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Supermode Dispersion of Strongly Coupled Silicon-on-Insulator Waveguides

C.E. de Nobriga[1,]*, W.J. Wadsworth[1], A.V. Gorbach[1], D.V. Skryabin[1], J.C. Knight[1], A. Samarelli[2], M. Sorel[2], R.M. De La Rue[2],

[1]*Centre for Photonics and Photonic Materials, Dept. of Physics, University of Bath, Claverton Down, Bath, BA2 7AY, UK*

[2]*Dept. of Electronics and Electronic Engineering, University of Glasgow, Rankine Building, Oakfield Avenue, Glasgow, G12 8LT, UK*

**C.E.deNobriga@bath.ac.uk*

Abstract: We report measurement of the group index dispersion of the supermodes of a three channel array of strongly coupled silicon-on-insulator waveguides, and compare results with numerical simulations. We observe strong coupling-induced dispersion.

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1. Introduction

Ultrafast nonlinear photonics in structured materials is currently being intensely researched. Over the past few years, the well-established waveguide technology of silicon-on-insulator (SOI) has been recognized as having great potential in this field. In particular, nano-sized silicon waveguides, or photonic wires, offer a very promising way of realizing photonic components on a microchip. Research efforts have yielded some understanding of nonlinear propagation effects in single photonic wires [1], but there has recently been an interest in the use of arrays of photonic wires [2,3] and slot waveguides. Of particular relevance for nonlinear optical studies is the recognition [2] that coupling-induced dispersion can be a major factor in determining the overall group-velocity dispersion characteristics of such arrays. In this work we report the first experimental observation of such dispersion.

2. Method

The waveguide arrays were fabricated on a silicon-on-insulator (SOI) wafer consisting of a 220 nm thick, slightly p-doped silicon guiding layer on top of a 2 μm thick silicon oxide layer, on top of a silicon substrate. The waveguides were patterned using electron beam lithography in HSQ (hydrogen silsequioxane) electron-beam resist and then transferred after development into the guiding layer using fluorine based chemistry in an inductively coupled plasma (ICP) reactive ion etching machine. After electron irradiation, HSQ becomes an amorphous inorganic material with a structure and composition close to that of SiO_2, thus removing the need for an additional pattern transfer stage into a harder etch-mask material. For the chosen etching gas combination, the HSQ electron-beam resist provides good etch resistance, with minimal edge roughness, leading to small propagation losses. The top silicon layer was completely etched through, leaving rectangular arrays of waveguides with a cross section of 220 nm by 420 nm. The waveguides were surrounded by air on the sides, by a residual 160 nm thick HSQ resist layer on the top, and by a 20 nm tall silica pedestal underneath that results from a small amount of over-etching. We have studied light propagation in an array of three closely spaced waveguides with an inside wall-to-wall separation of 600 nm.

Spectral dispersion measurements were taken using low coherence interferometry in a free-space Mach-Zehnder interferometer geometry. The light source used was an optical supercontinuum generated by using a Q-switched microchip laser at 1064 nm, together with a length of solid-core photonic crystal fibre. Wavelengths below 1220 nm were removed from the input spectrum by a low-pass (long wavelength) filter, in order to reduce the thermal and optical load on the samples. The waveguide array was placed in one arm of the interferometer and light was coupled into and out using bulk optics (60× objective lenses, NA=0.65), which were aligned using a DFB diode laser at 1480 nm. An InGaAs array camera allowed visualization of the scattered light from above the waveguides, using a binocular microscope, and visualization of the output field profile. These not only allowed consistency in coupling into each array but allowed also repeatability in the exact excitation condition. The reference arm delay was controlled using a mirror on a motorized stage. The light in the two arms of the interferometer was recombined using a beam splitter and delivered by a single-mode collecting fibre to a high-gain, amplified photodiode. Interferograms were recorded for different central wavelengths using 10 nm band-pass filters before the interferometer. A lock-in-amplifier, referenced to an optical chopper in the sample arm, increased sensitivity. The fringe packets for both the quasi-TE_{01} and quasi-TM_{01} supermodes were resolved and the position was recorded. The group index was calculated for each filter using the fringe position when no sample was present.

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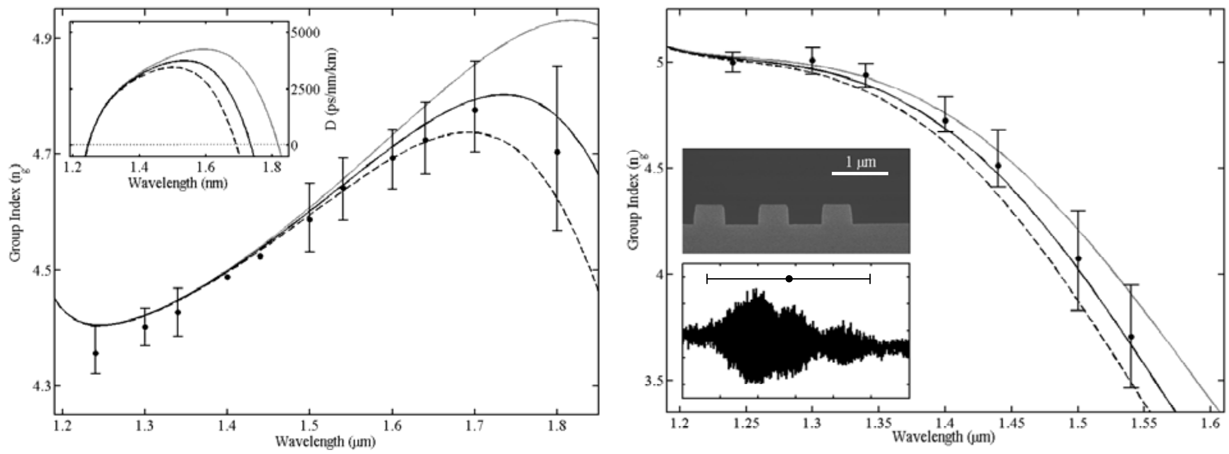
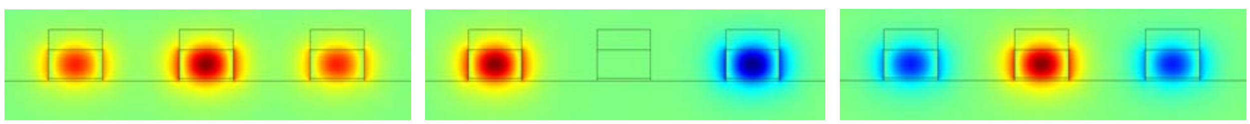


(a) (b)



(c) (d) (e)

Fig. 1: (a) Graph showing the experimental values of interferogram centroid (filled circles) and full width at the background intensity (capped vertical lines) along with numerical modelling of the group index of the three quasi-TE_{01} supermodes of a 3-channel array (lines). Inset is numerical calculation of the group velocity dispersion. (b) Shows the group index for the quasi-TM_{01} supermodes. Inset is an example of an interferogram taken at 1800 nm for in the TE polarization mode and an SEM micrograph of the fabricated device. The solid black line on the group index plots correspond to the antisymmetric supermode (d) while the black dashed line and solid grey lines correspond to the symmetric supermodes (c & e respectively). The field profiles shown (c-e) are the transverse component of the electric field for TE polarization at 1500 nm.

3. Results

Interferograms were recorded at 11 filter wavelengths between 1240 nm and 1800 nm using 10nm bandpass filters. The centroid and the full width at the background signal level were calculated for each interferogram. Each interferogram contained information on the group index of all the supermodes at that wavelength. The splitting between the antisymmetric supermode and the two symmetric supermodes is approximately equivalent. Thus the centroid of the interference fringe packet is the component of the fringe associated with this antisymmetric mode. The component of the fringe associated with the two symmetric modes was difficult to isolate due to uneven modulation of the fringe envelope, so the full width at the background signal level was used (as shown in the lower inset of fig.1(b)). This measurement was invariant to any modulation for a given filter wavelength. The exact modulation was dependent, *inter alia*, on the input coupling conditions. Numerical solutions to Maxwell's Equations in a similar geometry yielded the effective modal index of the three TE and TM supermodes. The group index was obtained by differentiation using a two-point difference method and the result verified by the differential of a polynomial fit to the effective index. The result was consistent with the experimental measurement of the group index of both the TE and TM modes across the entire range of measurement.

4. Conclusion

We have shown the experimental splitting of the dispersion of supermodes of an array of three silicon photonic nanowires due to strong coupling dispersion and compared the experimental results with numerical models.

5. References

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