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An Overview of Photonics and Its Uses

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Abstract

Photonic crystals are periodic patterns of dielectric constants with thicknesses ranging from a nanometer to a micrometer. Light or Electromagnetic Wave (EMW) cannot pass through the Photonic Band Gap (PBG) for some range of wavelengths if the periodic arrangement of the PCs is of the order of the wavelength. Photonics technology plays a vital role in various fields, such as manufacturing, biomedical, alternate energy sector, aerospace, telecommunications, etc. It generates and controls light in the form of radiant energy as photon. The light can be manipulated or molded using band gaps in photonic crystals. There are many materials that can be integrated to further the application of photonics. The common material is Graphene, which is a single atom carbon. Application areas of the technology include LEDs, photo detectors, photovoltaic devices, etc. This article presents the review of state of the art of photonics and its application.

Keywords: Photonics Photonic, Crystals, Graphene Photonics, Sensing Photonic Applications.

1.INTRODUCTION

The word photon, which refers to the smallest unit of light, was the source of the term photonics. Signal generation, detection, and manipulation are all part of photonics. It is a method for controlling light and radiant energy in the form of a quantum unit known as a photon. The development of technology for integrated circuit miniaturization and high speed performance relies heavily on semiconductor technology. Unfortunately, higher speeds, a high level of power dissipation, and resistance are required for the miniaturization of circuit components. A greater sensitivity to signal synchronization could be the cause of this. Scientists are now returning to light as the information carrier rather than electrons in an effort to advance high-density integration and system performance [1] [2]. It can transmit large amounts of information per second because it can move faster in dielectric materials than electrons can in metallic wire. In comparison to metals, the dielectric materials have a wider bandwidth. Fiber-optic communication systems have a bandwidth of about one terahertz, whereas telephones only have a handwidth of a few hundreds of kilohertz. Photons also don't interact as much as electrons do, which helps reduce energy losses which stated that the field of photonics is still in its infancy and that the term "photonics" itself was coined in reference to electronics, both made the same point. The control of electric-charge flow-whether in a Vacuum or in matter in electronics and the control of photons whether in free space or in matter is the primary distinction between these two fields [3] [4].

The fact that the fields overlap is abundantly clear from this description. This could Indicate that electrons direct photon flow and vice versa. It also demonstrates the significance of light's photon nature in relating the operation of numerous optical devices. The photonic technologies have a lot of potential to have an impact on the economy in the coming decades, with a growth rate of about 25% predicted by various industrial organizations. According to a CPIC study, it is expected to have a market value of more than €600 billion in 2020 and a global industry worth 650 ($CDN) billion.

Lasers, optics, fiber-optics, opto-electrical devices, alternative energy, healthcare, telecommunication, aerospace, and numerous other fields all made extensive use of photonics technology. The power source is the most important parameter in the use of nanophotonic devices which suggested that solar-based source power has promising devices for cheaply converting energy in solar cells on a large scale. As integrated power sources, the miniaturized version can also be incorporated into nanophotonic systems to create a self-powered system. Many applications, including information and communication technologies, sensors, enhanced solar cells, and lighting require the tightly confined optical fields of nanoscale photonic devices, which can effectively focus the optical field into a nanometer-sized volume. New optoelectronics devices with improved performance, lower costs, and better energy efficiency semiconductors and bulk crystals in LEDs and lasers, this could be accomplished. Crystals and have been discovered thanks to photonics technologies. By manipulating photons in metamaterials are used in optical computers today [4] [5] [6] [7].

Nanowire photonics could be used to control light and pulses in volumes smaller than one micrometer. Due to their high transparency and low sheet resistance, graphene photonics devices perform better than semiconducting materials in transparent conductors. The non-invasive treatment of brain tumors provided by Optical Coherence Tomography (OCT) is another example of a medical imaging application for photonics. Intelligence, surveillance, and reconnaissance all make use of photonic sensors and systems. Terabits of data were transferred through photonic communication. Online monitoring, inspection, and measurement are now available for the majority of industrial machine applications, particularly computer numerical control machines. In this paper, numerous industrial applications of photonics were discussed. Consequently, a comprehensive review is required for photonics application in a variety of fields, including manufacturing, biomedical, aerospace, and telecommunications. Photonics, its development, and its application were the primary topics of this paper [8] [9] [10].

2. Photonic Crystals

The advantages of photonic energy are utilized in photonics. The energy carried by a single photon is referred to as photon energy. Photons' higher energy is determined by their frequency, whereas shorter photon wavelengths can result in lower energy. Therefore, understanding how light energy can be manipulated and controlled is essential after grasping the concept of light energy. The solutions consist of photonic crystals. Simply put, the concept of a photonic crystal is to design materials so that they can influence the properties of photons, similar to how ordinary semiconductor crystals influence electron properties. The total internal reflection mechanism has been the foundation of conventional optical photon manipulation when light crosses an interface with a lower index of refraction, it is partially and beyond a certain critical angle refracted as a result of the incidence angle. Total internal reflection (TIR) benefits from this.

Using this phenomenon, light pipes, optical waveguides, and fiber optics could effectively and without loss transport light that travels through a material with a high dielectricity can be reflected at the boundary by a material with a low dielectricity. Optics component miniaturization may be hampered as a result. The interface of optical components that are being reduced to size must be smooth in relation to the wavelength of the light. This issue is solved by photonic crystals by utilizing the concept of bandgap. It is possible to drive the analogy between semiconductor electronic bandgap and photonic bandgap. The atomic lattice in a semiconductor is like a periodic potential for an electron as it moves through the electronic crystal [11] [12] [13] [14].

The periodic "potential" in photonic crystals is caused by a lattice of microscopic dielectric media rather than atoms. In addition, photonic crystals are materials with a dielectric constant that can create an optical analog of an electronic bandgap in semiconductors for a range of prohibited frequencies.

Bandgap prevents the photons from spreading throughout the medium. In the gap, localized photonic states could result from a defect. The photonic shapes and their properties can be determined based on the defect's nature. The photonic crystal defect can take on any form or size with any dielectric constant. As a result, photonics defect states in the band gap have the potential to change at any frequency or spatial extent of interest

to design. Point defect, line defect, and line defect, respectively, can be used to create micro cavities, wave guides, and perfect mirrors. For photonic information technology, photonic defects can offer the opportunity to alter the flow of light. Techniques like electron beam lithography and Xray lithography could be used to create photonic crystals with intricate structures.

3. Photonic Cavity

Light can be trapped at a point in the crystal, as previously mentioned. Changing the dielectric medium in a specific local area of the crystal is one method. For instance, a single "dielectric atom" can be altered by altering its size, changing its dielectric constant, or simply removing it from the crystal. Fig. 1 demonstrates the effect of creating a vacancy; where a defect with a radius of r 0 is a vacancy. As a result, a cavity was created by removing a rod from the lattice and enclosing it with reflecting walls.

If, as depicted in Fig., the defect involves the elimination of dielectric (an "air defect," as in the case of the vacancy), I then changes the amount of dielectric removed as the cavity mode progresses from the dielectric band to sweep across the gap. Similarly, the cavity mode departs from the air band when additional dielectric material is added to the defect (a "dielectric defect"). At the symmetry level, it is also possible to control the localized photonic state in addition to tuning the frequency. Take, for instance, 2 depicts the localized photon mode symmetries for three distinct defect radius values [15] [16] [17].

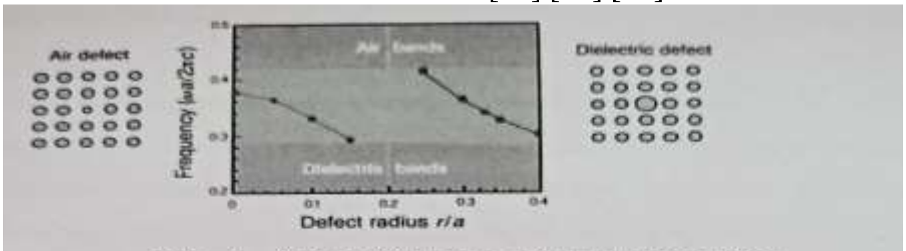


Fig. 1. Air defect and Dielectric defect

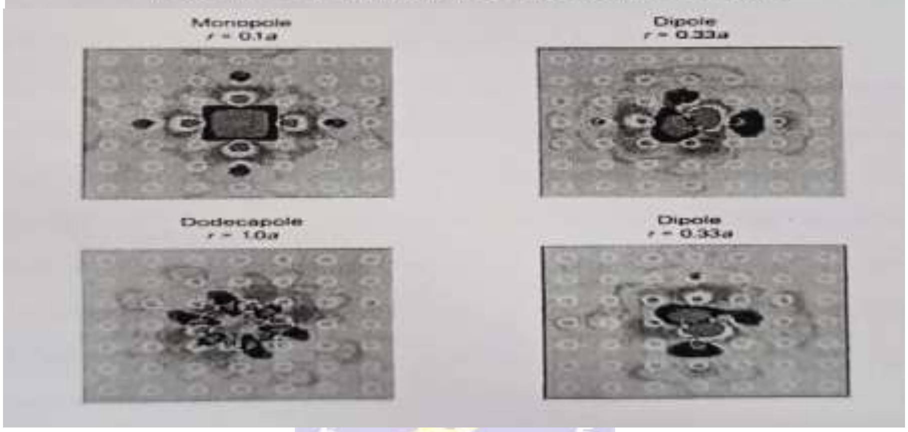


Fig. 2. Localized states in the gap for a defect formed by varying the radius r of a single rod

4. Nanowire Photonics-Utilization

Yan provided an explanation for the development of nanowire, or semiconductor nanostructures. Quantum dots are another well-known semiconductor microstructure with adjustable optical properties. Quantum confinement increases the band gap as the quantum dot's size decreases. Blue shifted light emission, also known as light with a shorter wave length or more energy, may benefit from this. Nanostructures with cross sections of 2-200 nm, on the other hand, allowed confinement to 2D, allowing electrons and photons to freely travel through the third dimension Bottom-up preparation of nanowire semiconductor microstructures may necessitate the highly controlled synthesis of single-crystalline, high-optical-quality materials for this procedure. The vapors-liquid-solid (VLS) process introduces a catalytic liquid alloy phase that has the potential to adsorb a vapor to super saturation levels, thereby encouraging seeding and growth. VLS can produce a large quantity of various nanowires for semiconductors. Morales and Lieber also talked about recent developments in physical deposition methods like laser ablation and thermal evaporation, as well as chemical deposition methods like chemical vapor transport and deposition and metal-catalyzed molecular beam epitaxy. When developing optical computers, computers that utilize crystals and meta-materials to control light and manipulate pluses within submicrometer volumes are more important. These methods could be effectively used to produce a wide range of inorganic nanowire compositions like Si, Ge, ZnO, CdS, GaN, GaAs, and InP. Additionally, nanowires belong to a significant group of photonic building blocks. They can be processed via chemical synthesis or the most recent lithography methods.

Chemically grown nanowires have the distinct advantages of being single-crystalline, atomic mismatches, despite the fact that lithography-fabricated nanowires have their own relatively defect-free, having atomically smooth surfaces, and being able to accommodate large characteristics 18] [19] [20].

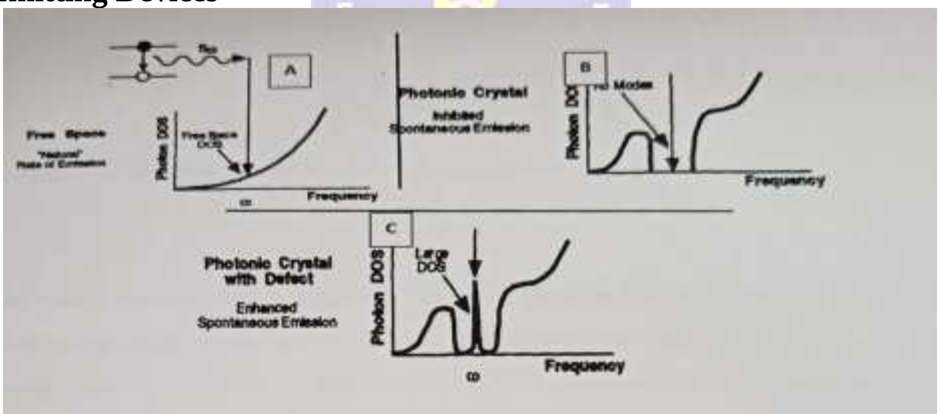
5. Graphene Photonics and Optoelectronics

Additionally, its charge carriers exhibit enormous intrinsic mobility, are optically transparent, have no effective mass, and can travel for micrometers at room temperature without scattering. At room temperature, it has a lower resistivity than any other material known and a high electrical current as its intrinsic property. It weighs less than a paper and is stronger than diamond. It belongs to a new group of theoretically novel materials that are only one atom thick. The term "Wonder Material" has been given to graphene because of its fascinating properties. Graphene's full potential can be realized in photonics and optoelectronics applications, particularly when its optical and electronic properties are combined. Due to the numerous advantages offered by photons, no large-scale commercialization of optical circuits has yet occurred. The performance of electronic circuits has significantly improved as a result of some hybrid optoelectronic circuits.

The main challenge in designing a multipurpose optical component is that all optical systems are still in their infancy. The photonic crystal's ability to localize defects makes it an appealing substrate for the development of novel filter couplers, lasers, and light-emitting diodes. Photonic crystals offer a singular capability for controlling spontaneous emission in laser or LED cavities. Emission on its own, as shown in Fig. 4, is the atom's natural tendency to "fall" to a lower energy state while releasing energy in the form of radiation. A photon is also released when an excited atom or molecule returns to its ground state during this process. Every optoelectronic device that emits light is processed in this manner.

For instance, the radiative recombination of electrons and holes in a forward-biased p-n junction produces light in LEDs. In addition, the junction region's number of electron-hole pairs can be sufficiently large for stimulated emissionemission triggered by other photons by increasing the applied voltage. A matrix's square and the density of the available final states at the transition frequency both have an effect on an initial state's spontaneous emission rate [21] [22] [23] [24].

6. Light-Emitting Devices



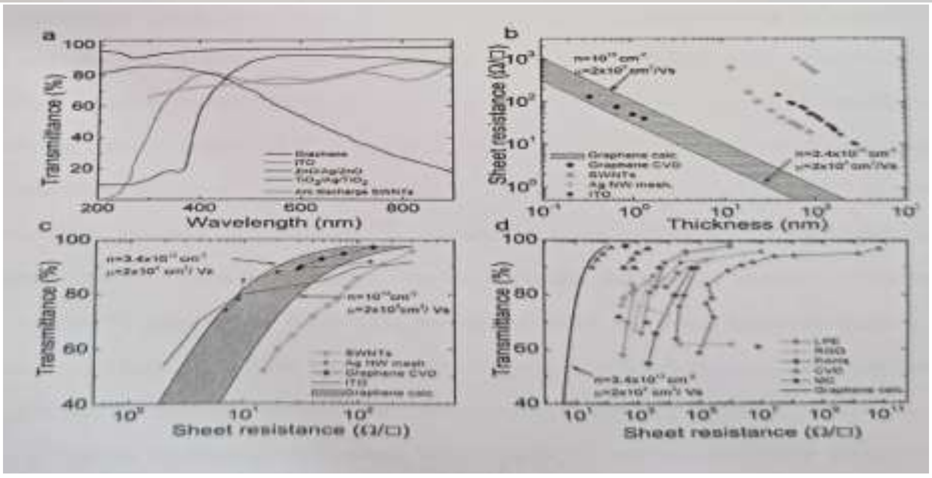


Fig. Density of states (A) free space (B) a photonic crystal (C) a photonic crystal with a local defect Figure reproduced with permission.

6. Photonics in Healthcare and Medicine Applications

The healthcare industry, which focuses on low-cost diagnosis, drug delivery, treatment, and disease prevention, relies heavily on photonics technology. Additionally, it involves minimally invasive elective surgeries for sight correction for the purpose of characterization of the human genome Additionally, the medication response of light-based technologies is superior [25] [26]. This may assist in minimizing side effects, lowering healthcare costs, and shortening hospital stays. Understanding a patient's condition and taking appropriate action for guidance and implementation are two areas in which medical imaging is also rapidly expanding. During surgery, fluorescent biomarkers that selectively bind to tumor cells are used in real-time images to clearly distinguish healthy tissue from diseased tissue [27]. Optical Coherence Tomography (OCT) is the primary medical imaging application of photonics in healthcare. Using light, a high-resolution three-dimensional image can be captured using this method. This is extremely useful for diagnosing solid state tumors without requiring invasive surgery. These methods can be used to keep an eye on how the disease is progressing and how the treatment affects the tumors. In addition, diagnosis of neurological and ophthalmic conditions, as well as monitoring of healing, was simple. The technology's low detection rate and non-invasive nature are major benefits for essential. Additionally, it is
advantageous to reduce the patient's hospital stay, recovery time, and time before treatment can begin, as well as the speed at which images can be produced. OCT also plays a role in treatment, the recovery phase, monitoring the shrinking of tumors, and quickly detecting recurrence during remission. Patients can be treated in particular ways and in specific locations thanks to the high regulation image [28] [29] [30] [31] [32] [33].

Conclusions

The advantages of photonics over other technologies are discussed in this paper's compressive review of the technology. The development of nanostructures using photonics technology, the band gap and cavity, and related issues are highlighted. Transparent conductors, light-emitting devices, photo detectors, and other photonics-related applications of graphene are discussed.
Sunlight is converted into electrical, thermal, and chemical energy through photonics. In addition, it makes a significant contribution to energy conservation through improved communication, displays, and lighting efficiency. In the fields of healthcare and medicine, defense and national security, sensing, lighting, and energy, photonics makes a significant contribution to the measurement of industrial emissions, environmental monitoring, night vision, and other areas.

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