Optik 127 (2016) 3333–3336

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

# Estimation of human-hemoglobin using honeycomb structure: An application of photonic crystal

K.P. Swain, G. Palai*

*Gandhi Institute for Technological Advancement (GITA), Bhubaneswar 752054, Odisha, India*

ARTICLE INFO

*Article history:*
Received 7 September 2015
Accepted 11 December 2015

*Keywords:*
Honeycomb photonic crystal structure
Photonic band gap
Transmitted energy

ABSTRACT

This paper proposes a method to estimate the hemoglobin concentration in human blood using 2D honeycomb photonic crystal structure. Though a few works deal with similar kind of investigation, present research delivers an accurate estimation of hemoglobin as compared to previous works. The principle of investigation is based on linear variation of both photonic band gap and absorbance's with respect to different concentration of hemoglobin in human blood. Aside these variations, energy transmitted through honeycomb photonic crystal structure is also varied linearly with respect to same concentration. In this work, photonic band gap of honeycomb structure is found using plane wave expansion method, whereas absorbance of same structure is computed by employing Maxwell Curl equation. Finally, simulation result revealed that transmitted energy through two dimensional honeycomb photonic crystal structure containing blood is nicely fitted with linear trend line ($R^2 = 1$) which lead to an accurate investigation of hemoglobin in human blood. At last, this paper proposes an experimental set up to measure the said concentrations with the help of an Arduino development board (Uno) containing Atmega 320 microcontroller.



## 1. Introduction

Photonics crystals are made, artificially created materials in which refractive index is periodically modulated in a scale comparable to the scale of the wavelength. Though the concept of photonic crystal has originated in the year 1857 by Lord Rayleigh, the research work in the field of photonic crystals is realized after almost 100 years, when Yablonovitch and John published two milestone papers on photonic crystals in 1987 [1–3], since then, photonics have been progressing hastily and showing a remarkable research in the field of science and technology. As far as, application of photonic-devices are concerned, photonic crystal play an important role to envisage various application in modern technology [4–6]. Though photonic crystal is used for different application, sensing application is one of the major relevance in photonics. As far as literature surveys on sensing application using photonic crystal structure is concerned, recently few papers deal with similar type of research [7–13]. Considering a brief remark on above references, it is seen that reference [7] presents a novel method to find out the concentration of sugar, salt, and alcohol in their aqueous solution. In this case, the author used 2D photonic crystal structure with $11 \times 11$ air holes. Also using same technique, concentration of PAM hydrogel and strength of Cygel is investigated in Refs. [8,9], respectively. Also in Refs. [10,11], the concentration of potassium chloride in their aqueous and intrallipid in human blood is estimated using photonic crystal fiber. Apart from these, measurement of glycerol in B–H–G solution and concentration of hemoglobin in human blood is investigated using 3D photonic crystal structure in Refs. [12,13], respectively. Though Ref. [13] measures the concentration of hemoglobin in human blood using 3D photonic crystal structure, it is hard to fabricate 3D owing to photonic crystal structure. We in this paper investigate the concentration of hemoglobin in human blood using 2D honeycomb photonic crystal structure. The reason for choosing such structure is that it can be easily fabricated; secondly, these structures predict accurate result as compared to 3D photonic crystal structure, which is carried out in Ref. [13].

Hemoglobin is a main component of the blood, which is important for transportation of oxygen in blood, which leads to circulation of blood in vein. This circulation of human blood system has default functions, such as supply of oxygen to tissues, supply of nutrients such as glucose, amino acids, and fatty acids, removal of waste such as carbon dioxide, urea, lactic acid, immunological functions, including circulation of white cells, and detection of foreign materials by antibodies, coagulation, messenger functions, regulation of body PH, regulation oh core body temperature hydraulic function etc. for normal human body. A deficiency of hemoglobin in

* Corresponding author. Tel.: +91 9439045946.
*E-mail address:* gpalai28@gmail.com (G. Palai).

http://dx.doi.org/10.1016/j.ijleo.2015.12.081
0030-4026/

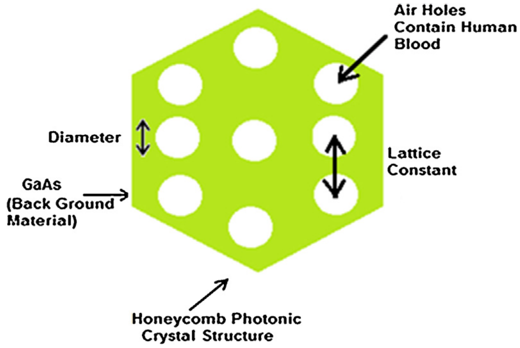


**Fig. 1.** 2D honeycomb photonic crystal structure.

human blood creates serious problem such as downstream tissue dysfunction, Leukemia, iron deficiency, anemia, multiple myeloma, etc. [14–17]. Keeping the importance of hemoglobin in human blood, this paper estimates the concentration of hemoglobin in both oxygenated and deoxygenated blood.

This paper is organized as follows: Section 2 presents the structure of the honeycomb photonic crystal structure including the principle of measurement. Simulation result and interpretation is made in Section 3. Section 4 proposes an experimental set up and finally conclusions are drawn in Section 5.

## 2. Honeycomb structure and principle of measurement

As far as measurement of hemoglobin in human blood is concerned, we use 2D honeycomb photonic crystal structure for the same, which is shown in Fig. 1.

Fig. 1 represents honeycomb photonic crystal structure having gallium Arsenide as background material containing air holes, where bloods with different percentage (g/L) of hemoglobin are infiltrated. The proposed structure consists of 9 numbers of air holes such that diameter of air holes is 420 nm and lattice spacing of the structure is 1 μm. The principle of measurement is based on linear variation of reflected energy and absorbance with respect to concentration of hemoglobin in human blood. When light having wavelength of 589 nm incident on honeycomb structure containing blood with different percentage of hemoglobin then, some amount of light will get reflect and some amount of light will be absorbed by the structure. The rest amount of light will be transmitted through the structure. Since the principle is based on linear variation of both reflected and absorbance, intensity transmitted through honeycomb structure also varies linearly with respect to hemoglobin concentration in the blood which is a key factor (linear variation) to realize accurate investigation of hemoglobin in human blood. We use simple mathematical equation to find out the reflected energy, absorbance and transmitted energy for investigation of hemoglobin. As far as, energy reflected from honeycomb structure is concerned, it is obtained from dispersion diagram, which is carried out by employing plane wave expansion method [18].

In this case, we computed normalized frequency ($a/\lambda$) from dispersion diagram, then the values of reflected energy ($E_R$) is calculated using following simple equation:

$$E_R = \frac{hc}{\lambda_R} \tag{1}$$

where $\lambda_R$ is reflected wavelength, which is found from dispersion diagram.

Since, wavelength 589 nm is used to investigate hemoglobin concentration; the energy of incident light ($E_I$) corresponding to this wavelength is found using following expression.

$$E_I = \frac{hc}{\lambda_I} \tag{2}$$

where $\lambda_I$ is the incident wavelength (589 nm)

Using (1) and (2), the energy transmitted through the structure is written as

$$E_T = E_0 - E_R \tag{3}$$

Eq. (3) represents as transmitted energy without consideration of absorption loss. However, from literature it is found that GaAs structure and blood with different concentration of hemoglobin absorb some light of wavelength, 589 nm. So, absorption loss should be cogitated during this investigation. Using Ref. [19] and employing Maxwell curl equation, Eq. (3) is modified as

$$E_T = (E_0 - E_R)e^{-(\alpha t + \beta d)} \tag{4}$$

From the above equation, it is seen that absorption loss takes place due to two factors, such as absorption loss due to background material ($e^{-\alpha t}$) and absorption loss due to blood ($e^{-\beta d}$).

Where 'α' is called the absorption coefficient of gallium arsenide material and 't' is the thickness of background or substrate.

$\beta$ is called the absorption coefficient of blood at wavelength 589 nm, which is expressed as

$$\beta = \varepsilon c \tag{5}$$

where 'ε' is called the extinction coefficient of blood at wavelength 589 nm and 'C' is the concentration of hemoglobin in human blood and 'd' is the diameter of air holes, where blood samples are infiltration.

Using the above equation, output energy through 2D honeycomb photonic crystal structure is obtained corresponding to each concentration of hemoglobin in human blood sample.

## 3. Result and interpretation

From previous section, it is seen that output energy through the photonic crystal structure corresponding to each concentration is a function of both reflected energy from the structure and energy absorbed by the structure. As both reflection energy and absorption loss are important to obtain transmitted energy, we divide this section into three sub-sections such that first sub-section discusses reflected energy, second sub-section analyses absorption loss and then transmitted energy is given in third subsection.

### 3.1. Reflected energy

We use dispersion diagram to compute the energy reflected from honeycomb photonic crystal structure. Dispersion diagram is a graph between normalized frequency ($a/\lambda$) with wave vector ($k$), which gives an idea about the photonic band gap or reflected energy from same structure. So before going to compute reflected energy, we focus on dispersion diagram of 2D photonic honeycomb structure containing human blood sample with different percentage of hemoglobin. The dispersion relation (relation between normalized frequency and wave vector) depends on structure parameters such diameter of holes, lattice spacing, refractive indices of both background and blood sample including the configuration of the structure.

In this case, we consider honeycomb structure whose lattice spacing is 1 μm and diameter of air holes is 420 nm. Using the above parameters and employing plane wave expansion method, simulation is made to obtain the dispersion graph of 2D honeycomb photonic crystal structure. Though, we have made simulation