. To compensate for the instability of driving plasma with a voltage power source, a filter is added to modify the parallel resonant power supply. Unfortunately, energy collects within the filter, adding to the energy delivered to an arc.

Because the Crystal power supply uses a LCC resonant circuit, its current-source properties maintain a stable plasma—without the need of a filter system. Combined with the stability of its LCC resonant circuit, the Crystal power supply offers stable, adjustable parameters, allowing you to run either in a high-voltage transitional mode, or in a high-current, fully poisoned mode.

Q Factor

The low-arc energy performance of the Crystal power supply is in part due to its circuit topology, which maintains a very low quality factor, or Q-factor. The Q of a resonant circuit is the ratio of the total energy in the circuit to the energy lost in the circuit during each cycle.

$$Q = \frac{\text{EnergyStored}}{\text{EnergyLost/Cycle}}$$

The Crystal power supply stores very little energy with its resonant circuit and rapidly uses up this energy within each cycle. It can adjust quickly to variations within the plasma and deliver full requested power to the cathodes without inducing arcs—thereby maximizing the deposition rate. In fact, at a same requested power, the Crystal power supply can deliver a deposition rate up to 50% higher than competing solutions.

A voltage-source power supply, on the other hand, stores more energy in its resonant circuit than a current-source power supply. The high Q elements within parallel circuit power supplies are required when a voltage source is used to drive a plasma environment. Energy stored in the filter and in the resonant circuit will impede the power supply's control loops and greatly add to the energy delivered to an arc. For example, when running at 100 kW, the Crystal platform delivers approximately 100 mJ into an arc. Meanwhile, competing parallel circuit power supplies will deliver several joules, or 30 to 50 times more energy. With the low energy that is stored in the Crystal power unit, the potential for inclusions, pitting, and arc tracks incurred during arc discharge are minimized. This leads to higher yields and optimal film quality.

Conclusion

The Crystal power supply uses a topology that is inherently more stable than competing power supplies. Designed specifically to work with plasmas, using a low-Q LCC resonant circuit, the Crystal power supply provides greater control of the process plasma while storing very little arc energy. As a result, the Crystal platform maximizes throughput, enhances film quality, and increases yield for all types of dual cathode systems. In comparison, competing induction heating supplies that are merely adapted to run plasma use a high-Q parallel resonant circuit with a problematic corrective filter that can slow response time, cause instability at high power, and store large amounts of arc energy.

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