Preface

With the continuous miniaturization of electronic components over the last 50 years we have grown accustomed to the idea of micro-electronics where transistors are measured in microns, and today, with the advent of transistor grid lengths of around 10 nanometers, we are getting used to nano-electronics. Besides, we should not forget about Moore's law[1], a predictive law, according to which the length of the transistor grid is reduced by a factor of two approximately every 18 months.

The concept of nanophotonics, although not surprising, remains, however, less clearly understood by the scientific community than that of nano-electronics. Admittedly, we realize that optoelectronic components, such as the lazer diode, modulators and detectors developed for the needs of optical telecommunications, are small nowadays, but there does not exist a Moore's law of optoelectronics and the most usual limit naively imagined for optics is that of wavelength, i.e. a size close to the micron for waves of the visible and near infrared spectrum.

It is, therefore, the main objective of this work to try and give a more precise overview of the rapidly emerging field of nanophotonics, wherein optical fields at the scale of a fraction of wavelength and even mainly sub-wavelength are sought to be controlled and designed.

In fact, if the optical "chip" does not exist in the liking of the electronic "chip", photonic crystals have recently led to great hopes for large-scale integration of optoelectronic components. Two-dimensional photonic crystals obtained through periodic structuring of a planar optical waveguide, in particular, have many characteristics which bring them closer to electronic micro- and nanostructures. In a simple vision, it suffices to introduce periodicity defects at suitably selected spots within the crystal to obtain the desired optical components (waveguides, bending light, micro-resonators, filters, etc.) and to pair them up with each other to form true

1 G. Moore, founder of INTEL.

photonic circuits. Admittedly, reality is more difficult than it appears, if only for the precision needed in the manufacturing of structures. In many cases it is considered lower or equal to 10 nanometers, and then all the relevance of parallels between nano-electronics and nanophotonics become apparent. The first two chapters are thus mainly dedicated to photonic crystals in planar optics, referring to other recently published works on the subject[2], while focusing on the photonic components themselves, the dynamics of the photons plunged into a periodically structured medium and the prospect of obtaining high integration photonic circuits.

On the subject of two-dimensional photonic crystals radically differing from planar guided optics, Chapter 3 tackles the topic of photonic crystals fibers and, more generally, of structured fibers. Not only is the propagation of light achieved then perpendicular to the plane of periodic structuring, but also the unique production technology is based on the first assembly performed on a macroscopic scale, the final micro-nano-structures obtained by a stretching process at the second stage. It is impressive to be able “to unravel” micro-nanophotonics over distances of several kilometers! From a practical standpoint, microstructured fibers and photonic crystal fibers open up unprecedented prospects with respect to the control of the propagation mode in fiber-optics and to the control of chromatic dispersion. By controlling optical confinement, we may also easily control the processes of nonlinear optics that can be developed within these fibers.

Before the concepts of photonic circuit or fiber even appear, it should be remembered that the first studies of photonic crystals and structured materials for optics had been motivated, at the beginning of the 1980s, by the desire to control and even inhibit spontaneous emission in optoelectronic components. The largely conveyed emblematic image is that of the single transmitter in a uni-modal micro-cavity, every emitted photon being in the unique electromagnetic mode of the cavity. That aside, for the image to become reality over time, it was initially necessary to control the realization of nano-transmitters in the solid state, then to know how to combine nano-transmitters and micro-cavities. Chapter 4, in particular, deals with semiconductor quantum boxes and their association to various types of optical micro-cavities. The chapter introduces the concepts of weak and strong coupling in micro-cavity, as well as giving reports on the applications to semiconductor lazers with a very weak threshold and to single-photon micro-nanosources required for quantum cryptography.

Micro-nanostructuring of materials is also full of prospects for other active components of nonlinear optics. In fact, it is not only possible to achieve true engineering of the refraction index dispersion, but also to control the dispersion of group velocity as well as the localization of the electromagnetic field. Adapting the

2 J-M. Lourtioz, H. Benisty, V. Berger, J-M. Gérard, D. Maystre, A. Tchelnokov, *Les cristaux photoniques ou la lumière en cage*, Collection Technique et Scientifique des Télécommunications, Hermès, Paris, 2003.

phase and group velocity of electromagnetic waves with very different frequencies in order to reinforce their interactions is an example of application in the case of second-order optical nonlinearities. Chapters 5 and 6 thus develop various aspects of nonlinear optics in micro- and nanostructured materials such as the second harmonic generation, the optical Kerr effect, the propagation of solitons or the mix of four degenerated waves. After a short theoretical introduction to nonlinear optics, the various effects are illustrated on the basis of experiments performed very recently.

In Chapter 7 we openly approach the field of sub-wavelength optics with the analysis techniques of near optical field. The sub-λ nature stems not only from the distances between a point and a diffracting object, but also from fading waves whose space extension may be clearly lower than that of the light wavelength. Until recently limited to particular cases, the analysis of near fields today assumes all its interest with the development of nanotechnologies and optical micro-nanodevices. Having defined the near field concept and recalled the alternatives of microscopy in the near field, this chapter thus illustrates certain recent characterizations of semiconductor micro-components in planar integrated optics.

Metallic devices involving surface or localized plasmon-polaritons are also choice objects for the studies of near fields, because these waves are not detectable in far fields. Chapter 8 is mainly dedicated to them as well as to the optical technique of microscopy by tunnel effect. The coupling between an optical wave and electric charges oscillating in a metal is a phenomenon that has been known for a long time and generally considered as a parasite, since it is dissipative over propagation lengths typically exceeding 10 microns. However, the development of micro-nanotechnologies allowed an unprecedented revival of the studies with the creation of a new set of themes known today under the name of plasmonics. The now-famous experiment of Ebbesen[3] was one of the determinant elements of the renewed interest for the plasmon waves. More generally, miniaturization of metal structures appears a possible way of optical connections alongside photonic crystals.

Of a smaller size than all the devices evoked previously, including quantum box nano-transmitters, nanocrystal semiconductors composed of a few hundred to a few thousand atoms belong to the category of nano-objects of great interest for small scale optics. Developed by processes different from semiconductor quantum boxes, nanocrystals can be incorporated into transparent matrices, as they can also be grafted into biological entities. Excellent candidates for the emission of “single photons”, they are also used as biological markers and present potential applications for the creation of tunable microlazers. Chapter 9 thus makes us discover the structures of the electronic levels and the optical properties of these nano-objects which, like carbon nanotubes, still remain just as attractive for the physicist.

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3 J-M. Lourtioz, H. Benisty, V. Berger, J-M. Gérard, D. Maystre and A. Chelnokov (eds.), *Photonic Crystals: Towards Nanoscale Photonic Devices*, Springer, Berlin-Heidelberg-New York, 2005.

Also dealing with small-scale objects but in a very different context, the tenth and final chapter of this book completes the review of nanophotonics by addressing the interdisciplinary topic of the nanobiophotonics. The marriage of optics and biology is certainly not completely new, because while electronic microscopy offers a nanometric solution for the study of molecular cell entities, optical techniques in turn allow a slightly invasive, even non-invasive, analysis of live cells. In particular, the chapter describes the traditional fluorescence techniques for the detection of a unique molecular entity as well as more recent techniques, building on the interactions between ultra-short optical impulses and biological environments. The emergent topic of nanophotonics aims more particularly at reducing the observation volume below the limit imposed by diffraction. The chapter shows how to achieve this goal using nonlinear optical effects or nanostructured photonic devices close to the studied biological objects.

The book that we have just briefly presented was written by internationally recognized specialists, each in their field. Thus, it constitutes a follow-up to the first spring school of the CNRS on nanophotonics held in Houches (France) in June 2003 and organized by the four coordinators of the book. It is, to our knowledge, one of the first times that such various and complementary aspects of nanophotonics have been gathered together. It would, undoubtedly, be useless to allot an exhaustive nature to the book, but students and scientists working in nanosciences would, however, still be able to find in it a rich source of information on the new fascinating and rapidly expanding field.

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