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Polarization-Angle SPDC Spectrum and its Effect on Generated Photon States

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Abstract. Analytical formulas for vector components of the polarization vector of spontaneous parametric down-conversion (SPDC) radiation in the degenerated regime and its dependencies on the angle between the principal sections for the pump and SPDC rays are derived. The entanglement losses in the double-crystal SPDC scheme caused by the Migdal effect are analyzed. The analytical expressions are illustrated numerically for the case of BBO crystal.

Keywords: quantum optics, spontaneous parametric down-conversion.

The effect of type-I SPDC (e-oo) is one of the best ways to generate correlated and entangled photon pairs both for applied end fundamental researches. The polarization structure of SPDC is not isotropic [1], i.e. polarization of SPDC radiation depends on the scattering direction. This effect is called sometimes the 'Migdall' effect [2]. The presence of this effect leads to entanglement losses in entanglement photon sources such as the double-crystal Kwiat scheme.

In this work we present the results of calculations of the 'entanglement value' of polarization-entangled states generated in a double-crystal source in presence of the Migdall effect. To characterize the entanglement of states we have chosen the widely used quantity called "Entanglement of formation" [3]. Fig. 1 shows the origin of entanglement losses under consideration. The nonorthogonality of the polarization vectors of photon pairs arises from the fact that the radiation emerging from the first crystal lies in the plane which is perpendicular to the principal section belonging to the pump while radiation emerging from the second crystal lies in the plane of the principal section. This leads to the fact that polarization of the first photon pair to be turned relative to $|H\rangle$ basis by an angle γ_0 defined by the noncollinearity angle and the angle at which the crystal is cut.

In the report we performed an analysis of entanglement losses taking into account the Migdall effect. The Migdall effect can be taken into account by introducing the angle of rotation relative to the standard $|H\rangle-V\rangle$ basis of polarization generated in the first crystal. The explicit formula for the generated quantum state can be written as

$$\left|\psi\right| = \infty\left(S\left(\gamma_0\right)\left|H\right\rangle \otimes S\left(-\gamma_0\right)\left|H\right\rangle + e^{i\delta}\left|V\right\rangle \otimes \left|V\right\rangle\right), \quad (1)$$

where S (γ_0) is the rotation matrix.

We show that the entanglement of states generated in double-crystal type-I SPDC sources is strongly dependent on an angle γ 0 and on a relative phase δ between radiation generated in the first and the second crystals. The numerically calculated "Entanglement of formation" curves depending

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on a phase δ are depicted in Fig. 2. It is clear that the value of "Entanglement of formation" changes dramatically when a phase δ approaches π.

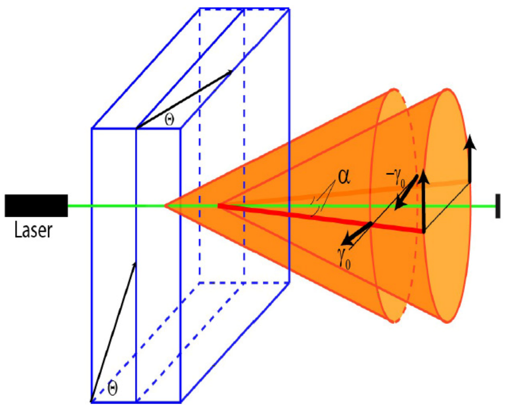

Figure 1. The origin of entanglement losses caused by the Migdall effect

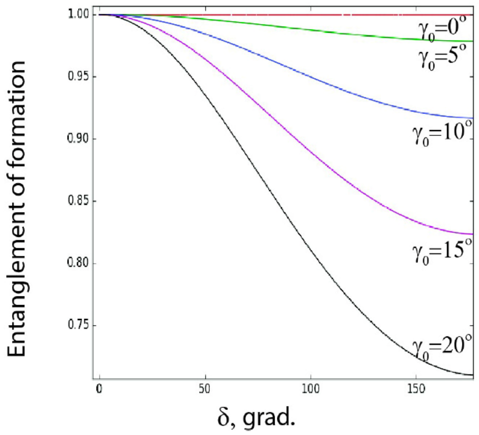

Figure 2. Calculated curves of "Entanglement of formation" of photon pairs emitted by double crystal source in the presence of the Migdall effect

We also report detailed analysis of the polarization-angle SPDC spectrum for the case of an uniaxial crystal matched for e-oo interaction. We deduce compact formulas for the polarization vector components of signal and idler waves of the frequency-degenerated SPDC as a function of γ. The angle γ is the angle between the principal sections of the pump and scattering rays and it has a clear physical meaning. This angle is shown to define the inclination of the polarization vector of SPDC in the pump basis.

The analytical expressions for polarization-angle SPDC spectrum anisotropy and for "Entanglement of formation" are illustrated numerically for the case of BBO crystal.

The results presented here can underlie new methods to construct type-I SPDC polarizationentangled sources having better entanglement properties.

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