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# Electron density measurement of magnetic confinement plasma and high-pressure plasmas with a phase-modulated dispersion interferometer

# 位相変調2倍高調波干渉計を用いた磁場閉じ込めプラズマと高気圧プラズマの電子密度計測

T. Akiyama[1], K. Urabe[2], N. Shirai[3], R. Yasuhara[1], K. Kawahata[1], K. Nakayama[4], S. Okajima[4], T. Murakami[5], K. Tomita[6], and K. Terashima[2]

秋山毅志[1]、占部継一郎[2]、白井直機[3]、安原亮[1]、川端一男[1]、中山和也[4]、岡島茂樹[4]、村上朝之[5]、富田健太郎[6]、寺嶋和夫[2]

[1]*National Institute of Fusion Science, Toki, Gifu 509-5292, Japan*
核融合科学研究所，〒509-5292　岐阜県土岐市下石町322-6
[2]*Department of Advanced Materials Science, The University of Tokyo, Kashiwa, Chiba 277-8561, Japan*
東京大学 物質系専攻，〒277-8561　千葉県柏市柏の葉5-1-5
[3]*Department of Electrical & Electronic Engineering, Tokyo Metropolitan University, Hachioji, Tokyo 192-0397, Japan*
首都大学東京 電気電子工学専攻，〒192-0397　東京都八王子市南大沢1-1
[4]*College of Engineering, Chubu University, Kasugai, Aichi 487-8501, Japan*
中部大学 工学部，〒487-8501　愛知県春日井市松本町1200
[5]*Department of Energy Sciences, Tokyo Institute of Technology, Yokohama, Kanagawa 226-8503, Japan*
東京工業大学 創造エネルギー専攻，〒226-8503　神奈川県横浜市緑区長津田町4259
[6]*Department of Applied Science for Electronics & Materials, Kyushu University, Kasuga, Fukuoka 816-8580, Japan*
九州大学 量子プロセス理工学専攻，〒816-8580　福岡県春日市春日公園 6-1

The dispersion interferometer is a powerful electron density measurement tool for both the magnetically confined fusion plasmas and the high pressure plasmas. It is less affected by the mechanical vibrations and changes in the neutral gas density, which cause significant measurement errors. The feasibility is demonstrated on LHD and with an atmospheric pressure plasma.

## 1. Introduction

An interferometer is a conventional tool to measure the electron density of a plasma. It measures the phase difference between a probe and local lights. The phase difference depends on not only the electron density, but also the change in the optical path length due to mechanical vibrations, and the changes in the neutral gas density. Since the phase shifts caused by the three terms cannot be distinguished in the conventional interferometer, the latter two terms lead to measurement errors.

In the case of the measurement of the magnetically confined fusion plasmas, the phase shift caused by the neutral gas density can be negligible because the neutral gas pressure in a vacuum chamber is quite low. Since the main error term is the mechanical vibrations, some of the interferometer installed on fusion devices are equipped with a vibration isolation bench and/or an additional interferometer with the same line of sight with the different wavelength. By using these, the density resolution is improved.

As for the measurement of the high-pressure plasmas, changes in the neutral gas density due to the temperature rise during the discharge cause the significant error in phase measurement, in addition to the mechanical vibrations. Since the time constants of vibrations and the gas density change are much larger than that of the electron density, the density is evaluated at the begging of the discharge [1].

A “dispersion interferometer” [2,3] measures the phase difference originated from dispersion between the fundamental and the second harmonic light in a medium. While the refractivity of a plasma has strong dependence on the wavelength, the refractivity of the neutral gas has quite small dependence. Hence the phase difference caused by the mechanical vibration and changes in the neutral gas density is much smaller than that by the changes in the electron density. Then the dispersion interferometer does not affected by the mechanical vibrations and changes in the neutral gas density. In this study we applied the $CO_2$ laser dispersion interferometer to the magnetically confined fusion plasma in the Large Helical Device (LHD) and the atmospheric pressure plasma.

## 2. Measurement Principle

Figure 1 shows the principle of the dispersion

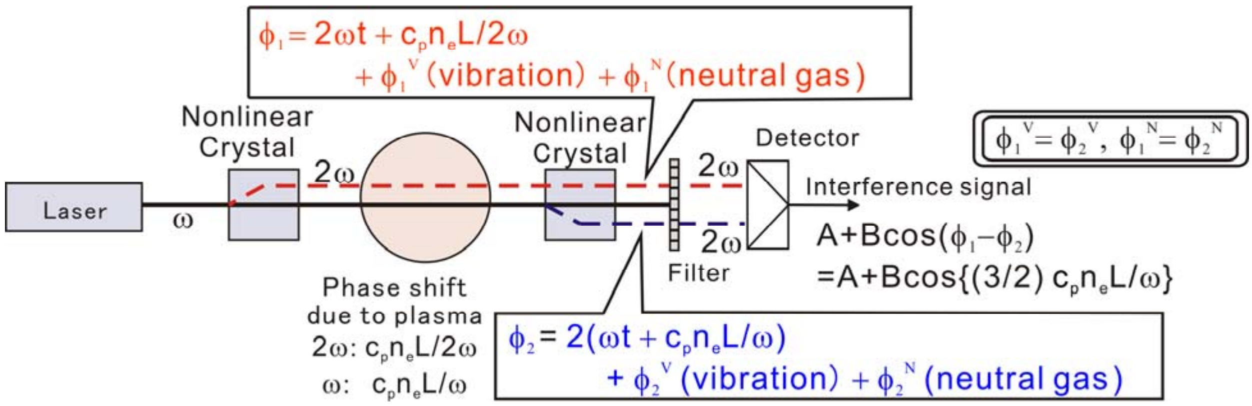


Fig. 1: Principle of the dispersion interferometer

interferometer. The probe light is a mixture of the fundamental and the second harmonic light. After passing through a plasma, the second harmonic light is generated again and the interference between two second harmonic lights is detected. Since the phase shifts caused by the mechanical vibration $\phi^V$ and $\phi^N$ are almost the same between two second harmonics, the electron density term only remains in the phase of the interference signal, which is subtraction between two phases of the two second harmonics. In this way, the dispersion interferometer is less affected by the mechanical vibrations and changes in the neutral gas density.

One of the problems of the "conventional" dispersion interferometer is that the changes in the detected intensities (A and B in Fig. 1) lead to the measurement errors. This is the same problem as that of the homodyne interferometer. Hence the phase modulation technique and the new phase extraction method are introduced [4].

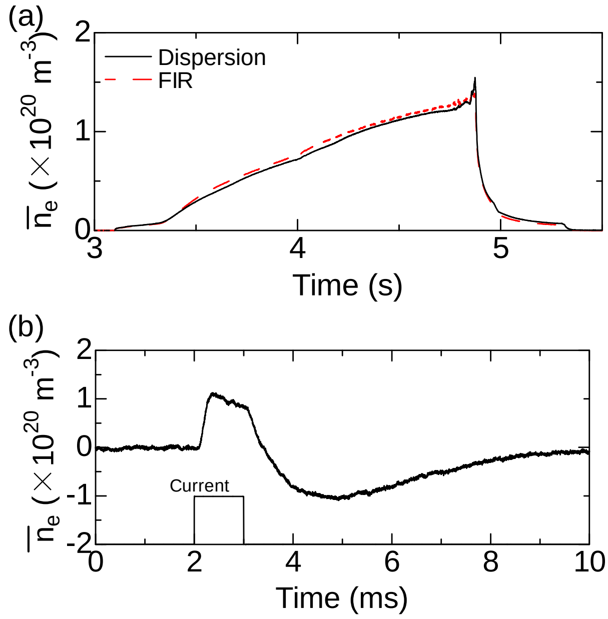


Fig. 2: Measurement results of (a) a LHD plasma and (b) an atmospheric pressure plasma

## 3. Measurement results

### 3.1. Magnetic-confined plasma

Figure 2 (a) shows an example of measurement results of the LHD plasma with the dispersion interferometer. It agrees with the density measured with the existing far-infrared laser interferometer. The present density resolution is $2\times10^{17}$ $m^{-3}$ with a time response of about 100 μs. This high resolution is obtained without any vibration isolation bench. The feasibility that the dispersion interferometer is insensitive to the mechanical vibrations is demonstrated.

### 3.2. High-pressure plasma

Figure 2 (b) shows a measurement result of an atmospheric pressure plasma. The discharge is 2-3 ms and the gradual change after 3 ms is caused by the change in the neutral gas density, not the electron density.

## 4. Summary

The dispersion interferometer is applied to the electron density measurement of the magnetically confined fusion plasmas and the high pressure plasmas. It is demonstrated that the dispersion interferometer can significantly reduce the measurement errors by the mechanical vibrations and the changes in the neutral gas density.

## References


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