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Temperature dependence of signal spectra generated via spontaneous parametric down-conversion in strongly frequency non-degenerate regime

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The process of spontaneous parametric down-conversion (SPDC) represents the process of decay of photons of monochromatic radiation (pumping) with a frequency ω_p on pairs of photons due to interaction with quantum fluctuations of the electromagnetic field in a medium with a non-zero quadratic susceptibility $\chi^{(2)}$. As a result, radiation occurred inside the medium, consists of pairs of correlated photons. We propose to consider properties of biphotons with extremely different frequencies, when the signal photon frequency is very close to ω_p, while the idler photon frequency hits the terahertz range. This regime can be referred as strongly frequency non-degenerate parametric down-conversion (SFND PDC). The frequency-angular distributions of the power of signal photons generated in the Stokes and anti-Stokes ranges are measured. We study the dependence of the power of signal photons generated in Stokes and anti-Stokes ranges from the temperature of the non-linear $LiNbO_3$ crystal.

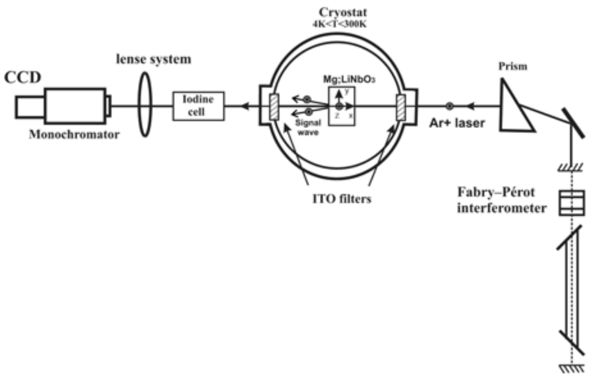

Fig. 1. Experimental setup

In our experiment we use argon laser with generation at a wavelength of 514.5 nm as a pumping source for SPDC. The design of this laser provides the possibility of narrowing the generation line to 100 MHz using the Fabry-Perot interferometer that allow to use narrowband iodine vapor filter for later exclusion of pump radiation. Using the prism we create two beams. One of them allows measuring the pump power without disturbing the main beam, which is a pumping source for 5 mol% MgO-doped $LiNbO_3$ crystal. This crystal is an excellent material for optical frequency converters and it is widely used in quasi-phase-matched conversion applications, because of its large optical nonlinearity. The length of the crystal was L=1.5 cm.

In order to study the influence of thermal fluctuations on the PDC signal the nonlinear crystal has been placed into the cryostat (SCONTEL, Russia) and held at 5 - 300 K. Also, the cryostat in this case has been equipped with a second window for optical pump and signal radiation removal. Stray light from the optical pump was blocked with an iodine cell heated at 75°C. The cryostat windows diameter was D ~ 20 mm. Input and output window of the cryostat were closed by filters, based on indium tin-doped oxide (ITO). They do not allow external thermal terahertz radiation to get into the cryostat. Filters save us from external terahertz thermal photons. We use three lens system in order to focus all signal radiation on the entrance slit of monochromator and get the frequency-angular distributions of emitted photons from CCD camera.

According to the nonlinear Kirchhoff law the power of Stokes and Anti-Stokes radiated photons depends on the crystal temperature in the following way:

$$P_S \sim 1+\langle N_T \rangle \quad (1)$$

$$P_{AS} \sim \langle N_T \rangle \quad (2)$$

where $\langle N_T \rangle = \frac{1}{e^{\frac{\hbar\omega}{\kappa T}}-1}$ - the mean number of thermal photons per mode. So, emitted signal photons in Stokes range arise due to up-conversion of thermal and quantum fluctuations. But anti-Stokes signal photons arise due to up-conversion of thermal fluctuations only. One can see the power of Anti-Stokes photons tends to zero while the temperature tends to zero. During the experiment we cooled the crystal up to 4 K and observed a total disappearance of the Anti-Stokes branch.

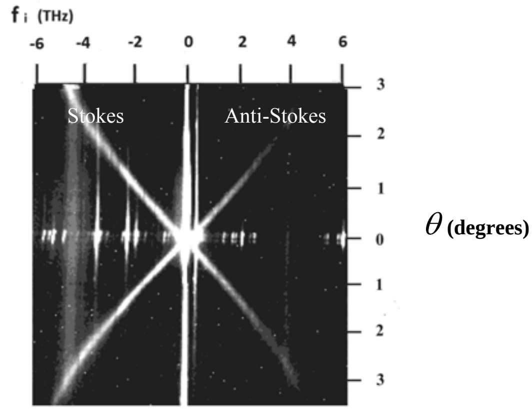

Fig.2.
Frequency-angular spectrum of PDC at T=297K

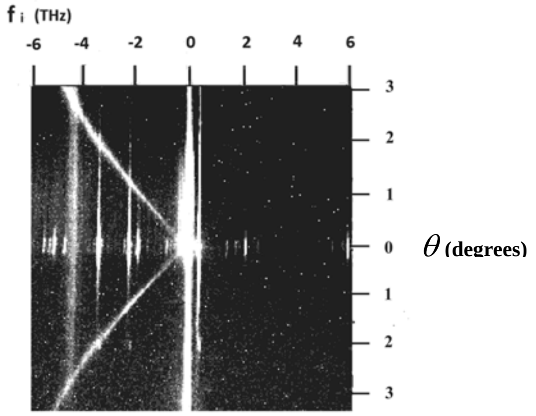

Fig.3. Frequency-angular spectrum of PDC at T=4K

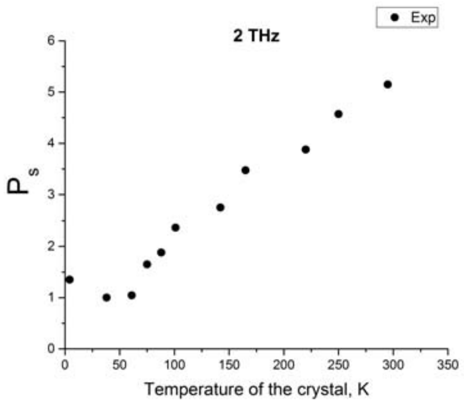

Fig.4. Experimental data for 2 THz

Using the nonlinear Kirchhoff law, formulated by D.N. Klyshko [1], with account of crystal absorption in the THz idler-frequency range and presence of classical thermal field fluctuations at THz frequencies, it is logical to offer such a theoretical model to describe the obtained results:

$$P_s^{SPDC} = C_{\omega_s}\left(1+\langle N_T\rangle\right)\int S_\omega^{SPDC}(\vartheta_i,\varphi_i)d\vartheta_i d\varphi_i d\vartheta_s d\varphi_s \qquad (3)$$

where

$$S_\omega^{SPDC}(\vartheta_i,\varphi_i) = \left(Lw_p\chi^{(2)}\right)^2 \omega_i^3 tg\vartheta_i e^{-\frac{w_p{}^2(\mathbf{k}_{s\perp}+\mathbf{k}_{i\perp})^2}{2}} *$$
$$*\left[\frac{1+(i\Delta k_z-\mu_i)L-e^{(i\Delta k_z-\mu_i)L}}{(\Delta k_z+i\mu_i)^2 L^2}+c.c.\right] \qquad (4)$$

Here, $\mu_m \equiv \alpha_m / 2\cos\vartheta_m$ depends on the intensity absorption coefficient α_m, Δk_z is a longitudinal projection of the wave-vector mismatch, w_p is a Gaussian beam waist, L is the length of our crystal, ϑ_i is the angle of idler wave inside the crystal.

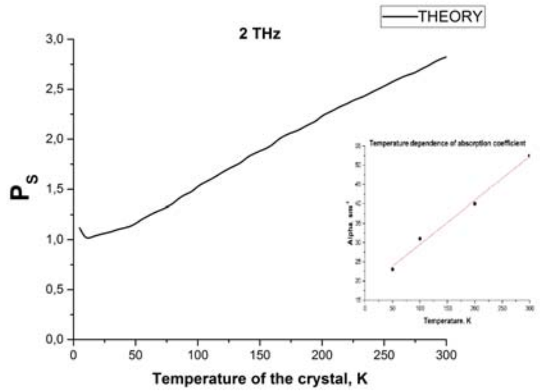

Fig.4. Calculation for 2 THz

The absorption coefficient α_m was taken from the [2]. For crystal absorption in the THz idler-frequency range there were given several values for different temperatures. These data were linearly extrapolated in our calculations. From this extrapolation we took numerical values for our temperatures near 5K. So, considering theoretical values of P_s^{SPDC} we should take into account the approximation error.

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References

1. Klyshko D.N. Photons and Nonlinear Optics // New York: Gordon and Breach. 1988.
2. *Xiaojun Wu, Chun Zhou, Wenqian Ronny Huang, Frederike Ahr, and Franz X. Kärtner.* Temperature dependent refractive index and absorption coefficient of congruent lithium niobate crystals in the terahertz range // OPTICS EXPRESS. 2015. V. 23, No.23. P. 29729–29737.