Subwavelength nanophotonic structures for integration and sensing

P. Cheben,1 H. Podmore,2 R. Halir,3 J.H. Schmid,1 A. Sánchez-Postigo,3 A. Ortega-Moñux,3 G. Wangüemert-Pérez,3 I. Molina-Fernández,3 J.M. Luque-Gonzalez,2 J.D. Sarmiento-Merengué,3 D.-X. Xu,1 S. Janz,1 J. Lapointe,1 S. Wang,1 M. Vachon,1 D. Benedikovic,1 C.A. Ramos,4 R. Lee,2 A. Scott,2 A. Velasco,6 J. Litvik,1 J. Mullerova,1 and M. Dado7

1. National Research Council, Information and Communications Technology, Ottawa, Canada
2. Department of Physics and Astronomy, York University, Toronto, ON, Canada
3. ETSI Telecommunications, Universidad de Málaga, Spain
4. Université Paris-Saclay, France
5. Honeywell Aerospace, Kanata, ON, Canada
6. CSIC and Universidad Complutense de Madrid, Spain
7. University of Žilina, Slovak Republic

1. Introduction

We report our advances in development of subwavelength engineered metamaterial structures in silicon waveguides, specifically high-efficiency fiber-chip couplers, ultra-broadband surface grating couplers and nanophotonic beam splitters, evanescent field waveguide sensors and on-chip Fourier-transform spectrometers.

2. Subwavelength grating (metamaterial) silicon waveguide structures

By locally engineering the refractive index of silicon by forming a pattern of holes at the subwavelength scale, it is possible to manipulate the flow of light in silicon photonic waveguides [1]. The subwavelength metamaterial engineered structures are likely to become the key building blocks for the next generation of integrated photonics. Building up on this concept, we demonstrated a broadband fiber-chip edge coupler with a coupling efficiency of 0.32 dB (92%) and polarization independent operation for silicon-on-insulator (SOI) waveguides [2] and several types of fiber-chip surface grating couplers with coupling efficiency as high as 0.7 dB (85%). These grating couplers are critical elements in the NRC photonic wire biosensor microarray platform, capable of monitoring up to 128 optical sensor outputs simultaneously and in real time. We have also demonstrated a new coupler concept which achieves for the first time both broadband operation bandwidth and high coupling efficiency. The coupler operates in the zeroth diffraction order, for which the radiation angle variation with wavelength is minimized, hence broadening the bandwidth [3]. The calculated fiber-chip coupling efficiency is 91% (-0.41 dB) and 3-dB and 1-dB bandwidths are 200 nm and 126 nm, respectively. This is the first time that a sub-decibel coupling efficiency and a 1-dB bandwidth exceeding 100 nm are obtained at the same time for a surface grating coupler design in silicon waveguides. We have also leveraged, for the first time, the anisotropy and dispersion of a subwavelength structured photonic metamaterial to demonstrate ultra-broadband integrated beamsplitting [4]. Integrated splitters and photonic components with large spectral bandwidth and controlled dispersion are critical for applications such as coherent communications and coherent comb generation in optical metrology. The fundamental advantage of our broadband splitter device arises from the inherent anisotropy of the subwavelength grating: two guided waves traveling in the central multimode region along the longitudinal and transverse directions experience optically different structures. Our device achieves virtually perfect operation over an unprecedented 500 nm design bandwidth, making it arguably the most broadband nanophotonic waveguide component designed to date. We also show that by subwavelength patterning of silicon-wire waveguides the field delocalization can be engineered to increase the sensitivity of an evanescent field waveguide sensor. Finally, we present applications of subwavelength engineered waveguides in a new type of a compressive-sensing Fourier-transform spatial heterodyne spectrometer chip. We successfully demonstrate the retrieval of various sparse input signals by collecting data from a truncated interferometer array and show that the spectral retrieval maintains the full resolution and bandwidth of the original device despite a sampling factor as low as 1/4th that of conventional designs.

3. References