§14. Conceptual Design of a Dispersion Interferometer with a Ratio of Modulation Amplitudes

Akiyama, T., Kawahata, K.,
Okajima, S., Nakayama, K. (Chubu Univ.)

A conventional heterodyne interferometer is widely used and has a high density resolution. It, however, suffers from fringe jump errors, which degrade reliability of the interferometer, in a high density range. The mechanical vibrations also cause measurement errors. One of candidates of the solution is a dispersion interferometer. The dispersion interferometer uses both fundamental and second harmonics, which is generated with a nonlinear crystal, as a probe beam. After passing through a plasma, the probe beam is injected into another nonlinear crystal, to generate the second harmonic from the fundamental again. The remained fundamental is cut by a filter. The phase of interference signal between two second harmonics includes only the phase due to the dispersion of a plasma not due to mechanical vibrations. Hence, the dispersion interferometer does not need a vibration isolator and the two-color interferometry system even if a short-wavelength laser (a CO_2 laser or a Nd:YAG laser), which can reduce fringe jump error, is used.

Since the detected interference signal of a usual dispersion interferometer is similar to that of a homodyne interferometer, the dispersion interferometer has the same problem as the homodyne one; changes in the detected intensity lead to the phase errors. In order to be insensitive to intensity variations, a photoelastic modulator (PEM) is placed between the nonlinear crystal and the plasma as shown in Fig. 1 [1]. In this optical configuration, the detected interference signal is given by as follows.

$$I(t) = A + B\cos\left(2\rho_0 \sin\omega_m t + \frac{3}{2}\frac{c_p \bar{n}_e L}{\omega} + \phi\right) \qquad (1)$$

where A and B are constant, which are determined by the detected intensity of the probe beam, ρ_0 is the maximum retardation of the PEM, ω_m is the modulation frequency of the PEM, $c_p = e^2/(2\varepsilon_0 m_e c)$, $\bar{n}_e$ is the line averaged electron density, L is the optical path length in the plasma and ϕ is an initial phase. The amplitudes of fundamental and the second harmonics I_{ω_m} and $I_{2\omega_m}$ of the modulation frequency ω_m of Eq. (1) can be measured with lock-in amplifiers and are described with the Bessel function of the first and second order J_1 and J_2.

$$I_{\omega_m} = -2BJ_1(2\rho_0)\sin\left(\frac{3}{2}\frac{c_p \bar{n}_e L}{\omega} + \phi\right) \qquad (2)$$

$$I_{2\omega_m} = 2BJ_2(2\rho_0)\cos\left(\frac{3}{2}\frac{c_p \bar{n}_e L}{\omega} + \phi\right)$$

From the ratio of these amplitudes, $\bar{n}_e$ can be obtained.

$$\bar{n}_e = \frac{2}{3}\frac{\omega}{c_p L}\left\{\tan^{-1}\left(\frac{I_{\omega_m}}{I_{2\omega_m}}\right) - \phi\right\} \qquad (3)$$

Here, ρ_0 is set at 1.3 radian by adjusting the voltage to the photoelastic material for $J_1(2\rho_0) = J_2(2\rho_0)$. This new method of the phase extraction from the dispersion interferometer is completely free from variations of detected intensities A and B. In addition, the processing way is simple and suits to real time measurements.

An important component for a good SNR is a nonlinear crystal for second-harmonic generation (SHG), because the power of the second harmonics is generally small in the case of a continuous wave laser (i.e. small power density) and depends strongly on the specifications of the nonlinear crystal. Silver gallium selenide ($AgGaSe_2$) has the relatively high conversion efficiency and the small absorb coefficient. Figure 2 shows the generated power of the second harmonics. In the case of the crystal with a length of 15 mm-long, about 100 μW is generated when the beam waist at the crystal is 0.69 mm. This power corresponds to several-volts-interference signal, which is enough to be detected.

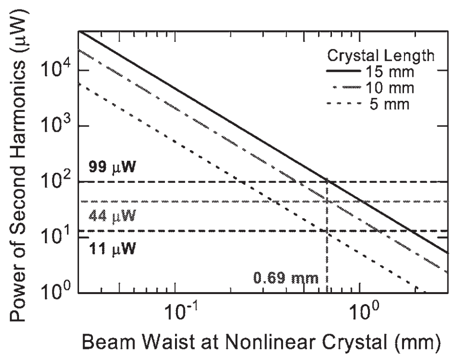

Fig.2 Generated power of the second harmonics in the case of an incident beam with a power of 7.5 W. The nonlinear crystal is $AgGaSe_2$.

[1] T. Akiyama et. al., to be published to Plasma and Fusion Research.

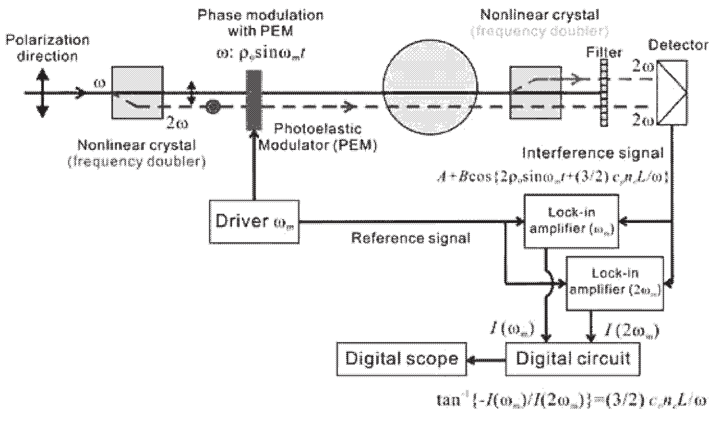

Fig.1 Dispersion interferometer with a photoelastic modulator (PEM) and a signal processing using ration of modulation amplitudes