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TITLE	**Functional description of a linear quantum photonic processor**
PROJECT	FGQT Roadmap
REFERRING TO	New proposal
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ABSTRACT

Explanation of changes

This proposal would extend section annex G (Photonic Quantum Computing) to include a functional description of linear optical quantum photonic processor, which is a platform for photonic quantum computing. It will fall under layer P1 (Quantum Photonic Devices) of the photonic architecture.

Why are the changes needed?

Linear optical quantum photonic processors are a platform for photonic quantum computing. A functional description of such devices will serve as the basis for developing standards for them, since it defines their function, interfaces, and operation.

Instructions for the editor: This contribution should be added as a chapter of Annex G in the FGQT roadmap (N020f). This text should be added as chapter 4, such that the existing chapters 4-6 are renumbered to chapters 5-7.

1 Functional description of a quantum photonic processor

1.1 Quantum photonic processor

A linear quantum photonic processor is a multimode quantum interferometer, which performs can perform any unitary transformation on the creation and annihilation operators of a photonic quantum state. This state is a superposition of creation and annihilation operators of the optical modes of the interferometer. The user is responsible for the photonic quantum state that serves as the input to the processor. The unitary transformation of the creation and annihilation operators is fully controllable by the user. These devices have multiple applications in photonic quantum computing. For example, linear gates can be encoded in combination with photonic qubit encoding. Also, they can be used to implement (Gaussian) boson sampling. For this application certain optimization problems can be mapped onto unitary transformation that are implemented on the quantum photonic processor. A certain quantum photonic state can then be sent through the processor and the resulting output distribution will correspond to the optimal solution or an approximation of the optimal solution for the implemented optimization problem. Also

1.2 Optical interface

The main component of a quantum photonic processor is a photonic integrated circuit (PIC), which interfaces with the user via optical fibers. The PIC contains a network of interconnected waveguides. These waveguides support only a single polarization and can be designed for a specific wavelength. The photonic quantum state enters and exits the PIC via polarization maintaining optical fibers. The wavelength and polarization of the input state must match the design wavelength of the PIC.

1.3 Photonic integrated circuit components and layout

The most fundamental components of a quantum photonic processor are waveguides, couplers, and phase delays. A waveguide guides the light over the processor without altering the photonic state it is guiding. Two waveguides can be connected by a coupler. In coupler photons have a probability of coupling to the other waveguide depending on the coupling ratio of the coupler. A coupler is created by bringing two waveguides close enough together so that guided modes can evanescently couple from one waveguide to another. A phase delay adds an additional phase to photons passing through that component. A phase delay can be induced through various means. The thermo-optic effect, where the refractive index of a material changes with temperature, can be used to create a phase delay in a waveguide by heating it using resistive heaters. Additional stress in a waveguide also changes its refractive index, this can be induced using piezo-electric tuners.

1.3.1 Unit cell

With the fundamental linear quantum photonic processor components, a unit cell can be defined that allows for all arbitrary unitary transformations on two modes. There are multiple possibilities to define a unit cell. An example is shown in Figure 2. This example consists of a tunable beam splitter (TBS), designed as a Mach-Zehnder interferometer (MZI), and a phase shifter (PS). The TBS controls the interference between the two modes and the phase shifter controls the phase of the two output modes. The PS induces a phase delay on one of the waveguides to create a phase difference between them. The configuration shown in Figure 1 is an example of an asymmetric unit cell where there is tuning element on only one of the arms of the MZI. Symmetric designs are also possible with tuning elements on both arms of the MZI. A symmetric unit cell does not require tuning elements outside of the MZI.

1.3.2 Network

Unit cells are combined into a network with a specific topology such that it can perform any unitary transformation on the creation and annihilation operators of the state, see **Error! Reference source not found.** for an example. A square topology, proposed by *Clements et al.* [1] is show in Figure 2, but other topologies such as a triangular layout, proposed by *Reck et al.* [2] also exist.

1.4 Implementing unitary transformations

A unitary transformation is implemented on the network by setting the phase shift of each unit-cells’ TBS and PS. The phase is set by applying a specific voltage across the resistive heaters or piezo-electric tuner. The voltage-phase relation is determined by characterizing the phase delays. The phases that are required to implement the unitary are determined by performing a decomposition algorithm on the unitary. The decomposition algorithm depends on the structure of the network and of the unit-cells [1, 2].

To implement a specific transformation, the user passes the phases necessary for that transformation to the quantum photonic processor. Another possibility is that the quantum photonic processor accepts a unitary transformation directly and performs the decomposition algorithm itself.

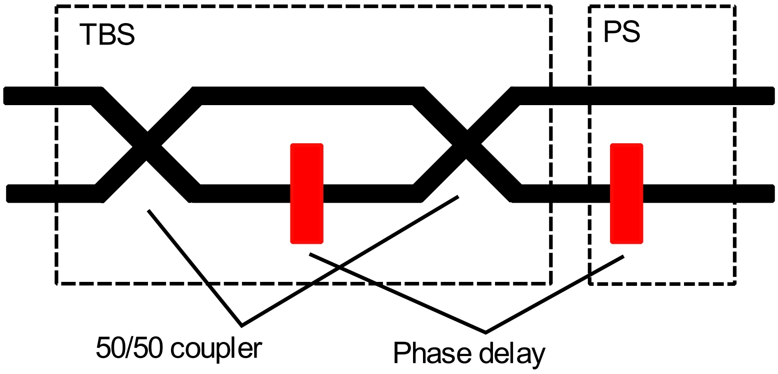

Figure 2: An example of a unit cell in a quantum photonic processor. The unit cell consists of two input and output waveguides on which a tunable beam splitter (TBS) and a phase shifter (PS) are applied. The TBS is built of a Mach-Zehnder interferometer (MZI), which consists of two 50/50 couplers and a phase delay on one of the arms. The TBS can be tuned to a specific splitting ratio by tuning the phase delay. The PS consists of a phase delay on one of the two arms, which induces a tunable phase difference between the two arms.

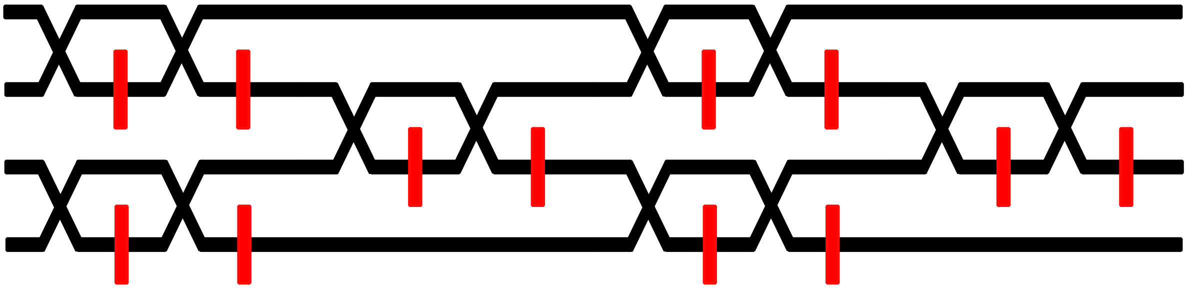

Figure 1: An example network of a 4 mode quatum photonic processor. Six unit cells are combined using the architecture of *Clements* [1].

References

[1] William R. Clements, Peter C. Humphreys, Benjamin J. Metcalf, W. Steven Kolthammer, and Ian A. Walmsley, "Optimal design for universal multiport interferometers", Optica 3, 1460-1465 (2016)
[2] Michael Reck, Anton Zeilinger, Herbert J. Bernstein, and Philip Bertani, “Experimental realization of any discrete unitary operator”, Phys. Rev. Lett. 73, 58 – Published 4 July 1994