optica

Topological protection of two-photon quantum correlation on a photonic chip: supplementary material

YAO WANG[1,2], XIAO-LING PANG[1,3], YONG-HENG LU[1,3], JUN GAO[1,2], YI-JUN CHANG[1,3], LU-FENG QIAO[1,3], ZHI-QIANG JIAO[1,3], HAO TANG[1,3], AND XIAN-MIN JIN[1,3,*]

[1]*State Key Laboratory of Advanced Optical Communication Systems and Networks, School of Physics and Astronomy, Shanghai Jiao Tong University, Shanghai 200240, China*

[2]*Institute for Quantum Science and Engineering and Department of Physics, Southern University of Science and Technology, Shenzhen 518055, China*

[3]*Synergetic Innovation Center of Quantum Information and Quantum Physics, University of Science and Technology of China, Hefei, Anhui 230026, China*

[*]*Corresponding author: xianmin.jin@sjtu.edu.cn*

Published 25 July 2019

This document provides supplementary information to "Topological protection of two-photon quantum correlation on a photonic chip," https://doi.org/10.1364/OPTICA.6.000955, **giving a comprehensive description on fabrication, two-photon source and the enhancement of quantum bunching effect in the main text.**

FABRICATION OF THE PHOTONIC LATTICE

We use the parameters t, λ, b and ϕ to describe our system, and these parameters determine the coupling coefficient jointly. In other word, all the coupling coefficients are determined when the parameters t, λ, b and ϕ are fixed, then the lattice structure can be completely determined with coupling parameters. In our system, the coupling parameter is modulated by the separation between two adjacent waveguides. The relationship between them have been carefully characterized before we design the lattice. The waveguides and the whole lattice are written in borosilicate glass (refractive index $n_0 = 1.514$) by using a femtosecond laser with the working wavelength 513nm, repetition rate 1MHz and pulse duration 290fs. We reshape the laser writing beam with a cylindrical lens, and then focus the beam inside the borosilicate substrate with a 50X objective lens (NA 0.55), We move the substrate during fabrication with a constant velocity of 10mm/s using a high-precision three-axis motion stage.

GENERATION AND MEASUREMENT OF THE CORRELATED PHOTONS

The pair-like photons are generated by pumping a periodically-poled KTP (PPKTP) crystal via spontaneous parametric down conversion process. We theoretically calculate the pump envelope intensity, phase matching intensity and joint spectrum of the source. The results, as shown in Fig.S1, imply that the line width of the source is very narrow and the frequency domain is strongly correlated, such that the Hong-Ou-Mandel interference would be very weak in experiment. Meanwhile, the coincidence count of the two-photon source increases linearly with the pump power, as shown in Fig.S2, we can tune the pump power to generate the photon pairs with a suitable flux in experiment as mentioned in main text.

With designed polarization rotation and projection, as shown in the inset of Fig.2 in main text, we can prepare the correlated photons in identical polarization with a probability of 25%. To measure the cross-correlation, the photons out of the lattice are detected with APDs and a FPGA counter after being split by a fiber beam splitter. It should be noticed that the photon flux injected into the lattice is not fair with the case of two photons if we just move the half wave plate to measure the auto-correlation $g_{s\text{-}s}(g_{i\text{-}i})$ of signal (idler) photon. We add one polarizer before the half wave plate to make sure the photon flux the same for all measurement scenarios. To measure the outgoing photons, we inject them into the lattice using a 20X objective lens, and observe the evolution results from the lattice using a 10X microscope objective lens.

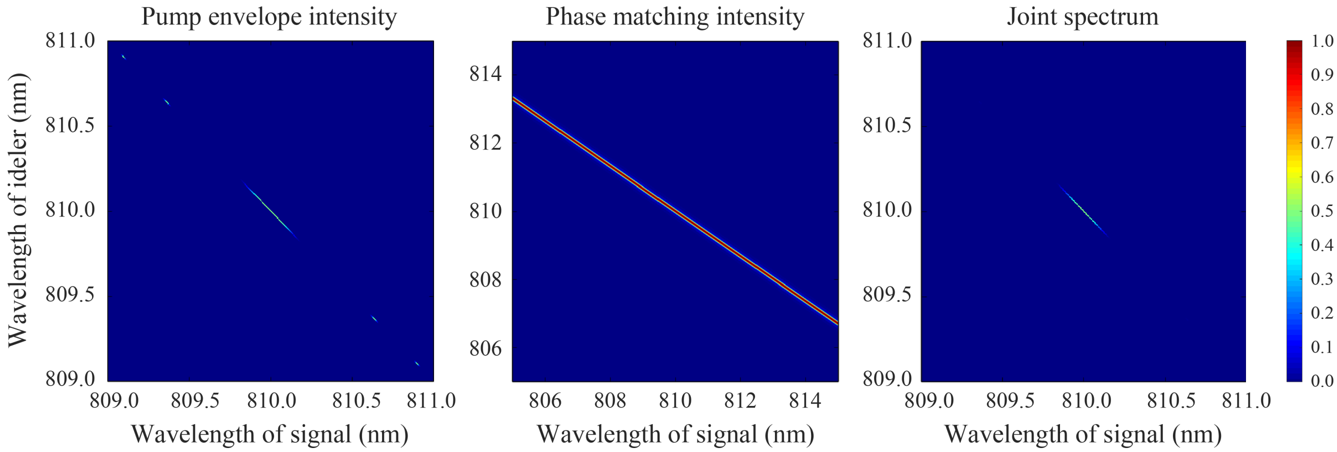

Fig. S1. Details of the two-photon source. The pump envelope intensity (left), phase matching intensity (middle) and joint spectrum (right) show that the line width of the source is very narrow and the frequency domain is strongly correlated.

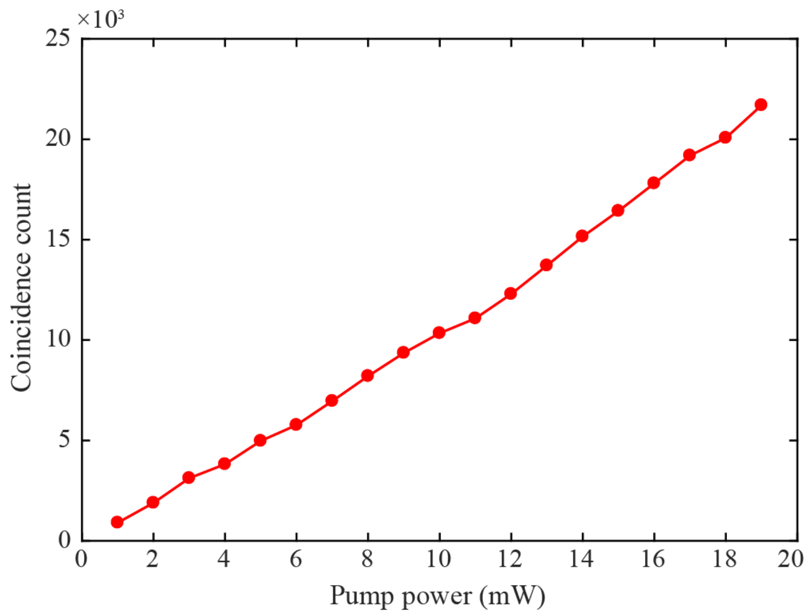

Fig. S2. Measured relationship between the coincidence count of the source and pump power. The coincidence count of the two-photon source per second increases linearly with the pump power.

THE ENHANCEMENT OF QUANTUM BUNCHING EFFECT

We have discussed the behaviors of indistinguishable and distinguishable photons in the main text, we will give the theoretical analysis in this section. The n-ports system have a $n \times n$ evolution matrix U as

$$U = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix}. \tag{S1}$$

In our work, the two photons are injected and detected from the same port simultaneously. It means that both the input ports $|I\rangle$ and the measured output ports $|O\rangle$ are same for the two photons, then we can find that the elements in the submatrix $U_{I,O}$ for the two-photon evolution are uniform, which can be read as the generalized form as

$$U_{I,O} = \begin{bmatrix} a+bi & a+bi \\ a+bi & a+bi \end{bmatrix}. \tag{S2}$$

For the indistinguishable photons, the probability for observing two photon is the same output site is

$$P_{s\text{-}i}^{indis} = \frac{|Perm(U_{I,O})|^2}{2!2!}, \tag{S3}$$

where the $Perm(M)$ means the permanent of matrix M. The probability is

$$P_{s\text{-}i}^{dis} = \frac{Perm(|U_{I,O}|^2)}{2!2!} \tag{S4}$$

for the distinguishable photons [1]. Now, we can find the relationship between $P_{s\text{-}i}^{indis}$ and $P_{s\text{-}i}^{dis}$ by substituting Eq.S2 into them respectively.

For the indistinguishable photons,

$$\begin{aligned} P_{s\text{-}i}^{indis} &= \frac{1}{4}|(a+bi)^2+(a+bi)^2|^2 \\ &= |a^2-b^2+2abi|^2 \\ &= (a^2-b^2)^2+(2ab)^2 \\ &= (a^2+b^2)^2. \end{aligned} \tag{S5}$$

For the distinguishable photons,

$$\begin{aligned} P_{s\text{-}i}^{dis} &= \frac{1}{4}Perm\left(\begin{bmatrix} a^2+b^2 & a^2+b^2 \\ a^2+b^2 & a^2+b^2 \end{bmatrix}\right) \\ &= \frac{1}{4}\left[(a^2+b^2)^2+(a^2+b^2)^2\right] \\ &= \frac{1}{2}(a^2+b^2)^2. \end{aligned} \tag{S6}$$

Comparing the results of Eq.S5 and Eq.S6, we can find $P_{s\text{-}i}^{indis} = 2P_{s\text{-}i}^{dis}$, which results from the quantum bunching effect.

In our experiment, the quantum bunching effect manifests on preparing two-photon state, which twice enhances the probability of obtaining two-photon state from 25% (shown in inset **i** in Fig.2 in the main text) to 50%. The ability of boundary state protecting quantum correlation against the decoherence in diffusion in coupled waveguides maintains the same for the indistinguishable and distinguishable photons.

REFERENCES

1. J. B. Spring, B. J. Metcalf, P. C. Humphreys, W. S. Kolthammer, X.-M. Jin, M. Barbieri, A. Datta, N. Thomas-Peter, N. K. Langford, D. Kundys, J. C. Gates, B. J. Smith, P. G. R. Smith, and I. A. Walmsley, "Boson sampling on a photonic chip", Science **339**, 798-801 (2013).