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An analysis of band structure of linear and non-linear one dimensional photonic crystals

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Abstract

The present work stems from the development of the field of Nano-photonics which is revolutionizing the electro-optics today with number of applications in industry, medicine, clothing, space science, Nano-medicines etc. therefore, in this study the researcher intended to explore the brand structure of linear and non-linear one dimensional photonic crystals. It can be concluded that the structures we have studied are intended to exploit the unique properties of photonic crystals, rather than to replicate conventional devices on a smaller scale. As we have demonstrated, this design philosophy, combined with physical insight can lead to simple but efficient devices with highly attractive properties. The combination of powerful general methods and semi-analytic solutions for particular structures is one which will help the rapid progress in photonic crystal optics to continue.

Keywords: Band structure, linear and non-linear one dimensional, photonic crystals

Introduction

As optics merges with electronics to fuel a revolution in computing and communication, it is natural to compare and contrast electrons and photons. The former are for the moment the more active members of the partnership, but for future progress we look increasingly to photons. Electrons have enjoyed the advantage in the contest because of the ease with which they can be controlled: piped down wires, stored in memories, or switched from one channel to another. Semiconductors are the medium in which they operate, and semiconductors enjoyed their control of electronic properties because of diffraction effects in the atomic lattice. Photons also have a wave-like mature but on too large a scale to be diffracted by atomic lattice. Therefore to a large extent they have escaped detailed engineering of their properties. However there is no reason that we should not artificially structure material on the scale of the wavelength of light to produce band gaps, defect states, delay lines and other novel properties by analogy with the electron case. This agenda of reworking semiconductors physics for the photon has been seized upon, largely by condensed matter theorists well versed in the intricacies of band theory. Photonic crystals are periodic optical material that is designed to affect the motion of photons in a similar way that periodicity of a semiconductor crystal affects motion of electrons. Photonic crystal occur in nature and in various forms have been studied by science for the last 100 years. Photonic crystals are composed of periodic dielectric or metallic-dielectric structures that affect the propagation of electromagnetic waves (EM) in the same way as the periodic potential in a semiconductor crystal affects the electron motion by defining allowed and forbidden electronic energy bands. Essentially, photonic crystals contain regularly repeating internal regions of high and low dielectric constant. Photons (behaving as waves) propagate through this structure depending on their wavelength. Wavelengths of light (stream of photons) that are allowed to travel are known as “modes”. Disallowed bands of wavelengths are called photonic bad gaps. This gives rise to distinct optical phenomena such as inhibition of spontaneous emission, high-reflecting Omni-directional mirrors and low-loss-wave guiding, amongst others. Then analogy between an electronic crystal of a semiconductor with a periodic lattice and a photonic crystal with periodic dielectric in similar. In a photonic crystal, for a certain range of energy of photons and certain wave vectors, light is not allowed to propagate through this medium. In case of a large refractive index, photonic crystal with a proper shape of building blocks (domains) and proper crystal symmetry, a complete band gap develops.

In this case, the band gap is not dependent on the direction of the wave vector, which defines the direction of the propagation in addition; the density of photon states goes to zero in the band gap region. These materials with a complete gap are often called photonic band gap material. Basically, photonic crystals are artificial material, which can be fabricated as, 1-D, 2-D and 3-D photonic crystal. Keeping the above justification under consideration the researcher intended to explore the below mentioned research problem:

Research problem: The statement of the research problem is as under:
"An analysis of band structure of linear and non-linear one dimensional photonic crystals"

Purpose of the study: The present work stems from the development of the field of Nano-photonics which is revolutionizing the electro-optics today with number of applications in industry, medicine, clothing, space science, Nano-medicines etc. therefore, in this study the researcher intended to explore the brand structure of linear and non-linear one dimensional photonic crystal.

Rationale of the study: Photonic crystals are periodically structured electromagnetic media, generally possessing photonic band gaps: ranges of frequency in which light cannot propagate through the structure. This periodicity, whose length scale is proportional to the wavelength of light in the band gap, is the electromagnetic analogue of a crystalline atomic lattice, where the latter acts on the electron wave function to produce the familiar band gaps, semiconductors, and so on, of solid-state physics. The study of photonic crystals is likewise governed by the Bloch-Floquet theorem, and intentionally introduced defects in the crystal (analogous to electronic dopants) give rise to localized electromagnetic states: linear waveguide and point-like cavities. The crystal can thus form a kind of perfect optical "insulator," which can confine light lossless around sharp bends, in lower-index media, and within wavelength-scale cavities, among in lower-index media, and within wavelength-scale cavities, among other novel possibilities for control of electromagnetic phenomena. Below, we introduce the basis theoretical background of photonic crystals in one, two, and three dimensions (schematically depicted in Fig 1.1), as well as hybrid structures that combined photonic-crystal effects in some directions with more-conventional index guiding in other directions.

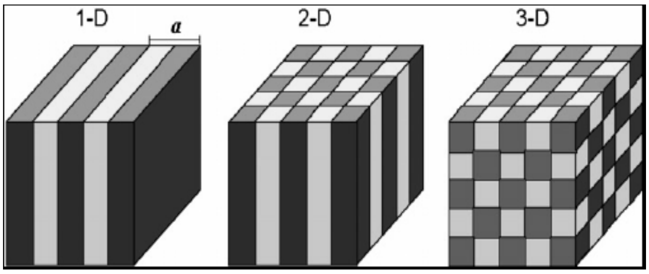

Fig 1: Showing the theoretical background of photonic crystals in one, two, and three dimensions

The rules of thumb given above. Many variations on these topologies continue to be proposed for example, the structure of is diamond/graphite like mainly in conjunction with different fabrication strategies, of which we will mention three successful approaches. First, layer-by-layer fabrication, in which individual crystal layers (typically of constant cross section) are deposited one-by-one and etched with a 2d pattern via standard lithographic methods (giving fine control over placement of defects, etc.); can be constructed in this fashion (as well as other diamond-like structures with large gaps). Second, colloidal self-assembly, in which small dielectric spheres in a fluid automatically arrange themselves into close-packed (fcc) crystals by surface forces these crystals can be back-filled with a high index material, out of which the original spheres are dissolved in order to form inverse-opal crystals with a complete gap. Third, holographic lithography, in which a variety of 3d crystals can formed by an interference pattern of four laser beams to harden a light-sensitive resign (which is then back-filled and dissolved, as with colloids, to achieve the requisite index contrast). The researcher in this study inbreed that with the remarks that the Maxwell equation are the workhorse of the PCs band structure calculations. The origin of band gap is due to Brillouin zones and the methods of periodic calculations are shown. The structures of 1-D, 2-D and 3-D photonic crystals are explained and the origin of band gaps explained. The factors responsible and the defects are also discussed. The researcher employed the well-known plane wave expansion method to estimate the band structure of a linear and nonlinear photonic crystal (NLPC). The effect of the control beam intensity and number of Fourier components on the photonic density of states is investigated. It has been found that, in a NLCP, the first band is not affected very much but the third band is highly affected with control beam intensity, which has been explained using scalar's approach. The effect of fill factor and the number of Fourier components of plane wave is estimated and discussed.

Conclusion

It can be concluded that the structures we have studied are intended to exploit the unique properties of photonic crystals, rather than to replicate conventional devices on a smaller scale. As we have demonstrated, this design philosophy, combined with physical insight can lead to simple but efficient devices with highly attractive properties. The combination of powerful general methods and semi-analytic solutions for particular structures is one which will help the rapid progress in photonic crystal optics to continue.

Competing interest: The research declared that no potential if interest with respect to authorship, research and publication of this article.

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