# Four-Port Interference Device on an Integrated Photonics Platform Based on Tilted Bragg Gratings

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We propose and numerically simulate an integrated photonics platform to implement a compact, universal, and tunable 4x4 mode coupler for quantum information processing. We have previously developed technology for the simultaneous inscription of planar optical waveguides and Bragg gratings by direct UV writing for use in integrated photonic circuits [1]. By providing the gratings with a tilt angle, we are able to achieve wavelength selective coupling of light between two parallel channel waveguides. Recently, we have exploited 45° tilted gratings in order to demonstrate a polarising waveguide-to-waveguide coupler using this platform [2].

Here, a new type of interference device based on tilted Bragg gratings is investigated. It is based on a single ridge structure with a photosensitive core layer in which two parallel waveguides are written (see Fig. 1a). Each waveguide supports two modes, which means that there are four co-propagating waveguide modes in total. On each of the waveguides we have two superimposed Bragg gratings. This has the effect of coherently coupling light from each of the four waveguide modes to the modal structure of the ridge. As the ridge modes propagate at a wide angle compared to those of the waveguides, we must introduce a tilt angle in order to have phase matching in both the longitudinal and transverse directions. By tailoring the parameters of the four gratings we can ensure that all the waveguide modes are coherently coupled to a single backward propagating cladding mode of the ridge that acts as a bus. By controlling the amplitude of the gratings during fabrication we can couple light from any mode to any arbitrary superposition of other modes. This results in a very compact four-port interferometer device that could be used on single photons for quantum information processing.

Using coupled mode theory, we derive a general analytical solution for the dynamics of four waveguide modes coupled to a single cladding mode. This allows us to calculate the values of the complex coupling coefficients, and thus of the grating parameters, that are required to produce any given behaviour. Subsequently we verify the analytical predictions by calculating the full set of modes of the ridge structure by a finite difference method and simulate light propagation through the device in this complete model.

As an example, we demonstrate here a device that couples light from a single launched mode to an equal superposition of all four waveguide modes of the system. For this we need to achieve equal coupling coefficients between the waveguide modes and the bus mode as well as equal phase mismatch. In Fig. 1b we show the device output as we sweep the wavelength around the grating resonance. We see the formation of a photonic bandgap. Inside the bandgap, the light exponentially approaches a steady state during propagation through the device, but outside of the bandgap power is exchanged between the modes in an oscillating fashion. The device is designed to achieve a maximum of 25% power in each of the output waveguide modes on either side of the bandgap. Light propagation at this specific wavelength through the device is shown in Fig. 1c. In this case the power in the bus mode vanishes at the output and thus a perfect 25:25:25:25 beam splitter is achieved.

In conclusion, we have proposed a new platform for the realisation of arbitrary universal 4x4 mode couplers for single photon interferometry [3]. Analytical and numerical modelling frameworks have been established and a sample device of a uniform 25:25:25:25 beam splitter has been demonstrated.

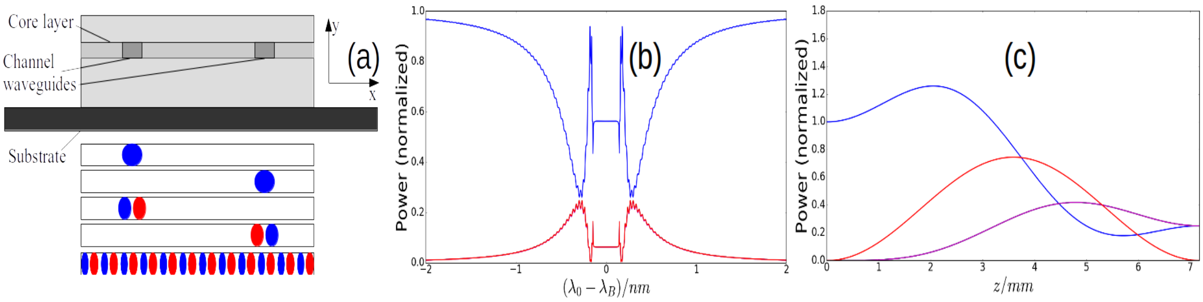


**Fig. 1** Four-port interference device with equal coupling coefficients and all light launched into one mode. (a) Schematic cross section of the device and of the waveguide and cladding bus modes. (b) Power output of the launched mode (blue) and all other waveguide modes (red) versus wavelength. (c) Power distribution between the launched mode (blue), the bus mode (red) and all other modes (purple) versus propagation distance for an optimised 25:25:25:25 beam splitter device.

## References

[1] C. Sima et, al, "Ultra-wide detuning planar Bragg grating fabrication technique based on direct UV grating writing with electro-optic phase modulation," Opt. Express, 21 pp. 15747–15754 (2013).
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[3] J. B. Spring et al, "Boson Sampling on a Photonic Chip," Science, 339, pp. 798 – 801 (2013)