Simulation studies on multilayer coatings for solar absorptance

Muralidhar Singh M., K. V. Nagesha, and Garimella Raghu Chandra

Citation: AIP Conference Proceedings **1992**, 040014 (2018); doi: 10.1063/1.5047979
View online: https://doi.org/10.1063/1.5047979
View Table of Contents: http://aip.scitation.org/toc/apc/1992/1
Published by the American Institute of Physics

Simulation Studies on Multilayer Coatings for Solar Absorptance

Muralidhar Singh M [1, a)], K.V. Nagesha[1, b)], Garimella Raghu Chandra [2, c)]

[1]*Sr. Assistant Professor, Department of Mechanical Engineering, Madanapalle Institute of Technology and Science, Angollu, Madanapalle, Chittoor District, Andhra Pradesh*
[2]*Assistant Professor, Department of Electrical and Electronics Engineering, Madanapalle Institute of Technology and Science, Angollu, Madanapalle, Chittoor District, Andhra Pradesh*

[a)]drmuralidharsinghm@mits.ac.in
[b)]drnageshakv@mits.ac.in
[c)]raghuchandhra@gmail.com

Abstract: Concentrating solar power technologies is one of most promising and competitive energy source for the future and it is necessary to develop multilayer coating material that has high Absorptance and under harsh condition in outdoor environments. Oxidation significantly reduces multilayer coatings absorptance in the infrared region 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 life of the absorbers. The front surface of the protected nickel coating on glass substrate has an average absorptance of 0.62 over UV Vis NIR spectrum region. Nickel coated with a ceramic film arrests oxidation, minor abrasion resistance and helps maintain a high absorptance. Over coating metallic thin film coatings with a hard, single, ceramic layer of halfwave optical thickness improves the hardness and resistance to scratch but marginally reduces optical absorptance from 0.62 to 0.60. Optimised thickness of nickel thin film is 200nm and the thickness adhesive and protective layer (Si_3N_4) of 50nm gives a maximum absorptance of 0.62.

Keywords: Absorptance, UV- Vis- NIR, Solar Absorber, Simulation & Optimization.

INTRODUCTION

The design and simulation of the absorptive multilayer optical coatings on different substrate for solar absorber application, Light weight, lower cost and durable solar absorbers made with multilayer coatings are an attractive alternative to other types of solar absorbers. To make concentrating solar power technology more cost effective, it is necessary to develop advanced absorber thinfilm materials that are low in cost and maintain high absorptance for extended life of these coatings under severe outdoor environments [1-5]. Several materials combinations being developed by industry include copper, aluminum, nickel and chromium metal layers with combination of ceramic layers like alumina, silicon oxide and silicon nitride with solar absorptance throughout the UV, visible and NIR secular region. While nickel thin film exhibits slightly higher absorptance than aluminum and copper thin films through most of visible spectrum, the advantage is temporary because of oxidation resistance [6-9]. Nickel also oxidizes, though more gradually, and its oxide is hard and corrosion resistant. Oxidation of thin film coatings significantly reduces nickel absorptance in the ultraviolet and causes light scattering throughout the spectrum [10-13]. In this paper simulation study was carried out to find best combination of material among adhesion layer such as alumina silicon nitride and silicon oxide, and each of the protective layers on nickel absorber layer and to maximize absorptance. We have carried out modeling and simulation of multilayer system with nickel as an absorptive layer by varying the thickness of the bond and protective layer material. It is important to improve the efficiency of solar absorber system which will depend on the optical properties of solar absorptive material and multi-layer with combination of Ceramic layers.

International Conference on Renewable Energy Research and Education (RERE-2018)
AIP Conf. Proc. 1992, 040014-1–040014-5; https://doi.org/10.1063/1.5047979
Published by AIP Publishing. 978-0-7354-1708-3/$30.00

MATERIALS AND METHODS

Using CODE software optical property like absorptance in UV Vis NIR region [250nm -2500nm] were simulated by choosing nickel has a absorptive coating along with an adhesive and protective layer. The solar-absorber systems can be optimally designed to achieve maximum absorptance of the solar energy in the solar spectral region. The solar absorber stacking sequence consists of adhesive layer, reflective layer and protective layer. The Design of experiment (DOEs) provide a organized and efficient approach for the optimization of the parameters. The Taguchi method has been used to determine suitable design parameters for optimum conditions to achieve required properties. Taguchi employs an orthogonal array (OA) that ensures a balanced comparison of levels of any parameters. OA are a special standard simulation design method that requires only a less number of experimental trials to find the main factors influencing on output. Before selecting an OA, the minimum number of experiments to be performed is to be fixed based on the formula below [10]. Hence, a minimum of 9 experiments are to be performed based on these OA as shown Table 1 which gives the parameters and the levels. Table 2 gives the absorptance values for 9 different combinations of multi-layered coatings.

Table 1 Parameters and Levels for Thickness of Multilayer Coatings for Absorptance

	Parameters	**Levels**		
		1	**2**	**3**
A	**Bond Layer Si_3N_4 (nm)**	50	100	150
B	**Nickel (nm)**	100	200	400
C	**Protective Layer Si_3N_4 (nm)**	50	100	150
D	**Substrate**	Glass	Steel	PC

Table 2 L9 Array to Determine the Optimum Coating Thickness for Absorptance

Expt. No.	**Bond Layer Si_3N_4 (nm)**	**Nickel (nm)**	**Protective Layer Si_3N_4 (nm)**	**Substrate**	**Absorptance (%)**
1	**50**	**100**	**50**	**Glass**	**62**
2	50	200	100	Steel	55
3	50	400	150	PC	53
4	100	100	100	PC	54
5	100	200	150	Glass	52
6	100	400	50	Steel	56
7	150	100	150	Steel	51
8	**150**	**200**	**50**	**PC**	**62**
9	150	400	100	Glass	53

The simulation results of single layer coatings indicate that nickel is the preferred functional material, while Si_3N_4 would be suitable for bond and protective layer for any of the three substrates selected for the present study. Table 1 shows the parameters and levels to determine coating thickness for absorptance; However it is important to determine the optimum coating thickness of bond layer, functional layer and protective layer. In this case Si_3N_4- Ni-Si_3N_4. Taguchis design of experiment approach was adopted to optimize the coating thickness of this multilayered coating. In the simulation the bond layer thickness was varied from 50 to 150nm, functional layer coating was varied from 100 to 400nm and protective layer coating was varied from 50 to 150nm. Table 2 provides the L9 experimental array adopted for simulation to determine the optimum thickness of the multi-layer coatings.

From Table 1 the percentage effect of each parameter was computed i.e., bond layer has 14% effect, nickel has 14% effect, and protective layer has 58% effect on absorptance of multilayered thin films and substrate has 14%

effect on absorptance as shown in Figure 1. Figure 2shows the corresponding main-effect plots for thickness optimization as a function of absorptance.

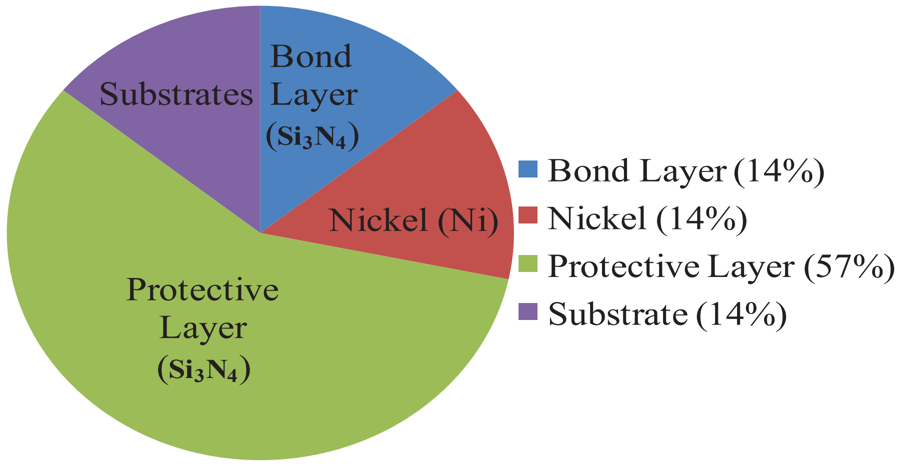


Figure 1 Percentage Effect on Absorptance

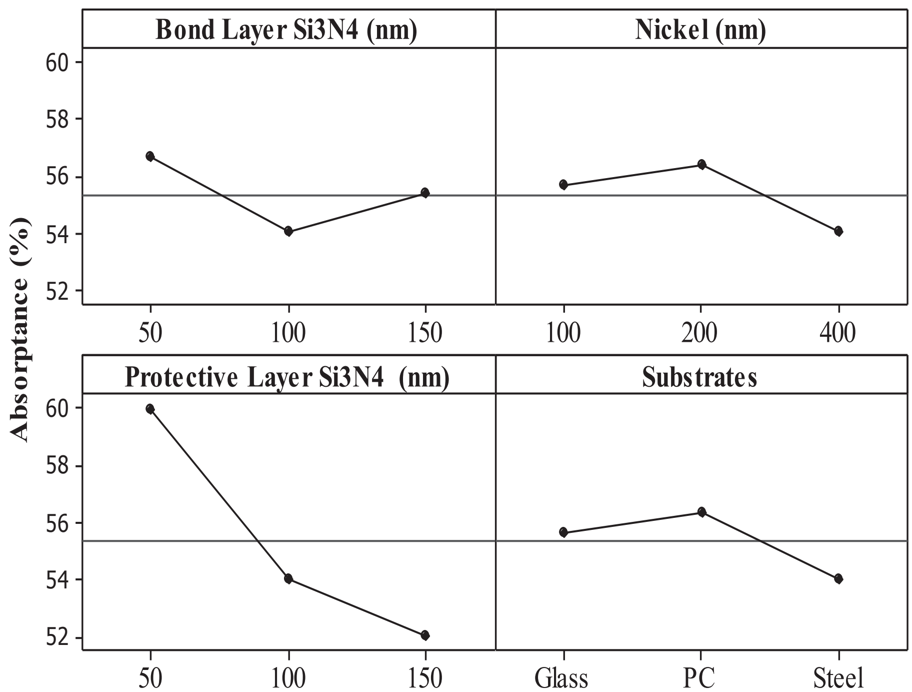
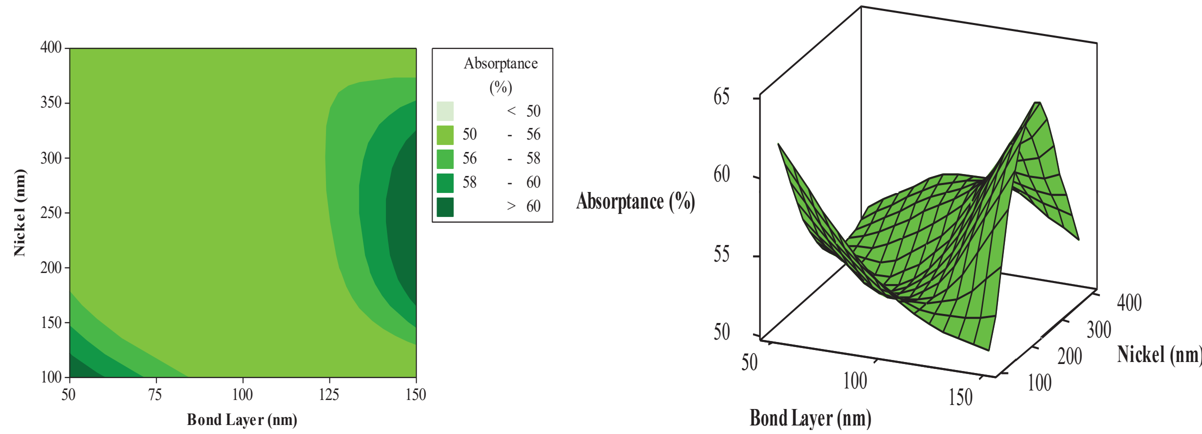


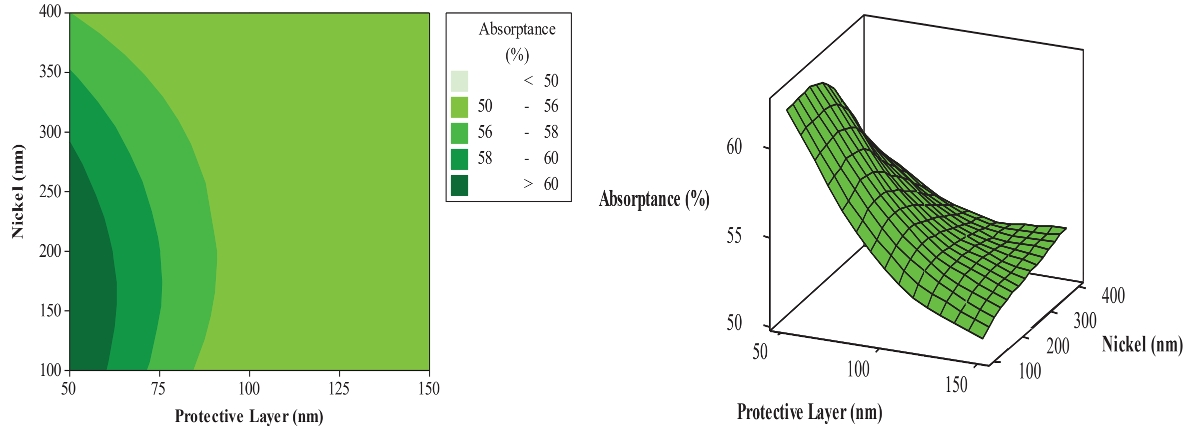
Figure 2 Main Effects Plots for Thickness Optimization for Absorptance

Figure 3 (a) & (b) shows contour and surface plots for absorptance as a function of the thickness of nickel and bond layer. Figure 4 (a) & (b) shows contour and surface plots for absorptance as a function of the thickness of nickel and protective layer. It indicates that the thickness of protective layer should be between 50 to 60nm, thickness of nickel coating should be between 100 to 270nm and bond layer should between 140 to 150nm in order to achieve a maximum absorptance of 62%. The Analysis of Variance (ANOVA) was used to determine the optimum thickness of bond layer, nickel and protective layer using ANNOVA. The optimum thickness of bond layer is 50nm; nickel layer thickness is 200nm and protective layer thickness of 50nm respectively obtained and these results in an absorptance value of 62.22% as shown in Figure 5.



(a) (b)

Figure 3 (a) Contour Plots and (b) Surface Plot for Absorptance as function of Thickness of Nickel and Bond Layer



(a) (b)

Figure 4 (a) Contour Plots and (b) Surface Plots for Absorptance as a function of thickness of Nickel and Protective Layer

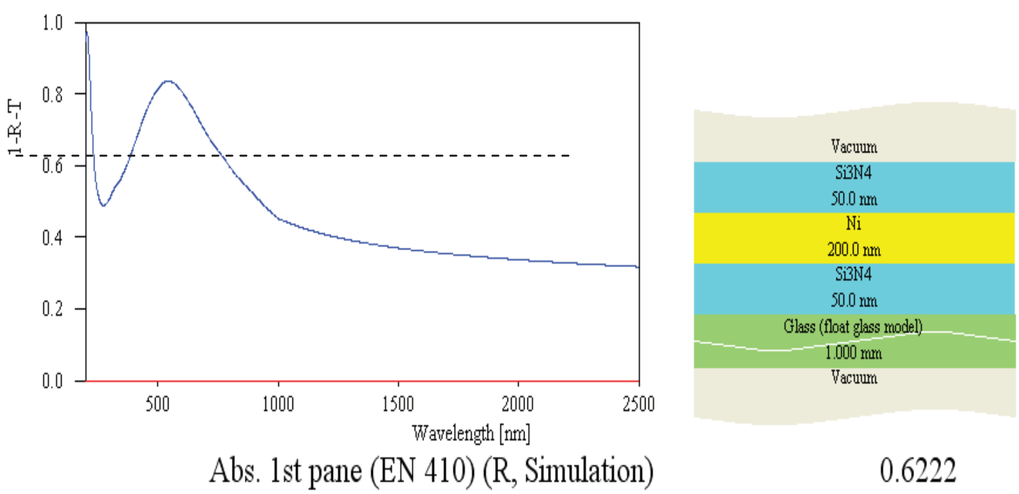


Figure 5 Optimized Thicknesses for Maximum Absorptance on Glass Substrate

CONCLUSION

In the present work, Nickel thin films with thickness of 300 nm were modeled and simulated with Si_3N_4 bond layers and protective layers on Glass, SS304 and polycarbonate substrate for solar absorber application. Absorbers with thin film coated nickel does not withstand outdoor ageing, the initial total and specular solar absorptance of nickel thin film is 0.62. The multilayer thin films for absorptance, Si_3N_4–Ni–Si_3N_4 with optimum thickness ratio of 50:200:50nm gives a absorptance of value of 0.62 on glass substrate, which is 26% more than that of single layer nickel thin films. The simulation results were also conducted for glass, steel and polycarbonate substrates for absorptance. In certain solar receiver tube application for low pressure hot water system that would utilize glass as the substrate, Nickel would be an ideal functional layer with Si_3N_4 as a suitable bond layer and protective layer. Hence glass is a preferred substrate for low and mid temperature solar thermal applications.

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 Madanpalle institute of technology, India.

REFERENCES

1. References: Jian-mei lI, Chao cai, Li-xiao song, Jin-feng li, Zhao zhang, Min-zhao xue, Yan-gang liu "Electrodeposition and characterization of nano-structured black nickel thin films", *Trans. Nonferrous Met. Soc. China*, Vol. 23, 2013, pp. 2300−2306.
2. Tobias Bostrom "Solution-Chemically Derived Spectrally Selective Solar Absorbers" *Acta Universitatis Upsaliensis Uppsala*, 2006, ISBN 91-554-6663-X.
3. Soteris Kalogirou, *"Solar thermal collectors and applications"*, *Progress in Energy and Combustion Science*, Vol. 30, 2004, pp. 231–295.
4. John Dascomb and Anjaneyulu Krothapalli, "*Low-cost concentrating solar collector for steam generation*", Thesis Report, Department of Mechanical Engineering, University of California, March 26, 2009, pp. 24-67.
5. Maria Brogrena, Anna Helgesson, Bjorn Karlsson, Johan Nilsson, Arne Roos, "Optical properties, durability, and system aspects of a new aluminum-polymer-laminated steel reflector for solar concentrators" *Solar Energy Materials & Solar Cells,* Vol. 82, 2004, pp 387–412.
6. Wolfgang Theiss "M. Theiss Hard and software for optical Spectroscopy" Printed 25-11-2002 in Aachen, Germany.
7. Maria Brogren, Bjorn Karlsson, Arne Roos, Anna Werner "Analysis of the effects of outdoor and accelerated ageing on the optical properties of reflector materials for solar energy applications", *Solar Energy Materials & Solar Cells*, Vol. 82, 2004, pp 491–515.
8. Figen kadirgan, Ewa wackelgard, Mete sohmen "Electrochemical Characterization of Al2O3-Ni Thin Film Selective Surface on Aluminum" *Turk J Chem*, Vol. 23, 1999, pp. 381 - 391.
9. Z.Ghasempour, S.M. Rozati, "Characterization of nanostructure black nickel coatings for solar collectors", *World renewable energy congress*, Sweden, 2011, pp. 3985-3990.
10. G.Toghdori, S.M.Rozati, N. Memarian, M.Arvand, M.H.Bina, "Nano structure black cobalt coating for solar absorber", *World renewable energy congress*, Sweden, 2011, pp. 4021-4026.
11. O.R.M. Khalifa, E.A. Al Hameda, M.A. Shoeib, H.A. Mohamed , S.Y. Ahmed, "Characterization of black nickel solar absorber coatings on aluminum substrate", *Global Journal of Pure and Applied Chemistry Research* Vol.3 (2), 2015, pp. 1-13.
12. Xueqiang Qian, Xiaolu Pang, Kewei Gao, Huisheng Yang, Jie Jin, and Alex A. Volinsky "Adhesion of Sputtered Nickel Films on Polycarbonate Substrates" *Journal of Materials Engineering and Performance*, Vol. 23 (3), 2013, pp. 4-5.
13. Cheng-Chung Lee, Jin-Cherng Hsu, Cheng-chung Jaing "Optical coatings on poly methyl methacrylate and polycarbonate" *Thin Solid Films*, Vol. 295, 1997, pp. 122-124.