# Electron Cyclotron Rotation Enhanced Hollow Cathode Plasma Source (ECR-HCPS)

Plasma sources are essential in semiconductor manufacturing for applications such as etching, cleaning, and thin-film deposition. Common plasma generation techniques include RF (radio frequency), ICP (inductively coupled plasma), microwave, and hollow cathode configurations. RF plasmas, widely used in reactive ion etching (RIE), are simple and cost-effective but typically offer lower plasma densities. ICP sources, by contrast, deliver high-density, low-pressure plasmas with excellent uniformity, making them suitable for advanced pattern transfer and deep etching. Microwave plasmas, often employed in high-purity or high-efficiency deposition processes, provide very high energy efficiency and are compatible with remote plasma configurations.

Hollow Cathode Plasma Sources (HCPS), however, offer unique advantages by utilizing confined electron oscillations within a cathodic cavity to enhance ionization efficiency dramatically. This leads to exceptionally high plasma densities at relatively low power and pressure, making them ideal for high-rate, uniform deposition or treatment over complex topographies. In semiconductor processing, HCPS are increasingly valuable in applications requiring conformal coatings, low thermal loads, or high-aspect-ratio structure coverage, particularly in atomic layer deposition (ALD), PECVD, and surface modification. Their ability to operate at lower voltages with high electron density contributes to reduced substrate damage and greater control over film properties—critical for advanced semiconductors fabrication.

Nano-master’s patented technology introduces an advanced plasma source design that integrates Electron Cyclotron Rotation (ECR) with a Hollow Cathode Plasma Source (HCPS) to enhance plasma generation for thin-film deposition processes.

**How it works**

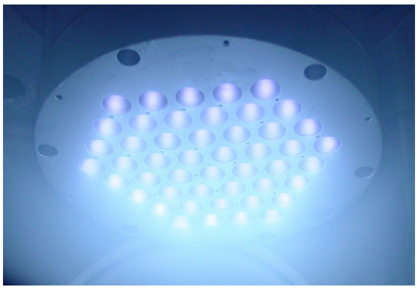
A Hollow Cathode Plasma Source (HCPS) relies on the oscillation of electrons between closely spaced cathode surfaces to increase the probability of ionizing collisions with neutral gas atoms or molecules. This confinement effect leads to higher plasma density than in conventional DC or RF glow discharges. However, the efficiency and uniformity of ionization can still be limited by electron energy losses and escape paths.

Electron Cyclotron Rotation (ECR) enhances this mechanism by introducing a perpendicular magnetic field to the electric field present in the plasma. When the frequency of an applied RF field matches the natural cyclotron frequency of electrons in the magnetic field, electrons begin to spiral (gyrate) along magnetic field lines—this is called cyclotron resonance.

**Enhancement mechanisms:**

**Increased electron path length**

When cyclotron radii is smaller than the hallow cathode internal diameter, ECR causes electrons to spiral around magnetic field lines rather than move linearly. This increases their effective path length in the plasma, significantly raising the number of collisions with neutral gas molecules and thus increasing the ionization rate.



**Higher ionization efficiency**:

Because more energetic electrons remain confined within the hollow cathode longer, they undergo multiple inelastic collisions, generating a dense and stable plasma at lower pressures and power levels.

**Improved plasma uniformity and stability**:

The ECR-enhanced HCPS produces a more homogeneous and denser plasma column, which is particularly beneficial for coating or treating substrates with complex geometries or requiring highly uniform thin films.

**Lower operating voltage and pressure**:

ECR allows effective plasma generation at reduced voltages and pressures, which is critical for processes sensitive to substrate heating or damage (e.g., low-temperature ALD or PECVD on fragile layers).

**Energy efficiency**:

The resonance condition allows more selective energy transfer to electrons, increasing energy efficiency and reducing overall power consumption.

**Configurable in arbitrary surface geometry**