Experimental multimode interference of two single photons in integrated waveguides

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Abstract—Multiport beam splitters are interesting and useful to the field of quantum information. (QI) They have applications including the production of highly entangled photonic states that form the basis of many of the powerful protocols in QI. We report details on multiport interferometers on integrated devices that rely on multimode interference.

Keywords-component; quantum entanglement; multiport beamsplitter

I. Introduction

Integrated quantum photonic devices promise the miniaturization and scaling of the quantum logic circuits that will be required in future quantum technologies [1-4]. The basic building blocks in these circuits are beam splitters. Beam splitters are fundamental devices in quantum optics enabling classical interference of a single photon with itself and quantum interference (or the Hong Ou Mandel dip) [5] between different photons. This multi-photon interference allows the generation of non-classical states of light that have applications in quantum communication, quantum computation, quantum metrology, and quantum lithography.

We give details of the experimental investigation of beam splitter devices based on the interference of different Gaussian light modes: multimode interferometers in silica-on-silicon waveguide. MMI devices are based on the self-imaging principle, by which an input field profile is reproduced in single or multiple images at periodic intervals along the propagation direction of a multimode guide [6]. This is designed to support a large number of lateral modes. These devices allow the design of N by M splitters and with a greater tolerance to wavelength variations and relaxed fabrication requirements compared to the other main beam splitting technology, directional couplers.

We give data on the two-photon quantum interference in a 2x2 MMI. We also discuss results from quantum interference in a 4x4 MMI (see Figure 1), which exhibits both Hong-Ou-Mandel dips and anti-dips. This is the first realization of quantum interference via multimode interferometry.

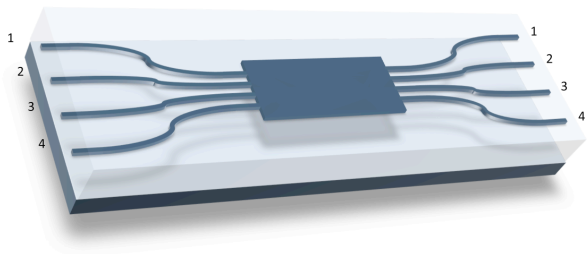

Figure 1. A 4x4 multimode interferometer, silica on silicon waveguide.

II. Method

Testing the MMI devices to their full potential required the construction of a spontaneous parametric down conversion (SPDC) source: the process by which a nonlinear crystal splits a very small proportion of photons from a strong pump beam into pairs of daughter photons (See Fig 2). A 402 nm continuous wave laser was focused to a waist of around 40 µm in a 2 mm thick Type-I BiBO crystal. The crystal was cut to output degenerate photon pairs (804 nm) at 3 degrees either side of the pump beam. The daughter photons were filtered to a bandwidth of 2nm and focused into polarisation maintaining fibres. The source was then fine tuned to ensure indistinguishable properties of polarisation and centre wavelength of the daughter photons.

This photon pair source was previously tested for quantum interference in a directional coupler waveguide and was found to produce a Hong Ou Mandel Dip of near unit visibility [7]. This provided a useful benchmark for the testing of the MMI devices.

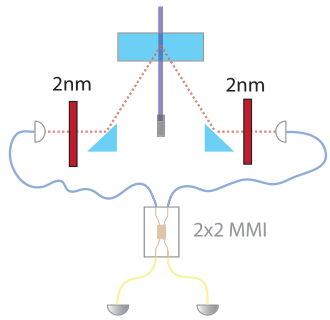

Figure 2. An SPDC two photon soure with 2x2 MMI waveguide

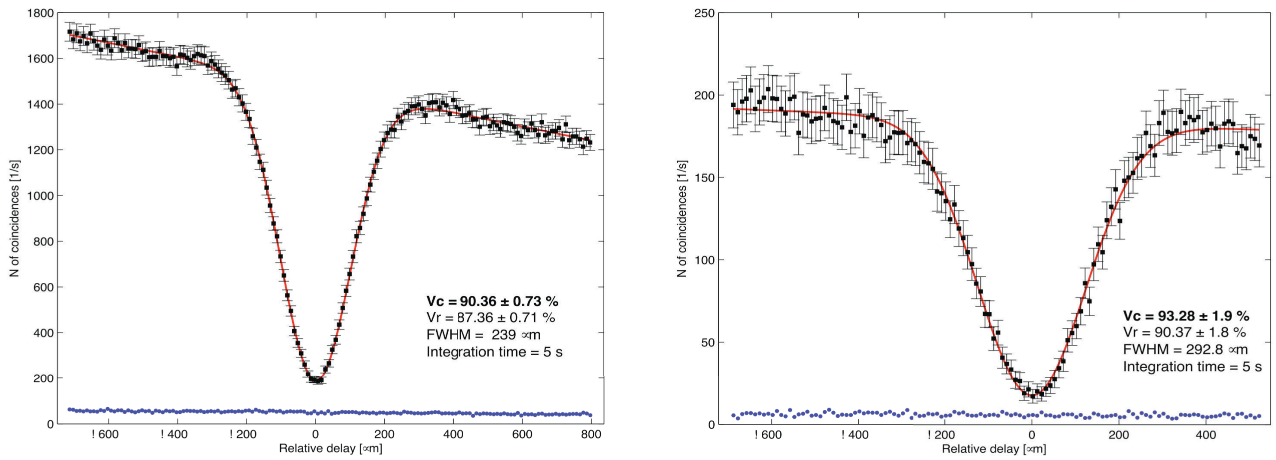

Figure 3. Quantum interference in a 2x2 MMI quantified by Hong Ou Mandel Dips. The two dips are from the same experimental set up, with the only difference being that the one on the right received post-filtering with a 0.5nm bandwidth interference filter inserted between the chip and the detector.

III. Results

We find that that the quantum interference visibility at 89.74 ± 1.3% is significantly lower than that of a directional coupler with the source described above. A major reason for the reduced visibility is the coherence length of the photons, which is set by the 2nm interference filters. Since the different modes see different effective refractive indices within the interferometer, a jitter is introduced which allows distinguishibility between the photons. To overcome this problem we introduced a narrower 0.5nm filter in one of the channels between the device and the detector, i.e. not affecting the source. This quantum erasure technique increases the visibility significantly to 95.12 ± 2.5%. This difference can be appreciated in Fig 3, although here the dips are shown with a Sinc function that gives slightly different visibilities than the more usual Gaussian fitting, which produces the data quoted here.

IV. On-Going Work

Finally, we observed the novel interference effects from a 4x4 interferometer. Here, one observes the very interesting multiport interference effects of dips and anti-dips. One can use the sign of the dips (dip or anti dip) and their visibilities to determine an internal free parameter that occurs for multiport interferometers of dimension greater than four [8]

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