C. R. Physique 3 (2002) 1, 2

MICROCAVITÉS ET CRISTAUX PHOTONIQUES

MICROCAVITIES AND PHOTONIC CRYSTALS

Foreword

The interaction of light and matter is at the heart of many essential phenomena, be it in fundamental or applied science. Therefore, the artificial control of this interaction has become a major field of activity. While some efforts have been devoted to the design of novel electronic systems, such as Rydberg atoms in atomic physics or quantum dots in solid-state physics, it appears that the best way to control the light–matter interaction is to design the photon modes which interact with electronic degrees of freedom through microcavity or photonic crystal effects.

In the basic research field quantum effects appear, or are strongly reinforced. Cavity quantum electrodynamics (cavity QED) is now a major field of investigation due to its impact on the experimental verifications of the quantum theory of measurement (quantum non demolition (QND) measurements) and to the possibilities of designing new quantum light-handling capabilities such as quantum optical gates, quantum beam-splitters, etc. Strongly coupled microcavities (either based on atoms or on semiconductors) might be the essential enabling components of the very promising (but hotly debated) quantum computer. Non-linear effects also appear renewed or enhanced in microcavities. Besides providing the means to create entangled quantum states, they could be at the root of quantum optics systems such as squeezed photon-state generators, spatial soliton, 2D optical memories, etc.

Many future applications in consumer goods, information processing and optical communications are pivotal on the development of new photonic structures such as efficient light emitters, ultrafast light detectors and light-handling devices based on non-linear or electro-optical effects. Such components will ultimately allow processing at the lowest power levels limited by the quantum nature of light itself. It may even be possible to exploit that very quantum nature for more efficient computation.

As will become evident on reading the contributions to this special issue, the leverage provided by the control of optical modes in such wavelength-scale structures as microcavities and photonic bandgap (PBG) materials opens new avenues both in basic research, by providing new means of controlling the light–matter interaction, and in numerous applications.

If we try to classify the concepts according to their maturity, it is fair to say that microcavities constitute a first generation of devices, well understood in most of its implementations. Both weak and strong coupling cases have been observed, either in atomic or solid state physics. New phenomena are numerous, from the control of spontaneous emission (recently most convincingly demonstrated in atomic and solid-state physics) to high-efficiency light-emitting diodes (LEDs), already in production.

The paper by Ochoa et al. introduces the concepts of planar semiconductor microcavities in the weak coupling regime and puts them to use in the context of high brightness LEDs. Houdre et al. then describe a situation where semiconductor microcavities are in the strong coupling regime and discusses the various novel phenomena which then occur. Turning now to full 3D light confinement, Gérard et al. describe their outstanding recent results on quantum dots in pillar microcavities, which represent a unique case of solid-state system with both zero-dimensional electron and photon states. They were both able to obtain a remarkable increase in spontaneous emission rate (Purcell effect) of six, and then use their system to design a solid-state emitter of single photons. Finally, Giacobino et al. apply the concept of strong coupling to the study of quantum optics effects in the solid state.

A second generation of systems will rely on the fuller control of photon modes in photonic crystals. This field, after the original controversies, is still stimulating much basic effort: the design of 'manufacturable'

S1631-0705(02)01289-6/EDI

dielectric systems in 1D, 2D or 3D still requires a major conceptual effort, if one wishes to achieve real-world performance. Metallic photonic bandgap structures, due to their low-frequency gap, appear rather easier to manufacture.

Busch discusses the various theoretical approaches and results for three-dimensional crystals. The experimental situation for 3D photonic crystals is described with great lucidity by Koenderink et al. Lourtioz and de Lustrac review metallic photonic crystals, with their applications to microwaves while Benisty and Rattier do the same for planar 2D systems and their applications to optical telecommunications systems.

Overall the papers in this special issue give a good overview of the status of microcavities and photonic crystals and should stimulate the reader to learn more about this fascinating field, which associates some of the most fundamental concepts, like those of quantum optics, to wide scale applications. This is truly, in our mind, physics in action!

Claude Weisbuch
Henri Benisty
École polytechnique
Palaiseau
France