Slow light in photonic crystal waveguides

Thomas F Krauss
School of Physics and Astronomy, University of St. Andrews, KY16 9SS, UK
tfk@st-andrews.ac.uk

Abstract: Slow light in photonic crystal waveguides can be used to enhance linear and nonlinear functionality resonantly. Applications in nonlinear optics and in electro-optic switching and modulation, as well as the limitations of the phenomenon, will be discussed.

1. THE SLOW LIGHT PHENOMENON

Slow light in photonic crystals is an interference phenomenon similar to Bragg scattering; Bragg scattering is well known from periodic structures and gratings and occurs at the bandedge, namely when the wavelength of light corresponds to half the grating period. A standing wave forms as a result. The slow light effect, however, occurs away from the bandedge, so instead of a standing wave, a slowly travelling envelope forms; this is the slow mode (fig. 1) [1]. These slow modes have a number of remarkable properties. For example, due to the resonant buildup of intensity, nonlinear effects are enhanced.

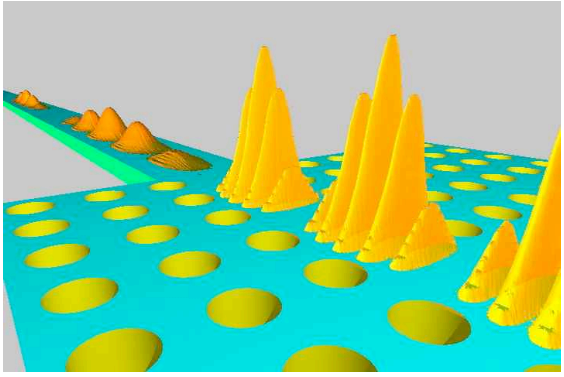

Figure 1. Sketch of the phenomenon of intensity enhancement in the slow light regime. A fast mode enters from the top left and is resonantly enhanced in the slow photonic crystal waveguide.

If multiple waves interact, such as in four-wave mixing or in second and third harmonic generation, the enhancement scales with the number of slow waves. As an example, we have recent observed third harmonic generation in silicon, which scales as the third power of the slowdown factor, resulting in the remarkable observation of green light emission [2]. Another useful effect of the slowdown is the reduction in length and power consumption of all-optical and electro-optic switches; here, we have shown the reduction of the switching length in a Mach-Zehnder and in a directional coupler switch. The MZI is as short as 80µm and the directional coupler is only 5µm long - one of the smallest optical switches ever reported [3].

2. LIMITATIONS

An important question is the interplay between slow light enhancement and the bandwidth over which the enhancement occurs, as well as the question of the ultimate limitation. By carefully studying the dependence of the propagation loss and achievable bandwidth on slowdown factor/group index, we find a favourable regime around a group index of 30-40; the loss is low and typically scales directly with the group index (e.g. 5dB/cm for ng=5 and 30 dB/cm for ng=30). For higher group indices, we observe multiple scattering and light localisation, which distorts optical pulses and precludes optical signal processing. Therefore, while group indices up to ng=1000 have been observed in photonic crystal waveguides, such high values can not be used in practise, at least not with present technology. An example for a State-of-the-Art photonic crystal waveguide is shown in figure 2; even though the structure appears perfect, the remaining roughness on the scale of 1-2 nm RMS is sufficient to limit the slow light operation as discussed above.

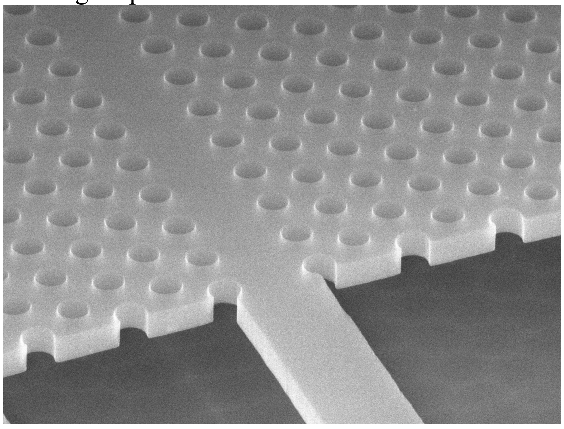

Figure 2. Micrograph of a photonic crystal waveguide. The structure consists of a 220 nm thick membrane of lattice constant 420 nm.

REFERENCES

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