COMBINED PHOTONIC CRYSTALS AND GRAPHENE FOR LIGHT HARNESSING

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Inside the wide family of periodic photonic structures, dielectric photonic crystals have played a fast growing part during the last 25 years, their specificity inherently lying in the high index contrast of the periodic modulation (generally more than 200%) introduced in the optical medium. The concept of three dimensional photonic crystal (3D PhC) was simultaneously introduced by S. John [1] and E. Yablonovitch [2]: it is currently considered as a must for 3D spatial and temporal confinement of the light. In practice the fabrication of 3D PhCs is very difficult, and most of the developments have concerned the production of 1D and 2D PhCs formed in wave-guiding dielectric slabs. These high-index-contrast periodic structures can indeed be fabricated using planar technological approaches that are familiar to the world of integrated optics and microelectronics. They consist practically in 1D or 2D structuring of a planar dielectric/semiconductor membrane waveguide, where photons are “index guided”, that is to say vertically confined by the profile of the optical index. In most of the reported works, 1D-2D PhCs are meant to operate solely in the 2D wave-guiding configuration and, hence, are limited to a 2D control of photon trajectory: in this context, they have been the matter of an innumerable number of reports, publications, conferences and tutorials. In the present tutorial, we will not therefore contribute further to this abundant literature and will not talk about 2D PhCs operation, where control of light is restricted to the sole in plane wave-guiding configuration. We will instead concentrate on more recent developments where use is made of 1D-2D PhC membranes for efficient 3D harnessing of light, along a variety of configurations including both in plane wave-guided and free space radiated regimes and where the basic building block of devices consists in a surface-addressable resonant PhC membrane structure.

The physical principles of surface-addressable resonant PhC membrane structures will be presented in detail: they are based on the resonant coupling of incoming optical beam (radiated mode) with wave-guided Bloch modes in the PC membrane, which may occur whenever wavelength and *k*-vector matching conditions are met. The essential driving forces and controlling parameters will be described and routes for simple design rules, resulting in the production of structures endowed with the desired characteristics in the space-time domain will be given. Exemplifying use of surface-addressable resonant PhC membrane structures in a variety of devices will be presented [3].

The richness of optical and electronic properties of graphene is currently attracting enormous interest. A considerable potential lies in photonics and optoelectronics, where the combination of its unique optical and electronic properties can be fully exploited [4]: for example, the linear dispersion of the Dirac electrons in graphene is the distinctive feature which makes this material ideal for wide spectral bandwidth (from 0,4 µm up to middle and far infrared) and ultra-fast saturable light absorption. Also, it has been recently demonstrated that graphene possesses a very large 3rd order non-linear coefficient (χ3). In addition, a major asset of graphene lies in the fact that its remarkable photonic properties can be easily tuned by shifting the Fermi level around the Dirac singularity, where the density of electronic states is rather low. In this presentation, we further argue that the exceptional photonic properties of graphene can be further magnified if the material is combined with surface-addressable resonant PhC membrane structures, taking advantage of their remarkable photonic confining properties. In particular it is shown that the heterogeneous planar integration of graphene with silicon on insulator PhC membrane structures provides an ideal generic platform for this purpose.

References

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[2] E. Yablonovitch, “Inhibited Spontaneous Emission in Solid-State Physics and Electronics” *Phys. Rev. Lett.*, vol. 58, pp. 2059-2062, 1987.

[3] See the review paper and refernces there in: P. Viktorovitch, B. Ben Bakir, S. Boutami, J.-L. Leclercq, X. Letartre, P. Rojo-Romeo, C. Seassal, M. Zussy, L. Di Cioccio, and J.-M. Fedeli, “3D harnessing of light with 2.5D photonic crystals,” *Laser & Photon. Rev*., vol. 4, no. 3, pp. 401–413, 2010.

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