Research Paper Physics

The Propagation of Light in Photonic Crystal

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ABSTRACT

Photonic bands predict the behavior of light accurately. In photonic band gap, light cannot enter the crystal because the band gap acts as an insulator of light and the light velocity changes from velocity of light to zero and thus light and matter interaction is controlled. The basic phenomenon of propagation of light is based on diffraction in photonic crystals.

Keywords : Bloch theorem, potential energy, Photonic crystals, Brillouin zone

INTRODUCTION

Photonic crystals have periodic repeating and alternately arranged dielectric regions of different values of dielectric constant with a band gap that forbids the propagation of certain light frequency similar to that of periodic potential regions in a metal (or) semiconductor crystal affects the electron motion due to the presence of allowed and unallowed zones (or) energy bands.

Photonic Crystal:

In photonic crystals, the dielectric medium is periodically arranged such that between any two dielectric regions there exist gaps (or) separations called as band gaps similar to that of periodic potential regions in a metal. The study of motion of electron is described by kronig-penney model in periodic potential regions in a metal and the study of photonic crystals [1] can be done by Bloch-Floquet theorem.

The propagation of light in photonic crystal can be studied by four Maxwell equations which are to be modified for the study of photonic crystals. Photonic crystal consists of regular arrays of materials with different dielectric constant with the period of order of optical wavelength and the spatial periodic distance of the crystal is called lattice constant 'a'.

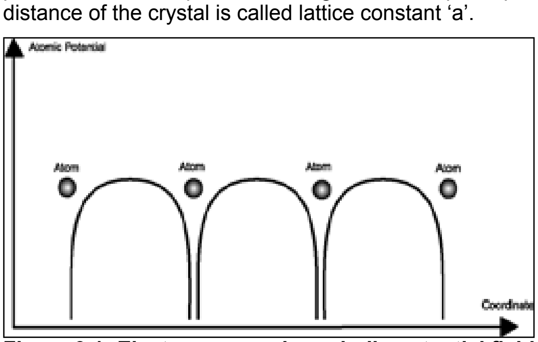

Figure 3.1: Electron moves in periodic potential fields. Sources: Wikipedia

2D & 3D photonic crystals:

Photonic Crystal can control light freely by using 2D & 3D photonic crystals. The 2D photonic band structure possess band gap near infrared region and in 3D photonic crystal, full band gap can be obtained.

The existence of photonic band gap is a forbidden gap for photons [2]. Light cannot enter this region as well as electrons cannot enter this region as well as electrons cannot emit photons, thus it acts as insulator of light [63].

2D Photonic crystals have close packed triangular lattice and 3D photonic crystal have FCC lattice and diamond like structure and both have band gap in TE and TM modes.

According to classical theory and quantum theory electron moves in a constant (zero) potential field established by the positive ions but in a real substance (metal) electron moves in a periodic potential fields such that potential energy is minimum near positive ion and maximum in between 2 positive ions. At the surface potential energy[3] is very large (or) infinite for simplicity the periodic variation of potential energy is considered in rectangular steps which consists of potential well of barrier in which Schrodinger equation for the motion of electron is considered.

For the potential barrier strength(P) tends to zero leads to the situation of an isolated (single) atom where energy level is quantized and for P tends to infinity leads to results of classical theory where electron possess only kinetic energy and electron behaves as free particle.

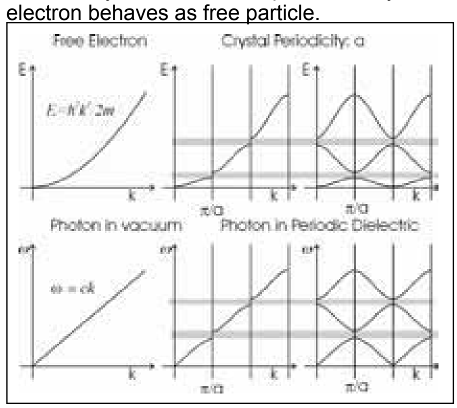

Figure 2: Band diagrams and photonic band gaps.

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Sources: photonic crystal molding the flow of light.

In between two bands forbidden gap exist [4]. They are also called as Brillouin zone.

Continuous curve gives allowed energy level and breaks gives unallowed energy levels.

The concept of unallowed energy levels which forbids or prevents light propagation was given by Bowden [1].

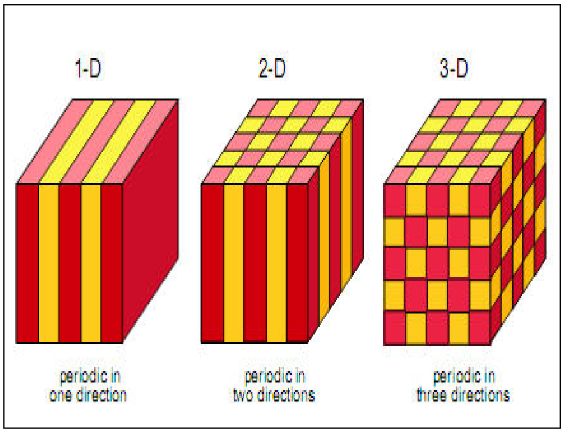

Figure 3: shows photonic crystals periodic in one, two, and three directions.
Sources: photonic crystal molding the flow of light.

The origin of the photonic band gap
Origin of photonic band Gap: considering a periodic one dimensional system with uniform value of permittivity.

The band diagram of wavenumber and frequency of such one dimensional system which has periodic dielectric variation lead to band gap at k = -π/a and k = π/a Brillouin zone boundaries.

By adding controlled amount of impurities in photonic band gaps the location of light and spontaneous emission of light can be controlled and also by artificially introduced defects PC finds wide applications in scientific and engineering fields [5].

Using PC, PCF can be fabricated such as holey fiber, photonic band gap fiber and Bragg fiber.

1D Photonic System: - It is the simplest possible system and applying principles of electromagnetism and symmetry, the result in terms of band structure and band gaps can be obtained.

The simplest photonic crystal consists of arrangement of alternating layers of material such that each material has different dielectric constant (or) specific inductive coefficient (or) relative permittivity. This system can act as Bragg mirror; because light of certain frequency can be localized the working can be understood by imagining wave propagation and considering the number of reflections and transmission [6] occurring at each boundary of the system under consideration.

Results and Discussion:
Considering each layer is uniform and extending to infinity along X & Y directions and the periodicity also extending to infinity but along Z-direction (or) in other words considering material homogeneous in XY plane & periodic along Z-axis. It can be shown that the gap widens as the dielectric constant value increases.

The photonic gap appears as the electric field vectors of light and gap occurs at the edge of Brillouin zone. By electromagnetic variational theorem, the result shows that high dielectric constant regions concentrates low frequency (or) lower fraction of energy & similarly low dielectric constant regions Concentrates lower energy & thus there is a frequency difference and energy difference and this leads to the bands above and below the gap of high & low dielectric constant regions.

Also the band gap above photonic band gap is treated as air band and band below the gap can be treated as dielectric band gap which is similar to that of valence & conduction band gap in semiconductor.

Thus, the gap occurs at edge (or) centre of Brillouin zones and gap occurs for any dielectric constant such that the gap is small for small differences of dielectric constant [7] and existence of the gap can be measured by the frequency width.

If the defect is introduced, it disturbs the periodicity and the multilayer films existing on both sides of defect behave like two mirrors and localize light within the regions and the frequency modes one quantized [8].

If the thickness of defect is increased (or) doubled, the discrete modes are pulled down and it thickness kept constant (or) increased we observe the following change, a defect pulls modes from upper bands to lower bands and push modes from lower band to the gap.

The origin of the photonic band gap can be known from the consequences of periodicity for a simple one-dimensional system [2].

Figure 3.5 shows photonic band gaps appearing in the plane of periodicity.

CONCLUSIONS:
The main problem of a fiber optic cable is its attenuation and in order to overcome this problems photonic crystal fiber (PCF) which is based on the properties of photonic crystals can be used.

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REFERENCES

1) Bowden .C. M., J. P. Dowling, H. O. Everitt, "Development and applications of materials exhibiting photonic band gaps," J. Opt. Soc: Amer., B l0, p.280, Feb.1993. | 2) Hojo.H. & A. Mase (2004) "Dispersion relation of electromagnetic Waves in one- dimensional Plasma Photonic Crystals", J. Plasma Fusion Res., 80, 89-90. | 3) Kiskinen M. J & R. Fernsler, (2000) "Photonic band gaps in dusty plasma crystals", Appl. Phys. Lett., 77, 1925-1927. | 4) Soukoulis .C.M. (1995) "Photonic bans gap materials", NATOASI Series E: Applied Sciences, 315, K1uwer Academic Publishers. | 5) Steven. G., Johnson and J. D. Joannopoulos, "Introduction to Photonic Crystals: | Bloch's Theorem, Band Diagrams, and Gaps" MIT, 2003, 10-15". | 6) Scalora. M et al (1998), "Transparent, metallo-dielectric, one-dimensional, photonic band gap structures", J. Appl. Phys., 83, 2377-2383. | 7) Xu. P & Z. Y. Li, (2004) "Study of frequency band gaps in metal-dielectric composite materials", J. Phys. D: Appl. Phys., 37, 1718-1724. | 8) Zhang L. T., W. F. Xie, J. Wang, H. Z. Zhang & Y. S. Zhang (2006) "Optical properties of a periodic one-dimensional metallic-organic photonic crystal", J. Phys. D: Appl. Phys. 39, 2373-2376. |