Lasers, switches and non-reciprocal elements based on photonic crystal Fano resonances

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Abstract: **We discuss the realization of active photonic devices exploiting Fano resonances in photonic crystal membranes.**

The rich physics of Fano resonances [1] has recently been explored in a number of different photonic and plasmonic systems [2], [3]. In two-dimensional photonic crystal structures, where a thin semiconductor membrane is embedded in air, Fano resonances can be realized by side-coupling a point-defect nanocavity with a line-defect waveguide [4]. Such Fano resonances can be exploited to realize efficient all-optical switches [5], non-reciprocal elements [6], or lasers that can generate short optical pulses [7,8].

Fig. 1 shows examples of the investigated Fano structures, where a line-defect waveguide is coupled to a point-defect nanocavity. In this case, the Fano resonance arises due to interference of the continuum modes of the waveguide with a discrete mode of the nanocavity. By incorporating a single (or multiple) airholes in the waveguide below the nanocavity, the transmission profile can be controlled from being Lorentzian (right-most figure) or of the general Fano-shape (all other cases), with different values of the shape-parameter, indicating the degree of symmetry.

The properties of the Fano resonance can be exploited for different applications. Thus, the fast transition between maximum and minimum transmission can be used to realize switches, requiring much less energy than conventional switches [4,5]. The narrow transmission dip seen in the left-most figure implies a narrow reflection peak, which can be used as a laser mirror. In comparison to standard line-defect lasers implemented in the same membrane structure [7], the Fano laser wavelength is pinned by the nanocavity resonance, independently of the laser cavity length. In the case where the nanocavity also incorporates quantum dots, it turns out that the laser undergoes a transition to self-pulsing, with pulswidths on the order of 10 ps and repetition rates in the gigahertz region [9]. Theory presented in [8], indicates that such photonic crystal Fano lasers may have intrinsic modulation bandwidths exceeding 1 THz. By implementing an asymmetric structure, where the air-hole in the waveguide is displaced from the symmetry-line of the nanocavity, one can realize an element displaying non-reciprocity, i.e., the transmission depends on the direction of propagation [6].

In the presentation we will emphasize the physics of these novel structures as well as the models that have been developed based on coupled-mode theory to understand the dynamics and design the structures.

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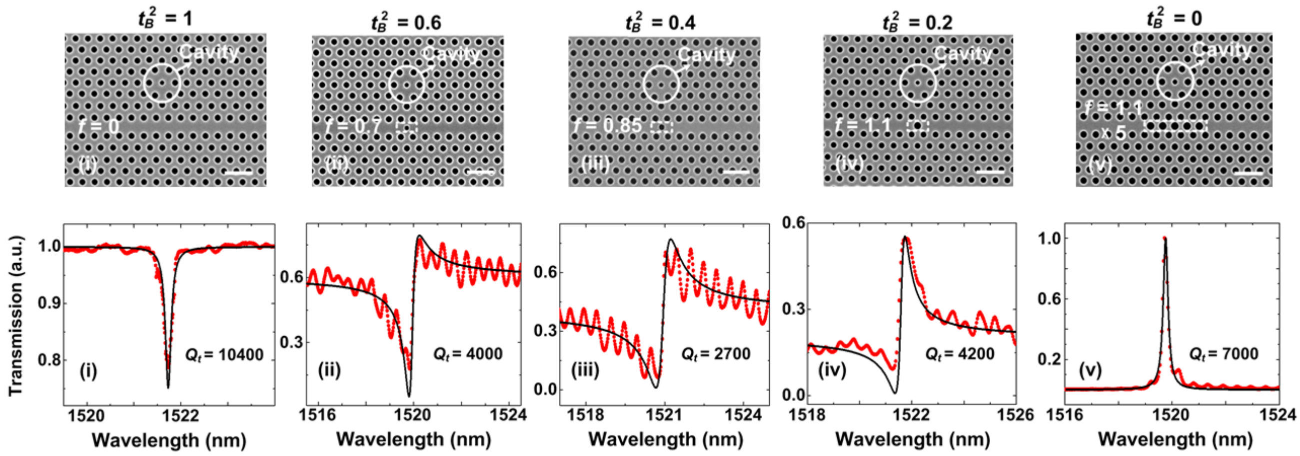

Fig. 1. Upper: Electron microscope picture of photonic crystal membrane structure, where a line-defect waveguide is side-coupled to a point-defect nanocavity. Below the nanocavity, one or several air-holes may be present, leading to a modification of the waveguide transmission, indicated by the transmission coefficient, t_B. Lower: Measured (red line) intensity transmission from left to right and corresponding fit (black) line, using coupled-mode theory and with the indicated value of the quality factor of the nanocavity.

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