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ORIGINAL ARTICLE

Comparison between different solar cells based on perovskite types

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ABSTRACT:

Perovskite solar cells (PSCs) are getting popular as promising photovoltaic technology due to their high efficiency and economical manufacturing costs. PSCs' effectiveness and stability have continuously improved in recent years, and research into minimizing lead leakage and creating environmentally acceptable lead-free perovskites is advancing the commercialization of PSCs step by step. The goal of this paper is to design a solar cell model based on getting higher light transmission and lower light reflection. Three-layer solar cell structure containing perovskite, titanium dioxide, and metal Nano layer sandwich between a silicon substrate and glass cover. The Maple 17 software is used to create the numerical results for the Transfer matrix, which determines the transmission and reflection of the incident light for various physical parameters of the structure. The results showed that the cell with aluminum cell has an excellent transmittance for a wide range of incident angles, perovskite thickness, and effective layer thickness. The short circuit current density reaches the most significant value at (α = 0), and it has zero value for parallel incidents. The cell of $CH_3NH_3PbI_3$perovskite type and the aluminum metal nanolayer has the highest current density and a non-zero value for a wide range of incident angles.

KEYWORDS: Antireflection coating; metal nano layer; Perovskite; Solar cell; Transfer matrix method.

INTRODUCTION:

Sustainable and renewable energy sources are needed because of the world's growing energy needs, environmental concerns, and the depletion of fossil fuels (Kerr, 2007; Alnahhal et al., 2019). An environmentally beneficial and renewable energy source that directly converts photon energy into electricity is solar photovoltaic (PV) technology (Green et al., 2018; Al Farra & Elaydi, 2019) . Silicon (Si) solar cells have established record device efficiencies of more than 26% after decades of development (Bokov & Ye, 2020). But to effectively implement solar cell technology on a worldwide scale, materials and device stores must advance to lower the cost of manufacture and improve power conversion efficiency (PCE) (Adwan & Shabat, 2020). Due to the high light absorption coefficient, long carrier diffusion length, and solution processability of metal halide perovskite materials, perovskite solar cells (PSCs) have emerged as a viable thin film photovoltaic (PV) technology (Godding et al., 2019). PSCs, which were first developed in 2009 with an efficiency of 3.8%, have since improved to a lab-scale power conversion efficiency of 23.3% , which is comparable to that of commercial multicrystalline silicon solar cells, copper indium gallium selenide (CIGS), and cadmium telluride (CdTe) thin-film solar cells (Wang et al., 2029).The creation of innovative perovskite light harvesters is a promising but underutilized path to improve-efficient devices. In particular, those in which lead is replaced with other metals like tin which results in lower band gap energies, improving the ability to use incident sunlight (Hao, Stoumpos, Cao, Chang, & Kanatzidis, 2014). Since this specific type of perovskite is the only one that allows extending the band gap to the near-infrared (NIR) and therefore reaching the Shockley-Queisser (SQ) limit, there is great interest in them (Kaur & Singh, 2020; Kerr, 2007; Kim et al., 2018; Noel et al., 2014; Elblbeisi, 2022).

Theory

The basic chemical formula of cubic perovskite composites is ABX_3, where A and B are different-sized cations; A is larger than B, and X is usually oxygen but might also be fluorine, chlorine, nitrogen, sulfur, or carbon. The ideal structure of perovskite compounds is a cubic structure with the larger A cation (Ba, Ca, or Sr; charge state 2^+) on the cube's corner positions (0, 0, 0) and the smaller cation B, e.g. (Ti_4^+) in the body's centre (1/2, 1/2, 1/2), and the O ions (-2) in the centre of each cubic face (1/2, 1/2, 0). As a result, twelve oxygen anions coordinate the A-cation, whereas the B-cation is found in the octahedral interstices. The corners of the BX_6 octahedra joined to form a three-dimensional framework (Hassan, 2016; Jeon et al., 2015).

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We consider a solar cell with a structure consisting of three layers sandwiched between the upper cover (glass, n= 1.47), and the substrate (silicon, n= 3.775) (Kim et al., 2018; Noel et al., 2014; Stoumpos, Malliakas, & Kanatzidis, 2013).

The inner three layers are metal nano layers such as (Ag, n_1= 0.031165, Al, n_1= 2.3669, and Au, n_1= 0.13883, d_1=50nm), Titanium dioxide (TiO_2, n_2=2.4, d_2=90nm). The Perovskite($CH_3NH_3PbI_3$, n_3=1.954, $CH_3NH_3Sn_{0.5}Pb_{0.5}I_3$, n_3=1.95, $CH_3NH_3SnI_3$, n_3=1.956, d_3=250nm) respectively(Bhalla, Guo, & Roy, 2000; Noel et al., 2014; Stoumpos et al., 2013; Walsh, 2015; Wang et al., 2019). As shown in figure (1).

This paper presents several numerical results for transmittance (T) and short circuit current density (J_{sc}) for the proposed solar cell in TM mode. All computations and graphs are represented using the Maple 17 application (Al-Turk, 2011; El-Khozondar, El-Khozondar, Shabat, & Schaadt, 2018).

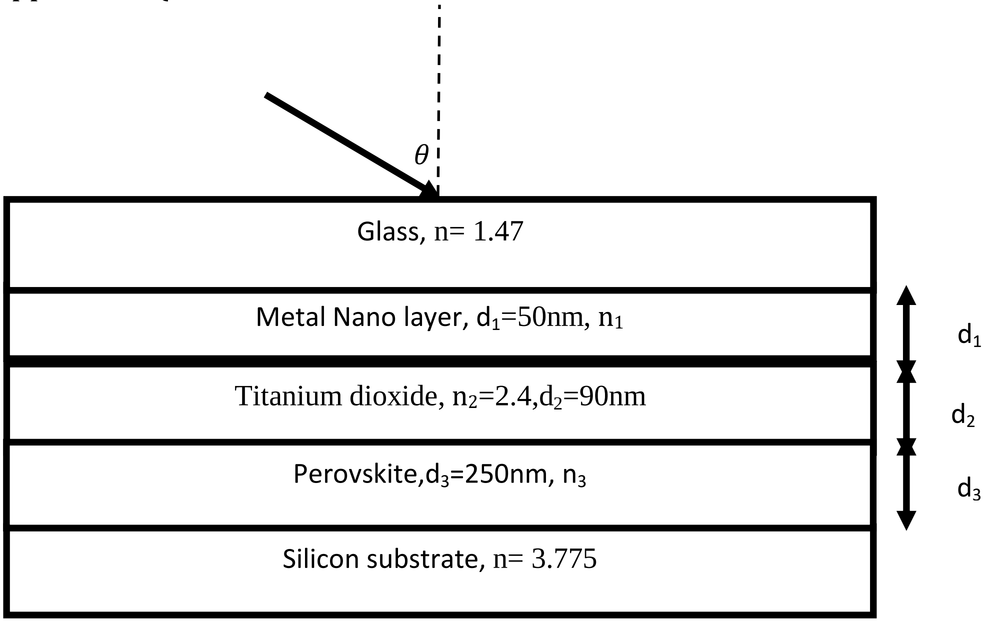

Figure 1. The heterojunction perovskite solar cell's geometry.

The method uses a matrix formulation to determine the boundary conditions at the film surfaces, which are obtained from Maxwell's equations and used to determine a system of thin films' reflectance (R) and transmission (T). The procedure produces the following Matrix for the 2x2 transfer matrix which joins the field components at two successive boundaries:

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$$\begin{bmatrix} E_a \\ B_a \end{bmatrix} = \begin{bmatrix} \cos(\delta_k) & \left(\frac{i\sin(\delta_k)}{\gamma_k}\right) \\ i\gamma_k \sin(\delta_k) & \cos(\delta_k) \end{bmatrix} \begin{bmatrix} E_b \\ B_b \end{bmatrix}$$

Where, $\delta_k = \left(\frac{2\pi}{\lambda}\right) n_k d_k co\, s(\theta_k)$ is the phase difference, $d_k\ its\ thickness,$
$\theta_k\ is\ the\ propagation\ angle, and\ \gamma_k\ is\ the\ optical\ admittance$

$gation\ angle, and\ \gamma_k\ is\ the\ optical\ admittance$

$$\gamma_k = \left\{\frac{n_k}{cos(\theta_k)},\quad forTM\ polarization\right.$$

The transfer matrix in equation 1 is a 2x2 matrix that is commonly represented by

$$M = \begin{bmatrix} m_{11} & m_{12} \\ m_{21} & m_{22} \end{bmatrix}$$

Where, $m_{11} = \cos(\delta)\,, m_{12} = \left(\frac{i\sin(\delta)}{\gamma_k}\right), m_{21} = i\gamma_k \sin(\delta)\ and m_{22} = \cos(\delta).$

Each layer of a multilayer stack of K-thin films is assigned its transfer matrix. Then (1) may be generalized as:

$$\begin{bmatrix} E_a \\ B_a \end{bmatrix} = M_1 M_2 M_3 \dots M_K \begin{bmatrix} E_b \\ B_b \end{bmatrix}$$

The product of the total transfer matrices yields an overall transfer matrix that represents the complete stack in the order that light rays pass through it:

$$M_T = M_1 M_2 M_3 \dots M_K$$

For the transmission coefficient and transmittance, equations can be solved :

$$t = \frac{\det M}{M_{22}}$$

$$T = \frac{S_2}{S_1}$$

Where S is the Pointing's vector.

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Results and discussions

We investigate the TM polarization transmittance for the proposed cells. Three types of perovskites materials used as a light absorber layer at different incidence angles, perovskite thickness, metal nano layer type and thickness of the metal nano layer.

Figures 2, 3, and 4 display the transmittance for the proposed structure for different metal nano layers (Al, Au, and Ag) of TM polarization mode for the proposed cells with ($CH_3NH_3PbI_3$, $CH_3NH_3Sn_{0.5}Pb_{0.5}I_3$, and $CH_3NH_3SnI_3$) perovskites type at different incident light wave length (300, 500, 700, 900, and 1100) nm as a function of the incident angles.

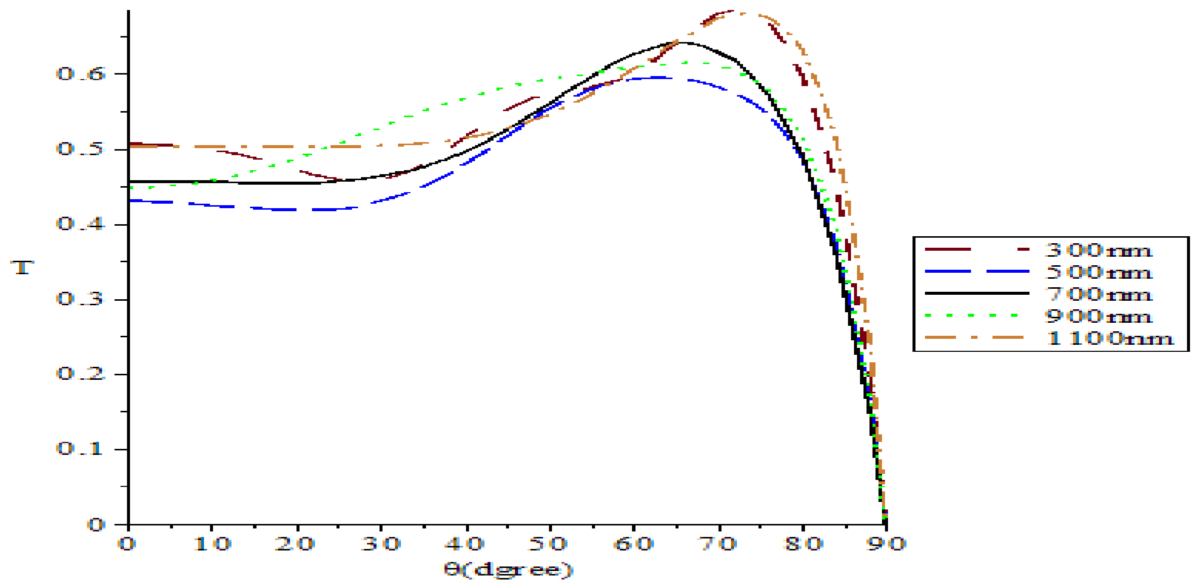

Figure 2. The transmitted light of TM polarization of the proposed structure with $CH_3NH_3PbI_3$ perovskite for different incident angles and Al nano layer.

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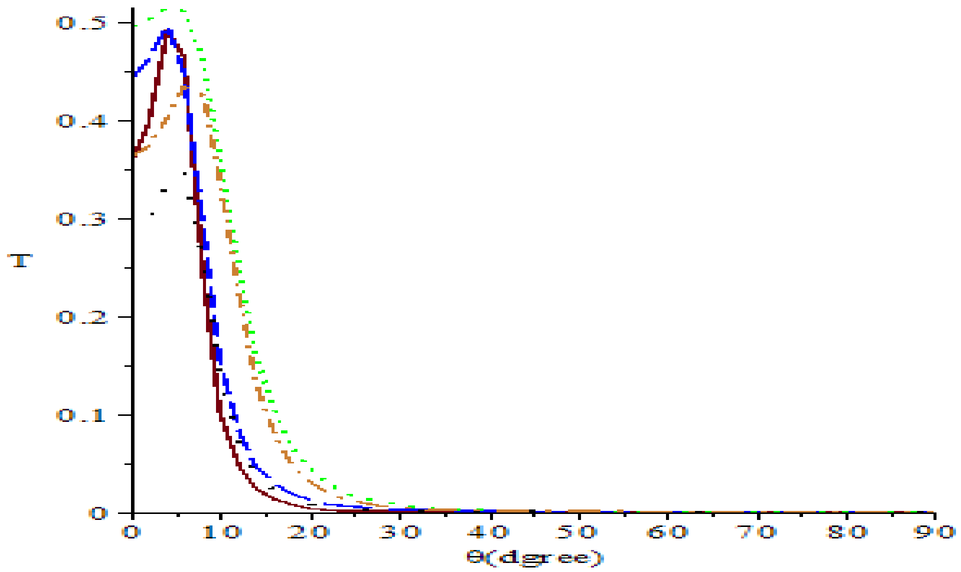

Figure 3. The transmitted light of TM polarization of the proposed structure with $CH_3NH_3Sn_{0.5}Pb_{0.5}I_3$ perovskite for different incident angles and Au nano layer.

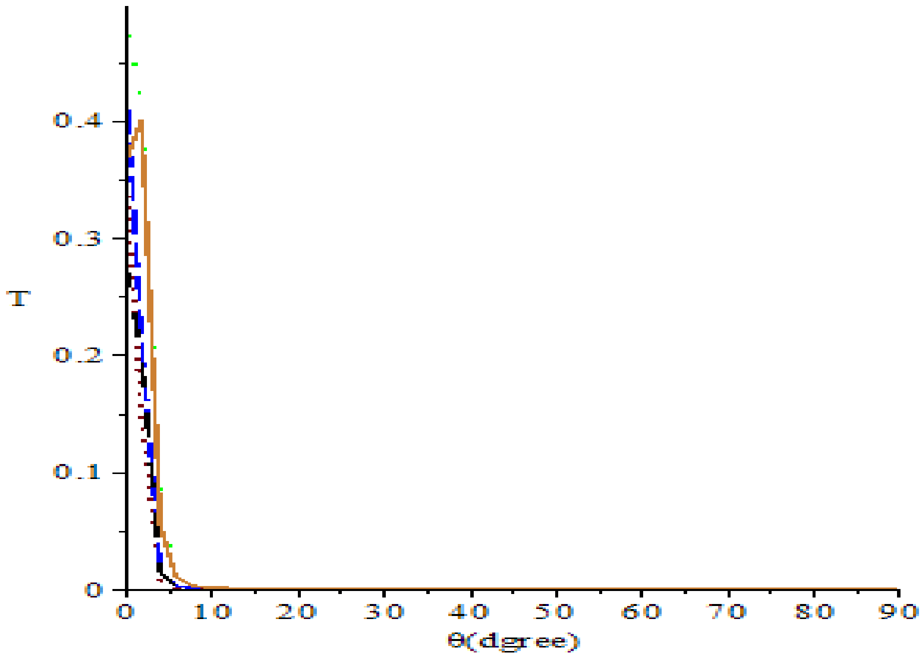

Figure 4. The transmitted light of TM polarization of the proposed structure with $CH_3NH_3SnI_3$ perovskite for different incident angles and Ag nano layer.

Figures (2, 3, and4) show that the best transmittance came from structures with aluminum, gold, and silver respectively. Excellent transmittance is provided by the aluminum cell for a wide range of incidence angles. The gold nano layer cell has a good transmittance in the range of zero to 20 degrees, and the silver cell has the poorest range of incident angles of less than 10 degrees. The wavelengths of

(300,900, and 1100) nm have the best transmittance in all cells. However, TE polarization exhibits better transmittance than TM polarization in the proposed cell results under submission.

Figures 5, 6, and 7 illustrated the transmitted light for the proposed cell which ($CH_3NH_3PbI_3$, $CH_3NH_3Sn_{0.5}Pb_{0.5}I_3$, and $CH_3NH_3SnI_3$) perovskite thickness is variable and, Ag, Al, and Au nano layers are at normal incidence.

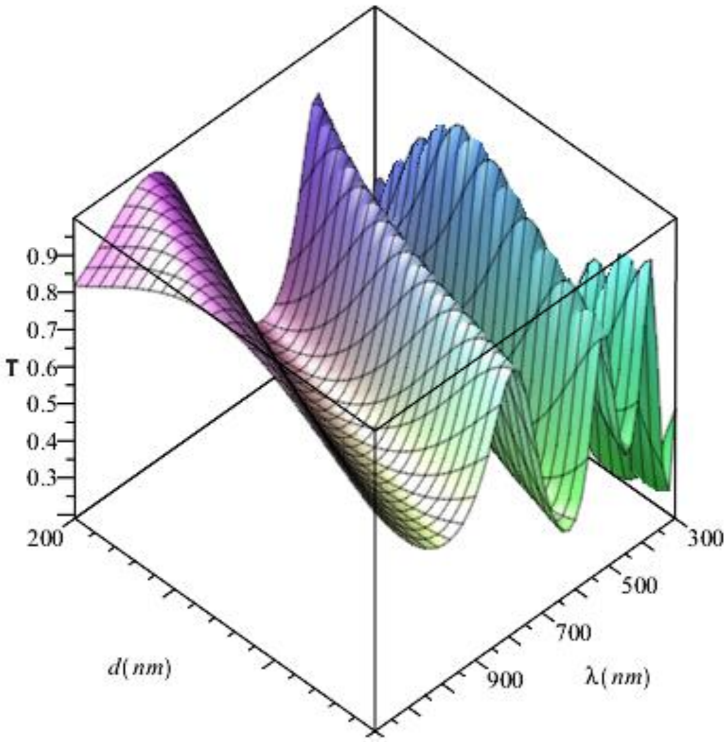

Figure 5. The transmitted light of TM polarization for the proposed cell where $CH_3NH_3PbI_3$ perovskite thickness is variable and Ag nano layer.

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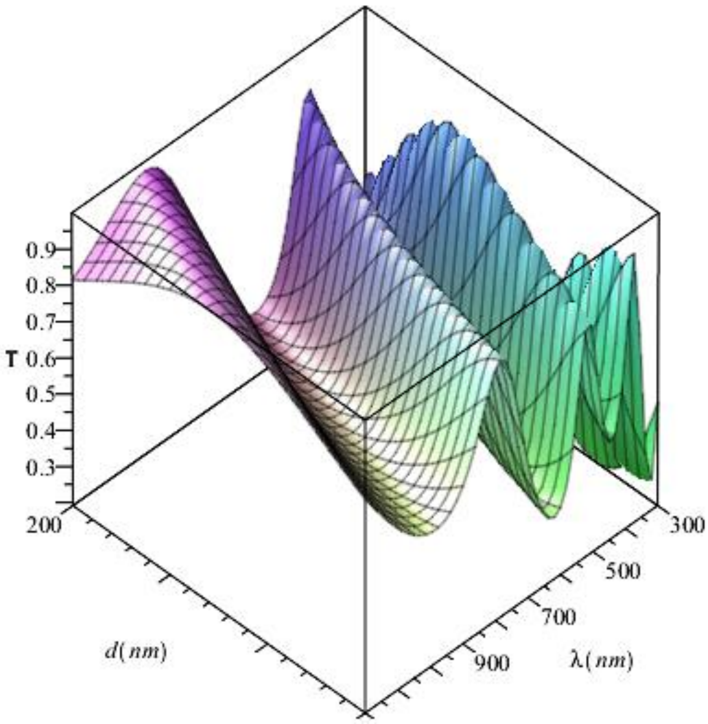

Figure 6. The transmitted light of TM polarization for the proposed cell where $CH_3NH_3Sn_{0.5}Pb_{0.5}I_3$ perovskite thickness is variable and Au nano layer.

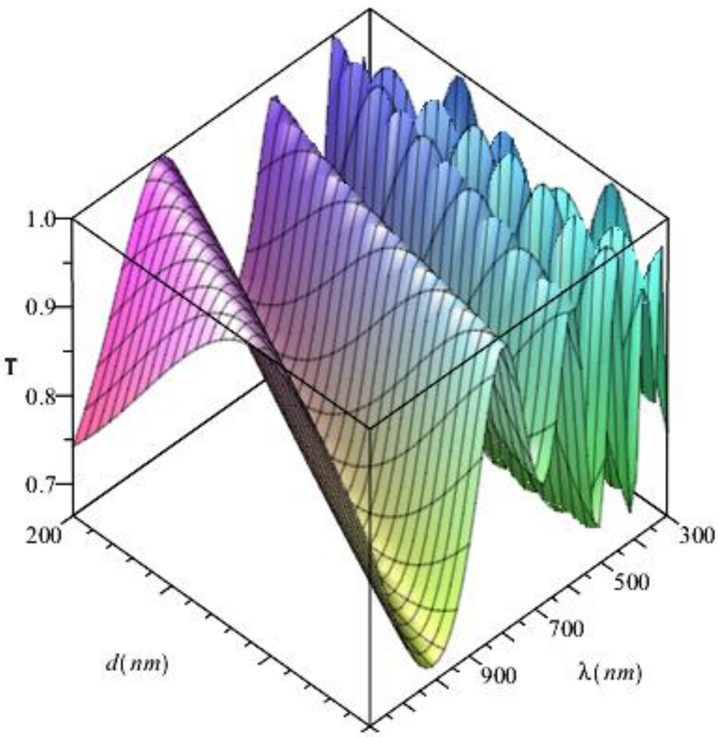

Figure 7. The transmitted light of TM polarization for the proposed cell where $CH_3NH_3SnI_3$ perovskite thickness is variable and Al nanolayer.

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Figures show that the transmittance has a value of more than 65% at 1200nm wavelength and perovskite thickness is 200nm. It also reveals that at 1200nm wavelength, the transmittance of cells with silver and gold nano layers rises as the perovskite thickness increases.

Figures 8, 9, and 10 display the transmitted light of TM polarization for the cell with $CH_3NH_3PbI_3$, $CH_3NH_3Sn_{0.5}Pb_{0.5}I_3$, and $CH_3NH_3SnI_3$ perovskite, where Al, Au, and Ag nanoparticles thickness are variable.

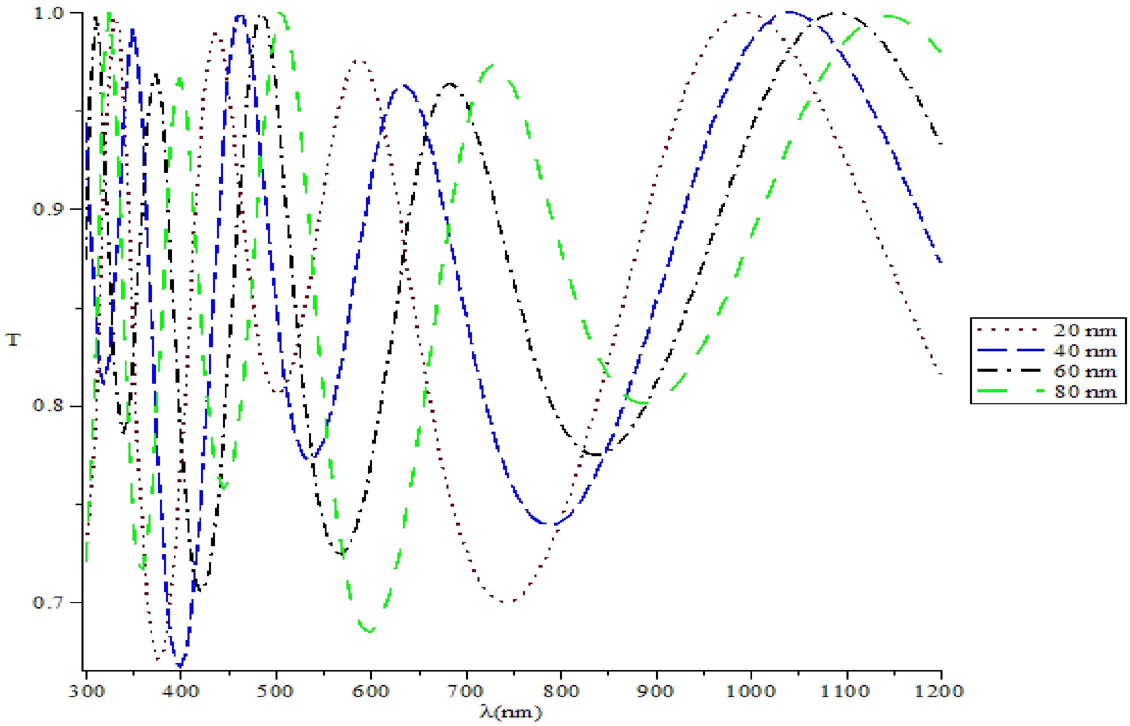

Figure 8. The transmitted light of TM polarization for the proposed cell with $CH_3NH_3PbI_3$ perovskite Which Al nano layer thickness is variable

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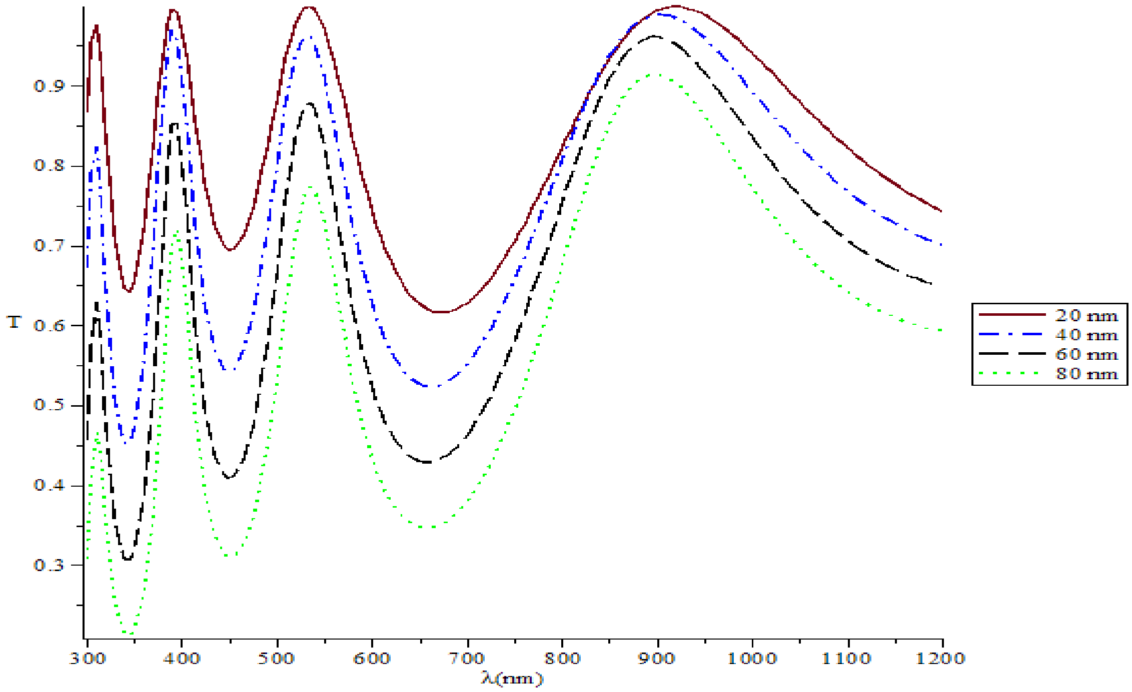

Figure 9. The transmitted light of TM polarization for the proposed cell with $CH_3NH_3Sn_{0.5}Pb_{0.5}I_3$ perovskite where Au nano layer thickness is variable.

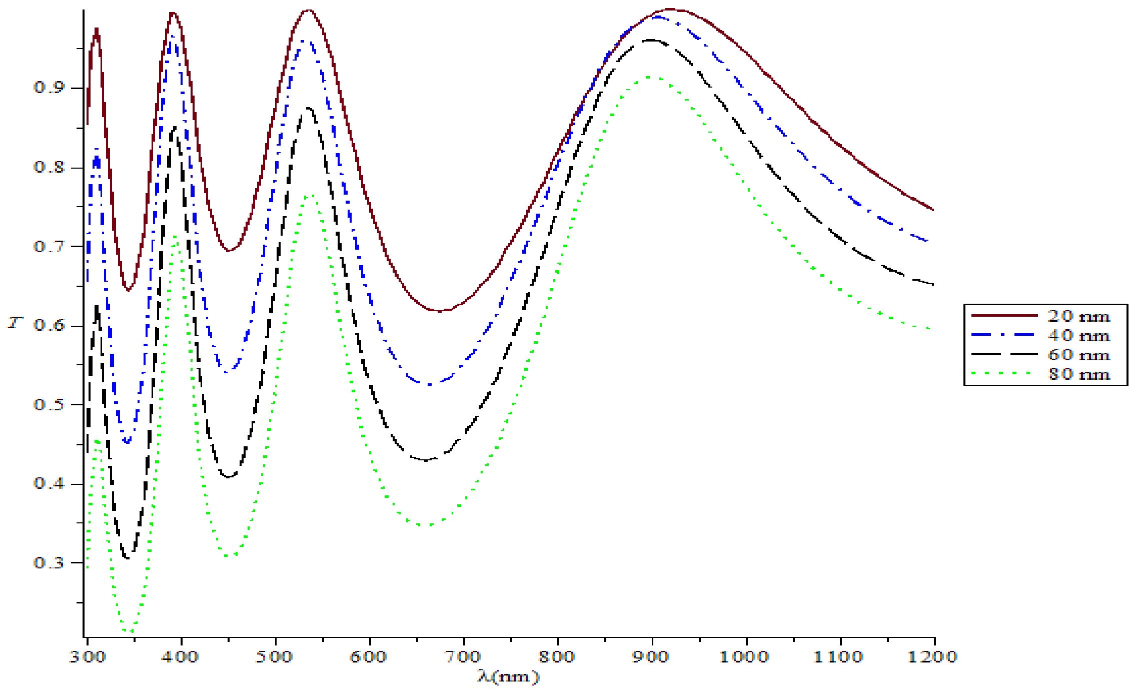

Figure 10. The transmitted light of TM polarization for the proposed cell with $CH_3NH_3SnI_3$ perovskite where Ag nanolayer thickness is variable.

These figures show that the transmittance of cells with silver and gold has values from 0.20-0.95 for

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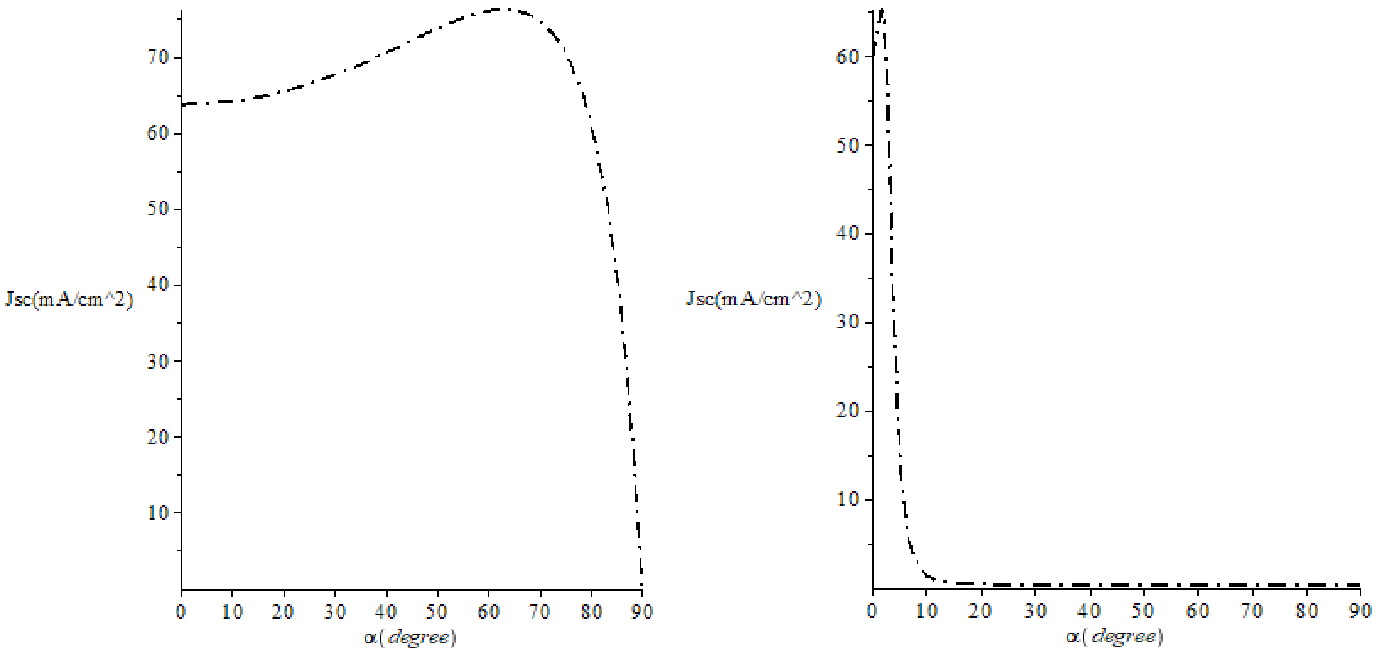
different metal nano layer thicknesses from (20-80) nm.

Fig.11 illustrates the short current density (J_{sc}) for TM polarization for $CH_3NH_3PbI_3$, $CH_3NH_3Sn_{0.5}Pb_{0.5}I_3$, and $CH_3NH_3SnI_3$ perovskite types and Al, Au, and Ag metal nano layer respectively for the wavelength range (300-1200 nm), at a standard solar spectrum irradiance of 1000 W/m^2 and varying incoming angles (Wang et al., 2019; Wu et al., 2021). The short current density (J_{sc}) of TM polarization versus the incident angle is shown in the figure above. It can be shown that the short current density reaches the greatest value at (α = 0), and it has zero value for parallel incidents. The cell of $CH_3\ NH_3Pb\ I_3$ the aluminum metal nanolayer has the highest current density and a non-zero value for a wide range of incident angles It also has a higher short circuit current density than TE mode, whereas other metal nano layers have values only for a narrow range of incident angles.



(a) (b)

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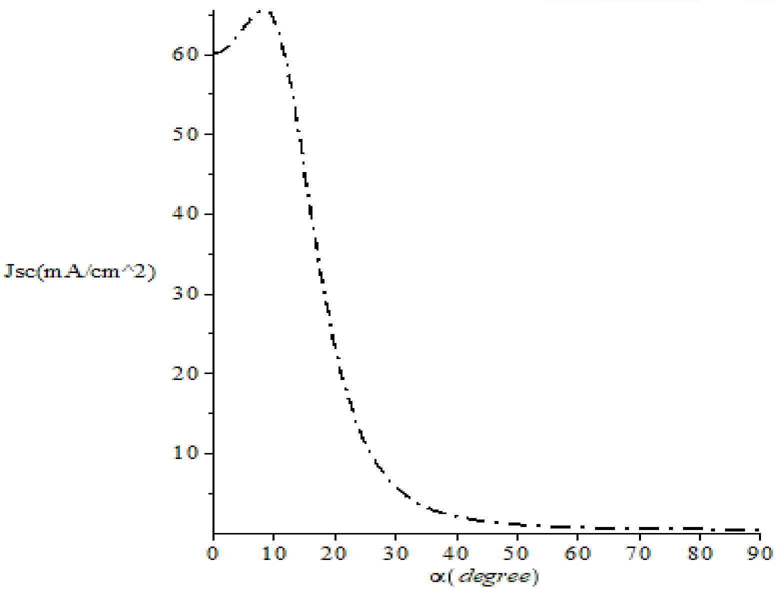

(c)

Figure 11. Short current density (J_{sc}) of TM polarization for (a): $CH_3NH_3PbI_3$ perovskite and Al, (b):$CH_3NH_3Sn_{0.5}Pb_{0.5}I_3$ perovskite and (c): Ag, $CH_3NH_3SnI_3$ perovskite and Au nanolayer

Conclusions

A computational and numerical analysis of light transmission using a perovskite solar cell has been studied. It has been demonstrated that the proposed solar cell exhibits a significant efficiency of the light transmitted and a decreased reflected light. We investigate the numerical computations for the proposed cell of three types of perovskites at different incidence angles, perovskite thickness, metal Nano layer thickness, and types. The results showed that $CH_3NH_3PbI_3$ perovskite type and aluminum metal nano layer provide the best structure for the proposed goal. Also, other materials have a bright future in design and improve the efficiency of future solar cells.

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