Type-I frequency-nondegenerate SPDC 의 분광특성

Spectral properties of entangled photons generated via type-I frequency-nondegenerate SPDC

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Entangled photon generation schemes based on spontaneous parametric down-conversion (SPDC) usually make use of frequency-degenerate processes in which the pair photons have exactly twice the wavelength of that of the pump laser. Recently, entangled states of two photons of different wavelengths became important in quantum communication and in atomic quantum memory research. Although these entangled photon sources make use of frequency nondegenerate SPDC, the spectral and temporal properties of frequency-nondegenerate SPDC have not been studied extensively so far. In this paper, we report experimental and theoretical studies on the spectral properties of entangled photons generated via type-I frequency-nondegenerate SPDC pumped by a cw laser.

In type-I SPDC, the phase mismatch term $\triangle = k_p - k_1 - k_2$ of entangled photons generated via SPDC can be expanded for the detuning frequency as follows(1):

$$\triangle(\omega_1,\omega_2,\theta_1^o) \approx \nu\left[k_1'(\Omega_1)c_1(\Omega_1)+k_1(\Omega_1)c_1'(\Omega_1)-k_2'(\Omega_2)c_2(\Omega_2)-k_2(\Omega_2)c_2'(\Omega_2)\right] \equiv \nu D(\Omega_1,\Omega_2,\theta_1^o)$$

Here, $k_i' \equiv dk/d\omega|_{\Omega_i}$, $c_1(\omega_1)=\sqrt{1-\left(\frac{\sin\theta_1^o}{n_o(\omega_1)}\right)^2}$, $c_2(\omega_2)=\sqrt{1-\left(\frac{\Omega_p-\omega_2}{\omega_2}\right)\left(\frac{\sin\theta_2^o}{n_o(\omega_2)}\right)^2}$, and θ_1^o is the mean emission angle (outside the crystal) of the signal photons. The spectral properties of SPDC can be then fully investigated by examining the joint spectrum function of the two photon state,

$$S(\lambda_1,\lambda_2,\theta_1^o)=\mathrm{sinc}^2\left(\frac{\triangle(\lambda_1,\lambda_2,\theta_1^o)L}{2}\right)\approx \mathrm{sinc}^2\left(\frac{\nu D(\lambda_1,\lambda_2,\theta_1^o)L}{2}\right) \qquad \text{eq.(1)}$$

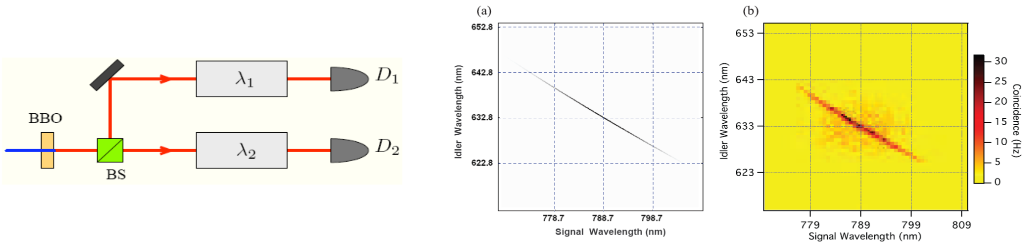

Fig. 1: Left: The experimental setup for measuring the joint spectrum function. 1 and 2 are monochromators. Right: (a) Numerically calculated (b) Experimentally obtained two-photon joint spectrum for collinear nondegenerate type-I SPDC.

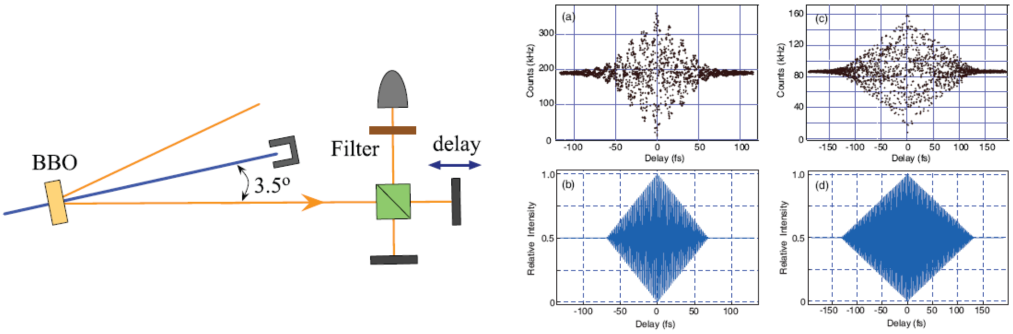

Fig. 2: Left: The experimental setup for measuring the single-photon wave packet for the noncollinear and nondegenerate SPDC. Right: Experimentally measured single-photon wave packet centered at (a) 632.8 nm and (c) 788.7 nm. (b) and (d) are corresponding theoretically predicted single-photon wave packet.

From eq.(1), by defining finite collection angles determined by the experimental geometry, we can theoretically predict two-photon joint spectra as well as the single-photon spectra(1).

Fig. 1 (Left) shows the experimental setup for measuring the joint spectrum function of collinear nondegenerate type-I SPDC. The signal and idler photons are centered at 632.8 nm and 788.7 nm, respectively. As shown in Fig. 1 (Right), the experimentally observed two-photon joint spectrum function agrees very well with the numerical calculated one using eq. (1).

The single-photon spectral property is then examined by using a Michelson interferometer with the signal or the idler photon at its input. The output interferogram can be calculated easily and is known to be(2),

$$R_s = \frac{1}{2}\left(1 + g^{(1)}(\tau)\cos(\Omega\tau)\right), \qquad \text{eq.(2)}$$

where $g^{(1)}(\tau) = |G^{(1)}(\tau)/G^{(1)}(0)|$. Here $G^{(1)}(\tau)$ is the first order correlation function calculated as $G^{(1)}(\tau) = \int_{-\infty}^{\infty} d\nu |S(\nu)|^2 \exp[-i(\Omega+\nu)\tau]$. By studying eq.(2) numerically, we predict that the single-photon wave-packet will be triangular as in the case of type-II SPDC. Fig. 2 (Left) shows the experimental setup for measuring the single-photon wave packet. The experimental data in Fig. 2, indeed, show triangular single-photon interference envelopes and they agree well with the theoretically evaluated ones using eq. (2).

In summary, the joint spectral measurement and the single-photon interference measurements reveals that cw-pumped nondegenerate type-I SPDC shows well-known features of cw-pumped type-II SPDC. We expect that these findings will be essential in developing ultrabright two-color entangled photon sources for generating photon pairs of different wavelengths entangled in polarization and in other photonic degrees of freedom.

Reference

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