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USAGE PATTERNS OF PHOTONIC CRYSTAL SENSORS FOR ASSORTED DIMENSIONS AND KEY APPLICATIONS

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ABSTRACT
Research into photonic crystals has grown in importance because of its potential uses. Reflectance/transmittance, enhanced sensitivity and the dazzling visual quality they exhibit in the visible range of wavelengths make them ideal candidates for use as sensors because of their well-defined physical features. When photonic crystal technology is used, the sensor itself is relatively tiny and distant measurements may be made by connecting the incident and reflected/transmitted light to optical fibres and analysing them at a distance. The long-term viability of any sensing technology depends on the product's cost effectiveness and measurement reliability compared to other existing approaches. Photonic Crystals Sensors

employ nanostructures of dielectric materials arranged in periodic patterns that reflect specified wavelengths at precise angles. An observer or spectrometer may detect a different hue depending on how the structure's periodicity or refractive index changes. With such a basic basis, these colorimetric intuitive sensors may be used for a wide range of applications including environmental analysis and temperature detection as well as magnetic detection and biosensory detection.

Keywords : Photonic Crystals, Photonic Crystal Sensors, Usage Patterns of Photonic Crystals

INTRODUCTION

In recent years, photonic sensors have seen a massive development because of the increasing demand of sensing applications in healthcare, defence, security, automotive, aerospace, environment, food quality control, to name a few [1].

The development and integration of Microfluidic and Photonic technologies, with specific reference to the CMOS-compatible silicon-on-insulator (SOI) technology, allows to enhance sensing performance in terms of sensitivity, limit-of-detection (LOD) and detection multiplexing capability [2]. Photonic sensors have been the subject of intensive research over the last decade especially for detection of a wide variety of biological and chemical agents.

Animals like fish and insects use photonic crystals to signal, hide, or lure their prey in nature. Because of the wide range of materials that may be used in these structures, including inorganic, organic, and plasmonic metal nanoparticles, they are extremely adaptable and customizable [3]. While periodicity change is more prevalent in polymer-based sensors, inorganic materials, the refractive index is the most typically utilised effect in sensing. In addition to their tiny size, contemporary manufacturing technology have made them mass-produced and practical, making them easy and affordable to build on a wider scale.

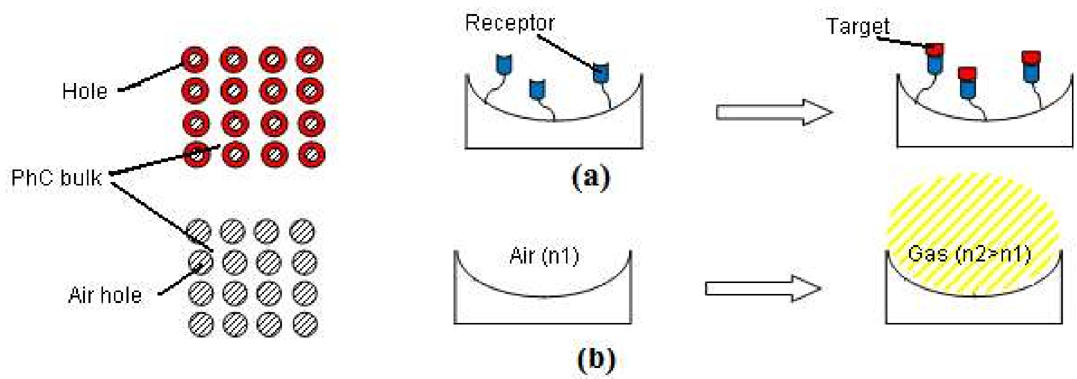

Figure 1 : Surface and Homogenous Sensing

Periodic Structures and Wave Propagation

One of Optics and Optoelectronics' most active study topics is light propagation control and manipulation. For more than a century, scientists have studied how waves move through periodic structures,. Due to significant advances in the field of electronics, semiconductors have had a significant impact on people's daily lives during the previous half century. The movement of electrons within these semiconductors allows for all of their functions [4].

Photosynthetic crystals have a variety of energy bands. These fascinating optical properties are owing to the occurrence of permissible and prohibited energy bands. For example, the dispersion relation that determines the band structure of photonic crystals can shed light on a variety of optical features.

In the visible and near-infrared wavelength bands, photonic crystals have been intensively explored and various phenomena have been anticipated. There are several obstacles in attempting to fabricate these crystal formations in the laboratory [5]. A photonic crystal for use in the visible and near infrared spectrum must have a spatial modulation of refractive index length scale of 300, as described in the preceding sections.

Photonic crystals have a variety of practical uses. The photonic crystals might be used in a variety of ways. It's not uncommon for them to be integrated circuit-ready devices. A 3D photonic crystal with a full band gap is required to fully realise the promise of photonic crystals. An anomaly in a photonic crystal structure causes a defect mode to be injected into the photonic band gap. Defect mode wavelength and emission wavelength are matched when active materials like dyes or quantum dots are doped into the defect layer

Sensors based on photonic crystals

Current awareness of environmental and safety concerns, rapid information collecting, and high-precision data processing have made sensors essential to the development of technological infrastructure. Sensors are used in a broad variety of fields, including manufacturing and biomedicine [6]. In light of recent breakthroughs in the field of sensors and photonic crystals, it is appropriate to bring together the contributions of various organisations.

To measure the pH and ionic strength of liquids, photonic crystals can be employed as chemical sensors. An opal photonic crystal or colloidal crystal array (CCA) was created by the authors of using highly charged monodisperse polystyrene spheres, which substantially diffract light. A polymerized CCA array was then formed by polymerizing an acrylamide hydrogel network around the CCAs (PCCA). Because of its remarkable softness and intriguing volume-phase transitions, this hydrogel offers a lot of potential for new applications [7, 8]. A PhC sensor based on a ring resonator cavity has been proposed for monitoring the level of seawater salinity between 0% to 40%.

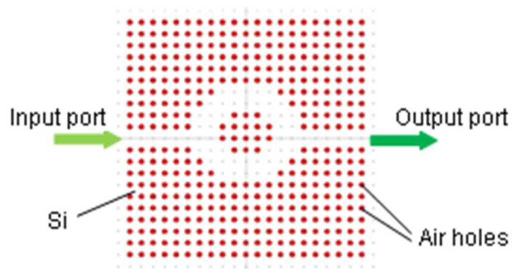

Figure 2 : Seawater Sensing

Photonic crystal sensors typically employ changes in reflectivity spectrum or cavity mode frequency when a quantitative characteristic of the functional material (the substance being sensed) is altered. The capacity to detect changes in high reflection or cavity mode frequency is then determined by comparing these two frequencies. With the photonic crystal, you can control how many states each photon may occupy.

Types and structures

Biosensors and integrated lab-on-a-chip

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 analytics 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.[9] Certain chemical or biological target molecules can be integrated within the structure to provide specificity.

Chemical sensors

As chemical analysis 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 analysis, 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.

Mechanical sensors

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.

3D photonic crystals

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.

Photonic crystal fibers

Photonic crystal fibers are a special types of optical fibers that has contain air holes distributed in specific patterns around a solid or hollow core. Due to their high sensitivity, inherent flexibility, and small diameters, they can be used in a variety of situations requiring high robustness and portability [10, 11]. Compared to traditional optical fibers, they are highly birefringent with tailorable dispersion, limited loss and endless single-mode propagation for a long range of wavelengths and have a very fast sensing response [12].

One-dimensional slabs with two dimensional order cause by selective removal of material, creating a pattern of holes or grooves in an otherwise homogeneous material is a popular photonic crystal structure used in sensing.

CONCLUSION

The numerous documented uses of photonic crystal sensors have been discussed in conclusion. Photonic crystals were used extensively in these applications because of their capacity to adjust their lattice constant or effective refractive index by external stimuli. Parameter adjustments were made with the use of photonic crystal waveguides and microcavities. Fabry-Pérot mirrors are planar photonic crystal where the periodicity is maintained only in the z-dimension. sputtered porous inorganic sensors, spin-coated polymer sensors and self-assembled block-copolymers are a few of the commonly used planar 1D structures.

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