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# Revolutionizing plasma power solutions for etching and deposition

**Prodrive Technologies proposes a next-gen, revolutionary etching and deposition plasma power solution with its Tailored Waveform Generator.**

Developed in collaboration with acclaimed international research institutes, the Axiom offers direct control over the ion energy directed at the wafer surface with the benefit of obtaining a very narrow ion energy distribution (IED) of various shapes according to the needs. In addition, it offers the possibility to decouple the ion energy control from the ion flux control. By improving control of key plasma characteristics, such as IED and the ion angular distribution (IAD), the Axiom opens the gate to new possibilities in etch rate control and high selectivity for low plasma energy regimes.

Axiom Tailored Waveform Generator

PRODRIVE TECHNOLOGIES

## Semiconductor industry

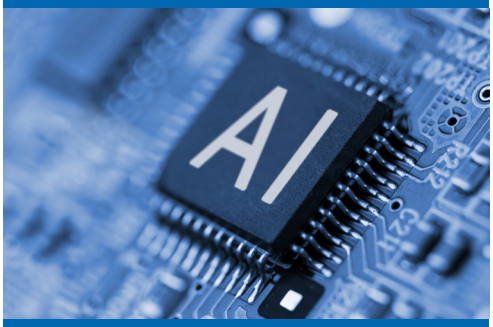
The demand for more computing power is ever-growing. To accommodate for better processors and faster computers - essential for artificial intelligence - integrated circuits (ICs) are pushed beyond their limits. In logic, the semiconductor industry is currently operating at the 3 nm node, but even smaller details are around the corner, bringing the world into the Angstrom era. On the memory side, new architectures are coming into play, where layers are stacked, creating ultra-complex 3D structures.

Future devices will certainly require smaller critical dimensions (CD) and incorporate new materials and structures. While self-assembly is considered for some structures and materials, dry etching will remain the primary method for pattern transfer of the ever-shrinking lithographic features in the foreseeable future. In some cases, new materials will be incorporated into cavities formed in traditional semiconductor materials. In others, these materials will require dry etching, necessitating the development of new etching processes. The choice of structures and materials will be influenced greatly by the capabilities of available dry-etching processes and equipment.

Key factors such as control of selectivity (to the substrate and the mask), profile and CD control, lattice damage, plasma damage, particle formation, process reproducibility, and equipment reliability will dominate future etching technologies and equipment.

These trends are straining existing production technologies and challenging equipment manufacturers to push all technological boundaries. Better control of ion and neutral fluxes, as well as ion energy, will be required to address issues such as CD control, line-edge roughness, and lattice damage caused by ion bombardment. In addition, improvements in uniformity and precise control of the amount of material removed or deposited will be necessary.

Plasma etching technology has come a long way, evolving from a manually loaded quartz tube with a coil wound around it to sophisticated automatic multimillion-dollar machines, with advanced equipment and process control.




Semiconductor innovations drive the AI evolution

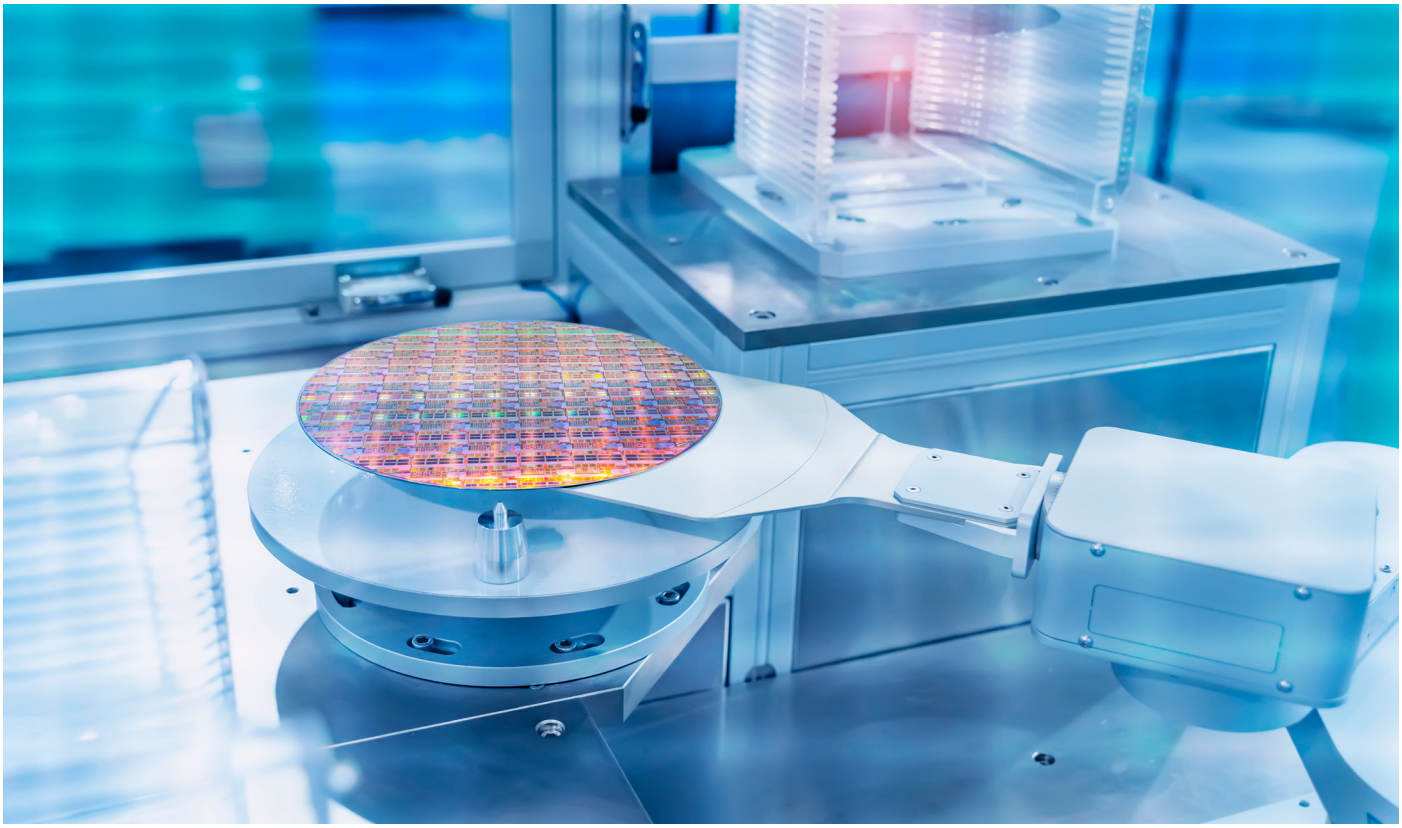
Still, to sustain the continuous advancements in semiconductor manufacturing, a whole new generation of tools and techniques is essential.

## The process

One of the many essential steps in semiconductor manufacturing is etching. A procedure following the lithography process where light is projected through a blueprint of the intended pattern that will be printed on a wafer. In an etching solution, the unmasked material is removed from the wafer, leaving the desired nanostructure intact. A commonly used method for this procedure is plasma-enhanced etching.

Along with solid, liquid, and gas, plasma is the fourth state of matter. In essence, it is an ionized gas, consisting of positive ions, (negative) electrons, and neutral particles. Plasma can be created and sustained in a reactor chamber by applying a power source to a feedstock gas. They can create plasma in a reactor chamber and sustain it by applying a power source to a feedstock gas. That source gas can be anything from simple Argon to highly complex molecules, depending on the specific etching process needs. Gasses can even be switched between different etching steps.

Plasma etching and deposition is an essential semiconductor manufacturing technology that will shape the microelectronics industry in the future.



When an electric potential difference is built over the sheath, the surface potential becomes lower than the plasma potential. As a result, the positively charged ions are accelerated within the plasma sheath. That shower of speeding particles bombards the entire substrate, etching away the unmasked material on the wafer while causing minimal damage to the masked layer of the nanostructure.

## Next-gen RF generators

Building up the alternating biasing potential between the plasma and the wafer surface is another demanding technical challenge. The generally accepted solution, which has been around for decades, is an RF power supply that generates a sinusoidal waveform to accelerate the ions. With the increasing demands in semiconductor manufacturing accuracy, the drawbacks of the RF power supply begin to hamper progress.

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Arguably, the biggest disadvantage is the broad ion energy distribution (IED). The acceleration and final speed of the particles are determined by the applied waveform. Since the RF power supply gives out a sinusoidal voltage, creating a time-varying voltage potential on the wafer surface, some ions receive lower energy while others receive higher energy. The resulting broad IED means that ions with low energies might hardly contribute to the etching process, while ions with high energies can impair the etching mask, degrade selectivity, and damage the substrate.

Another shortcoming of RF power supplies is the angle of the incoming ions. As High Aspect Ratio etching is getting more complex, the necessary trenches are deepening. A slight deviation to the optimal perpendicular ion trajectory means that the side walls of the trenches will be askew, causing the risk of profile distortion.

In the current Angstrom era of semiconductors and with the continuous evolution, traditional RF power supplies will inevitably fall short. Chip manufacturers need non-sinusoidal etching tools that deliver better control of IED and Ion angle distribution
(IAD). It is all about delivering the right amount of energy, at the target material, and at the right time.

## The tool

Prodrive Technologies proposes a revolutionary solution with its Tailored Waveform Generator, the Axiom, which generates a tailored waveform. Every period consists of a long interval when the ions are attracted and their ion energy is precisely controlled, followed by a narrow, high pulse that rapidly attracts electrons to neutralize the build-up of positive charge from the bombarding ions. As the voltage potential between the plasma and the substrate electrode is much more constant than in an RF power supply, most of the ions get the same boost, meaning the IED is narrow.

The tailored bias waveform approach inverts the traditional method to determine the IED. Instead, choose the desired ion energy distribution first. Then determine the waveform that will produce that IED, synthesize it, and apply it to the substrate.

Equipment suppliers are the driving forces that will affect plasma etching and deposition of the future.

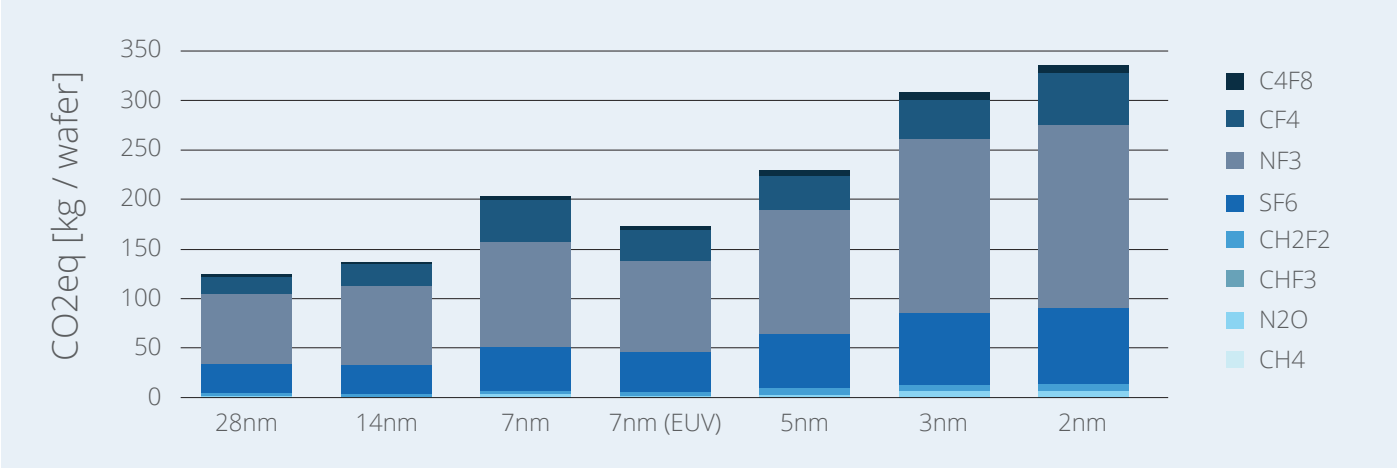
## Added values - Product

A traditional RF power supply always needs additional matching networks to maximize its output power. The Axiom replaces both systems, so it can reduce system complexity, a feature that is highly appreciated in cleanroom environments where every square inch matters.

Another huge advantage of the Tailored Waveform Generator is the low power consumption. In comparison to RF power supply, users can potentially save more than 25 percent. Since this part of the system, together with the plasma source, are the most active components in an etching tool, this will make a tremendous difference, helping semiconductor manufacturers in reducing their operating expenses (OPEX).

Figure 1: Estimated equivalent CO2 emissions from greenhouse gases used in process flows across different nodes.

*Source: imec, published 17.12.2020*




## Added values – Process

The improved control with a tailored waveform increases the selectivity of the etching tool. In the atomic layer deposition (ALD) and atomic layer etching (ALE) processes, the required ion energy window is typically smaller than RIE, this is the reason why we use the tailored waveform biasing. Other etching methods such as Reactive Ion Etching (RIE) are more aggressive and therefore need higher energy ions. The Axiom is very versatile and can accommodate etching and deposition techniques from all sides of the spectrum.

Uniformity is very important in semiconductor manufacturing. To reach high yields, the same behavior is required across the surface of the wafer. The dies in the center should get the same optimal treatment as the ones on the edge. With a tailored waveform, users can attain the same level of

uniformity as with an RF generator.

Another critical point is the frequency characteristics of the system. RF power supplies generate an output with normally a fixed frequency, typically around 13,56 MHz. RF power supply has high-frequency harmonics, and higher-frequency harmonics have shorter wavelengths, which might be comparable to the substrate dimensions. These nonuniformities in bias voltage across the substrate cause the process nonuniformities.

With a tailored waveform, however, a wide range of frequencies come into play, offering better flexibility of IED control. Alpha users of the Axiom have evaluated this thoroughly through blanket wafer etching tests. Moreover, because of the relatively low frequency of the tailored waveform – between 100 and 300 kHz, depending on the process – a better uniformity is expected compared to RF biasing.

## Power electronics and RF expertise

Creating the necessarily tailored waveform is an electronic conundrum, but one that fits perfectly with the strengths of Prodrive as it requires in-depth knowledge of both power electronics and RF technology. Thus, the main challenge is the combination of the high voltages involved and the high frequencies that come into play. The Axiom generates up to 2kV peak-peak with a frequency between 100 and 300 kHz which covers a wide scope of plasma processing applications in semiconductor manufacturing.

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In other processes, like the aforementioned ALE and ALD techniques, a lower voltage suffices because a voltage window is defined is typically less demanding. On the flip side, the requirements for the precision of that voltage are often much more stringent. The Axiom can cover a wide range of voltage requirements and ensure high precision.

Switching 2 kV at these high frequencies has only become possible with the advent of innovations such as silicon carbide switches and especially gallium nitride switches. They enable the electronics to switch very fast between these voltage

levels, while also ensuring fast rise times. In this case, an extremely narrow pulse can be achieved.

## Status

Prodrive Technologies has been developing the Axiom for the last five years. The current functional air-cooled model is ready to be integrated into etching and deposition tools, so R&D engineers can test and evaluate how the technology performs in their specific set-up. Client-specific modifications and adjustments can be made to ensure a 100 percent fit.

Once these assessments have been completed successfully, tool manufacturers can take the Tailored Waveform Generator as a differentiator to their clients and embed it in their successive semiconductor manufacturing processes.

Please contact us to explore how our Tailored Waveform Generator can help optimize manufacturing processes in the semiconductor industry: sales@prodrive-technologies.com