Nonlinear quantum interferometry in terahertz spectroscopy

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At present time, biphoton fields are widely studied both in quantum optics and spectroscopy. There are many experimental and theoretical works devoted to nonlinear interferometers [1-5]. However, there is a lack of studies of generation for optical-terahertz biphotons in nonlinear interferometers. The goal of this work to analyze the possibility of observation for interference of the optical-terahertz biphoton fields in Young and Mach-Zehnder schemes, and calculating the angular-frequency intensity patterns at the output of the interferometers.

Earlier a special approach was applied for measuring of the dielectric function imaginary part at THz frequencies, based on the analysis of visibility of three-wave interference under spontaneous parametric down-conversion (SPDC) in the Young scheme [6]. The experiments were performed using SPDC-based three-wave interferometric technique in geometry of near-forward Raman scattering by phonon polaritons. This technique provides measuring absorption coefficients at frequencies of infrared and terahertz phonon polaritons using crystal samples of any arbitrary length with respect to propagation depth of absorbed waves.

In this paper, we calculated the frequency-angular spectrum of the biphoton field at the output of the nonlinear Mach-Zehnder interferometer in the regime of strongly frequency-non-degenerate parametric light scattering. The lithium niobate crystal doped by magnesium ($LiNbO_3$: Mg) was considered as a model of a nonlinear interferometer (Fig.1), as two plates of thickness L with a layer L ' of the other medium being placed between them. The scattering geometry was chosen as follows: x(y,y) xz.

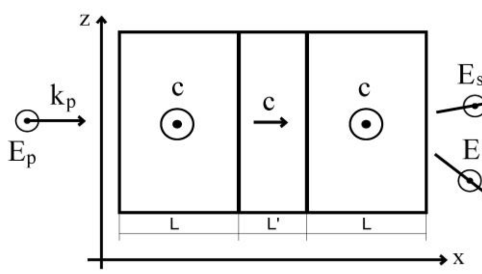

Fig. 1. The geometry of the nonlinear Mach-Zehnder interferometer, c - the optical axes of lithium niobate crystals.

It is well known that frequency-angular SPDC spectrum from one $LiNbO_3$ crystal can be written as:

$$I_1(\theta_s,\omega_i) \propto \left(\frac{\sin(\delta_x/2)}{\delta_x/2}\right)^2 \cdot \left(\frac{\sin(\delta_z/2)}{\delta_z/2}\right)^2 \qquad (1)$$

where δ_x, δ_z – longitudinal and transversal wave mismatches, respectively. According to [4], the modulation function of the middle layer was calculated as:

$$m(\theta_s,\omega_i) = \cos^2\left(\frac{\delta_x+\delta'_x}{2}\right) \qquad (2)$$

The resulting interference pattern is described by the following expression:

$$I(\theta_s,\omega_i) \propto I_1(\theta_s,\omega_i)m(\theta_s,\omega_i) \qquad (3)$$

Two lithium niobate plates of 0.023 cm thickness with Mg content 5.1 mol% MgO were oriented as in Fig.1. The axes of the crystals are perpendicular to the wave pump vector, so eee- interaction was realized. In order to avoid the total internal reflection of idler wave at the boundary of a lithium niobate crystal, a material with a sufficiently high refractive index (~6) should be used as an intermediate layer. Between the plates of the interferometer is placed another plate of $LiNbO_3$: Mg with a thickness of 0,007 cm with a Mg content of 4.1 mol% MgO. The optical axis of this layer was parallel to the wave pump vector.

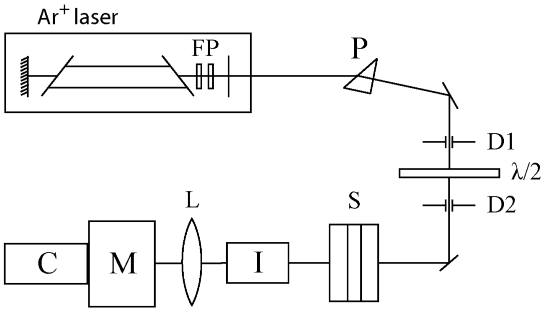

Fig. 2. Schematics of the experimental setup.

Measurements were carried out using Ar+-laser generating a single-longitudinal mode at a wavelength of 514.5 nm. To enable the subsequent attenuation of the pump by an iodine chamber, an additional Fabri-Perot interferometer was placed in the laser resonator, separating one longitudinal mode and significantly reducing the spectral width of the generation so that it does not exceed the spectral band of the absorption line of the iodine cell. The radiation power of one longitudinal mode was about 100 mW. To rotate the polarization of the pump we used a λ/2 plate. Heated up to temperature of 75°C an iodine vapor cell has many absorption lines near the generation frequency of the argon laser, so an iodine cell was used to filter the pump radiation. The signal radiation is eight orders of magnitude weaker than the pump radiation and is shifted from the pump frequency by 0.1-7 THz, so the use of an iodine cell makes it possible to detect the frequency-angular spectrum of the signal radiation without the parasite background of the laser pump. Using a system of three lenses, the signal radiation was focused on the entrance slit of the MDR-41 monochromator. CCD-camera Proscan HS-101H with a Hamamatsu matrix recorded resulting interference patterns; the size of one pixel of the matrix was 24 microns.

Calculated and measured frequency-angular spectra are shown in Fig.3, one can see a good agreement between them. We suppose, that interferometry of optical-terahertz biphoton fields in the scheme of the Mach-Zehnder can be used as a method of spectroscopy for various substances in the terahertz range.

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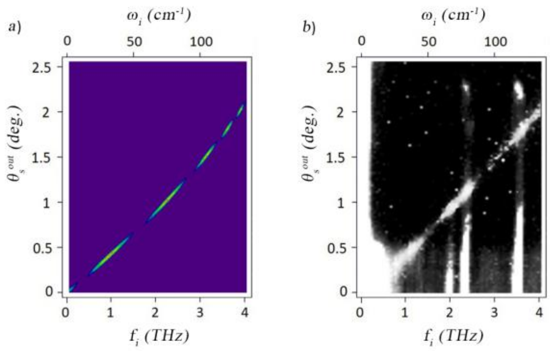

Fig. 3. a) calculated frequency-angular spectrum, b) experimental frequency-angular spectrum

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