Study of a High-Power, Pulsed Plasma Jet with a Heterodyne Interferometer

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Abstract

Presented is a method to measure the line-averaged electron density and velocity of a plasma jet generated by a pulsed plasma source, using a heterodyne interferometer. This source will produce a plasma jet that exhibits instabilities [1] and magnetic reconnection [2] inside Embry-Riddle's two meter long, cylindrical plasma chamber. A heterodyne interferometer is similar to a Michelson interferometer, with the difference that the non-plasma beam is passed through an acoustic-optical modulator that isolates the 1st harmonic of the beam[3]. A fiber optic cable is used to transmit the scene beam to the vacuum chamber from the optics bench and back, allowing easy variation to sampling location across experiments. The Interferometer measures the change in the index of refraction of the plasma chamber, this enables the determination of the change of the line-averaged electron density of the plasma jet [4]. By interpreting this data over system parameter variations, changes in the density of the plasma jet over the course of the experiment will be studied. This study will investigate fundamental plasma physics and applications, such as the drivers and patterns of reconnection and may lead to improved fusion energy generation and pulsed plasma propulsion.

Experimental Setup

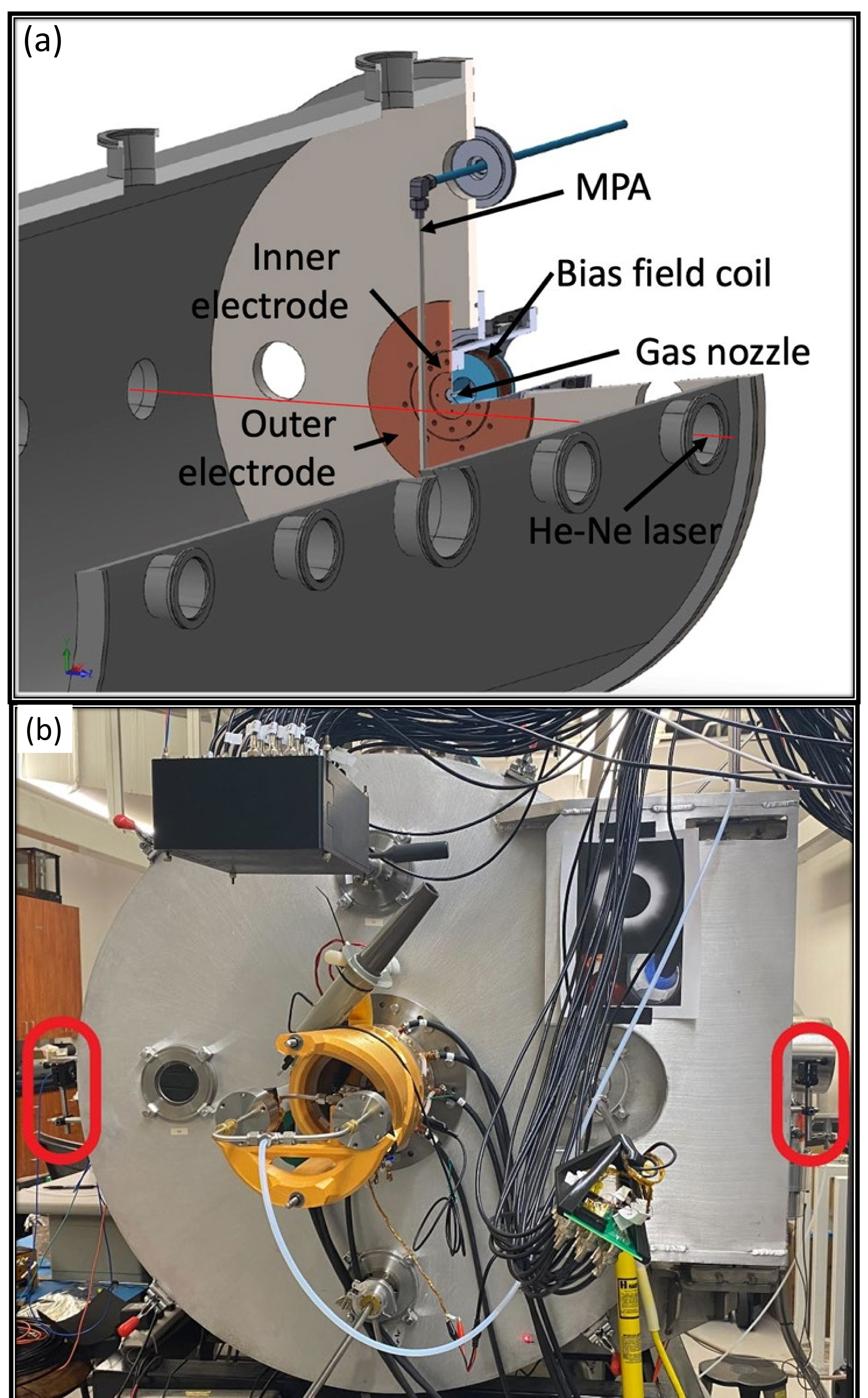

Figure 1. (a) Interior and (b) exterior of plasma chamber with interferometer fiber launcher and mirror in circled in red.

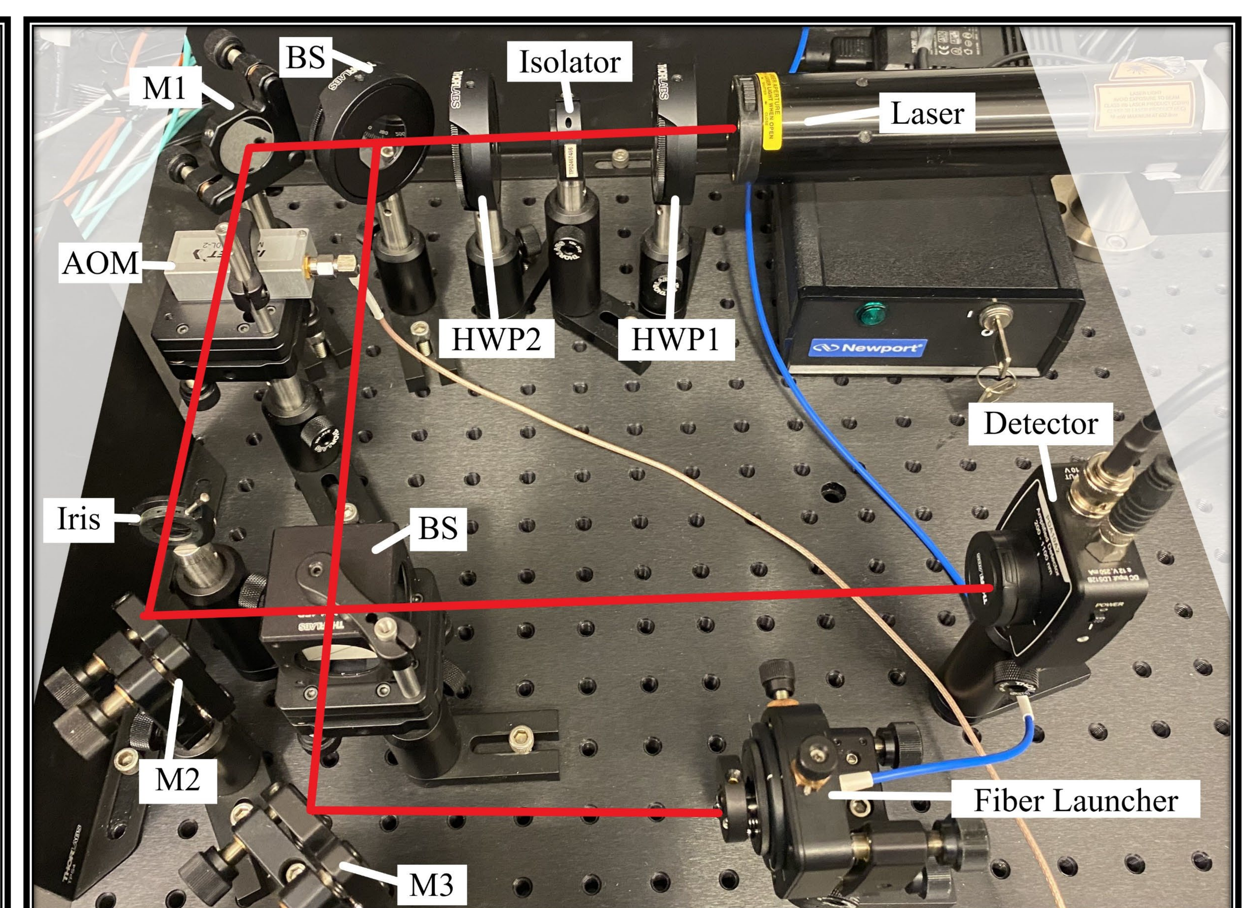

Figure 2. Heterodyne Interferometer Optics Bench Setup.

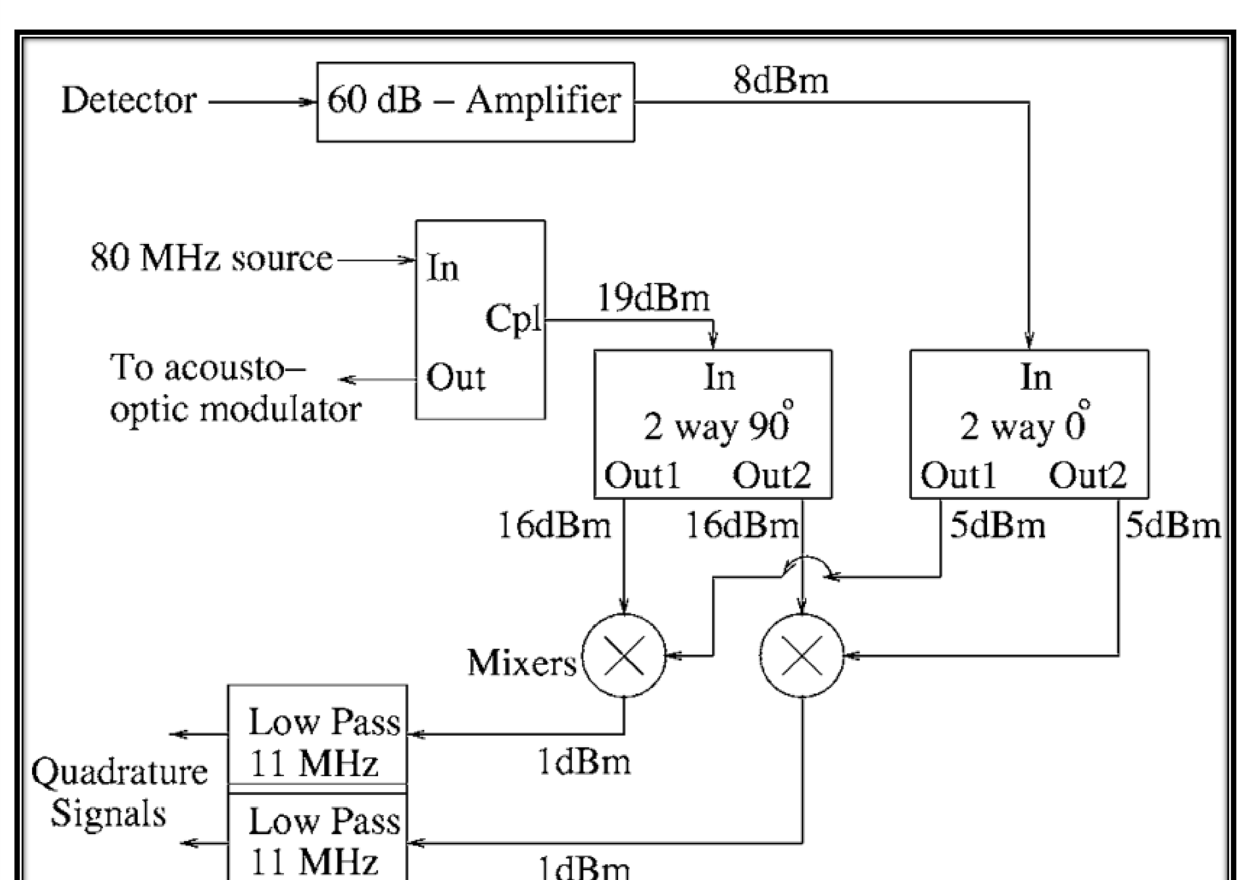

Figure 3. RF Circuit Diagram of the Heterodyne Interferometer[3].

Procedure

Plasma Evolution

1. Plasma Jet created by plasma source.
2. Magnetic helicity injected via bias field coil.
3. MHD instabilities and/or magnetic reconnection.
4. Ion heating(conversion of magnetic to thermal energy).
5. Dispersion.

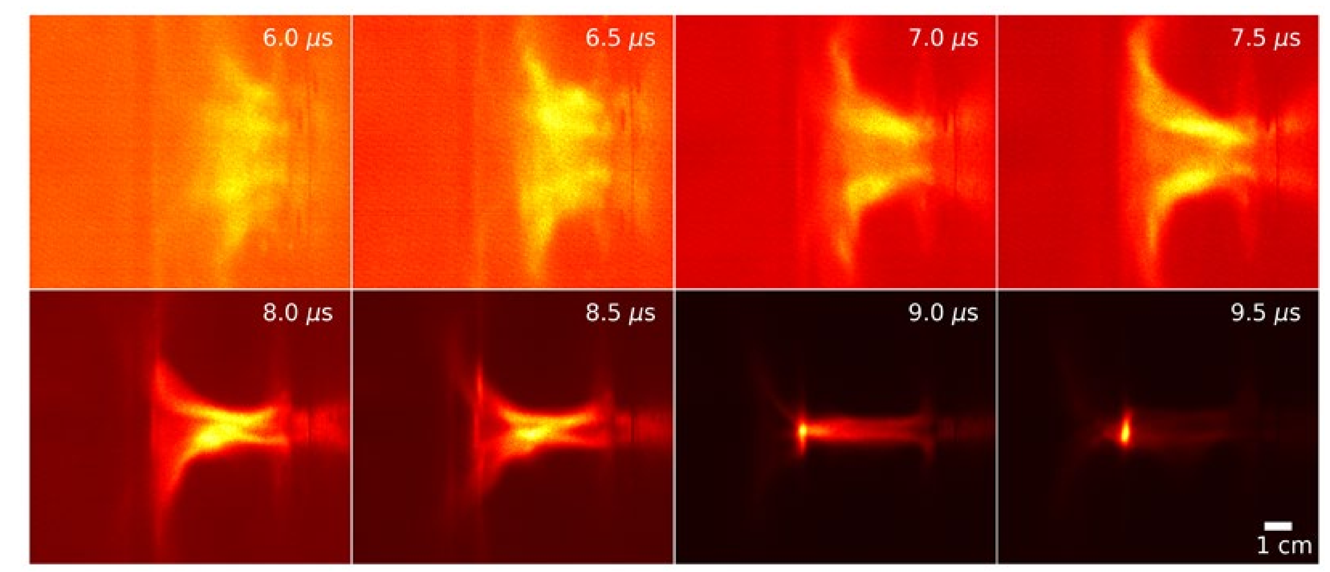

Figure 4. Photos of plasma jet taken at 0.5 microsecond interval show the evolution of the plasma jet.

Interferometer Data Analysis

The scene beam which passes through the plasma, is interfered with the modulated beam on the detector. The detector's signal is passed through a RF Circuit, Fig. 3, where it is mixed with the modulated signal to produce two quadrature signals. Which are used to determine the phase shift in the laser beam caused by passing through the plasma.

The plasma density can be determined by the phase shift observed in the quadrature signal compared to the phase before the plasma jet is initiated, using the equation below.

Equation to Find Plasma Density from Change in Phase-Shift of Quadrature Signal

$$\int_0^L n(x)\,\mathrm{d}x = \frac{4\pi c^2 m_e \varepsilon_\circ}{e^2 \lambda_\circ}\Delta\varphi_p,$$

Where $\Delta\varphi_p$, is the phase-shift induced by the plasma, m_e is electron mass, c is the speed of light, ε_0 is the permittivity of free space, e is electron charge, L is the length in the plasma the laser beam travels, and λ_0 is the wavelength of He-Ne laser[4].

Plasmoid Velocity

The velocity of the plasmoid can be determined by dividing the distance from the plasma source to the scene beam by the amount of time it takes the plasmoid to reach to the interferometer. This can be done by taking the time that the line-averaged number density is at maximum to be the time at which the plasma arrives at the scene beam.

Results

Preliminary data is displayed in, Fig. 5, of the average of shots 1006-1008. The interference signal has a maximum line–averaged electron density of $2.6 * 10^{21}$ m^{-3}.

For these shots the time at which the electron density is maximum is t = 11.4 microseconds after the plasma gun was fired. The plasma velocity for this shot was calculated to be 12.7 km/s.

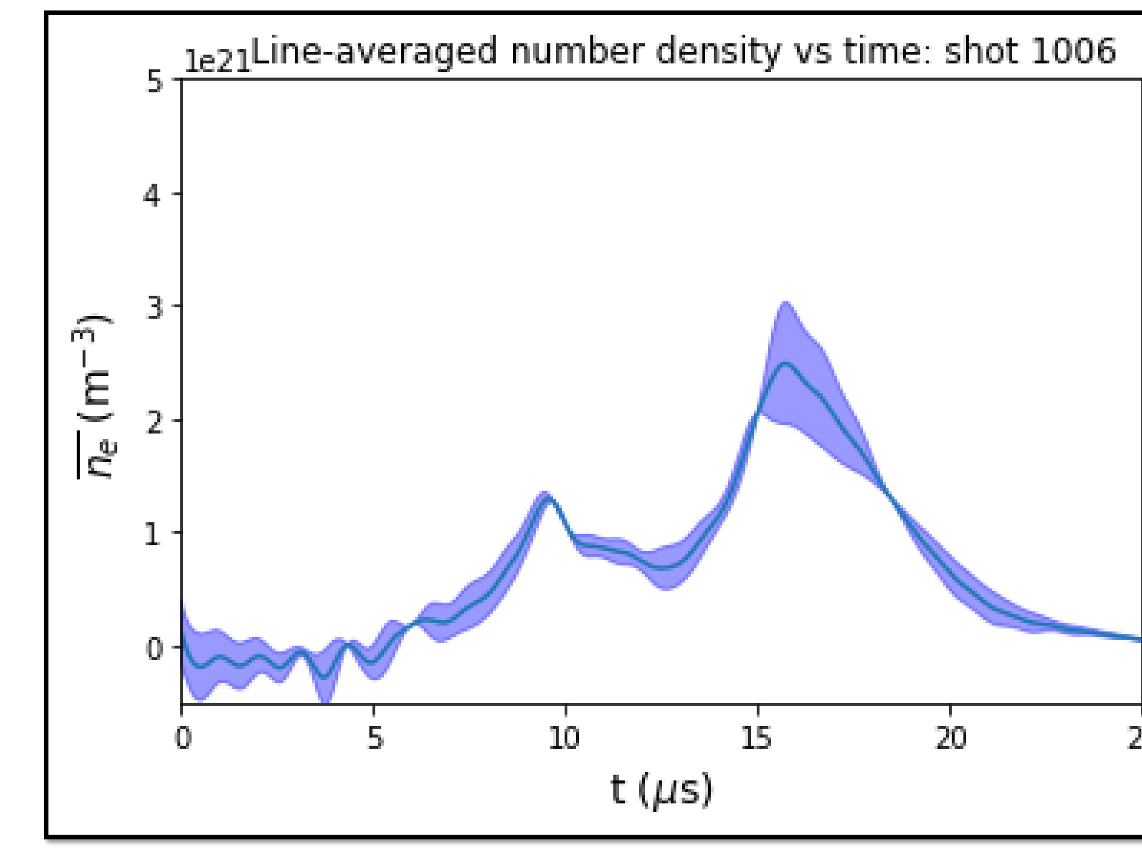

Figure 5. Line-averaged number density vs. time plot, created using the average of the 3 shots with same parameters. The highlighted blue region is the mean +/-standard deviation at that time.

Discussion

The interferometer is functional, however minor adjustments need to be made before comprehensive data collection can take place. The line-averaged density measurements will enable the observation of ion heating due to different plasma instabilities and conditions. Because it is easily spatial translatable it could be used to observe the plasma velocity at various location, yielding information about its acceleration as well.

References

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