REPUBLIQUE ALGERIENNE DEMOCRATIQUE ET POPULAIRE

MINISTERE DE L'ENSEIGNEMENT SUPERIEUR ET DE LA RECHERCHE SCIENTIFIQUE

Université Mohamed El-Bachir El-Ibrahimi - Bordj Bou Arreridj

Faculté *des Sciences et de la technologie*

Département : Èlectronique.

Mémoire

Présenté pour obtenir

LE DIPLOME DE MASTER

FILIERE : Électronique

Spécialité : Télécommunication.

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Intitulé

Smart windows based on photonic crystals.

Soutenu le : …………………………

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Année Universitaire 2023/2024

Dedication:

looks only at Allah.
I dedicate the results of my work to my father. Allah have mercy on him, who supported me and was the greatest source of my knowledge.
This master's thesis especially dedicated to my mother, my reason for living, in remembrance of her patience, love, and sacrifices.
To you, my parents, I say thank you for creating the person I am today. No sacrifice could ever fully convey my regard, consideration, and immense admiration for you.
This work honors my deep love and affection for you.
My dear sisters and brothers, who know how important success is to them, thank you very much. Allah keeps you safe for me.
The person who showed me the right path by reminding me that self-made men and determined people will always succeed in life is me.
To our teachers and others that helped me once, may Allah reward you for all of your blessings.
Finally, we give this master's thesis to all of the people we love and who inspire us.

No Nejments:

It is nice for a person to strive for success and achieve it.

We would like to use this opportunity to express our sincere gratitude to everyone who has supported and helped us throughout the process of creating this master's thesis.

A special thanks to our master's thesis director ***Dr. Bendib Sara*** *for his support, patience, and priceless advice, all of which were crucial to finishe this work.*

We would also like to express our gratitude to the jury members ***Dr. F. Faress_ M. F. Kherrat*** *for their time in evaluating our work and for their comments and ideas.*

My gratitude also to our friends and coworkers for their support, moral assistance, and the insightful conversations we had.

Finally, we would never forget our family—our parents, sisters, and brother—for their unwavering love, tolerance, and unwavering support.

We appreciate everyone's contribution, in whatever way you were able, to making this memory a reality.

Abbreviation list :

B

Band gap: BGP, 35

F

far-infrared: FIR, 13
Finite Difference Time Domain: FDTD, 21

I

Infrared: IR, 13

L

L'acide désoxyribonucléique: DNA, 14

M

mid-infrared: Mir, 13

N

near-infrared: Nir, 13

P

perfectly matched layer,: PML, 20
photonic crystals: PC, 24
polymer-dispersed liquid crystal: PDLC Windows, 15

R

refractive index: RI, 30

S

silica alone: SiO_2, 19
Suspended Particle Device: SPD, 15

T

The plane wave expansion: PWE, 20

U

Ultraviolet light: UV, 13

V

Vanadium dioxide: VO_2, 19

FIGURE LIST :

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SUMMARY :

Abstract :

This thesis develops an energy-efficient smart window based on one-dimensional photonic crystal structures that operate without an external power source. and discusses the design and analysis of the proposed smart windows that are composed of SiO_2/Vo_2 layers , their interaction with light and heat,the effect of the incident waves, and their potential to reduce energy consumption and radiation exposure. The proposed window proves its performance in blocking harmful rays of ultraviolet and infra-red, even when the temperature and incident wave angles change, and transmitting visible light except for the green color that the window appears with, which adds to its beauty.

Résumé:

Cette thèse développe une fenêtre intelligente économe en énergie basée sur des structures cristallines photoniques unidimensionnelles qui fonctionnent sans source d'énergie externe. et aborde la conception et l'analyse des fenêtres intelligentes proposées qui sont composées de couches SiO_2/Vo_2, leur interaction avec la lumière et la chaleur, l'effet des ondes incidents, et leur potentiel de réduction de la consommation d'énergie et de l'exposition aux rayonnements. La fenêtre proposée prouve son efficacité dans le blocage des rayons nocifs d’ultraviolet et l'infrarouge, même lorsque la température et les angles d'ondes d'incidence changent et transmettent la lumière visible sauf la couleur verte avec laquelle la fenêtre apparaît, ce qui lui ajoute une belle vue.

ملخص :

تعمل هذه الأطروحة على تطوير نافذة ذكية موفرة للطاقة تعتمد على هياكل بلورية ضوئية أحادية البعد تعمل بدون مصدر طاقة خارجي. ويناقش تصميم وتحليل النوافذ الذكية المقترحة والتي تتكون من طبقات SiO_2/Vo_2 ، وتفاعلها مع الضوء والحرارة، وتأثير الموجات الساقطة، وقدرتها على تقليل استهلاك الطاقة والتعرض للإشعاع. تثبت النافذة المقترحة فعاليتها في حجب الأشعة فوق البنفسجية والأشعة تحت الحمراء الضارة، حتى عندما تتغير درجات الحرارة وزوايا الموجة وتنقل الضوء المرئي باستثناء اللون الأخضر الذي تظهر به النافذة مما يضفي منظرا جميلا.

General Introduction :

Windows are an important part of any building or transport system, allowing natural light and air to enter while offering a view of the outside world. But what if you could control the amount of light, heat, and privacy your windows offer ? That's where smart windows come in; they use advanced technologies to block light, insulate, and give you privacy, making them the future of window design.

Smart windows offer many benefits to both commercial buildings and residences. They provide cleaner environments, reduce energy costs by blocking heat, and allow for greater control over privacy and light. They also offer a modern and sleek design that can add value to a property. In addition to their practical benefits, smart windows are also more sustainable than traditional windows. They reduce energy consumption by blocking heat and allowing for greater control over indoor temperatures, making them an eco-friendly choice [1].

Its advantages are not limited to their comfortable benefits alone; it also protects humans from skin and eye diseases, cancer, and burns due to filtering ultraviolet and infra-red rays. It also protects them from some external threats, such as laser threats, which represent a weapon that threatens drivers or pilots behind these windows.

Although there are multiple materials used in smart buildings to conserve energy, most of these materials require additional inputs of electricity or heat to function. Photonic crystals have the ability to be highly controllable without an external power source due to the periodicity of the refractive index contrast, which can dynamically regulate infra-red and ultraviolet light.

In this thesis, we have introduced photonic crystals in a smart window structure in order to control light and heat. Which is organized on three chapter as follows :

- The first chapter provides detailed information that leads to the objective of the thesis.
- The second chapter describes the design, parameters, and structure of the proposed window.
- The third chapter, discuss the obtained results and compare them with recent work.

Chapter 01 :

Objective and generalities

I. Introduction :

Smart windows have recently received a lot of attention due to their ability to control visibility and transfer power between indoor and outdoor spaces. These smart windows can be categorized into various types, including electrochromic windows, thermochromic windows, photochromic windows, and gaschromic windows [2]. In this window, photonic crystals are materials that have a periodical contrast of refractive index, which can be used to control the transmission of light [2]. By integrating photonic crystals into smart windows, the intensity of solar radiation entering a building can be controlled, reducing the need for heat for cooling or ventilation [3]. Photonic crystal smart windows can ensure energy savings by not requiring any additional heat or electricity to operate [3].

In addition to energy savings,photonic crystal smart windows can provide other benefits such as improved magnetic control, entertainment, etc. [4].

In this chapter, we will highlight the smart windows, especially the photonic crystal, which works without an external power source,

1. The solar spectrum :

The solar spectrum refers to the distribution of electromagnetic radiation emitted by the sun over a range of wavelengths. It represents the different colors and energies of light that make up sunlight. The solar spectrum is usually divided into different regions based on wavelength, as shown in Figure 1.

Ultraviolet region : this region includes wavelengths shorter than those of visible light, ranging from about 300 to 400 nm [5].

Visible region : this is the part of the solar spectrum visible to the human eye. It ranges from about 380 Nm to 760 Nm and includes the colors of the rainbow : violet, blue, green, yellow, orange, and red [6].

Infrared region : the infrared region extends beyond the red end of the visible.

Spectrum and includes wavelengths longer than 700 nm. It is also divided into three

Categories : near-infrared (Nir), mid-infrared (Mir), and far-infrared (FIR) [7].

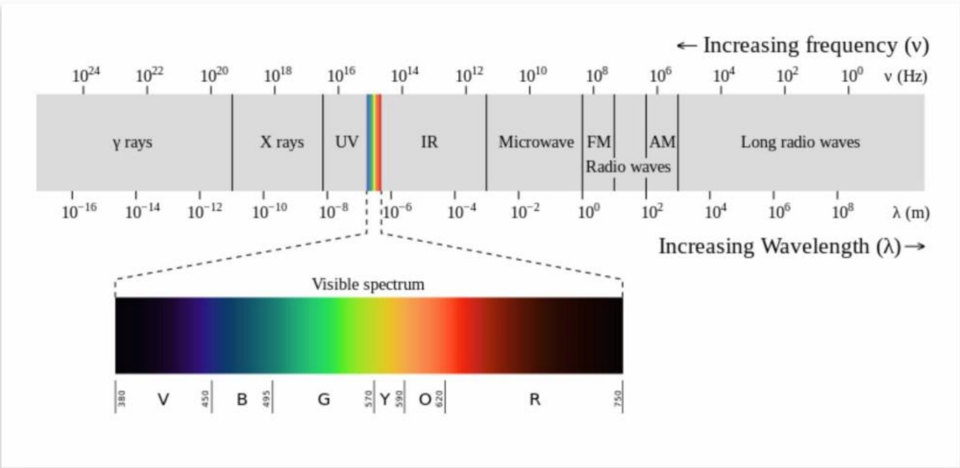


Figure 1 : solar spectrum [27]

2. The danger of sunlight on humans :

Sun exposure has both positive and negative effects on human health. On the positive side, sunlight stimulates the synthesis of vitamin D, which has many health benefits, including strengthening bones.

- Ultraviolet light UV is used in photo-therapy to treat a variety of skin diseases. It is also used in cancer therapy to kill cancer cells in the human body.
- In the detection of crime, forgery is detected by revealing the security of banknotes, passports, and other important documents [8].

Infrared (IR) radiation has many uses in many fields.

- It was used to treat autoimmune diseases or heal wounds [9]. It provides quality control [10].
- Infrared data transmission is used for short-range electronic communication between computer peripherals, digital assistants, and remote controls [11]

Effects of UV on the human body :

Excessive exposure can be harmful to humans, It can :

- damage your skin and underlying tissues. Therefore, more wrinkles and fine lines will appear on your skin.
- increases the risk of skin cancer, the most common type of cancer. When UV rays penetrate the skin, they damage genetic material (DNA).
- DNA damage causes changes in cells that cause cells to grow and divide faster. This growth can lead to the formation of extra cells called tumors. These may be cancerous (malignant) or benign (benign) [12].
- increases the amount of collagen that begins to deplete in the skin, causing it to lose its structure, causing wrinkles and sagging on the skin, causing premature aging. Skin condition Cancer first appears in small areas of the skin. Some cancers spread deep into tissues. They can also spread from the skin to other organs of the body.
- Exposure to small amounts of UV radiation over long periods of time may increase the risk of cataracts or macular degeneration. UV exposure increases over time. Prolonged exposure to UV rays can cause swelling of the eye tissues.

Damages caused by infrared rays :

- Overexposure to infrared radiation can cause thermal burns, similar to sunburn. The severity of the burn depends on the intensity of the infrared radiation, the duration of exposure, and the sensitivity of the person. Since infrared rays emit high heat, the body may become dehydrated.
- Damage to the eyes occurs when directly exposed to the rays or when viewed for a long time. Because the eye tissue absorbs the rays and causes changes in the eye cell. Tissues and membranes. These rays can cause a condition called solar retinopathy.
- The laser threat by the pulse laser [13].

If we want to protect ourselves from, laser pulse of less than 10 ns (especially in an airplane during the landing phase), the entire chain (pulse detection, control of the protection system, and response time of the protection system) must be much lower than these 10 ns. This excludes electronic control systems : they are too borrowed.

The protection system must be triggered directly from the light source without an electronics system intermediate. This brings us to thinking about smart windows that prohibit infrared light.

On the other hand,
as people begin to do their work completely indoors, it is necessary to consider protecting Them with smart windows technology that can change their characteristics in response to external stimuli or user control. And offer adjustable features and benefits such as switching from clear to opaque, providing privacy at the flick of a switch, ,controlling light and heat, being tinted to block sunlight and heat, and also ensuring better views by reducing glare, making it easier to see out the window on a bright day.

There exist two types of smart Windows :

- **Smart windows with an external power source :** refer to smart window systems that require an external electrical supply to operate.

  Such as PDLC Windows **(**polymer-dispersed liquid crystal) technology [14], Switchable Glass Windows [15], Control and Automation using switches or remote controls, and Suspended Particle Device (SPD) Technology [16].

- **Smart windows without an external power source :** How are they known as self-powered or self-sustaining smart windows. These windows utilize innovative technologies that can generate their own electricity or operate without the need for a continuous external power supply. Such as :

  Electrochromic Windows [17], Photovoltaic Technology [18] [19] [20] [21], Transparent Solar Cells [22], Thermotropic Windows [23] [24], and Photochromic Windows [25].

Now, can the photonic crystals [26] filter the sunlight spectrum without an external power source?

Yes, it is possible to construct a filter that blocks out particular wavelengths of sunlight. The photonic crystal's [26] periodicity and refractive index contrast can be precisely engineered to produce a bandgap, or range of wavelengths, that the structure prevents from propagating.

A photonic crystal can be made to have a bandgap that matches specific light colors or wavelengths in order to filter the sunlight spectrum. This indicates that some wavelengths will be transmitted or reflected by the crystal, while others will be blocked. The location and width of this photonic bandgap may be precisely controlled by scientists through the careful design of the photonic crystal structure This enables them to filter light or particular portions of the solar spectrum. In order to create a bandgap that inhibits near-infrared (NIR) light, researchers are working to create photonic crystal [26] windows that: enable visible light and warmth to flow through while reflecting heat,Smart windows could be possible with more complex photonic crystal [26] designs.

In 2017, Guofa Cia created a smart window by assembling inkjet-printed SiO_2/TiO_2 and Wo_3/Poly films as anode and cathode, respectively [28]. High optical adjustment, fast switching, high tinting efficiency, and excellent binary stability are achieved through the built-in smart windows. Also in 2020 [29]. Dipti studied a smart window design for energy-efficient buildings. They focused on vanadium dioxide (VO_2), which turns infrared reflective at hightemperatures. By combining VO_2 with photonic crystals, they achieved excellent infra-red absorption at high temperatures. as well in 2022. Zaky A. Zaky and al [2]. developed smart windows as an effective way of minimizing energy consumption. At room temperature, the proposed structure has the ability to block a wide range of IR by filling the air layers with water. It is composed of (SiO_2/Air) N photonic crystal, without studding the UV range filtering.

3. Problematic :

Can we propose a smart window that works without an external power source, allows only visible light to penetrate, forbids both ultraviolet and infrared regions, and is not affected by temperature?

4. Objective :

The main aim of this thesis is to develop a smart window that works without an external power source using a one dimensional photonic crystal structure, that allows only visible light to penetrate it and forbids both ultraviolet and infrared regions.

Results will be compared with the proposed design in paper ref [3] published in 2022 by Zaky A. Zaky,which prohibits just the near infrared region.

5. Conclusion :

Smart windows using photonic crystals represent a major advance in energy conservation and building design. Photonic crystals can control light and heat in windows by manipulating light. This feature not only improves the energy efficiency of buildings by reducing the need for lighting and temperature control, but also improves occupant comfort by blocking harmful ultraviolet and infrared rays. In the next chapter, we will focus on the design and structure of the proposed smart window.

Chapter 02 :

Design and Structure

II. Introduction :

Smart windows, or switching windows, represent a significant advance in the management of energy efficiency and comfort in buildings. They use innovative materials that can change their properties in response to external stimuli, such as temperature or light intensity. Various materials are utilized to give windows their "smart."

These materials have aroused great interest as a promising candidate for smart windows. For their unique properties and contributions to the functionality of such windows. that allow changing the optical properties in the near-infrared and ultraviolet regions, which are widely adopted in crystals. Photonics are classified into two types according to their working mechanisms, thermochromic and electrochromic. For thermochromic smart windows, VO_2, SIO_2, and electrochromic smart windows, including TiO_2, MoO_3, NiO, and V_2O_5.

Vanadium dioxide (VO_2) is a thermochromic material that represents the energy-saving smart window capability. VO_2 has an adjustable refractive index that depends on its temperature [30] [31]. The unique temperature and thickness-dependent refractive index properties of VO_2 make it transparent and opaque to near-infrared rays, which gives VO_2-based windows the ability to adjust solar heat flux in response to temperature.

Compared with other materials, VO_2 is more attractive due to the poor change in light transmission with temperature changes, which can provide good illumination for buildings. These features of VO_2 make it an ideal candidate for the main product in modern smart windows [30].

SiO_2, or silica alone, is not as ideal as VO_2 for smart windows. However, it plays a crucial role in some smart window designs . Their chemical formula is SiO_2. It usually occurs in nature as quartz and is the main component of sand. SiO_2 can improve the light transmittance and solar modulation capability of smart windows [31], and it has excellent thermal stability and high chemical inertness. SiO_2 can be used together with VO_2 in multi-layer structures to improve the light transmittance and solar transmittance modulation of thermochromic smart windows [32] [33]. The SiO_2 layer in smart windows plays a vital role in changing surface color, improving optical properties, and solving the color-related challenges of thermochromic materials.

6. Simulator tool :

OptiFDTD [34] is a comprehensive tool for the design and analysis of photonic devices and materials that could actually play an important role in the development of smart windows. They often contain complex optical structures such as thin films, photonic crystals, or nano-composites that have unique interactions with light. The program is based on the finite difference time domain method (FDTD) and the plane wave expansion method (PWE).

The tool is based on 1D, 2D and 3D photonic crystals. In our study, we rely on uni dimensionality, which consists of two (or more) layers. The periodicity is in one dimension. A key feature of photonic crystals is the photonic band gap. In one-dimensional photonic crystals, this bandgap is particularly effective for light incident perpendicularly to the layers, but may also have an effect at other angles.

7. Design description :

We will discuss the design of a one-dimensional photonic crystal, which consists of N-photonic crystal layers of (SiO_2 / Vo_2). Sio_2 layes will be deposited on VO_2 substrate. We use SiO_2 as a dielectric material because the imaginary part is close to 0 and can be ignored.

We chose VO_2 because, compared with other materials, VO_2 is more attractive due to the poor change in light transmission with temperature changes.

The SiO_2 layers have a thickness of 200 nm and are distributed in the Y direction with a respected lattice constant of about 300nm. The refractive index of SiO_2 and Vo_2 is, respectively, 1.4424, 2.722. [35]

As the incident sunlight is completely unpolarized, each polarized component (TE and TM components) has its own proper behaviour inside the proposed design. a portion of the photonic crystal structure is excited from the light source by a Gaussian pulse and by applying an appropriate boundary condition (perfectly matched layer, PML).

The transmittance of the proposed smart windows for TE and TM electromagnetic waves will be calculated by the FDTD method to investigate how the proposed smart windows react to incident waves, which will be detected at the end by a photo-detector.

Parameters	Value
dA	*0.2*
dB	*0.26 /0.30*
nVo2	*2.722*
nSio2	*1.4244*
N	*8*

Table 1:summarize the parameters design.

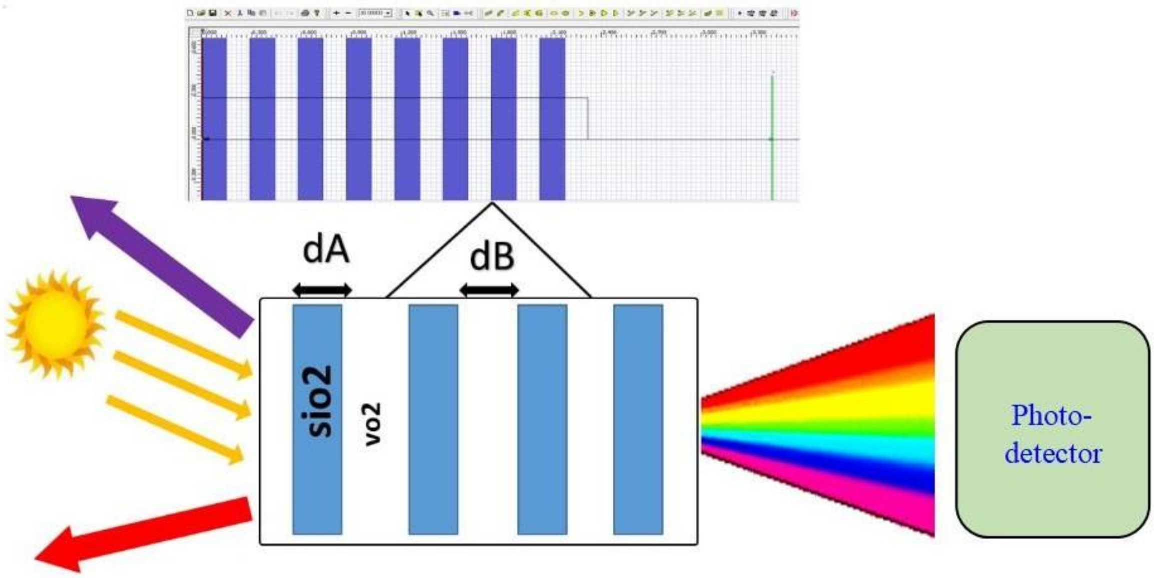


Figure 2 : Structure and detection mechanism.

8. <u>Conclusion</u> :

In this chapter, we describe the proposed design and parameters of a smart window based on 1D photonic crystals, where we have used materials that can change their properties in response to external stimuli.

In the next chapter, we will discuss the light, heat and incident wave angle responses.

Chapter 03 :

Results and discussion

III. Introduction :

In this chapter, we will discuss the reaction of the proposed structure with light and heat to prove that the proposed smart window blocks most of the infra-red and ultraviolet rays.

9. Geometrical study :

Our objective is to prove that smart window design blocks infra-red and UV rays.

The question is :

Which number of layers will be used for the best transmission results ?

For the first time, A detailed simulation study of a smart window PC at room temperature is proposed.

To demonstrate the performance of our smart window structure, we conducted a series of simulation studies using Optifdtd.

Figures (1) and (2) represent the transmission spectrum where the number of layers is changed from 2 to 8 for both TE and TM polarizations, but other conditions remain unchanged.

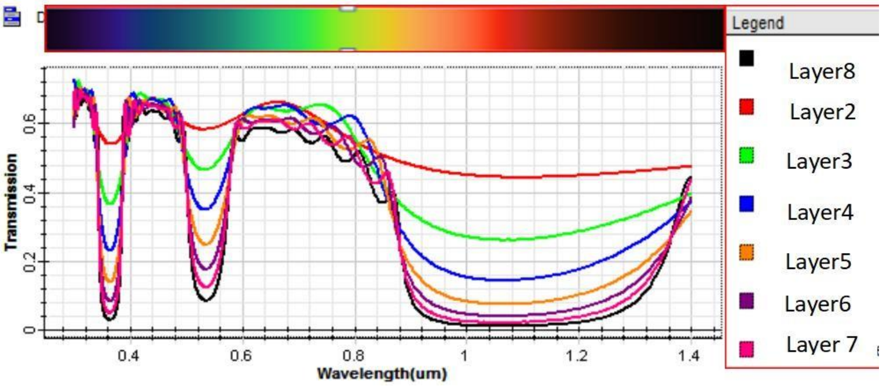


Figure 1: Transmission spectrum according to change of layers from 2 to 8 in TE polarizatio

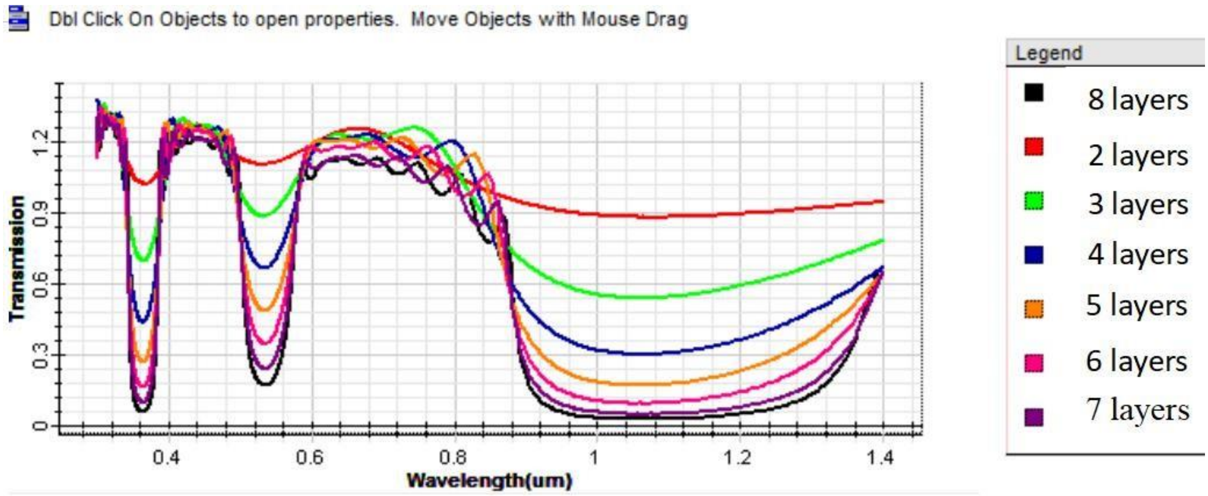


Figure 2:Transmission spectrum according to the change of layers from 2 to 8 in TM polarization.

The intensity in TM polarization is greater than TE one but in term of wavelength Which is what we focus on, we remark that TE and TM polarizations lead to the same results, so no need to repeat the simulation again.

It means that this structure is not sensitive to polarization type.

The results shows the effect of changing the number of layers on transmittance.

We can say that the material's structure (sio2/vo2) has the ability to block both near-infrared (NIR) radiation from (800 nm to 1400 nm) and ultraviolet (UV) radiation from (300 nm to 400 nm). And let just visible light from (400 nm to 700 nm) to penetrate the structure.

Results Shows a potential performance improvements as the number of layers increases.

Among them, the curve with black color when N=8 shows wavelength gaps with the lower intensity (near to 0) So, it has a better ability to block the near infra-red and ultraviolet rays than other layers.

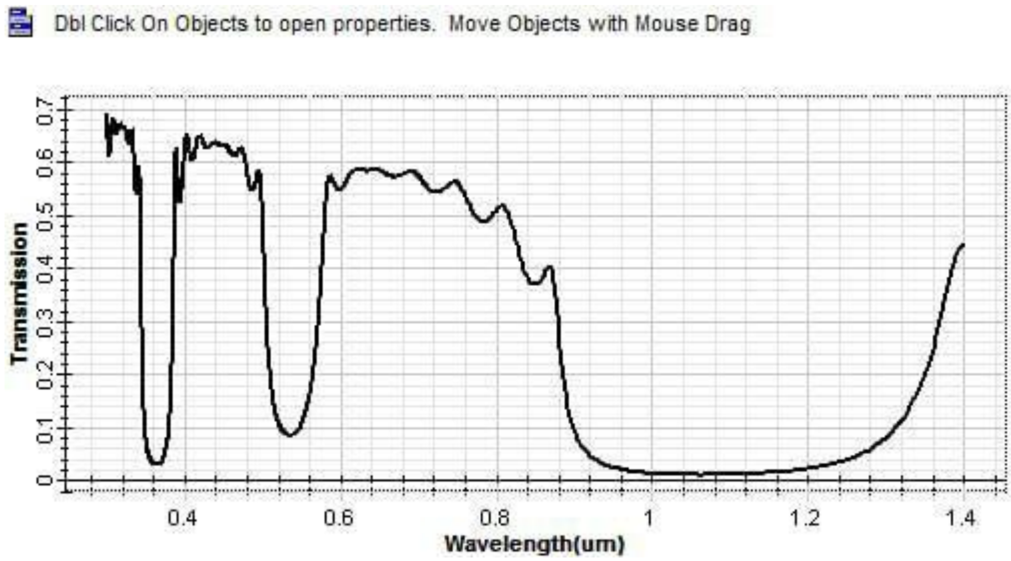


Figure 3:The transmission spectrum of the 8th layer.

The visible range allows all colors to pass through the structure except the green color, which leads to the appearance of the window with a green color, and that adds beauty to the windows.

Fig. 4 shows how the window reacts to green color blocking.

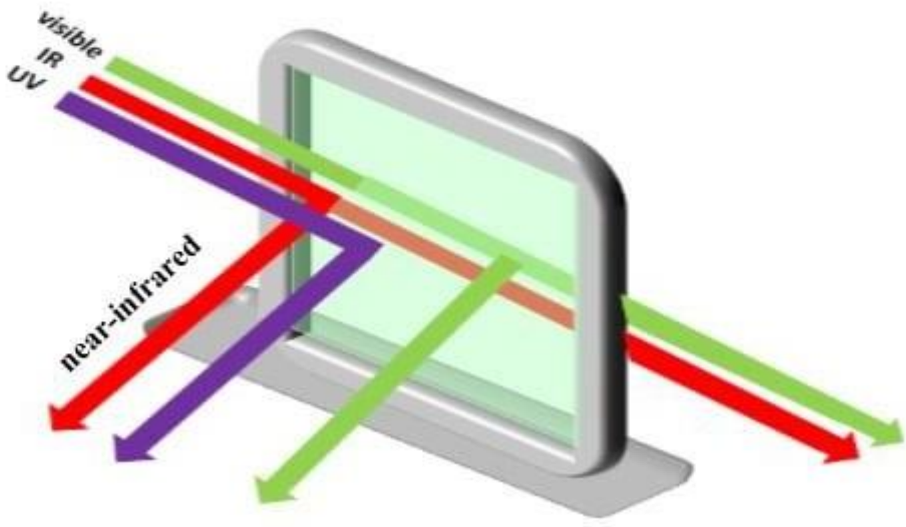


Figure 4:The window reaction with green color blocking.

Based on the results below, we chose the eighth layer also because, it blocks most of the near-infrared from 0.802nm to 1.398 nm and part of the ultraviolet rays from 0.304 nm to 0.394 nm.

Now, can we make a parameter ajustement that allows us to get a gap that covers the entire ultraviolet and IR range ?

To get a gap larger than the one we have,we move to the next step and change the inter-layer (lattice constant) distance from 0.26 nm to 0.3nm (Figure 4).

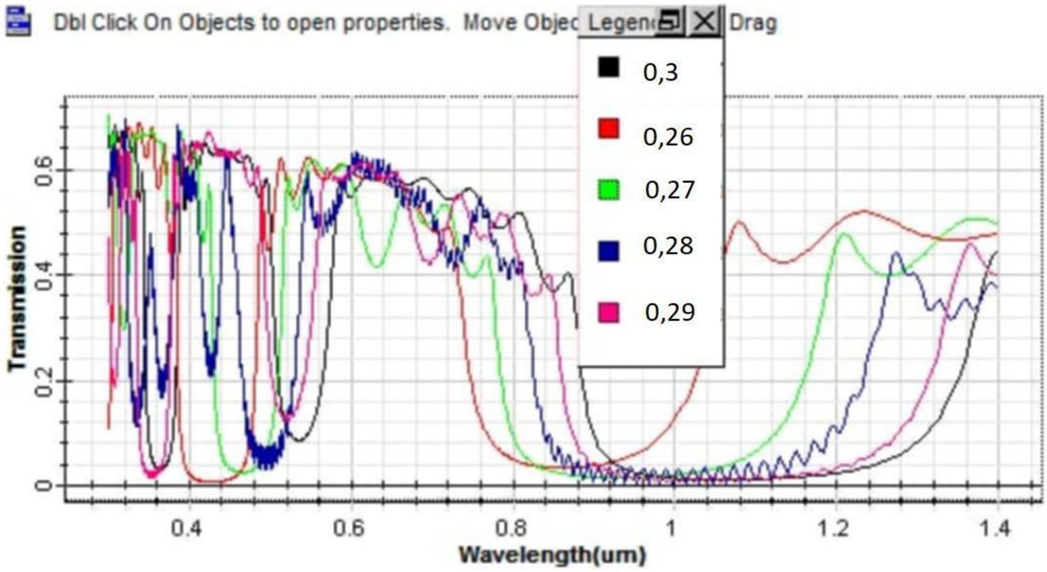


Figure 5:Transmission spectrum with lattice constant change from 0.26 nm to 0.3 nm.

The curve in Fig. 5 represents the transmittance response with the lattice constant change, where we have gaps in the infra-red and ultraviolet ranges. We have obtained the larger gap where the lattice constants are at 0.29 nm (the curve with pink color) and 0.30 nm (the curve with black color).

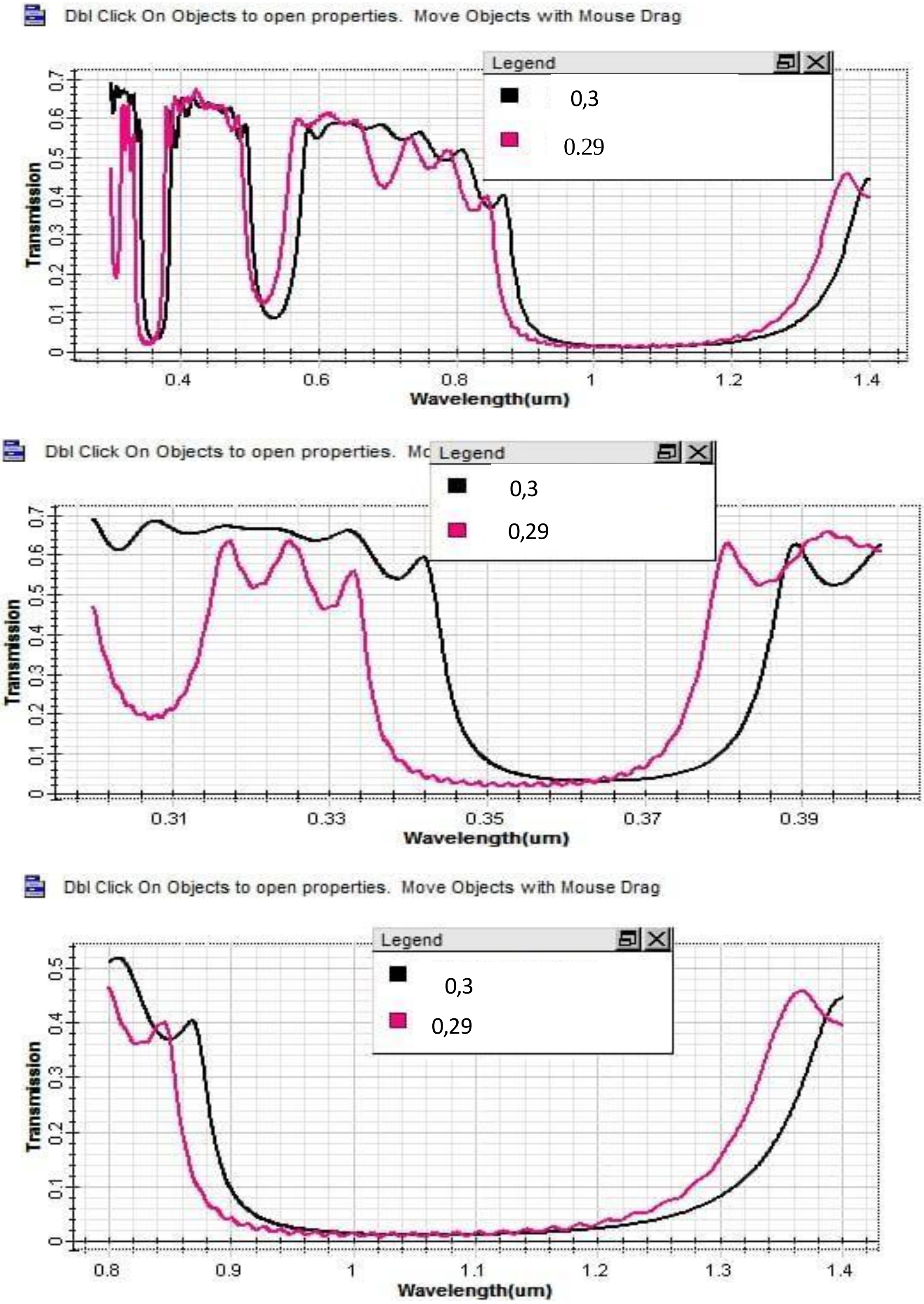


Figure 6:The transmittance of the proposed smart windows at 0.29 nm and 0.30nm (A) (B) BGP of UV (C)BGP of IR.

The results show two band gaps in (UV and IR) at the lattice (0.30 nm, 0.29 nm).

- **For the IR region in both 0.29 nm and 0.3 nm inter-lignes :**

The pink band gap of infra-red is from 0.844 nm to 1.369 nm, and the black band gap is from 0.871 nm to 1.399 nm, respectively.

- **For the UV region in both 0.29 nm and 0.3 nm inter-lignes:**

The pink band gap of ultraviolet is from 0.333 nm to 0.38 nm and the black one is from 0.341 nm to 0.38 nm respectively.

Since the results are close we will choose the lattice constante with 0.3nm in the last of the study.

a. <u>Heat study :</u>

Is the obtained results steel unchanged even the temperature increase ?

From Fig. 7, we note that the refractive index of SIO2 is unchanged while the refractive index of VIO2 changes with temperature. The VIO2 is affected by temperature starting from 20°C [35]

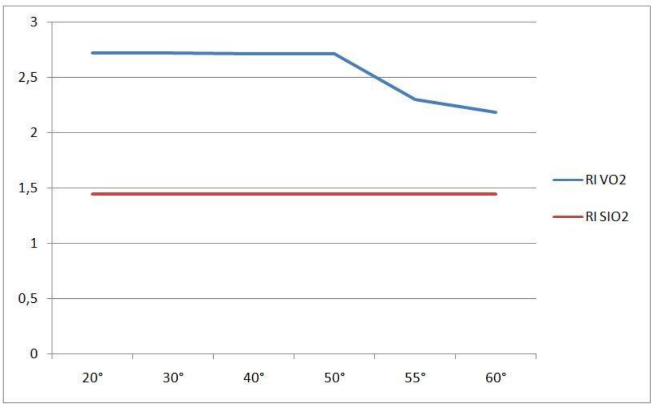


Figure 7:RI changes Vs temperature .(data source from).

To determine how temperature affects the proposed window, we conducted a series of simulations and attract the transmission spectrum for each temperatur level:

Figure 8:Transmission spectrum with temperature change.

Figure 8 shows the results of wavelength changes at different temperatures .

We noticed that we have got the same transmission spectrum where temperatures are 20, 30, 40, and 50 °C, except at the two temperatures of 55°C (blue) and 60°C (yellow), the transmittance has changed.

Figure (9) represents the transmission UV, where the temperature is changed from 20°C to 60°C at lattices 0.3 nm.

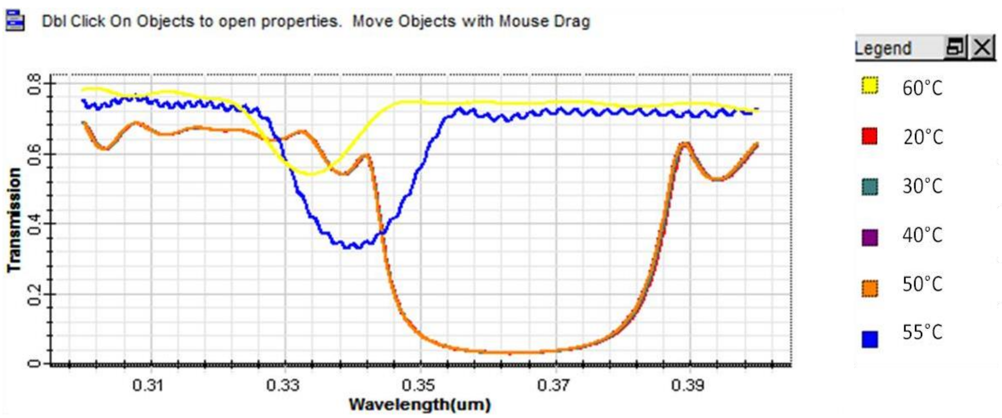


Figure 9:Transmittance of UV range when temperature change.

The diagram shows the UV changes when the temperature changes from 20°C to 60°C, where we observe at temperatures 20°C, 30°C, 40°C, and 50°C the appearance of BGP that covers a strong part of the UV range which is from 0.342 nm to 0.389 nm with the intensity (near to 0), but starting from 55°C temperature the gap are losing.

Figure (10) represents the IR transmission where the temperature is changed from 20°C to 60°C.

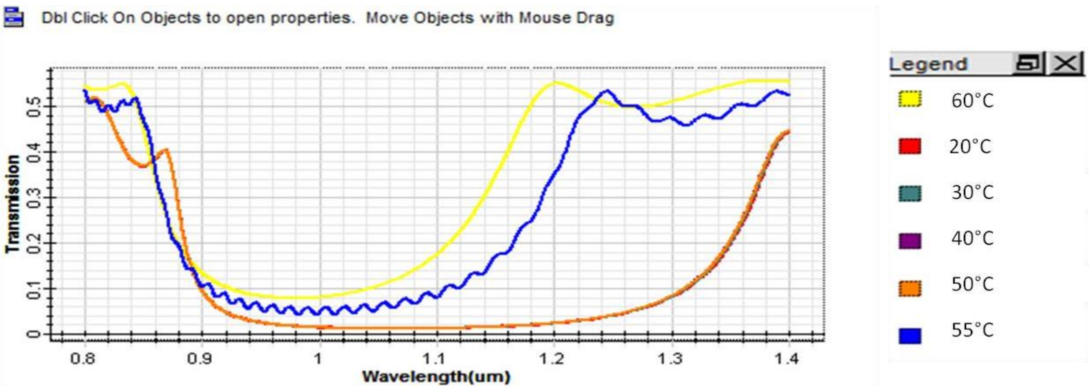


Figure 10:IR transmittance change with temperature change.

The diagram shows the IR transmittance change with temperature change. From 20°C to 60°C, where we observe at temperatures 20°C, 30°C, 40°C, and 50° the appearance of BGP that covers all the IR range which is from 0.869nm to 1.400nm with the intensity (near to 0), but starting from 55°C temperature, the band gap will be lower than previous temperatures with an average wavelength from 0.817nm to 1.170nm.

Figure 13 represents the transmission of the visible range where the temperature is changed from 20°C to 60°C.

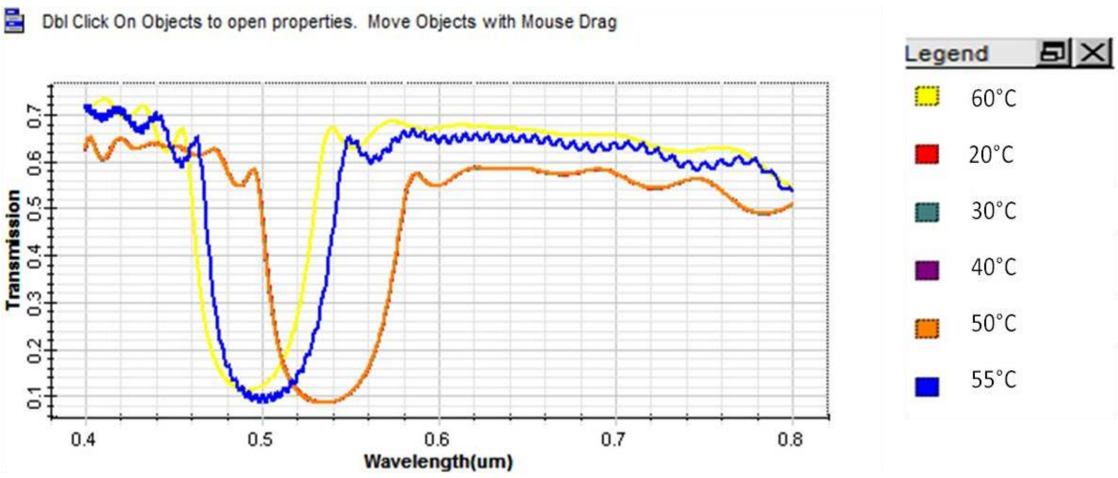


Figure 11:Visible transmission spectrum with temperature change.

At temperatures from 20°C to 50°C, the same Bgp appears, which is from 0.48nm to 0.58nm, and the window steel appears with a green color.

For the temperatures of 55°C and 60°C, the obtained band gap is (from 0.43 nm to 0.53 nm) (from 0.44 nm to 0.52 nm) and the window appears with a cyan color.

b. Incident wave effect study :

Now, the effect of the incident wave variation on the transmittance values is examined, from the results shown in figure(14).

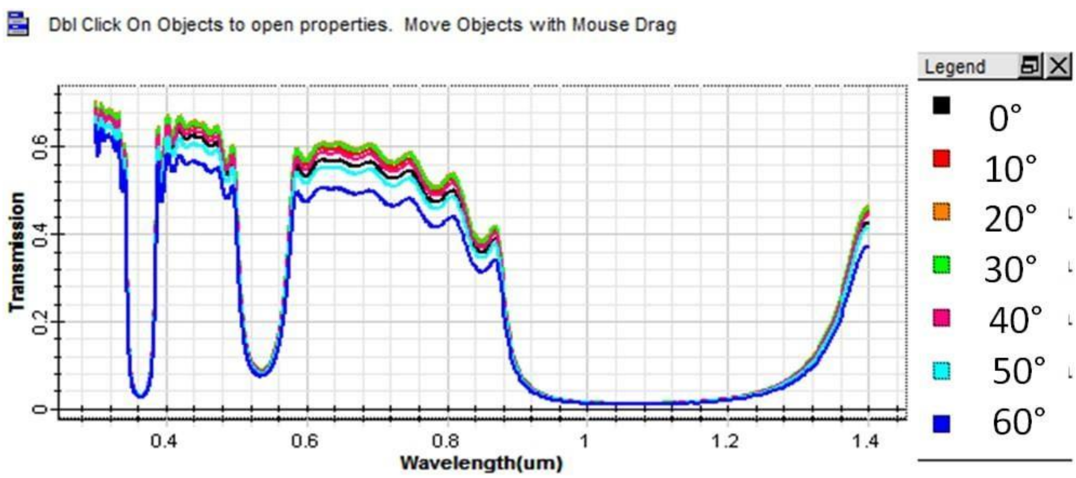


Figure 12:Transmission spectrum with incident wave angle change.

We may conclude that the suggested window was not sensitive to incident wave angle because the design remained unchanged despite variations in incident wave.

c. **Simulation view in a hot summer day:**

Figure 15 represents a simulation of a hot summer day where the temperature reached at noon more than 50°C.

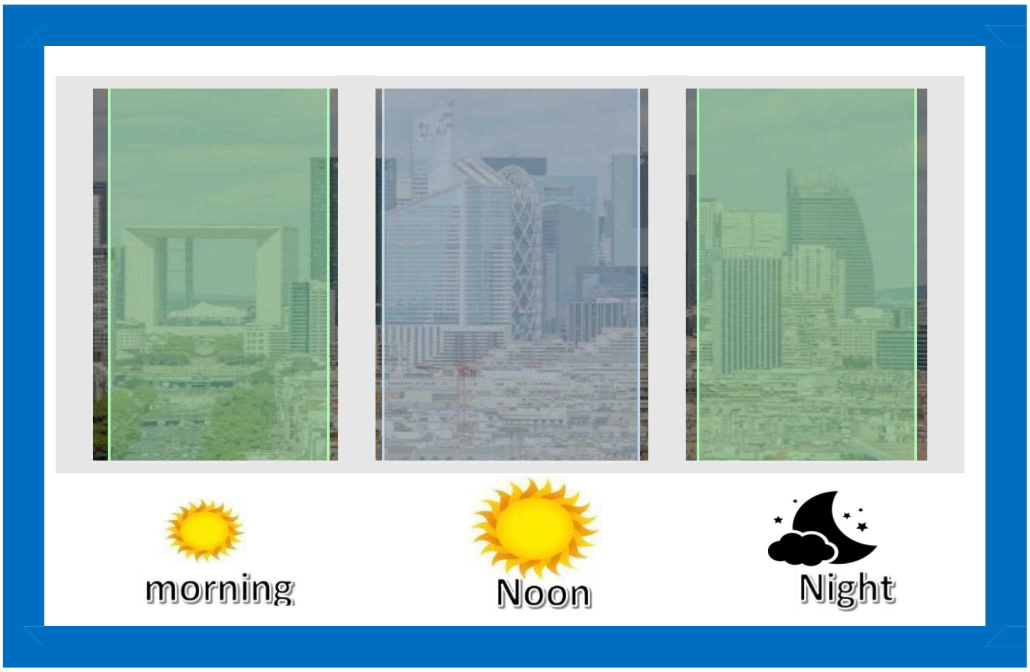
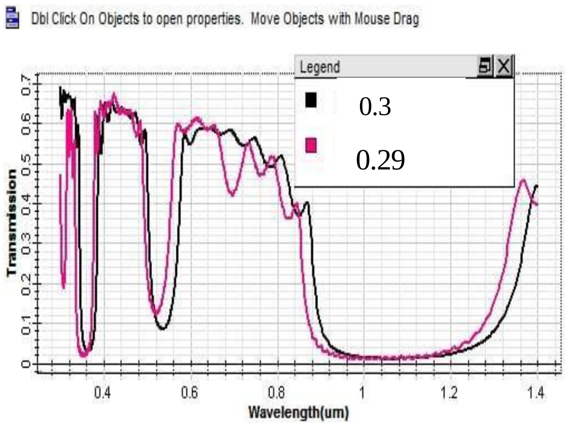


Figure 13:Simulation view in a hot summer day.

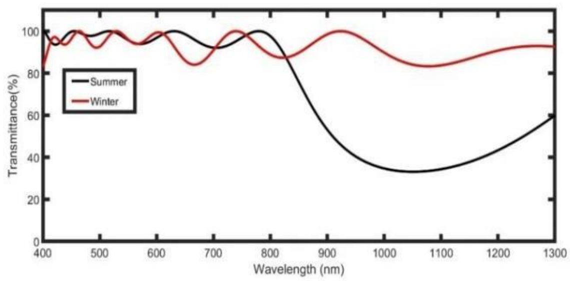
10. Comparaison :

Materials used in paper [3] are (air or water/Sio2). While we used (Sio2/VO2).Our results are close to those obtained in this paper except he study only the response of IR region. With the addition of water inside window each summer. And this is considered an exaggeration of the burden, especially if it is in strong buildings with many windows.Additionally, the type of water used is not specified, so it can rot. This will cause the window to fog up and may also cause it to change color from clear to yellow over time. The accumulation of water can corrode the metal components used in smart windows frontiers. Which may damage the structure and reduce the service life. While we used (Sio2/Vo2) in the summer and winter and avoided negative affects of adding water.

Fig 16 represents the deference between our results and the compared paper:



Graph of smart window results based on (sio2/vo2)



Graph of smart window results based on (sio2/air) (sio2/water) [1]

Figure 14:The difference between our results and the results of the published paper.

The author in paper [3] obtained one weak BGP that blocks parts of infra-red rays only, while we obtained a large BGP that cover both (UV and IR range). additionally the temperature study is not carried out.

His structure depend on polarization sunlight while our structure not.

11. **Conclusion** :

Now, we can summarize the results obtained by saying that the proposed window blocks infra-red and ultraviolet radiation with 8layers of Sio2 /Vo2 at lattice constants 0.3 nm. Also, at temperatures from 20 to 50 degrees Celsius, ultraviolet and infra-red rays are blocked, but after 50 degrees Celsius, the window does not block the UV rays. The propose design was unaffected by the variation of the incident wave angle.

Our results are better than the compared paper and we can say that we can use this type of window in air-planes, vehicles, and buildings in medium and moderate areas.

General conclusion :

In this thesis, we design and simulate a smart window based on one-dimensional photonic crystals with vanadium dioxide and silicon dioxide layers as materials. In which several studies have been carried out.

- In the first stage, we studied the number of layers needed in both TE and Tm polarization, which significantly block infrared and ultraviolet rays, We found that the best results were with 8 layers, as well as that the window reflected the green color in the visible range.
- In the second stage, we touched on changes in the distance between the layers (lattice constant) to get a larger gap that covers all UV and near-IR regions.
- In the third stage, we conducted a heat and incident wave angles studies to find out how temperature and incident wave angle affect the band gap, so we found that the window blocks both infrared and ultraviolet radiation at temperatures ranging from 20 to 50 degrees Celsius, generally we can say that the proposed window is not sensitive to temperature and incident wave angles

We finish our study by comparing our results with a recently published paper, where our results proved to be the best and our study proved to be the most comprehensive.

The proposed window proved its performance in blocking harmful rays of ultraviolet and infra-red, even when the temperature and incident wave angles change, and transmitting visible light except for the green color that the window appears with, which makes it more beautiful.

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