Planar waveguide coupler based on tilted Bragg gratings and a discrete cladding mode

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We have recently developed a new technology for direct UV-written integrated waveguide circuits. In particular, we exploit tilted Bragg gratings to couple light between parallel channel waveguides, which potentially allows for wavelength and polarisation selective optical coupling. A polarising coupler between two waveguides with close to 30 dB polarisation extinction ratio has already been demonstrated experimentally based on gratings with a tilt angle of 45° [1]. However, this device exhibited a waveguide-to-waveguide loss of 10.5 dB, which even in theory cannot be reduced to less than 3 dB because of light being lost into the continuum of radiation modes.

Here we investigate theoretically and numerically an improved design with tailored cladding modes that overcomes this intrinsic loss. In this case the substrate is structured into a wide ridge waveguide, e.g. by micromachining two channels separating the ridge from the rest of the substrate. Two parallel single-mode waveguides containing tilted Bragg gratings are then written into this ridge. Light is now coupled between the two waveguides utilising the modal structure of the ridge instead of the continuum of modes in an unstructured substrate. By tailoring the period and tilt angle of the gratings, forward and/or backward propagating ridge modes can be coupled and the grating bandwidth can be adjusted to form a wavelength selective coupler with improved coupling efficiency.

We use coupled mode theory to simulate the complete system of the two waveguides coupled to the full set of ridge modes as an N-by-N coupler using the weakly guiding approximation, where the coupling strength of the gratings is calculated from spatial overlaps of modes obtained by finite element simulations. In the case of weak gratings, we find that the effect of non-resonantly coupled modes can be neglected. This leads to a simplified model of only three coupled modes, the two waveguide modes and a single ridge mode. By using a counter-propagating ridge mode and introducing a slight wavelength detuning away from the grating resonance we are able to switch between two operation modes of the device. In one solution, the power in the input waveguide decays exponentially with propagation distance. The other solution has periodic oscillations as power is exchanged between the two waveguides. In the latter case, the power exchange reaches a theoretical maximum efficiency of 100%.

Finally, we will present the validation of our coupled mode theory model by finite element simulations in two dimensions and further details of an analytic solution that fully describes the simplified three-mode system. This will allow us to quickly design and optimise devices for subsequent fabrication and experimental demonstration.