ON THE THEORY OF DISPERSION INTERFEROMETER WITH TWO NONLINEAR CRYSTALS

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Theory of double crystal dispersion interferometer is given in the constant intensity approximation taking into account the reverse reaction of excited harmonics on the phase of fundamental wave. It was shown that unlike the traditional interferometers the dispersion interferometer is not sensitive to the mechanical vibrations and intensity of second harmonics is a function of electron density in a plasma medium.

Keywords: dispersion interferometer, second harmonic generation, plasma electron density.
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1. INTRODUCTION

It is known that conducting controlled thermo nuclear fusion is one of the most important things that can be done by plasma . In order to control the plasma and determine the electron density the thermo-nuclear devices should have higher relability and resolution. Currently purposeful research works are being carried out in the direction of obtaining plasma media with stable parameters at higher temperatures and electron concentration as well as long retention time etc. At temperatures (about $10^8 K$) required for nucleus synthesis all atoms are ionized, ordinary metals are vaporized and storage of plasma becomes impossible. For this purpose the magnetic fields are employed. It was possible to increase the storage time of plasma with the toroidal camera having magnetic coils. In order to have a mutual interaction the plasma should possess significant higher density during retention. According to S.D.Louson criterion when condition $n\tau \geq 3\cdot 10^{14} s\,|\,cm^3$ (n –refers to electron density, τ - is the retention time) is met the amount of energy obtained in the nuclear reactor becomes more than the expended energy. From this point of view determination of the electron density of plasma as its important characterics becomes actual problem. There are polarimetric methods based on Faraday's and Cotton -Mouton effects [1-5]. As it was described in those works a monochromatic light beam whose polarization plane makes angle of 45^0 with respect to the magnetic field passes through plasma medium in between poles of electromagnet. The plasma possess optical anysotropy in the magnetic field (its optical axis is parallel to the magnetic field vector-H).Then the light undergoes the elliptical polarization i.e. propagates as the ordinary and extraordinary two waves with different phase velocities in the plasma medium. Difference in the refractive indices of ordinary and extraordinary waves is then given by $n_{q|a} - n_a = CH^2\lambda$. Here H- is the magnetic field intensity, C- Cotton-Mouton coefficient, λ- refers to the wavelength of light.

The electron density of plasma is determined by the dispersion of refractive index. To determine the electron density in addition to polarimeters the interferometric methods are widely used too (for examp.heterodine [6,7]). In traditional interferometers optical path instability due to mechanical vibrations produces an additional phase shift which causes errors in the measurement of plasma electron density. To compensate effect of vibrations in the determination of the phases the massive vibration isolators- solid frames, the far IR radiation, as well as the double colored interferometer with two different wavelengths can be used. Realization of interferometric system on the rigid frame with large sizes in the plasma burning equipment may create some difficulties. Also the use of long waves is related to the influence of refraction as well as the existence of density gradient in plasma equipment. Shortcomings related to the small differences in optical paths and wave fronts are eliminated by use the dispersion interferometers [8-11]. The dispersion interferometers have been offered for diagnosis of micro-relief on the surface of optical elements [8, 9], for determination the electron density in a laser spark [10], as well as the arc discharge of argon laser [11]. Dispersion interferometers also can be successfully used for determination the refractive index and thickness of transparent micro-objects as well as for sanitary-hygienic purposes. Unlike the traditional interferometers the waves travel the same geometrical path in dispersion interferometers.

The operational principle of dispersion interferometer composed of two crystals and plasma placed between them is widely presented in [9, 10, 12]. A portion of fundamental wave with frequency ω is converted to the second harmonics with frequency 2ω (its polarizatin plane is perependicular to that of fundamental wave) in the first crystal. As a result those two waves travel roughly identical geometrical paths in the plasma. In the second crystal these waves

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again interact with each other. An interference of first and secnd harmonic waves is analyzed in the constant field approximation (CFA) in which a varion in the amplitude and phase of fundamental wave is not taken into account [8, 9,10,11]. Reverse reaction of harmonic wave on the fundamental wave is considered in [12], for the absence of linear losses and occurrence of phase matching condition.

2. THEORETICAL APPROACH

In this paper a theory of dispersion interferometer with two nonlinear optical crystals is analyzed in the constant intensity approximation (CIA) [13]. Unlike the constant field approximation (CFA) no restrictions are imposed to the phases of interacting waves in CIA. Note that this apporoximation was successully employed in previously studies [14-21]. This circumstance has allowed to find the intensity of harmonic wave at the output of second crystal as a function generelized phase shift between interacting waves. Since variation in phases causes change in output intensity, finding variations in intensity makes possible to determine dispersion of refractive index of plasma and hence its electron density. Generation of second harmonics in both nonlinear crystals is considered by use the set of reduced equations given for complex amplitudes of interactiong waves

$$\frac{dA_1}{dz} + \delta_1' A_1 = -i\gamma_1' A_2 A_1^* \exp(i\Delta_2 z)$$
$$\frac{dA_2}{dz} + \delta_2' A_2 = -i\gamma_2' A_1^2 \exp(-i\Delta_2 z) \qquad (1)$$

where $\delta_{1,2}'$- refer to the linear losses for the fundamental wave of frequency ω_1 and second harmonics of frequency $\omega_2 = 2\omega_1$. $A_{1,2}-$ are the complex amplitudes of interacting waves , $\gamma_{1,2}'$ $-$indicate nonlinear coefficients of coupling, $\Delta_2 = k_2 - 2k_1$ -is the difference in wave numbers for the second crystal. Note that the parameter Δ has an important role in the spatial distribution of electromagnetic waves.

Differentiaon of second equation of (1) with respect to the z- coordinate yields

$$\frac{d^2A_2}{dz^2} + (2\delta_1' + \delta_2' + i\Delta_1)\frac{dA_2}{dz} + [2\gamma_1'\gamma_2' I_1 + \delta_2'(2\delta_1' + i\Delta_1)]A_2 = 0 \qquad (2)$$

As distict from the first crystal the complex amplitudes of waves at the input of second crystal are determined by their values at the exit from the first crystal and properties of plasma medium :

$$A_{1,2}(z=0) = A_{1,2}(l_1) x \exp\left[i\varphi_{1,2}(l) + i\varphi_{1,2}(L)\right], \qquad (3)$$

where, L- is the path travelled by the waves in plasma medium , $\varphi_{1,2}$ - are the phases due to mechanical vibration as well as due to passage of waves along the plasma , z=0 corresponds to the entrance of second crystal. Solution of (2) with boundary conditions (3) for complex amplitude of second harmonics at the output of second crystal is

$$A_2(z) = A_2(l_1 + L)\cdot e^{-\frac{\delta_2 + 2\delta_1 + i\Delta_2}{2}z}\left\{\cos\lambda_2 z - \left[\frac{\delta_2 - 2\delta_1 - i\Delta_2}{2\lambda_2} - \left(\frac{\lambda_1}{\lambda_2} ctg\lambda_1 l_1 + \frac{\delta_2 - 2\delta_1 - i\Delta_1}{2\lambda_2}\right)\cdot e^{i\psi}\right] x \sin\lambda_2 z\right\} \quad (4)$$

Expression for the amplitude $A_2(l_1)$ in (4) is given [21] by

$$A_2(l_1) = -i\gamma_2 A_{10}^2\, l \operatorname{sinc}\lambda_1 l_1 \cdot \exp\left[-(\delta_2 + 2\delta_1 + i\Delta_1)\frac{l_1}{2}\right] \qquad (5)$$

where

$$\lambda_1^2 = 2\Gamma_1^2 - \frac{(\delta_2 - 2\delta_1 - i\Delta_1)^2}{4},\ \Gamma_1^2 = \gamma_1\gamma_2 I_{10},\ \lambda_2^2 = 2\Gamma_2^2 - \frac{(\delta_2 - 2\delta_1 - i\Delta_2)^2}{4},\ \Gamma_2^2 = \gamma_1\gamma_2 I_1(l_1),$$

$$I_1(l_1) = I_0 e^{\frac{\delta_2 + 2\delta_1}{2}l_1} x\left[\left(\cos\lambda_1 l_1 + \frac{\delta_2 - 2\delta_1}{2\lambda_1}\sin\lambda_1 l_1\right)^2 + \frac{\Delta_1^2}{4\lambda_1^2}\sin^2\lambda_1 l_1\right]^{1/2}, \qquad (6)$$

On the basis of (4) output intensity of second harmonics is determined by

$$I_{2,out.} = I_2(l_1)\exp[-(\delta_2' + +2\delta_1')l_2] \times \left|sin\lambda_2 l_2[b + \frac{\gamma_2'}{\gamma_2}\left(\frac{\lambda_1}{\lambda_2}a + c\right)\cdot\exp(i\Psi) + d]\right|^2 \qquad (7)$$

where $a = tan^{-1}\lambda_1 l_1$, $b = tan^{-1}\lambda_2 l_2$, $c = \frac{\delta_2 - 2\delta_1 - i\Delta_1}{2\lambda_2}$, $d = \frac{2\delta_1' - \delta_2' + i\Delta_2}{2\lambda_2}$

According to equation (7) intensity of harmonic wave is a function common phase difference ψ which in turn depends on the phase shift in the plasma medium

$$\psi = \Delta_1 l_1 + \Delta\varphi \qquad (8)$$

here Δ_1 - is the difference in wave number for the first crystal, l_1 - is the length of the first crystal. Using the simple relationship $\Delta\varphi = \frac{2\pi}{\lambda}\Delta l$ between phase of wave and optical path difference through the plasma can be seen that if a small optical path difference due to mechanical vibrations is for instant, l then phases for the waves with the given frequencies are given by $\varphi_1 = \frac{\omega}{c} l$ and $\varphi_2 = \frac{2\omega}{c} l$. However the quantity of phase difference becomes zero and hence the phase shift related to the mechanical vibrations disappears. This property shows main advantage of dispersion interferometer i.e. phase difference is determined with dispersion of plasma and is independent on the travelled geometrical path. By use the expression for the dispersion of plasma [6]

$$n(\omega) = 1 - \frac{2\pi\, n_e e^2}{m\omega^2}$$

for the phase difference in plasma we get

$$\Delta\varphi = \frac{3}{2}\frac{e^2}{mc^2}\lambda < n_e L > \qquad (9)$$

here e - is the charge of electron, m is the mass of electron, c- refers to the speed of propagation of radiation, λ - indicates wavelength of laser radiation, n_e - is the electron density in plasma medium.

3. CONCLUSIONS

As the intensity of second harmonic is a function of electron density in plasma this quantity can be found through determination the maxima and minima of intensity. Comparison of interference patterns in the existence as well absence of investigated plasma medium a dispersion of refractive index can be determined due to shifts of pattern. Sensitivity of interferometer can be increased through performance nonlinear conversion of frequencies in resonator. This interferometric system based on the second harmonic generation can be used in modern equipment of nuclear synthesis for diagnosis of plasma as well as in the plasma burning experiments.

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