

N92-22070

NONDESTRUCTIVE MEASUREMENT OF INTENSITY OF OPTICAL FIELDS USING SPONTANEOUS PARAMETRIC DOWN CONVERSION

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Results of nondestructive measurements of intensity (photons per mode) of light from different sources are discussed. The procedure of measurement does not destroy the state of the optical field. The method is based on using the second order nonlinearity of crystal media lacking a center of symmetry and the nonclassical properties of the process of Spontaneous Parametric Down Conversion (SPDC).

The interaction of laser radiation with nonlinear crystal leads to the spontaneous emerging of correlated photons in two modes (ω_1 and ω_2) of the optical field connected by phase matching conditions $\omega_1 + \omega_2 = \omega_L$, $\mathbf{k}_1 + \mathbf{k}_2 = \mathbf{k}_L$. The quantum theory of the parametric amplification process /1-4/ shows that if all initial modes of radiation are in the vacuum state (except the pump radiation), then photon flux after the nonlinear interaction in mode with , for example, frequency ω_1 (Fig.1) is:

$$N_1'(t) = \sinh^2(gt) \quad (1)$$

Where $g=(2\pi/h)\chi^{(2)}E_0$, $\chi^{(2)}$ = an effective value of second order susceptibility, and E_0 = amplitude of pump radiation. If we have initial radiation from an external source S producing an intensity n_2^0 in the mode of frequency ω_2 , then after the nonlinear crystal the intensity of radiation in mode of frequency ω_1 is given by:

$$N_1'' = (1 + n_2^0) \sinh^2(gt) \quad (2)$$

Thus the value of the intensity n_2^0 of the initial radiation can be easily calculated without destruction of initial optical state after two

measurements of average intensity n_1 of radiation in the parametrically conjugated mode of frequency ω_1 :

$$n_2^0 = \frac{N_1''}{N_1'} - 1 \quad (3)$$

This result is a reflection of the intrinsically quantum character of the SPDC process. The main point of this method is the use of universal properties of electromagnetic vacuum fluctuations, i.e. that the brightness is equal to one photon per mode. This explanation reflects the phenomenological approach in an effective treatment /5/. Detailed quantum description of nondestructive measurement of parameters of optical fields using third-order Kerr nonlinearity was made in /6/. That results could be easily transformed for the case of second order nonlinear susceptibility $\chi^{(2)}$.

The outline of the experimental setup for the nondestructive measurement of intensity of optical fields is shown in Fig.1. The radiation of argon ion laser $\lambda = 488.8$ nm interacts with a LiIO_3 nonlinear crystal. The scattered (spontaneously generated) radiation of frequency ω_1 is registered by a photomultiplier tube. The radiation from the external source S falls on the crystal in the direction defined by phase matching conditions. The position of the chopper disc divides the process of measurement into two stages: measurement of n_1' and n_1'' values. After the propagation inside the crystal the external radiation of frequency ω_2 can be used for other purposes. In the visible region of the spectrum we can neglect absorption of radiation inside the nonlinear crystal and consider this kind of measurement as nondestructive.

The accuracy of this method improves the closer the brightness of the measured radiation is to the brightness of electromagnetic vacuum fluctuations of the same frequency. It has advantages in measurements of laser radiation and radiation from other bright (high effective temperature) sources of light such as plasmas, high voltage discharges etc.

For our first measurements we used an infrared region of radiation from a high temperature tungsten spiral incandescent lamp as a source of external radiation. In the IR region this thermal radiation has an intensity of about 10^{-2} photons per mode (in the visible region in accordance with Planck formula $N_{\text{therm}} \approx 10^{-4}$

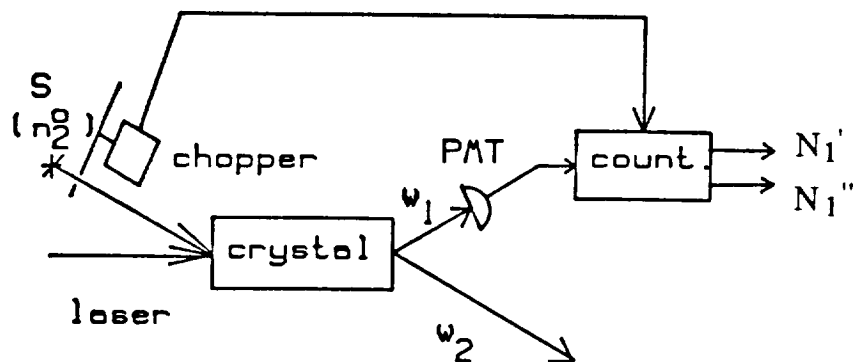


Fig.1. The outline of the experiment for nondestructive measurement of the intensity n_2^0 of light from an external source S.

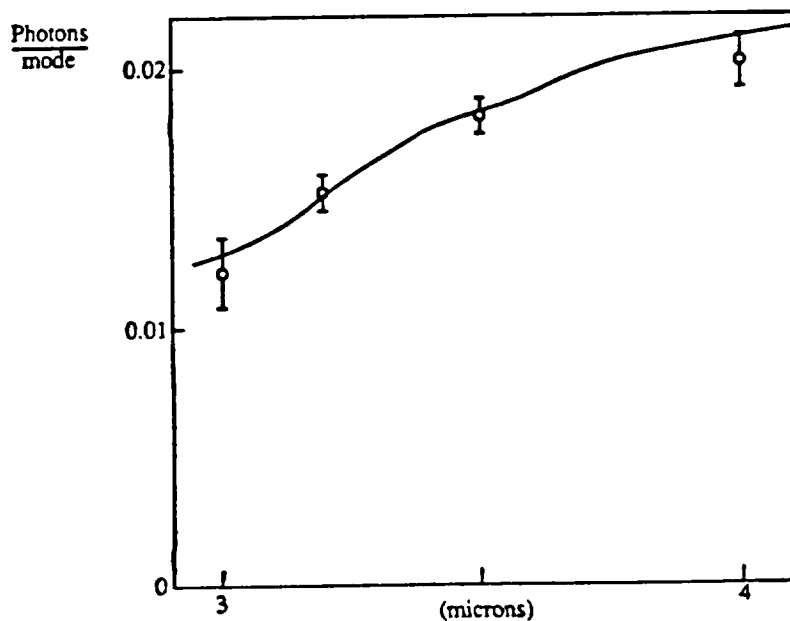


Fig.2. Result of measurement of intensity of thermal radiation source (tungsten spiral incandescent lamp) in the IR region of spectrum. Solid line corresponds to the calculation by Planck formula intensity distribution for the temperature measured by pyrometric technique. All results include correction on crystal absorption coefficient.

photons/mode). The results of measurement are presented in Fig.2. The solid line corresponds to the result calculated by the Planck formula for the temperature measured by a pyrometric technique. The accuracy of these measurements was about 5-20%. Fresnel reflection of radiation on the crystal borders gives an additional source of systematical error in this measurement. This effect could be eliminated by using of a correction coefficient.

The laser (in our case a CW He-Ne laser at $\lambda=3.39 \mu$) has a much higher spectral density of radiation (10^6 photons/mode) and can be measured with better accuracy. However, in this case a special procedure of matching external and internal radiation space modes inside the crystal is needed.

The same problem arises in measurements of intensity of second harmonic radiation generated in a KDP crystal by a Nd:YAG pulsed laser. For the radiation at $\lambda =532$ nm the measured intensity was $4 \cdot 10^3$ photons/mode.

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