Photonic Nano crystal and its impact

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ABSTRACT

Photonic crystals are periodic dielectric nano structures that are made to affect the propagation of electromagnetic waves. Due to the recently known attractive optical properties in the controlling the flow of light, there is the need to develop higher dimensions of such a material. Despite some fabrication challenges, several methods like the photonic –crystal fiber and photolithography have been successfully used in two and three dimensional PC. We employed SiN in the research and compared with other research work by applying various techniques in this research. The results proved to be promising after our analysis.

1.0 INTRODUCTION

In recent years there have been numerous research works on different material so as to improve upon their properties and also to characterize them into different groups depending on their band gaps, elasticity, electrical and thermal conductivity, optical properties etc., as well as its environmental impact. In the last two decades of the past century, researchers found a new type of material which is assumed to have a property that enables one to control light and also produce effects that are impossible with conventional optics. This material is known to have periodic dielectric structures that have a **band gap** which forbids propagation of light within certain frequency range. This material can be described by Maxwell's Equations and it is easily solved using the application of massive computational power. This material is called **Photonic Crystal**.

In this report we will learn a lot about Photonic crystals: that is the different types and the different designs proposed earlier, the production, properties as well as the applications.

1.0.1 DEFINITION OF PHOTONIC CRYSTALS

Photonic crystal is defined as a wavelength scale, periodic, dielectric microstructures. This crystal has periodic patterning which creates photonic band gaps that forbids the propagation of light through the structure. The absence of allowed propagating electromagnetic wave modes inside the structures, gives rise to certain optical properties such as inhibition of spontaneous emission, high-reflecting omni directional mirrors and low-loss-wave guiding among others.[9]

The basic principle of photonic crystal is based on Bragg's diffraction and the periodicity of the structure has to be in the same length-scale as half the wavelength of the EM waves. [8]

I.0.2 ONE, TWO AND THREE DIMENSIONAL PHOTONIC CRYSTALS

A One Dimensional Photonic Crystal which can be used as high-Q filters is formed by adding a periodic structure to a conventional waveguide. [1]
The idea of having two- and three-dimensionally photonic crystal for the past years has not been ascertained owing to the fact that different band gaps exist in these structures. Although several research works are currently going on, no vital conclusion on the structure has been made so far even though the idea sounds promising.

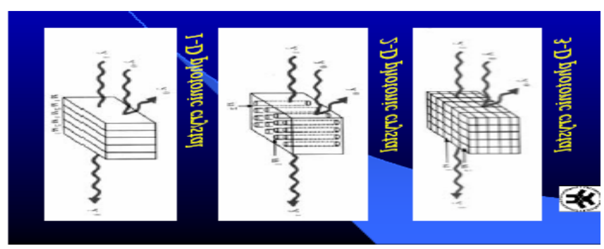

Fig. 1.0b: showing 1D, 2D and 3D photonic crystals.

If $\lambda 1 \neq \lambda o$ (outside the gap), light goes penetrating the structure, no or very little reflection.
If $\lambda = \lambda o$ (within the gap), there is a total reflection of the light.

i. 2D CRYSTALS

Since the periodicity of the medium must be comparable to the wavelength of the electromagnetic waves to inhibit their propagation, PBGs in the optical or infrared domain require submicronic structures. 2D crystals consisting of parallel cylinders are easier to realize and the feasibility of such structures is now well demonstrated at the submicron lengths. [8]In 2D PBG materials, the electromagnetic waves propagating into the plane perpendicular to the cylinders can be separated in two polarizations according to whether

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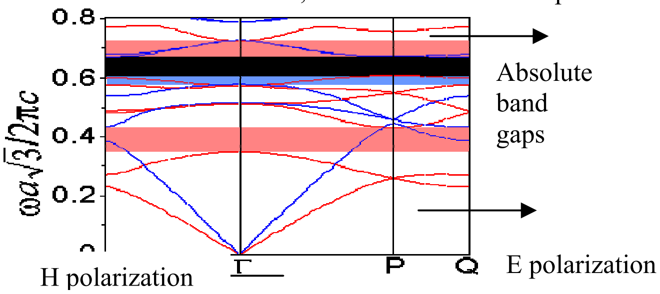
the electric (E polarization) or magnetic (H polarization) field is parallel to the cylinder axis. The band gaps occurring in each case must overlap to form an absolute band gap which prevents the propagation of the light of any polarization. [5]

An example of a photonic band structure

Many very useful concepts for electrons, like Brillouin zones and band structures, can be extended to photons.



This figure is the band structure of a graphite photonic crystal showing the various bands and Polarization.

2.0 SOME RESEARCH ON PROPERTIES AND STRUCTURE OF PHOTONIC CRYSTALS

Many research groups have been working on the properties of photonic crystals so as to aid in their classification and also assist in the studying of their behaviours in different material. We employed Computer simulation in the analysis. We considered SiN photonic crystals which show both negative refraction of a Gaussian beam and the focusing of a microwave point source through a photonic crystal slab with sub wavelength resolution when studied experimentally. [1] Evidence of this is shown in figure 2.a.

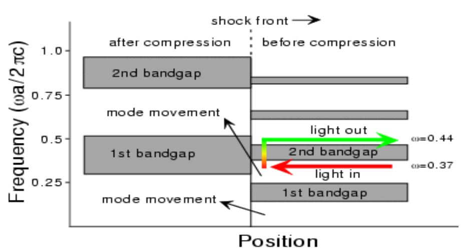


Fig. 2.a

2.0.1 Photonic Crystals through the Color of Shock Waves

Light was made to enter from the right hand side with an angular frequency of 0.37 receives shocks as it enters the 1st bandgap on the left where it is compressed and reversed. The light then retraces its path out parallel to the first direction with an increase in frequency of 0.44. [1]

2.0.2 Frequency shift across the bandgap.

Computer simulation of shocks moving to the right, after the light has been trapped at the shock front on the left hand side using four moment time, indicated that simulation occurs below the gap. Its frequency shifts across the band gap. [1]

2.0.3 Bandwidth narrowing

It was seen that, the bandwidth narrowed as, the Light was trapped between the reflecting shock front on the left and a fixed reflecting surface on the right using two moments in time during computer simulation of the shock. As the shock moved to the right, the bandwidth of the confined light decreased by a factor of 4. [1]

3.0 PRODUCTION AND PROCESSING OF CRYSTALS AND NANOSTRUCTURES FOR PHOTONIC APPLICATIONS.

We conducted a research on Ion irradiation of semiconductors for the formation of nanostructures such as the creation of a band of small voids or cavities that exhibit interesting properties. Direct ion implantation of these into silicon dioxide can also lead to the production of small nano-crystals that can emit light and have potential applications in optical devices on a silicon chip. And also, optically-emitting semiconductor nanostructures such as quantum wells and quantum dots can be grown by metal organic chemical vapour deposition on both gallium arsenide and indium phosphide substrates and ion irradiation can be used to tune the Wavelength of the emitted light for device applications.

Nano-cavities was produced in Si using ion implantation of high doses of H or He followed by an annealing treatment [7, 9].

The figures (fig 3.0a &b) below show a typical collision cascade for a single ion penetrating into a solid. Annealing at 500^{o}C leaves gas-filled bubbles but also a dense network of defects surrounding the cavity band. However, annealing at 750^{o}C results in well formed voids within essentially perfect Si crystal as shown below.

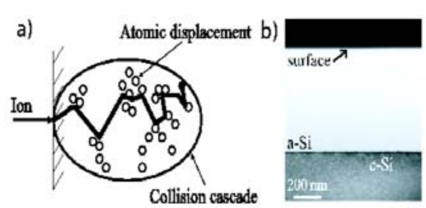


Fig 3.0a.

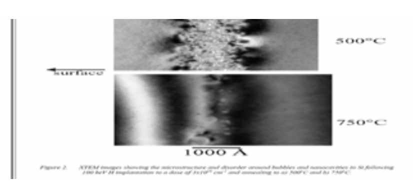


fig.3.0b

The nanocavities are very attractive trapping sites for diffusing metals in Si. This is illustrated for the case of Au in Figure 3.0c [9]

Fig

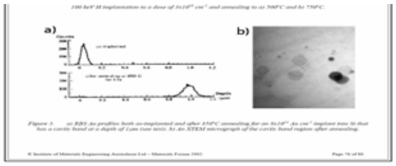


fig. 3.0c

As a result, the wavelength of the emitted light shifts to shorter wavelengths. The figure below illustrates the effect of irradiation-induced when wavelength of light from a typical heterostructure laser is intermixed [6]. These results show that ion-implantation induced intermixing is a very promising way to fine-tune laser wavelength.

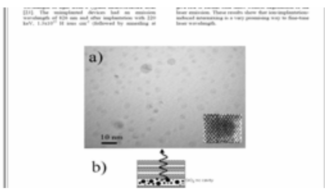


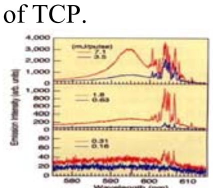
fig.3.0d

3.0.1 TUNABLE PHOTONIC NANOCRYSTAL (TPC)

The TPC is a newly discovered crystal which consist of periodic particle arrays in which either the particles or a matrix component is either optically or electrically tunable- thereby enabling the crystal to have a tuneable property. This makes the PC three-dimensional and also to have a periodic arrays of spherical nano-particles. Conducting organic polymers are used as the tunable component. [9]

Fig.3.2a. Three-dimensional periodic structure made of nano-dispersed SiO_2 spheres of 210 nm in diameter

Tunable photonic crystals when studied showed some diffraction patterns under brag's condition. The figures below show the different conditions under which different spectral were observed which are the various characteristic of TCP.



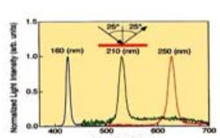


fig.3.2b. sharp diffraction peaks of three-dimensional periodic structure of opal photonic crystal made of sio_2 spheres of different diameter.

4.0 IMPROVEMENT OF PHOTONIC CRYSTAL PROPERTIES

4.0.1 MODULATED LED SOURCE

It is very difficult for Silicon nano-crystal which is based on optical sources to be electrically pumped due to the fact that, the injection of electrons and holes electrically, into optoelectronic device made of crystals is more difficult than that those of bulk and quantum-well semiconductor devices. This charge injection can be controlled in an FE-LED to attain a balance. [3,8]

4.0.2 SURFACE PLASMONS

Surface plasmons enable emission from silicon crystals with transfer of energy from the nanocrystal to the surface-plasmon mode, followed by the scattering of this energy into the far field. It was seen that charge injection into the array of crystals can be used to directly modulate the photoluminescence output of the device at speeds above 300kHz.[2,4]

4.0.3 QUANTUM-MECHANICAL & OPTICAL COMMUNICATIONS

In considering a particle in a box and by Schrödinger's wave equation which concludes that particles trapped in smaller containers must necessarily be in a more energetic state than particles with more free accommodations. Since silicon crystals, with excitonic luminescence can easily be observed even at room temperature in the near-Infra red and it considered being brighter than the bulk luminescence at ordinary and higher temperatures.

In modern communications systems, audio or video the voltage pulses are applied to a light-emitting diode (LED) or a semiconductor laser, which converts them into short pulses of light that can be sent along an optical-fibre network. [5]

4.0.5. MICRO-CAVITIES & QUASI-CRYSTALS IN PHOTONIC CRYSTALS

Semiconductors materials of group III-V can be used to a make narrow-line width lasers that could be fixed into other components in an optical-communications system. The lasers are made by introducing a small number of holes that are slightly smaller or larger than the other holes in the photonic-crystal lattice. [5]

The quasi-periodic structures, irrespective of the angle the light travels, have a photonic band gap and they also allow a photonic band gap to be form in materials with a low refractive index, such as conventional silica glass.

4.0.6 INTERCONNECTS FOR OPTICAL CIRCUITS

Interconnects makes it possible for light to be confined within the line of defects for wavelengths that lie within the band gap of the surrounding photonic crystal. [5]

4.0.7 PHOTONIC-CRYSTAL FIBRES

This is a material with different wavelength of light made from Photonic crystal with improved distance transmission signals and they are used to speed up the Internet. This fibre has a property such that, it transmits a single mode of light, even if the diameter of the core is very large. [5, 6]

4.1 APPLICATIONS OF PHOTONIC CRYSTALS

4.1.1 RESONANT CAVITIES IN PHOTONIC CRYSTALS

When a point defect is created in a photonic crystal, it is possible for that defect to pull a light mode into the band gap. Point defects are very important to photonic crystal devices, such as channel drop filters. Another application of resonant cavities is enhancing the efficiency of lasers; taking advantage of the fact that the density of states at the resonant frequency is very high. When the size or the shape of the defect is changed, its frequency can easily be tuned to any value within the band gap and the *symmetry* of the defect can also be tuned. [1]

4.1.2 WAVEGUIDE BENDS & CHANNEL-DROP FILTERS

With photonic crystals, it is possible to create waveguides that permit 90 degree bends with 100% transmission. One of the weaknesses of such waveguides is that creating bends is difficult. Unless the radius of the bend is large compared to the wavelength, much of the light will be lost. With photonic crystal, a linear defect is created in the crystal which supports a mode that is in the band gap. When a bend is created in the waveguide, it is impossible for light to escape.

Photonic crystals can be used to design a perfect channel-drop filter which picks out a small range of frequencies from a waveguide and re directs it in another path, leaving the other frequencies unaffected. Photonic crystals can be used to construct a *perfect* channel drop filter--that is, one which redirects the desired channel into the drop waveguide with 100% transfer efficiency. [1,4,5]

4.1.3 WAVEGUIDE INTERCONNECTS & THE PHOTONIC MICROPOLIS

This can be achieved by if the waveguides are mirror symmetry about their axis, and are of single-mode in the range of frequency and the resonant modes must be odd with respect to one waveguide and even with respect to the other.

Photonic micropolis is a collage of many different photonic crystal devices which are of three-dimensional which has been fabricated at sub-micron length scales. It has different colours representing one, two and three dimensional states of the crystal. The micropolis have ring resonators, which are a conventional way to achieve a resonant cavity for use in channel-drop filters, etc. [1,5]

5.0 CONCLUSION

Photonic crystals have shown to have a very promising future and we assume that in the next decades new technologies would be seen. It is estimated that within the next five years a number of basic applications will appearance in the trade show.

Some of these are a highly efficient photonic-crystal lasers and extremely bright LEDs, drop filters" and a common components in optics. In less than 5-10 years timescale, the first photonic- crystal "diodes" and "transistors are expected as well as the first photonic- crystal logic circuit. In the next 20 years, a prototype optical computer driven by photonic crystals should be made available.

Also photonic crystal could be used to produce synthetic Opals and thin photonic-crystal films could also be used be created to be used as a strong detective tool.

The future of Photonic crystals looks very bright in this case.

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