A novel way for preparation of Bell state using femtosecond pulse pumped spontaneous parametric down-conversion

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Abstract

It is clear that preparation of maximally entangled state , or Bell state , is an important subject in modern experiment quantum optics. In this paper, we present a novel way to produce polarization entangled photon pair using ultrashort pulse laser as pump. In our scheme, two identical 5x2.5x1mm BBO crystals are used. They are oriented with their optical axes aligned in perpendicular plane, and stacked in vertical direction. Please refer to Fig. 1. These two crystals are cut collinearly in type-I phase matching, phase matching angle $\Theta_m = 29.18°$. If one pump beam with 45 degree polarization pumps these two crystals , then for example, up crystal will produce horizontal polarization photon pair, and down crystal will produce vertical polarization photon pair. If we make the spatial information for these two possible SPDC process indistinguishable, (In our experiment, we use the single mode fiber to realize it.) then these two possible downconversion processes are coherent. In our two-crystal geometry, we just consider the collinear process, so a postselection on amplitude is needed in order to get the polarization entangled state $|HH\rangle + |VV\rangle$. (But postselection is not needed in principle, for example, we can use non-degenerated phase matching to solve it) We also demonstrate the polarization correlation experimentally. Observation of high-visibility quantum interference is a test of the degree of quantum entanglement. In our experiment, more than 86% visibility of two-photon quantum interference is obtained without narrow band filter. The main advantages of this scheme are as follows: we do not need to consider the suitable optical delay; In principle, visibility should be insensitive to the thickness of crystal, so we can use thicker crystal to increase the intensity of photon pair; This way also is insensitive to bandwidth of filter.

Consider the experimental setup shown in Fig. 2. A femtosecond laser from a mode-locked Ti: sapphire laser is used to pump a 1mm BBO crystal cut with type-I phase matching to get frequency doubled radiation. About 70mw 400nm laser with 45 degree polarization is used to pump our two-crystal SPDC source. After that, we couple SPDC light to a 1m long single mode fiber (operation wavelength 800nm). The output of fiber is input to a 50/50 beamsplitter. At each output port of the beamsplitter, a detector package consisting of a Glan-Thompson analyzer A_1 or A_2 and a single-photon detector (PerkinElmer SPCM-AQR-14-FC) are placed. We do not use any narrow interference filter before detector, just place a bandpass filter (CVI company, LPF-750-1.00, transmit from 750nm) before the beamsplitter. The outputs of detectors are sent to coincidence circuit for coincidence counting. The coincidence circuit consists of a time-to-amplitude converter and single-channel analyzer (TAC/SCA) and a counter. The window of coincidence counting is 2ns. In experiment, firstly, we make coincidence counting producing from two crystals almost equal by adjusting the height of crystal. Then we fix the polarizer A_2 in 45 degree, and rotate the polarizer A_1 with each step 10 degree. From theory, we know, for the state $|HH\rangle+|VV\rangle$, should exhibit the polarization interference in coincidence counting rate as expression: $R_c \propto \cos^2(\Theta_1 + \Theta_2)$, where, Θ_1 and Θ_2 are angles of polarizer A_1 and A_2. We get the polarization interference shown in Fig. 3. The visibility is more than 86%. The reason that it does not reach 100% , we think, is the photon pairs from different crystals are not equal exactly, although we make them equal as soon as possible. To make sure the state is really a polarization Bell state, we change the polarizer A_2 to different angles and do same experiments. Experimentally, interference patterns also shift the same angle as polarizer A_2 shifts and almost same visibilities of quantum interference are observed.

One of main advantage of this scheme is that no suitable and stable optical delay is needed. In our setup, two pumps arrive at crystal at the same time. In each crystal, the SPDC light is ordinary light, so no delay is introduced between two SPDC processes if two crystals have same length. The photon pair from up or down crystal leaves the crystal at the same time averagely, they just separate in space. So from temporal point, we do not need to do any compensation like in previous experiments [1-5] using optical delay or narrow band interference filter. Another advantage is that our scheme is insensitive to length of crystal. The wavepacket of each photon pair is same irrespective of crystal lengthen. So, we can increase photon pair by using thicker crystal. The disadvantage of this scheme is that it need to erase the space distinguishable information between two possible SPDC processes. In our experiment, we use the degenerate collinear phase-matching, so it need amplitude postselection to get entangled state. But in principle, we can overcome this problem, for example, using collinear non-degenerate phase-matching.

The other three Bell states can be prepared by inserting the combination of a half waveplate and a π phase shifter. Using our scheme, non-maximally-entangled state , i.e., states of the form $HH+\epsilon VV$,where, $|\epsilon| \neq 1$, may be produced, simply by adjusting the height of crystals or the angle of half waveplate. This kind of state has been shown useful in reducing the required detector efficiencies in loop-free tests of Bell's inequalities [6]. Moreover, by our scheme, the arbitrary (partially) mixed state of type $\cos^2\Theta \left|HH\right\rangle \left\langle HH\right| + \sin^2\Theta \left|VV\right\rangle \left\langle VV\right|$ can be produced. We need only do no compensation in space (for mixed state) or partially compensate in space (for partially mixed state).

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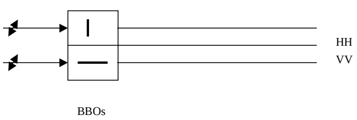


Fig. 1. Two-crystals geometry.

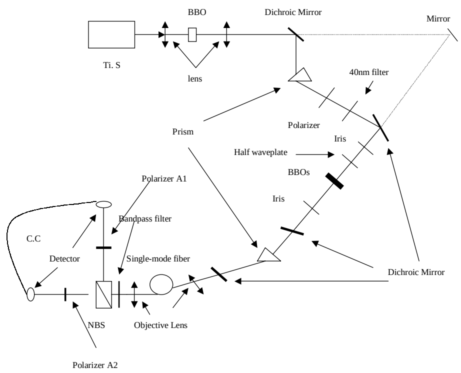
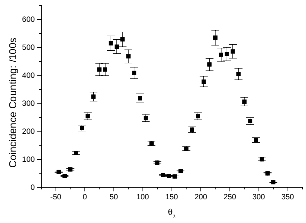


Fig. 2. Set-up for experiment. The dash line used to align all system.



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