Photonic crystals: from fancy to reality

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Photonic crystals (PCs) in the visible range are slowly emerging from a conceptual phase to physical implementations. In the past few years, several 3D fabrication techniques have been demonstrated which lead/should lead to the observation of full 3D bandgaps. However, 3D PCs do not easily yield *sizeable physical effects*, such as the control of spontaneous emission or lifetime changes, in structures that can be exploited in the optoelectronics field. On the other hand 2D PCs in thin-slab or waveguide structures open a number of new possibilities in optoelectronics or in the realization of various integrated optics components such as mirrors, micro-resonators, couplers, *etc*. In that case waveguiding in the third direction orthogonal to the PC design leads to full 3D confinement of optical modes.

Earlier physics studies consisted in establishing the basic kinematic properties of 2D PCs such as *transmission, reflexion and diffraction coefficients*. It is now well established that for a variety of structures and materials excellent, quasi-intrinsic properties can be obtained [1]. To further assess the potential of PCs in optoelectronics applications, it is essential to evaluate in-depth specific properties of these structures beyond their basic kinematic properties. For instance, *radiation losses* in the substrate or superstrate around the slab represent either an unwanted loss mechanism for resonator or integrated optics purposes or a welcome extraction mechanism for light in LEDs. We have developped an analytical perturbation method which gives a realistic estimate of such radiation losses as a function of the basic system parameters (hole diameter and height, index contrasts of super- and sub-strate with respect to the core). Its results are described by an imaginary index of refraction in the air holes representing radiative losses and give trends in excellent agreement with existing 3D calculations as well as quantitative experimental results. They thus provide a universal tool to make predictions and improve 2D PCs [2].

Several building blocks for photonic integrated circuits have been studied. Very high-performance devices can be foreseen from the measured quality factors in excess of 1000. Recently, we have demonstrated a coupled PC device incorporating a PC-bounded waveguide and a hexagonal PC microcavity. A specific coupling mechanism between cavity and waveguide is observed, based on optical tunneling between cavity and waveguide modes and subsequent mode conversion in the waveguide [3]. We have also shown that losses can be engineered towards useful applications concepts. We have recently used new PC structures to yield LEDs with ultimate emission efficiencies, although fabricated by a fully planar process.

It thus appears that photonic crystals might have a huge impact in various essential areas of future technologies, although not exactly in the way originally predicted.

[1] H. Benisty *et al*., J. Lightwave Technol. **17**, 2063 (1999).

[2] H. Benisty *et al*., Appl. Phys. Lett. **76**, 532 (2000).

[3] H. Benisty *et al*., *Proc. QELS/CLEO* (2000), p. 88.