Chapter

Photonics for AI and AI for Photonics: Material and Characteristics Integration

Sunil Sharma and Lokesh Tharani

Abstract

We are living in the technological era, where everything is integrated with each other. If we are discussing regarding communication, it is integrated with one or two technologies. If we are discussing regarding automation, discussing regarding Image processing, discussing regarding embedded system, they all are integrated with a combination of technologies. Correspondingly Artificial Intelligence (AI) and Photonics are also integrated with each other. Now a day as AI is utilizing with photonics in abundant fields as well photonics is also serving AI to facilitate ultrafast AI networks to offer a novel class of Information Processing Machines (IPM). This chapter is based on identification and implementation of photonics for AI utility and AI for photonics. In this category a Dual core Photonics crystal fiber (PCF) is proposed which serve to identify infected cells of human being along with the integration of AI. This proposed design of PCF is providing relative sensitivity and confinement loss in an optimized manner with the impact of AI. Here potency of AI as well as of Photonics is explained to serve their applications related to each other.

Keywords: Artificial Intelligence, Fiber Optics and Photonics, Optical Networks, Photonic Crystal Fiber, Integration

1. Introduction

Latest technological development in photonics has multiplied only due to integration of photonic platform with conception of Opto-electronic elements [1]. The Photonic Integrated Circuits (PICs) [2] have facilitated the ultrafast Artificial Neural Networks (ANN) [3], to propose a novel class of Information Processing Machines (IPM) [4]. There are number of reasons available which reveals that photonics is somewhere associated with AI. In this direction the latest example can be considered as development of Neuro-morphic [5] electronics, which shows that *high processor delay* can be eliminated by offering a consequent technology to extend the vicinity of AI. It offer sub-nanosecond [5] delay and consequently conquers challenges in terms of present and future aspects.

This latest developed technology 'Neuro-morphic electronics system' [5] is integrated with most recognized technology which is known as semiconductor photonics. It is composed of third and fifth group of elements i.e. GaAs and InP [2].

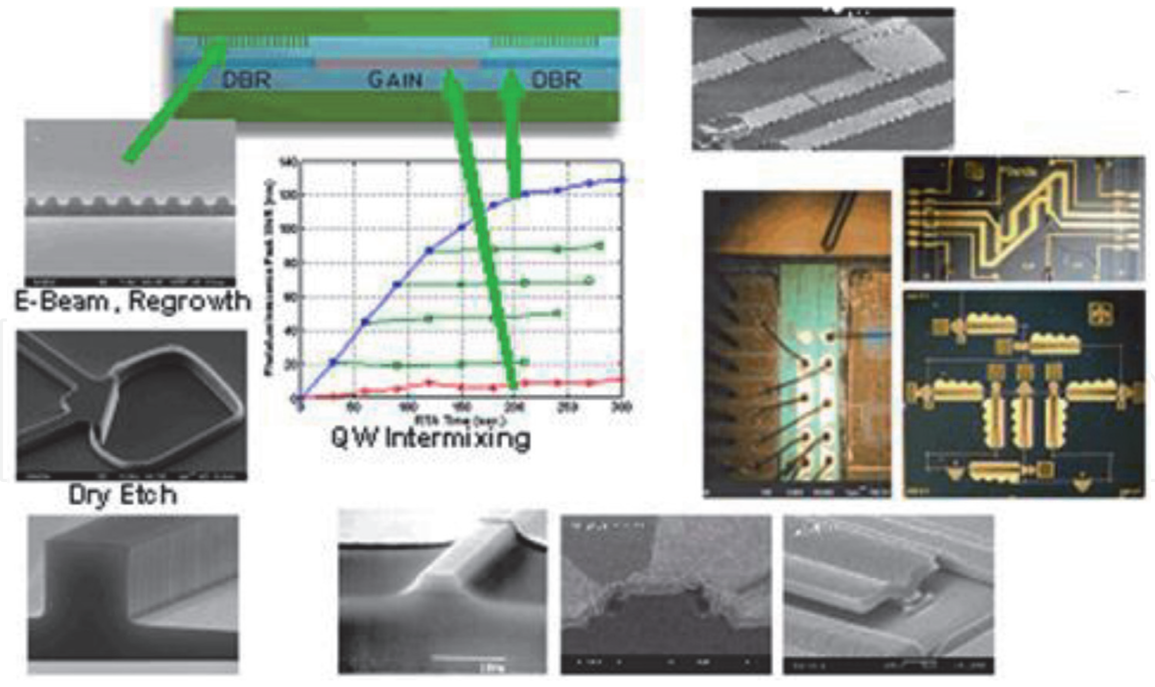

Figure 1.
GaAs & InP Composed Photonic Integrated Circuits [2].

Below **Figure 1** represents the photonic integrated technology indicating fabrication, characteristics like growing and mixing of GaAs and InP materials to provide efficient, robust, and monolithic optoelectronic integration platform. It was developed and observed by Sandia National laboratory services.

The developmental growth of photonic crystals, components and meta-materials [6] lead to the advancement of photonics in the area of designing, modeling and technological integration. This kind of integration investigates AI with photonics. This promising domain is someway sustained by 'photonic materials' [7] which assist to find out and intend innovative applications of AI. It should be noted down that how photonics is contributing for the implementation of AI tools and techniques.

The contributing field of photonics towards AI includes Neuro-morphic electronic system, Optical Neural Network (ONN), Nano Photonics,

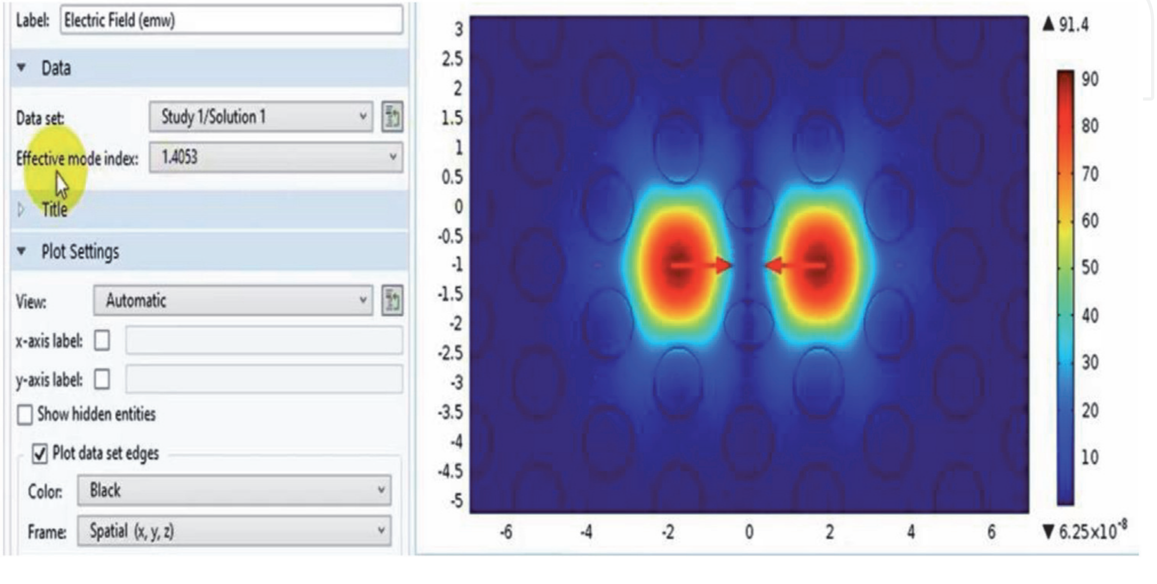

Figure 2.
Proposed dual cores PCF with different mode indexes.

meta-materials, optical sensing, optical imaging [8], optical computing, Information Processing Machines etc. These above mentioned optics emerging domains can be integrated with AI tools [9] to enhance the efficiency and performance of these systems.

Figure 2 represents the design structure of dual core silica PCF with an effective index mode of 1.4053. By changing the mode index value we can have light confinement variation which is shown below in **Figure 3 (a & b)**.

As shown below in **Figure 4** indicates contribution of photonics in terms of machine intelligence with Neuro-morphic computing along with Optical neural network and optical sensing for AI technology. These latest technologies helped AI to diagnose critical disease.

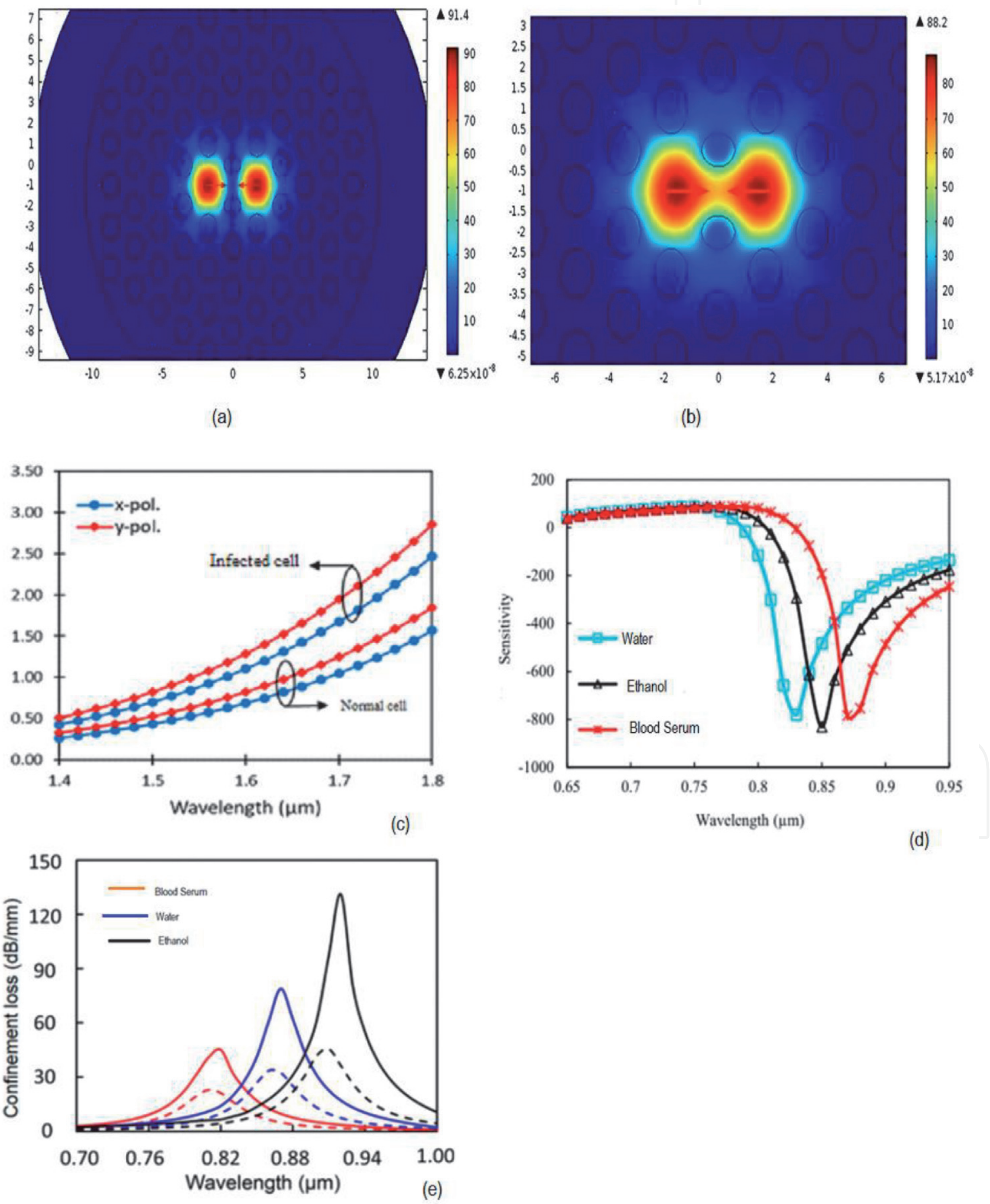

Figure 3.
(a, b) Light Confinement through proposed design for different values of Index Modes (c) Identification of infected cells with AI (d) Relative sensitivity (e) confinement loss of proposed design.

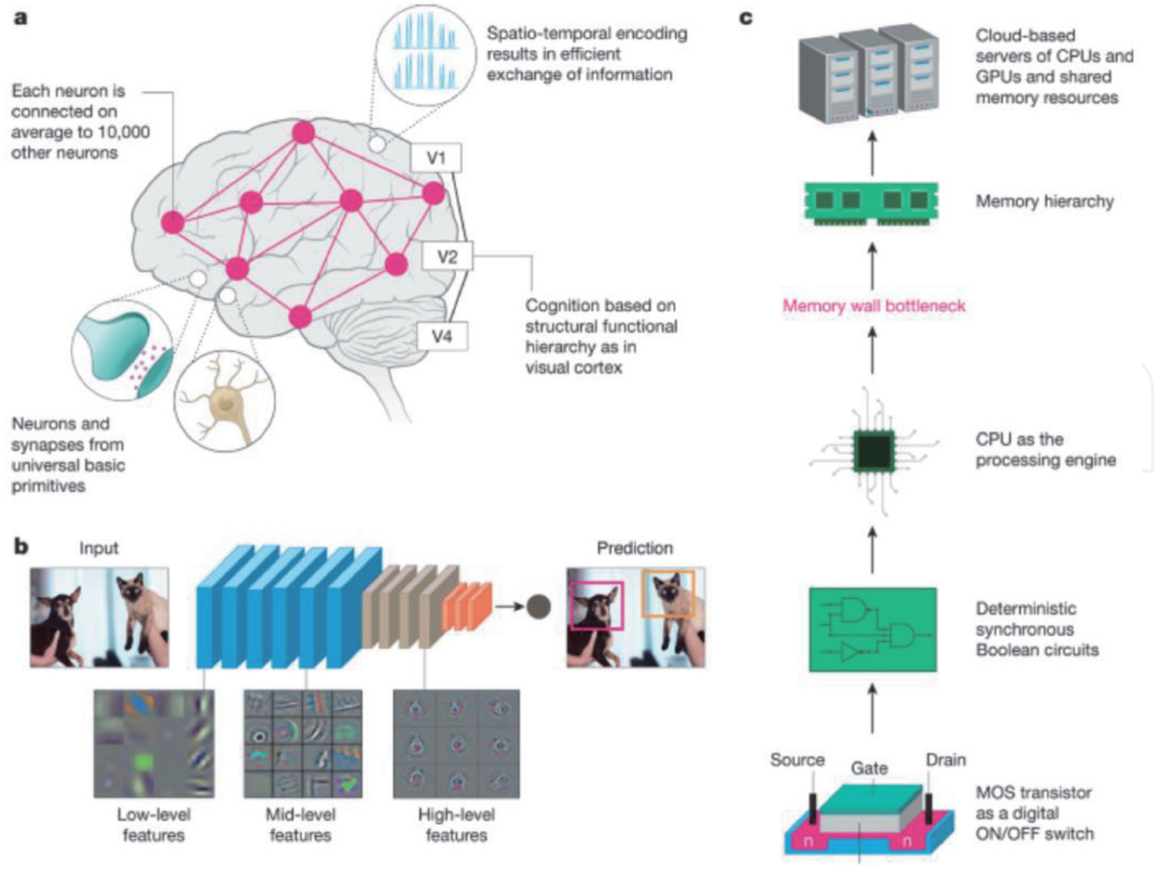

Figure 4.
Contributing field of photonics for AI (a) AI with Neuro-morphic computing (b) Optical Neural Network (c) Optical sensing and computing [5].

2. Photonics materials and their characteristics for AI

We all are witnessing an inconceivable age of drastically development in applications that necessitate expansion in AI [10]. If we are discussing about the ingenious novel outcomes that are gradually trending towards the market place and many more are preferred and expected. Fiber Optics & Photonic materials [11] are widely used for these products like new display, personalized mobile devices, novel sensors, and new information processing machining products for both storage and data processing. It is trending in very clear manner that the areas of Fiber Optics & Photonic materials are fundamental technologies for the globe. Inventing and uncovering new materials [12] in the Fiber Optics & Photonics domain will be exceedingly critical to see more and more novel outcomes to improve normal people’s lives.

Materials that have been exposed at the crucial point of life, always changes the history of human being along with the country. Materials that are used to senses, materials that are used to stores, materials that can be used as energy efficient, some translucent materials which can be folded easily and some materials that are manufacturable at low cost. New discovered materials such as doped silica materials [13], resistance changing materials and spontaneously magnetize and polarize materials have been discovered and using widely for AI integration and their applications.

In the line of discovery of new materials, the Picometer [7] can also be considered as a vibrant example in the field of atomic structures. There are numerous atomic structures available that were simulated and their data were utilized for AI analysis to identify artificially controlled ‘oxygen octahedral rotation’ (OOR) patterns as shown in below **Figure 5**.

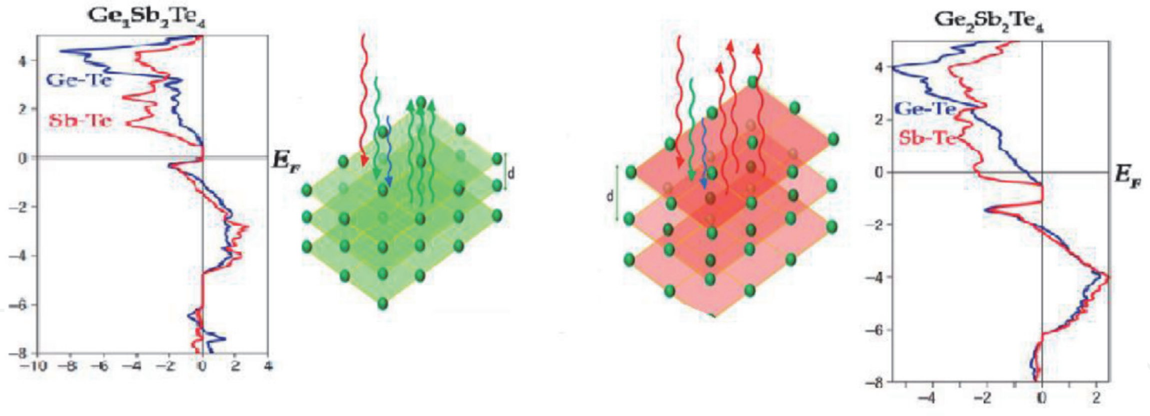

Figure 5.
Oxygen Octahedral Rotations and its characteristics [7].

It was used as Disorder-Driven Metal–Insulator Transition in Crystalline Vacancy-Rich Ge-Sb-Te Phase-Change Materials [7].

2.1 New Investigative Materials for AI

The discovery and development in the new materials plays an important role in the technological progress. As we have already seen that how silica has revolutionized the microelectronics industry. Materials discovery and design efforts require interplay between materials prediction, synthesis and characterization [12] have increased applications of computational tools and techniques, increased generation of material's databases, and accelerated advances in experimental methods significantly. Some of them are composed of three special elements i.e. germanium, antimony and tellurium which is defined as Ge-Sb-Te alloy [2] and can be termed as phase-change memory materials. This alloy is selected from the group of chalcogenide glass (As_2Se_3) [12] which can be used in rewritable optical discs.

The above mentioned **Figure 6** is used as a non-volatile quasi-continuously reprogrammable platform. This phase-change memory material rapidly changes its atomic structure from crystalline to solid amorphous when swiftly melted in presence of temperature. These kinds of materials are widely used in 'electronic memory' applications of AI tools such as *data storage*. Even though there are countless integration is possible with Ge-Sb-Te alloy, the new material **GST467** [6] revealed by CAMEO (Closed-Loop Autonomous System for Materials Exploration and Optimization) is most favorable for phase-changing applications.

CAMEO found the best Ge-Sb-Te alloy that had the largest difference in "optical contrast" [6]. GST467 also found applications in photonic switching devices that can be used to control the direction of light in given circuit. These devices can also be utilized in Neuro-morphic computing [5], which is an emerging field focusing on development of devices which imitate the formation and role of neurons in human brain. Materials science or solid-state physics is plagued by the 'curse of dimensionality'.

3. AI for photonics

When the words "artificial intelligence" (AI) comes to mind, our first thoughts may be of super-smart computers or robots that perform tasks without needing any help from humans.

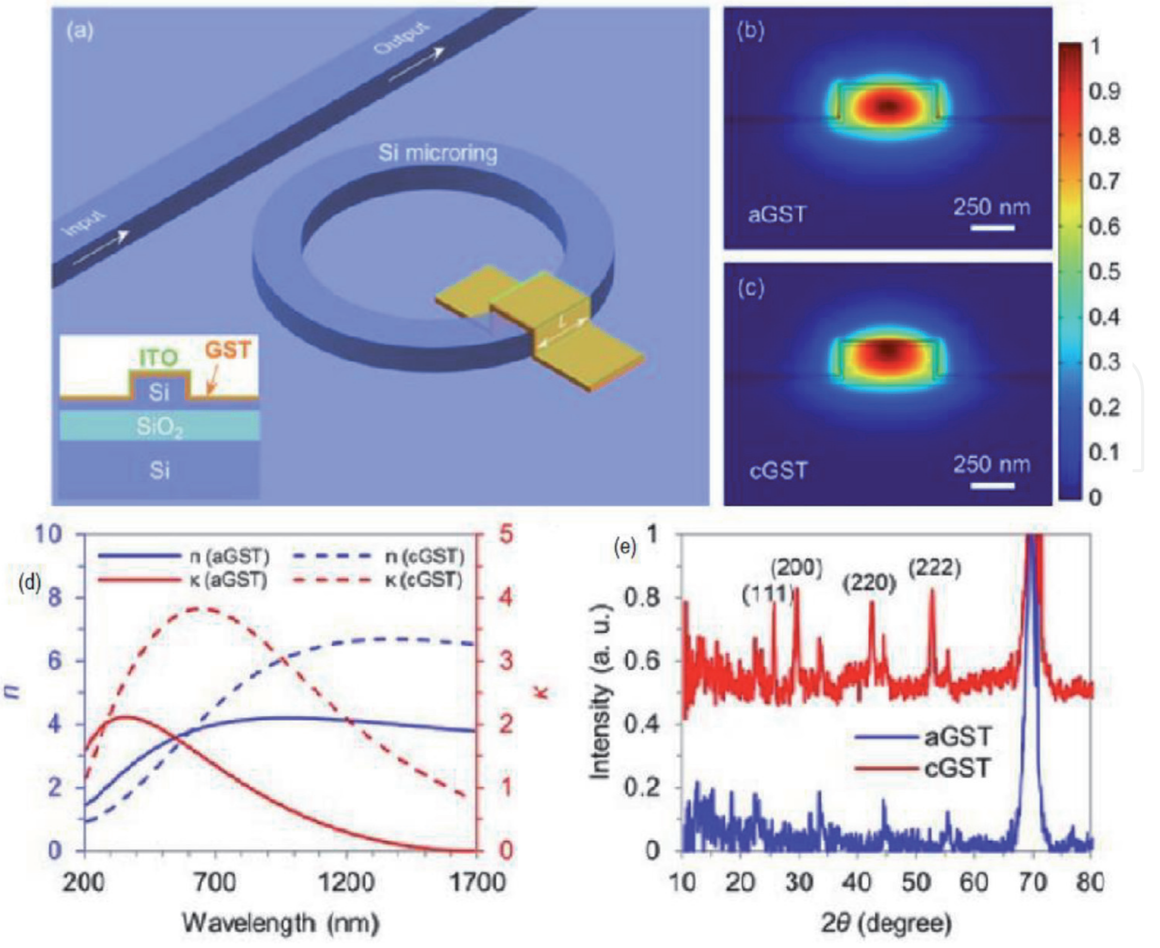

Figure 6.
GST467 with AI (a) Schematic cross-section of the hybrid waveguide. (b)&(c) Fundamental quasi-transversal electric (TE) mode profiles of the hybrid waveguide at 1550 nm for (d) complex refractive index of GST and GST as a function of wavelength. (e) XRD data of GST [6].

A multi-institutional team of research scholars from National Institute of Standards and Technology (NIST) [6] have developed an AI algorithm known as CAMEO. It was used for the discovery of potentially applicable new photonic material without any additional preparation and efforts from the scientist. These AI systems helped to reduce the trial-and-error time which generally scientists use up in the lab. Along with this these systems maximizes the productivity and efficiency of their research work. Another research scientists team at POSTECH (Pohang University of Science and Technology) [7] got succeed in creating a novel substance that generates electricity by effect of polarization at room temperature. The variation so observed would be confirmed in crystal structure by analysis of deep neural network. The above mentioned examples revealed the techniques behind making materials used in new memory devices by using artificial intelligence. So it is very much clear that the use of modern computational techniques like AI can be used to improve the rate of discovery of these new photonics materials and vice versa. Helping scientists in reaching their outcomes more efficiently and quickly by performing only few experiments with limited resources. All these things became possible only because of integration of AI and Photonics.

The optical properties are typically calculated by using Maxwell's Equations [13]. The desired optical response can be obtained by adjusting the initial design and performing multiple simulations until the outcome is achieved. Despite designing issues AI can help optics and nano photonics in different tasks, for example AI used to estimate the optical properties of black carbon fractal aggregates. Another example is reported where they combines finite element simulations and clustering for the identification of photonic modes [14] with large local field energies and specific spatial properties. It is shown that the combination of machine learning with photonics [15] can revolutionize one of the most important fields in optical imaging.

4. Proposed dual core PCF design integrated with AI

The silica glass is easily available and have some characteristics due to this it is preferred for designing PCF structures. Below **Table 1** depicts some properties of silica glass [15].

Silica is the purest form of SiO_2 which is easily available from the sand as a raw material. This raw silica is used to convert into Electronic Grade Silicon (EGS) from various processes. This glass has superior transmission chatcteristics in the UV (Ultra-violet) and IR (Infra-red) spectra, a very low dielectric coefficient and excellent properties where fluorescence or polarization is an issue. This silica can be shaped too many forms and sizes. It has excellent resistance to non-fluorinated acids, solvents and plasmas. The finite-difference method is the most accurately and numerically efficient method to solve Maxwell's Equation [15] and needs less computational time.

By selection of Silica glass as a core material for designing of PCF structure, below mentioned **Figure 7** depicts the cross-sectional view of proposed dual core Silica PCF with circular sensing ring. The diameter of the air hole is 1.2 μm. Here elliptical air hole is also used in the first layer and the semi major and semi minor axis for that ellipse is 1.2 and 0.8 μm respectively. The pitch value for the proposed structure is 2 μm.

After designing the structure of Dual Core PCF if there is a variation of index mode then due to different mode index values, there must be some variation measured in confining light through designed PCF. This variation is already mentioned in above **Figure 3 (a & b)**.

It indicates that as index mode value varies like 1.4053, 1.4055, 1.4088, 1.41 … .. The variation is observed in confining the light through core of the proposed fiber.

The proposed dual core PCF for sensing various applications like blood sample detection, alcohol detection, disease detection, White Blood Cells (WBC), Red Blood Cells (RBC) detection and for many more pathological detection can be integrated with AI technology which provides optimized results to diagnose infected cells. For this purpose below mentioned setup as shown in **Figure 8** is

Properties	Silica Glass
Density (g/cm^3)	2.2
Refractive Index (micrometer)	1.458
Light Transmission wavelength (micrometer)	0.18–2.5
Max Temperature (Degree Centigrade)	1120
Poission's Ratio	0.17
Specific heat capacity (J/Kg-K)	720
Speed of sound (m/s)	180×10^3

Table 1.
Properties of Silica Glass Material [12].

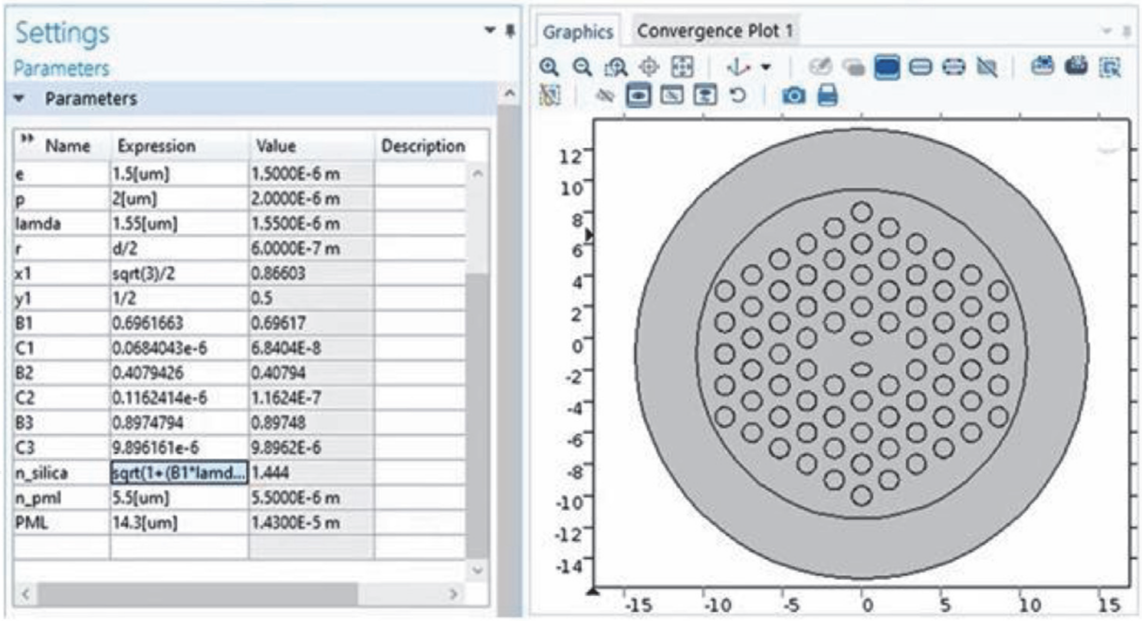

Figure 7.
Proposed Dual Core PCF with Perfectly Matched Layer (PML) Boundary.

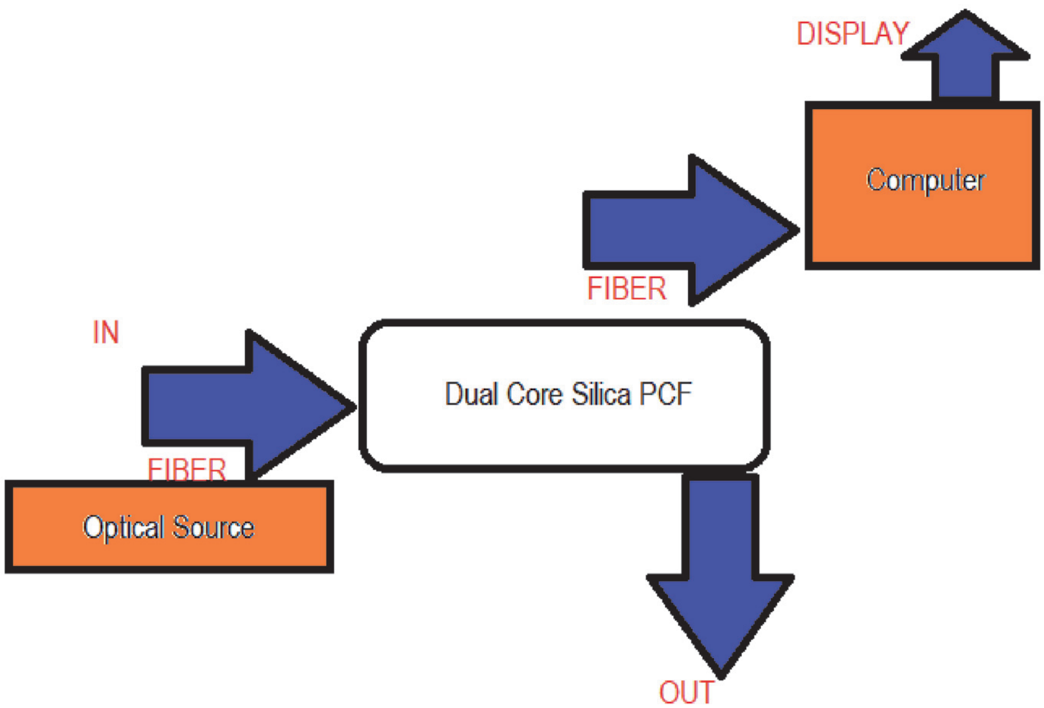

Figure 8.
Experimental Setup to Obtain Outcomes.

arranged. With the help of this setup the proposed dual core PCF can be utilized with AI to serve better and improved outcomes. The above mentioned **Figure 3 (c)** represents the infected cell by using designed PCF structure integrated with AI. Relative sensitivity and confinement loss is also displayed in **Figure 3 (d & e)**.

In this setup the optical source is used to supply power to the Fiber. By using the splicing technique fiber can be connected with the proposed PCF. IN and OUT ports are used to control the unknown analytes whose refractive Index (RI) need to be identified. When analyte interacts then the variations in terms of lows and peaks occurs which can be observed and displayed using computer. The outcomes so obtained can be enhanced to provide efficient result with AI. Dual core silica PCF

Parameter Tested	Refractive Index	Relative Sensitivity (%)	Confinement Loss (dB/km)
Ethanol	1.33	56.90	2.37×10^{-6}
Blood Serum	1.39	46.51	3.814×10^{-10}
Water	1.32	53.57	8.063×10^{-11}

Table 2.
Test Performed for various parameters.

serve as a sensing element used to sense the selected parameter and the AI technology boost the effects of results so obtained.

With the Above mentioned proposed design the following tested have been performed using Dual core Silica PCF.

Depending upon the refractive index of blood serum, the intensity of light is modulated and detected at other end of PCF [16]. The relation between evanescent field absorbed by sensing species and intensity modulation at output end is observed.

Sensitivity is obtained by using

$$r_f = f\left(\frac{n_r}{n_c}\right) \tag{1}$$

Where n_r is the refractive index of the fluid, n_c is core refractive index, r_f is relative sensitivity coefficient and 'f' is the ratio of optical power with in large holes to the total power which is given as

$$f = \int\left[(E_x H_y - H_x E_y)_{samples} / \int\left[(E_x H_y - H_x E_y)\right]_{total}\right. \tag{2}$$

Confinement loss [17, 18] is calculated by

$$L_C = (40\pi/\ln(10)\lambda)\,\mathrm{Im}(\mathrm{neff})\,[\mathrm{dB/km}] \tag{3}$$

or it can be written as

$$L_C\,(\mathrm{dB/m}) = 8.686\,k_0\,I_m\left(n_{eff}\right) \times 10^6 \tag{4}$$

Here n_{eff} signifies imaginary part of effective refractive index, and k_0 is the free-space number.

The data set of blood serum, ethanol and water for this case of investigation is selected as an input which can be passed through the setup and results so obtained have been optimized by using AI. These results obtained numerically and experimentally have been presented in above mentioned **Table 2**.

5. Discussion

The potency of the AI standards lies in its capacity to deal with anonymous computing troubles. It is practically identified that it is giving not only innovative or optimized solutions and forecasting, but also original substantial impending to the structure by using integration with technologies. Here we have presented an integrated discussion between AI and Photonics. The AI has been utilized to nurture tiny investigational datasets in iterative method to envisage new materials and execute multi objective optimization of properties for selected materials. Correspondingly Photonics is also offering new materials for booming realization and performing computation takes in an efficient manner to AI. The characteristics of the dual-core photonic crystal fiber (PCF) sensor are studied using the finite element method (FEM), and the structure is improved according to the numerical simulation results.

6. Conclusions

In the revolutionary field of optics and photonics, most of the work has so far been offered on purpose of photonics to the realization of AI to the intend, expansion and optimization of photonic meta-materials and various devices. AI techniques present prospects both to expand physical approaching and to investigate constraints in a more proficient manner.

Most successful paradigms of AI and photonics like Neuro-morphic electronic system, Optical Neural Network (ONN), Nano Photonics, meta-materials, optical sensing, optical imaging have also been demonstrated here in this chapter in which AI is boosting photonics and similarly photonics is also helping AI to perform efficiently. The proposed Dual core Silica PCF is used to identify infected cell in a human body. Due to easily presence of Silica glass and its vibrant characteristics it is preferred for the proposed PCF design. The refractive index of selected material is 1.458, Specific heat capacity is 720 J/Kg-K, Light Transmission wavelength is 0.18–2.5micrometer. It has been observed that the relative sensitivity for ethanol, blood serum and water is 56.90%, 46.51% and 53.57% respectively. Similarly the confinement loss for the proposed structure is 2.37×10^{-6}, 3.814×10^{-10} and 8.063×10^{-11} dB/km respectively for the same parameters as mentioned above.

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Conflict of interest

I declare no conflict of interest for this research article.

Data availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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