Manipulation of telecom photon path and polarisation in lithium niobate devices

Mirko Lobino, Damien Bonneau, Pisu Jiang, Mark G. Thompson, and Jeremy L. O'Brien
Centre for Quantum Photonics, H. H. Wills Physics Laboratory & Department of Electrical and Electronic Engineering
University of Bristol
Bristol, United Kingdom

Chandra M. Natarajan, Michael G. Tanner, and Robert H. Hadfield
Scottish Universities Physics Alliance and School of Engineering and Physical Sciences
Heriot-Watt University
Edinburgh, United Kingdom

Sanders N. Dorenbos and Val Zwiller
Kavli Institute of Nanoscience,
Technische Universiteit Delft
Delft, The Netherlands

***Abstract*— We demonstrate fast polarisation and path control of photons at 1550 nm in lithium niobate waveguide devices using the electro-optic effect. A common technological platform is used to show heralded single photon state engineering, fast two photon state preparation and feedback control of quantum interference. These results point the way to a single platform that will enable the integration of nonlinear single photon sources and fast reconfigurable circuits for future photonic quantum information science and technology.**

***Keywords-component;* quantum information, quantum photonics, quantum interference.**

I. Introduction

Integrated optical circuits are a promising approach for the implementation of optical quantum information protocols [1]. Manipulation of single photons in optical waveguide have been recently demonstrated in reconfigurable circuit that work at visible wavelength and use slow thermo optical phase shifters [2].

Fast operation of reconfigurable waveguide circuits at telecom wavelengths is crucial for their integration with the existing optical telecom networks as well as to benefit from the technologies developed in that area.

A fast electro-optic effect and a consolidated technology for the fabrication of low loss waveguides at telecom wavelengths using either proton exchange or titanium indiffusion (Ti:LN) makes lithium niobate (LN) an appealing platform for fast reconfigurable quantum photonic devices. Lithium niobate is used in telecommunications networks where 40 GHz modulators are standard and polarization manipulation based on the electro-optic effect have also been demonstrated for bright light [3,4]. Furthermore lithium niobate is particularly appealing for the prospect of directly integrating periodically poled waveguide photon sources [5] on a single substrate.

Here we demonstrate fast polarization and path control of photons at 1550 nm using a common technology based on lithium niobate electro-optical devices [6].

II. Experimental Set-up

A. Photon generation and detection

Photon pairs at 1550 nm wavelength were generated by spontaneous parametric down-conversion (SPDC) in a bismuth borate (BiBO) crystal and collected into two polarization maintaining optical fibers [see Fig. 1(a)]. Superconducting single photon detectors (SSPDs) [7] provide telecom wavelength single photon sensitivity with low dark counts and high timing resolution in the experiments presented here.

B. Single photon path manipulation

Figure 1(b) shows the experimental setup used for heralded single photon state preparation. One photon from a pair is measured directly by an SSPD providing the trigger signal for the pulse generator that controls a Mach-Zehnder interferometer (MZI).

For every trigger event, a voltage pulse was sent to the MZI with a controllable delay. This pulse induced a relative phase shift which prepares the single photon in a superposition of being in the two possible output of the MZI. We drove the MZI with a voltage pulse of 20 ns duration and 4 ns rise time that switched between a π, corresponding to the identity transformation, to a 0 phase shift, for the swap transformation, which routed the photon to the second SSPD.

By measuring the number of heralded counts as a function of the delay applied to the driving pulse we reconstructed the time response of the interferometer and measured a switching efficiency of 97.9±0.1%.

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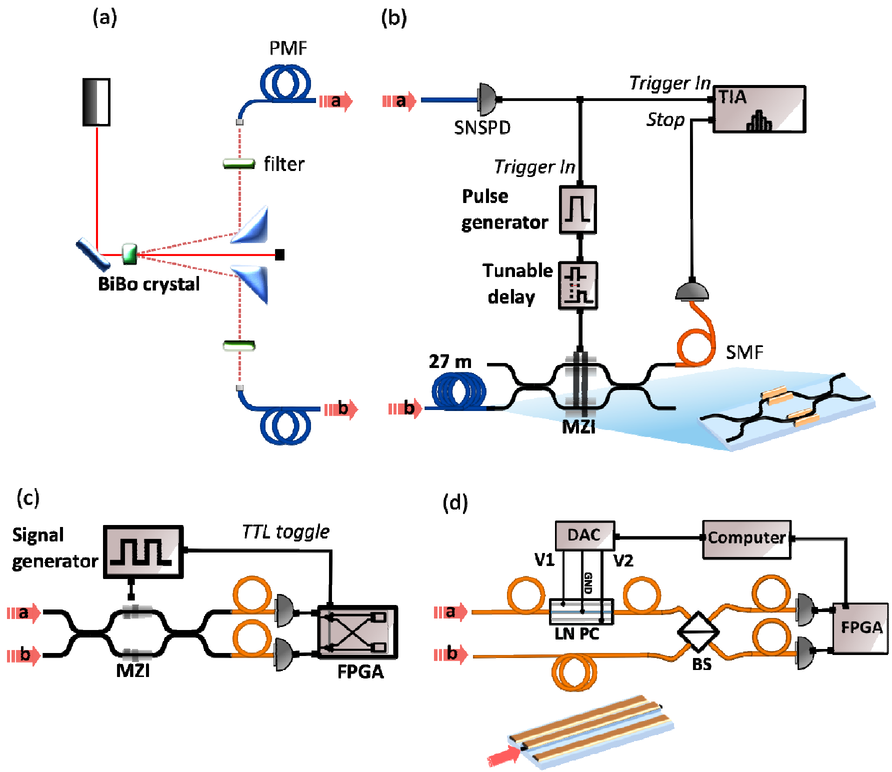

Figure 1: Fast path and polarisation control of single photons in lithium niobate waveguides.

C. *Two photon state preparation*

Figure 1(c) shows the scheme for the fast switching of a two-photon entangled state. Two photons from the same pair are injected in the two inputs of the MZI. A signal generator drives the MZI with square waves alternating between two voltages V(0) and V(π/2) at 4 MHz. These voltages correspond to a crosser and a balanced beam splitter configuration respectively.

Coincidental events for the two voltages are recorded in separate counters embedded in a field programmable gate array (FPGA) board. In the case where the MZI acts as a balanced beam-splitter, quantum interference occurs and the two photon NOON state is prepared. By delaying the arrival of one photon with respect to the other we were able to show the NOON state preparation in a Hong-Ou-Mandel dip measurement [8]. On the contrary when the MZI acted as a crosser, the number of coincidence counts was independent on their relative delay.

D. *Polatization manipulation*

Using a lithium niobate polarization controller driven by two voltages, we manipulate the polarization of single photons to implement a feedback loop for robust quantum interference between two paths which interfere on a beam splitter [Fig 1 (d)].

We demonstrate a bidimensional quantum interference pattern in the number of coincidental events recorded after the beam splitter as a function of the two driving voltages. Starting from random overlap in polarization between the two photons, we then use a gradient descent algorithm to iteratively choose the two applied voltages and demonstrate recovery of the quantum interference.

III. CONCLUSIONS

Rapid manipulation of the polarization and path degrees of freedom of single photons will be essential for future quantum technologies as well as fundamental quantum science. The ability to perform both path and polarization manipulation in a single platform is particularly appealing. Furthermore, lithium niobate promises the ability to directly integrate periodically poled LN single photon sources. Ultimately it should also be possible to integrate SSPDs into the waveguide circuit via growth of NbTiN directly onto LN substrates [9].

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