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Refractive-Index Engineering of Planar Waveguides with Subwavelength Gratings

Jens H. Schmid, Pavel Cheben, Przemek J. Bock, Jean Lapointe, Siegfried Janz, Dan-Xia Xu, Adam Densmore, André Delâge and Trevor J. Hall

In integrated photonic circuits, the refractive-index contrast is usually set by the choice of the material platform. For example, for silicon photonic circuits operating at a wavelength near $\lambda = 1.55 \mu\text{m}$, the waveguide core and the cladding indices are given by the material constants of silicon ($n = 3.5$) and silicon dioxide ($n = 1.44$), and waveguide devices must be designed within the constraint of these fixed values.

From free-space optics, we know that periodic dielectric structures with a periodicity smaller than one half of the wavelength do not diffract any light. Instead, such so-called subwavelength gratings (SWGs) act as homogeneous effective media with spatially averaged refractive index.¹ We have recently demonstrated the first use of SWGs for refractive-index engineering in micro-photonic waveguides, providing a powerful method for controlling the refractive index of a waveguide core in any specific location of a photonic chip. Importantly, our method only relies on standard fabrication techniques and can be implemented without any modifications to the chip fabrication process flow.

The structure shown in (a) exemplifies refractive-index engineering of a silicon photonic wire waveguide. By etching periodic gaps of a well-defined width w and pitch Λ into a standard silicon photonic wire, an SWG waveguide is formed with an effective core index determined by the duty ratio w/Λ . Calculation of the dispersion relation of the segmented waveguide and comparison with the dispersion of an equivalent photonic wire waveguide with identical cross section and a core index of $n = 2.65$, as shown in (b) confirms theoretically the concept of spatial refractive-index averaging.

Experimentally, we have observed waveguiding in such SWG structures with a propagation loss as low as

(a) SEM image of an SWG waveguide. (b) Dispersion relation of an SWG waveguide and an equivalent photonic wire waveguide with core refractive index of 2.65 (TE polarization). (c) SWG waveguide crossings.

2.1 dB/cm, comparable to the best photonic wire waveguides reported, and with a low and nearly wavelength-independent group index, as predicted by theory.² Although consistent with Bloch theory, it is fascinating to observe light propagating almost unperturbedly through so many strong discontinuities.³

Among the applications of SWG waveguides⁴ is an SWG slab waveguide structure that simultaneously acts as a lateral cladding for a photonic wire waveguide in a novel microspectrometer design and an efficient in-plane fiber-chip coupling structure. The coupler structure works by gradual modification of the waveguide core index, leading to mode-size transformation between a high-index photonic wire and the low-index optical fiber. Measured coupling loss is 0.9 dB for TE and 1.2 dB for TM polarization. SWG waveguides were also implemented for highly efficient waveguide crossings,⁵ such as those shown in (c).

Having the ability to intersect waveguides with low loss and crosstalk is an important prerequisite for designing complex high-density photonic circuits. SWG waveguide loss per crossing was measured to be as low as 0.02 dB with polarization-dependent loss of less than 0.02 dB and crosstalk less than 40 dB. These applications demonstrate the obvious advantages of having the new degree of freedom in photonic circuit design afforded by SWG refractive-index engineering. ▲

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