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# **2D Photonic Crystal Biosensor to Identify Concentration of Glucose in the Urine Sample**

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**ABSTRACT:** This work uses urine, samples to detect diabetes utilizing rods made of a gallium nitride (GaN) composite semi-conductive material with an air backdrop lattice point as a photonic crystal. The relationship between light and analyte is ascertained by measuring the refractive index (RI) of bio-samples at different concentrations. Light confinement and a good wavelength shift are thus present in the detecting zone. The finite difference time domain (FDTD) approaches are used to assess the photonic bandgap (PBG) and optical characteristics of light, respectively. The impact of altering the sensing rod's radii on the biosensor is investigated. The biosensor's performance parameters were as follows: amplitude sensitivity of 200 au./RIU, compact area of  $17 \times 17 \mu\text{m}^2$  99% transmission efficiency sensitivity of 400 nm/RIU, and Q-factor of 5233.66. The suggested structure is a label-free biosensing structure that may identify several medical conditions, including diabetes.

**KEYWORDS:** Photonic crystal, Biosensor, Diabetes, Bio-sample, Sensitivity, Quality factor.

## **I. INTRODUCTION**

At this centennial, we have expressed our ability to manipulated materials to incorporate their electrical characteristics. By enabling us to modify the conducting characteristics of specific materials, Developments in the physics of semiconductors sparked. The advent of transistor-based electronics. It is difficult to overestimate the influence that these fields. Advancements have had on our culture. To develop high superconductors at low temperature, possess additional materials. could serve as the foundation for future technologies, scientists have created novel alloys and ceramics. Over the past over the fast new decades a new set of materials optical characteristics has been opened up: the goal is regulated optical characteristics of materials, We would able to create the materials that that responds to regulates the light wave across the specific frequency range by either causing total reflection, emitting movement in selected directions , or localizing them in a specific zone volume, we could achieve a wide range of technological advancements. Fiber optic connection have already transformed telecommunications by providing vast array by merely guided light , and the next fields to benefit from the advancements in material that are optical are laser engineering rapid computing , and spectroscopy.

### **Photonic Crystals**

A regular lattice of atoms or molecules is called a crystal. The crystal lattice refers to the spatial organization of molecules and atoms is called crystal. An electron travelling through a crystal is presented with a periodic potential, and the crystal's condition qualities are determined by its composition as well as the lattice's structure. According the quantum mechanics theory in a periodic potential, electrons move in waves, then the waves satisfy specific requirements can pass using a periodic potential doesn't being scattered, albeit they will be dispersed by impurities and defects. Crucially, though, some waves might be unable to go through the lattice, there might be crystal band gap configuration would be stop flow the electrons in specific directions or at specific energies. A complete band may occur from the gap expanding to span all energies' complete band may occur from the gap expanding to span all potential spreading directions if the lattice potential. Three dimensions are distinguished in photonic crystals: one-dimensional(1D),three-dimensional (3D),and two-dimensional (2D).DPCs ,or two -dimensional photonic crystal structures, are a new technology. They have more benefits ,such as a small sizes, a straightforward structure, and precise Calculations that results in good light confinement. Additionally embedded and integrated photonics are very sample. Additional researchers have been attracted to a photonic crystal-based sensors during the last two decades. they suit the demands require circuits with new technology are tiny in size, have quick reaction, and detect great sensitivity of biological and physical factors.



## OBJECTIVES

The main objective of this project is to design and simulate a two-dimensional photonic crystal- based glucose sensor capable of detecting glucose concentration in urine, utilizing changes in refractive index to measure glucose concentrations effectively and accurately. The structure design is tested in COMSOL Multiphysics simulation tool to analyze its photonic bandgap behavior and evaluate its performance parameters Quality factor and sensitivity. Objective of this project is to design a sensor that is capable to detect glucose concentration in urine sample. Sensor consists of square ring resonator and it is important to have resonating wavelength to be in third window and important objective us to have high Q factor for the designed sensor.

## II. SYSTEM REQUIREMENTS

COMSOL Multiphysics is a powerful finite element method (FEM) software used for simulating various engineering and physics problems, including those in photonics. It allows users to model and analyze complex geometries, material properties, and boundary conditions, enabling the simulation of photonic devices and systems. In the context of electromagnetic simulations, COMSOL provides specialized modules such as the RF Module, Wave Optics Module, and AC/DC Module to model the behavior of electric and magnetic fields in devices such as antennas, waveguides, photonic crystals, and biosensors. These modules allow users to define properties like dielectric constants, permeability, conductivity, and boundary conditions, enabling accurate simulation of electromagnetic wave propagation, field distributions, and resonance behaviors. For example, when designing photonic crystal-based biosensors, COMSOL enables the simulation of how light behaves within a periodic dielectric medium. By using TE (Transverse Electric) or TM (Transverse Magnetic) polarization modes, users can study the formation of photonic band gaps (PBGs), field confinement, and sensitivity to changes in the refractive index caused by biochemical interactions. COMSOL's parametric sweep, optimization, and Multiphysics coupling capabilities make it a versatile platform for research and development in numerous disciplines. The post- processing tools allow users to visualize electric field intensity, power flow, resonance wavelengths, and more, in both 2D and 3D representations. Furthermore, COMSOL supports scripting in MATLAB and its own built- in language, COMSOL Script, for more advanced simulations, automation, and custom modeling features. Models created in COMSOL can be exported for further analysis or embedded into standalone simulation apps using the Application Builder, which is especially useful in educational and industrial environments. Overall, COMSOL Multiphysics is not just a simulation tool but a comprehensive modeling environment that empowers engineers, researchers, and designers to innovate and optimize technologies across multiple domains. In this project, COMSOL play essential role in designing and analyzing the performance of a 2D photonic crystal- based glucose sensor, providing insight into light-matter interactions and aiding in the optimization of the sensor's geometry for maximum sensitivity and performance.

## III. METHODOLOGY

A 2D-PC based biosensor structure is presented to detect the glucose concentration in urine. The structure consists of a 2D square lattice over a Gallium Nitride (GaN) substrate of dimensions  $17\mu\text{m} \times 17\mu\text{m}$ . The GaN substrate has a refractive index of 2.305, in which air holes have been etched with a refractive index of 1 and another refractive index of normal glucose is of 1.335. These air holes are exchanged with the glucose concentration in urine, when the sensor is inserted in the sample under consideration. Two bus waveguides with square ring resonator defect are introduced into the crystal structure by removing certain holes from the substrate. The distance between the two air holes known as the lattice constant is kept as  $440\mu\text{m}$  and is denoted by 'a'. The air holes have a radius of  $0.342*a$ , are circular in shape. The Finite Element method (FEM) method is used to obtain the PBG  $1.50\mu\text{m}$ - $1.60\mu\text{m}$ . COMSOL Metaphysics tools has been made used to simulate the model, and the model is validated under 1000 samples.

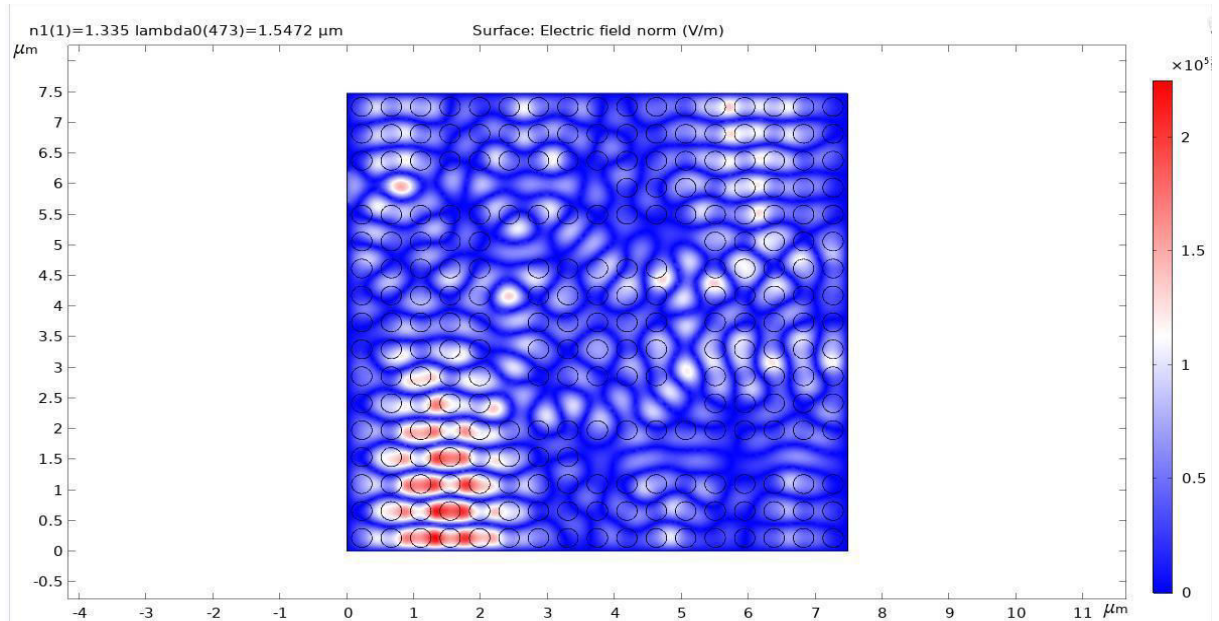


Fig (1). OFF RESONANCE  $\lambda=1.5472$

The signal does not reach the ring resonator at the OFF resonance condition when optical energy is applied, where there is no transmission. After being linked to the resonator, the signal from the input bus waveguide travels through a square micro-ring resonator at resonance to the output bus waveguide. When there is a high transmittance's electric field distribution of the suggested sensor at ON resonance and OFF resonance is shown in figure 1. The input signal is reflected to the input port at OFF resonance (0  $\mu\text{m}$ ), however, at ON resonance (1.5635  $\mu\text{m}$ ), the input port signal is coupled from the input waveguide to square micro-ring resonator which in turn, outputs through output waveguide.

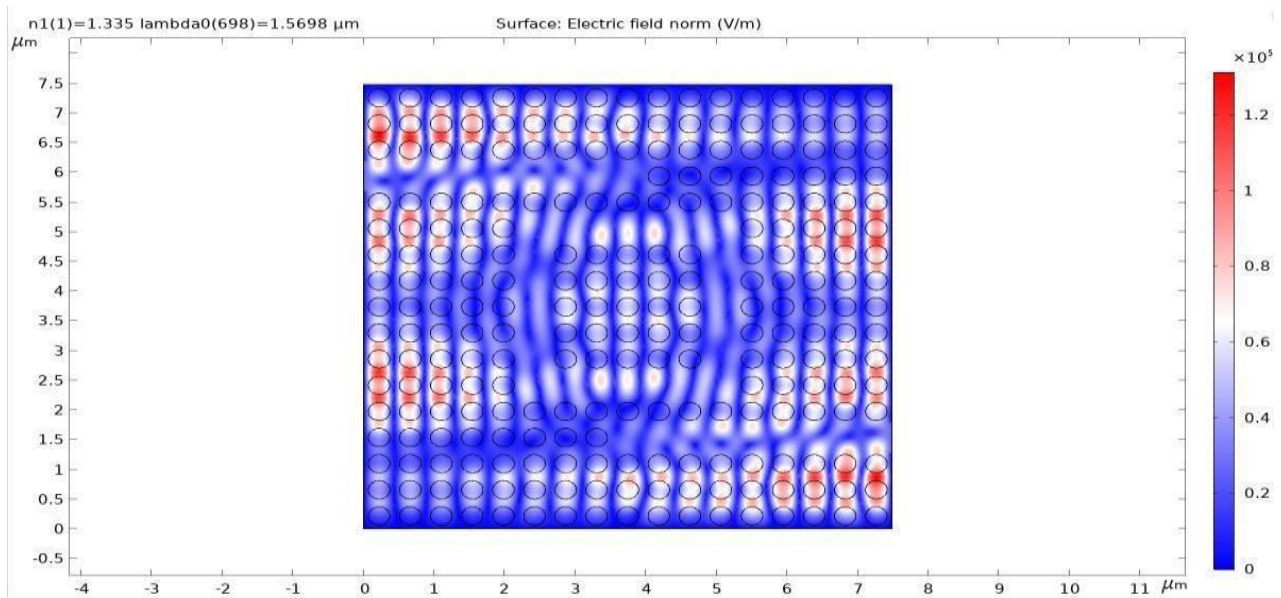


Fig (2): ON RESONANCE  $\lambda=1.5698$

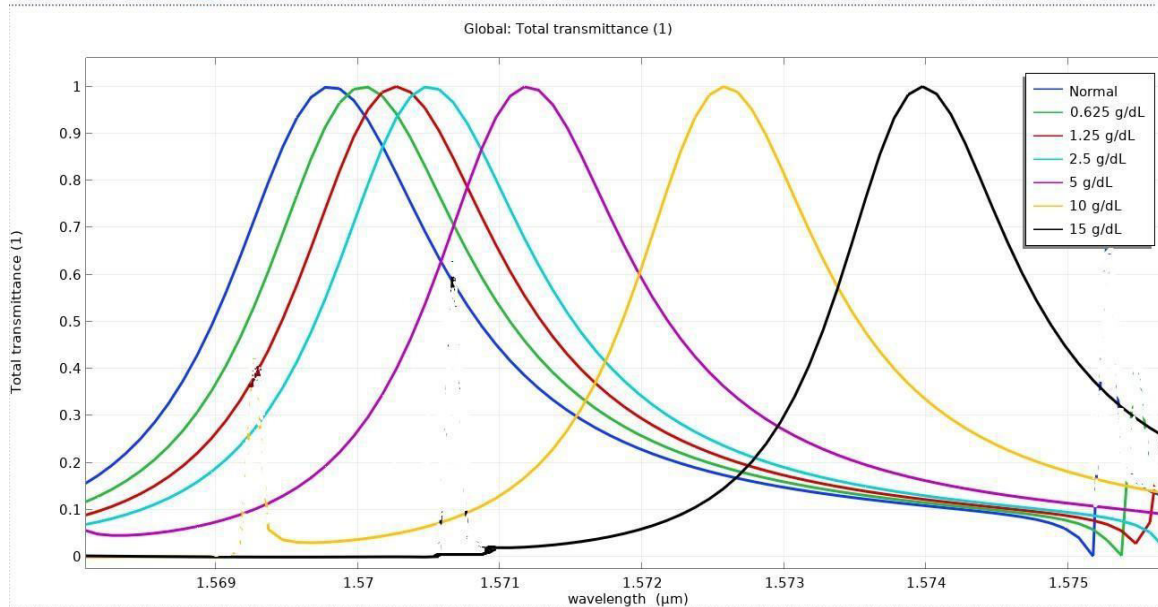


Fig (3): Wavelength graph

Upon the applying of optical energy, the signal does not reach the ring resonator at OFF resonance condition. Where the transmittance is zero. The signal from the input bus waveguide is coupled to the ring resonator and reaches the output bus waveguide through square micro- ring resonator at resonance Where the transmittance is high. Figure 1 depicts the electric field distribution of the proposed sensor at ON resonance and OFF resonance

The considered  $r$  is  $r = 0.344$

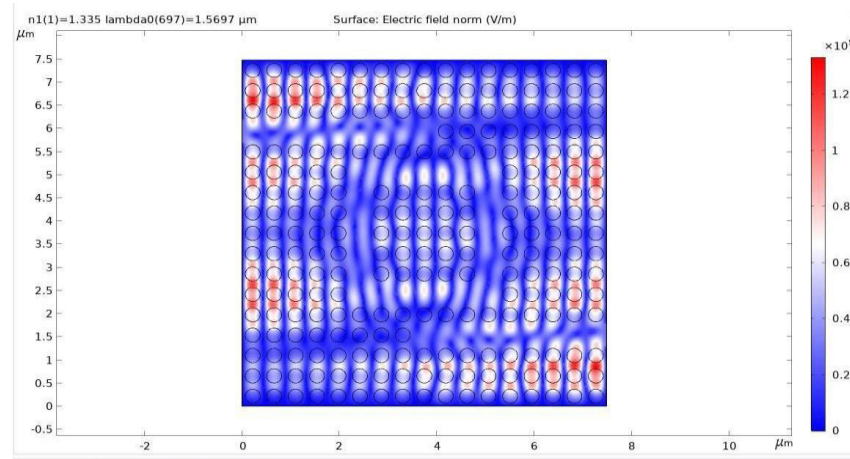


Fig (4): OFF RESONANCE  $\lambda = 1.5697$

In photonics, resonance occurs when the structure supports a standing wave (resonant mode) at a specific frequency. You see enhanced transmission, reflection, or field intensity. off-resonance refers to conditions where the input light frequency (or wavelength) is not aligned with the resonant frequency (or mode) of the photonic device — such as a cavity, waveguide, ring resonator, or photonic crystal. Destructive interference or no coupling → Signal bypasses ring or is blocked.



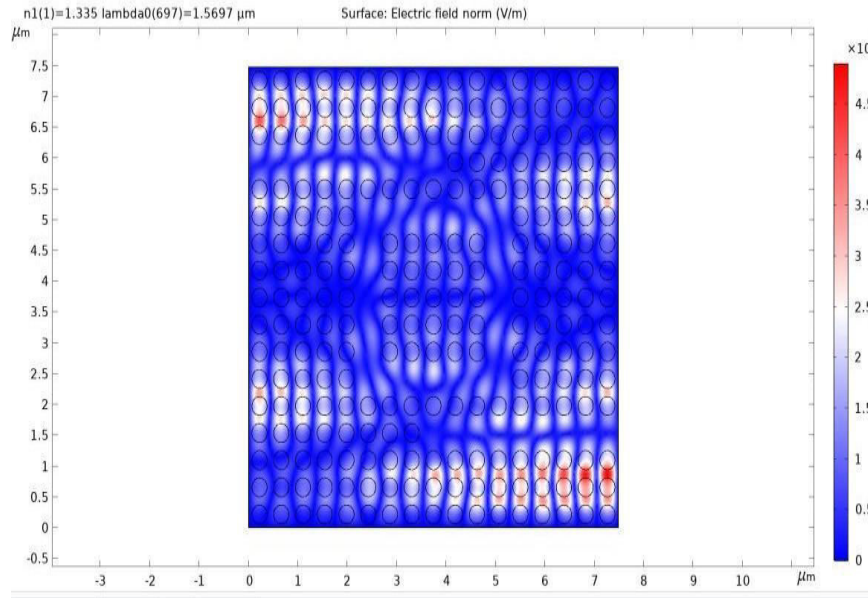


Fig (5): ON RESONANCE  $\lambda=1.5697$

The electric field distribution of the proposed sensor at ON resonance and OFF resonance. It is clear that the signal couples in to the sensor at the resonance wavelength. The signal couples in to the sensor at the resonance wavelength. The signals getting couples only at and above the resonance wavelength. This condition can be termed ON resonance. when the signal is not able to couple below the resonant wavelength is about at 1300nm then that condition is called OFF resonance. Input light constructively interferes in the ring → High transmission or drop-port signal.

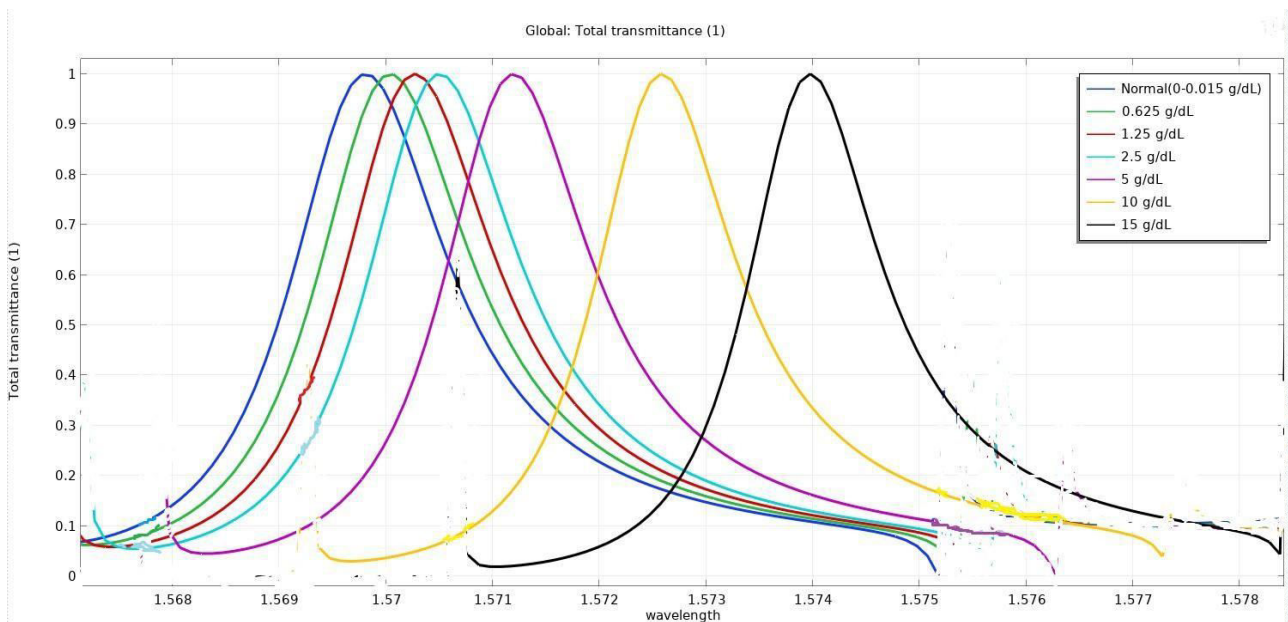


Fig (6): Wavelength graph

#### **IV. RESULT AND DISCUSSION**

We observe a shift of approximately 1nm for a refractive index difference of 0.002. The sensitivity is between 200 and 400(nm/RIU), and the quality factor is between 2248.571 and 5246.33. The claim says that this research offers a step towards the evolution of future urine-based refractive index phc sensors. The proposed sensor can accurately and simultaneously distinguish between normal and polluted blood glucose levels.

A design for two bus wave guides with a micro-ring resonator and a square lattice of GaN rods is proposed and optimized to successfully achieved compactness, a superb quality factor, and a relatively high sensitivity, as demonstrated by comparing them to relevant works. These benefits are linked to the price of the complexity of the proposed design. This work has an outstanding quality factor in addition its more than excellent sensitivity. The higher the quality factor, the shaper the resonance peaks. This suggests that the proposed sensor can accurately and quickly detect and distinguish between normal and contaminated blood glucose values. Finally, a remarkable compactness of  $17 \times 17 \mu\text{m}$  is achieved. An array of sensor or quasi-distributed sensors may be used in this work in the future.

The phc structure exhibits both line and point defects in the biosensor structure. Materials si rods in the background of the glucose, albumin, and urea air sample. If the amount of glucose constrained in the urine is changed. The urines refractive index is also changed. The pc-based sensor often modifies the structures effective refractive by shifting the resonant wavelength from its initial position or altering the output intensity. In this work, the intensity variation scheme is taken into consideration urine's glucose levels and corresponding refractive index.

#### **V. CONCLUSION**

The study effectively demonstrates the design and simulation of a 2D photonic crystal-based glucose sensor using gallium nitride GaN rods air matrix. By combining a square ring resonator with waveguide constraint biosensor employs refractive index modulation to detect changes in glucose concentration with exceptional sensitivity and specificity. Finite Element Method (FEM) The analyses used to COMSOL Multiphysics to complete task, the sensor's performance in terms of sensitivity, quality factor, and resonant wavelength shifts. The sensor's significant potential for precise glucose detection in physiological ranges was proved by the clear correlation it showed between the measured resonance peak changes and glucose concentration. Furthermore, the field confinement properties and observed photonic band gaps (PBGs) confirm that the photonic crystal can serve as a trustworthy sensing platform. This device is a viable substitute for traditional enzymatic or invasive techniques because of its modest dimension is little power usage , and label- free detection. All things considered, the project offers a significant advancement in the creation of optical biosensors for real-time health monitoring systems.

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