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QUANTUM ENTANGLED PHOTONS SOURCES QUESTIONNAIRE

Thank you for choosing OZ Optics. In order to help you choose the best components for your system, we would appreciate it if you could answer the following questions. If you do not know what to enter, write DON'T KNOW beside the question. We will then recommend an option. If you need assistance filling out the form, you are welcome to contact your nearest distributor or our sales office where a sales representative will be happy to assist.

To help you fully understand all the relevant issues involved in designing the ideal laser to fiber delivery system, we ask you to read our *Quantum Entangled Photons Sources Application Notes* before completing this questionnaire.

Section 1 of 3: Client Information

To process your information as quickly as possible, please ensure that the fields marked in *red italics* are completed before submitting

As initial requirements, if this data is not entered, OZ will be unable to respond to your request.

Name : ____

Position : ____

Company : ____

Address: ____

City: ____

State / Province: ____

Country: ____

Postal / Zip Code: ____

Telephone : ____

Fax: ____

Email : ____

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Section 2 of 3 : Quantum Entangled Photons Sources characteristics:

1. Are you interested in a polarization-entangled photons source or correlated photons source?

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2. Please put the priority from your perspective of the following specs in order I) II) or III):

   __ High counts rate (high photon pairs generation rate)

   __ Center Wavelength

   __ Bandwidth

3. What is the required photon pairs generation rate? Options ❑ GHz, ❑ sub-GHz, ❑ MHz, ❑ sub-MHz

____

4. What is the required center wavelength? Options ❑ 1550 nm, ❑ 1560 nm, ❑ 810 nm, ❑ Other (Specify)

____

5. What is the required bandwidth? Options ❑ 80 nm, ❑ 3 nm

____

6. What is the fiber connector type? Options ❑ FC/UPC, ❑ FC/APC, ❑ Other (Specify)

____

7. Do you need a 2-QuBit entanglement tomography analyzer including the control box and software?

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Please use this section to provide any additional information that you feel can help us provide you with the source you require. For instance, you could provide a block diagram of your application needs. See our standard and customized products and the associated PNs. If you have any special requirements other than the ones listed in the datasheets, then please describe them in the space provided.

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QUANTUM ENTANGLED PHOTONS SOURCES QUESTIONNAIRE

Section 3 of 3 : Concept and Definitions

Concept

Spontaneous parametric down conversion (SPDC) is one of the most passive optical processes implemented in generating correlated photons. In general, the SPDC process occurs in birefringent crystals and waveguides that have a large second-order nonlinearity, $\chi^{(2)}$. In SPDC, a pump photon at high frequency $\omega_p$travelling in a non-linear medium is converted into two correlated lower energy photons. The signal and idler photons, ω_s and ω_i, are referred to as **photon pairs**, where the energy and momentum, $\vec{K}$,are conserved. Energy conservation is expressed by

$$\omega_p = \omega_s + \omega_i \quad \text{EQ. 1}$$

Momentum conservation that is also called phase matching requires

$$\vec{K_p} = \vec{K_s} + \vec{K_i} \quad \text{EQ. 2}$$

where $|\vec{K_p}| = \frac{2\pi}{\lambda}$ and λ is the wavelength.

When these three photons, ω_s , ω_i and ω_p, travel in the same direction, the phase matching is collinear. Given the dispersion of nonlinear optical media, optical birefringence is deployed to equalize the speeds of those three photons through phase matching. Birefringence refers to the dependence of the refractive index of anisotropic material on the polarization direction.

Consequently, phase matching is polarization dependent and hence the presence of Type-0 and Type-2 phase matching. Type-0 SPDC is defined by parallel polarization of the pump photon, signal and idler photons. In Type-2 SPDC, the polarization of the pump photon is orthogonal to the polarization of either the signal or idler while parallel to the other.

SPDC Media and Bright sources

In collinear crystals, and despite the strong dispersion, phase matching is achieved through material engineering using quasi-phase matching (QPM) technique. The concept of the QPM is based on the periodic reversal of the local electric field in ferroelectric nonlinear crystals. This enhances the flow probability of the pump wave energy into the daughter waves while interacting with considerably longer path in the crystal.

Periodically poled media are therefore produced in three main forms:

1- Bulk: Periodically Poled Nonlinear Crystals (PPNC)
   A large optical loss is inevitably encountered when collecting SPDC photon pairs, generated in bulk PPNCs.
2- Waveguide: Periodically Poled Waveguide (PPNW).
   A waveguide is inscribed within a PPNC and ensures high optical confinement and outstanding photon conversion efficiency. This is besides an excellent optical coupling when collecting SPDC photon pairs, created within the waveguide. As a result, high generation rates of photon pares are accessible and thus, PPNW-based sources are called ***Bright Sources***
3- Fiber: Periodically poled single-mode fiber.
   It generates moderate broadband photon pairs, given the silica fiber nonlinearity.

Correlated photon sources

The pump photon are converted via the SPDC to photon pairs when a travelling pump wave propagate in a Type-0 SPDC medium. The photon pairs are subject to energy entanglement. The energy entanglement is eliminated once the Signal/Idler photons are separated via a wavelength splitter. The photon pairs are entanglement in temporal degrees of freedom. In other words, these photons are entangled in the time at which they are detected.

QUANTUM ENTANGLED PHOTONS SOURCES QUESTIONNAIRE

Section 3 of 3 : Concept and Definitions

Polarization Entangled-Photon Sources

In general, the entanglement in frequency (energy) and polarization can be achieved by incorporating SPDC media within optical interferometers.

Interferometric schemes

Mach-Zehnder:

Two PPNCs are placed in the two arms of a Mach-Zehnder interferometer. It can be constructed using two sets of polarizing displacers (PDs). One set splits the pump beam at the input while the other combines the photon pairs into a single spatial output port. The critical condition is to have both of the PPNCs identical, which is challenging and limits the quality of the photon pairs entanglement.

Sagnac:

In the case of using a Sagnac interferometer, a single PPNC substitutes the two PPNCs. This is possible because of the bidirectional pump experienced by the PPNC. In addition, the need for the active phase-stabilization system is eliminated duo to its intrinsic phase-stability or the so-called self-compensation effect of a Sagnac interferometer. Implementing a single PPNW in the fiber-based Sagnac interferometer, the attributes of an excellent entanglement quality is associated with high photon pairs generation rates leading to high-end bright sources.

Polarization Entanglement Tomography Analyzer

This device consists of two programmable rotation stages. Each stage contains a rotatable quarter-wave plate (QWP), rotatable half-wave plate (HWP) and fixed polarizer, which can be replaced with a polarizing beam splitter (PBS) if required. This polarization system rotates the polarization states of the photon pairs with a sub-degree precision, realized in a closed loop operation. As a result, precise tomography through two single-photon detectors is realized at high precision with excellent repeatability in the course of a quick experiment.