Enable Highly-Stable Plasma Operations at High Pressures with the Right RPS Solution

Created by

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Abstract

Conventional applications for remote plasma sources (RPS) include: chamber clean, process chamber exhaust abatement, stripping, or ashing processes. However, the application space for remote plasma generation is expanding. In recent years, RPS technologies are being considered – and demonstrating advantage – in a wider scope of applications, such as: radical generation for direct processing, low energy processing, and augmentation or replacement of in-situ sources. [1]

As plasma-enhanced chemical vapor deposition (PECVD) processes evolve, the need for RPS usage has increased dramatically, enabling a diverse range of processes and chemistries. An RPS application for a chemical vapor deposition (CVD) process may involve operating at high gas pressures up to 100 Torr. Considering that the typical operation range of toroidal sources are less than 10 Torr, the high-pressure operation faces operational challenges around ignition, plasma stability, and species concentration control. To satisfy the need for this advanced, higher pressure process, engineers require a stronger solution – one that better adapts to needed design functions and

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process capabilities. Advanced Energy (AE) developed the Quanta® RPS to meet these challenges. The Quanta includes a very high frequency (VHF) power, solid-state switching match, and capacitively coupled electrode design to enable process engineers and tool designers to use remote plasma sources for processes at high pressures up to 100 Torr.

Quanta VHF RPS

Most current remote plasma sources are designed to operate at very high plasma densities using microwave or inductively-coupled RF energy. Often, these systems are highly tailored for specific applications, and due to the coupling mechanism or chemical incompatibility, the operating ranges are limited. [2] The disadvantages of the limited operating range are realized when developing or optimizing processes outside the original design space; in this situation, a more capable RPS device with an expanded operating range would offer numerous benefits by enabling: optimization of operating pressure, both in the remote source and in the downstream chamber; experimentation with different feedstock chemistry; expanded flow rate, and residence time capability; and ignition and operational stability across a wider range of power levels, including pulsed power.

The Quanta employs a new remote source design using capacitively coupled plasma (CCP) technology driven by very high frequency (VHF) energy at 60 MHz to produce a flexible and unique remote plasma generator. The electrode design and internal construction are compatible with most processing chemistries and allow generation of very low to very high plasma densities across extensive flow and pressure regimes. This new design has demonstrated operating range versatility not seen in existing, comparable remote plasma source devices.

Quanta RPS vs Toroidal Source

The optical measurement results below show the Quanta operating range is significantly greater than typical toroidal plasma sources. Operating at VHF frequencies around 60 MHz increases plasma density while decreasing operating voltage, allowing stable operation across a broader space when compared to typical 400 kHz toroidal RPS designs.

The ability to operate across a wide range of conditions allows the process to be optimized without restriction of the RPS operating range. Optical data shows that by varying pressure and power, Quanta can generate various mixes of radicals and metastables that are unachievable with traditional toroidal plasma sources. This expanded operating range allows more customization of the plasma for improved process flexibility. For processes particularly sensitive to different species types, this plasma flexibility can be very valuable.

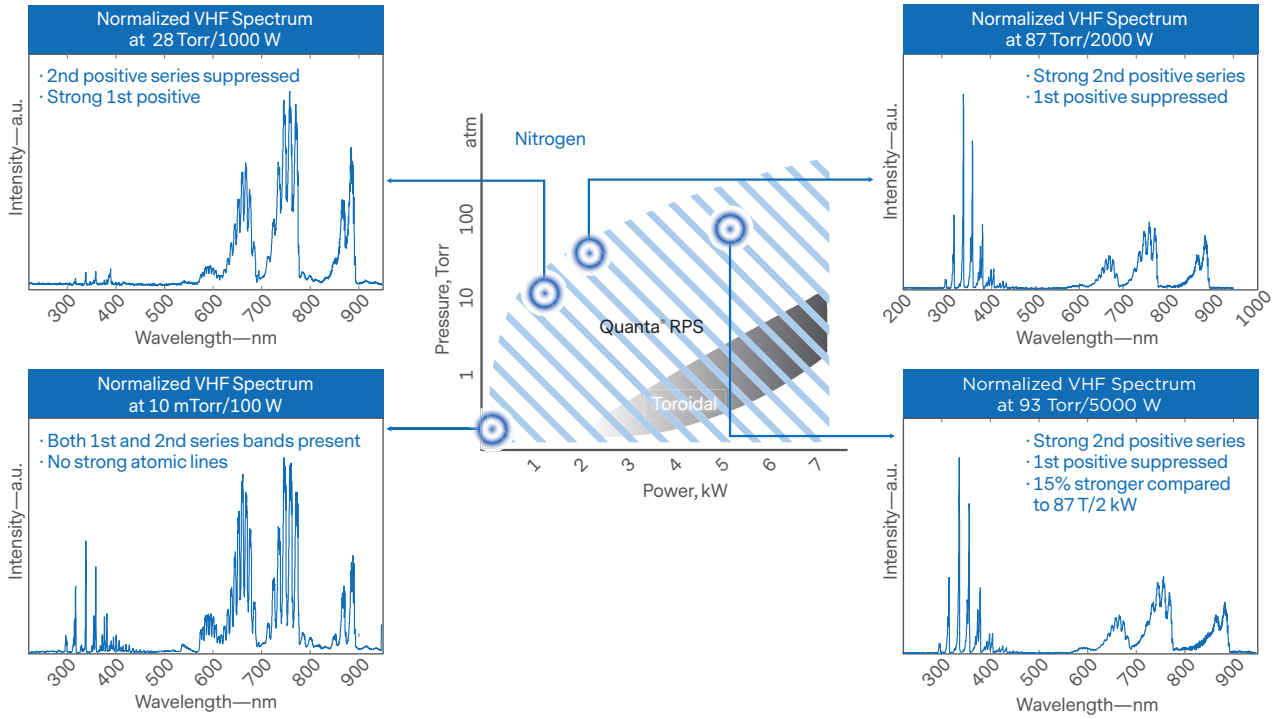

Figure 1. Optical emission spectroscopy measurements on nitrogen gas plasma at extreme operating conditions.

Ignition and Operation – Tuning and Matching Network

Quanta employs a high-speed solid state matching circuit in order to ignite and maintain a plasma over a wide operating range. Along with frequency tuning, the solid state match maintains impedence matching across a wide range of gas, pressure, and flow regimes. As pressure increases, the impedence of the plasma changes and a steady plasma is much more difficult to maintain in a typical toroidal device. Because Quanta is capacitively coupled and has a sophisticated matching network, it is able to operate outside of typical RPS parameters. Quanta can also maintain this match at extremely low power, substantially less than 100 W in many cases, while still maintaining stable plasma operation.

Quanta also employs an enhanced ignition circuit which enables ignition at much higher flows and pressures than typical RPS products can achieve. For many gases, the Quanta can ignite in pressures exceeding 10 Torr and, in some cases, even higher pressure. It is important to note that Quanta can ignite in most process gases, saving critical time and complexity over standard toroidal RPS units that need to ignite in argon. The Figure 2 shows the capabilities of the enhanced ignition feature in Quanta.

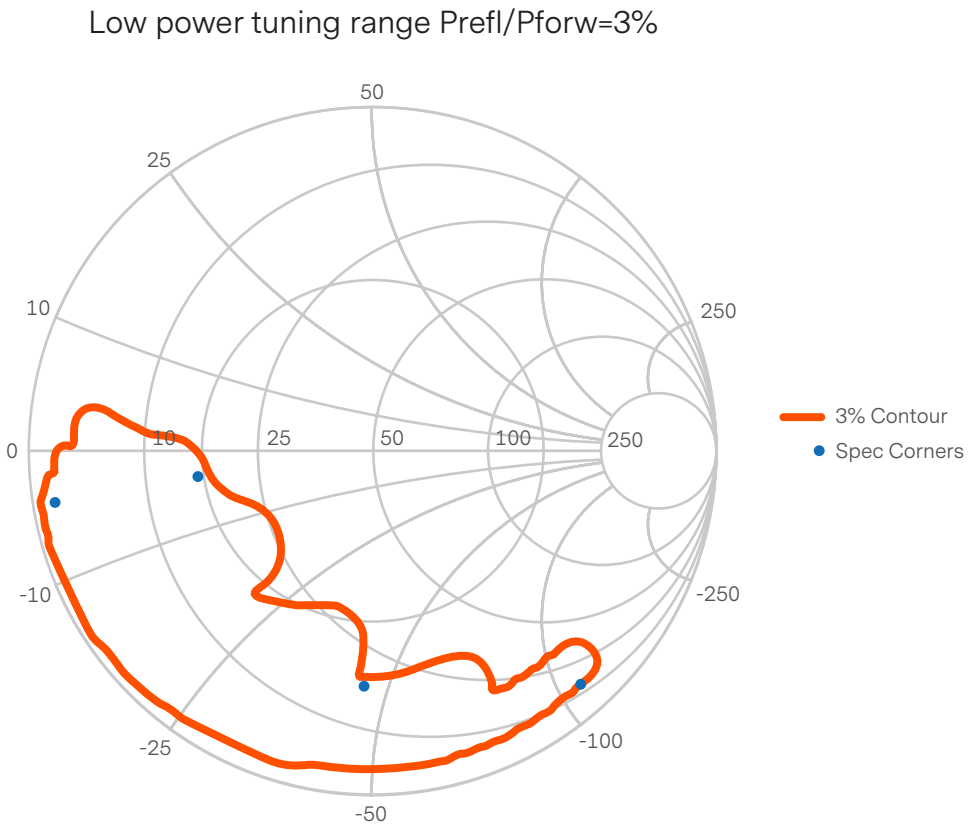

Figure 2. Impedance Tuning in Quanta

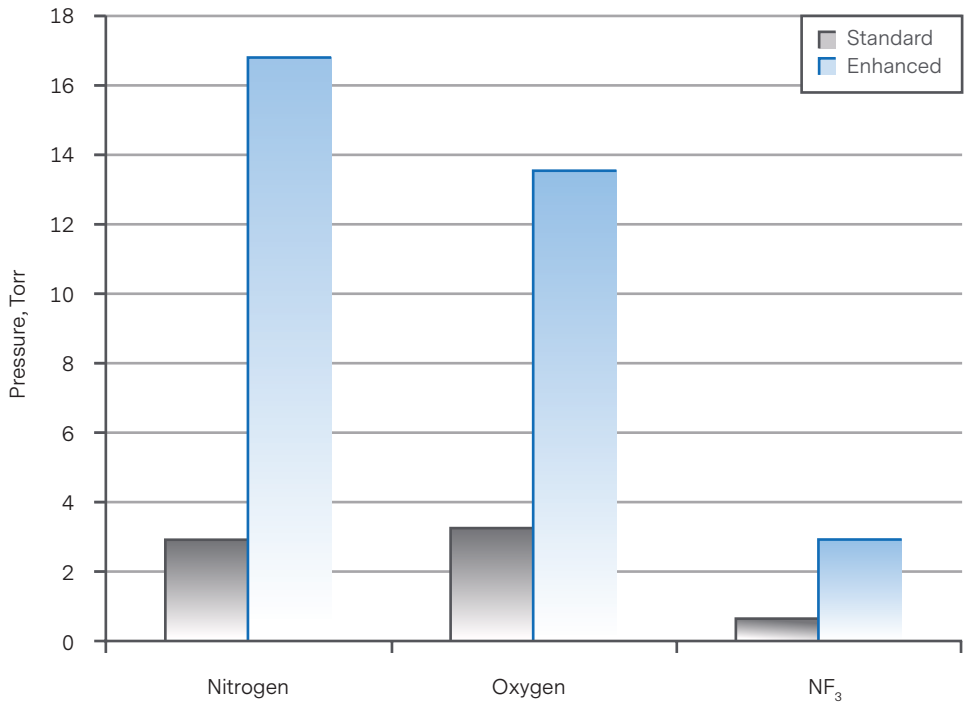

Figure 3. Enhanced ignition in Quanta

Downstream Projection of Plasma to Improve Performance

In remote plasma generation applications, the goal of delivering a stream of ions and neutrals to the surface being processed can be limited by the distance of the RPS from the wafer. However, practical and mechanical constraints often restrict the installation of an RPS close to the work chamber. While toroidal RPS designs create a highly-confined plasma that does not project downstream, the Quanta can deliver significant plasma density downstream to a remote chamber. Because of its capacitively coupled design and VHF frequency operation, the Quanta can reduce the impact of recombination effects caused by volumetric and wall interaction compounded by distance to the wafer surface. [3]

The ion density measured with a Langmuir probe, shown below, clearly indicates the high-density plasma of the Quanta in the downstream chamber as compared to a toroidal source.

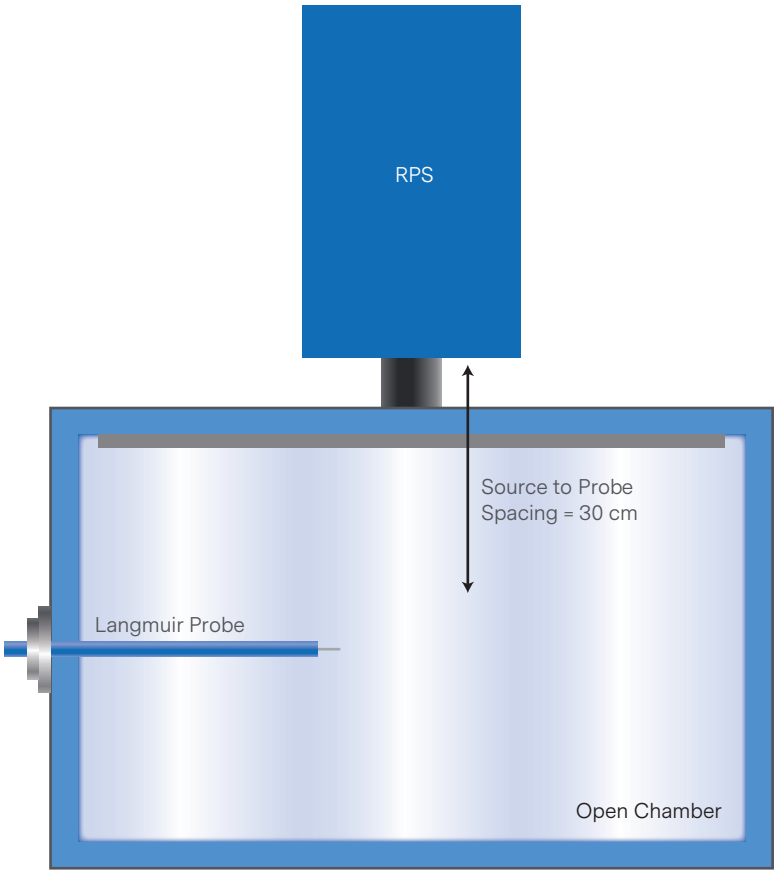

Figure 4. Configuration used for testing downstream projection of plasma into an open volume chamber.

QUANTA VHF RPS

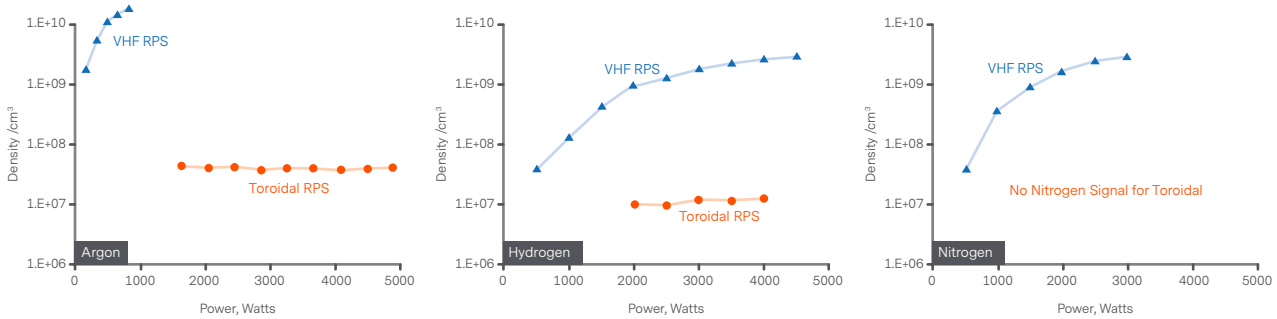

Figure 5. Projected densities at downstream chamber.

Thin Film Applications

AE's Quanta enables sophisticated plasma generation and expansion into new thin film processes. This advanced VHF source produces high-density plasma with the ability to project radicals and ions to downstream chambers, enabling the plasma to get closer to the wafer surface for processing. The technical features of Quanta RPS allow for operations not previously available from toroidal sources, including:

- High output plasma density (10^{11} to 10^{12} ions/cm^3 in Ar, N_2, and H_2 gases)
- High downstream plasma density (10^8 to 10^{10} ions/cm^3)
- Wide process range, 100 W to 6 kW, 5m Torr to 100 Torr in a variety of chemistries
- Customization of plasma radicals and metastables
- Ignition in process gas, at high pressures and flows

Conclusion

The Quanta RPS is the latest innovation from Advanced Energy in remote plasma generation for semiconductor processes. The VHF frequency and capacitively coupled plasma generation features allow a much broader operating range compared to typical plasma sources. Adjusting flow and pressure gives the operator precise control for customization of the metastable/radical mix. The solid state matching network and frequency tuning capabilities expand the impedance range that the unit will operate in, thus further increasing the pressure and flow capabilities of the Quanta. Enhanced ignition also improves ease of operation and expands the power, flow, and pressure range for successful ignition in process gases, further improving the versatility of the Quanta in next-generation semiconductor processes.

References

1. D. Carter, D. Hoffman, R. Grilley, K. Peterson, and S.Polak, “Downstream Plasma Delivery From a Remote VHF Source,” 56th Annual Technical Conference Proceedings of the Society of Vacuum Coaters, pp. 301, 2013. http://dx.doi.org/10.14332/svc13.proc.1055

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ABOUT ADVANCED ENERGY

Advanced Energy (AE) has devoted more than three decades to perfecting power for its global customers. AE designs and manufactures highly engineered, precision power conversion, measurement and control solutions for mission-critical applications and processes.

AE's power solutions enable customer innovation in complex semiconductor and industrial thin film plasma manufacturing processes, demanding high and low voltage applications, and temperature-critical thermal processes.

With deep applications know-how and responsive service and support across the globe, AE builds collaborative partnerships to meet rapid technological developments, propel growth for its customers and power the future of technology.

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