

Intrinsic entanglement generation on polymer-based integrated circuit

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Abstract

We present a novel way to generate polarisation-entangled photon pairs which is both, highly efficient and simplistic in its experimental implementation. Consisting only of a single unidirectionally pumped nonlinear crystal, our source is predestined for miniaturisation and photonic integration, as we show by presenting a polymer-based integration methodology of this source.

Compact and efficient entangled-photon sources are of paramount importance for scalable and widely deployed quantum-optics applications. The most common approach for generating photon pairs is based on spontaneous parametric downconversion (SPDC), a process where a high-energy pump photon probabilistically decays into two lower-energy daughter photons (*signal* and *idler*) by interaction with a nonlinear optical material. Until recently, the generation of collinearly propagating entangled photon pairs was based on a superposition of paths [1] or on elaborate modifications of the crystal's internal domain structure [2].

We present a novel way to generate collinear entangled photons pairs in a frugal experimental setup. Our method is based on the quasi-phase-matching (QPM) technique where momentum conservation is satisfied by periodic alternation of the nonlinear coefficient along the nonlinear crystal. The length of the periodic poling domain Λ depends on the absolute value of the momentum mismatch $\Delta k = k_p - k_s - k_i$, where $k_{p,s,i}$ is the pump, signal and idler momentum, respectively. Since one poling periodicity Λ provides phase-matching for positive *and* negative Δk , one periodically poled nonlinear crystal, pumped by a single laser, can emit *two* different photon pairs at the same time: one with phase mismatch Δk and one with $-\Delta k$. We use this property to satisfy phase-matching for two SPDC processes with same wavelengths but interchanged polarisations: $\lambda_{H+} = \lambda_{V-}$ and $\lambda_{V+} = \lambda_{H-}$ where λ_{H+} (λ_{V-}) is the wavelength of the horizontally (vertically) polarised photon of the SPDC process with positive (negative) phase mismatch. Our method thereby allows for entanglement generation by unidirectionally pumping a single, uniformly poled nonlinear crystal, a setup with unparalleled simplicity.

A first experimental test of this method using a periodically poled KTP crystal underlined not only the frugality of the setup but also its high brightness and entanglement visibility [3]. As a drawback, however, the produced signal and idler wavelengths adhere to the material properties of the respective nonlinear crystal and cannot be chosen arbitrarily. In order to augment the repertoire of possible wavelength configurations, we performed an extensive numerical investigation of not only KTP but also four more exotic nonlinear materials that allow for ferroelectric poling: CsTiOAsO₄ (CTA), KTiOAsO₄ (KTA), RbTiOAsO₄ (RTA), RbTiOPO₄ (RTP). Our search revealed a large number of promising experimental configurations [4].

So far, integration of (entangled) photon pair sources have either been based on $\chi^{(2)}$ crystals with waveguides or $\chi^{(3)}$ processes in silicon nitride (SiN) or silicon on insulator (SOI) on photonic integrated chips (PICs). The drawback of these realisations is that only a restricted number of optical components can be implemented and more complex system require additional hardware located off the chip. The PolyBoard integration platform is set to radically change the integration capabilities for quantum systems on a PIC by offering a hybrid integration of bulk crystals with readily available optical and optoelectronic functionalities on a single chip. In the UNIQORN project this micro-optical bench concept will be applied to $\chi^{(2)}$ crystals, allowing for the miniaturisation of existing free-space optical setups. In addition to the design studies for our entangled-photon source on the PolyBoard, we will also present preliminary results from the photonic-chip characterisation.

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- [1] B. S. Shi and A Tomita, *Generation of a pulsed polarization entangled photon pair using a Sagnac interferometer*, *Phys. Rev. A* **69**, 013803 (2004).
- [2] H. Herrmann, X. Yang, A. Thomas, A. Poppe, W. Sohler, and C. Silberhorn, *Post-selection free, integrated optical source of non-degenerate, polarization entangled photon pairs*, *Opt. Express* **21**, 27981 (2013).
- [3] F. Laudenbach, S. Kalista, M. Hentschel, P. Walther, and H. Hübel, *A novel single-crystal & single-pass source for polarisation- and colour-entangled photon pairs*, *Sci. Rep.* **7**, 7235 (2017).
- [4] F. Laudenbach, R.-B. Jin, C. Greganti, M. Hentschel, P. Walther, and H. Hübel, *Numerical Investigation of Photon-Pair Generation in Periodically Poled MTiOXO₄ (M=K, Rb, Cs; X=P, As)*, *Phys. Rev. Appl.* **8**, 24035 (2017).