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LASER THOMSON SCATTERING MEASUREMENT TO DIAGNOSE THE LOW TEMPERATURE PLASMAS

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Abstract: This paper describes how to measure the plasma temperature and density using laser Thomson scattering signal. Electron energy probability functions (EEPFs) having a fine resolution of electron energy were measured in low-pressure inductively coupled plasma with laser Thomson scattering method (LTS) at various plasma conditions (rf powers and gas pressures) and compared with the EEPFs measured by a single Langmuir probe (SLP) at the same experimental conditions. The result of LTS showed that the measured electron density normally increases with the rf power and the gas pressure, and the electron temperature decreased with the rf power and the gas pressure. The results have a good agreement not only with the previous reports qualitatively but also with our SLP measurement result quantitatively.

Keywords: Laser Thomson Scattering, plasma diagnostics, plasma density, electron temperature.

1. INTRODUCTION

Laser Thomson scattering (LTS) has been known as the most accurate diagnostic method in measurements of plasma, which normally has been used for high electron density and temperature of fusion plasma research [2]. Although it is hard to measure plasma parameters in processing plasma due to using molecular species for processing gases that cause Raman scattering which makes signals distorted, its low electron density, low electron temperature and small cross section of electron itself, many researches have been performed on various plasma sources and conditions. Starting from the first measurement in Electron Cyclotron Resonance (ECR) plasma of low temperature plasma sources performed by M. Bowden, et al. [3], many studies on the sources of Inductively Coupled Plasma (ICP) [4], Capacitively Coupled Plasma (CCP) [5], Magnetized Inductively Coupled Plasma (MICP) [6] and others [7–9] have been performed for measurements of EEPFs. Those results normally showed a typical maxwellian distribution [3, 4, 6–9] or a bimaxwellian distribution [4, 5, 10] in high pressure or low pressure respectively, and its transition via pressure change, which is consistent with the result of probe EEPFs diagnostics [11]. Some of the researches have been performed to compare the LTS result with the Single Langmuir Probe (SLP) result [11, 12, 12–14], and a research of more reliable LTS EEPFs diagnostics including a comparative result with SLP EEPFs is still needed not only to establish the reliable LTS EEPF diagnostic but also to support the uncertainty and accuracy for the SLP.

In this paper, we measured EEPFs with LTS of fine electron energy resolution in low-pressure inductively coupled plasma at various plasma conditions (rf powers and gas pressures) and compared with the EEPFs measured by a single Langmuir probe (SLP) adequately at the same experimental conditions. The result of LTS showed that the measured electron density normally increases with the rf power and the gas pressure, and the electron temperature decreased with the rf power and the gas pressure. This result have a good agreement not only with the previous reports qualitatively but also with our SLP measurement result quantitatively [15]. The reasons for the discrepancy between two methods in absolute value might be expected to these facts as following: the probe perturbation effect from the probe holder volume, RF noise, and not sufficient signal level of laser Thomson scattering.

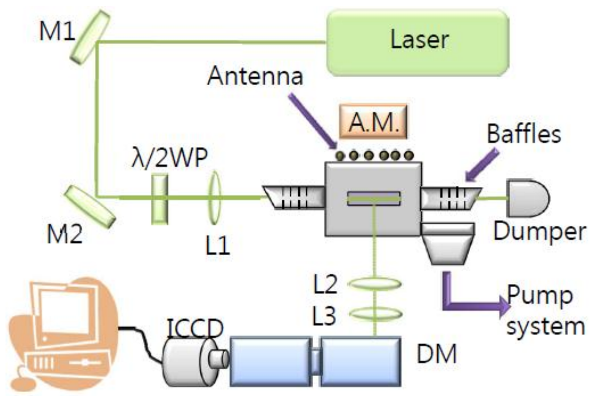


Figure 1. A schematic arrangement of Thomson scattering experiment in ICP

2. EXPERIMENTAL DETAILS

Figure 1 is a schematic arrangement of the experimental apparatus of LTS for the ICP plasma. The cylindrical ICP chamber of which inner diameter and height are 400mm is covered by a cylindrical ceramic window of which diameter and thickness are 350mm and 15 mm, respectively. The discharge is ignited and sustained by 13.56MHz rf current delivered by the RF power supply (300W to 1000 W) through L-type matching network and a coaxial cable. A constant gas flow of Argon 100 sccm was fed during the discharge operation to maintain the gas purity and an automatically controlled throttle valve which is synchronized with Baratron gauge (MKS.INC) was used to keep and control the gas pressure in the range of 5mTorr-100mTorr. For the measurement of LTS, a frequency doubled Nd:YAG laser (Continuum Inc., Powerlite 9010) working at 10 Hz with a pulse energy of 400 mJ at 532 nm was used. A pair of Brewster window coated for the antireflection of 532 nm wavelength light and a series of baffles in arms of Brewster windows were mounted at the both sides of ICP chamber along the light trace of the laser to minimize stray light and loss of laser energy. The vertically polarized laser beam made by a l=2 wave plate was focused at the center of the discharge chamber using a lens L1 (focal length f = 700 mm). The Thomson scattered light was collected by a pair of achromatic lenses (L2, L3) which can compensate abberation of the light and be coated for antireflection of 532 nm wavelength light as well. These two lens (L2 f = 300 mm, L3 f = 250 mm) are used to collimate the scattered Thomson light and focus onto the slit width of 600 mm in double-monochromater. An ICCD camera (Princeton Instruments, PI-MAX) was employed to intensify and accumulate the scattered signals. The ICCD camera is operated at doubled trigger signals (20 Hz) generated from laser trigger (10 Hz) to extract background signals emitted by plasma simultaneously (strictly, the time difference between Thomson signal and background plasma signal is 0.05 S). The detected Thomson scattering signals and background signals measured by ICCD were recorded and transferred to a computer for further data processing.

3. RESULT AND DISCUSSION

Figure 2 shows the measured light intensity of scattered laser signal from the discharge center when the plasma on (red line, we call original row data in this paper) and off (black line), respectively. As shown in figure 2 (see red line), although an incident laser light used in experiments is quasi-monochromatic spectrum laser light having a centered wavelength of 532 nm and a band width around 1 nm, the measured scattered signal is broadened(see the in-box which is a magnified spectrum of bottom part of an original spectrum). Because this is due to the Doppler effect induced by moving species in the plasma (electrons and ions), the broadened scattered laser signal from the centered wavelength (532 nm) in the wavelength spectrum contains the information of velocity distribution of these moving species.

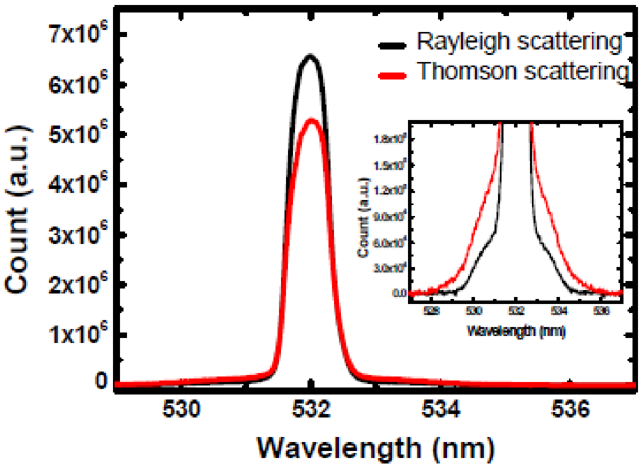
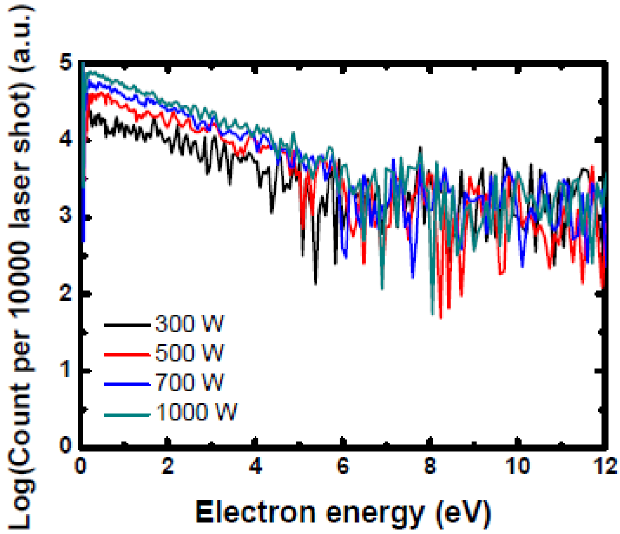


Figure 2. Spectrums of scattered lights measured by ICCD which indicate plasma off for Rayleigh scattering

Among the moving species, the electron is the fastest one, thus one might want to believe that the broadened scattered laser signal is mainly influenced by the electron movements and directly related to the one dimensional Electron Velocity Distribution Functions(EVDFs) of the electrons [17]. However, because there are a number of neutrals of which number density is one or two order of magnitude higher than that of electrons, the measured light intensity of scattered laser signal when plasma is on is the superposed signals between neutrals and electrons, thus one have to take account with the scattering light due to neutral (Rayleigh scattering) for the measurement of proper laser Thomson signal. Indeed, as shown in figure 2 (see the black line), the scattered laser signal from the discharge center when the plasma is off, i.e., Rayleigh scattering signal, is not negligible but significant. Therefore, the proper laser Thomson scattering signal can be obtained by subtracting the Rayleigh scattering signal from the laser scattered signal when the plasma is on.

Figure 3 (a) shows a Thomson spectrum at various discharge powers (300W-1000 W) presented in semilog plot (x:linear scale, y:log scale). The Dl2 referenced from the wavelength of incidence laser light (532 nm) is proportional to the electron energy, this spectrum is corresponding to EEPF as explained before, thus we can compared it with the result Langmuir probe EEPF (figure 3 (b)). Indeed, our Thomson spectrum signal of figure 3 (a) is well recognized as a Maxwellian distribution which is typical one in ICP discharge, with clear straight line slope, high signal to noise ratio, and little distortion compared with other previous results [3–5, 9]. As the discharge power increases, the level of EEPF increase with a little increase of slop in EEPF, ie, while increasing the discharge power, the electron density increases and the electron temperature decreases a little. This trend of electron density and temperature with discharge power is also reflected in the EEPF measured of Langmuir probe (figure 3 (b)).



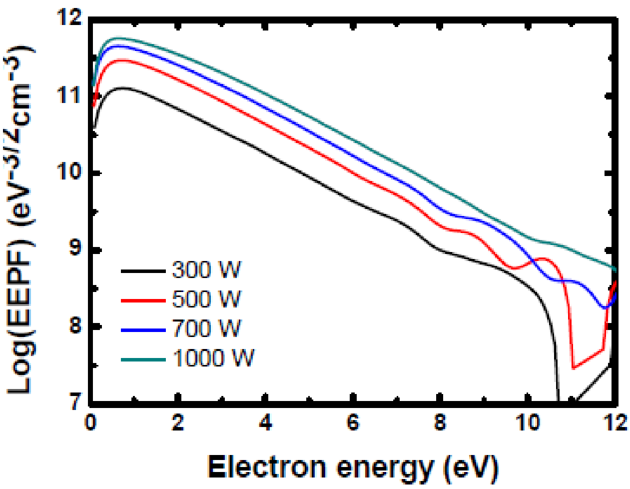


Figure 3. (a) EEPFs measured by LTS with power variation at a fixed Ar pressure of 100mTorr (b) EEPFs

4. SUMMARY AND CONCLUSION

In conclusion, we measured EEPFs with LTS of fine electron energy resolution in low-pressure inductively coupled plasma at various plasma conditions (rf powers and gas pressures) and compared with the EEPFs measured by a single Langmuir probe (SLP) adequately at the same experimental conditions. The results show that two methods are in a good agreement with each other but there are some discrepancy of which degree is changed depending on the experimental condition. The reasons for the discrepancy between two methods in absolute value can be explained by considering the probe perturbation effect from the probe holder volume, RF noise, and not sufficient signal level of laser Thomson scattering.

Acknowledgments

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