Four-port integrated waveguide coupler exploiting bi-directional propagation of two single-mode waveguides

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We propose and numerically simulate a new and highly compact integrated 4x4 mode coupler based on two single-mode waveguides exploiting both propagation directions to double the number of modes. The two parallel waveguides are coupled via long and short-period gratings to the co- and counterpropagating directions, respectively, of a single, isolated cladding mode of the device which acts as a bus to transfer light between the waveguides. By connecting all end facets of the two waveguides to optical circulators we construct a device with four input and four output ports but only using two single-mode waveguides.

Such a device can be fabricated by uv-writing the waveguides in a single micromachined silica ridge structure with a photosensitive raised index layer that supports multiple modes. A single cladding mode of the ridge is used as a bus between the two waveguides. Coupling is achieve using long and short-period waveguide gratings in order to couple to the cladding mode in the co-propagating and counter-propagating direction. Tilted gratings are necessary for efficient coupling. Previously, we have developed UV writing technology for tilted gratings and demonstrated its use for waveguide-to-waveguide coupling experimentally [1] and numerically [2]. We have also simulated a unidirectional 4x4 coupler based on two two-mode waveguides [3].

We use coupled mode theory to simulate the system numerically. We begin by calculating the full set of waveguide and cladding modes using the finite differences method. We choose one of the cladding modes to act as a bus and tailor the grating parameters to couple the waveguide modes only to that cladding mode. Then, we calculate the coupling coefficients by using the overlap of these modes with the gratings. We solve the system as an eigenvalue/eigenvector problem to simulate the propagation of light in all modes.

By tailoring the grating parameters, we are able to achieve a wide variety of coupling ratios between the modes. For certain sets of coupling coefficients, we are able to couple light from one input port equally into all output ports. Using analytic derivations, we are able to confirm this and find that for one set of coupling coefficients, we are able to implement a Walsh-Hadamard transformation. In the future, we will investigate if we can implement a universal 4x4 mode-coupler on this platform, and if, by encoding the qubits in the waveguides and using a photon in each propagation direction, for example, it could be used for quantum information processing.

[1] M. T. Posner et. al. “Integrated polarizer based on 45° tilted gratings” Opt. Express, Vol. 27, pp. 11174-11181 (2019)
[2] M. J. Weisen et. al. “Low-loss wavelength-selective integrated waveguide coupler based on tilted Bragg gratings,” J. Opt. Soc. Am. B, Vol. 36, pp. 1783-1791 (2019)
[3] M. J. Weisen et. al. “Four-port interference device on an integrated photonics platform based on tilted Bragg gratings”, CLEO/Europe-EQEC 2019, Munich, Germany (2019)