Efficient pulse excitation of a nonlinear microcavity

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Summary

Nonlinear microcavities are known to exhibit an intensity-dependent refractive index. This effect causes a mismatch between the resonance of the cavity and the input pulse frequency, resulting in a limitation of the energy coupling efficiency. We show here that a phase shaping of the input pulse allows to maintain the benefit of light localization.

Introduction

Photonic crystal (PhC) microresonators are well known to exhibit a high quality factor and a small mode volume. These structures enable a strong enhancement of the light-matter interactions, and especially of the nonlinear interactions. Indeed, nonlinear microcavities offer promising applications in all-optical signal processing.

For instance, all-optical switching relies on the nonlinear index change that is induced by the optical Kerr effect or by the free carrier refraction (FCR), generated by two-photon absorption (TPA). The optical nonlinearities are provided by a high-intensity control pulse that can be ideally coupled into a cavity resonance. However, since this control pulse is inducing a nonlinear refractive index change, the resonance frequency of the cavity is then varying with time. Before the peak of the pulse reaches the cavity, the mismatch between the resonance and the pulse frequencies reduces significantly the coupling efficiency of the excitation signal. This leads to a ringing behavior, introducing a distortion of the intra-cavity field and a reduction of the light localization effect.

A first way to partially overcome this limitation is to introduce a detuning between the control pulse and the initial resonance frequency, nevertheless, this is not the optimal case. Following the example of coherent control of atomic and molecular systems [1], a second approach consists in introducing a phase shaping of the excitation pulse. Sandhu *et. al.* [2] have recently numerically shown that the peak energy coupled into a resonator can be enhanced with an appropriate phase shaping of the incoming pulse. The spectral phase is set to compensate for the linear dispersion of the cavity resonance which allows to reduce the incoming energy to switch a bistable device, based on a pure Kerr effect cavity.

We propose to extend this principle by compensating the nonlinear induced frequency drift of the resonance using an adapted phase-shaped pulse. For illustration, we study the case of a Silicon PhC microcavity, for which the frequency drift of the resonance is mainly governed by FCR.

Discussion

Using the coupled-mode nonlinear model [3], we have simulated the nonlinear dynamics of a PhC Si microcavity. We first consider a pulse excitation with a gaussian temporal shape, a duration equal to 1.7 times the cavity photon lifetime τ, and an initial frequency centred towards a cavity resonance. During the excitation, the accumulation of free-carriers tends to temporally shift the cavity resonance frequency. The beating between the incoming pulse and the time-varying frequency resonance leads to a ringing behavior on the temporal shape of the intra-cavity field that is shown in fig. 1(a) (see red line). In order to increase the quantity of stored energy, we consider a second excitation using a linear chirped pulse with a gaussian shape. For comparison, the chirped pulse duration and energy are equals to that of the previous excitation. As shown in fig. 1(b), the linear chirp (magenta curve) has been optimized to fit the resonance frequency shift (solid black curve). In such a coherent excitation, the intra-cavity temporal shape undergoes less distortions (see the black curve in fig. 1(a)) and enables to increase the stored energy by a factor 1.77.

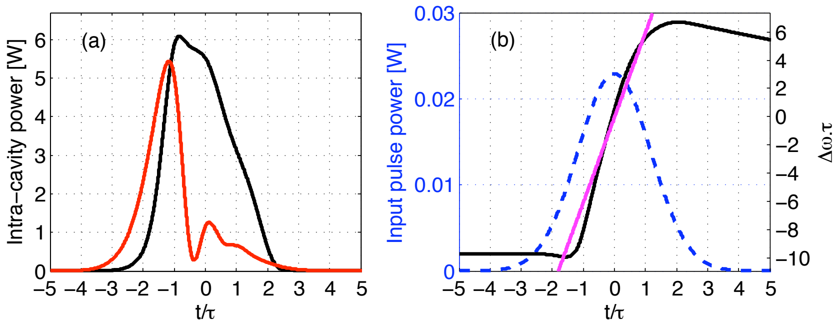

Fig. 1: (a) Intra-cavity power temporal shapes for a non-chirped gaussian pulse (red line), and a linearly-chirped pulse (dark line). (b) Excitation pulse temporal shape (dashed blue line), cavity frequency drift (dark line) and instantaneous frequency of the input chirped pulse (magenta line). τ is the cavity photon lifetime.

Conclusions

We have proposed an efficient way to control the intra-cavity field dynamics and to improve the coupling efficiency of an input pulse into a nonlinear microcavity. In the case of a Silicon microcavity, an optimized linearly chirped input pulse enables to compensate for the nonlinear induced frequency drift of the resonance, which leads to an enhancement of the intracavity stored energy by a factor 1.77. By doing so, the benefit of light localization effect can be maintained throughout the pulse duration. Moreover, the frequency drift of the resonance is enhanced by a factor 2.56, due to the FCR strengthening, which may contribute to reduce the energy consumption of all-optical devices based on nonlinear microcavities.

References

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