Salinity Sensor Based on 1-D Photonic Crystals by Tamm Resonance With Different Geometrical Shapes

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Salinity sensor based on 1-D photonic crystals by Tamm resonance with different geometrical shapes

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Abstract

In this paper, we demonstrate a novel Salinity sensor based on Tamm-Plasmon-polariton (TPP), comprising of different shapes of Bragg reflector (ordinary, texturing, and Sawtooth) and metallic layer, is proposed. The finite element method is used to study the considered structure and sensing performance by using the COMSOL multiphysics simulation procedure. Here, we study the effect of surface morphology on the sensitivity; firstly, in the case of one-dimensional photonic crystals centered defect, it has a negative effect on the sensitivity, secondly, texturing and sawtooth in the case of Tamm resonance is increase the sensitivity as For texturing the surface, the sensitivity (S) = $569 \text{ nm}/RIU$, quality factor (Q)=236, and figure of merit (FOM) = $170 RIU^{-1}$. While, for Sawtooth surfaces, $S = 612.29 \text{ nm}/RIU$, $Q = 272.4$, and FOM = $199 RIU^{-1}$. The consequences of structural parameters on the efficiency of sensing are studied and new procedures are proposed to enhance TPP-based sensors. A simple and functional alternative to conventional salinity sensors may be the proposed solution.

Key words

Salinity sensor, Tamm-Plasmon-polariton (TPP), Bragg reflector, texturing, Sawtooth, and COMSOL muiltpysics

1. Introduction

Photonic crystals (PCs) are an artificial structure arrangement in high-low dielectric materials in periodicity to governor the propagation of electromagnetic waves (EMW) through structures [1–3]. PCs are classified into three categories according to the number of dimension periodicity. As a consequence, it can be as one-dimensional (1D), two-dimensional (2D) and three-dimensional (3D). Recently, photonic crystals (PCs) received great attention due to their unique properties in optical applications

such as optical fiber [4], Bragg mirrors, optical and temperature sensors [5-10], waveguides, solar energy applications [11-13], light-emitting diodes (LEDs) [14], optical switches, and solar water desalination [15-16]. From this point of view, 1D PCs attract much more attention in the manufacturing owing to their low cost and easy to fabricate comparable to 2D PCs and 3D PCs. The Properties of 1D PCs considerably depend on the optical parameters of the individual constructing layers. The most significant parameters for 1D PCs are refractive index (n) and extension coefficient (k) of the used materials in addition to the number of periods (N) [17]. The photonic bandgap (PBG) is an essential feature of PCs; electromagnetic modes cannot spread in the photonic bandgap region. As a consequence, electromagnetic waves cannot pass through these PBGs [18-19]. Thus, by controlling the dielectric contrast between the used materials we can appoint the structure to be suitable for our application. So that 1D PCs has been growing day by day owing to their promising properties, and flexibility to use as we need [20-22].

In recent decades, sensors are considered as one of the most applications of photonic crystals owing to their ability to distinguish the different materials. Whereby, due to the change in the analyte refractive index, the detection procedure mainly depends on the shift of the resonance peak in the transmission or reflection range. Practically, for the saline water, the change in the refractive index is owing to the variation of salt concentration. Sensitivity, quality factor, and the figure of merit are the parameters that determine the sensor efficiency. Owing to their high sensitivity, optical sensors with surface plasmon resonance (SPR) have seen tremendous growth in environmental and chemical monitoring [23, 24]. Nearly all current SPR-based sensors, however, employ metal and dielectric hybrid systems with nanostructures appropriately considered, requiring an expensive and complicated fabrication process [25]. Therefore, as a result of these shortcomings, a portion of the devotion is diverted to planar scenarios for cost-effective strategies. Unfortunately, planar architectures' poor optical efficiency in light trapping remains one of their major defects. As a result, some well-thought-out planar structures appear [26, 27]. Tamm Plasmon resonance (TPR), proposed by Kavokin et al. [28], is gaining popularity [29]. With a satisfactory light-trapping property, it can provide an alternative to the planar structure.

The electromagnetic modes at the interface of a metal and a one-dimensional distributed-Bragg-reflector are referred to as Tamm-Plasmon-polariton (TPP) (DBR)[30]. TPP offerings promising methods for avoiding the shortcomings of SPR-based geometries. [31, 32]. Because of the photonic bandgap (PBG) in the DBR and high electromagnetic attenuation in metals, TPP modes are confined to the interface. In other words, the normal part of the wave vector of propagating wave in the periodic region (Bloch wave vector) falls inside the photonic stop-band of DBR structure which brings about the direction of electromagnetic wave alongside the interface. Interestingly, the TPP modes have exceptional control over the mode-volume by preferentially operating at a desired wavelength in the DBR's PBG [33]. The flexibility in modifying the dispersion properties of the TPP modes is therefore significantly greater than that of the SPP modes. The dispersion curve that often lies above the light-line of a high-index component of DBR is the most attractive characteristic of TPP modes. This feature facilitates direct free-space excitation of TPP modes at normal as well as angular incidence [34]. Wherein, PBG exists for both the electric component (TE) and magnetic component (TM) polarization. Thus, TPP modes could be motivated for both TE and TM polarization states. Owing to these unique properties, TPP modes provide a promising platform in photonic applications for potential applications such as integrated photonic devices, and highly sensitive optical sensors [35, 36].

The motivation and novelty of this paper is the coupling between the TPP resonance and different morphology of 1D PCs as we change the shape of the surface (ordinary, Texturing, and sawtooth) of each layer in the Bragg reflector structure as we will discuss in section 2. Thus, the different structures of texturing and sawtooth have a good ability to localize and distinguish the different defect modes in the PBG regions. Then, we will examine the sensor performance by calculating many parameters such as the sensitivity (S), the figure of merits (FOM), and the quality factor (Q).

2. Modeling and simulation

In this section, the modelling and theoretical analysis of our proposed structure is study by COMSOL multiphysics based on the finite element method [FEM]. For more accurate results, the meshing size must be ten times smaller than the lowest

incident wavelength [37,38]. Here, our design is one-dimensional photonic crystals with different surface shapes as in figure (1). In figure (1), a periodic structure of one-dimensional photonic crystals with refractive indexes n_1 and n_2 respectively, also with thicknesses d_1 and d_2 as we have shown. Since we take a periodic boundary condition in every two sides of the structures and the two ports as port 1 is the incident electromagnetic waves, and port2 is the transmitted electromagnetic waves as shown in figure (1).

Firstly, we design the considered structures of one-dimensional PCs with a defect layer from saline water in the center of the structure and determine the sensitivity as in the following section. The optical constants of the water such as refractive index depend on the following parameters, the salinity S (%), the temperature of the seawater (T), and the probing wavelength (λ) in nm as in equation(1) [39,40].

$$n(S, T, \lambda) = 1.314 + (1.779 \times 10^{-4} - 1.05 \times 10^{-6}T + 1.6 \times 10^{-8}T^2)S - 2.02 \times 10^{-6}T^2 + \left(\frac{15.868 + 0.01155S - 0.00423T}{\lambda} \right) - \left(\frac{4382}{\lambda^2} \right) + \left(\frac{1.1455 \times 10^{-6}}{\lambda^3} \right) \dots \dots \dots (1)$$

Where, S , λ , T and n are the salinity (%), the incident wavelength in nm, the temperature of the seawater ($^{\circ}\text{C}$), and the refractive index of the seawater represented in refractive index units (RIU), respectively. Thus, the refractive index of the saline water is varies from 1.3326 to 1.3505 as a function of the change in salinity level from 0 to 100% at room temperature, according the last equation.

(a) A Schematic diagram of an ordinary 1D- binary PCs structure.

(b) A Schematic diagram of the Texturing 1D- binary PCs structure

(c) A Schematic diagram of the Sawtooth 1D- binary PCs structure

Figure (1):- Schematic structure of different constructions of 1D- binary PCs; the thicknesses of the materials are denoted by d_1 and d_2 , respectively, and the corresponding refractive indices are separately indicated by, n_1 and n_2 . and N is the number of periods, n_o is the refractive index of the air, and n_s is the refractive index of the substrate layer. (a) A Schematic diagram of an ordinary 1D- binary PCs structure. (b) A Schematic diagram of the Texturing 1D- binary PCs structure with the width and height of the texturing are donated by W and H , respectively. (c) A Schematic diagram of the Sawtooth 1D- binary PCs structure with the width and height of the texturing are donated by W and H , respectively.

Then in this part, we offer a novel methodology by FEM to modeling one-dimensional Tamm resonance modes with different structures and surface morphology as we see below, that includes all the relevant physics and proposals a simpler method to study trends of fluid sensors or especially salinity sensor in the desalination process. As in figure (2)

Figure (2):- Schematic structure of the one dimensional Tamm resonance sensor which consist of one dimensional PCs, water layer and metallic layer as shown. The thicknesses of the 1D PCs materials are denoted by d_1 and d_2 , respectively, and the corresponding refractive indices are separately indicated by, n_1 and n_2 . and N is the number of periods. While, n_o , n_s are the refractive indices of the air and substrate layer, respectively, n_a , d_a are the refractive index and thickness of the saline water layer, And finally, n_m , d_m are the refractive index and thickness of the metallic layer.

Finally, the efficiency and performance of any sensor type are determined by the values of the many parameters like the sensitivity (S), the figure of merits (FOM), and

therefore the quality factor (Q). These parameters are often obtained using the subsequent expressions [41].

$$S = \frac{\Delta\lambda}{\Delta n} \quad (2)$$

$$Q = \frac{\lambda_r}{FWHM} \quad (3)$$

$$FOM = \frac{S}{FWHM} \quad (4)$$

Where, $\Delta\lambda$, Δn and λ_r are the differences in wavelengths, change in refractive index, and the central wavelength, respectively. And $FWHM$ is the full-wave at half maximum.

3. Results and discussions

Our results and discussions here are display through two parts corresponding to the different structures of one- dimensional photonic crystals. In the first part, we study the effect of surface morphology on the defected one dimensional photonic crystal of the ordinary 1D PCs, texturing 1D PCs and sawtooth 1D PCs as in figure (1), by adding a central defect layer from saline water and we calculate the sensitivity of the considered structure. Then, in the second part, we study also the effect of surface morphology of Tamm-Plasmon-polariton (TPP) resonance structure by add a metallic layer to the last structures of the Bragg reflector. Moreover, we calculate the sensitivity of the sensor and its properties to determine the optimum parameters for our device.

3.1 One dimensional photonic crystal

3.1.1 Defected One dimensional photonic crystal

Beginning with one-dimensional photonic crystals which we discussed previously as in figure (1.a) in section 2. Here, the transmission spectrum curve is formed using FEM, as shown in Figure (3), in figure (3.A) this structure is composed of multilayer having the form $(AB)^N$, where A is silicon (Si) and B is silicon dioxide (SiO_2) with thicknesses are 40 nm 20 nm respectively, for different periods (N) as shown. It is observed that there is a photonic bandgap formed in the visible region (286–390) nm for each number of periods equal 10 and 15. While, in figure (3.B) we added a defect layer from saline water in the center of the structure with a thickness equal to 60 nm, thus we noticed that we have a defect peak at a wavelength equal to 308 nm but we don't able to discrimination between the different refractive index of saline water so

that we zoom on the wavelengths range (303-313) nm as in figure (3.C). That's why to calculate the properties of this sensor. Thus, the sensitivity (S) = $57.1 \text{ nm}/RIU$, $Q = 123.36$, and figure of merit(FOM) = 22.84 RIU^{-1} .

Figure (3):-Transmission spectrum of 1D DBR -PCs that consists of Si and SiO_2 with the thicknesses of the materials are denoted by 40 nm and 20 nm , respectively. (A) At different number of periods as shown, (B) At number of periods equal 10, with centered defect layer of saline water equal to 60 nm . And (C) The same as in figure 3B with different range of wavelength.

3.1.2 Defected Texturing 1D PCs

Here, we change the morphology of one-dimensional photonic crystals layers as in figure (2.b) which we discussed previously in section 2. Thus, the transmission spectrum curve is formed using FEM, as shown in Figure (4), in figure (4.A) this structure is composed of multilayer texturing surface having the form $(AB)^N$, where A is silicon (Si) and B is silicon dioxide (SiO_2) with thicknesses are donated by 40 nm , 20 nm respectively, for different periods (N) as shown, the width and height of the textured are 20 nm and 10 nm respectively. Here this structure formed a photonic band gap as in the ordinary 1D PCs but it is differ from it in the resonance peaks as a result of the surface morphology. While, in figure (4.B) we added a defect layer from

saline water in the center of the structure with a thickness equal to 40 nm, thus we noticed that we have a defect peak at a wavelength equal to 287 nm but we don't able to discrimination between the different refractive index of saline water so that we zoom on the wavelengths range (282-292) nm as in figure (4.C). Here, we have a redshift owing to the increase in the saline water refractive index. Then by calculate the sensing parameters, we have $S = 48 \text{ nm/RIU}$, $Q=99.3$ and figure of merit (FOM) $=16.6 \text{ RIU}^{-1}$. Also increasing the defect layer thickness effected the sensing parameters, where, at the defect layer thickness equal to 50 nm, $S = 44.69 \text{ nm/RIU}$, $Q=835$ and figure of merit (FOM) $=89.38 \text{ RIU}^{-1}$. While at the defect equal to 110 nm, $S = 34 \text{ nm/RIU}$, $Q=248$ and figure of merit (FOM) $=36.17 \text{ RIU}^{-1}$ as we shown in figure (5). In the other word, by increasing the analyte layer the sensitivity is decreased. Therefore, the effect of analyte thickness in this case is the inversion of its effect in the ordinary defected 1D- PCs.

Figure (4):-Transmission spectrum of 1D Textured DBR -PCs that consists of Si and SiO_2 with the thicknesses of the materials are denoted by 40 nm and 20 nm, respectively, the width and height of the textured are 20 nm and 10 nm respectively. (A) Non defected structure at different number of periods

as shown, (B) defected structure at number of periods equal 10, with centered defect layer of saline water equal to 40 nm. And (C) The same as in figure B with different range of wavelength.

Figure (5):-Transmission spectrum of a defected 1D Textured DBR -PCs that consists of Si and SiO_2 with the thicknesses of the materials are denoted by 60 nm and 50 nm, respectively, the width and height of the textured are 20 nm and 20 nm respectively. (A) At thickness of the defect layer equal to 50 nm (B) At thickness of the defect layer equal to 110 nm.

3.1.3 Defected Sawtooth 1D PCs

In this subsection, we change the morphology of one-dimensional photonic crystals layers surface as in figure (2.c) which we discussed previously in section 2. Thus, the transmission spectrum curve of the considered structure is shown in Figure (6), in figure (6.A) this structure is composed of multilayer texturing surface having the form $(AB)^N$, where A is silicon (Si) and B is silicon dioxide (SiO_2) with thicknesses are donated by 35 nm and 40 nm respectively, for different periods (N) as shown, the width and height of the sawtooth are 10 nm and 15 nm respectively. in figure (6.B) we added a defect layer from saline water in the center of the structure with a thickness equal to 30 nm, thus we noticed that we have a defect peak at the PBG and then we differentiate between the different refractive index as in figure (6.c),

Finally, we calculate the sensor parameters, $S = 22.9 \text{ nm/RIU}$, $Q=480$ and $\text{FOM} = 36.9 \text{ RIU}^{-1}$. In figure (7), we have the localization of EMW in the top of the sawtooth.

Figure (6):-Transmission spectrum of 1D Sawtooth DBR -PCs that consists of Si and SiO_2 with the thicknesses of the materials are denoted by 35 nm and 40 nm, respectively, the width and height of the textured are 10 nm and 15 nm respectively. (A) Non defected structure at different number of periods as shown, (B) defected structure at number of periods equal 10 with centered defect layer of saline water equal to 30 nm. And (C) The same as in figure B with different range of wavelength.

Figure (7):- P- color of 1D Sawtooth DBR -PCs that consists of Si and SiO_2

3.2 Tamm resonance

3.2.1 1D distributed Bragg reflector (DBR) PCs Tamm resonance

In this subsection, we present the simulated results of Tamm resonance which considered as 1D distributed Bragg reflector (DBR) PCs with a defect and metallic layer as in figure (2). The 1D distributed Bragg reflector is designed from two dielectric materials that repeated for N periods. Here, the dielectric first layer is set to be aluminum dioxide (Al_2O_3) with a refractive index of 1.86 and thickness of 90 nm. Wherein, the other layer of dielectric material is titanium dioxide (TiO_2) with a refractive index of 2.5 and the thickness of this layer is chosen to be 80 nm.

Figure (8):-Reflection spectrum of 1D DBR -PCs that consists of Al_2O_3 and TiO_2 with the thicknesses of the materials are denoted by 90 nm and 80 nm, respectively, at different number of periods as shown.

As in figure (8) we have a photonic bandgap in the range of wavelengths from 675 nm to 850 nm. Thus, we set the number of periods to be 10 to justify the defect resonance peak in this range of PBG. Then, By adding an analyte layer from saline water with a refractive index (1.3326-1.3505) as we discussed previously in section 2 with a thickness equal to 4000 nm and a metallic layer from gold with a thickness of 500 nm, Therefore, we will optimize parameters of the structure in figure 2 such as

the number of periods, the thickness of the analyte layer, and the thickness of the metallic layer to get the optimum condition with high sensitivity.

Figure (9):- Reflection spectrum of the considered Tamm resonance structure which consists of $Al_2O_3(95nm)/TiO_2(80nm)$ with the number of periods equal 10 and thickness of gold layer equal to 500 nm and silicon dioxide substrate with 200 nm with different thickness of saline water layer as shown.

Beginning with the optimization of the thickness of the analyte layer as in figure (9). Here, in figure (9) the thickness of saline water is a variable from 1000 nm to 4000 nm . Thus, we noticed that by increasing the saline water thickness the number of defect resonance peak which appears in the photonic bandgap region increase. So that, we can consider that increasing the defect layer thickness is adding another layer of water to the structure and the new defect water layer is caused a new defect peak in the PBG as we see in the figure. Wherein, we have a redshift of the resonance defect peak owing to the increase in the refractive index of the saline water. In addition, we determine the efficiency and performance of the sensor by calculating values of many parameters such as the sensitivity (S), the quality factor (Q), and the figure of merits (FOM) as we discussed previously in section 2. Therefore, the sensitivity of the

structure also increases by a remarkable ratio as a result of increasing the saline water defect layer thickness. Firstly, at $d_w = 1000 \text{ nm}$, $S=327.37 \text{ nm/RIU}$, $Q=316.27$ and figure of merit (FOM) = 148.8 RIU^{-1} . Then, at $d_w = 2000 \text{ nm}$, $S=358.65 \text{ nm/RIU}$, $Q=429.8$ and $FOM = 224.15 \text{ RIU}^{-1}$. Thirdly, at $d_w = 3000 \text{ nm}$, $S=514.52 \text{ nm/RIU}$, $Q=621.9$, and $FOM = 467.7 \text{ RIU}^{-1}$. Finally, $d_w = 4000 \text{ nm}$, $S = 547.5 \text{ nm/RIU}$, $Q=729.8$ and $FOM = 484.5 \text{ RIU}^{-1}$.

Figure (10):- Reflection spectrum of the considered structure Tamm resonance from $Al_2O_3(95\text{nm})/TiO_2(80\text{nm})$ with different number of periods bragg reflector number (BRN) as shown. The thicknesses of gold and water are 500 nm and 4000 nm, respectively, at silicon dioxide substrate with 200 nm.

Here, in figure (10), we optimize the number of periods for distributed Bragg reflector with Tamm resonance structure. By calculate the sensor parameters we find that the sensitivity have a small change by increasing the number of periods, but the other parameters such as quality factor and figure of merits change by a remarkable ratio as we shown below.

At $N=5$, $S = 547.5 \text{ nm/RIU}$ $Q=256$ and figure of merit (FOM) = 179 RIU^{-1}

At $N=7$, $S = 541.7 \text{ nm/RIU}$ $Q=536.6$ and figure of merit (FOM) = 356.4 RIU^{-1}

At $N = 10$, $S = 547.5 \text{ nm/RIU}$ $Q=729.8$ and figure of merit (FOM) $=484.5 \text{ RIU}^{-1}$

Wherein, by increasing the thickness of saline water to be 6000 nm and N equal to 10, we have $S = 559.7 \text{ nm/RIU}$, $Q=2882$, and $\text{FOM} = 1998 \text{ RIU}^{-1}$.

3.2.2 1D Texture distributed Bragg reflector (DBR) PCs Tamm resonance

In this subsection, we present the simulated results of 1D Texture distributed Bragg reflector (DBR) PCs Tamm resonance which considered as the coupling between the 1D texture distributed Bragg reflector (DBR) PCs with a defect and Tamm resonance structure. We presented the optimization procedure of this structure, beginning with the number of periods optimization as in figure (11).

Figure (11):- Reflection spectrum of the textured considered structure $Al_2O_3(95\text{nm})/TiO_2(80\text{nm})$ with a different number of periods bragg reflector number (BRN) as shown. The thicknesses of gold and water are 500 nm and 1000 nm , respectively, at silicon dioxide substrate with thickness equal to 200 nm . Also, the width and height of the texture are 40 nm and 40 nm , respectively.

Here, by increasing the number of periods, the PBG edges become sharper than the others, but we have the sensitivity decrease by increasing the number of periods as we

shown, so that, we prefer to use a structure with a small number of periods. In addition, we have a redshift owing to the increase in the refractive index of the saline water.

At $N=5$, $S = 421 \text{ nm}/RIU$ $Q=51.7$ and $FOM = 25 \text{ RIU}^{-1}$.

At $N=7$, $S = 370 \text{ nm}/RIU$ $Q=75$ and $FOM = 33 \text{ RIU}^{-1}$.

At $N=10$, $S = 336 \text{ nm}/RIU$ $Q=121.4$ and $FOM = 49 \text{ RIU}^{-1}$.

Then we optimize the thickness of analyte layer to get the high sensitivity at number of periods 5, we change the thickness of saline water layer from 4000 nm to 6000 nm as in figure (12), we noticed that by increase the thickness of saline water the number of defect resonance peaks are increased as we shown that's why for the same reason as we discussed previously at **3.2.1 (1D distributed Bragg reflector (DBR) PCs Tamm resonance)** subsection.

Figure (12):- Reflection spectrum of the textured considered structure $Al_2O_3(95nm)/TiO_2(80nm)$ with number of period's equal 5. The thicknesses of gold layer are 500 nm at silicon dioxide substrate with 200 nm . Also, the width and height of the texture are 40 nm and 40 nm , respectively. (a) $d_w = 4000 \text{ nm}$, (b) $d_w = 5000 \text{ nm}$, and (c) $d_w = 6000 \text{ nm}$.

We can conclude these results in the following:

At $d_w = 4000 \text{ nm}$, $S = 536 \text{ nm}/RIU$ $Q=182$ and $FOM = 128 \text{ RIU}^{-1}$.

At $d_w = 5000 \text{ nm}$, $S = 554 \text{ nm/RIU}$ $Q=212$ and $\text{FOM} = 151 \text{ RIU}^{-1}$.

At $d_w = 6000 \text{ nm}$, $S = 569 \text{ nm/RIU}$ $Q=236$ and $\text{FOM} = 170 \text{ RIU}^{-1}$.

3.2.3 1D Sawtooth distributed Bragg reflector (DBR) PCs Tamm resonance

In this subsection, we present the simulated results of 1D Sawtooth distributed Bragg reflector (DBR) PCs Tamm resonance which considered as the coupling between the 1D Sawtooth DBR- PCs with a defect and Tamm resonance structure. We presented the optimization procedure of this structure, beginning with the number of periods optimization as in figure (13). Here, we found that by increasing the number of periods the sensitivity of the structure is decreased as we have shown in figure (13), therefore we chose the number of periods to be 5 for its higher sensitivity than the others.

Figure (13):- Reflection spectrum of TE component of the Sawtooth DBR- PCs considered structure $\text{Al}_2\text{O}_3(95\text{nm})/\text{TiO}_2(80\text{nm})$. The thicknesses of gold and water are 500 nm and 1000 nm , respectively, at silicon dioxide substrate with 200 nm . Also, the width and height of the sawtooth are denoted by 20 nm and 40nm , respectively with different number of periods as shown.

Then, in figure (14) we study the effect of saline water thickness on the reflection spectrum, wherein, we can calculate the sensitivity of the structure. From calculation,

we found that the sensitivity is increased by increasing the saline water thickness as the following;

At $d_w = 1000 \text{ nm}$, $S = 436 \text{ nm/RIU}$, $Q=65.8$ and $\text{FOM} = 33.5 \text{ RIU}^{-1}$.

At $d_w = 2000 \text{ nm}$, $S = 503 \text{ nm/RIU}$, $Q=115.7$ and $\text{FOM} = 67 \text{ RIU}^{-1}$.

At $d_w = 3000 \text{ nm}$, $S = 519 \text{ nm/RIU}$, $Q=165$ and $\text{FOM} = 98 \text{ RIU}^{-1}$.

At $d_w = 4000 \text{ nm}$, $S = 562 \text{ nm/RIU}$, $Q=182.4$ and $\text{FOM} = 125.7 \text{ RIU}^{-1}$.

At $d_w = 6000 \text{ nm}$, $S = 612.29 \text{ nm/RIU}$, $Q=272.4$ and $\text{FOM} = 199 \text{ RIU}^{-1}$.

Also, as in figure (15), we have a localization of electric field on the saline water layer as we shown, wherein, it assist in Discrimination between the different refractive index of a saline water which corresponding to the salinity level.

Figure (14):- Reflection spectrum of the Sawtooth DBR- PCs considered structure $Al_2O_3(95nm)/TiO_2(80nm)$ with number of periods bragg reflector number (BRN) equal 5. The thicknesses of gold is 500 nm , at silicon dioxide substrate with 200 nm . Also, the width and height of the texture are 40 nm and 40 nm , respectively. At different saline water thickness, (a) $d_w = 1000 \text{ nm}$, (b) $d_w = 2000 \text{ nm}$, (c) $d_w = 3000 \text{ nm}$. , and (d) $d_w = 4000 \text{ nm}$.

Figure (15):- P- color of 1D Sawtooth DBR -PCs for the same structure as in figure (14).

Parameter		N	Defect layer d_a (nm)	S $\frac{nm}{RIU}$	Q	FOM (RIU^{-1})
Tamm resonance	Ordinary	5	4000	547.5	256	179
		7	4000	541.7	536.6	356.4
		10	4000	547.5	729.8	484.5
		10	1000	327.37	316.27	148.8
		10	2000	358.65	429.8	224.15
		10	3000	514.52	621.9	467.7
		10	4000	547.5	729.8	484.5
		10	6000	559.7	2882	1998
	Texturing	5	1000	421	51.7	25
		7	1000	370	75	33
		10	1000	336	121.4	49
		5	4000	536	182	128
		5	5000	554	212	151
		5	6000	569	236	170
	Sawtooth	5	1000	436	65.8	33.5
		7	1000	363	84.6	36.3
		10	1000	279	137.6	45.8
		5	1000	436	65.8	33.5
		5	2000	503	115.7	67
		5	3000	519	165	98
		5	4000	562	182.4	125.7
		5	6000	612.3	272.4	199

Table (1):- the sensor parameters of different structure as we shown.

From table (1), we summarize this part of results and calculations about Tamm resonance salinity sensor. Thus, we have found a remarkable enhancement on the sensor parameters like sensitivity (S), quality factor (Q), and figure of merit (FOM), by changing the morphology of the layer surface. Here, we noticed that the sensitivity changed from $559.7 \text{ nm}/RIU$ (ordinary Tamm resonance) to $612.3 \text{ nm}/RIU$ (Sawtooth Tamm resonance) at the thickness of saline water equal to 6000 nm . Finally, we can say that the Sawtooth Tamm resonance structure and texturing Tamm

resonance structure is a good candidate for salinity sensor application. Also, Change the morphology of the layer surface of PCs is a promising point to research.

Conclusion

Finally, from the last results, we can found that a change in the surface morphology could affect strongly on the sensitivity, we have two cases corresponding to the last results; firstly, change the surface morphology in one-dimensional centered defect PCs are caused the decrease in sensitivity of the structure. Secondly, change the morphology (Textured and Sawtooth) in the case of Tamm resonance with a defect is caused an increase in the sensitivity of the considered structure by a remarkable ratio. Here, we noticed that the sensitivity changed from $559.7 \text{ nm}/RIU$ (ordinary Tamm resonance) to $612.3 \text{ nm}/RIU$ (Sawtooth Tamm resonance) at the thickness of saline water equal to 6000 nm . Thus, change the morphology of the layer surface of PCs is a promising point to research owing to its ability to photon tapping.

***Data availability statement**

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

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Figures

(a) A Schematic diagram of an ordinary 1D- binary PCs structure.

(b) A Schematic diagram of the Texturing 1D- binary PCs structure

(c) A Schematic diagram of the Sawtooth 1D- binary PCs structure

Figure 1

Schematic structure of different constructions of 1D- binary PCs; the thicknesses of the materials are denoted by d_1 and d_2 , respectively, and the corresponding refractive indices are separately indicated by, n_1 and n_2 . and N is the number of periods, n_0 is the refractive index of the air, and n_s is the refractive

index of the substrate layer. (a) A Schematic diagram of an ordinary 1D- binary PCs structure. (b) A Schematic diagram of the Texturing 1D- binary PCs structure with the width and height of the texturing are donated by W and H , respectively. (c) A Schematic diagram of the Sawtooth 1D- binary PCs structure with the width and height of the texturing are donated by W and H , respectively.

Figure 2

Schematic structure of the one dimensional Tamm resonance sensor which consist of one dimensional PCs, water layer and metallic layer as shown. The thicknesses of the 1D PCs materials are denoted by d_1 and d_2 , respectively, and the corresponding refractive indices are separately indicated by, n_1 and n_2 .and N is the number of periods. While, n_0 , n_s are the refractive indices of the air and substrate layer, respectively, n_a , d_a are the refractive index and thickness of the saline water layer, And finally, n_m , d_m are the refractive index and thickness of the metallic layer.

Figure 3

Transmission spectrum of 1D DBR -PCs that consists of Si and SiO₂ with the thicknesses of the materials are denoted by 40 nm and 20 nm, respectively. (A) At different number of periods as shown, (B) At number of periods equal 10, with centered defect layer of saline water equal to 60 nm. And (C) The same as in figure 3B with different range of wavelength.

Figure 4

Transmission spectrum of 1D Textured DBR-PCs that consists of Si and SiO₂ with the thicknesses of the materials are denoted by 40 nm and 20 nm, respectively, the width and height of the textured are 20 nm and 10 nm respectively. (A) Non defected structure at different number of periods as shown, (B) defected structure at number of periods equal 10, with centered defect layer of saline water equal to 40 nm. And (C) The same as in figure B with different range of wavelength.

Figure 5

Transmission spectrum of a defected 1D Textured DBR-PCs that consists of Si and SiO₂ with the thicknesses of the materials are denoted by 60 nm and 50 nm, respectively, the width and height of the textured are 20 nm and 20 nm respectively. (A) At thickness of the defect layer equal to 50 nm (B) At thickness of the defect layer equal to 110 nm.

Figure 6

Transmission spectrum of 1D Sawtooth DBR-PCs that consists of Si and SiO₂ with the thicknesses of the materials are denoted by 35 nm and 40 nm, respectively, the width and height of the textured are 10 nm and 15 nm respectively. (A) Non defected structure at different number of periods as shown, (B) defected structure at number of periods equal 10 with centered defect layer of saline water equal to 30 nm. And (C) The same as in figure B with different range of wavelength.

Figure 7

P- color of 1D Sawtooth DBR-PCs that consists of Si and SiO₂

Figure 8

Reflection spectrum of 1D DBR -PCs that consists of Al_2O_3 and TiO_2 with the thicknesses of the materials are denoted by 90 nm and 80 nm, respectively, at different number of periods as shown.

Figure 9

Reflection spectrum of the considered Tamm resonance structure which consists of $\text{Al}_2\text{O}_3(95\text{nm})/\text{TiO}_2(80\text{nm})$ with the number of periods equal 10 and thickness of gold layer equal to 500 nm and silicon dioxide substrate with 200 nm with different thickness of saline water layer as shown.

Figure 10

Reflection spectrum of the considered structure Tamm resonance from $\text{Al}_2\text{O}_3(95\text{nm})/\text{TiO}_2(80\text{nm})$ with different number of periods bragg reflector number (BRN) as shown. The thicknesses of gold and water are 500 nm and 4000 nm, respectively, at silicon dioxide substrate with 200 nm.

Figure 11

Reflection spectrum of the textured considered structure Al₂O₃(95nm)/TiO₂(80nm) with a different number of periods bragg reflector number (BRN) as shown. The thicknesses of gold and water are 500 nm and 1000 nm, respectively, at silicon dioxide substrate with thickness equal to 200 nm. Also, the width and height of the texture are 40 nm and 40 nm, respectively.

Figure 12

Reflection spectrum of the textured considered structure $\text{Al}_2\text{O}_3(95\text{nm})/\text{TiO}_2(80\text{nm})$ with number of period's equal 5. The thicknesses of gold layer are 500 nm at silicon dioxide substrate with 200 nm. Also, the width and height of the texture are 40 nm and 40 nm, respectively. (a) $dw=4000\text{nm}$, (b) $dw=5000\text{nm}$, and (c) $dw=6000\text{nm}$.

Figure 13

Reflection spectrum of TE component of the Sawtooth DBR- PCs considered structure $\text{Al}_2\text{O}_3(95\text{nm})/\text{TiO}_2(80\text{nm})$. The thicknesses of gold and water are 500 nm and 1000 nm, respectively, at silicon dioxide substrate with 200 nm. Also, the width and height of the sawtooth are denoted by 20 nm and 40nm, respectively with different number of periods as shown.

Figure 14

Reflection spectrum of the Sawtooth DBR- PCs considered structure $\text{Al}_2\text{O}_3(95\text{nm})/\text{TiO}_2(80\text{nm})$ with number of periods bragg reflector number (BRN) equal 5. The thicknesses of gold is 500 nm, at silicon dioxide substrate with 200 nm. Also, the width and height of the texture are 40 nm and 40 nm, respectively. At different saline water thickness, (a) $dw=1000\text{nm}$, (b) $dw=2000\text{nm}$, (c) $dw=3000\text{nm}$, and (d) $dw=4000\text{nm}$.

Figure 15

P- color of 1D Sawtooth DBR -PCs for the same structure as in figure (14).