International Journal of ChemTech Research
CODEN (USA): IJCRGG ISSN: 0974-4290
Vol.8, No.12 pp 360-366, 2015

Simulation Studies on Ceramic Coatings on Aluminium thin films for Solar Reflector Application

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Abstract: Concentrating solar power technologies is one of most promising and competitive energy source for the future and it is necessary to develop aluminum reflector coating on polycarbonate substrate material that are low in weight and cost , maintain high reflectance under harsh condition in outdoor environments. Oxidation significantly reduces aluminums reflectance in the ultraviolet and causes lightly scattering throughout the spectrum. For long-term performance, protective layer will be necessary and the addition of adhesion-promoting layer could improve durability. The front surface of the protected aluminum coating on polycarbonate substrate reflects an average of 0.90 over UV Vis NIR spectrum region. Aluminum coated with a ceramic film arrests oxidation, minor abrasion resistance and helps maintain a high reflectance. Overcoating metallic coatings with a hard, single, ceramic layer of half-wave optical thickness improves abrasion and tarnish resistance but marginally reduces optical reflectance from 0.92 to 0.90.Optimised thickness of aluminum thin film of 200nm and protective layer SiO_2 of 200nm gives a maximum reflectance of 0.90.
Keywords: Reflectance, UV- Vis- NIR,Solar reflector, Simulation&Optimization.

Introduction:

The design and simulation of the reflective multilayer optical coatings on polycarbonate substratefor solar reflector application, Light weight, lower cost and durable solar reflectors made with polymer mirror film are an attractive alternative to other types of solar reflectors. To make concentrating solar power technologies more cost competitive, it is necessary to develop advanced reflector materials that are low in cost and maintain high reflectance for extended lifetimes under severe outdoor environments. Several materials combinations being developed by industry include silvered glass mirrors, aluminized reflectors, and front-surface mirrors. Aluminum thin film, the most widely used metal for reflecting films, offers consistently high reflectance throughout the UV, visible and near-infrared regions of the spectrum. While copper and silver exhibits slightly higher reflectance than aluminum through most of visible spectrum, the advantage is temporary because of oxidation tarnishing. Aluminum also oxidizes, though more slowly, and its oxide is tough and corrosion resistant. Oxidation significantly reduces aluminums reflectance in the ultraviolet and causes light scattering throughout the spectrum.

Protected aluminum is the very best general - purpose metallic coating for use as an external reflector in the visible- near infrared spectra. Protected aluminum is aluminum coated with a ceramic film arrests oxidation, enhances minor abrasion resistance and helps maintain a high reflectance.

Reflective layer systems on polycarbonate sheet are optimized regarding their optical function. Objective of this paper is to identify the best combination of multilayer coating for high reflectance in the solar spectrum, wavelength ranging from 250nm to 2500nm as shown in Figure 1.Extensive researchhas been carried out on Al/Al2O3 multilayer thin film coating deposited on silicon wafers using RF magnetron sputtering with better wear-resistance mechanical property [1]. The reflectivity or reflectance (R), of a surface is an intrinsic optical property of a surface.

The deposition of aluminum thin film on low weight polycarbonate substrate is one of the promising candidates in solar thermal reflector. Modeling of thin film multilayer coating performed using CODE software to find out the optimum reflectance of aluminum based reflector. Protective coatings which are transparent in UV VIS NIR region were used on top of aluminum reflective coating to simulate optical reflection. Ceramic adhesive layer provides the binding force between substrate and aluminum thin film.

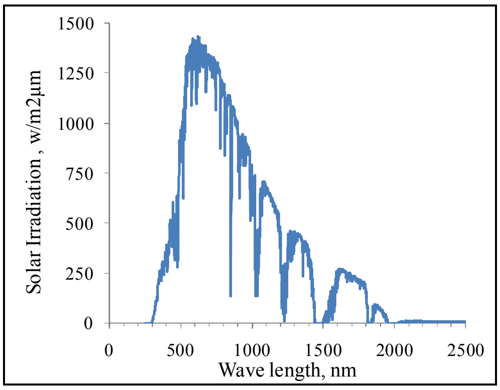


Figure1: Spectrum of Solar Irradiation on Earth Surface

The model assumes film has homogeneous, continuous, isotropic and ideal interfaces. Solar reflector system is to a large extent determined by the optical property like reflectance. Optical characterization is essential in finding out performance of solar reflector system. Scope for deposition and characterization of metallic thin films on polymer substrates compared to other substrates for reflector applications is one of major challenge[3-5].

Multifunctional high reflectance layer systems were successfully deposited on glass and polyethylene terephthalate (PET) substrates at a low deposition temperature of 150 °C, demonstrating the possibility of coating certain polymer materials [6].

Simulation study was carried out to find best combination of material among adhesion layer, and each of the protective layers on aluminium reflective layer and to maximize reflection. We have carried out modeling and simulation of multilayer system with aluminum as a reflective layer by varying protective layer material and its thickness as model shown in Figure 2.It is significant to improve the efficiency of solar reflector systems which will strongly depend on the optical properties of solar reflective materials and multi-layer structure [7-12].

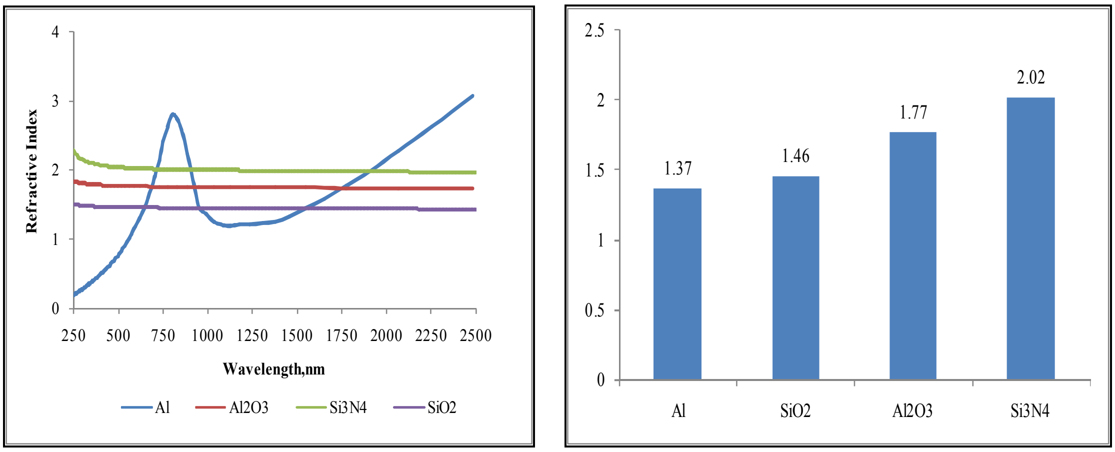
	Protective Layer
	Metal High Reflective Layer
	Ceramic Adhesive Layer
	Polycarbonate Substrate

Figure 2: Schematic of Multilayer Design of Reflective Coating

2. Materials and Methods:

Using CODE software optical property like reflectance in UV Vis NIR region [250nm -2500nm] were simulated by choosing aluminum has a reflective coatingalong with an adhesive and protective layer. The solar-reflector device can be optimally designed to achieve maximum reflection of the solar energy in the solar radiance spectral region. The solar reflector stacking sequence consists of adhesive layer, reflective layer and protective layer. Based on literature review SiO_2, $Si_3N_4$and Al_2O_3have been selected for optimization and work was undertaken to study the spectrally reflective thin film structure with different combination of materials and thickness as schematically shown in Figure 2.

The typical film structure from surface to substrate is composed of protective layer that protects the reflective aluminum metal layer from oxidation as it is exposed to air, a thin solar aluminum reflective metal layer, designed with a thickness such that solar radiation is effectively reflected back to a maximum extent on adhesive bond coated polycarbonate substrate. Selected Adhesive bond coatings for design considerations are SiO_2, $Si_3N_4$and Al_2O_3. Based on the refractive index of the protective layer at a wavelength of 632.8nm and its oxidation characteristics at atmospheric condition selection was made and used for optical simulation. The variation of the refractive index with respect to wavelength in UV Vis NIR region and refractive index at 632.8nm plotted as shownFigure 3(a) and 3(b) respectively.



(a) (b)

Figure 3: (a) Variation of refractive index of protective layers with respect to wavelength(b) Refractive index of coating material at 632.8nm

The Fresnel reflection coefficient of an interface between two semi-infinite media of complex refractive indices n_m , $n_s$for polarized radiation incident at non normal angle is given by equation 1 [17]. When n_m , n_s correspond to air and the metal, respectively, and when the angle of incidence is zero, where k_s is the extinction co-efficient of material the equation 1 reduces to equation 2:

$$R = \left[\frac{n_s - n_m}{n_s + n_m}\right]^2 \quad [1]$$

$$R = \frac{(n_s - 1)^2 + k_s^2}{(n_s + 1)^2 + k_s^2} \quad [2]$$

From the above equation thickness of the protective layer is taken in to consideration by considering the interference effects between the two layers(optical thickness > λ/4), and to get the maximum reflection throughout UV Vis NIR region. Thickness of the protective layer considered is above 100nm so that the constructive interference will give maximum reflection and the thickness above the visible spectrum will have less influence on the total percentage of reflectance.

The simulation was carried out by varying the protective layer and its thickness from 100nm-200nm with an increment of 50nm. Aluminum reflective material with a thickness of 200nm was taken into consideration based on its maximum specular reflectance.

Results and Discussions:

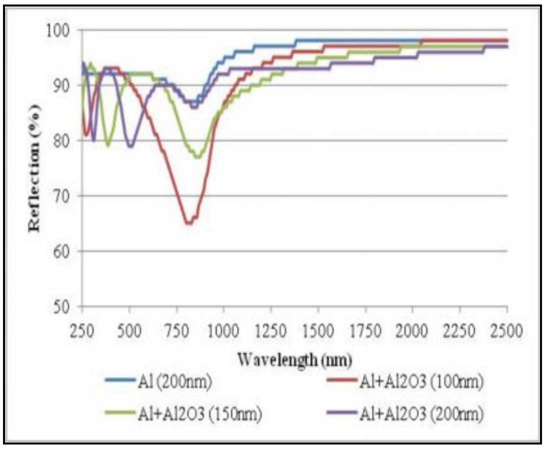
Using CODE software reflection of multilayer coating simulated by varying the thickness of Al_2O_3, Si_3N_4 and $SiO_2$from 100nm-200nm with an increment of 50nm, keeping 200nm aluminum thin film constant on polycarbonate substrate. Reflectance calculated using standard AM 1.5 solar spectrum and the equation 3 gives reflectance value as shown below.

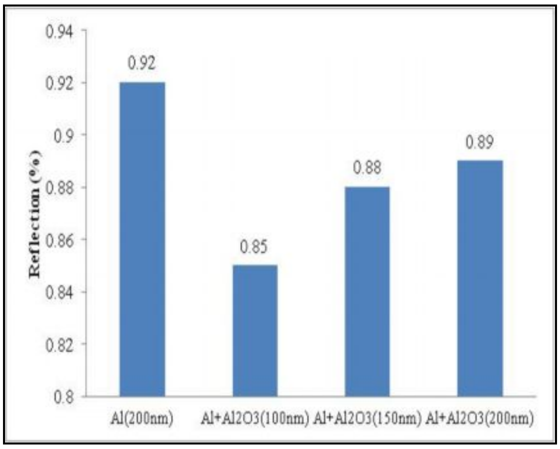
The solar reflectance of the surface may therefore be written as

$$\varepsilon_t = \frac{\int_{\lambda 1}^{\lambda 2} [\rho_d(\lambda)] J(\lambda) d(\lambda)}{\int_{\lambda 1}^{\lambda 2} J(\lambda) d(\lambda)} \quad [3]$$

Where J (λ) is the solar irradiance function, the limits on the integrals (λ_1 & λ_2) are typically 0.2µm and 2.5µm respectively. These limits are chosen such that the equation can be adequately calculated without significant error.

The simulation was carried out by varying Al_2O_3thickness, and percentage (%) of reflection was plotted against the wavelength is as shown in Figure 4 (a) and solar Reflectance plotted as shown in the Figure 4 (b). In general, metals have very high extinction coefficients, making them good reflectors, while k for insulators are generally small, making them poor reflectors. From the Figure 4(a) and 4(b) it clearly seen that there is a limit for the reflection of aluminum thin film that is around 0.92 which is called as reflectivity of the aluminum thin film and even after increase in the thickness of aluminum thin film there is no variation (in simulation it is around 100-150nm but in practical it depends on the process and microstructure of the deposited film). With respect to change in the thickness of Al_2O_3 that is from 100 to 200nm, the reflectance increases from 0.85 to 0.89 (5% increase) because of shift in the antireflection part.

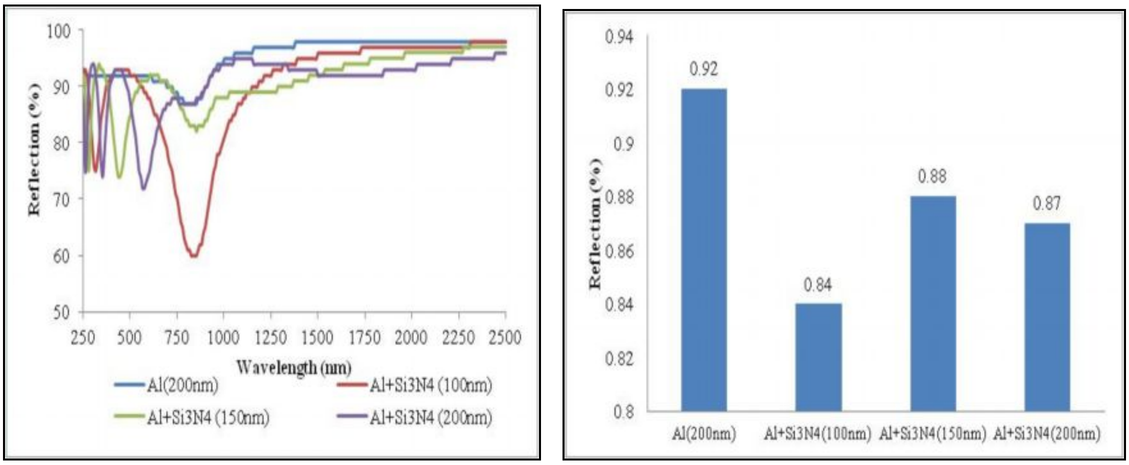




(a) **(b)**

Figure 4: (a) Variation of thickness of Al_2O_3 protective layers with respect to wavelength(b) % of reflectance with varying Al_2O_3 coating material

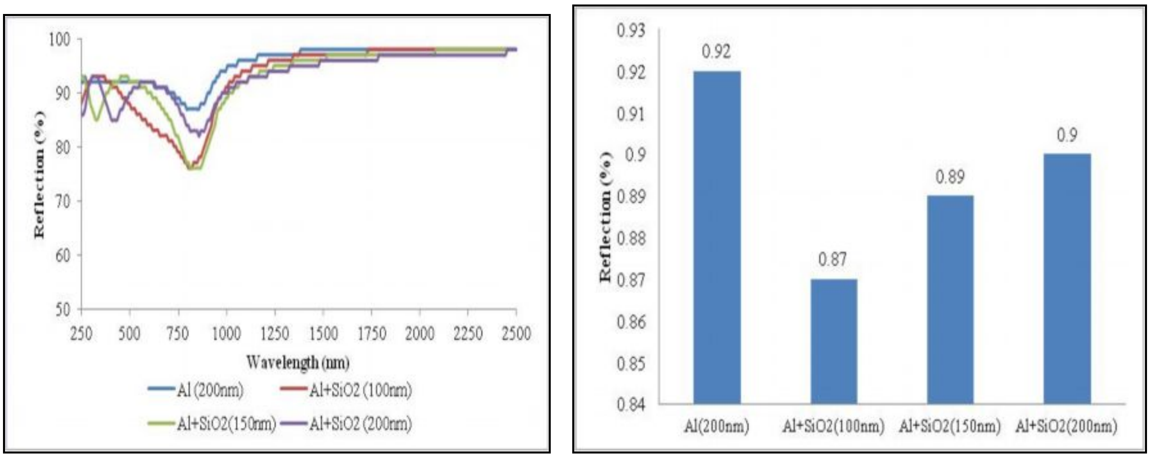
The simulation carried out by varying Si_3N_4 thickness, and percentage (%) of reflection was plotted against the wavelength is as shown in Figure 5 (a) and solar Reflectance plotted as shown in the Figure 5 (b). With respect to change in the thickness of Si_3N_4 that is from 100 to 200nm, the reflectance increases from 0.84 to 0.87 (3% increase) because of shift in the antireflection part.



(a) **(b)**

Figure5: (a) Variation of thickness of Si_3N_4 protective layers with respect to wavelength (b) % of reflectance with varying Si_3N_4 coating material

The simulation carried out by varying SiO_2 thickness, and percentage (%) of reflection was plotted against the wavelength is as shown in Figure 6 (a) and solar Reflectance plotted as shown in the Figure 6 (b). With respect to change in the thickness of SiO_2 that is from 100 to 200nm, the reflectance increases from 0.87 to 0.9 (3% increase) because of shift in the antireflection part.



(a) **(b)**

Figure6: (a) Variation of thickness of SiO_2 protective layers with respect to wavelength (b) % of reflectance with varying SiO_2 coating material

From the simulation study of multilayeraluminum reflective coating with Al_2O_3, Si_3N_4 and SiO_2 as a protective layer it clearly shows that there is a clear trend that with increase in the thickness of the protective layer there is a marginal increase in the reflectance value which nearer to aluminum reflectance value. Protected aluminum reflector coating with SiO_2 shows high reflectance because of lower refractive index compared to Al_2O_3, Si_3N_4. High reflection aluminum coatings can be applied to the outside of a component, such as a flate piece of glass, polycarbonate and steel to produce a first surface reflector. Aluminum coatings do not relay on the principals of optical interference, but rather on the physical and optical properties of the protective coating material. However, metallic coatings are often coated with thin ceramic films to increase reflectance over a desired range of wavelengths. Overcoating metallic coatings with a hard, single, ceramic layer of half-wave optical thickness improves abrasion and tarnish resistance but marginally affects optical properties. Depending on ceramic material like Al_2O_3, Si_3N_4 and SiO_2 used, such over coated aluminum are referred to as durable, protected, or hard- coated metallic reflectors.

Conclusion:

In the present work, Aluminum thin films with thickness of 200 nm were modeled and simulated with different bond layers and protective layers on polycarbonate substrate for solar reflectors application. Reflectors with thin film coated Aluminum does not withstand outdoor ageing, the initial total and specular solar reflectance of Aluminum thin film is 0.92. Additional issues to address include determining the coating thickness needed to ensure optical properties for reflection. The fast degradation of the specular reflectance of Aluminum thin film will decrease unless it is protected by ceramic coatings like Al_2O_3, Si_3N_4 and SiO_2. Thickness of 200nm protective layer (SiO2, Al2O3 and Si_3N_4) on 200nm aluminum thin film gives maximum reflectance of 0.87, 0.89 and 0.90 respectively. Therefore, recommendations of ceramic layer on aluminium reflector materials to use are made here based on the simulation results. However, a reflector coated with ceramic layer on aluminiumthinfilm on a polycarbonate substrate shows promising stability of the optical properties for cost-effective in concentrating solar energy applications. The material under development offers promise as a commercially viable for solar reflector materials.

Acknowledgements:

The authors would like to thank the Solar Energy Research Initiative (SERI) Department of Science and Technology, New Delhi, India for funding this research work. The authors gratefully acknowledge the support from management of R.V. College of Engineering, Bangalore, The National Institute of Engineering Mysuru, and Visveswaraya Technological University, Belagavi.

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