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MACROPOROUS MATERIALS BASED OPTICAL PROPERTIES OF PHOTONIC CRYSTALS AND USE CASES

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ABSTRACT

A periodic variation in the refractive index characterises a photonic crystal. The atomic lattices (crystal structure) of semiconductors impact their electron conductivity, and this has an effect on light propagation in the same way that natural crystal structure causes X-ray diffraction. Nature provides photonic crystals in the form of structural colouring and animal reflectors; however, they may also be synthesised artificially and show promise in a variety of fields. One, two, or three-dimensional photonic crystals can be created. Thin film layers put on top of each other can be used to create one-dimensional photonic crystals. Photolithography or drilling holes in an appropriate substrate can be used to create two-dimensional ones. There are a variety of techniques that may be used to create three-dimensional objects, such as drilling at different angles and stacking two-dimensional layers on top of each other. Direct laser writing can also be used to create three-dimensional objects. In theory, photonic crystals can be used in any application where light manipulation is required. Thin-film optics with coatings for lenses are already in use. Nonlinear devices and exotic wavelengths both benefit from the usage of two-dimensional photonic-crystal fibres.

Optical computers may one day employ three-dimensional crystals. Photonic crystals with a three-dimensional structure may enable more effective solar cells in the future. Despite the fact that light's energy (and that of all electromagnetic radiation) is quantized using photons, only classical physics is needed to analyse photonic crystals.

Keywords : Optical Properties and Photonic Crystals, Photonic Crystals, Taxonomy of Photonic Crystals

INTRODUCTION

Electronic energy bands are allowed or banned by the cyclic potential in a semiconductor crystal in the same manner as photonic crystals determine the propagation of electromagnetic waves via periodic dielectric, metallo-dielectric, or even superconductor micro- or nanostructures. High and low refractive index zones are routinely repeated in photonic crystals. In this structure, light waves may be permitted to propagate or blocked, depending on their wavelength. In physics, modes and bands refer to the range of wavelengths that may propagate in a particular direction. Photonic band gaps refer to wavelengths that are not allowed. optical phenomena such as low-loss waveguiding, and prevention of spontaneous emission can be observed as a result of this. Similar to electron bandgaps in solids, the photonic crystal bandgap may be thought of as the destructive interference of numerous light reflections propagating through the crystal at each interface between layers of high- and low-refractive-index zones [1].

Name "Photonic" refers to the study of light (optics) and optical engineering, which is known as photonics. When English scientist Lord Rayleigh experimented with periodic multi-layer dielectric stacks in 1887, he showed how they might produce a photonic band gap in one dimension. This work may have been the earliest investigation into what we now term photonic crystals. In 1987, the work of Eli Yablonovitch and Sajeev John on periodic optical

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structures with more than one dimension—now called photonic crystals—sparked increased interest in the field of optics research [2].

There must be an interference effect when the periodicity of the photonic crystal structure is half or more the light waves' wavelength (in the medium). The wavelength of visible light varies from 400 nm (violet) to 700 nm (red), and the resultant wavelength inside a material is calculated by dividing that value by the average index of refraction. This is the scale at which the repeating zones of high and low dielectric constant must be created. Using thin-film deposition, this may be done in one dimension on a regular basis [3, 4].

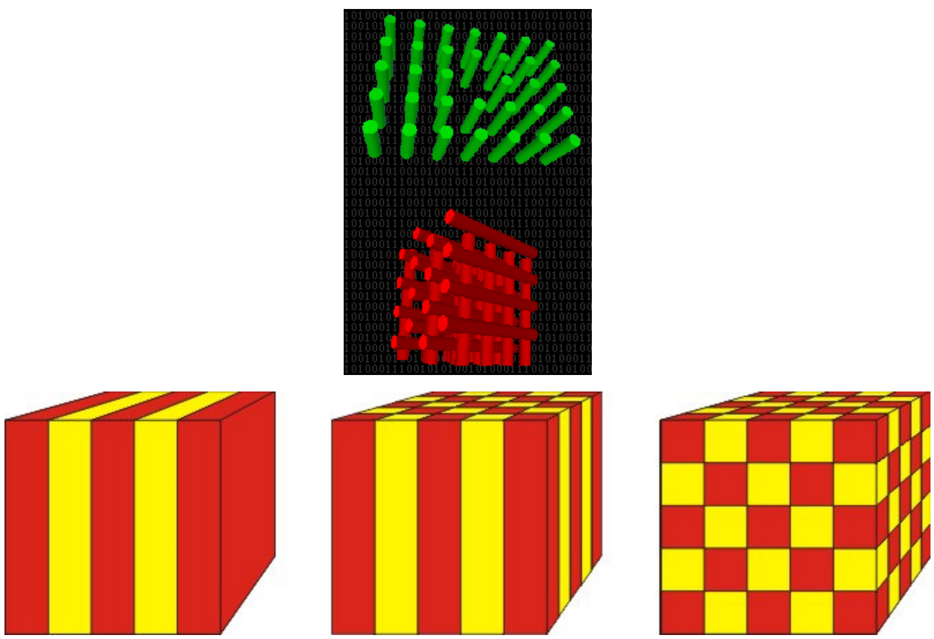

Figure 1 : 2D and 3D Photonic Crystal

In the near future, silicon-based photonic crystal nanolasers will be available for use. Throughout this chapter, we explore the fundamental ideas and concepts of photonic crystal nanolasers [5, 6], beginning with the design principles and moving on to particular nanolaser

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solutions. The goals for future photonic crystal nanolaser development have been established. The transition between electrically and optically pumped photonic crystal nanolaser systems is examined. To wrap things off, the chapter presents alternate applications for technology like optical memory [7, 8].

Key Applications and Use Cases

For regulating and altering light flow, photonic crystals are interesting optical materials. Photonic crystals in the form of thin-film optics are already in widespread use, with applications ranging from low and high reflection coatings on lenses and mirrors to colour shifting paints and inks. In both basic and applied research, higher-dimensional photonic crystals are of significant interest, and the two-dimensional ones are beginning to have commercial uses as well [9].

As properly designed photonic crystals exhibit high sensitivity, selectivity, stability, and their electricity-free operation if needed, they have become highly researched portable biological sensors. Developments in analysis, device miniaturization, fluidic design and integration have catapulted the development of integrated photonic crystal sensors in what is known as lab-on-a-chip devices of high sensitivity, low limit of detection, faster response time and low cost. A large range of analytes of biological interest such as proteins, DNA, cancer cells, glucose and antibodies can be detected with this kind of sensors, providing fast, cheap and accurate diagnostic and health-monitoring tools that can detect concentrations as low as 15 nM. Certain chemical or biological target molecules can be integrated within the structure to provide specificity.

As chemical analytes have their own specific refractive indices, they can fill porous photonic structures, altering their effective index and consequently their color in a finger-print like manner. On the other hand, they can alter the volume of polymer-based structures, resulting in a change in the periodicity leading to a similar end effect. In ion-containing hydrogels, their selective swelling results in their specificity. Applications in gaseous and aqueous environment have been studied to detect concentrations of chemical species, solvents, vapors, ions, pH and humidity. The specificity and sensitivity can be controlled by the appropriate choice of materials and their interaction with the analytes, that can achieve even label-free sensors. The concentration of chemical species in vapor or liquid phases as well as in more complex mixtures can be determined with high confidence [10].

Different mechanical signals such as pressure, strain, torsion and bending can be detected with photonic crystal sensors. Commonly, they are based on the deformation-induced change in the lattice constants in flexible materials such as elastomeric composites or colloidal crystals, causing a mechano-chromic effect as they stretch or contract.

Synthetic opals are three dimensional photonic crystals usually made of self-assembled nanospheres of diameters on the order of hundreds of nanometers, where the high refractive index material is that of the spheres and the low-index material is air or another filler. On the other hand, inverse opals are structures where the interstitial space between the spheres is filled with another material and the spheres are consequently removed, providing a larger free volume for faster diffusion of chemical species [11].

It's already possible to buy commercially available photonic crystal fibres that use a microscale structure to confine light in ways that conventional optical fibres simply cannot. These fibres can be used in nonlinear devices and to guide exotic wavelengths because they are ideal for nonlinear applications. Some technological aspects such as manufacturability and fundamental difficulties such as disorder are yet to be addressed, but the three-dimensional counterparts may offer additional features, such as the nonlinearity required for

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the operation of optical transistors used in optical computers, when these issues are addressed [12].

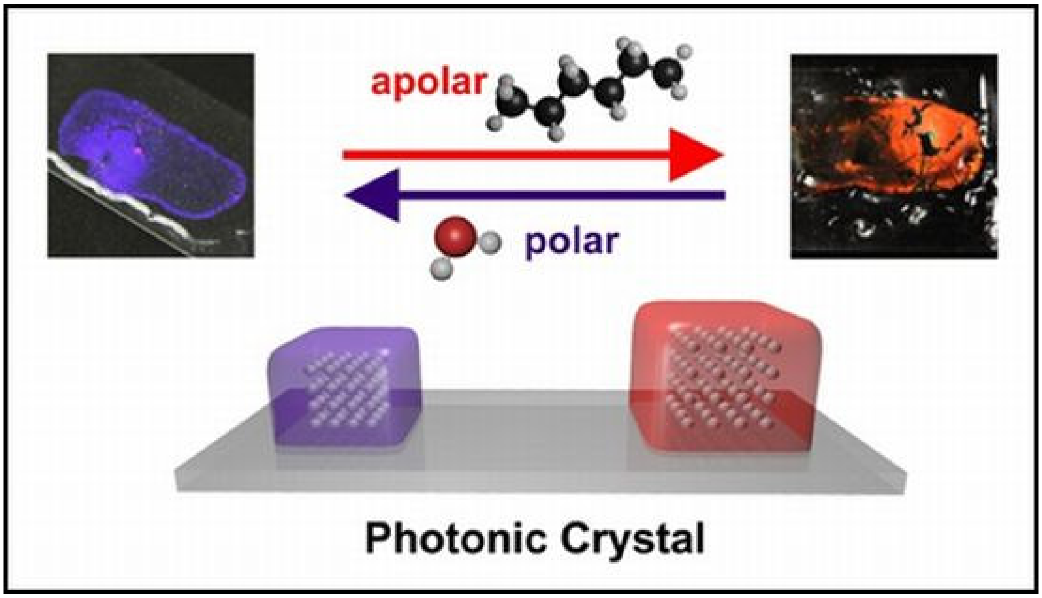

Figure 2 : Photonic Crystal Sensors

Photonic crystal sensors use photonic crystals: nanostructures composed of periodic arrangements of dielectric materials that interact with light depending on their particular structure, reflecting lights of specific wavelengths at specific angles. Any change in the periodicity or refractive index of the structure can give rise to a change in the reflected color, or the color perceived by the observer or a spectrometer [13]. That simple principle makes them useful colorimetric intuitive sensors for different applications including, but not limited to, environmental analysis, temperature sensing, magnetic sensing, biosensing, diagnostics, food quality control, security, and mechanical sensing. Many animals in nature such as fish or beetles employ responsive photonic crystals for camouflage, signaling or to bait their prey. The variety of materials utilizable in such structures ranging from inorganic, organic as well as plasmonic metal nanoparticles makes these structures highly customizable and versatile. In the case of inorganic materials, variation of the refractive index is the most commonly exploited effect in sensing, while periodicity change is more commonly exhibited in polymer-based sensors. Besides their small size, current developments in manufacturing technologies have made them easy and cheap to fabricate on a larger scale, making them mass-producible and practical.

In photonic crystals, the refractive index of the material is modulated at regular intervals, often on the order of optical wavelengths, to create a periodic nanostructure. Even if in certain circumstances, such as between a glass or semiconductor and air, the refractive index disparity is relatively great, in other cases, the contrast is fairly small. A substantial index contrast is required for some of the most impressive photonic crystal features (such as full photonic band gaps), which is why some writers recommend that photonic crystals have a big index contrast.

Eli Yablonovitch and Sajeev John were pioneers in this area of study, which is significant both in terms of basic science and practical applications, and have been followed by a great number of other researchers. As far back as 1887, Lord Rayleigh was working on one-dimensional periodic structures (dielectric stacks and dielectric coatings as Bragg mirrors). Even though photonic crystals are most commonly associated with contemporary technology, they have also been detected in the natural world, such as in minerals (such as opal) and live beings (such as butterfly wings).

CONCLUSION

Photonic crystals, a novel class of material, occupy the attention of more than half of the members of our group (also known as photonic band-gap materials). Periodic dielectric structures with a band gap that prohibits the transmission of a given frequency range are known as photonic crystals. The ability to manipulate light in a way that is unachievable with traditional optics is made feasible by this characteristic. We can solve Maxwell's Equations for photonic crystals using tremendous computer power, and we have done so. Rather of relying on brute force calculations to forecast and understand the behaviour of complex systems, the majority of our research is focused on gaining a deeper knowledge of them. Photonic crystals and photonic metamaterials have a number of characteristics, such as the use of periodic structures with optical effects. These structures look homogenous to optical fields because of photonic metamaterials' sub-wavelength structuring. The amazing features that come from this are not explained by exceptional values of the refractive index, however.

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