IC/85/213
INTERNAL REPORT

International Atomic Energy Agency
and
United Nations Educational Scientific and Cultural Organization
INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS

AN INVESTIGATION OF ROOM TEMPERATURE "OXIDIZED" THIN FILMS OF Al FOR PHOTOVOLTAIC APPLICATIONS *

G.A. Adegboyega **
International Centre for Theoretical Physics, Trieste, Italy.

ABSTRACT

Sheet resistance and transmittance changes of thin films of Al evaporated in high vacuum were measured during sorption of oxygen at room atmosphere. An increase of both sheet resistance and transmittance with a tendency to saturation has been observed. Evaluation of various thicknesses of the films for possible use as transparent electrode material for photovoltaic applications shows that for very thin films (< 130 Å), the "unoxidized" films are better while for thicker films (> 200 Å) the "oxidized" films are superior.

MIRAMARE - TRIESTE
December 1985

* To be submitted for publication.

** Permanent address: Department of Electrical Engineering, University of Ife, Ile-Ife, Nigeria.

I. INTRODUCTION

It is known that the MIS (metal-insulator-semiconductor) solar cells have the potential for combining ease of fabrication with low cost and hence will be suitable for large scale terrestrial conversion of solar energy. The MIS structure contains a thin (∿ 10-30 A) insulating layer which is used to separate a semitransparent metal barrier layer from the semiconductor. Metals used to date on silicon substrates include aluminium [1]-[6], chromium [7], titanium [8], gold [9] and berilium [10]. These cells have efficiencies between 8 and 9%, as compared to estimated efficiencies of 13 to 16% maximum for such devices [11]. The effects of the interface oxide layers have been found critical in improving the performance of an otherwise Schottky barrier device. Specifically, it improves the open circuit voltage and hence the efficiency of the device. Generally also, the substrate semiconductor material is well understood. However, a lot of work is still required for the characterization of the thin transparent metal layer. Apart from the usual application of antireflection coating which cuts down the high reflectivity of these thin metal layers, a survey of the literature shows that more work needs to be done on the material properties of the semitransparent barrier layer before efficient, stable MIS devices can be fabricated.

In this paper, we report the spectral and thickness dependence of the transmittance as well as the sheet resistance of vacuum-deposited semitransparent films of aluminium with a view to correlating the variations in their spectra and resistances with modifications of the deposit due to oxidation process in the laboratory atmosphere.

II. EXPERIMENTAL

Varying thicknesses of thin films were formed by vacuum evaporation of 99.99 pure aluminium metal wire from a tungsten filament onto ultrasonically cleaned glass slides maintained at room temperature. The vacuum pressure was about 5×10^{-6} Torr for each run. The thickness of the films was determined by the optical interferrometer technique by the use of the NACET 300 interferrometer. The thickness readings obtained by this method were checked against the readings obtained by the differential increase in weight after evaporation. Optical transmittance measurements were made at normal incidence in the spectral range 0.40 - 0.90 mm at intervals of time during the process of oxidation. Measurements were carried out in the laboratory atmosphere using a Varian 634 double beam spectrophotometer with a Varian 9176 recorder. A substrate with a film deposit was placed in one of the light beams and a clean substrate was placed in the other in order to take care of the influence of the substrate.

Sheet resistance measurements of the layers were also carried out at intervals of time during the process of oxidation using a four-point probe Kokusai V2D resistivity-resistance measuring system.

III. RESULTS AND DISCUSSION

Fig. 1 shows the transmittance spectra for three aluminium films of as deposited thicknesses of 60, 120 and 200 Å. These spectra show that the as grown films (0d) gave optical transmissions of 65-70%, 48-64% and 14-32% for the 60 Å, 120 Å and 200 Å thick films respectively. These results agree fairly well with those of Hovel [12] and Charlson and Lien [2]. These spectra also show that higher transmittance evolves with time; that is, the transmittance of the as deposited samples (0ds) increases with age (10d, 50d) after deposition. This evolution can be attributed to the lowering of the metal concentration in favour of that of the oxide, mainly Al_2O_3, due to the adsorption of oxygen [13]-[16].

Variation of the sheet resistance, R_s, of the films with time after deposition are shown in Fig. 2. The sheet resistances of the as grown films (0d) are not so high (vary between 3.5 ohm/sq and 40 ohm/sq). As the curves show, R_s increases with time, gradually at first and then asymptotically, indicating the growth of an insulating oxide. A model describing the time and thickness dependence of the sheet resistance has not been easy to obtain based on our data.

For use as transparent electrode material, a thin film can be evaluated from its optical transmission and electrical conductivity, both of which should be as large as possible. However, the interrelationship between these two parameters excludes the simultaneous achievement of maximum transmission and conduction. Haacke [17] has defined a term, ϕ_{Tc}, called figure of merit which can be used to evaluate a transparent conductor, as

$$\phi_{Tc} = T^{10}/R_s \qquad (1)$$

where T is the optical transmission and R_s is the electrical sheet resistance. According to Haacke, larger values of ϕ_{Tc} indicate a better transparent electrode material.

Table I shows a comparison of the figure of merit values computed from the data of figures 1 and 2 for the deposited films at different stages of oxidation. The table clearly shows that the 60 Å thick "unoxidized" metallic film is preferable here as a transparent electrode material when compared to the other two films. The table also shows that for a transparent electrode material, oxidation proved to be a disadvantage for thinner (< 130 Å) films, whereas, it is an advantage for

thicker (< 200 Å) films. This is due to the fact that variation in the value of R_s due to oxidation is more pronounced in thinner films.

IV. CONCLUSION

The correlation observed between the time variation of sheet resistance of aluminium films with the transmittance can serve as a process control tool for transparent metal layer formation for devices. While film oxidation is an advantage for thick (> 200 Å) films, it is an inhibitor for thinner (< 130 Å) films when considered for use as transparent electrode materials for devices.

ACKNOWLEDGMENTS

The author would like to thank Professor Abdus Salam, the International Atomic Energy Agency and UNESCO for hospitality at the International Centre for Theoretical Physics, Trieste. The author also acknowledges with thanks the generous grant from the Swedish Agency for Research Cooperation with Developing Countries (SAREC) which has supported his visit to the Centre.

REFERENCES

[1] M.A. Green and R.B. Godfrey, Appl. Phys. Lett. 29, 610 (1976).

[2] E.J. Charlson and J.C. Lien, J. Appl. Phys. 46, 3982 (1975).

[3] D.L. Pulfrey, Solid-State Electron 20, 455 (1977).

[4] D.R. Lillington and W.G. Townsend, Appl. Phys. Lett. 31, 471 (1977).

[5] N.G. Tarr, D.L. Pulfrey and P.A. Iles, Appl. Phys. Lett. 35, 258 (1979).

[6] A. Neugroschel, IEEE Trans. Electron. Dev. ED-27, 287 (1980).

[7] W.A. Aderson, A.E. Delahoy, J.S. Kim, S.H. Hyland and S.K. Dey, Appl. Phys. Lett. 33, 588 (1978).

[8] E. Fabre, J. Michel and Y. Baudet, Proceedings 12th IEEE Photovoltaic Spec. Conf., pp. 904-907 (IEEE, New York, 1976).

[9] J.P. Ponpon and P. Siffert, J. Appl. Phys. 47, 3248 (1o76).

[10] Y. Maeda, Appl. Phys. Lett. 33, 301 (1978).

[11] L.E. Murr (Editor), Solar Material Science, (Academic Press, 1980), pp. 603.

[12] H.J. Hovel, J. Appl. Phys. 47, 4968 (1976).

[13] C. Benndorf, G. Keller, H. Seidel and F. Thieme, Surface Sci. 67, 589 (1977).

[14] J.M. Khan and D.M. Makowiecki, Surface Sci. 77, L155 (1978).

[15] H.L. Yu, Surface Sci. 94, L184 (1980).

[16] M. Bujer, L.A. Larson and Poppa, J. Vac. Sci. Technol., 20, 392 (1982).

[17] G. Haacke, J. Appl. Phys. 47, 4086 (1976).

TABLE I

Comparison of figure of merit values at different stages of oxidation.

Specimen	ϕ_{Tc}		
	0 days	10 days	50 days
60 Å	7.06×10^{-4}	3.98×10^{-4}	1.94×10^{-4}
120 Å	3.40×10^{-4}	1.73×10^{-4}	1.19×10^{-4}
200 Å	2.93×10^{-8}	3.81×10^{-7}	8.61×10^{-7}

FIGURE CAPTIONS

Fig. 1 Time variation of the transmittance of Al films. (0d = 0 days; 10d = 10 days; 50d = 50 days after deposition).

Fig. 2 Variation of sheet resistance with time.

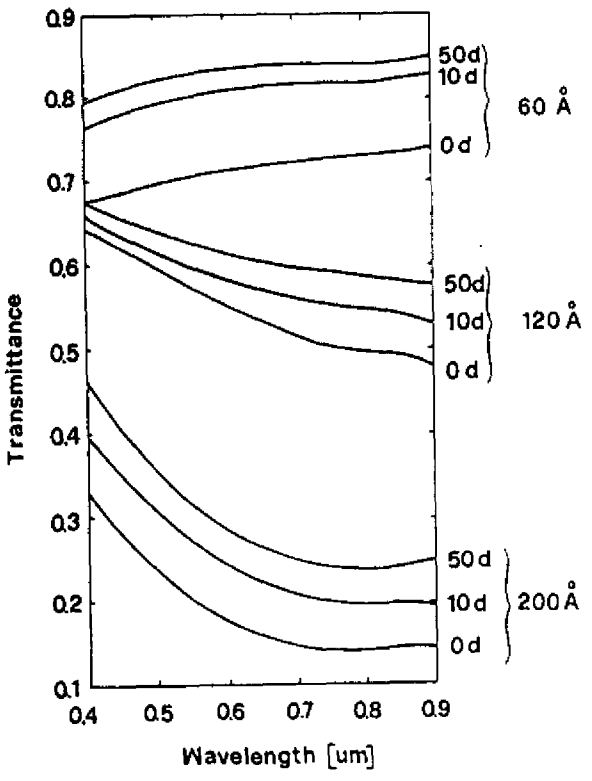
Transmittance
Wavelength [um]
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.4
0.5
0.6
0.7
0.8
0.9
50d
10d
0d
60 Å
50d
10d
0d
120 Å
50d
10d
0d
200 Å

Fig.1

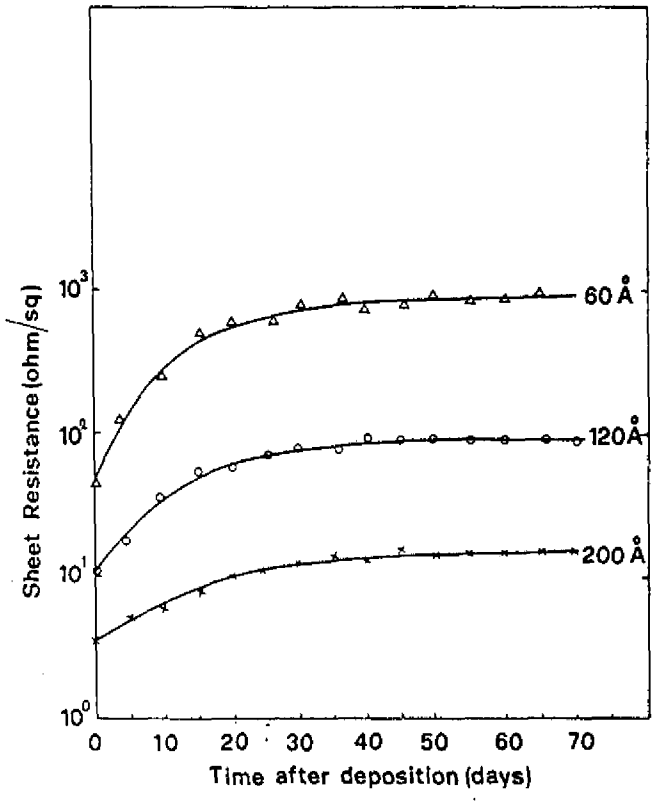
Sheet Resistance (ohm/sq)
Time after deposition (days)
10^3
10^2
10^1
10^0
0
10
20
30
40
50
60
70
60 Å
120Å
200 Å

Fig.2