AFRL-AFOSR-JP-TR-2018-0042

Polarization-entangled photon-pair source in the near-NIR for free-space QKD

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05/02/2018
Final Report

DISTRIBUTION A: Distribution approved for public release.

Air Force Research Laboratory
AF Office Of Scientific Research (AFOSR)/ IOA
Arlington, Virginia 22203
Air Force Materiel Command

REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED** *(From - To)*
18-05-2018	Final	03 Apr 2017 to 02 Apr 2018

4. TITLE AND SUBTITLE
Polarization-entangled photon-pair source in the near-NIR for free-space QKD

5a. CONTRACT NUMBER

5b. GRANT NUMBER
FA2386-17-1-4008

5c. PROGRAM ELEMENT NUMBER
61102F

6. AUTHOR(S)
Alexander Ling

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
NATIONAL UNIVERSITY OF SINGAPORE
21 LOWER KENT RIDGE ROAD
SINGAPORE, 119077 SG

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
AOARD
UNIT 45002
APO AP 96338-5002

10. SPONSOR/MONITOR'S ACRONYM(S)
AFRL/AFOSR IOA

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
AFRL-AFOSR-JP-TR-2018-0042

12. DISTRIBUTION/AVAILABILITY STATEMENT
A DISTRIBUTION UNLIMITED: PB Public Release

13. SUPPLEMENTARY NOTES

14. ABSTRACT
This grant has enabled the development of a new optical design for producing polarization-entangled photon-pairs. This design, based on Type-1 critical phase-matching, utilizes two optical nonlinear crystals aligned with parallel optical axes. The objective of the grant is to support on-going research at the Centre for Quantum Technologies, which seeks to develop entanglement-based QKD. Entanglement-based QKD is the most secure form of QKD as the presence of an eavesdropper is revealed by a violation of fundamental quantum correlations. Furthermore, entanglement is a resource for entropy, negating the need for a trusted random number generator. Specific objectives in this grant were to study how polarization-entangled photon-pairs could be generated in a compact manner to minimize Size, Weight and Power (SWAP) requirements on mobile platforms, such as small drones or CubeSats.

15. SUBJECT TERMS
Quantum Key Distribution, Rugged entangeled photon pairs, bright entangled photon pairs

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			SERNA, MARIO
Unclassified	Unclassified	Unclassified	SAR	5	**19b. TELEPHONE NUMBER** *(Include area code)* 315-227-7002

Final Report for AOARD Grant FA2386-17-1-4008 "Polarization-entangled photon-pairs for QKD"

27th April 2018

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Period of Performance: 04/01/2017 – 04/02/2018

Summary: This grant has enabled the development of a new optical design for producing polarization-entangled photon-pairs. This design, based on Type-1 critical phase-matching, utilizes two optical nonlinear crystals aligned with parallel optical axes.

Introduction: The objective of the grant is to support on-going research at the Centre for Quantum Technologies, which seeks to develop entanglement-based QKD. Entanglement-based QKD is the most secure form of QKD as the presence of an eavesdropper is revealed by a violation of fundamental quantum correlations. Furthermore, entanglement is a resource for entropy, negating the need for a trusted random number generator. Specific objectives in this grant were to study how polarization-entangled photon-pairs could be generated in a compact manner to minimize Size, Weight and Power (SWAP) requirements on mobile platforms, such as small drones or CubeSats.

Experiment: The experimental layout is shown below in Figure 1. The basic idea is to use two beta-Barium Borate (BBO) crystals with parallel optical axes, sandwiching a half-wave plate. The photon-pairs are generated via Spontaneous Parametric Downconversion (SPDC) when a pump beam interacts with the BBO material. In this geometry, the pump light remains in a single polarization state as it traverses both crystals. This doubles the photon-pair generation rate, unlike in other designs with two crystals but having crossed axes. When using crossed axes, the pump light must be polarized such that only half the power is available for SPDC in each crystal.

The polarization-entangled photon-pairs are generated when an achromatic half-wave plate (HWP) is inserted between the two crystals, to rotate the polarization of the SPDC photons from the first crystal (this HWP leaves the pump polarization untouched). This rotation enables a superposition of horizontal and vertical polarized photon-pairs to generate the HH+VV polarization state of a maximally entangled photon-pair. As can be observed from Figure 1, the spatial mode overlap of the photon-pairs is also very good with this geometry; this is unique to the source that uses parallel optical axes. This improves the ruggedness of the source because photon-pairs can be collected from any position of the overlap ellipse, and still exhibit high quality entanglement. Finally, this mode overlap enables the use of very long crystals to increase the interaction length, leading to higher brightness.

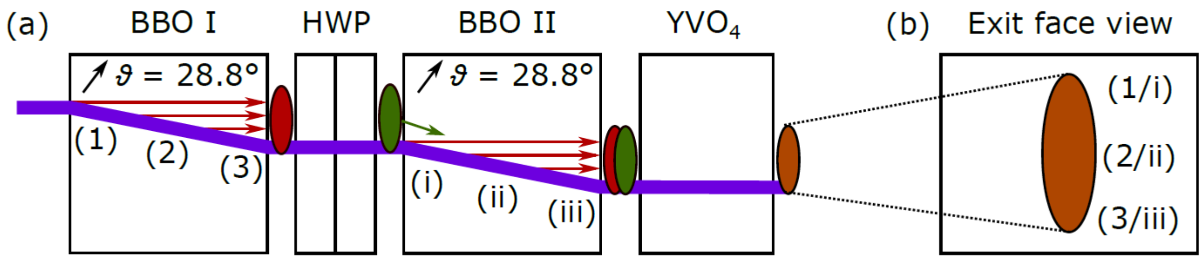

Figure 1: Panel (a) shows the layout of the two crystal geometry for producing polarization-entangled photon-pairs. The labels (1,2,3) and (i, ii, iii) refer to positions within the crystal where the photon-pairs have spatial indistinguishability between crystals. Panel (b) on the right show where these spatially indistinguishable photons are located within the output mode of the SPDC light after it leaves the final phase compensator based on yttrium vanadate (YVO4). BBO: beta Barium Borate; HWP: Half-wave Plate.

Results and Discussion: The photon-pairs can be collected into a single-mode fiber before being sent to single photon detectors for measuring the polarization correlations. The result of the polarization correlations is shown in Figure 2 below.

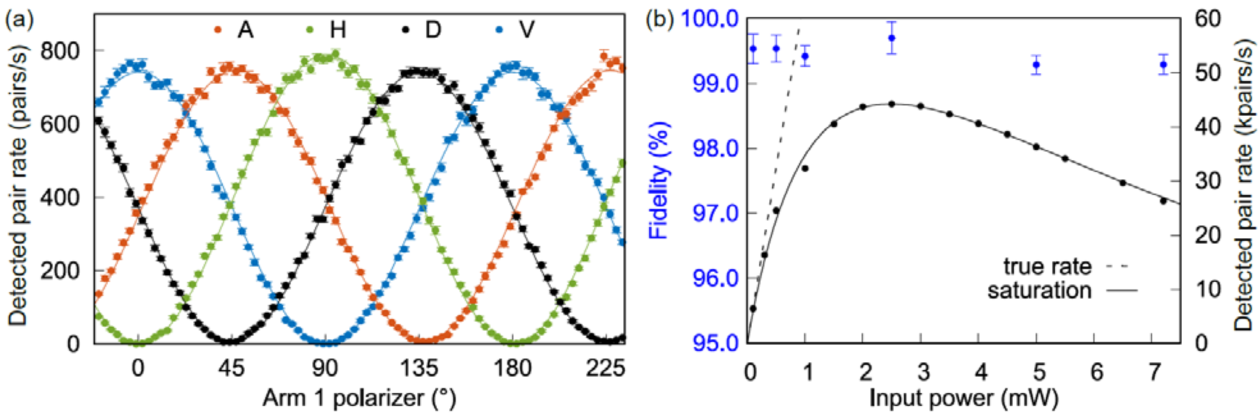

Figure 2. Panel (a) shows the polarization correlations measured in two different linear basis corresponding to Horizontal-Vertical (H-V) and Diagonal-AntiDiagonal (D-A). The visibility of these curves are over 99%. From these data, the fidelity to the maximally entangled quantum state Φ^- can be obtained. Panel (b) shows the plot of the fidelity of the photon-pairs to the Φ^- state is well above 99%, even when the detectors are saturated. This shows that the probability of multiple photon-pairs is very low.

From Figure 2, the brightness of the source into a single-mode fiber is approximately 65,000 pairs/s/mW. Figure 2 also shows that up to an input power of 7 mW, the photon-pairs show good fidelity to a maximally entangled Bell state. The conclusion from this result is that the probability of generating multi-photon-pairs is very low; this is in accordance with the fact that the photon-pair source is pumped with a CW laser at 405 nm (the SPDC photons are slight non-degenerate around 810 nm).

In conclusion, we have developed a compact entangled photon-pair source that is useful for broadband quantum communication. The fidelity of the maximally entangled photon-pairs is very high. We propose that this source will be useful for free-space quantum optical communications.

List of Publications and Significant Collaborations that resulted from your AOARD supported project: In standard format showing authors, title, journal, issue, pages, and date, for each category list the following:
a) one paper is in preparation. The first is a SPIE Proceedings paper (see below).
b) none published
c) 1 conference presentation in SPIE Photonics Europe 2018 (Strasbourg, France)
d) none in this stage
e) the technology will be licensed of S-Fifteen Pte Ltd, a CQT spin-off. The Principal Investigator is a co-founder of this company. This work has also been discussed with Dr Mark Gruneisen of AFRL. Talks are on-going about how a portable photon-pair source based on this design will be loaned to Dr Gruneisen in late 2018.

DD882: As a separate document, please complete and sign the inventions disclosure form. Put n/a in boxes 5 a/b if no inventions resulted from the research.

SF425: Include the Federal Financial Report that has been signed by an official from your business office who can certify that all funds have been expended.

Important Note: If the work has been adequately described in refereed publications, submit a summary that describes all research conducted as described above, and also include summary paragraphs for each cited publication. If possible, submit any reprint(s). If a full report needs to be written, then submission of a final report that is very similar to a full length journal article will be sufficient in most cases.

This document may be as long or as short as needed to give a fair account of the work performed during the period of performance. There will be variations depending on the scope of the work. As such, there is no length or formatting constraints for the final report. Keep in mind the amount of funding you received relative to the amount of effort you put into the report. For example, do not submit a $300k report for $50k worth of funding; likewise, do not submit a $50k report for $300k worth of funding. Include as many charts and figures as required to explain the work.