A Magneto-Plasma-Dynamic Arcjet(MPDA) Plasma Density Measurements by Using Multi-Reflection Type He-Ne Laser Interferometer

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(Received: 29 August 2008 / Accepted: 12 December 2008)

A magneto-plasma dynamic arcjet(MPDA) is utilized as a high-enthalpy plasma source. Detailed measurement of plasma parameters in the vicinity of a MPDA is important to evaluate its performance. We have developed a multi-reflection type He-Ne laser interferometer for measurement of a high density plasma in the vicinity of a MPDA. We estimated the maximum value of electron density of $1.5 \times 10^{21} m^{-3}$ near the MPDA muzzle.

Keywords: magnet-plasma-dynamic arcjet, high density plasma, laser interferometer, multi-reflection, Abel inversion

1. Inroduction

A magneto-plasma-dynamic arcjet (MPDA) is utilized as a high-enthalpy plasma source not only for a plasma injection source for open magnetic confinements but for an electric propulsion and several applications. Detailed measurement of plasma density in the vicinity of an MPDA is important to evaluate its performance.

The interferometry method using electromagnetic waves is useful and convenient to obtain a line-integrated plasma density[1] and can be used in the high density plasma more than $10^{20} m^{-3}$, where it is difficult to measure the plasma density by an electrostatic probe. The MPDA plasma density had been measured by an interferometry method using a CO_2 laser[2] or a dual-beam laser[3]. However, the interferometer was not always used as an electron density measurement method and detail measurement has not been achieved yet,.

The purpose of this research is to measure a high density plasma in the vicinity of an MPDA using a laser interferometer. The feature of this interferometer is to use a He-Ne laser (λ=632.8nm) and a multi-reflection optical system. A He-Ne laser is easily obtained and easy to handle as visible light. As it doesn't have enough phase shift when the light passes through the MPDA plasma once, we adopt a multi-reflection optical system in this interferometer to improve the phase sensitivity.

2. Interferometer system

A Schematic of the Michelson-type interferometer system is shown in Fig.1, where a He-Ne laser (10mW) is used as a light source. The laser beam is divided into a reference beam and a probe beam by a beam splitter (BS). The probe beam is reflected between a corner cube mirror and a flat mirror with a convex lens and passes through a plasma many times. The multi-reflection optical system[4], which was developed to measure a high accuracy displacement, has a simpler structure for an easy alignment than the two lenses and flat mirrors used in this system. One of the additional advantages in this system is that the number of reflection can be easily changed. We adopted the optical system to the plasma measurement. However, the spatial resolution is rather poor because the average values of the integrated line density along with an optical path is obtained.

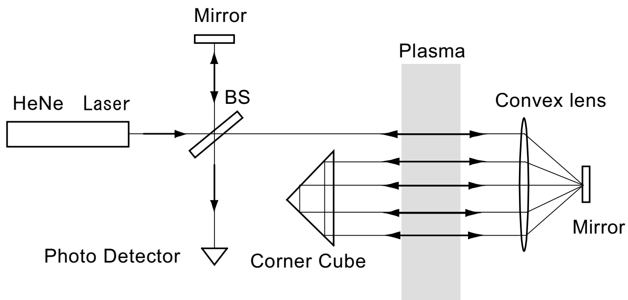

Fig.1. Schematic view of the multi-reflection type laser interferometer

A mockup experiment was attempted in order to confirm the performance of the system. We measured a phase shift when the light passes through air gas, since the refractive index is changed according to gas pressure. The experimental results are in good agreement with the calculated results[5].

3. Experimental setup

The interferometer is attached to a HITOP device[6] of Tohoku University as shown in Fig.2(a). The HITOP consists of a large cylindrical vacuum chamber (0.8m in

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diameter, 3.3m in length) with eleven main and six auxiliary magnetic coils, which generate a uniform magnetic field up to 0.1T. A high power quasi-steady MPDA as shown Fig. 2(b), is installed at one end-port of the HITOP. An MPDA has coaxial electrodes with a central cathode rod and an annular anode. The discharge current I_d up to 10kA is supplied with a quasi-steady duration of 1ms. A high density plasma (more than $10^{20}m^{-3}$) is produced with helium as working gas and accelerated axially by an electromagnetic force generated by a radial discharge current and an azimuthal self-induced magnetic field. The MPDA plasma characteristics are measured by a several diagnostics installed on the HITOP. Spatial profiles of electron temperature T_e and density n_e are measured by a movable electrostatic probe and a fast-voltage-scanning electrostatic probe at the downstream region. T_e and n_e are derived from a current-voltage characteristic line detected by the electrostatic probes[7]. Ion temperature and plasma flow velocity are measure by a spectrometer with an ICCD detector at the vicinity of the MPDA. Typical ion temperature is 10-20eV, higher than electron temperature T_e (5-10eV), and axial flow velocity is 3×10^4m/s.

The vacuum windows, are made of fused-quartz with 0.11m×0.31m, and located at the vicinity of the MPDA as shown in Fig.2(c). The distance between the vacuum windows is 0.5m. The center of the laser beam of the installed interferometer is set at Z=0.135m. Although the diameter of a single laser beam at the plasma center is around 0.1cm, the density measurement region is broadened to 3cm in width due to the multi-reflection. As the spatial variation along the axial direction is weak, we set the multi-beam path shifting in axial direction to minimizing the error due to the change of n_e during the multi-reflection. The resolution of the electron density of the interferometer is around $10^{20}m^{-3}$. The multi-reflection system of the laser interferometer can be moved in a vertical direction (Y-axis). In order to reconstruct the density profile from the line integrated density measurement, the Abel inversion is employed. The line integrated density profile is obtained by moving the laser beam that pass through the plasma to the radial direction each discharges. A mechanical vibration is one of the most serious problems for the interferometer. Many interferometers used on existing plasma experiments are two-color interferometers [8] that decouple the phase shift caused by mechanical vibrations. Mechanical vibrations are not so important because of the short duration (1msec) of the HITOP discharge, since the mechanical vibration frequency in the system is several hundred Hertz .

4. Experimental results

Figure 3 shows electron density profiles measured by an electrostatic probe set at Z=0.17m, the laser interferometer where the light passes 6 times through the plasma at Z=0.05m. These results are similar to each other. Please note that the measured direction is different through the location is roughly the same. We assumed the axis-symmetry cylindrical plasma with Gaussian density profile. The radius of the electron density profile is 3cm in e-folding length. The radius is not changed through the maximum electron density increases according to an

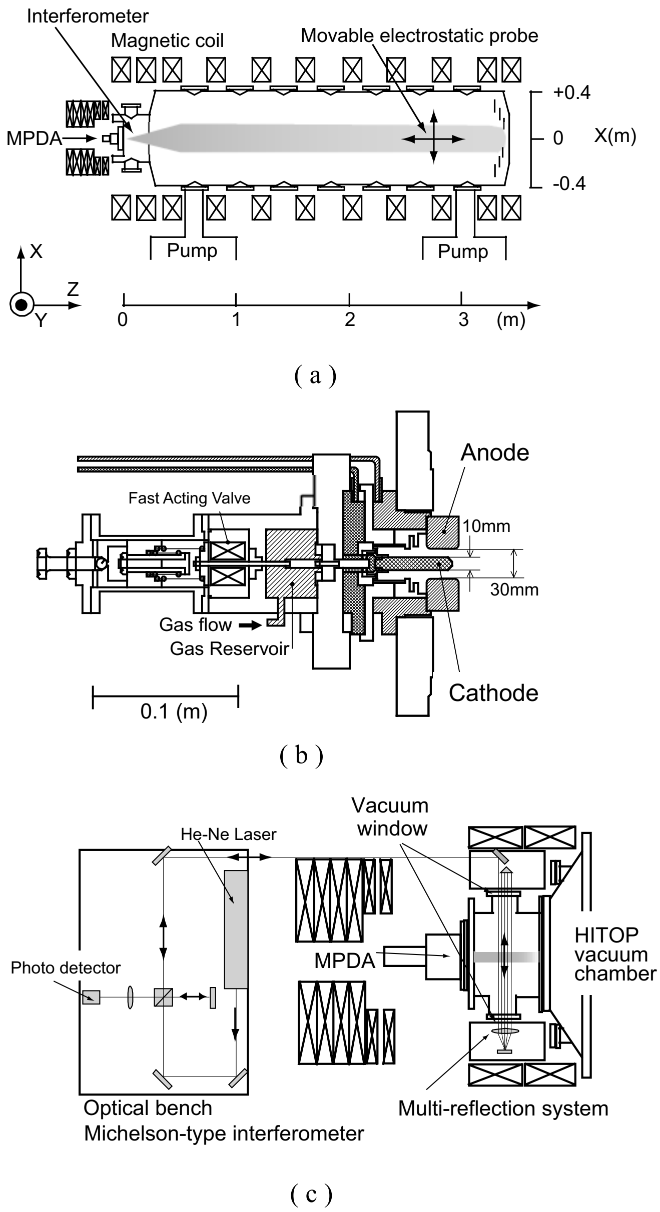

Fig. 2 Schematic views of (a) the HITOP device, (b) the MPDA device and (c) the multi-reflection type laser interferometer.

increase in the discharge current I_d. This radius is the same as the inside diameter of the anode. We estimated from these results that maximum value of electron density is $1.5\times10^{21}m^{-3}$. The density of neutral particles is estimated to be $2\times10^{22}m^{-3}$ from the calculated gas flow rate. The ionization degree is about 10 percent in this experimental condition.

Line-integrated density is measured as a function of a discharge current I_d and plotted in Fig.4 for different values of operating gas pressure in MPDA discharge. The line-integrated density increases almost linearly with I_d.

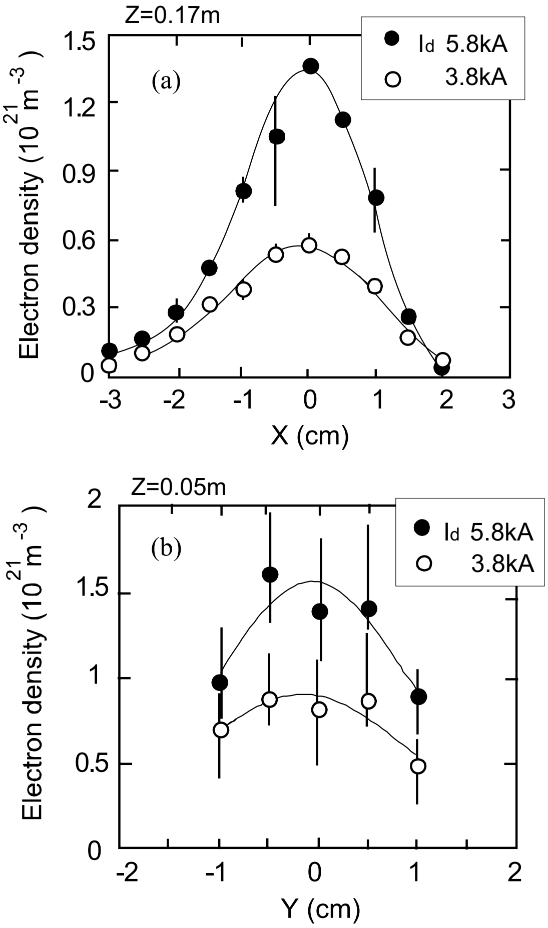

Fig. 3 Electron density profiles measured by the electrostatic probe(a) and the interferometer(b).

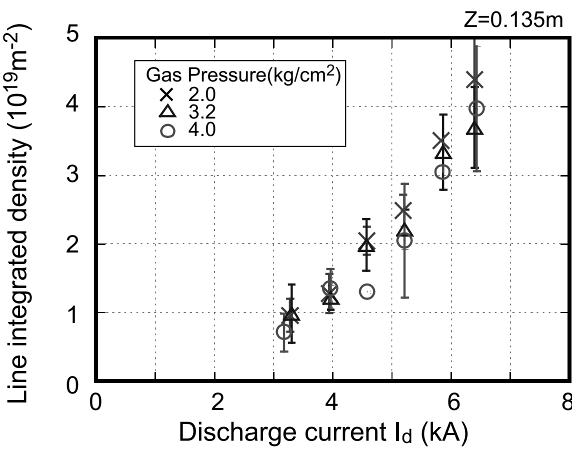

Fig.4 Dependence of the line integrated density with the discharge current I_d.

The axial profiles of the plasma density measured by the electrostatic probe is shown in Fig.5. Plasma density decreases in the downstream region in the experiment. The estimated plasma density on axis at Z=0.05m using the laser interferometer also plotted in Fig. 5. This tendency agrees with that of the electrostatic probe measurement in the downstream region. We don't understand the detailed reason why the density decreases with axial distance from MPDA. One reason is that the plasma is diffused by the collision of the neutral particles. It is necessary to investigate about the reason in the future.

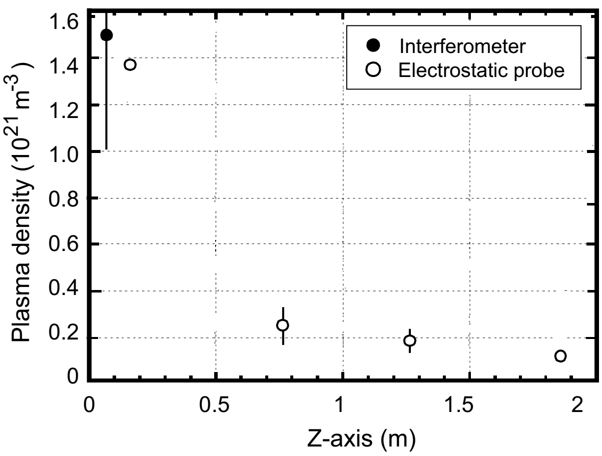

Fig. 5 Axial profile of the plasma density measured by the interferometer and the electrostatic probes. (Discharge current I_d=5.4kA, Uniform magnetic field strength=0.087T).

5. Summary

We have developed the Michelson-type interferometer with a multi-reflection optical system. A He-Ne laser(λ =632.8nm) is used as a light source. As the wavelength of the laser is short, the phase shift is magnified by a multi-reflection optical system. The interferometer system is adopted to measure the MPDA plasma. The maximum value of electron density in the vicinity of the MPDA is estimated to be $1.5\times 10^{21}m^{-3}$ at I_d=6.5kA. These experimental results are consistent with that of electrostatic probe measurement in the downstream region. The radius of the electron density profile is 3cm in e-folding length. This radius is the same as the inside diameter of the MPDA anode.

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