Realization of novel corona virus kit using silicon based 2D photonic structure via finite difference time domain method

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Abstract

The present research proposes the novel corona virus kit using silicon based two (2D) photonic structure. The basic principle of the estimation of different corona viruses relies on the computation of reflectance, absorbance, and transmittance at the signal of 412 nm. Here reflectance is investigated through the analysis of photonic band gap where absorbance is calculated using analytical treatment. The present investigation is made for different corona virus such as N5H1, N5H2, H9N2, H4N6, FAdV, and IBV. The numerical analysis indicates that the sample could be affected by novel corona virus if the transmitted signal lies with red spectrum. Similarly, sample could be normal viruses if the transmitted signal would green spectrum

1 Introduction

Severe acute respiratory syndrome corona virus 2 (SARS COV-2) causes the pandemic of corona virus diseases 2019 (COVID-2019). The outbreak of such viruses was identified in Wuhan City of China on December 2019. The World Health Organization declared outbreak a public health on 30 January 2020 and subsequently they declared as pandemic on 11 March 2020. Since then a black cloud wrapping over the world and creating havoc situation on the earth. As far as current situation pertaining to the COVID-19 is concerned; a million and million number of people has been affected and it seems to be out of control as no medicine or vaccine has not been entered to the market. The corona viruses are not new pertaining to the medical science but the present virus is quite different from other corona viruses. Primarily the present virus spread

between to human during their close contact via droplets which is produced by taking, coughing and sneezing etc. Aside this, there is a chance of infected if anyone would come to the contaminated surface where droplets falls on it. Normally these viruses remain alive in the contaminated surface over 1–24 h. The common symptoms are fever, cough, shortness of breath, and loss of smell. Further it leads to the chance of pneumonia and acute respiratory distress syndrome (Cui et al. 2019; Forni et al. 2017). The time for exposure of such diseases is normally 2–5 days. However, sometimes it is up to 14 days. Recently (a week before) it is also found the time of exposure is extended up to 21 days. Even though no medicine has been invented till now, the basic treatment is based on symptomatic and supportive therapy. Apart from this, some preventive measures (frequently hand washing, covering mouth when coughing and sneezing, maintaining distance from other people, wearing a face mask in public places, self isolation of suspected people, avoid excess travel etc.) have been recommended to keep away the such diseases. However all common colds are not belonging to the novel corona viruses. As far as different corona viruses are concerned; mainly N5H1, N5H2, H9N2, H4N6, FAdV, and IBV are important (Ahmed et al. 2018). Off these, infectious bronchitis viruses (IBV) have different characteristics with respect to the others. Moreover, the properties of the IBV are similar to the present novel corona viruses (Crossley et al. 2012; Editorial Commentary; One Health 2020). So SARS COV-2 or novel corona virus or COVID-19 is

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belonged to the family of IBV. So all common colds are not SARS COV 2 but it may be belonging to the ordinary viruses. So diagnosed plays a vital role for the same (ScienceDaily 2020; Ai et al. 2020; Coronavirus Disease (COVID-19) Technical Guidance 2020; Vogel 2020; McNamara 2020). Basically there are two type of testing such as “reverse transcriptions polymerase chain reaction (rRT-PCR) (ScienceDaily 2020) or CT imaging of chest” (Ai et al. 2020) are being conducted now days. Tough these tests are available but it has a limitation pertaining to delay for generating the result. Keeping the importance of the same, the present research proposes a method to identify the novel corona viruses through 2D photonic crystal and zirconium quantum dots solution.

2 Proposed structure and operational mechanism

In this research, proposed structure deals with the silicon based square type two dimensional photonic crystals where 5×5 air holes are etched on the substrate material through which one can investigate the corona viruses, which is indicated in the Fig. 1a.

Figure 1a represents a two dimensional photonic structure where silicon acts as substrate material. Further the number of air holes of 25 is considered where different solutions of the viruses would be infiltrated. In this case, the solution contains zirconium quantum dots with the targeted viruses which are found in the literature (Ahmed et al. 2018). Though the present structure is not new pertaining to the current research scenario (Sethi et al. 2018; Palai 2017; Swain and Palai 2016; Palai et al. 2014; Palai and Tripathy 2012), the intrinsic parameters (configuration,

number of air holes, lattice period of the structure, and radius of air holes) are different from other research. Aside this, its operational mechanism is quite different from previous work. The same operational mechanism is indicated in the Fig. 1b.

Figure 1b represents the working mechanism to distinguish the novel corona (IBV) viruses from ordinary corona viruses (N5H1, N5H2, H9N2, H4N6, FAdV). From the Fig. 1b, it is observed that a wavelength of 412 nm emanates from the source and incidents to the photonic structure, which contains the corona virus solution. Then there will be an interaction between photon particles with silicon material along with infiltrated solution. This interaction leads to the different losses in the structures where reflection and absorption plays a key role to investigate the nature of the viruses. After suffering these losses, the transmitted light collected at the output end and measured at the photometer. After measuring the output result at the photometer, the interesting result is divulged. For example; the sample could be affected by corona viruses, if transmitted signal is red colour. Similarly the sample has ordinary virus if the transmitted signal would be green signal.

3 Mathematical formulation

From the Sect. 2, it is understood that the transmitted signal determines the status of the corona virus whether it is affected by the SARS COV-2 or ordinary viruses. The same transmitted signal is function of both absorption and reflected efficiency. The reflected efficiency (reflectance) is computed through the analysis of photonic band gap of photonic structure, which is done by FDTD technique

Fig. 1 **a** Schematic diagram of silicon based 2D structure. **b** Operational mechanism of investigation of investigation of corona virus

(Pendry 1996). Similarly absorption efficiency (absorbance) is obtained through analytical treatment.

As far as photonic band gap of two dimensional photonic structure is concerned, it deal with the Maxwell's differential equation, which can be written as:

$$\begin{aligned}\mu_0 \frac{\partial H_x}{\partial t} &= \frac{\partial E_y}{\partial z}, \mu_0 \frac{\partial H_z}{\partial t} = \frac{\partial E_y}{\partial x} \\ \varepsilon \frac{\partial E_y}{\partial t} + \sigma E_y &= \frac{\partial H_x}{\partial z} - \frac{\partial H_z}{\partial x}.\end{aligned}\quad (1)$$

Equation (1) is TE mode of propagation can be expressed as:

Similar equation used for TM mode 2D simulation

$$\begin{aligned}\mu_0 \frac{\partial H_y}{\partial t} &= \frac{\partial E_z}{\partial x} - \frac{\partial E_x}{\partial z} \\ \varepsilon \frac{\partial E_x}{\partial t} + \sigma E_x &= -\frac{\partial H_y}{\partial z} \\ \mu_0 \frac{\partial E_z}{\partial t} + \sigma E_z &= -\frac{\partial H_y}{\partial x}.\end{aligned}\quad (2)$$

Further considering the physics of the, when an electromagnetic structure is brought for theoretical analysis, the role of symmetric is quite vital. As most of the PBG structure of our interest are of periodic, this theorem is useful to study about few section which are as follows:

1. Periodic boundary condition
2. Brillouin zone
3. Translational symmetry
4. Dispersion diagram.

Mostly Bloch consider a periodic structure and develop the related the study on that. According to him, the wave can traverse in structure without scattering and it can be modelled as:

$$\varepsilon(\vec{r}) = \varepsilon(\vec{r} + S_1 \vec{a}_1 + S_2 \vec{a}_2 + \dots), \quad (3)$$

where $S_i = 0 \pm 1 \pm 2 \pm 3 \dots$

si = Periodic lattice.

Moreover Bloch's theorem tells us that for periodic structure, field components have the following properties:

$$\vec{\varphi}(\vec{r} + \vec{R}, t) = \vec{\varphi}(\vec{r}, t) e^{j \vec{k} \cdot \vec{R}}. \quad (4)$$

Here R is the 'lattice vector', k is the wave vector.

Using the expression (1–4), the PBG (photonic band gap) of 2D structure can be derived with the help of finite difference time domain (FDTD) method. More over the amount of reflected energy can be determined from it.

The reason for choosing such FDTD method in the present work is that has certain advantages pertaining to the sensing application, such as:

- (a) Finite difference time domain method is a versatile technique used to solve Maxwell's equations.

- (b) It is flexible to the uses because it is easily understand to use know what to expect from a given model.
- (c) Since FDTD computes the E and H fields everywhere in the computational region with the evolve of time, the generation of photonic band gap and electromagnetic wave propagation is indicated correctly.
- (d) This technique allows the user to specify the material at all points within the computational region.
- (e) It is also applicable for both linear and nonlinear material.

Since FDTD method calculates E and H fields at each and every point in the specified domain (c) and it is suitable for nonlinear material (e), this technique is suitable for sensing application.

Further the reflectance can be written as

$$R = \frac{E_R(\text{Amount of energy reflected})}{E_I(\text{Amount of energy incident})}. \quad (5)$$

Again the absorbance of the structure can be written as (Vijaya and Rangarajan 2003)

$$A = e^{-(AC_{Si}t_{Si} + AC_{co}t_{co})} \quad (6)$$

(AC is called absorption coefficient, 'si' is silicon and 'co' is column material (virus solution), 't' is the thickness). The absorption coefficient of the silicon can be written as (Vijaya and Rangarajan 2003)

$$AC_{Si} = \frac{4\pi n_{img}}{\lambda_i}, \quad (7)$$

where n_{img} and λ_i be an imaginary part of refractive index and incident wavelength respectively. Similarly the absorption coefficient of virus solution can be written as (Tomar 1447)

$$AC_{Si} = \frac{1}{t_2} \log_e(PL) \quad ('PL' \text{ Photo Luminous}). \quad (8)$$

So the transmittance of the signal can be expressed as

$$T = (1 - R \times A), \quad (9)$$

where " $R \times A$ " be the loss efficiency which are associated with the structure. Finally, the transmitted energy can be expressed as

$$E_T = TE_I. \quad (10)$$

The Eq. (9) can be expressed in terms of transmitted wavelength as

$$\lambda_T = \frac{\lambda_I}{T}. \quad (11)$$

So transmitted wavelength can be determined by knowing transmittance and incident signal.

Fig. 2 **a** Photonic band of 2D square crystals for corona virus N5H1, **b** photonic band of 2D square crystals for corona virus N5H2, **c** photonic band of 2D square crystals for corona virus H9N2,

d photonic band of 2D square crystals for corona virus H4N6, **e** photonic band of 2D square crystals for corona virus FAdV, **f** photonic band of 2D square crystals for corona virus IBV

4 Results and discussion

It is realized that the transmitted signal is a function of transmittance and incident signal. Further the transmittance relies on both absorbance and reflectance (Eq. 9). The reflectance is computed using Eqs. (1–5) where absorbance is computed through the Eqs. (6–8):

A. Reflectance

Basically the reflectance depends on the forbidden gap (PBG) of the chosen structure (Fig. 1a) pertaining to the N5H1, N5H2, H9N2, H4N6, FAdV, and IBV. Again the photonic band relies on the intrinsic structure parameters such real part indices of the background and column material, radius of holes and lattice

Fig. 3 Variation of transmitted signal with different corona viruses

constant of the structure at the wavelength, 412 nm. The refractive indices of substrate and column material are obtained from the references (Ahmed et al. 2018; Vijaya and Rangarajan 2003) respectively. Putting the aforementioned values in the solution of the Eqs. (1–4), which is made through FDTD technique and photonic band gap of the structure is shown in the Fig. 2a–f corresponding to the viruses N5H1, N5H2, H9N2, H4N6, FAdV, and IBV respectively.

Figure 2 represents the photonic band diagram for all viruses at the signal of 412 nm. Here the normalised frequency ($\omega a/2\pi c$) and wave vector (k) is chosen along perpendicular and parallel axis respectively. In this figure different allowed and disallowed bands are shown in each figure where the disallowed band is signified through red colour, which is represented as the reflected energy. As far as computation is concerned; the wavelength corresponding to the upper and lower band can be calculated by knowing the values of normalised frequency at these bands. Further the band gap corresponding to these bands are computed $[E_R = \frac{hc}{a}(\frac{a}{\lambda})]$ and subsequently the reflectance can be found using Eq. (5).

B. Absorbance

Primarily the absorbance relies on the absorption coefficient of background (silicon) and column material (virus solution). Again the absorption coefficient of the silicon depends on its imaginary part of the refractive indices (Vijaya and Rangarajan 2003) where the refractive indices of the column material depends on the photoluminescence of the different viruses (Ahmed et al. 2018). Finally, putting these values in the Eqs. (7) and (8) and subsequently in the Eq. (6), the absorbance corresponding to each viruses can be computed.

C. Transmittance

The absorbance and reflectance are represented as loss factor pertaining to the photonic structure at the signal of 412 nm. The resultant loss factor or loss efficiency is the product of reflectance and absorbance. The

transmittance corresponding to each viruses can be help of Eq. (9), where absorbance and reflectance are manipulated with Eqs. (6, 5) respectively. Further the transmitted energy can be computed with the help of Eq. (10). Finally the wavelengths of transmitted signal can be computed with respect to each viruses, using Eq. (11). The same result is indicated in the Fig. 3.

Figure 3 shows the different transmitted wavelengths in nanometer (vertical axis) corresponding to each viruses (horizontal axis). After analyzing the Fig. 3, it is found that the transmitted signal lies on two visible spectrums. For examples, the wavelength 526 nm, 517 nm, 514 nm, 502 nm, 501 nm corresponding to the viruses N5H1, N5H2, H9N2, H4N6, and FAdV respectively where the wavelength 707 nm is found corresponding to IBV (SARS COV-2). So it is inferred that the sample could be affected by novel corona viruses if the transmitted signal would red. Similarly the sample shall have ordinary virus if the transmitted signal lies within green spectrum.

5 Conclusion

In this paper, investigations of different corona viruses have been studied thorough photonic structures at the signal of 412 nm. The mechanism of such investigation is realised through the analysis of reflectance, absorbance and transmittance, where reflected is computed through the analysis of photonic band gap through FDTD technique and absorbance is analyzed via the analytical treatment. Similarly, the numerical investigation indicates the transmittance is a function of both absorbance and reflectance. Finally the transmitted signal indicates that sample could be SARS CoV-2, if the transmitted signal would red spectrum. Similarly the sample will have ordinary virus if the transmitted signal would green spectrum.

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