Photonic Crystals: Nanophotonics, from Fantasy to Reality

C. Weisbuch
Ecole Polytechnique, Palaiseau, France

Photonic crystals (PCs) in the visible are slowly emerging from a conceptual phase toward physical implementations. Several 3D fabrication techniques have been demonstrated in recent years, but these 3D PCs do not easily yield sizeable physical effects, such as the control of spontaneous emission or lifetime changes, or structures that could be exploited in the optoelectronics field. So far, the best efforts to inhibit spontaneous emission have yielded limited results, and recent quantitative calculations indeed point to small expected effects. On the other hand, 2D PCs in thin-slab or waveguide structures promise new possibilities in optoelectronics or in the realization of various optical components such as mirrors, micro-resonators, couplers, *etc*. In this case, waveguiding in the third direction orthogonal to the PC design leads to full 3D confinement of optical modes.

Earlier physics studies focused on the basic kinematic properties of 2D PCs such as transmission, reflection and diffraction coefficients. Today, excellent, quasi-intrinsic properties can be obtained that for a variety of 2D structures and materials.[1] To further assess the potential of PCs, it is essential to understand their specific properties beyond basic kinematics. For instance, radiation losses in the substrate or superstrate around the slab can represent either an unwanted loss mechanism for resonator or integrated optics purposes, or a useful extraction mechanism in LEDs. We have developed an analytical perturbation method which describe losses by an imaginary index of refraction in the air holes.[2] Thanks to the recent progress in etching procedures, extremely low propagation losses are now possible in PC waveguides.[3]

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 10^3. For applications in the cavity-QED field, it is expected that the 2D PC-based microcavities should lead to the ultimate quantum coupling strength. Recently, several complex photonic crytal assembly schemes have been demonstrated. Within the European PCIC (photonic crystal integrated circuits) project, single mode lasers were obtained with remarkable performance and ease of fabrication. Drop functions were also obtained in ultra-compact structures.[3,4]

Losses can be engineered towards useful applications concepts. We have recently used new PC structures to yield LEDs with ultimate emission efficiencies, although with a fully planar process.[5] 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.

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

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

3 PCIC IST European project # 1999-11239.

4 S. Olivier *et al*., to appear in *Appl. Phys. Lett.* (2003).

5 M. Rattier *et al*., to appear in *Appl. Phys. Lett.* (2003).