The physics of photonic crystal-based LEDs

C. Weisbuch, A. David, and H. Benisty
Ecole Polytechnique and CNRS, France and *UC-Santa Barbara, U.S.A.*

Photonic crystal (PhC)-based LEDs display a rare blend of fundamental and applied concepts in semiconductor physics. This is due to the fact that the properties of PhC-LEDs rely on a mix of *intrinsic optical* properties of the materials (most often nitrides these days) originating from their *electronic* structure and of *electromagnetic* properties of the PhC.

Focusing on the latter, PhC LED studies allow in-depth understanding of the properties of PhCs, including the determination of their key parameters (real and imaginary dispersion curves of the band structures for instance). This is to be contrasted with studies dealing with the better established confinement properties of PhCs which rely on non-propagating modes in the photonic forbidden bandgap and therefore mainly explore bandgap states, whereas PhC LEDs allow to explore propagating states of the photonic band structures.

In a series of recent papers in the nitride materials system, we have determined band structures of PhC lattices such as triangular [1] and Archimedean tilings [2]. These studies are a clear-cut example how physics *in* devices is a powerful tool to extract fundamental properties of matter (here light propagation in periodic structures).

Turning to studies of physics *of* devices led us to explore various structures that could pave the way to ultimate LED efficiency. In particular, we showed [3] that optimum PhC structures depend on the materials' indices of refraction: the triangular lattice works best for nitrides, while lattices with more nearest neighbors, such as Archimedean tilings lattices, are required for GaAs materials due to their higher index of refraction. We also demonstrated that the vertical design of LEDs largely determines the extraction efficiency of the photonic crystal [4].

Applications are here of major importance: PhC LEDs could be a favored solution for ultra-high-efficiency LEDs to be used in tomorrow's solid state lighting, providing huge energy savings. Time is of the essence, as several countries are on the verge of banning the sale of incandescent light bulbs in favor of higher efficiency solutions. Today, the preferred alternative on the basis of availability and low cost is the high-efficiency compact fluorescent lamp (CFL). The challenge to PhC LEDs is to reach efficiencies similar to CFLs or higher, with fabrication technologies allowing large volume production, low cost and high fabrication yield.

1. A. David *et al.*, *Appl. Phys. Lett.* **87**, 101107 (2005).
2. A. David *et al.*, *Appl. Phys. Lett.* **88**, 073510 (2006).
3. A. David, H. Benisty, and C. Weisbuch, *IEEE J. Display Technol.* **3**, 133 (2007).
4. E. Matioli *et al.*, *Phys. Status Solidi C*, to be published (2009).