Actively switchable non-degenerate polarization entangled photon pair distribution in a dense wave-division multiplexing

Zhi-Yuan Zhou[1*], Yun-Kun Jiang[2], Dong-Sheng Ding[1], Bao-Sen Shi[1+], Guang-Can Guo[1]

[1]*Key Laboratory of Quantum Information, University of Science and Technology of China, Hefei 230026, P. R. China*

[2]*College of Physics and Information Engineering, Fuzhou University, Fuzhou, 350002, P. R. China*

Abstract: We have realized experimentally a non-degenerate polarization-entangled photon pair distribution in a commercial telecom dense wave-division multiplexing device (DWDM) with 8 channels. A promising point of this experiment is that the entangled photon pair is obtained via the spontaneous parametric down conversion in a single type-II periodically poled $KTiOPO_4$ crystal without post-selection. Another promising progress is that we can actively switch the distribution of the photon pair between different channel pairs in DWDM at will. There is no crosstalk between the different channel pairs because of a limited emission bandwidth of the source. Maximum visibility of 98.88%±0.86% obtained in the Bell-type interference experiment and the CHSH inequality S parameter of 2.63±0.08 calculated prove the high entanglement of our source. Our work is helpful for building quantum communication networks.

Keywords: DWDM, PPKTP, Polarization entangled

[1]Dense wave-division multiplexing (DWDM) is a crucial technology used in classical optical communication networks, it can dramatically increase the transmission capacity of a single fiber communication channel. A combination of this technique with a photon source prepared by the spontaneously parametric down conversion (SPDC) can help one to distribute entangled non-degenerate photon pairs to a large number of users, which is a key step for building a quantum network. There are some reported works related to the combination of DWDM and photon pairs. What we have done here is very different compared to the previous works. The photon pair is generated via SPDC in a single type-II periodically poled $KTiOPO_4$ (PPKTP) crystal, the emission spectral bandwidth of the photon is 2 nm, which is within the channel distance of a 200-GHz DWDM we use. The central wavelength of the generated photon can be continuously adjusted over a broad range by tuning the pump wavelength and the crystal temperature. When the central wavelength of the emission photon is tuned to the center between two adjacent channels of DWDM, the outputs from these two channels are entangled, and a non-degenerate polarization entangled photon pair is obtained. Therefore we can realize the active control and switch of photon pair distribution among different adjacent channels at will by simply tuning the pump wavelength and the crystal temperature. We also experimentally find that there is no crosstalk between the different channel pairs. This work is promising for building quantum communication networks

The layout of our source is depicted in figure 1. The pump light beam from a continuous wave

*zyzhouphy@mail.ustc.edu.cn
+ drshi@ustc.edu.cn

(CW) Ti: Sapphire laser (Coherent MBR110) is focused into a 10-mm long type-II phase-matched PPKTP crystal by lens L1. The group delay between the down-converted signal and idle photons inside the PPKTP crystal is compensated by a 5-mm long KTP crystal with its optical axis rotated by 90 degree relative to the PPKTP crystal. The collected photons pass through a commercial 200 GHz DWDM, a non-degenerate polarization entangled photon pair is obtained at two adjacent channels of DWDM output. Two fiber polarization rotators, polarizers and one fiber arbitrary retarder are used to characterize the quality of entanglement. The output of FPR&P1 is connected to a single-photon detector directly, and the output of FPR&P2 is optically delayed using a 200-m long SMF before connecting to APD2. The output of APD1 is electrically delayed using a digital delay generator (DG535, Stanford Instr.). The electrical signal from DG535 is used to trigger APD2. The output of APD2 is connected to a counter to accumulate the coincidence counts.

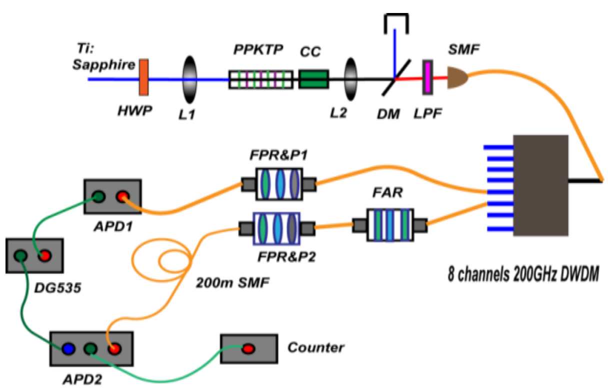


Figure 1. The layout of the experiment.

The operation principle of our source is depicted in figure 2. The central wavelength of the down-converted photon pair is tuned to the center of two adjacent channels of DWDM (red solid curve), then a non-degenerate polarization entangled photon pair is directly obtained from the outputs of this pair of channels. The output state of the photon pair from the DWDM can be expressed as

$$|\Phi\rangle = \frac{1}{\sqrt{2}}\left(\left|H(\lambda_s)V(\lambda_i)\right\rangle + e^{i\varphi}\left|V(\lambda_s)H(\lambda_i)\right\rangle\right)$$

Where H and V stand for horizontal and vertical polarizations, λ_s and λ_i are wavelengths for signal and idler photons, φ is a relative phase between the two polarizations due to phase mismatch arising from the different wavelength of signal and idler, and this phase can be compensated using a fiber arbitrary retarder.

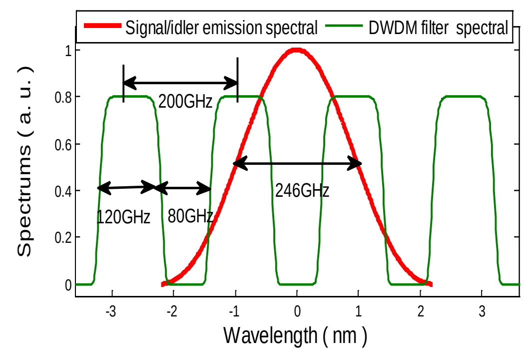
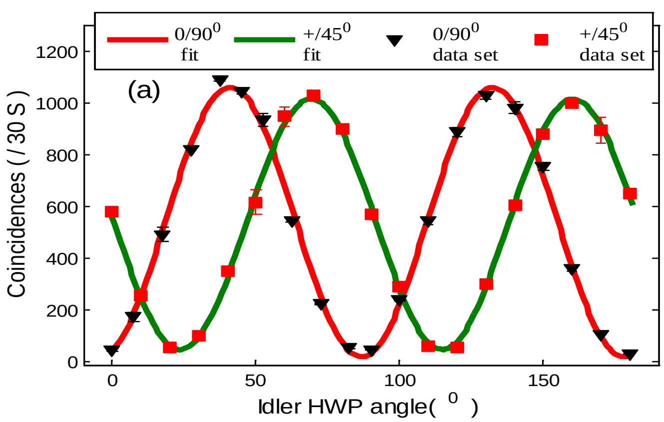
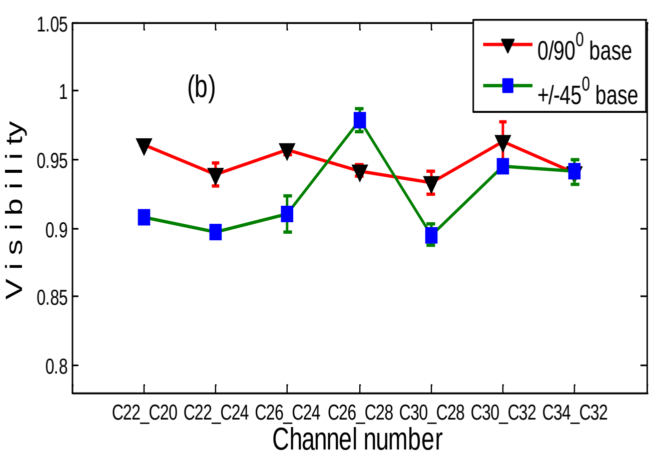


Figure 2. operation principle of our experiment. The red solid curve is the emission spectral of signal (idler), the green curve is filter spectral of 200GHz DWDM.

Different types of measurements are used to characterize the quality of entanglement. In the experiment, Bell-type interference is measured between channel 22 and channel 20. Channel 22 is connected to APD1 and channel 20 is connected to APD2. The pump power is 204 mW and the temperature of the PPKTP crystal is 23.4^{0}C. The single count of APD1 is about 9000 per second and the dark count of APD1 is about 400, the average coincidences is 34s^{-1}, the accidental coincidences is about 0.4s^{-1}, which can be neglected. The results are showed in figure 3(a), raw visibilities at 0/90^0 and +/-45^0 bases are (96.05±0.02)% and (90.77±0.07)% respectively. Such high visibilities (>71%) are sufficient for the violation of Bell-inequality, and imply a high polarization entanglement of our source. The interference curves between other channel pairs are not shown here, instead we give the raw visibilities in the two bases measured in figure 3(b), we can see that all the raw visibilities are equal or greater than 90%. The pump power is kept at 204 mW when we tune the wavelength of the pump to make the central wavelength of the down-converted photon pairs been in the center of a certain channel pair. The average coincidences for different channel pairs are showed in figure 3(c), the difference in coincidences rate is mainly due to non-uniformity of channel bandwidth and a wavelength dependent detection efficiencies of APD1 and ADP2. We calculate the S parameter of the CHSH inequality using the data we measure between channel 32 and 34, which is 2.63±0.08, a violation of CHSH inequality with 8 standard deviations.





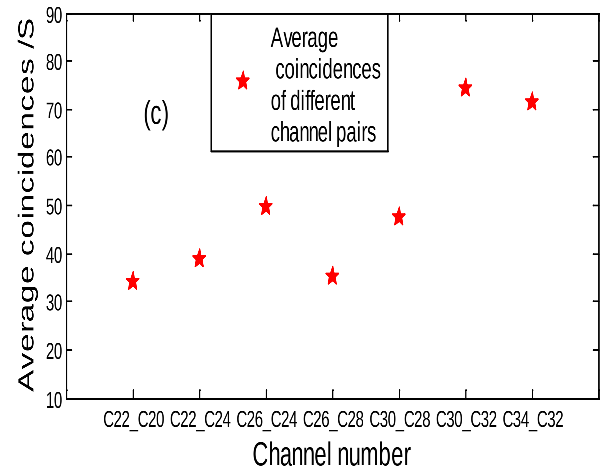


Figure 3. (a)Coincidences per 30 seconds as function of the half wave plate angle inserted in idler beam, the angle of half wave plate inserted in signal beam is keep at 0^0 or 45^0;(b) Visibilities at $0/90^0$ and $+/-45^0$ bases for different channel pairs. The horizontal axis is channel pairs of successive channels, the order of the channels means that the former channel is connected to APD1 and the detection output of ADP1 is used to trigger APD2 connected with the latter channel. (c) Average coincidences per seconds for different channel pairs.

References

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