

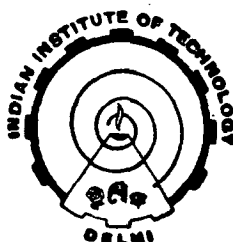
OPTICAL PROPERTIES AND SOLAR SELECTIVITY OF RF PLANAR MAGNETRON SPUTTERED Ni - Al₂O₃ COMPOSITE FILMS

By

T. STEPHEN SATHIARAJ

Thesis submitted in fulfilment
of the requirements for
the degree of

DOCTOR OF PHILOSOPHY



Department of Physics
INDIAN INSTITUTE OF TECHNOLOGY, DELHI
NEW DELHI-110016, INDIA
August, 1989

TH
537.663.5:53
SAT-0

I. I. T. DELHI
LIBRARY
Acc. No...1719...
TH-1719...

~~27.7.90~~
27.7.90

LIBRARY
FILE

CERTIFICATE

I am satisfied that the thesis entitled "Optical properties and solar selectivity of RF planar magnetron sputtered Ni-Al₂O₃ composite films" by T. Stephen Sathiaraj is worthy of consideration for the award of the Degree of Doctor of Philosophy and is a record of the original bonafide research work carried out by him. The results contained in it have not been submitted in part or full to any other University or Institute for the award of any Degree/Diploma.



Professor O.P. AGNIHOTRI

Department of Physics

Indian Institute of Technology

Hauz Khas, New Delhi - 110 016

Unless the LORD builds the house,
its builders labor in vain.
Unless the LORD watches over the city,
the watchmen stand guard in vain.

Psalms 127:1

ACKNOWLEDGMENTS

It has been a privilege of immense value to work with Prof.O.P.Agnihotri, my thesis supervisor. I express my deep sense of gratitude for his valuable guidance and constant encouragement throughout the course of this investigation.

It has always been an interesting and memorable experience to work with Dr.R.Thangaraj. But for his perfect understanding at personal level and unhindered encouragement associated with patience, this thesis which is the result of many hours of team work and a few gallons of tea, would not have been possible.

I enjoyed an extremely fruitful collaboration with my senior colleagues Dr.Rajaram, Dr.Raturi, Dr.S.P.Singh, Dr.A.K.Saxena, Dr.Rajesh Rampal and J.P.Mangalhora.

I wish to express my appreciation to my colleagues Rathi, Manju, Girish and Vipin.

I would like to thank my friends Rajkumar, Raghini, Peter and Shiela who have never let me feel that I was away from home during my stay at New Delhi.

I am indebted to Mr.S.R Pandian for his critical comments and valuable suggestions in the completion of this thesis.

The co-operation rendered by Dr.R.Sekhar in preparing Ni pellets is highly acknowledged.

I also acknowledge the Department of Science and Technology, Ministry of Science and Technology and the Department of Non-conventional Energy Sources, Ministry of Energy for the financial assistance.

Finally, but by no means last, I would like to extend my deepest appreciation to all my family members for their continual encouragement and substantial sacrifices which helped to bring this work to fruition

August, 1989

A handwritten signature in black ink, appearing to read 'T. Stephen Sathiaraj', written over a horizontal line.

(T. Stephen Sathiaraj)

Details of publications

1. Ni-Al₂O₃ cermet solar absorbers by RF planar magnetron sputtering for high temperature applications, T.Stephen Sathiaraj, R.Thangaraj and O.P.Agnihotri, Solar Energy Materials 18 (1989) 343.
2. High absorptance and low emittance AR-coated Ni-Al₂O₃ solar absorbers, T.Stephen Sathiaraj, R.Thangaraj and O.P.Agnihotri, J.Physics D: Appl. Phys. 23 (1990) 250.
3. Ni-Al₂O₃ selective cermet coating for photothermal conversion up to 500°C, T.Stephen Sathiaraj, R.Thangaraj, H.Al Sharbaty, M.Bhatnagar and O.P.Agnihotri. (Accepted for publication in Thin Solid Films)
4. Optical properties of selectively absorbing RF sputtered Ni-Al₂O₃ composite films, T.Stephen Sathiaraj, R.Thangaraj, H.Al Sharbaty, and O.P. Agnihotri. (Presented at the 8th International Conference on Thin Films and the 17th International Conference on Metallurgical Coatings, 1990, in San Diego, California, USA.)
5. Ni-Al₂O₃ coatings: experimental and calculated optical properties using effective medium theories, T.Stephen Sathiaraj, R.Thangaraj and O.P.Agnihotri .(Communicated to Thin Solid Films)

SUMMARY OF THE THESIS

The thesis entitled "Optical Properties and Solar Selectivity of RF Planar Magnetron Sputtered Ni-Al₂O₃ Composite Films" investigates the optical properties of RF planar magnetron sputtered Ni-Al₂O₃ cermet and their stability at elevated temperatures to fabricate selective absorbing surface for high temperature photothermal conversion of solar energy.

Ni-Al₂O₃ cermets were sputtered from hot pressed targets of two different composition. By using different substrates, the substrate effect on the optical properties and their influence on high temperature stability were evaluated. Films deposited on molybdenum coated nickel plated - stainless steel substrates were found to be stable upto 400°C in air. Composition of nickel was varied from that of the target by putting some additional nickel pellets distributed symmetrically on the magnetron ring that forms on the target.

Coatings were characterised by AAS, AES, ESCA, EDAX, TEM and SEM techniques. The effect of pre-sputtering on the chemical composition of the sputtered films was studied in detail. It has been observed that films prepared without proper pre-sputtering and degasing contains NiO, which effectively decreases the volume fraction of nickel.

Normal-incidence reflectance and transmittance measurements were combined with film thickness measurement to calculate the optical constants between 0.3 μm to 2.5 μm . Both n and k increase with increasing nickel content. The optical constants were interpreted in terms of effective medium theories. An

attempt was made to incorporate the shape of the particles in the Maxwell-Garnett theory to get better agreement between the measured and the predicted optical properties.

The influence of antireflecting layer on the solar selectivity and the temperature stability of the films were investigated by using RF sputtered SiO_2 and Al_2O_3 as anti-reflection coatings. It has been observed that both are having same optical properties and besides increasing solar absorptance they serve as a barrier for oxygen diffusion from the atmosphere into the cermet.

The solar absorptance α and the thermal emittance ϵ were calculated from the reflectance values and AM 1.5 solar spectrum and black body spectrum respectively. The reflectance values with and without AR coating on a metallic substrate were simulated through computer program using the experimental n and k values of cermet and the antireflection coatings and published n and k values of the metallic substrate. The solar absorptance α was evaluated from these reflectance values.

By the computer optimisation studies it was found that $\alpha = 0.94$ and $\epsilon = 0.07$ could be obtained with 650 \AA of $\text{Ni-Al}_2\text{O}_3$ ($f = 0.61$) antireflected with 780 \AA of SiO_2 on a nickel coated glass substrate. These results were verified by the experimentally prepared $\text{Ni-Al}_2\text{O}_3$ cermets. It has been observed that good selective properties can be obtained in the composition range 0.5 to 0.6 volume fraction of nickel. Films with SiO_2 antireflection coating deposited on molybdenum coated nickel-plated stainless steel substrates were found to be stable upto 500°C in air.

CONTENTS

Page

ABSTRACT LIST OF FIGURES

CHAPTER I INTRODUCTION

1.1 Introduction	1
1.1.1 Nature of Solar Energy	2
1.1.2 Solar Energy Conversion	3
1.1.3 Photothermal Conversion	4
1.1.4 Benefits of Spectral Selectivity	8
1.1.5 Application of Selective Surfaces	10
1.1.6 Methods to Obtain Spectral Selectivity	11
1.2 Review of Literature	
1.2.1 Low Temperature Selective Surfaces	13
1.2.2 High Temperature Selective Surfaces	16
1.3 Motivation	23
1.4 Contributions of the Thesis	27

CHAPTER II THEORY

2.1 Refractive Index of Solids	29
2.2 Rayleigh and Mie Scattering	34
2.3 Effective Medium Theories	37
2.4 Maxwell - Garnett Theory	39
2.5 Bruggeman Theory	42

CHAPTER III PREPARATION OF CERMET FILMS

3.1 RF Sputtering System	44
3.2 Targets	47
3.3 Composition Variation	47
3.4 Substrates	47
3.5 Deposition Parameters	48

CHAPTER IV CHARACTERISATION TECHNIQUES

4.1 Composition	49
4.1.1 Auger Electron Spectroscopy (AES)	49
4.1.2 Electron Spectroscopy for Chemical Analysis (ESCA)	50
4.1.3 Energy Dispersive Analysis by X-Rays (EDAX)	50
4.1.4 Atomic Absorption Spectroscopy (AAS)	51
4.2 Structure And Surface Topography	
4.2.1 Transmission Electron Microscopy (TEM)	52
4.2.2 Scanning Electron Microscopy (SEM)	52
4.3 Thickness	52
4.4 Characterisation of Antireflection Coatings	53
4.5 Optical Properties	54
4.5.1 Reflectance and transmission	54
4.5.2 Solar Absorptance and Thermal Emittance	54
4.5.3 Optical Constants n and k	56
4.6 Conversion Efficiency	64

CHAPTER V RESULTS AND DISCUSSIONS

5.1 Effect of Presputtering	66
-----------------------------	----

5.2	Effect of argon Pressure	68
5.3	Variation in Selective Properties with Substrate	69
5.4	Variation in Selective Properties with Thickness	70
5.5	Variation in Selective Properties with Composition	72
5.6	n and k for different composition	74
5.7	Optical Modelling	
5.7.1	Comparison of theoretical and experimental n and k	75
5.7.2	Particle shape	77
5.7.3	Altered Ni content	78
5.8	Simulation of selective properties with different thicknesses and composition	81
5.9	Stability	86
5.10	Conversion Efficiency	88
5.11	Comparison with previous work	89

CHAPTER VI CONCLUSIONS AND SCOPE FOR FURTHER WORK

6.1	Conclusions	92
6.2	Suggestions for Future Research	95

APPENDIX-A		97
------------	--	----

REFERENCES		101
------------	--	-----