Quantum Spectroscopy

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Abstract: We propose the high-sensitive technique for the measurement of refractive index of different substances in the infrared (IR) region. The technique relies upon the phenomena of non-linear interference in the process of Spontaneous Parametric Down Conversion (SPDC), where pairs of highly correlated photons (biphotons) are produced. Exploiting the nature of high frequency correlation between SPDC photons the characteristic features of the samples under study in the IR range are measured by conventional visible range equipment. The proposed technique demonstrates high sensitivity for determination of real and imaginary parts of the refractive index.

1. Introduction

The effect of quantum interference [1] plays a remarkable role in modern quantum optics. It has been used for study of fundamentals of quantum mechanics as well as for a number of practical applications, including quantum key distribution, quantum computation and sensing. Here we exploit the phenomena to visualize the unseen, - the characteristic features of the sample in the mid-infrared range are directly visualized and measured in the visible range.

In the proposed scheme the interference occurs due coherent interaction of SPDC radiation from two nonlinear crystals set into a common pump beam. The gap between crystals is filled with a medium under study. Two-dimensional interference pattern of SPDC signals was firstly described by D.N. Klyshko [2], and experimentally observed in [3, 4]. The interference pattern can be described as follows:

\[
I(\theta, \lambda) \propto \left[ \sin \left( \frac{\Delta k - 1}{2} \right) \cos \left( \frac{1}{2} (\Delta k \cdot l + \Delta k' \cdot l') \right) \right]^2
\]

where \( \Delta k = k_p - k_s - k_i \) and \( \Delta k' \) are the phase-mismatch in crystal of thickness \( l \) and in the medium of thickness \( l' \) correspondingly. The first term describes the envelope of intensity distribution, while the second one determines modulation due to interference.

2. Experimental setup and results

In the experiment we use two LiNbO₃ crystals. Crystals were placed in a vacuum chamber to investigate the CO₂ gas. A continuous wave laser with wavelength \( \lambda = 532 \) nm was used to pump crystals. Measurements were made by using a spectrograph and a CCD camera, which is sensitive in the visible range. The resonant absorption line of CO₂ at 4.2 μm coincides with the frequency of the idler photon. The experimental interference fringes at different CO₂ concentrations are shown in Fig.1 (a, b). With the increase of the CO₂ concentration the visibility of the fringes decreases due to the absorption of IR idler photons. The fringes also shift due to the sharp change in the dispersion coefficient in the vicinity of the resonance. From the analysis of the interference pattern we are able to determine both real and imaginary parts of the refractive index in the vicinity of IR resonance without the use of IR optics and IR sensitive equipment.

![Fig.1 Interference pattern of signal photons at (a) 0 Torr (b) 7.7 Torr (yellow line shows the position of \( \lambda = 608.4 \) nm; (c) cross section of a) and b) graphs at 608.4 nm.](image)

3. References