Patterning Effects in Ultrafast All-Optical Photonic Crystal Nanocavity Switches

Heuck, Mikkel; Kristensen, Philip Trøst; Mørk, Jesper

Published in:
2011 Conference on and 12th European Quantum Electronics Conference Lasers and Electro-Optics Europe (CLEO EUROPE/EQEC)

Link to article, DOI:
10.1109/CLEOE.2011.5942983

Publication date:
2011

Document Version
Publisher's PDF, also known as Version of record

Citation (APA):
Heuck, M., Kristensen, P. T., & Mørk, J. (2011). Patterning Effects in Ultrafast All-Optical Photonic Crystal Nanocavity Switches. In 2011 Conference on and 12th European Quantum Electronics Conference Lasers and Electro-Optics Europe (CLEO EUROPE/EQEC) (pp. CI2_3). IEEE. DOI: 10.1109/CLEOE.2011.5942983

Patterning Effects in Ultrafast All-Optical Photonic Crystal Nanocavity Switches

Mikkel Heuck, Philip Trøst Kristensen, and Jesper Mørk
DTU Fotonik, Technical University of Denmark, DK-2800 Kgs. Lyngby, Denmark

All-optical switches are expected to play a key role in increasing the bandwidth of future communication networks by replacing slower electronic components for certain signal processing tasks. Previous work has demonstrated the possibility of switching a single pulse [1,2]. However, a more realistic investigation of the switching performance requires longer random pulse sequences, since detrimental effects may accumulate over time scales longer than one pulse duration. This has been investigated for switches based on semiconductor optical amplifiers [3], but in this work the focus is on a photonic crystal material system, which facilitates a high level of integration with other components such as waveguides, light sources, beam splitters, etc.

We consider a geometry similar to that in [2], where two cavity modes are coupled to two input and two output waveguides. The theoretical framework is coupled mode theory (CMT), which has previously been shown to correspond very well with results from FDTD calculations [2], and therefore provides a powerful tool for extensive parameter-space investigations.

The patterning effect can have different physical origins such as a long lifetime of photons in the cavity or slow relaxation rates if carrier-induced nonlinearities are considered. Fig. 1 shows an example, where the signal and control beams couple via the Kerr effect. The switch is used for demultiplexing, where a target bit is extracted from the on/off modulated signal. To quantify the performance of the switch, we use a figure of merit based on the output energy of the signal in the target bit slot when the signal input was ”1”. It is defined as the minimum ratio between this energy, and the energies in the succeeding bit slots, both for a signal input of ”1” and ”0”.

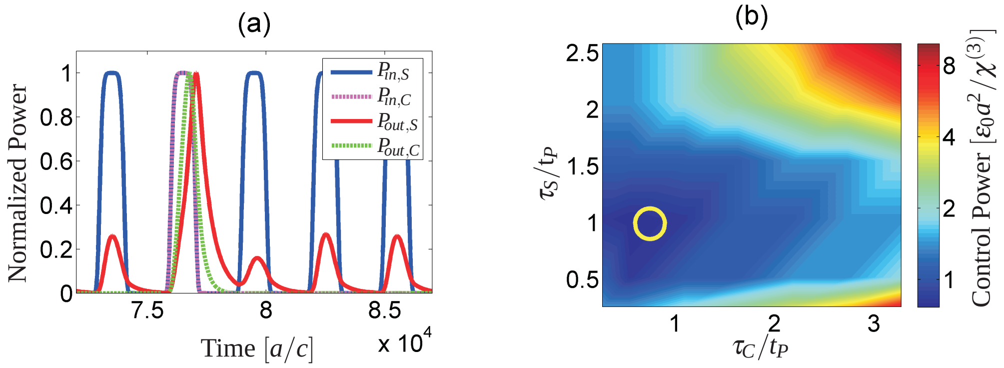

Fig. 1 (a) Example of input and output powers of the signal and control beams. $P_{in(out),S}$ is the input(output) signal power and $P_{in(out),C}$ is the input(output) control power. Notice that all power levels have been normalized to have a maximum of 1. The time unit is given in terms of the photonic crystal lattice constant, a, and the speed of light in vacuum, c. (b) The minimum control pulse energy required to obtain a threshold value of the figure of merit as a function of the ratio between the two decay times, τ_S, τ_C, of the cavity modes and the pulse width, t_P. The energy unit is given in terms of the vacuum permittivity, ε_0, the lattice constant, a, and the Kerr coefficient, $\chi^{(3)}$. The yellow circle indicates a minimum in the control pulse energy.

There is a trade-off between the reduction in switching energy and deteriorating patterning effect as the cavity decay time increases. Fig. 1 shows an optimum in the energy consumption when both decay times are close to the pulse width. We expect this type of optimization to be of importance when designing photonic crystal switching structures. Note that the CMT approach is not limited to the particular system studied here, but can be used to analyze switching configurations with different geometrical designs and different types of nonlinear interactions.

References

[1] K. Nozaki, T. Tanabe, A. Shinya, S. Matsuo, T. Sato, H. Taniyama, and M. Notomi, ”Sub-femtojoule all-optical switching using a photonic-crystal nanocavity,” Nature Photonics, **4**, 477-483 (2010).

[2] M. F. Yanik, S. Fan, M. Soljacic, and J. D. Joannopoulos, ”All-optical transistor action with bistable switching in a photonic crystal cross-waveguide geometry”, Optical Letters, **28**, 2506-2508 (2003).

[3] J. Xu, X. Zhang, J. Mørk, ”Investigation of Patterning Effects in Ultrafast SOA-Based Optical Switches”, IEEE Journal of Quantum Electronics, **46**, 87-94 (2010).