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Research Article

Analysis of Optical Thin-films: Towards Lower Reflectivity for High Performance Solar Cells and Modern Photonic Devices Applications

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Abstract

Recently, optical thin-films with lower reflectivity have attracted much interest for their suitability in high performance thin-film solar cells and various modern photonics devices, such as electronic display panels touchscreens, smart optical glass windows, spectacles frames, super-compact camera lenses, laser systems and optical fiber communications since lowering reflectivity coating improves the device performances. However, obtaining reduced reflectance from this arrangement remains challenging issue. As the film optical properties, such as the absorbance, reflection and transmission of particular wavelength of electromagnetic radiation can be carefully controlled by optimizing thin-film fabrication materials as well as structures, there is a lot of research scope in optimizing device reflectivity by assessing various film- and substrate materials as well as their thicknesses. Therefore, in this study, the reflectance performances of optical thin-films were characterized for obtaining lower reflectivity for various types of modern photonics applications. To obtain this, three novel optoelectronic materials InGaAs, CdTe and $CsPbBr_3$ for film layer, three widely used substrate materials glass, Al_2O_3 and steel as well as various thicknesses of film layer were evaluated. Reflectance studied of the thin-films for the three film materials have been clarified that $CsPbBr_3$ is the best among these three film materials to be used for reducing the light reflection of the thin-film. Lower reflectivity of thin-films on glass substrate suggested that glass is better than both Al_2O_3 and steel as substrate in high efficiency thin-film solar cells and various photonics devices. In addition, evaluation of reflectance for various film thicknesses showed that ultra-thin film layer is superior for reducing the reflection of solar energy by thin-film structure. We have therefore proposed that thin-film with the combination of $CsPbBr_3$ based ultra-thin film layer on glass substrate would be one of the best possible solutions for reducing reflectivity of solar cells and various photonics devices, thereby for possibly increasing the performance efficiency. This research result would be very beneficial for the development of renewable energy and photonics based nanotechnology, thereby play a significant role for reducing global energy crisis and green-house gas emission concurrently and sustainably in the modern world.

Keywords

Optical Thin-film, Thin-film Solar Cell, Optoelectronics Materials, Photonics, Renewable Energy, Solar Energy, Reflectance

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1. Introduction

Optical thin-film with lower reflectivity in the optical range of electromagnetic spectrum has attracted increasing interest of researchers because of their suitability for high performance thin-film solar cells [1-4] as well as various modern photonics devices [5, 6], such as electronic display panels [7, 8] touchscreens [9], smart optical glass windows [10, 11], spectacles frames [12], super-compact camera lenses [9], laser systems [13, 14] and optical fiber communications [15, 16] because the lowering reflectivity coating improves the device performances [17, 18].

Due to the progress of industrial revolution, the continuous rise in the quantity of carbon dioxide (CO_2) and other greenhouse gases (GHGs) in the atmosphere from energy combustion and industrial activities is a serious alert to everyone worldwide regarding climate change [19]. Furthermore, the declining reserve of fossil fuels, such as coal, natural gas and oil is a serious issue of worry considering the increasing demand for energy globally. Therefore, the potential use of renewable energy sources is an effective alternate and sustainable way to minimize the concentration of GHGs in the atmosphere and to meet the world's high energy demand [20-22]. Amongst renewable energy sources, solar energy may be the most appealing sustainable source for energy production by using photovoltaic technology [23, 24], such as solar cell as it is one the environmentally benign with vast global potential. The main issues with solar cells in comparison to traditional systems, however, continue to be their comparatively higher greater cost [25] and efficiency restrictions. A more modest option is a thin-film solar cell in terms of greater flexibility, lighter weight, lower processing cost [26] and minimal fabrication materials usage [27] etc. In addition to the photovoltaic application, lower reflectance thin-film coating is expected in many modern photonics devices which ensures the possibility of higher transmission of solar light to increase performance of the devices for particular application. Lower reflectance coating in cases of electronic display panels as well as touchscreens minimizes the reflection of light glare on the screen from outside lights, such as sunlight and fluorescent light and consequently enhances the display clarity. Similarly, in the eyeglasses or spectacles and lenses in super-compact cameras, image clearness through increasing transmission, elimination of glare, halos and ghost and eye protection can be improved by possibly lowering the reflectance of film coating on the lenses. Nevertheless, smart optical glass windows with the reduced reflection film coating provide significant benefits in terms of enhanced visibility, environmental comport through increasing natural day light usage, reduced conventional energy consumption for lighting purposes and security, which are mostly desirable for residential buildings, houses, gas station, store, bank and post office.

However, optical thin-films for solar cells and other modern photonic applications till suffer problems to achieve lower reflectivity which is mostly brought on by the thin active layer, which reduces the likelihood of incoming photons being absorbed and thereby results in the high reflectivity of this arrangement [28]. As technology advances, it is anticipated that the issues will be resolved. One possible solution to overcome the limitation is to reduce the reflectivity from the interfaces of different layers of the optical thin-film devices. As the film optical properties, such as the absorbance, reflection and transmission of particular wavelength of electromagnetic radiation can be carefully regulated by optimizing thin-film fabrication materials as well as structures, there is a lot of research interest in optimizing device reflectivity by assessing various film- and substrate materials as well as their thicknesses. Several studies on optical thin-films have been reported previously by many authors [1-4, 11, 15, 16, 29] for determining the optimum thickness and materials to be used as anti-reflecting coatings for various applications. In this study, thin film's reflectance characteristics have been evaluated for three film materials (InGaAs, CdTe and $CsPbBr_3$), three substrate materials (glass, steel and Al_2O_3) and finally for the film's thickness. Thus, the purpose of this research has been identified to optimize materials and structures of thin-film towards lower reflectivity in the optical range of the electromagnetic spectrum for high efficiency photovoltaic cells and many modern photonic applications.

Among different film materials, InGaAs [30], CdTe [31] and $CsPbBr_3$ [32] have drawn increased attention from researchers because of their special optical and electrical characteristics that make them appropriate for thin-film structure. InGaAs is a group III-V compound semiconductor alloy whose band gap energy can be adjusted between 0.35 to 1.45 eV within the visible range of light as well as lattice parameter can be matched to substrate by tuning In concentration in the alloy [33, 34]. In addition, this alloy has good temperature coefficient and radiation-resistance [35] which are importantly desirable for flexible optical and optoelectronic device applications. CdTe is the second most widely used photovoltaic material worldwide, behind crystalline silicon, presently holding a 5% market share. CdTe is a very robust and chemically stable material [30, 35-37] and, for this reason, CdTe-based thin-film solar cells can be manufactured quickly and inexpensively [38-40]. Also, CdTe is a direct-band gap material with possibility of band gap energy tuning from 1.4 to 1.5 eV, which is almost ideal for turning sunlight into electricity [41-43]. The ideal band gap of CdTe could surpass the Schockley-Queisser limit, allowing it to achieve efficiencies about 32% and a short circuit current density over 30 mA/cm^2 [44]. In addition to these advantages properties and efficient application, due to it's lower cost and high absorption coefficient [45, 46], it is also used in some other novel applications, such as detectors [47] and photovoltaics [48]. Various methods, such as atomic layer epitaxy (ALE) [49], pulsed laser [50], spin coating [51], electron beam evaporation [52], electro-deposit [53], metal-organic chemical vapour deposition (MOCVD) [50], close-space sublimation (CSS) [52], sputtering [54] and also thermal evaporation [55] have been investigated as suitable techniques for the fabrication of CdTe thin film. The third film materials used in this study, $CsPbBr_3$, a member of inorganic perovskites, has attracted much interest because of large light absorption coefficient, high carrier mobility and superior stability under harsh humid and thermal environments, which are suitable for various optoelectronic devices applications [56-59], such as solar cells and photo detectors [60, 61]. Nevertheless, the compositional elements of this inorganic perovskite have significant impact on its electrical and optical characteristics. In the recent year, organic–inorganic lead (Pb) halide (X) perovskite materials (PbX_3, X = I, Br, and Cl) have very promising performance in optoelectronic applications, such as solar cells, photodetectors, and light-emitting devices [62] due to their affordable price, easy fabrication process, excellent absorption coefficient and adjustable band gap. However, their relatively poor thermal stability remains major obstacle to further development of devices based on these materials. All-inorganic cesium (Cs) lead halide perovskites ($CsPbX_3$) have garnered a lot of interest due to their improved thermal and light exposure stabilities [61] in addition with other unconventional characteristics such as, higher photoluminescence quantum yields (PLQYs), longer carrier diffusion length, balanced carrier mobility etc. [63-65]. In all-inorganic perovskites crystal structure $CsPbX_3$, cubic (α) phase $CsPbI_3$ is the most suitable option for photovoltaic system because its smallest bandgap can absorb wide solar spectrum. However, crystal structure of $CsPbI_3$ remains unstable with respect to the temperature [66]. In $CsPbBr_3$, the addition of bromide ions into the lattice of inorganic perovskites makes the cubic black phase of the perovskite crystal at room temperature more stable [61, 67]. Nevertheless, lead and halogen have stronger ionic bonding characteristics due to their greater electronegativity differences, which produce shorter bond length and a wider band gap. $CsPbBr_3$ solar cell has a high open-circuit voltage (V_{OC}) due to its wide bandgap [68, 69]. There are multiple morphologies of $CsPbX_3$, such as single crystal, bulk polycrystalline films, and nanocrystal films etc. $CsPbBr_3$ nanocrystals exhibit the highest photoluminescence quantum yield (PLQY) of 95% and exceptional stability [70-72]. Therefore, $CsPbBr_3$ nanocrystals have been chosen as absorber layer in this study. Choosing an appropriate manufacturing method is essential to produce high performing $CsPbBr_3$ thin-film solar cells. Recently, the chemical solution approach, electrochemical route [69], mechanochemical synthesis [61], vapor-phase deposition method [73], and vacuum thermal evaporation method [74-76] are the most widely used techniques for creating high-quality $CsPbBr_3$ films.

Three widely used substrate materials i.e. glass [77], steel [78] and Al_2O_3 [79] have been evaluated in this study for applying thin-film to high performance optical and optoelectronics devices. Glass, first substrate material among these three, is a cost effective, high environmental stable, optically transparent and electrically conductive which mostly fulfill the requirements of substrates for applying to the thin-film solar cells. However, steel can be employed as the film substrates due to its' mechanical strength, ultraviolet durability and corrosion resistance properties. Al_2O_3, the third substrate material used in this study, is one of the most widely used substrates due to its great mechanical strength, exceptional heat resistance, abrasion resistance, and low dielectric loss. In addition, the Al_2O_3 substrate has a low porosity and a smooth surface.

The paper is organized with five sections. The paper begins with brief introduction in section 1. Methods and techniques including structure of four medium thin-film, the reflectance equation and the simulation method will be covered in section two of this work. In section 3, the reflectance properties of the thin-film for three film materials, three substrate materials and various thicknesses will be analyzed and discussed. Lattice mismatch at the point where the film layer meets the substrate was also evaluated. The findings will be briefly concluded in section 4.

2. Methods and Methodology

The evaluation of normal-incidence reflectance of an optical film over the ultraviolet-visible-infrared (UV-Vis-IR) regions of the electromagnetic spectrum is a powerful non-destructive method for characterizing optical thin film. The reflectance is the quantity of energy that is reflected of incident light. Previously, we reported optical properties of three-layered (air/film/substrate) optical thin film structure [80]. In this paper, we have studied and simulated reflectance performance for four-layered (air/film/substrate/air) structure to be used for high performance modern optical and optoelectronics applications, such as electronic display panels, touchscreens and thin-film solar cells. A simple model of the four-layered optical structure is that consists of a film deposited onto a substrate [81] as demonstrated in Figure 1. Suppose that a light of wavelength λ is incident normally on the film of thickness d_1 and complex refractive index $n_1 - jk_1$ from a non-absorbing medium of refractive index n_0(air). The film layer is mechanically supported by a transparent non-absorbing substrate $(k_2 = 0)$ layer. Finally, the substrate is surrounded by the fourth layer, air. Reflectance of optical thin film for any type of film and substrate materials can be determined based on the refractive index formulae [82]. Electromagnetic wave such as light propagating inside each layer of optical thin-film executes multiple back and forth reflection from the interface between two successive layers before entering to nearby layers. More specifically, the light beam incoming from the air medium (layer 1) on the air-film interface as depicted in Figure 1, it is partially refracted into the film (layer 2) and partially reflected back into this air layer. This beam of refracted light is then partially transmitted into the substrate (layer 3) and partially reflected back inside the film from the film-substrate interface and so on. In this process, the backward propagating reflective wave of light have been formed which is not desirable for thin film for photovoltaic applications. Lower the reflectance, higher the possibility of light absorption by the optical thin-film.

Reflectance of this thin-film structure have been derived as-

$$R_{eff} = \frac{\{(n_1+1)(n_1+n_2^2)\}-2x\cos\phi\{(n_1^2-1)(n_1^2-n_2^2)\}+x^2\{(n_1-1)^3(n_1-n_2^2)\}-16n_1^2n_2x}{\{(n_1+1)(n_1+n_2^2)\}-2x\cos\phi\{(n_1^2-1)(n_1^2-n_2^2)\}+x^2\{(n_1-1)^3(n_1-n_2^2)\}} \quad (1)$$

Where, n_0= refractive index of the air =1, n_1 = refractive index of the film, n_2 = refractive index of the substrate, phase difference, $\phi = \frac{4\pi n_1}{\lambda}$, λ = operating wavelength of electromagnetic spectra, $x = \exp(-\alpha_1 d_1)$, α_1 = absorption coefficient of the film $= \frac{4\pi k_1}{\lambda}$, k_1 = extinction coefficient of the film, and d_1 =thickness of the film. To visualise and examine the reflectance property of optical thin-film for novel film materials InGaAs, CdTe, and $CsPbBr_3$ on three substrates (Al_2O_3, glass, and steel), the Matlab code has been used to simulate the equation Eq. 1. Numerical values of various parameters that were employed during simulation in this research have been listed in the Table 1.

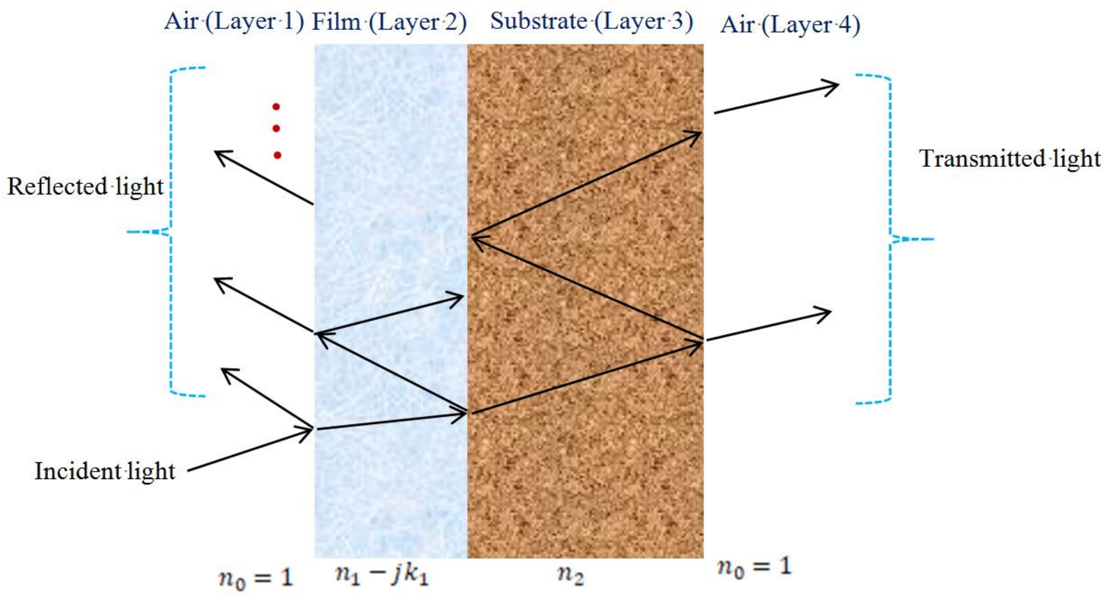

Figure 1. *Four-layered optical thin-film structure with incident, reflected and transmitted light.*

Table 1. *Numerical values of various parameters that were employed in this research.*

Symbols	Parameters	Numerical values
λ	Operating wavelength of incident electromagnetic radiation	0-1000 nm
n_0	Refractive index of air	1.0
	Refractive index of film material, InGaAs	3.98
n_1	Refractive index of film material, CdTe	2.98
	Refractive index of film material, $CsPbBr_3$	1.34
	Refractive index of glass substrate	1.47
n_2	Refractive index of Al_2O_3 substrate	1.77
	Refractive index of steel substrate	2.75
k_1	Extinction coefficient of the film, InGaAs	0.46

Symbols	Parameters	Numerical values
	Extinction coefficient of the film, CdTe	0.35
	Extinction coefficient of the film, $CsPbBr_3$	0.20
d_1	Thickness of the film layer	0-250 nm

3. Results and Discussions

3.1. Optimization of Reflectance Performance for Three Novel Film Materials InGaAs, CdTe and $CsPbBr_3$

To achieve optimized reflectance from the thin-film for different film materials, the reflectance (R_{eff}) properties have been examined as shown in Figure 2 as a function of wavelength for three film materials InGaAs, CdTe and $CsPbBr_3$.

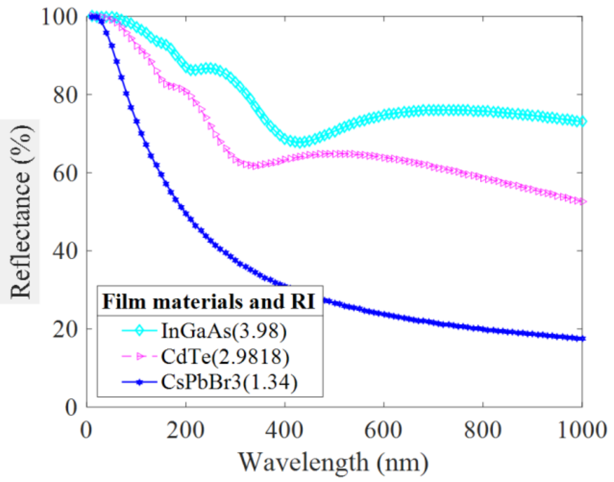

Figure 2. Reflectance performance of InGaAs, CdTe and $CsPbBr_3$ film materials on glass substrate.

It can be seen from Figure 2 that the amount of reflectance in percentage degrades with increasing wavelength of incident light for all film materials on glass substrate. The reflectance is found to be decreased more rapidly from 0 to 200 nm wavelength for $CsPbBr_3$ than InGaAs, and CdTe. It is also noticed that R_{eff} of $CsPbBr_3$ film is always lower than that of other two film materials, InGaAs and CdTe at any wavelength. As can be seen from the figure, R_{eff} of $CsPbBr_3$ is about 22% at 600 nm wavelength ($E = 2.066\ eV$) while R_{eff} of CdTe and InGaAs are more than 60% and around 80%, respectively. Thus, it can be concluded that $CsPbBr_3$ based optical thin-film reflects less energy of incident light, transmits more light into the devices and thereby possibly provides better performance efficiency which is desirable for various photonics and optoelectronics devices such as solar cells. This finding has a good agreement with the results reported previously [60, 61]. In other words, it can be said that $CsPbBr_3$ can play as better refractor than CdTe and InGaAs. Therefore, most of the incident light enters into that film. It is known that $CsPbBr_3$ has large light absorption coefficient and high carrier mobility [62, 83-85]. Thus, the absorption rate of photons of refracted light through the film layer is reasonably high enough so that a large number of free carriers (electron-holes pairs) might generate in that film material than other two film materials. Then, the large number of photo-generated carriers easily separated towards the collection terminals of the devices due to the high carrier mobility and thereby affects the photocurrent performances significantly which is desirable for solar cell, photodetectors and other optoelectronics applications [61, 62]. Since the refractive index of $CsPbBr_3$ ($n_1 = 1.34$) is lower than that of CdTe ($n_1 = 2.98$) and InGaAs ($n_1 = 3.98$), it is revealed that the reflectivity of thin-film rises with increasing refractive index of the film layer. It can be explained by a view point of optics that as the refractive indices ratio, $n_0 : n_1$ at the air-film interface decreases with increasing film refractive index, the probability of electromagnetic wave reflection from the interface becomes more. Similar phenomena have been occurred at the film-substrate interface. In the optoelectronics, we know that photon energy and wavelength of electromagnetic radiation are inversely related by the equation, $E = {hc}/{\lambda}$ where h = Planck's constant, and c = velocity of light. Thus, the higher energy photons in the shorter wavelength range of incident electromagnetic radiation are reflected mostly from the interfaces of air-film and film-substrate. As the wavelength of radiation increases, the energy of photon and thereby rate of photon reflection by thin-film decreases, simultaneously. In addition, an additional anti-reflecting coating layer on the top surface was not considered in this study, therefore some fraction of incident radiation naturally reflects from the front surface of the thin-film [28]. It should be noted that there exist some oscillations in Figure 2 on the reflectance curves which were found noticeably for InGaAs and CdTe based thin-films. This is because several reflected waves from the device's interfaces interfere with one another in both constructive and destructive ways. The oscillation period and amplitude of these features rise with wavelength. Thus the wavelength of electromagnetic spectra has a significant impact on the reflectance properties of multilayer thin-films. In addition, since the light reflection by either InGaAs film or CdTe film is greater than that of $CsPbBr_3$, the oscillation in reflectance curve caused by interference is more observable in InGaAs and CdTe-based thin-film characteristics.

3.2. Optimization of Reflectance Performance for Three Widely Used Substrate Materials Glass, Al_2O_3 and Steel

The R_{eff} characteristics curves for substrates Al_2O_3 and steel have been visualized in Figure 3 and Figure 4, respectively as a function of wavelength. The best substrate for obtaining lowest reflectivity among the three familiar substrates glass, Al_2O_3 and steel used in this study can be found by making comparison among Figure 2, Figure 3 and Figure 4. Similar degradation tendency of reflectance of the thin-film was investigated for all the three substrate materials as can be seen from Figures 2, Figure 3 and Figure 4. However, the amount of reflectance of $CsPbBr_3$ film on glass substrate and that on Al_2O_3 substrate are comparable, but are significantly smaller than that on steel substrate. The thin-film on steel substrate remarkably reflects the electromagnetic waves.

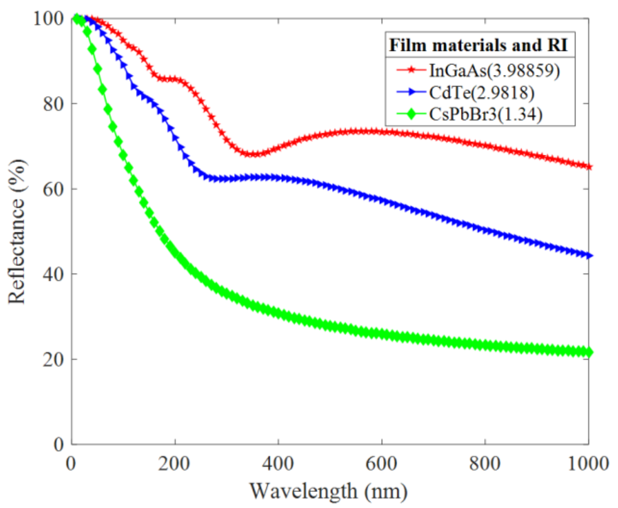

***Figure 3.** Reflectance of InGaAs, CdTe and $CsPbBr_3$ film materials on Al_2O_3 substrate.*

For examples, it is seen from the Figure 5, R_{eff} of $CsPbBr_3$ on glass substrate and on Al_2O_3 substrate are less than 10% and around 16%, respectively at 1000 nm wavelength while that on steel substrate is more than 35%. Thus, steel substrate is not suitable to be used as substrate to boost the thin-film solar cells' efficiency. Although glass substrate and Al_2O_3 substrate play nearly comparable role on reflectivity of thin-film solar cells, we proposed to use glass substrate for optoelectronics applications due it's lower cost, optical transparent and better electrical conductivity [77]. Since the glass's refractive index ($n_2 = 1.47$) is lower than that of Al_2O_3($n_2 = 1.77$) and steel ($n_2 = 2.75$), it can be concluded that as the refractive index of the substrate layer rises, the thin-film reflectivity rises as well. It can be explained in other words that as the refractive indices ratio, n_1:n_2 at the film-substrate interface decreases with increasing substrate refractive index, the amount of reflection of electromagnetic waves from the interface becomes more. Like Figure 2, some oscillations have also been observed noticeably for InGaAs and CdTe-based thin-film characteristics on Al_2O_3 substrate as illustrated in Figure 3 due to the similar phenomena explained earlier.

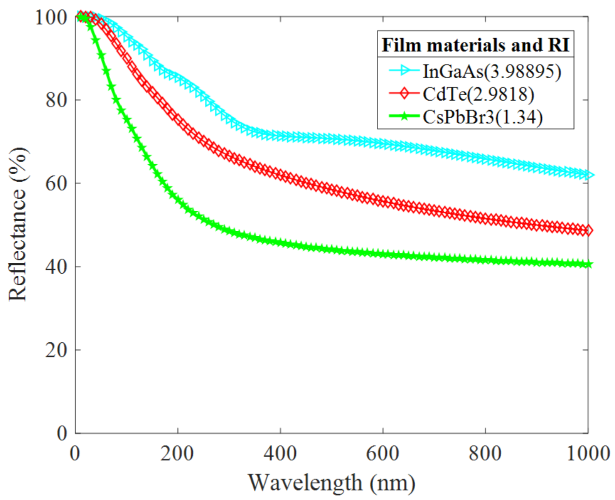

***Figure 4.** Reflectance of InGaAs, CdTe and $CsPbBr_3$ film materials on steel substrate.*

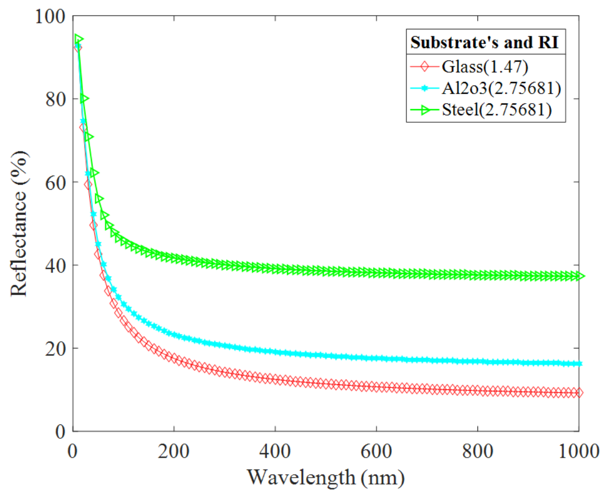

***Figure 5.** Reflectance of $CsPbBr_3$ film material on glass, Al_2O_3 and steel substrate.*

3.3. Optimization of Reflectance Performance for Film Thickness

In this section, the thin-film structure has been optimized for achieving lower reflectivity by varying thickness of the film layer. Figure 6 illustrates the reflectance properties of the thin film as a function of film's thickness for InGaAs, CdTe and $CsPbBr_3$ film materials. According to the figure, the reflectance of thin-film increases with increasing film thickness for all film materials on glass substrate. However, $CsPbBr_3$ based thin-film shows the lowest reflectivity among these three film materials at any thickness of the film.

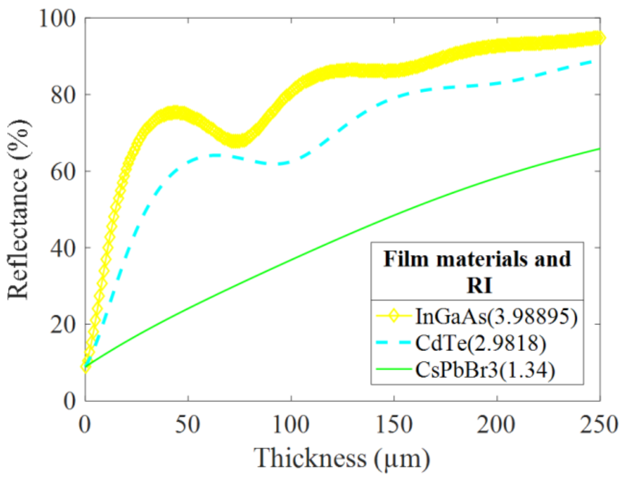

Figure 6. *Reflectance of $CsPbBr_3$ film material on Glass substrate as a function of thickness.*

It is also noticed that at lower thickness, the reflectance of film material is relatively lower. This can be explained by the fact that the possibility of photon reflection by thin-film with lower film thickness is minimum. As seen from Figure 6 that at 50 nm thickness, the reflectance of $CsPbBr_3$ is about 22%, while the reflectance becomes more than 65% at 250 nm. Thus, the film's thickness has a significant impact on the reflectance of optical thin film. In addition, $CsPbBr_3$ is better in comparison to both InGaAs and CdTe for thin-film solar cell for any thickness because of relatively lower reflectivity. As the film layer's thickness increases, the electromagnetic waves must take a longer route from the film's surface to the substrate, the possibility of bending, scattering and reflection of radiation obviously increases through the thicker film layer. This is evident from Figure 6 that the increment in thickness of the film layer results in uprising of the reflectance of the thin-film. The larger reflections of light through multiple reflections are affected strongly by interference, thus oscillation period and amplitude of reflectance characteristics become more investigable for InGaAs and CdTe-based thin-film with increasing film thickness.

Our findings from the simulated results on $CsPbBr_3$ have good agreement with the corresponding experimental results reported previously. Several researchers [73, 87] have successfully prepared $CsPbBr_3$-based high quality thin-film solar cells with good reproducibility and high stability. $CsPbBr_3$-based high-performance photodetectors have been fabricated and evaluated in early 2023 [88]. The most recent development of $CsPbBr_3$ crystal growth and its uses in solar cells, photodetectors and high-energy ray detectors have been presented in a reviewed article [84].

3.4. Evaluation of Lattice Mismatch of Film Materials $CsPbBr_3$, CdTe and InGaAs to Substrates Glass, Al_2O_3 and Steel

In this study, although the reflectance characteristics of film materials on different substrates have been evaluated by MATLAB simulation without considering lattice mismatch at the interface between two layers of film and substrate with different lattice constant, there is a possibility to generate misfit dislocations at the hetero-interface due to lattice mismatch to relax the compressive strain in the film layer. Therefore, it is important to evaluate lattice mismatch at the interface for the three film materials to three substrates in this study. Table 2 showed the calculated lattice mismatch of film materials $CsPbBr_3$, CdTe and InGaAs to substrates glass, Al_2O_3 and steel.

Table 2. *Calculated lattice mismatch of film materials $CsPbBr_3$, CdTe [46] and InGaAs to substrates glass, Al_2O_3 and steel used in this study.*

Parameters	**Film materials**			**Substrate materials**		
	$CsPbBr_3$	**CdTe**	**InGaAs**	**Glass**	**Al_2O_3**	**Steel**
Lattice parameter (Å)	5.87	6.48	5.85	3.90	4.79	2.87
Lattice mismatch to Glass substrate	33.51%	39.77%	33.28%	--	--	--
Lattice mismatch to Al_2O_3 substrate	18.48%	26.16%	18.21%	--	--	--
Lattice mismatch to Steel substrate	51.18%	55.77%	51.01%	--	--	--

Table 2 gives the evidence that the lattice mismatch of $CsPbBr_3$ and InGaAs to any particular substrate is nearly same. It is also noticed that among the three film materials and three substrate materials combination, the lowest lattice mismatch was occurred at the interfaces of $CsPbBr_3/Al_2O_3$ and InGaAs/Al_2O_3 structures while larger mismatch would possibly occur when any film materials was deposited on the steel substrate. For examples, the lattice mismatch for either $CsPbBr_3$ or InGaAs on Al_2O_3, glass and steel substrates are about 18%, 33.5% and 51% respectively. As the lattice mismatch becomes larger, dislocation motion as well as the generation or multiplication of defects which act as carrier recombination centres may easily occur at the hetero-interface of the structure which in turn lowering the output current of solar cell. Thus although we have recommended $CsPbBr_3$/glass structure for efficient thin-film solar cell in terms of lower reflectivity in this study, however considering lattice mismatch, $CsPbBr_3/Al_2O_3$ structure is comparatively suitable for lower carrier recombination centres.

4. Conclusions

Reflectance, one of the most important optical features, of the thin-film have been studied for getting lower reflectivity which is expected to increase performance efficiency of solar cells and various modern photonic devices, such as electronic display panels, touchscreens, smart optical windows, spectacles frames, super-compact camera lenses, laser systems and optical fiber communication. To achieve the goals, at first three novel optoelectronics materials InGaAs, CdTe and $CsPbBr_3$ have been considered as film materials and evaluated in this study. It was concluded that $CsPbBr_3$ shows the lowest reflectivity performances among these three film materials. Secondly, three widely used substrate materials glass, Al_2O_3 and steel have also been evaluated for optimizing reflectivity of the thin-film. The lower reflectivity of thin-film on glass substrate has suggested that glass is better than both Al_2O_3 and steel as a substrate in high efficiency photovoltaic cells and many modern photonic applications. In addition, the evaluation of reflectance for various film thicknesses exposed that ultra-thin film layer is better for achieving lower reflectivity of the optical thin-film. Finally, it has been proposed that thin-film solar cells with $CsPbBr_3$ based ultra-thin film layer on glass substrate would be the one of the best possible solutions for reducing reflectivity, thereby for boosting the effectiveness of thin-film solar cells and other contemporary optical and optoelectronics devices. The research finding from the study would be very helpful for emerging renewable energy and photonics based nanotechnology for minimizing demand for energy worldwide as well as for the sustainable ecofriendly-clean modern world. Additional layers as well as valuable materials could be added to this proposed construction in the future to further increase performance.

Abbreviations

R_{eff}	Reflectance
T_{eff}	Transmittance
GHGs	Green House Gases
CdTe	Cadmium Telluride
InGaAs	Indium Gallium Arsenide
$CsPbBr_3$	Cesium Lead Bromide
Al_2O_3	Aluminium Oxide
Å	Angstrom

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Author Contributions

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Rony Tota: Supervision, Validation, Writing – review & editing

Ershad Ali: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Software, Visualization, Writing – original draft

Mohamad Obayedulla: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Software, Visualization, Writing – original draft

BrijKishor Yadav: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Software, Visualization, Writing – original draft

Disclosure

The authors attest that this work is unique, hasn't been published anywhere else, and isn't presently being considered for publication anywhere.

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Conflicts of Interest

The authors declare no conflicts of interest.

Appendix

Graphical abstract

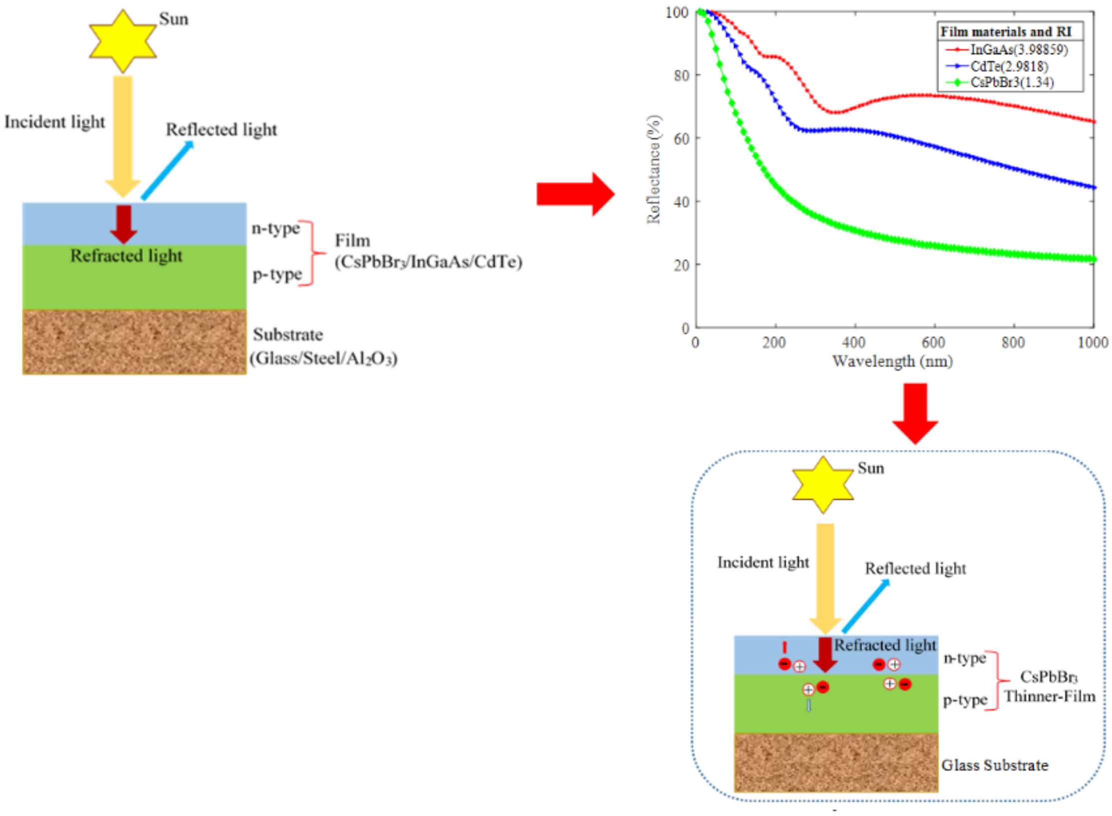

***Figure 7.** Graphical abstract.*

Research highlights:

1) Lower the reflection of light, thereby higher the refraction of light by the thin-film structure results in higher possibility of electron-hole pair generation.
2) Therefore, reflectance has been analysed and evaluated for the different thin-film structures.
3) By evaluating reflectance of different structures, the structure of the thin-film has been proposed.
4) Thin-film with the combination of $CsPbBr_3$ based ultra-thin film layer on glass substrate would be one of the better option for reducing reflectivity of solar cells and various photonics devices, thereby for possibly increasing the performance efficiency.
5) Considering lattice mismatch, $CsPbBr_3/Al_2O_3$ structure is comparatively suitable for lower carrier recombination centres.

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