The Reconfigurable Waveguide Array

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Introduction

Quantum walks have been highlighted as a method of exploring quantum interference ([1],[2]) and performing quantum simulations ([3]). A quantum walk can be performed in a photonic lattice, utilizing the evanescent coupling between narrowly separated waveguide and spontaneous parametric down conversion as a source of indistinguishable photon pairs.

Quantum Walk Hamiltonian

The Hamiltonian to describe a quantum walk through an array of waveguides is based on the coupling coefficient between each waveguide and the propagation coefficient, denoted β. The coupling coefficients are given as C_{ij}, where C^{-1} is the distance to couple from waveguide i to waveguide j and, in the reconfigurable array, will be a function of the voltage V applied to the electrodes between. Considering only nearest neighbour coupling and an array of N waveguides, the Hamiltonian is given as

$$\mathcal{H}_{array} = \begin{pmatrix} \beta_0 & C_{0,1} & 0 & 0 & \dots & 0 & 0 \\ C_{1,0} & \beta_1 & C_{1,2} & 0 & \dots & 0 & 0 \\ 0 & C_{2,1} & \beta_2 & C_{2,3} & \dots & 0 & 0 \\ 0 & 0 & C_{3,2} & \beta_3 & \dots & 0 & 0 \\ \vdots & \vdots & \vdots & \vdots & & \vdots & \vdots \\ 0 & 0 & 0 & 0 & \dots & \beta_{N-2} & C_{N-2,N-1} \\ 0 & 0 & 0 & 0 & \dots & C_{N-1,N-2} & \beta_{N-1} \end{pmatrix}. \qquad (1)$$

Each coupling constant C will be tunable by applying a voltage and the coupling between waveguides will be equal in both directions, ie. $C_{ij} = C_{ji}$. Applying voltages to alter the coupling coefficients will also have an affect on the propagations coefficients β_i.

The unitary of the waveguide array can be determined from evolving this Hamiltonian

$$\hat{U}_{array} = \exp(i\mathcal{H}_{array}z). \qquad (2)$$

A simulation of the propagation of light through a waveguide array is shown in figure (1) where the input is into the central waveguide.

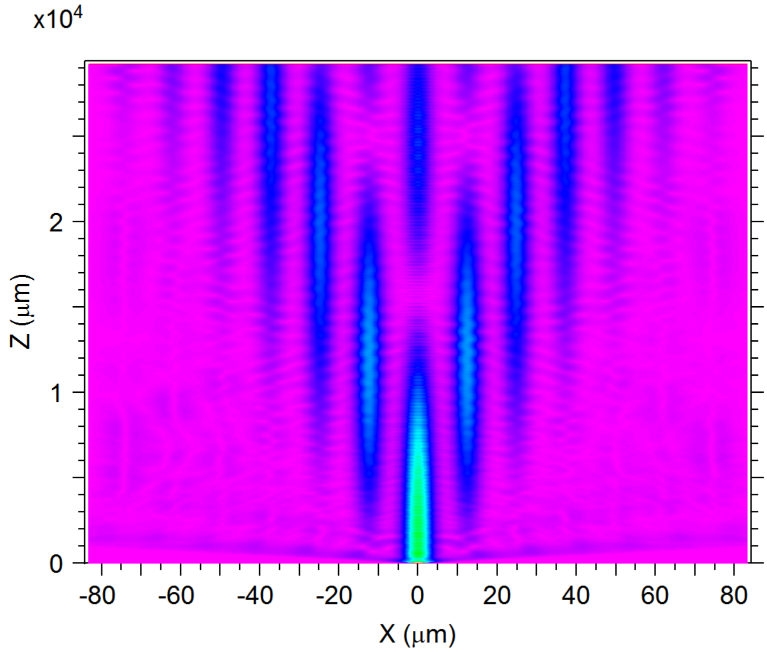

Figure 1: **Simulation.** Beam propagation method simulation of a 13 waveguide array with 12.4μm spacing.

Experiment Ideas

Here is a list of projects that we could work together on performing on the reconfigurable waveguide array platform:

- Boson sampling / Hamiltonian mixing / Performing identity
- Search/optimization algorithms
- A general study of possible Hamiltonians

Here is a list of other ideas we will look into with this device:

- Perfect State Transfer
- Controlled beam steering
- Anderson localization with tunable noise
- Optimizations for quantum simulations and quantum chemistry

Experimental Setup

Photon pairs are produced via spontaneous parametric down conversion (SPDC) of a 404nm laser to produce indistinguishable pairs of 808nm photons. Coupling into fibre gives control and capability to couple through a v-groove fibre array with 127μm pitch into the device. This source is stable and produces $\mathcal{O}(10^5)$ photon pairs per second.

To inject and retrieve photons from the waveguide array using commercially available v-groove fibre arrays requires the devices to have a fan-in and fan-out. These components will contribute to the coupling between the waveguides with a Hamiltonian of the form in equation (1), however, has been engineered to have the same coupling coefficient between all waveguides. The complete unitary for the device will therefore be

$$\hat{U}_{total} = \hat{U}_{fan}\hat{U}_{array}\hat{U}_{fan}, \tag{3}$$

the device mask is shown in figure (2).

Silicon single photon avalanche diode detectors are used in conjunction with an field programmable gate array in order to distinguish coincidence counts from single photon detection.

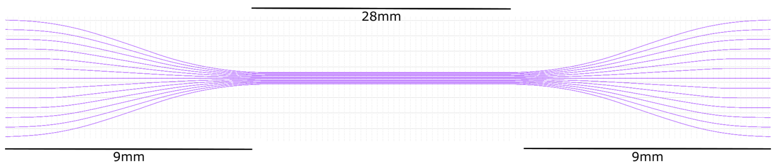

Figure 2: **Device Mask.** Mask for waveguide array inc. fan-in and fan-out. Electrodes run along either side of each waveguide as shown in figure (3).

Device Details

The reconfigurable waveguide array (RWA) consists of 13 titanium diffused $4\mu m$ wide lithium niobate waveguides, with spacings ranging from $12.4\mu m$ to $13.2\mu m$ and a coupling length of $28000\mu m$. Each waveguide has an electrode on either side. When a voltage is applied to a pair of electrode, the refractive indices of the waveguides and cladding change in opposing directions, as shown in figure (3). Each electrode can be controlled individually with a maximum potential of around 6-7V and the refractive index will change according to

$$\Delta n = n^3 r_{33} E, \tag{4}$$

where n is the refractive index of the waveguide, r_{33} is the electro-optical coefficient of lithium niobate and E is the electric field. This will give control over the coupling between adjacent waveguides and therefore a tunable Hamiltonian applied by the device.

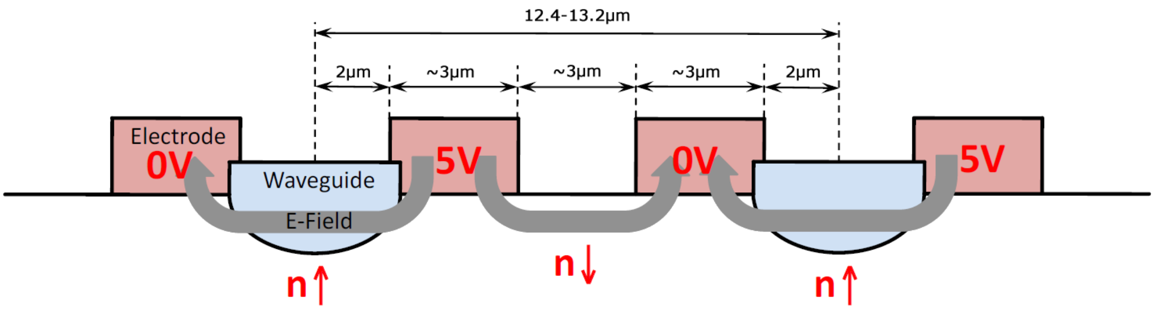

Figure 3: **RWA Electrode Design.** Arrangement of the electrodes for the 13 waveguides in the RWA. Each electrode is controlled via a PCB which is, in turn, controlled via a PC.

References

[1] *Quantum random walks*; Y. Aharonov, L. Davidovich & N. Zagury; Phys. Rev. A, Vol. 48 **2** (1993)

[2] *Quantum Walks of Correlated Photons*; A. Peruzzo *et al.*; Science, Vol. 329, pp.1500-1503 (2010)

[3] *A 2D Quantum Walk Simulation of Two-Particle Dynamics*; A. Schreiber *et al.*; Science, Vol. 336, pp.55-58 (2012)