IOP Publishing Physica Scripta
Phys. Scr. 95 (2020) 035504 (10pp) https://doi.org/10.1088/1402-4896/ab4c68

# Transmission investigation of one-dimensional Fibonacci-based quasi-periodic photonic crystals including nanocomposite material and plasma

**H A Elsayed[1] and M M Abadla[2,*]**

[1] Physics Department, Faculty of Science, Beni-Suef University, Egypt
[2] Physics Department, Faculty of Science, Al-Aqsa University, Palestinian Authority

E-mail: drhussien85sc@gmail.com and mm.abadla@alaqsa.edu.ps

Received 3 August 2019, revised 20 September 2019
Accepted for publication 9 October 2019
Published 3 February 2020

**Abstract**

In this communication, the transmittance characteristics of one dimensional quasi-periodic photonic crystals (PCs) is investigated. The proposed structure consists basically of plasma and nanocomposite layers arranged in accordance to the Fibonacci sequence. The effect of volume density of the plasma and the volume fraction of the nanocomposite material on the properties of the photonic band gaps are studied in detail. The effect of layers thicknesses and the sequence number are also taken into account. We believe that such structures can be potentially beneficial in many novel future applications such as multichannel and pass band filters and optical switches. Additionally, such PCs can be used to design tunable optical devises through controlling the plasma and nanoparticle densities.

Keywords: nanocomposite materials, plasma, photonic crystals, photonic band gaps, quasi-periodic crystals, fibonacci sequence

(Some figures may appear in colour only in the online journal)

## 1. Introduction

The exceptional characteristics of photonic crystals (PCs) have been receiving an increasing interest in physics and engineering [1–4]. These distinctive properties of PCs arise from the exhibition of the photonic band gaps (PBG) [5–7], a frequency region at which electromagnetic waves cease to propagate within the structure. Accordingly; variety of applications such as sensors, perfect reflectors, optical filters and logic switches have been established [8–10]. The structure of the PCs (including number of periods, thickness of layers and permittivity) has a great effect on the PBGs width [3, 11–13].

To enhance performance, scientists have been attempting to use different PCs constituent materials such as metals, superconductors, left handed materials, plasmas and nanoparticles [4, 12, 14–17]. Unluckily; metals, especially below the plasma frequency, are highly absorbents [18] and superconductors operate at special conditions and temperatures. Left handed materials are generally operating at GHz frequencies and those operating at optical frequencies are still a big challenge [19–21].

To reduce the absorption, researchers have recently used nanocomposite materials in which metal nanospheres are embedded into a dielectric material [12, 15, 22, 23]. PCs comprising nanocomposite materials have been reported to exhibit new PBGs in the plasma region of the material that are very sensitive to the polarization mode of the radiation [24, 25]. Moreover, the metallic nanocomposites are experimentally demonstrated for a great number of applications such as switches, optical filters, PC-integrated polarizers and harvesting of light [25–27]. Asad *et al* [26] fabricated a one dimensional PCs of metallic nanoparticles in a host material of polymer for the switching purposes. The novelty of using

∗ Author to whom any correspondence should be addressed.

 

nanocomposite materials rests on the possibility of limited values of absorption due to the limited concentration or volume fraction of the metallic nanoparticles. Such response could be of interest in many applications that depend on the high contrast and efficiency reliance to the appearance of Fano resonance near the plasmonic frequency [26].

Considerable efforts have been also directed to plasma photonic crystals (PPCs) because of the distinct beneficial applications such as manipulation of electromagnetic radiation and optical flip flops [4, 28–31]. Applications of PPCs like plasma stealth aircrafts, plasma lenses and plasma antennas [32–34] are now widely developing. When plasma is used in PCs, the time varying controllability and strong dispersion features are added [35]. According to these features together with the controllable electron density of plasma and response to magnetic fields [31, 36–39], these PCs can operate with electromagnetic waves ranging from microwaves to THz waves. In spite of showing immunity to electromagnetic waves propagating within plasma dispersive media below its plasma frequency, researches have ascertained that when combined with dielectrics in PPCs, the electromagnetic waves could be guided [4, 30]. Tunable properties of dielectric PPCs have been also reported [31, 40].

In recent times, a rapid growing interest has been given to quasi-periodic PCs due to their amusing properties over the conventional PCs [13, 23, 41, 42]. One of the most important technological features in simulating one dimensional photonic quasi-periodic crystals is that they are much closer to reality than ordered periodic PCs [41]. Another attractive property is that the PBGs in quasi-periodic PCs could be designed to enlarge band gaps width of light in any frequency range. It has been also shown that such band gaps are insensitive to changes in both polarization of electromagnetic waves and angle of incidence [43, 44]. Possibility of having multiple forbidden gaps within the spectrum is potentially leading to important applications [41, 44].

The term quasi-periodic crystals or quasi-periodic are defined as intermediate systems between totally periodic crystals and amorphous solids [45–47]. They can be also accounted for as structures incorporating non periodic refractive index artificially modulated materials [31].

Among the one dimensional quasi-periodic PC types, Fibonacci quasi-periodic crystals has been exposed to wide experimental and theoretical studies after they have been first introduced in the middle of the 1980s [13, 41, 42]. The forbidden frequency regions called pseudo band gaps within the transmission spectrum is analogous to the electronic band gaps in semiconductors. The earlier quasi-periodic PCs were based on conventional materials such as dielectrics, metals and superconductors [5, 42]. Most recently; nanocomposite materials have been given a considerable interest because of their superior properties in designing and fabrication of PCs [12, 15, 23]. Theoretical studies of the transmission properties of a Fibonacci based quasi-periodic PCs having nanocomposite materials assured that such structures exhibit multiple PBG.

In this study, however, we investigate in details the transmission characteristics of one dimensional quasi-periodic PCs including both nanocomposite materials and plasmas arranged due to Fibonacci sequence. The nanocomposite material is made of Ag metal nanospheres randomly immersed in a dielectric host material ($SiO_2$). The plasma frequency is chosen to be in peta hertz region (UV frequency band). The effect of various parameters on the proposed structure is numerically investigated through the transfer matrix method. The effect of layer thicknesses and the plasma density on the properties of the proposed structure are studied. The volume fraction of the nanocomposite material and the sequence number of Fibonacci quasi-periodicity is also investigated.

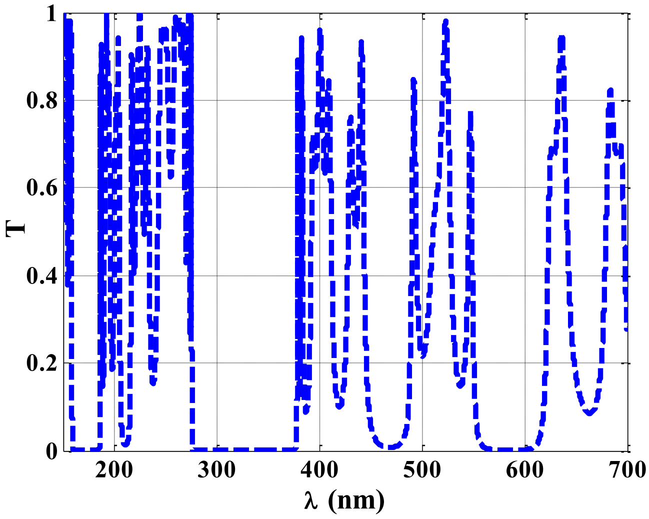


**Figure 1.** The transmittance spectrum versus the wavelength of the incident electromagnetic waves.

Our paper is organized according to the following pattern. The theoretical framework is discussed in section 2. In section 3, we present our numerical results. Finally, section 4 recapitulates the summary and conclusions.

## 2. Theoretical formulation

The PC structure under consideration consists of sequences of periods of two layers each comprising a plasma medium of thickness $d_A$ and refractive index $n_A$ adjacent to a nanocomposite material of thickness $d_B$ and refractive index $n_B$. Quasi-periodicity of the proposed structure is based on Fibonacci sequence [13, 39, 40] in which the $(j+1)$th layer is expressed as $S_{j+1} = \{S_j,\ S_{j-1}\}$; $j \geqslant 1$ such that $S_0 = \{B\}$, $S_1 = \{A\}$, where $A$ and $B$ represent the plasma and nanocomposite media; respectively. The number of layers is simply $N_{j+1} = N_j + N_{j-1}$.

The plasma layer permittivity depends on frequency according to the relation [30, 33, 35]:

$$n_A^2 = \varepsilon_A = 1 - \frac{\omega_A^2}{\omega^2 - i\omega\gamma_A}, \tag{1}$$

where, $\gamma_A$ is the loss factor, $\omega_A$ is the plasma frequency given

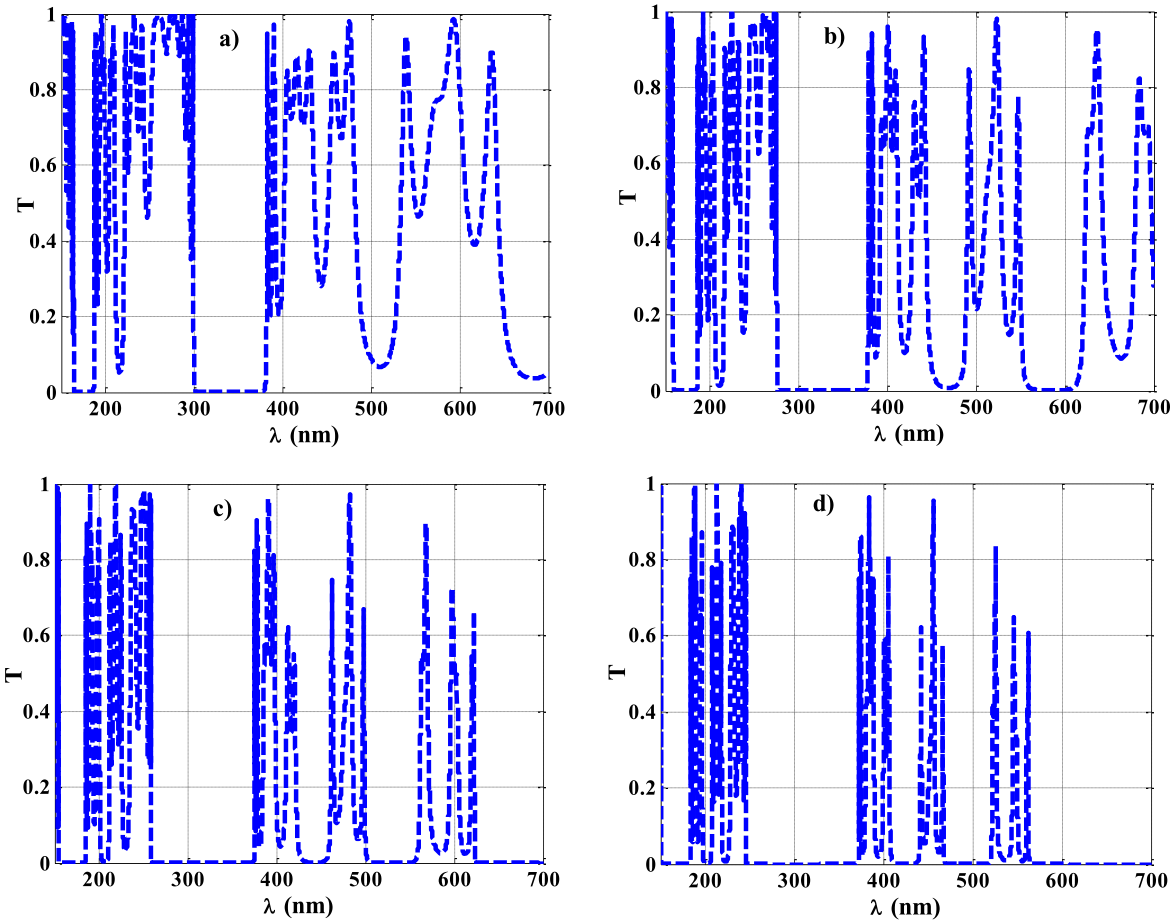


**Figure 2.** The effect of the volume density of plasma layer on the transmittance properties of the one dimensional quasi-periodic PCs at constant thicknesses of the nanocomposite and plasma layers: (a) $n = 1 \times 10^{28}\ \mathrm{m}^{-3}$, (b) $n = 2 \times 10^{28}\ \mathrm{m}^{-3}$, (c) $n = 3 \times 10^{28}\ \mathrm{m}^{-3}$ and (d) $n = 4 \times 10^{28}\ \mathrm{m}^{-3}$.

by:

$$\omega_A = \sqrt{\frac{ne^2}{m\varepsilon_0}}. \tag{2}$$

Here, $n$ is the volume density of electrons, $e$ electronic charge and $m$ is the electronic mass. All media are considered non-magnetic so that the relative permeability is unity for all layers. The other layer is the nanocomposite material of permittivity given by the Maxwell–Garnett formula [48, 49] as:

$$n_B^2 = \varepsilon_{\mathrm{eff}} = \varepsilon_{\mathrm{d}} \frac{\varepsilon_{\mathrm{m}} + 2\varepsilon_{\mathrm{d}} + 2\mathrm{f}(\varepsilon_{\mathrm{m}} - \varepsilon_{\mathrm{d}})}{\varepsilon_{\mathrm{m}} + 2\varepsilon_{\mathrm{d}} - \mathrm{f}(\varepsilon_{\mathrm{m}} - \varepsilon_{\mathrm{d}})} \tag{3}$$

such that: $\varepsilon_{\mathrm{d}}$ is the permittivity of the dielectric host material, $\varepsilon_{\mathrm{m}}$ is the permittivity of the metal nanoparticles and $f$ is the volume fraction of nanoparticles. Permittivity of the metal nanoparticles is given from Drude model as:

$$\varepsilon_m = \varepsilon_0 - \frac{\omega_B^2}{\omega^2 + \mathrm{i}\omega\gamma_B} \tag{4}$$

$\varepsilon_0$ being the relative permittivity of metal, $\omega_B$ the plasma frequency and $\gamma_B$ the frequency damping factor given by:

$$\gamma_B = \gamma_0 + q\frac{v_F}{a}, \tag{5}$$

where, $\gamma_0$ is the decay constant, $q = 1$ is the electron surface scattering from the nanoparticles, $a$ is the radius of the nanoparticles and $v_{\mathrm{F}}$ is the velocity of electrons at Fermi energy.

The laminar structure of the PC layers is directed along the $z$-axis so that the tangential electromagnetic components of the planer waves entering the crystal are confined to the $x$–$y$ plane. At any interface within the $j$th medium, the transverse electric field (with $e^{\mathrm{i}(\beta z - \omega t)}$ dependence) is given as:

$$F_j = A_j e^{-\mathrm{i}k_j x} + B_j e^{\mathrm{i}k_j x}, \tag{6}$$

where, $F_j$ denotes the field normal to the plane of incidence ( i.e. electric field in TE waves or magnetic field in TM ones), $k_j = \sqrt{k_o^2 n_j^2 - \beta^2} = k_o n_j \cos\theta_j$ is the wave number and $\beta = k_o n_j \sin\theta_j$ is the propagation constant along the $z$-axis and $\theta_j$ is the angle of incidence measured with respect to $x$-axis. The amplitudes $A_j$'s and $B_j$'s can be calculated through the boundary conditions. The other $z$-component of the electromagnetic field can be calculated to be:

$$G_j = \alpha_j [A_j e^{-\mathrm{i}\ k_j x} - B_j e^{\mathrm{i}\ k_j x}] \tag{7}$$

such that: $\alpha_j = \frac{-k_j}{\omega(-\varepsilon_j)^\rho}$; $\rho = \begin{cases} 0; & \mathrm{TE} \\ 1; & \mathrm{TM} \end{cases}$ provided $\mu_j = 1$ in all layers. Matching fields at the surrounding interfaces and

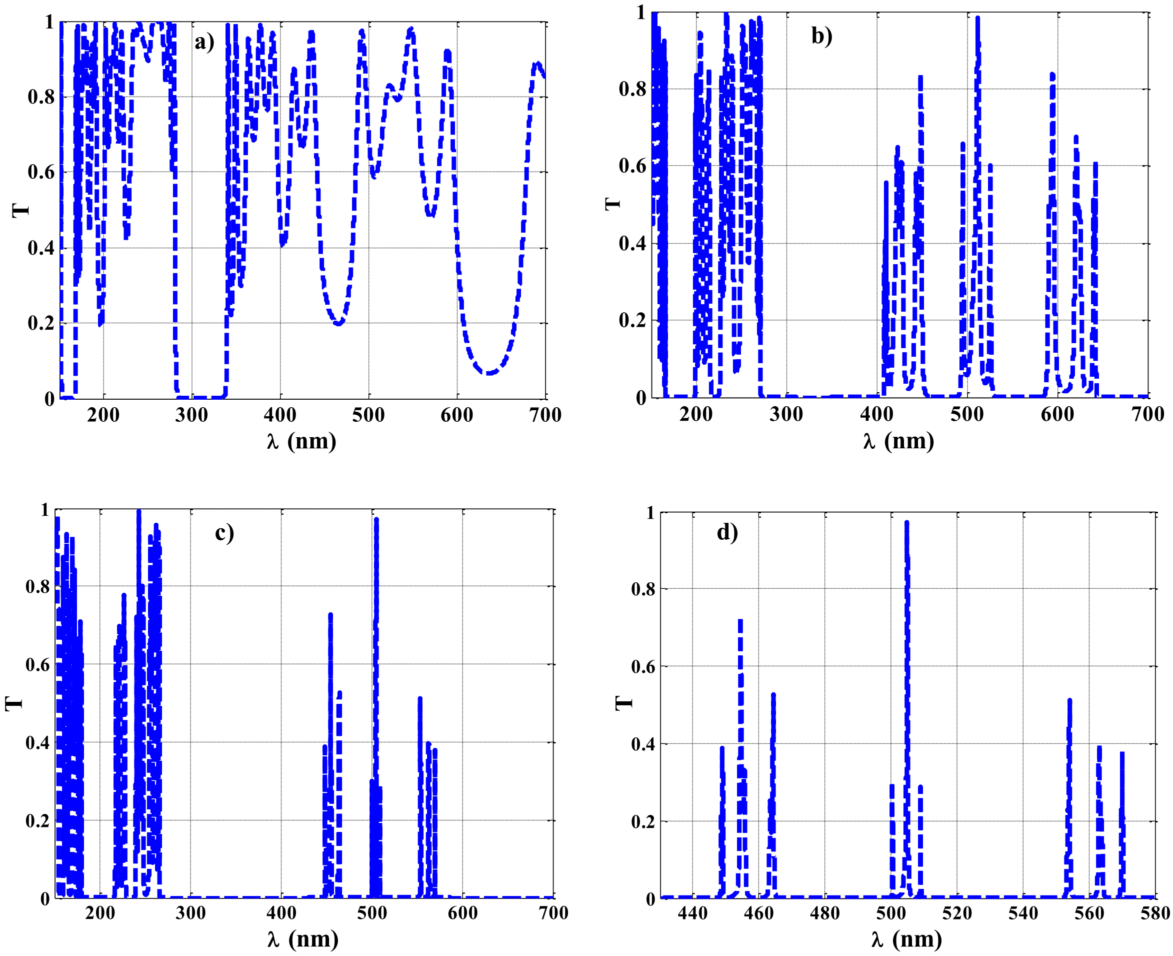

**Figure 3.** Variations of the transmittance properties of the one dimensional quasi-periodic PCs with the thickness of the plasma layer: (a) $d_A = 10$ nm, (b) $d_A = 30$ nm, (c) $d_A = 50$ nm, and (d) a detailed description of the resonant modes at $d_A = 50$ nm.

carrying out some mathematical arrangements, the transfer matrix [50, 51] relating the fields across one layer can be given as:

$$\mathbf{M}_l = \begin{pmatrix} \cos\delta_l & \dfrac{\mathrm{i}}{\alpha_l}\sin\delta_l \\ \mathrm{i}\alpha_l \sin\delta_l & \cos\delta_l \end{pmatrix}; \quad l = A, B, \tag{8}$$

where, $\delta_l = k_l d_l \cos\theta_l$, $\theta_l = \cos^{-1}\sqrt{1 - \frac{n_o^2 \sin^2\theta_o}{n_l^2}}$.

Now, the transfer matrix of the $(j+1)$th sequence of a Fibonacci structure is:

$$\mathbf{M}_{j+1} = \mathbf{M}_j \mathbf{M}_{j-1} = \begin{pmatrix} M_{11} & M_{12} \\ M_{21} & M_{22} \end{pmatrix}; \quad j \geqslant 1$$

such that: $\mathbf{M}_0 = \mathbf{M}_B$ and $\mathbf{M}_1 = \mathbf{M}_A$.

Having evaluated the matrix, the transmission coefficient is written as:

$$t = \frac{2\alpha_o}{(M_{11} + M_{12}\alpha_s)\alpha_o + (M_{21} + M_{22}\alpha_s)}. \tag{9}$$

Accordingly; the transmittance of the whole structure is then:

$$T = \frac{\alpha_s}{\alpha_0}|t|^2. \tag{10}$$

## 3. Results ad discussions

In what follows, we present the numerical results that describe the transmittance characteristics of our structure in a broad band of the electromagnetic waves from UV to visible light. These results are mainly investigated in view of the theoretical formulation described in the previous section. Here, the one dimensional quasi-periodic PC is designed using Fibonacci sequence of the 9th order. The plasma layer (layer A) has a volume density $= 2 \times 10^{28}\,\mathrm{m}^{-3}$ and loss factor $= 6.283 \times 10^7$ Hz. The nanocomposite layer (layer B) is designed from nanoparticles of silver (Ag) arranged into a dielectric medium of $SiO_2$. The silver nanoparticles are specified with plasmon frequency $= 1.365 \times 10^{16}$ Hz, decay constant $= 3.035 \times 10^{13}$ Hz, relative permittivity $= 5$ [22], spherical radius $= 20$ nm and volume fraction $= 2 \times 10^{-5}$. Wherein, the values of the parameters for the metallic nanoparticles are chosen to be compatible with the theoretical and experimental previous works [22, 25–27]. Then, the host dielectric material is characterized with permittivity $= 2.13$. Thicknesses of layers A and B are chosen as 20 nm and 100 nm, respectively. We consider the case of normal incidence for the upcoming investigated results. The main purpose of our results is to demonstrate the effect of the

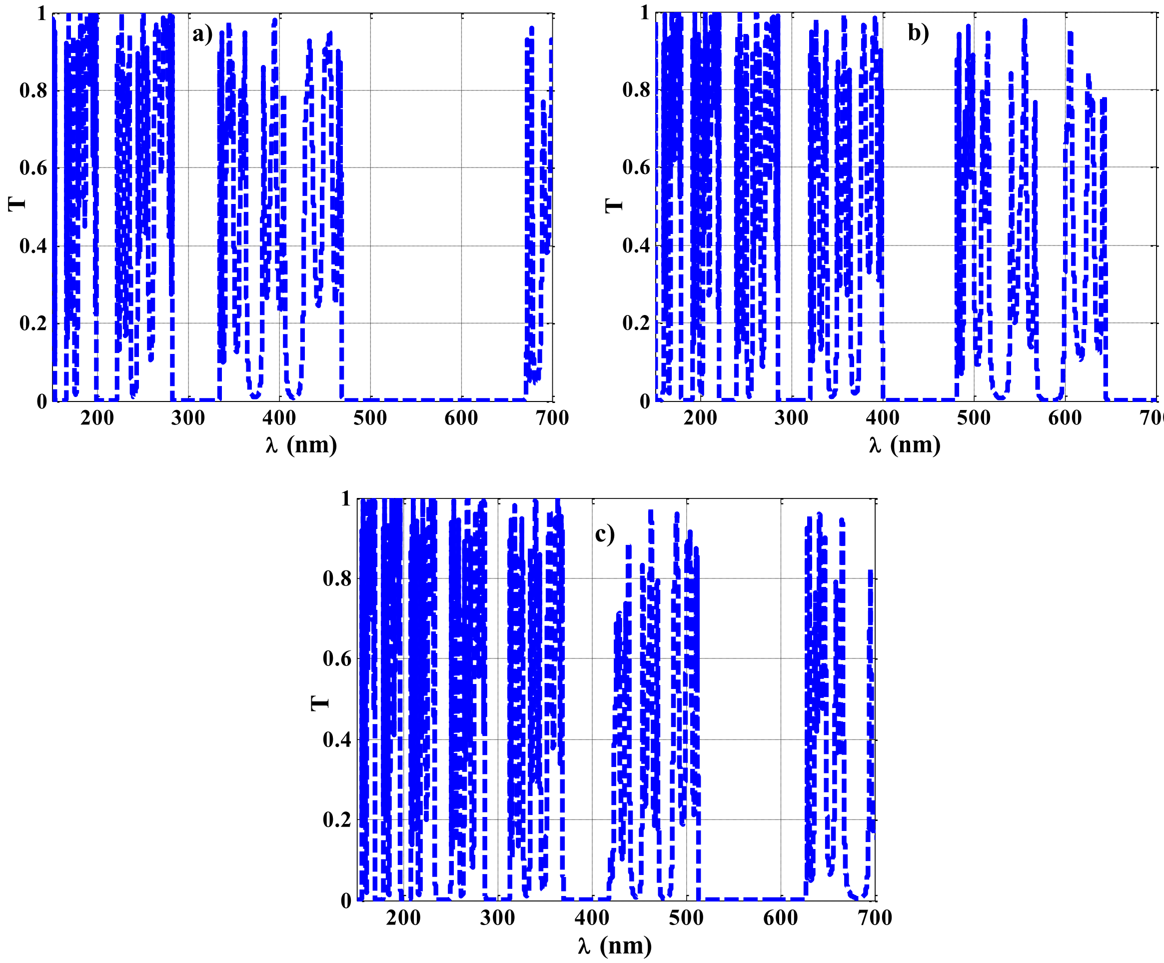


**Figure 4.** Transmittance properties dependence on the thickness of the nanocomposite layer for: (a) $d_B = 200$ nm, (b) $d_B = 300$ nm and (c) $d_B = 400$ nm.

characteristics of the plasma and nanocomposite layers on the transmittance characteristics of our structure. In addition, thicknesses of the constituents and the sequence number will be also taken into consideration.

Figure 1 shows the transmittance characteristics of our design through the different wavelengths of the incident electromagnetic waves. We observe the appearance of four PBGs along the wavelengths of interest. This number of the PBGs could be promising in many optical and physical applications especially through this region of the electromagnetic waves. The first PBG appears at UV wavelengths between 159 and 185.7 nm with width 26.7 nm. The second one is also formed within the UV limits with width 101.5 nm. This PBG is the largest one among the four PBGs. The third and fourth PBG appear through the visible light region with widths 32 nm and 58 nm, respectively. Here, the reason around the presence of this number of the PBGs is due to the nature of the quasi-periodic structure formulation. Wherein, the quasi-periodic PCs contain many different forms of periodicity compared with the binary or ternary PCs.

In figure 2, the role played of the electron volume density of the plasma layer on the transmittance response of the structure is carried out. The figure shows the significant effect of this parameter on the number, widths and positions of the produced PBGs. At $n = 1 \times 10^{28}\ \mathrm{m}^{-3}$, two PBGs are formed in the UV region as shown in figure 2(a). These two gaps have widths of 22.7 nm and 80.4 nm, respectively. As the value of the volume density increases to $2 \times 10^{28}\ \mathrm{m}^{-3}$, the number of the PBGs increases to four as shown in figure 2(b). Furthermore, the widths of the two PBGs in the UV region also increase to 26.7 and 101.5 nm with a little shift downwards the short wavelengths.

Upon increasing the volume density to $3 \times 10^{28}$ and $4 \times 10^{28}\ \mathrm{m}^{-3}$, as in figures 2(c) and (d) the widths of the PBGs begin to increase accompanied with larger shifting to the short wavelength region. In addition, the edges of the other two PBGs formed through the visible lights become sharper compared with the case studied in figure 2(b). Moreover, a new gap begins to appear at wavelengths greater than 600 nm. These changes in the characteristics of the PBGs are due to the strong dependence of the plasma frequency on the volume density. Such effect leads to a great variations on the values of the refractive index of the plasma layer and the contrast between the refractive indices of the nanocomposite material and plasma layers as well. Accordingly, the tunability of the PBGs could be verified based on the variation of the value of the volume density of electrons. This result demonstrates the significant importance of quasi-periodic PCs

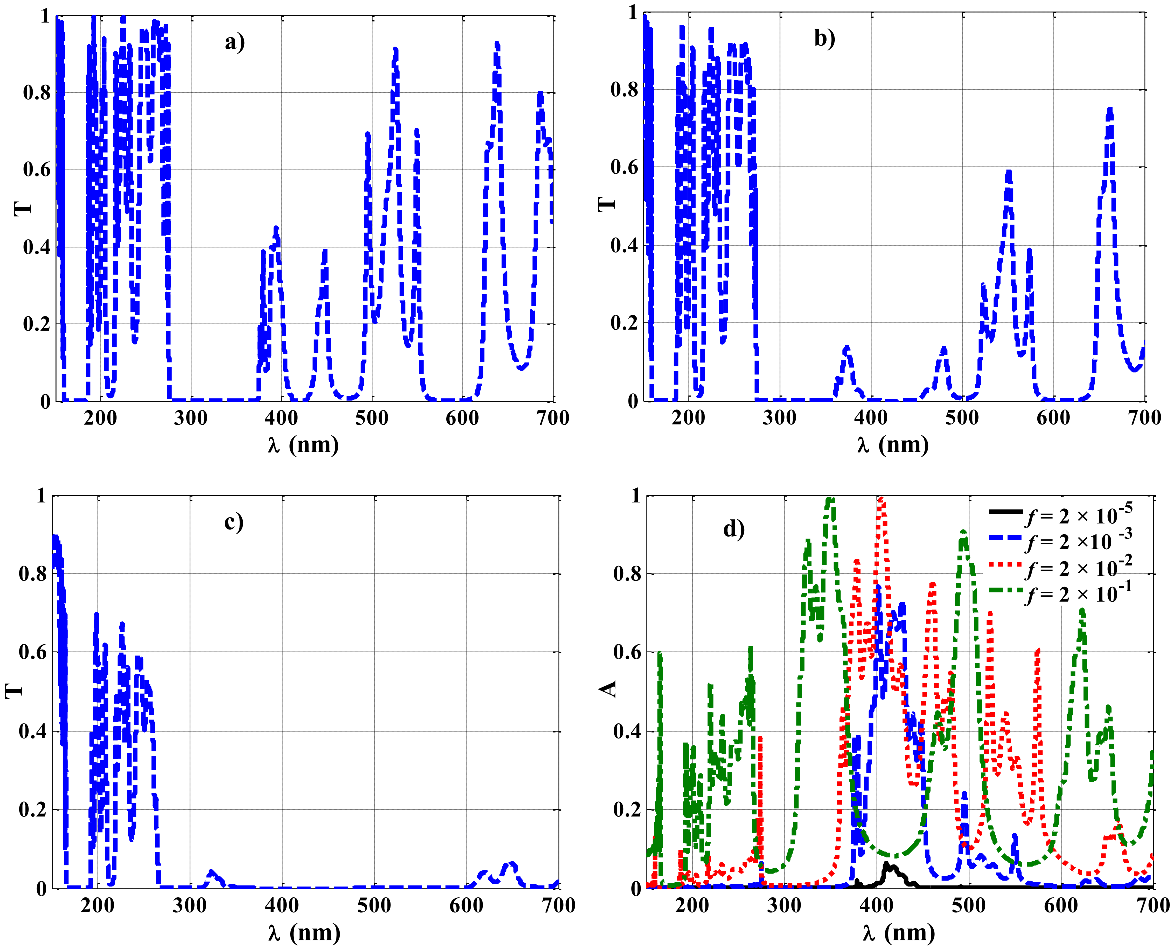


**Figure 5.** The transmittance dependence on the volume fraction of the metallic nanoparticles for: (a) $f = 2 \times 10^{-3}$, (b) $f = 2 \times 10^{-2}$ and (c) $f = 2 \times 10^{-1}$. (d) The variation of the absorption values of the volume fraction.

in the tunability of the PBGs over the previously investigated traditional PCs [4, 22, 52]. That is, both the number and the width of the PBGs could be remarkably controlled. In these works, the width of the PBGs instead of the number of the PBGs is affected despite the variation of similar parameters such as volume density of plasma and volume fraction of the nanocomposite material.

The behavior of transmittance of our PC according to changes in the plasma thickness is demonstrated in figure 3. The volume density of the plasma is set to be $2 \times 1028\ \mathrm{m}^{-3}$ and the thickness of the nanocomposite layer is 100 nm. As the thickness of plasma increases from 10 to 30 nm, the number of the PBGs increases as well as the widths of these gaps as shown in figures 3(a) and (b), respectively. Furthermore, these gaps are shifted downwards to the UV wavelengths. For further increase to 50 nm, the transmittance follows a different behavior, especially through the visible wavelengths as shown in figure 3(c). This change is included in the appearance of many resonant peaks with different intensities at wavelengths greater than 445 nm as clearly predicted from figure 3(d). This result could be of potential use in preparing a pass band optical filter for specified wavelengths in the visible light regime. This is a new advantage of quasi-periodic PCs over the totally periodic ones. Here, the appearance of the discontinuous electromagnetic waves within the transmittance spectrum could be considered to be a considerable advantage over the one dimensional defective PCs [7, 53]. These resonant modes appear without the insertion of a defect layer through the structure at different wavelengths with different intensities. Thus, our structure exhibits an additional valuable feature to the quasi-periodic PCs over the pure and defective PCs in producing the stop and pass bands together.

The effect of the nanocomposite layer thickness on transmittance is investigated in figure (4). Wherein, the thickness of the plasma layer is set to 20 nm. The thickness takes on the values: 200, 300 and 400 nm. As the thickness increases, the number of the PBGs also increases (relative to figure 1 above) especially in the UV region. Moreover, the width of the PBG formed in the visible light is significantly increased upon using 200 nm thick plasma as shown in figure 4(a). Therefore, the thickness of the nanocomposite layer may also investigate the tunability of the PBGs. At higher thicknesses however, multi PBGs evolve again.

To demonstrate the effect of other parameters on the transmittance behavior of our design, the plasma layer and the nanocomposite layer are fixed to 20 nm and 100 nm, respectively. The volume fraction of metallic nanoparticles,

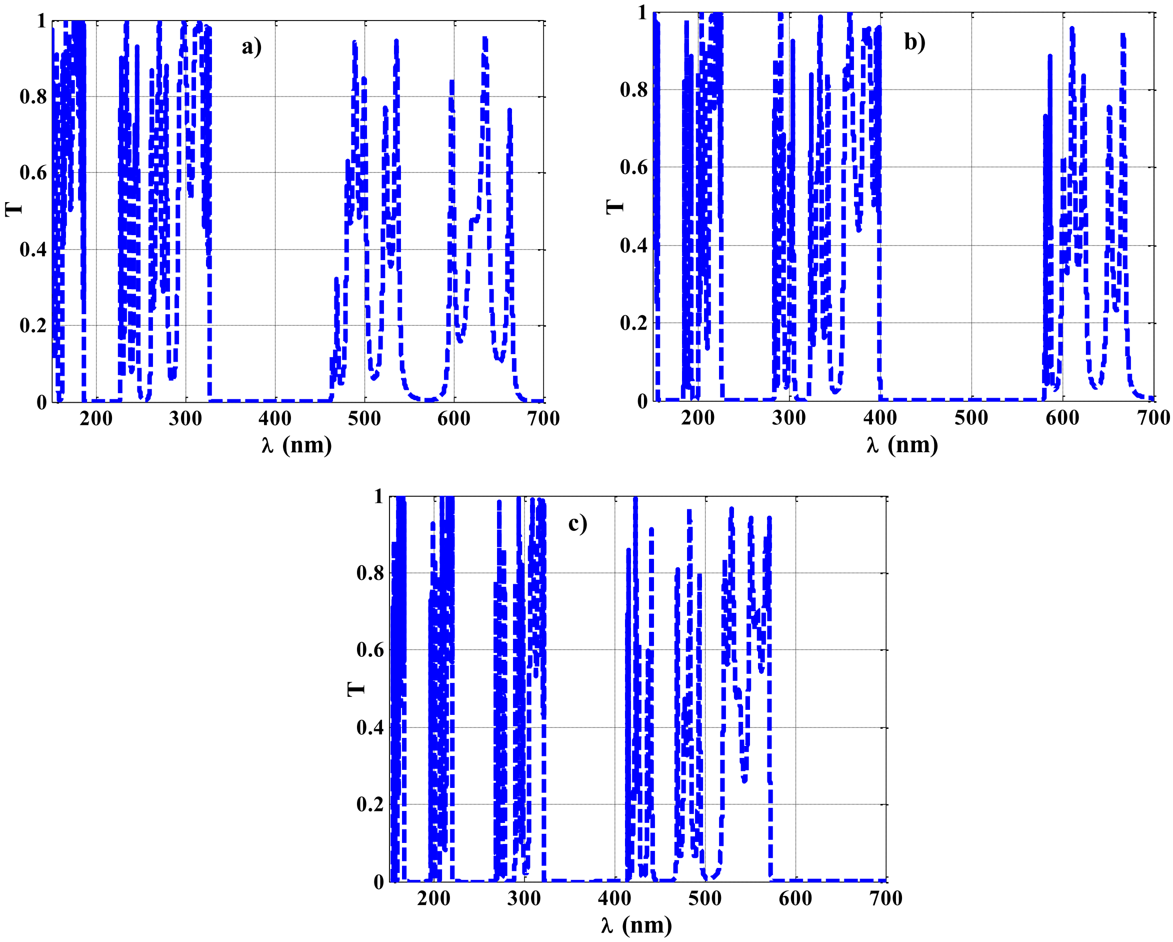


**Figure 6.** The variation of transmittance with the permittivity of the dielectric host material for: (a) $Y_2O_3$, (b) $TiO_2$ and (c) Si.

permittivity of the host material and the order of Fibonacci sequence are then set to investigation.

In figure 5, the effect of the volume fraction of the metallic nanoparticles on the transmittance is studied. Compared with the results investigated in figure 1, as the volume fraction increases from $2 \times 10^{-5}$ to $2 \times 10^{-3}$, the number, the positions and the widths of the PBGs are hardly unaffected as clearly shown in figures 5(a) and (b). The maximum attainable transmittance decreases dramatically with increasing the volume fraction of silver nanoparticles especially after 370 nm wavelength light. This is accounted for as a matter of increasing absorption due to the dense metallic particles especially at frequencies smaller than the plasma frequency of the metallic nanoparticles (relatively close to visible frequencies). This is clearly shown in figure 5(d). Thus, the low volume fraction is preferred in our design because of the limited absorption values at the wavelengths of interest for such value. Therefore, the investigated results in figure 5(d) completely agree with the experimental procedures [26] on controlling the absorption values through lowering the volume fraction of the metallic nanoparticles. Therefore, the controlling of the volume fraction values could present a good solution to avoid the high absorption values that could appear particularly in the visible and IR regions [52].

Figure 6 investigates the transmittance response of our structure to variation of the dielectric host permittivity. As the dielectric host material ($SiO_2$), shown in figure 1, is replaced with $Y_2O_3$, $TiO_2$ and Si, transmittance of our quasi-periodic PC is affected considerably as shown in figures 6(a)–(c), respectively. The PBGs are shifted towards the long wavelength regions with the appearance of new gaps within the UV regions. Moreover, the widths of these gaps increase with the increments of the permittivity of the host material.

Finally; in figure 7, the transmittance properties upon changing the Fibonacci sequence order (actually, the number of overall layers). In the case of the 7th order sequence, there are only two PBGs that appear in the UV region with absence of the gaps in the visible wavelengths as shown in figure 7(a). As the order of the sequence increases to 9th, 11th and 13th, new gaps within the visible region are obtained as shown in figures 7(b)–(d), respectively. Furthermore, the number of these gaps is significantly increased to reach six gaps in the case of the 11th order and ten gaps for the 13th order. That is; different forms of quasi-periodicity give rise to different numbers of PBGs obtained in the transmittance spectrum.

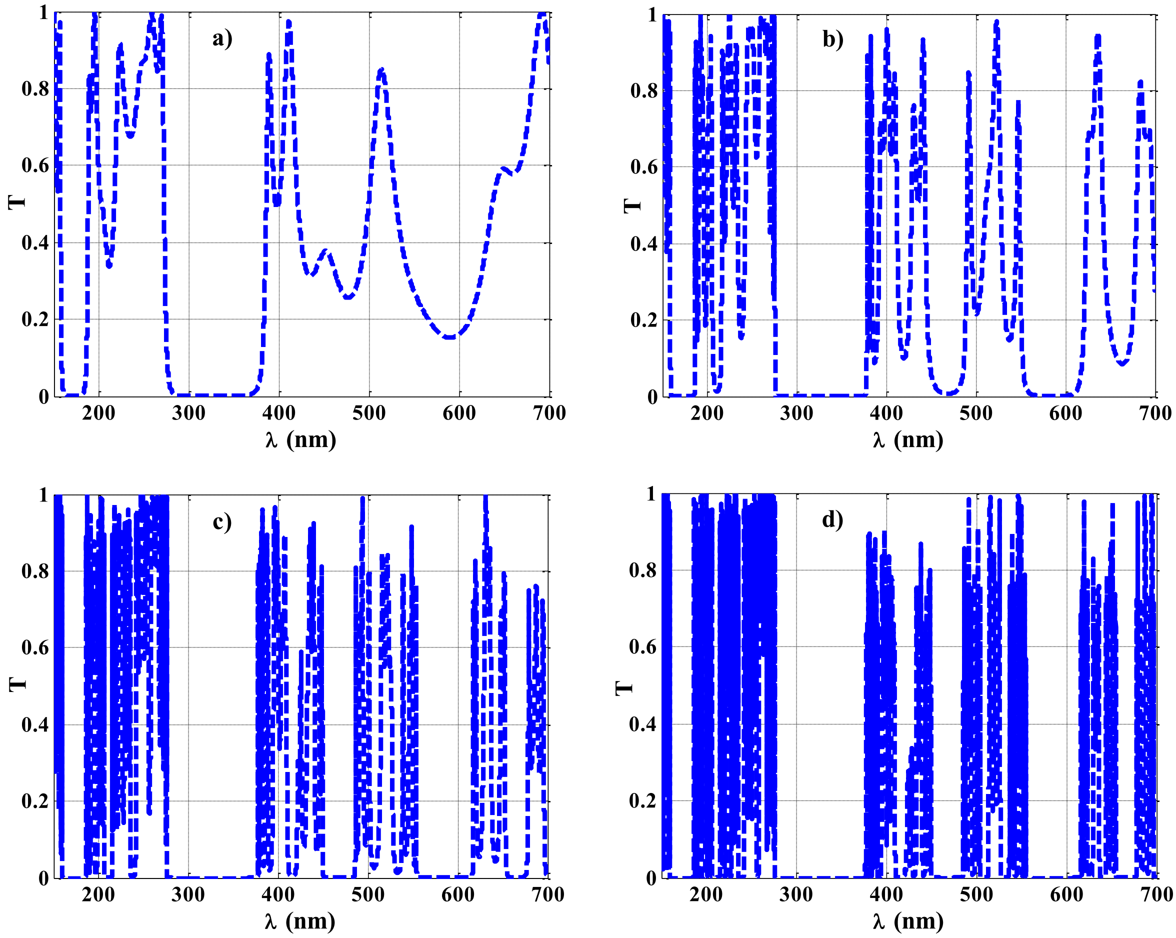


**Figure 7.** The dependence of transmittance on the sequence number for: (a) $M_7$, (b) $M_9$, (c) $M_{11}$ and (d) $M_{13}$.

## 4. Conclusion

We theoretically investigated the transmittance properties of one dimensional plasma nanocomposite quasi-periodic PCs through a broad band of electromagnetic waves from UV to visible light regions. The transfer matrix method is used to describe the theoretical framework and the investigation of the numerical results. The results show the appearance of more than four PBGs along the wavelengths of interest. Thicknesses of the constituent materials as well as the plasma density have a significant effect on the properties of the produced PBGs. The volume fraction of the nanocomposite material could be crucial in controlling absorption of the structure. Furthermore, the sequence number plays an important role in determining the number of PBGs appearing within the spectrum. Finally, our structure could be of potential use in controlling the propagation of the electromagnetic waves of wavelengths from UV to visible light regions besides the ability of using such design as a multichannel optical filter. In addition, plasma and nanoparticle densities could be used to construct a regime for controllable PC outputs.

## ORCID iDs

H A Elsayed https://orcid.org/0000-0001-7819-9476
M M Abadla https://orcid.org/0000-0001-5536-1477

## References

[1] Yablonovitch E 1993 Photonic band-gap structures *J. Opt. Soc. Am.* B **10** 283
[2] Aly A H, Sabra W and Elsayed H A 2017 Cutoff frequency in metamaterials photonic crystals within Terahertz frequencies *Int. J. Mod. Phys.* B **31** 1750123
[3] Johnson S G, Mekis A, Fan S and Joannopoulos J D 2001 Molding the flow of light *Comput. Sci. Eng.* **3** 38
[4] Abadla M M, Tabaza N A, Tabaza W, Ramanujam N R, Wilson K S, Vigneswaran D and Taya S A 2019 Properties of ternary photonic crystal consisting of dielectric/plasma/dielectric as a lattice period *Optik* **185** 784
[5] Wang F, Cheng Y, Wang X, Qi D, Luo H and Gong R 2018 Effective modulation of the photonic band gap based on Ge/ZnS one-dimensional photonic crystal at the infrared band *Opt. Mater.* **75** 373
[6] Elsayed H A, El-Naggar S A and Aly A H 2014 Thermal properties and two-dimensional photonic band gaps *J. Mod. Opt.* **61** 385
[7] Aly A H and Elsayed H A 2012 Defect mode properties in a one-dimensional photonic crystal *Physica* B **407** 120

[8] Zheng C, Tian H, Li C and Ji Y 2007 Tunable frequency and angular photonic crystal filter *Proc. SPIE* **6781** 678117
[9] Zyryanov V, Gunyakov V, Myslivets S, Arkhipkin V and Shabanov V 2008 Electro-optical switching in a one-dimensional photonic crystal *Mol. Cryst. Liq. Cryst.* **488** 1563
[10] Elsayed H, El-Naggar S and Aly A 2015 Two dimensional tunable photonic crystals and n doped semiconductor materials *Mater. Chem. Phys.* **160** 221
[11] Halevi P and Ramos-Mendieta F 2000 Tunable photonic crystals with semiconducting constituents *Phys. Rev. Lett.* **85** 1875
[12] Aly A, Elsayed H and Malek C 2017 Optical properties of one-dimensional defective photonic crystal containing nanocomposite material *J. Nonlin. Opti. Phys. Mater.* **26** 1750007
[13] Tavakoli M and Jalili Y S 2014 One-dimensional Fibonacci fractal photonic crystals and their optical characteristics *J. Theor. Appl. Phys.* **8** 113
[14] El-Amassi D M, Taya S A, Ramanujam N R, Vigneswaran D and Udaiyakumar R 2018 Extension of energy band gap in ternary photonic crystal using left-handed materials *Superlattices Microstruct.* **120** 353
[15] Elsayed H A and Aly A H 2018 Terahertz frequency superconductor-nanocomposite photonic band gap *Int. J. Mod. Phys.* B **32** 1850056
[16] Awasthi S K, Mishra A, Malaviya U and Ojha S P 2009 Wave propagation in a one-dimensional photonic crystal with metamaterial *Solid State Commun.* **149** 1379
[17] Lee H and Wu J 2010 Transmittance spectra in one-dimensional superconductor-dielectric photonic crystal *J. App. Phys.* **107** 09E149
[18] Smith D, Dalichaouch R, Kroll N, Schultz S, McCall S and Platzman P 1993 Photonic band structure and defects in one and two dimensions *J. Opt. Soc. Am.* B **10** 314
[19] Abadla M M and Taya S A 2011 Characteristics of left-handed multilayer slab waveguide structure, The Islamic *J. Nat. Stud. Eng.* **19** 57–70http://www.iugaza.edu.ps/ar/periodical/
[20] Taya S A, Farram E J and Abadla M M 2012 Symmetric multilayer slab waveguide structure with a negative index material: TM case *Optik* **123** 2264
[21] Abadla M M, Mousa H M and Shabat M M 2018 Nonlinear planar optical waveguide sensors comprising metamaterial guiding films at terahertz frequencies *Opt. Quant. Electron.* **50** 394
[22] Elsayed H A 2018 Transmittance properties of one dimensional ternary nanocomposite photonic crystals *Mater. Res. Express* **5** 036209
[23] Aly A H, Elsayed H A and Malek C 2018 Transmittance properties of a quasi-periodic one-dimensional photonic crystals that incorporate nanocomposite material *Int. J. Mod. Phys.* B **32** 1850220
[24] Labbani A, Saoudi R and Benghalia A 2009 Photonic band gaps in one- and two-dimensional photonic crystals based on a nanocomposite of ZnS and glass *J. Opt. A: Pure Appl. Opt.* **11** 085103
[25] Dadoenkova Y, Glukhov1 I, Moiseev S, Svetukhin V, Zhukov A and Zolotovskii I 2017 Optical generation in an amplifying photonic crystal with an embedded nanocomposite polarizer *Opt. Commun.* **389** 1
[26] Asadi R, Mohammad M M and Tavassoly M T 2011 Fabrication of metal nanocomposite photonic crystal for switching *IEEE Photon. Tech. Lett.* **23** 1436
[27] Xu M F, Zhu X Z, Shi X B, Liang J, Jin Y, Wang Z K and Liao L S 2014 Plasmon resonance enhanced optical absorption in inverted polymer/fullerene solar cells with metal nanoparticle-doped solutionprocessable $TiO_2$ layer *ACS Appl. Mater. Interfaces* **5** 2935
[28] Kiskinen M J and Fernsler R 2000 Photonic band gaps in dusty plasma crystals *Appl. Phys. Lett.* **77** 1925
[29] Hojo H and Mase A 2004 Dispersion relation of electromagnetic waves in one-dimensional plasma photonic crystals *J. Plasma Fusion Res.* **80** 89
[30] Shiveshwari L and Band S N 2011 Characteristics in one-dimensional plasma dielectric photonic crystals *Plasma Sci. Technol.* **13** 392
[31] Aly A H, Elsayed H A, Ameen A A and Mohamed S H 2017 Tunable properties of one-dimensional photonic crystals that incorporate a defect layer of a magnetized plasma *Int. J. Mod. Phys.* B **31** 1750239
[32] Vidmar R J 1990 On the use of atmospheric pressure plasmas as electromagnetic reflectors and absorbers *IEEE Trans. Plasma Sci.* **18** 733
[33] Goncharov A, Dobrovolsky A, Zatuagan A and Protsenko I 1993 High-current plasma lens *IEEE Trans. Plasma Sci.* **21** 573
[34] Dwyer T, Greig J, Murphy D, Perin J, Pechacek R and Raleigh M 1984 On the feasibility of using an atmospheric discharge plasma as RF antenna *IEEE Trans. Antenna Propag.* **32** 141
[35] Sakai O, Sakaguchi T and Tachibana K 2007 Plasma photonic crystals in two-dimensional arrays of microplasmas *Contrib. Plasma Phys.* **47** 96
[36] Hamidi S M 2012 Optical and magneto-optical properties of one-dimensional magnetized coupled resonator plasma photonic crystals *Phys. Plasmas* **19** 125031
[37] Aghajamali A, Zare A and Wu C J 2015 Analysis of defect mode in a one-dimensional symmetric double-negative photonic crystal containing magnetized cold plasma defect *Appl. Opt.* **54** 8602
[38] Qi L *et al* 2010 Properties of obliquely incident electromagnetic wave in one-dimensional magnetized plasma photonic crystals *Phys. Plasmas* **17** 25011
[39] Kee C S, Li S, Kim K and Lim H 2003 Tunable resonant transmission of electromagnetic waves through a magnetized plasma *Phys. Rev.* E **67** 366121
[40] Kong X, Liu S, Zhang H and Li1 C 2010 A novel tunable filter featuring defect mode of the TE wave from one-dimensional photonic crystals doped by magnetized plasma *Phys. Plasmas* **17** 103506
[41] Pandey J P 2017 F Q-periodic multilayers with internal symmetry *IOSR J. Appl. Phys., (IOSR-JAP)* **9** 59
[42] Lusk D, Abdulhalim L and Placido F 2001 Omnidirectional reflection from Fibonacci quasi-periodic one-dimensional photonic crystal *Opt. Commun.* **198** 273
[43] Zhang H F, Zhen J P and He W P 2013 Omnidirectional photonic band gaps enhanced by Fibonacci quasi-periodic one-dimensional ternary plasma photonic crystals *Optik* **124** 4182
[44] Zhang H F, Liu S, Kong X, Bian B and Dai Y 2012 Omnidirectional photonic band gaps enlarged by Fibonacci quasi-periodic one-dimensional ternary superconductor photonic crystals *Solid State Commun.* **152** 2113
[45] Levine D and Steinhardt P J 1986 Quasi-periodic *Phys. Rev.* B **34** 596
[46] Steinhardt P J and Ostlund S 1987 *The Physics of Quasi-Periodic* (Singapore: World Scientific)
[47] Janot C 1994 *Quasi-Periodic: A Primer* (Oxford: Clarendon)
[48] Skryabin I L, Radchik A V, Moses P and Smith G B 1997 The consistent application of Maxwell-Garnett effective medium theory to anisotropic composites *Appl. Phys. Lett.* **70** 2221
[49] Oraevskii A N and Protsenko I E 2001 Optical properties of heterogeneous media *Quan. Electr.* **31** 252
[50] Chuang S L 2009 *Physics of Photonic Devices* 2nd edn (New York: Wiley)
[51] Wang X, Yin C and Cao Z 2016 *Progress in Planar Optical Waveguides* (*Springer Tracts in Modern Phyics*) vol 266

(Berlin Heidelberg: Shanghai Jiao Tong University Press and Springer-Verlag)
[52] Wu C J, Chung Y H and Syu B J 2010 Band gap extension in a one-dimensional ternary metal-dielectric photonic crystal *Prog. Electromagn. Res. PIER* **102** 81
[53] Wu C J and Wang Z H 2010 Properties of defect modes in one-dimensional photonic crystals *Prog. Electromagn. Res. PIER* **103** 169