Confocal Measurements of the Plasma Meniscus

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Motivation

Ion beams have major applications in fusion device heating to semiconductor manufacturing.

Downstream beam parameters are determined by source parameters and extraction geometry.

Use our optical confocal system to measure previously inaccessible regions of an ICP reactor.

Background

The plasma meniscus is a boundary formed by the balance between plasma pressure from the source and the field energy density. Therefore manipulation of this boundary can be achieved by control of the system’s parameters.

The meniscus is important for calculation of beam properties such as emittance and brightness.

\[
e = \frac{\alpha (W^2 - D^2)(dp)^2}{\beta(z)}
\]

This quantity is assumed to be conserved in important in calculating beam effects like bunching rates.

Analytic solutions from numerical models of the meniscus are available but multiple lengthy simulations make it ineffective for predicting the ion beam. This is due in large part to the lack of an informed initial density guess for wide ranges of source parameters.

This picture is an Object-Oriented Particle-In-Cell (OOPIC) model of Ar ion extraction for our Applied Materials plasma source. Multiple menisci can be seen around the interior corners of the grounded electrodes and a fainter one around the biased blocker.

Our chamber is a simplified version with the biased blocker removed and a 5mm x 5mm aperture. The opening must be kept small so the grounded electrodes electric field can interact to form a meniscus.

To provide the vacuum electric field a piece of ITO coated glass was placed 10mm from the source aperture. This allowed us to have an optical path through our biased target.

Laser Induced Florescence

• Traditional laser induced florescence (LIF) measurements require two points of optical access. This has prohibited passive spectroscopic measurements in regions with geometric or chamber access constraints.

• Spatial localization of the collection ring is determined by the obstruction (3) and the pinhole (6).

• Pinhole determines outer radius (25 – 200 μm).

• Pinhole determines inner radius (1.2 – 4.5 cm).

• A larger obstruction and smaller pinhole give better localization but trade off with signal.

• The focusing doublet (2) determines focal length. A constrained depth of field at focal distances of up to 1m has been demonstrated with this system. Increasing the focal length negatively impacts the achievable collection waist.

• Laser induced florescence (LIF) is used as a non-perturbative method to measure ion properties with sub-millimeter resolution.

• Argon ions are collisionally excited to the 3dG5/2 metastable state. The injected light is absorbed at a vacuum wavelength of 611.6616nm. The electron then decays along a different path and emits blue light at 461 nm, which is collected with an optical fiber coupled filtered photomultiplier detector.

• LIF measurements of the ion velocity distribution functions (IVDF) are obtained axially along the beam path by scanning the injection laser through an 18 GHz range about the center wavelength.

• The injection is a Sirah Matisse dye laser with Rhodamine 6G in ethanol. The laser is mechanically chopped at 5 kHz and a lock-in amplifier used to isolate the LIF signal.

• Distribution function is assumed to be Maxwellian so that the relevant plasma quantities are determined from the fit instead of calculating moments.

• LIF gives a relative metastable ion density of the plasma. Absolute density could be calculated but requires in depth calculations of a collisional-radiative model and precise measurements of the electron temperature and ion and electron densities.

• This diagnostic is also sensitive to Zeeman and Stark broadening. However this experiment was carried out in an unmagnetized plasma well outside of the pressure broadening regime.

Future Work

• Improve LIF collection so that we can operate at lower powers with a finite extraction voltage.

• Perform measurements with customized, 3D scanning Langmuir probe to measure plasma density.

• Expand parameter range and link a wide range of source conditions to downstream beam characteristics.

• Determine meniscus effect on electrostatic lensing effects and control exit angle.

• Investigate the time dependent meniscus formation.

• Use meniscus location to increase convergence time for analytic beam solutions.

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