Fibre based Photon Pair Sources for Integrated Quantum Information

Matthaeus Halder, Jeremie Fulconis, Alex Clark, Bryn Bell, John Rarity
Centre for Quantum Photonics
University of Bristol
Bristol, UK
John.rarity@bristol.ac.uk

Chunle Xiong, William J. Wadsworth
Centre for Photonics and Photonic Materials
Department of Physics
University of Bath
Bath, UK

Mark Tame, Myungshik Kim
School of Mathematics and Physics
The Queen's University
Belfast, UK

***Abstract*—We report on the creation of entangled photon pairs in nanostructured photonic crystal fibres in an intrinsically pure state. Quantum interference between independent photons is shown and the creation of cluster state creation is demonstrated. We will present a photon pair source for integrated photonic devices.**

Keywords: Entangled photon pairs; Quantum information; Photonic crystal fibres.

I. Introduction

Single photons are at the heart of integrated optical quantum technologies such as quantum cryptography, quantum computing and quantum metrology. To achieve high visibility two-photon interferences, the photons need to be in a pure state which usually is achieved by narrow band filtering. This reduces the overall efficiency of detection (μ) and hence limits current experiments to a photon number in the order of 4-6. To achieve significant count rates for higher order multi-photon experiments (e.g. integrated cascaded CNOT or Cluster states) an improvement in μ to over 20% is essential. Here we report on the creation of photon pairs via four-wave-mixing (FWM) in birefringent Photonic Crystal Fibres (PCF) [1]. It has recently been suggested that for thoroughly engineering the phase matching condition of a birefringent PCF (Fig. 1), photon pairs can by created in an intrinsically pure state and narrow band [2,3]. This can be achieved for cross-polarized phase matching, where two pump photons in the slow axis (ss) are converted into a pair of photons, polarized in the orthogonal fast (ff) axis (Fig. 2, ss-ff). The aim is to produce such intrinsically pure and narrow-band photons and hence to achieve high non-classical interference visibility without any requirement for spectral filtering. A direct consequence is an increase in the collection efficiencies μ. The absence of any filters makes FWM hence a very promising approach for photon pair generation in integrated photonic technologies.

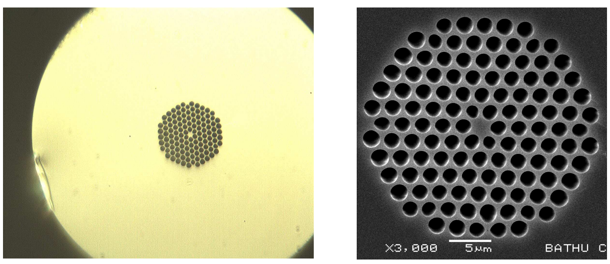

Figure 1. Profile of a nanostructured Photonic Crystal Fibre.

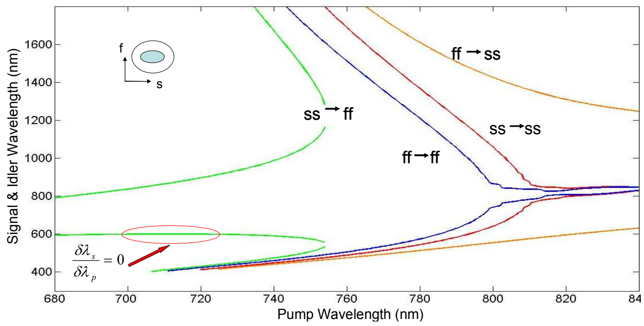

Figure 2. Phasematching curve for a birefringent fibre, with pairs annihilated and created in the fast (ff) and slow (ss) axis, respectively.

II. The Experiment

A. *Experimental Setup*

Pairs of signal (s) and idler (i) photons are created in an uncorrelated spectral state with factorable joint amplitude *f*:

$$f(\omega_s,\omega_i) = f_s(\omega_s) \otimes f_i(\omega_i) \tag{1}$$

with f_s and f_s the spectral distribution of signal and idler photon, respectively. In this case detecting one photon of the pair can be used to herald the other one in a pure quantum state. In order to experimentally test the purity of our single photons, we perform a Hong-Ou-Mandel experiment [4] using two heralded signal photons generated in two separate PCF sources. A pulsed laser (TiSa, 705 nm, 80 MHz, 1ps) pumps two 40 cm long separate pieces of PCFs. Photon pairs are created via FWM with an intrinsic bandwidth of $\Delta\lambda_s$=0.13nm and $\Delta\lambda_i$=2nm, respectively and split up by dichroic mirrors. Band pass filters of 40 nm and 10 nm bandwidth ($\gg\Delta\lambda_{s,i}$) block the residual pump light in each two arms. Raman background is significantly reduced by spatial and polarization filtering. The idler photons are launched into single mode fibres and the signal photons into a single-mode 50:50 coupler. All four outputs are connected to Silicon avalanche photodiodes linked to a four-fold coincidence electronics [5]. When the two signal photons arrive simultaneously on the beam splitter and polarization is controlled, a 78% reduction in the 4-fold coincidence count rate can be observed with μ_s ~0.21 and μ_i ~0.18.

B. *Source of entangled photon pairs*

In a further setup, we are using one piece of PCF in a Sagnac loop configuration (Fig. 3), in order to create pairs of entangled photons. Pump pulses with diagonal polarization are sent onto a PBS, propagating along the PCF in both directions and giving raise to photon pairs. By tilting the optical axis of the fibre on one end by 90° (as depicted), the pairs always take the same output, but with orthogonal polarizations. They are in a coherent superposition of horizontal and vertical polarization $\frac{1}{\sqrt{2}}\left(|H_s H_i\rangle + e^{i\varphi}|V_s V_i\rangle\right)$ and hence entangled. Fig. 4 shows real and imaginary part of a full quantum state tomography with a fidelity of 86%.

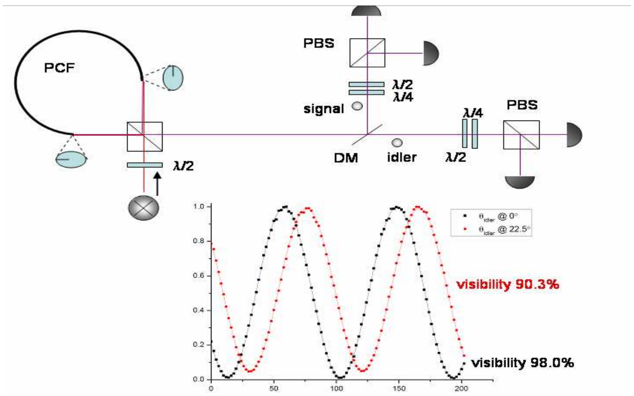

Figure 3. Setup of the entangled photon pair source.

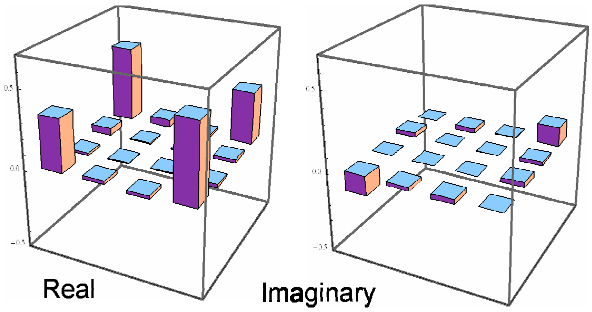

Figure 4. Quantum tomography of the entangled state.

III. Conclusion and Application

These sources of heralded and entangled photons now allow us to build integrated multi-photon setups as for example a cluster state or a teleportation gate. We will report on progress and details on these experiments at the conference and give an outlook on an integrated photon pair source for quantum information.

Acknowledgment

The work was supported by the UK EPSRC (QIP IRC and EP/F002424/1), the EU Integrated Project Qubit Applications (IP QAP) and ACDET. W.J.W. is a Royal Society University Research Fellow, J.G.R. is supported by a Wolfson Merit award and M.H. is supported by an AXA fellowship.

References

[1] J. Fulconis, O. Alibart, W. J. Wadsworth and J. G. Rarity, “Quantum interference with photon pairs using two micro-structured fibres” *New J. Phys.* **9** 276 doi:10.1088/1367-2630/9/8/276 (2007)

[2] K. Garay-Palmett et al., “Photon pair-state preparation with tailored spectral properties by spontaneous four-wave mixing in photonic-crystal fiber” *Opt. Exp.*,**15**, Issue 22, pp. 14870 (2007)

[3] O. Cohen, J. S. Lundeen, B. J. Smith, G. Puentes, P. J. Mosley, and I. A. Walmsley, “Tailored photon-pair generation in optical fibers” *Phys. Rev. Lett.* **102**, 123603 (2009)

[4] Hong, C.K., Ou, Z.Y. and Mandel, L. “Measurement of subpicosecond time intervals between two photons by interference” Phys. Rev. Lett. **59**, 2044 (1987)

[5] M. Halder, J. G. Rarity et al. "Nonclassical 2-photon interference with separate intrinsically narrowband fibre sources” *Opt. Exp.,* **17,** Issue 6, pp.4670 (2009)