S8-5

Application of Microwave Reflectometry to Reactive Plasma Diagnostics

マイクロ波反射法の反応性プラズマへの適用

A. Mase, Y. Kogi, K. Kudo, L. Bruskin
間瀬　淳，近木祐一郎，工藤光生，ブルスキン レオニド

Art Science and Technology Center for Cooperative Research, Kyushu University
Kasuga, Fukuoka 816-8580, Japan
九州大学産学連携センター，〒816-8580　福岡県春日市春日公園6-1

An ultrashort-pulse reflectometry using an impulse generator as a source has been applied to an inductively coupled plasma. The reflectometer signal is recorded to a digitizing scope, and analyzed by a signal record analysis of profile reconstruction that relies on a raw signal waveform rather than on the group delay of each frequency component of an impulse. The reconstructed density profiles agree with those obtained by a plasma absorption probe in edge plasma region. The discrepancy in core region seems to be caused by the difference of optical path for each frequency component. By rearranging the optical setup, both profiles became in good agreement in core plasma region.

1. Introduction

A pulse radar (reflectometer) is utilized to measure electron density profiles of plasmas. An incident wave with higher frequency is reflected from higher density cutoff layer. It enables us to reconstruct the density profile by collecting a time delay of the reflected wave with distinct frequencies from each cutoff layer.

In an ultrashort-pulse reflectometer (USRM) an impulse with less than 100 ps pulse width is used as a source. Since the bandwidth of the source is in inverse relation to the pulse width, we can easily employ the source with frequency up to 10 GHz. The density profile is reconstructed by measuring time-of-flight of each frequency component reflected from each cutoff layer. It is hardly influenced by the existence of density fluctuations, since the measurement can be completed during the impulse is reflected back to an antenna. Typical duration of the propagation inside plasma is less than a few ns. This implies that the plasma is thought to be frozen even when the density fluctuations with frequency up to 100 MHz are excited in the plasma. The data handling is also not difficult, since the measurement is performed in time domain. However, the above advantages cause increment of detection channels for each frequency component to attain precise reconstruction of the profile. We have proposed an efficient and precise solution to this problem, which utilizes signal record analysis (SRA) method [1]. We present here the application of an USRM to an inductively coupled plasma (ICP).

2. Experimental Apparatus

In Fig. 1 is shown the schematic of the experimental setup. Argon (Ar) plasma is produced by a spiral antenna and an RF source with frequency of 13.56 MHz and power of 1-5 kW. Diameter and height of a vacuum vessel are 60 cm and 50 cm, respectively. The electron density and temperature in core region attain over 4×10^{18} m^{-3} and 1-3 eV respectively when the flow rate of Ar is around 400 ccm. The impulse generator transmits a monopulse with amplitude of 8 V and a full width at half maximum (FWHM) of 65 ps. This impulse is fed into a waveguide via a coaxial cable, a power amplifier, and a coaxial-to-waveguide adapter, and transmitted into the plasma by a pyramidal horn located 2 cm in front of the side port through a fused-quartz window. Two types of horn antenna are used depending on the frequency band, 4.5-8.0 GHz and 7-20 GHz. The reflected wave from the plasma is received by an identical horn attached under the transmitter, and recorded by a sampling scope of 50 GHz bandwidth. Along with the USRM system, a plasma absorption probe (PAP) [2] is employed as shown in Fig. 1. The probe is located at the opposite port of the USRM.

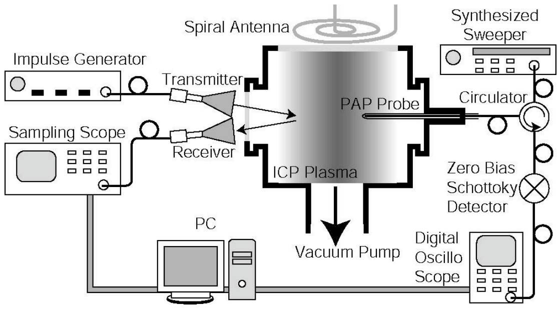

Fig. 1. Schematic of experimental apparatus.

3. Experimental Results

Figure 2 shows the density profiles measured by the USRM and the PAP. It is found that outer side of the density profiles are in good agreement. However, inner side of the density measured by the USRM reaches ~1.5 times of that measured by the probe. This phenomenon is considered to be due to the reflection waveform from the vacuum window. In the beginning the reflected waveform from the vacuum window is used for canceling the effect of frequency dispersion inside the waveguides and the antennas. This canceling process may not work properly when optical path route is different within the frequency-band. Multi-reflection effect and direct coupling between antennas can be considered as influences, which cause difference of optical path route within the frequency band. In the present experiment, the distance between the vacuum window and the antennas is relatively close compared to wavelength of the incident wave. When the lower frequency component of the incident wave is injected to the window, this wave is reflected and received directly. However, in the case that the higher frequency component of the wave is injected to the window, the wave is multi-reflected between the window and the antennas, since the directivity of the wave with higher frequency is better. Phase of the higher frequency component becomes larger corresponding to the optical path length. In order to improve accuracy of the USRM measurement, we have employed the reflection waveform from the opposite side of the vacuum vessel. Optical path length is fixed over the wide frequency range. The top of Fig. 3 shows the reflected waveforms from the vacuum window and from the backside vacuum wall, respectively. By using these waveforms as an initial condition, we can obtain the density profiles shown in bottom of Fig. 3. Broken and solid curve correspond to the density profile by using the former and later parts of the reflection, respectively. It is confirmed that the density profile becomes broadening in the latter case. Broadening of the density profile, i.e. decrease of the density value at specific radial position, is consistent with the density profile measured by the PAP.

Figure 4 shows the time evolution of the density profiles during the change of gas pressure. It is clearly seen that the plasma is expanded in radial direction.

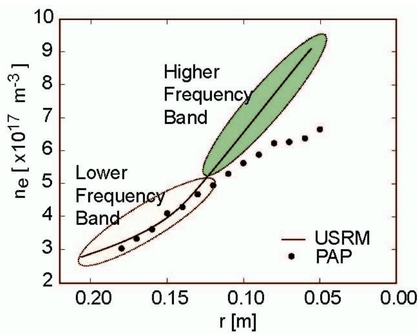

Fig. 2. Density profiles measured by USRM and PAP.

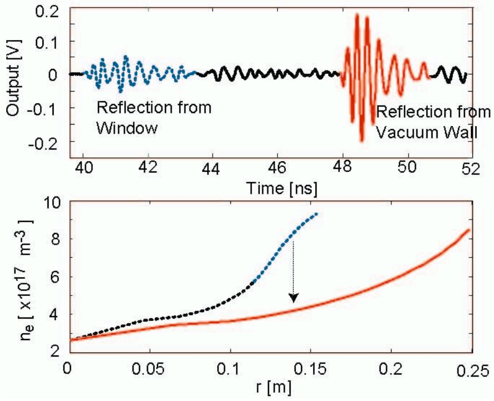

Fig. 3. Reflected wave from vacuum window and backside vacuum wall (top), and reconstructed density profiles (bottom).

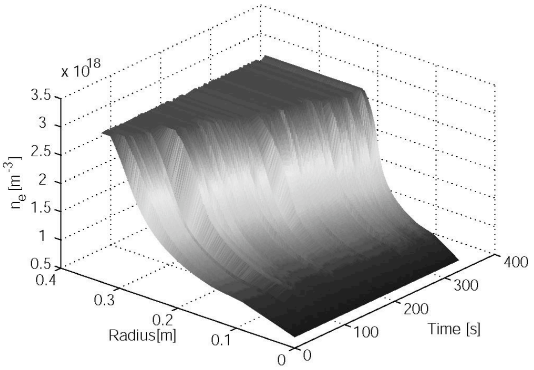

Fig. 4. Time evolution of reconstructed density profiles.

4. Summary

We have applied an USRM to an ICP for density profile measurement along with a PAP. It is found that the density in the edge plasma region agrees well with each other, however, there is a discrepancy in the core region. This discrepancy is considered to occur due to the difference of optical path route within utilized frequency band. Using the reflected wave from the backside vacuum wall as an initial condition, we confirmed that the density in core region agrees with that measured by the PAP.

Acknowledgments

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References

[1] L.G. Bruskin, A. Mase, A. Yamamoto, M. Ohashi, and T. Deguchi, Jpn. J. Appl. Phys. **40** (2001) 705.

[2] H. Kokura, K. Nakamura, I.P. Ghanashev, and H. Sugai, Jpn. J. Appl. Phys. **38** (1999) 5262