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Conceptual design of dispersion interferometer with 1 micron light source
波長1ミクロン帯光源を用いたディスパーション干渉計の概念設計

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A dispersion interferometer is less sensitive to measurement errors due to mechanical vibrations. It also becomes free from fringe jump errors in principle by selecting a short enough wavelength. Hence it is suitable for density measurement on future steady-state fusion reactors. A wavelength around 1 micron is one of candidates from viewpoints of the variety of optical components, the efficiency of the frequency doubling and a phase shift due to plasmas. In this paper, a conceptual design of the dispersion interferometer with 1 micron light source is shown.

1. Introduction

Electron density measurement is indispensable for fueling control and for physical analysis. Considering an operation of future high-density and steady-state fusion reactors, the density measurement should be reliable and accurate. Interferometers are used for the continuous density measurement on most of fusion devices at present. Although it has high time and density resolutions, a measurement error due to mechanical vibrations has to be suppressed. It sometimes suffers from "fringe jump errors", which significantly degrade the reliability. Two-color measurement, which uses two different wavelengths, can compensate the phase components due to the vibrations and a short-wavelength laser can reduce a risk of the fringe jump errors. However, they are not fundamental solutions and introduction of different schemes in principle is necessary to establish highly-reliable density measurement for the steady-state operation.

A dispersion interferometer (DI) is one of alternatives to the conventional interferometer. It is less sensitive to the mechanical vibrations. Hence it does not need vibration compensation systems. Since the phase error due to the vibrations is negligible, the phase shift due to a plasma smaller than one fringe is acceptable from the viewpoint of signal to noise ratio. This means that the DI can be free from the fringe jump errors by selecting an appropriate wavelength. From these advantages, the DI is suitable to future fusion reactors.

The DIs with CO_2 lasers (a wavelength of 10.6 μm) are operated or tested at present[1-3]. The wavelength, however, is so long that the phase shift exceeds one fringe in the case of large and high-density plasmas such as ones in ITER and Super Dense Core (SDC) plasmas in LHD. Hence, a development of the dispersion interferometer with a shorter wavelength, around 1 μm, is necessary.

2. Principle of Dispersion Interferometer Using a Ratio of Modulation Amplitudes

Figure 1 shows a schematic view of the DI. A mixed beam of the fundamental and the second harmonic components, which is generated with a nonlinear component, is used as a probe beam. The phase of the fundamental component is modulated with a photoelastic modulator (PEM). This modulation and the phase extraction method using a ratio of modulation amplitudes[4] are to solve the disadvantage of the DI: measurement errors caused by variations of the detected intensity. After passing through a plasma, another second harmonic component is generated from the fundamental again.

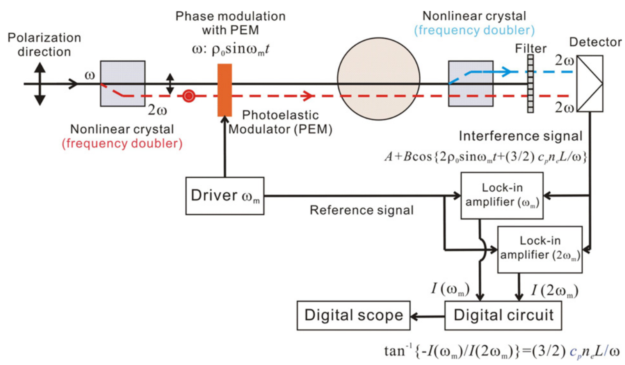

Fig. 1: Schematic view of the dispersion interferometer using a ratio of modulation amplitude

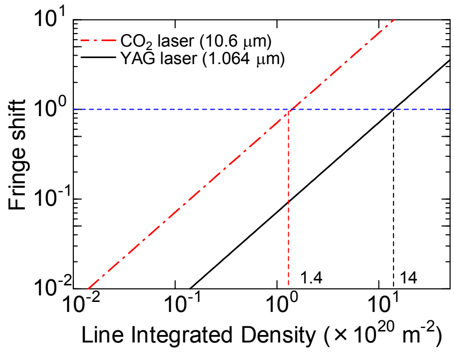

Fig. 2: Dependence of the fringe shifts of the dispersion interferometer on the laser sources.

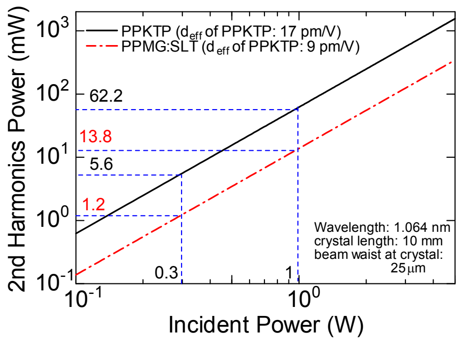

Fig. 3: Generated power of the second harmonics with PPMG:SLT and PPKTP.

The fundamental is cut with a filter and then an interference signal between two second harmonic components is detected. While the phase shift due to mechanical vibrations are the same between the second harmonic components, those due to the plasma are different because of the dispersion. Hence the phase shifts due to the vibrations are cancelled optically and that due to plasma only remains. This is the reason why the DI is less sensitive to the mechanical vibrations.

3. Conceptual design of Optical System

The fringe shift due to the plasma measured with the DI is $3c_p\bar{n}_eL/(2\pi\omega)$ where c_p is the constant, $\bar{n}_e$ is the line averaged density, L is the path length in a plasma, ω is the angular frequency of the laser light. Figure 2 shows the fringe shift of CO_2 and YAG (1.064 μm) lasers. If the expected maximum phase shift is smaller than one fringe, the phase is uniquely determined: no fringe jump in principle. While the line integrated density $\bar{n}_eL$ which corresponds to one fringe is 1.4×10^{20} m^{-2} for the CO_2 laser, 14×10^{20} m^{-2} for the YAG laser. Assuming ITER ($\bar{n}_e = 1\times10^{20}$ m^{-3}, L=8 m) for example, the YAG laser is preferable.

One of the key issues of the DI is the efficiency of the second harmonic generation. Generally speaking, the power density of a continuous-wave (cw) laser is too small to generate the second harmonic. Candidates of nonlinear components are periodically poled crystals such as PPMgSLT and PPKTP, which have a large conversion efficiency of the second harmonics. Figure 3 shows the calculated power of the second harmonic with above crystals (the crystal length is 10 mm and the beam radius at the crystal is 25 μm). A Si photodetecter with a conversion gain of 10^4 V/W (OE-200-SI, FEMTO Messtechnik GmbH) will be used for detection of the second harmonics. Mirrors are expected to be installed in a vacuum vessel and the reflectivity might degrade by two orders of magnitude because of impurity deposition or sputtering on the mirror surface for near IR and visible range[5]. The transmission losses in several optical components (window, beam splitter, and so on) are much smaller than the effect of in-vessel mirrors. Even in such a harsh situation, an output voltage of about 1 V will be obtained by the both crystals for a laser source with a power of 1 W. Since a cw YAG laser with a power of about 1 W is commercially available. The PEM is also available for this wavelength range. An electro-optic modulator (EOM), whose modulation frequency is higher (~1 MHz) than that of the PEM (~50 kHz), is also available. Hence it is possible to compose the phase-modulated YAG laser DI without any new developments of the optical components.

4. Summary

The dispersion interferometer (DI) is one of candidates of reliable density measurement on future fusion reactors. The DI with 1 μm laser source is appropriate for the reactor-size devices and the optical system can be composed of commercially-available components.

References

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