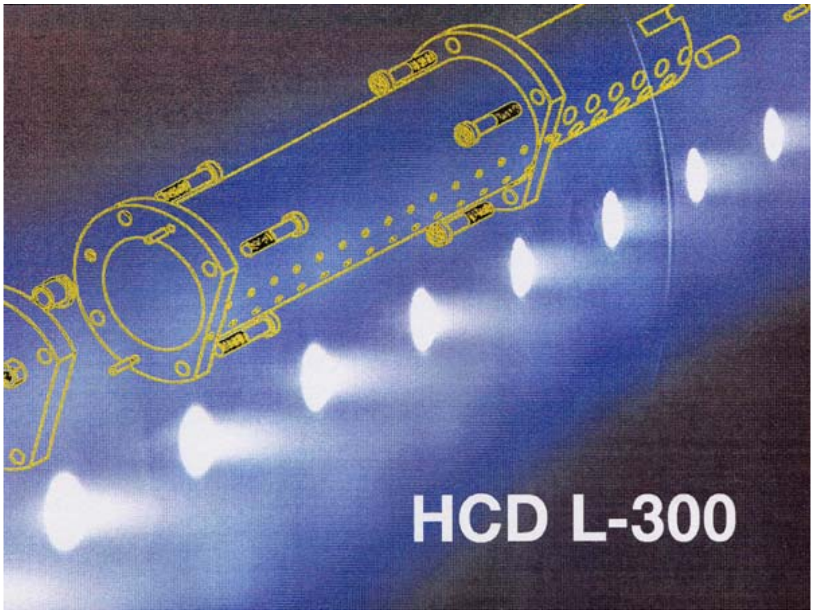
13.56 MHz Hollow Cathode Plasma Source HCD L-300 by

PlasmaConsult



Features

- Operation over an extended power range
- No mode jumps
- High plasma and radical densities with excellent axial homogeneity
- Compatible with chemically reactive and nonreactive gases
- cw and pulse operation
- Low contamination
- scaleable

Applications

- Plasma-enhanced chemical vapor deposition (PE-CVD)
- Plasma polymerisation
- Surface modification
- Plasma cleaning
- Plasma etching
- Reactive and non-reactive ion etching
- Materials Science (in general)

General

Hollow Cathode Discharges (HCD) represent a very effective and yet comparatively simple, cost effective means of high density, low temperature plasma generation.

The Hollow Cathode Effect

Consider two parallel metallic plates in a vacuum chamber filled with a low pressure gas. For a given plate separation d and pressure p there exists an optimum product p x d such that the plasma ignition voltage (or power) becomes minimum (so-called PASCHEN-Law).This voltage is applied to the two plates one of which is usually grounded (often being the vacuum chamber wall). A plasma excited in such a way has a comparatively low density being insufficient for advanced plasma processing.

If the negatively biased electrode is formed as a cavity or cylindrical cathode structure (as for the HCD L-300) the conservation of particles and photons leads to a drastically increased ionization and/or emission.

To understand the working principle it is in order to look a little closer to the underlying physics. Usually the so-called plasma potential is the most positive of the whole set-up including the vacuum chamber walls. As a consequence the negatively charged electrons tend to be confined to the plasma. To be more precise, this holds only for the lower energy electron population representing a substantial fraction of all electrons.

In the hollow cathode a negatively biased cavity or cylindrical tube encloses the plasma (Fig. 1). Electrons within this plasma are constantly being repelled when approaching the hollow cathode walls : An oscillatory motion of the electrons results yielding greatly improved ionization rates and thereby higher plasma densities.

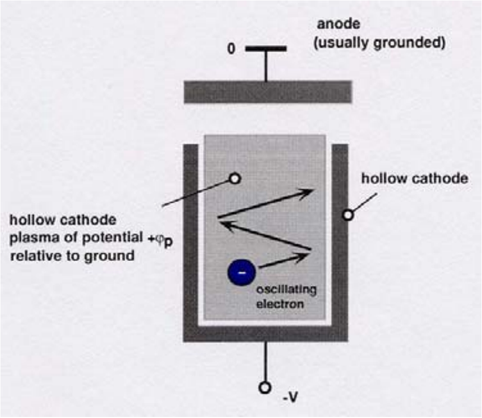


Fig. 1 Principle of a dC-hollow cathode discharge

The discharge is driven by direct current (dC). In the remote plasma processing mode the hollow cathode plasma shown is often referred to as the “primary” plasma.

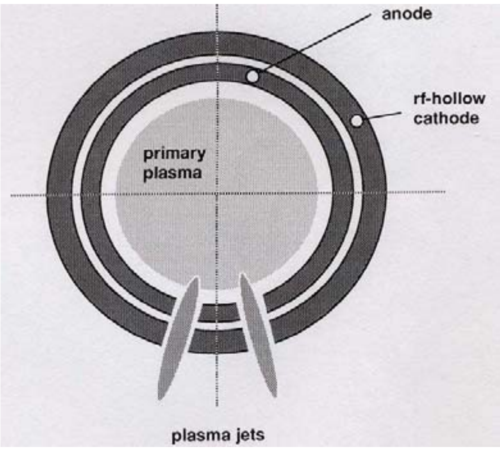


Fig. 2 Schematic cross section through a HDC L-300

Shown are two cylindrical tubes aligned coaxially. The inner tube enclosing the plasma is rf-powered; the outer tube is electrically grounded. Two rows of holes are arranged along the cylinder axis forming the high intensity primary plasma jets consisting of ions, electrons and excited species.

The plasma source HCD L-300 employs the hollow cathode effect as described above. Basically the HCD L-300 is of cylindersymmetrical symmetry featuring two aluminum cylinders of different diameters. These cylinders are inserted into each other and aligned coaxially (see Fig. 2). Both cylinders are electrically isolated from each other. The inner cylinder is connected to the rf-power generator; the outer cylinder is grounded. Along the cylindrical axis multiple holes are drilled into the inner and outer cylinder allowing plasma jets to be extracted after the primary plasma has been excited in the hollow cathode.

A proprietary internal cathode structure guaranties a homogenous plasma jet formation over extended source lengths.

The HCD L-300 extends over a length of 300 mm. By stacking together 2 or 3 HCD L-300 total source lengths are 600 (HCD L-600) and 900 mm (HCD L-900), respectively.

Performance

There are two major parameters controlling the performance and technical applicability of hollow cathode plasma sources such as the HCD L-300. These are the working pressure range of the hollow cathode (primary) discharge and the rf-power required for plasma breakdown, i.e. ignition. Typical data for an atomic (e.g. argon) and a molecular gas (e.g. oxygen) are given below (Figs. 3 and 4).

Once the plasma is excited the rf-power can be varied over an extended power and pressure range without affecting the stability of the discharge and overall plasma jet formation. When further reducing the rf power there is a minimum where the plasma no longer is stable (Figs. 5 and 6).

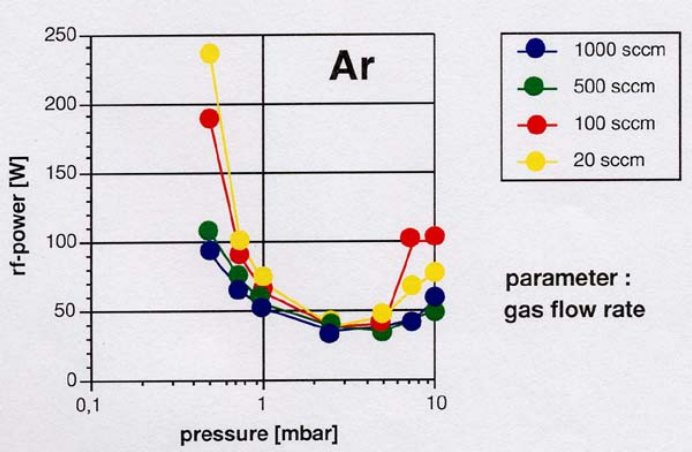


Fig. 3 Argon-plasma excitation in the HCD L-300
Shown is the pressure dependent minimum rf-power required for homegenous operation of all plasma jets. As can be seen from the data there exists a distinct power minimum in the pressure range from about 1 to 5 mbar defining the so-called mbar-processing window. This window is preferred for advanced materials processing.
One should also note that in this pressure-regime the minimum power is almost independent of the gas flow rates shown.

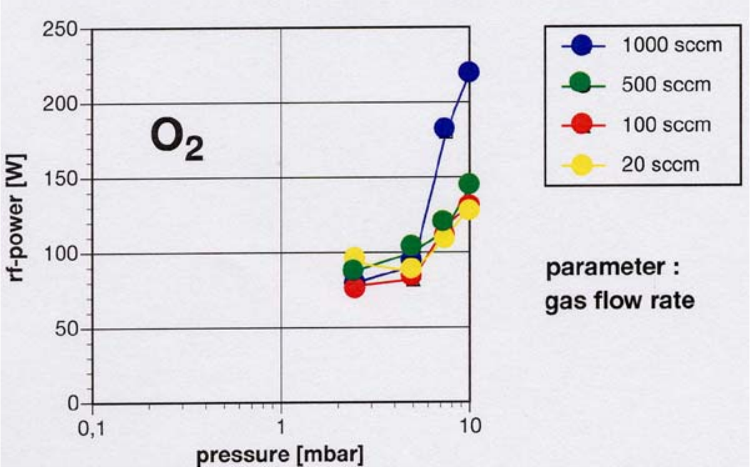


Fig. 4 Oxygen-plasma excitation in the HCD L-300
Shown is the pressure dependent minimum rf-power required for homogenous operation of all plasma jets. Compared to the Ar-plasma the pressure range is smaller converting 2….5 mbar. The flow rate dependance in this range is also not very pronounced. Once the plasma is excited the usuable pressure range extends considerably.

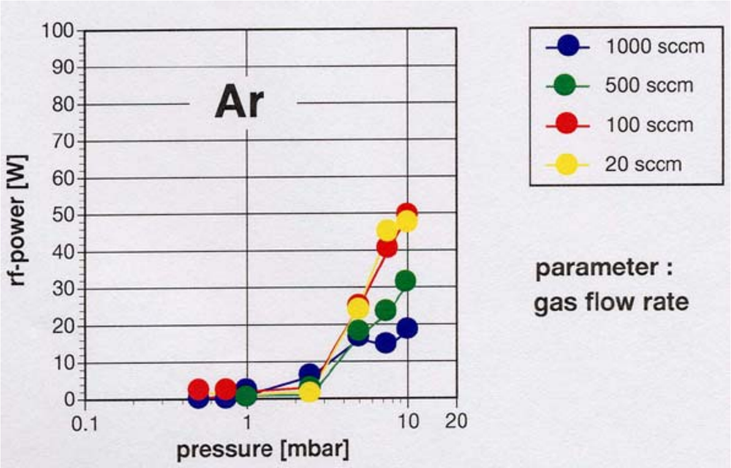


Fig. 5 Minimum rf-power required to maintain a stable argon-dischare in the HCD L-300
As can be seen this power is extremely low allowing, for instance, temperature sensitive substrates to be treated as well as polymer deposition with a high degree of monomer retention (in this case the argon plasma is used as primary interacting with a monomer injected downstream).

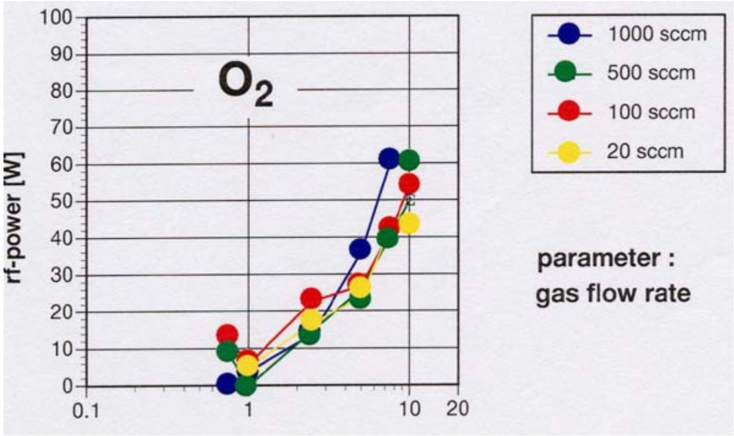


Fig. 6 Minimum rf-power required to maintain a stable oxygen-discharge in the HCD L-300
As can be seen this power is extremely low allowing, for instance, temperature sensitive substrates to be treated as well as polymer deposition with a high degree of monomer retention (in this case the oxygen plasma is used as primary plasma interacting with a monomer injected downstream).

Applications

The HCD L-300 has been used very successfully in the fields mentioned above, especially for

- plasma polymerisation,
- plasma-enhanced chemical vapor deposition (PE-CVD), e.g. SiOx, Si3N4, DLC, fluorocarbon thin films,...
- etching, e.g. removal of DLC,...
- surface modifications, e.g. controlling free surface energy, adhesion, wettability, paintability,….

The ion density variations along the source cylindrical axis were measured as

± 25 at a position 10 mm and
± 7 at a position 45 mm

downstream the plasma jet outlets. Since remote gases are typically introduced at about 50 mm downstream excellent thin film homogeneities are to be expected. This holds even more when actived neutral primary plasma particles are considered.

Contamination

The primary plasma is excited inside the inner aluminum cylinder (other materials on request). This cylinder encloses the plasma completely with the exception of the plasma jet holes.

Any possible contamination must have its origin in the inner cylinder or at the jet orifices. From the source geometry it is highly unlikely that contaminants (in this case aluminum) will leave the inner source body. The outer jet orifice is at ground potential.

In fact, so far no traces of aluminum have been identified (mass spectrometry) on different substrates even after extended periods of operation.

Lifetime

The HCD L-300 is manufactured using exclusively aluminum and ceramic parts for electrical insulation. No quartz windows etc. are necessary. Since all ceramic parts are shielded form direct plasma interaction and sputtering the source is extremely robust and offers extended lifetimes often superior to those of inductively and microwave excited plasmas.

Technical Data

• rf-power	Up to 300 W not water cooled Up to 1000 W water cooled
• Frequency	13.56MHz
• Pressure range	5….1000 depending on gas used and process
• Gas flow rates	5….300 sccm, primary gas. Monomer (examples): - C_4F_8 4….8sccm - HMDSO 10….50sccm Data may vary with process. Other monomers possible.

HCD L-300 dimensions

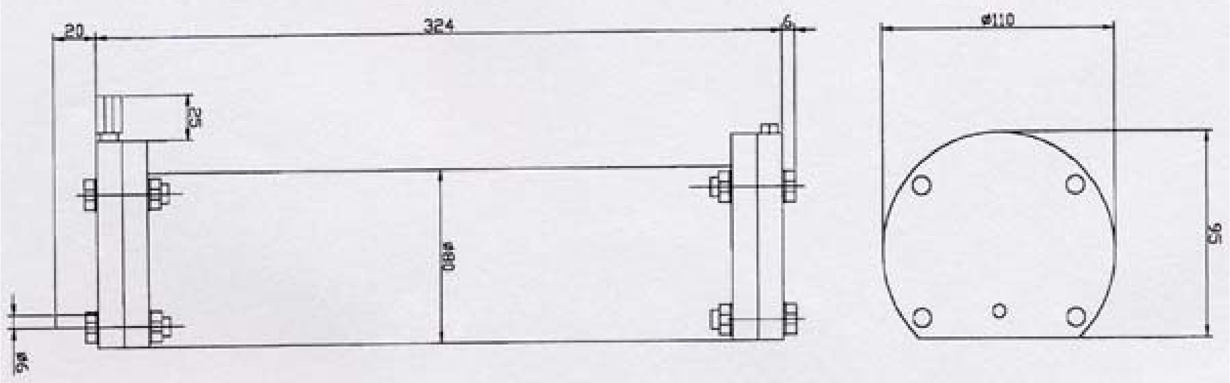


Fig. 7 HCD L-300 plasma source dimensions
Dimmensions in mm as shown.
Source weight: 3 kg (aluminum)