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THICKNESS DEPENDENCE OF THE ELECTRICAL PROPERTIES OF ALUMINUM THIN FILMS

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Abstract

This study deals with the preparation of aluminum (Al) thin films on glass substrates via thermal evaporation. The electrical conductivity of the prepared thin films as a function of film thickness was systematically investigated. Electrical conductivity was determined by measuring the current and voltage using the four-point probe method. This study shows that electrical conductivity increases linearly with film thickness in the thickness range studied in this work.

Key words: aluminum, thermal evaporation, four-point probe method.

I. INTRODUCTION

Aluminum (Al) is an abundant metal in the earth's crust and is the third most abundant element after oxygen (O_2) and silicon (Si). Al is silvery white in color, shows high electrical and thermal conductivity and has a melting point of 660°C. Al has been widely used for various applications. Al films are the most commonly used surface coatings for aspheric mirrors since Al is a good light reflector in the visible region and an excellent reflector in the mid and far infra-red (IR) regions [1]. In addition, Al is widely used in the microelectronics technology as Ohmic contacts, Schottky barrier contacts, gate electrodes and also as interconnects [2].

In addition, Al finds its application in the fabrication of thin film transistors (TFTs), photo detectors, solar cells and many other devices [3]. Al is heavily used as back contacts in the fabrication of solar cells due to its ease of deposition, Low sheet resistance and its capability to introduce back surface field effects (BSF) that could minimize carrier recombination rates at the rear side of device [4,5]. In solar cells, high reflectance property of Al contacts is exploited to serve as a light-trapping solution where low energy photons will be obliquely reflected back into the absorber layer. This increases the optical path length of the light (photons) in the device, there by increasing absorption efficiency, photocurrent generation, and quantum efficiency of the thin film solar cells particularly in the long wavelength region [6].

Deposition of Al contacts can be carried out by several physical vapor deposition (PVD) methods such as thermal evaporation, electron beam (e-beam) evaporation and also sputtering [7]. Since Al has a fairly low melting point (660ºC), thermal evaporation appears to be good enough for its deposition. In addition, thermal evaporation is the simplest and cost-effective compared to the other techniques which makes it a more appealing option.

Even though extensive research has been carried out on the evaporation of Al as contacts in bulk and thin film solar cells. Most of the research activities employ either wafers or glass materials as substrates [8]. Al back contacts which are also used on polymeric materials like polyimide (PI) and polyethylene terephthalate (PET) plastic substrates, still in their infancy phase. Both PI and PET are excellent polymeric materials. They are important in photo voltaic (PV) and other related fields due to their reasonable temperature resistance, flexibility, light-weight, low-cost properties [9].

In this work, a study of electrical properties of Al thin films deposited by physical vapor deposition (PVD) technique on glass substrates is described. The obtained results may be of great interest due to the direct application in the microelectronic industry.

II. THEORY

The sheet resistance R_s is given by

$$R_s = \left(\frac{V}{I}\right) k \qquad (1)$$

Where R_s is the sheet resistance (in Ω/□), V is the dc voltage across the voltage probes, I is the constant dc current passing through the current probes, and 'k' is the correction Factor [10,11].

For more conductive metal films and semi conducting films, it is common to place all electrodes on the same film surface. Such measurements employ terminals-2 to pass current and 2 to pass voltage. A very convenient way to measure the sheet resistance of a film is to press a 4-point- metal tip probe assembly into the surface as shown in fig.1. The outer probes are connected to current source and inner probes to detect the voltage drop.

Electrostatic analysis of the electric potential and field distributions within the film yields,

$$R = \frac{(\rho X L)}{(w X t)} = R_s\left(\frac{L}{W}\right)$$

where sheet resistance $R_s = \rho/t$.

Resistivity

$$\rho = (R_s \times t) = \left(\frac{k \times V \times t}{I}\right)$$

i.e. resistivity $\rho = R_s$ x t (μΩ-cm) where 't' stands for thickness, 'R_s' sheet resistance is independent of film dimension other than thickness, 'k' is a constant dependent on the configuration and spacing of the probes. If the thickness of the film is very small as compared to the probe spacing, then

$$k = \frac{\pi}{\ln 2} = 4.53$$

Thus, sheet resistance , $R_s = 4.53\left(\frac{V}{I}\right) \qquad (2)$

Resistivity $\rho = (R_s \text{ x } t) = 4.53\left(\frac{V}{I}\right) t \qquad (3)$

and conductivity $\sigma = \frac{1}{\rho} \qquad (4)$

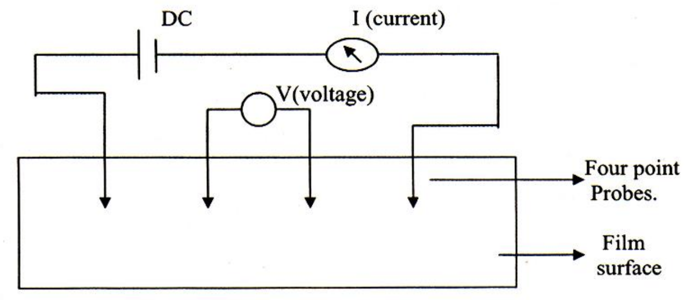


Figure 1: Four-Probe Technique

The probe can be made from thin tungsten wires (approximately 0.05cm diameter), which are sharpened electrolytically and fixed in a refractable plexi glass header by suitable cement. Commonly used spacing between the probes is s (0.159 cm). Thus, 4-point probe methods measure the average resistivity of the film on a substrate; provided film is either isolated from substrate or its resistivity is much lower than that of the substrate.

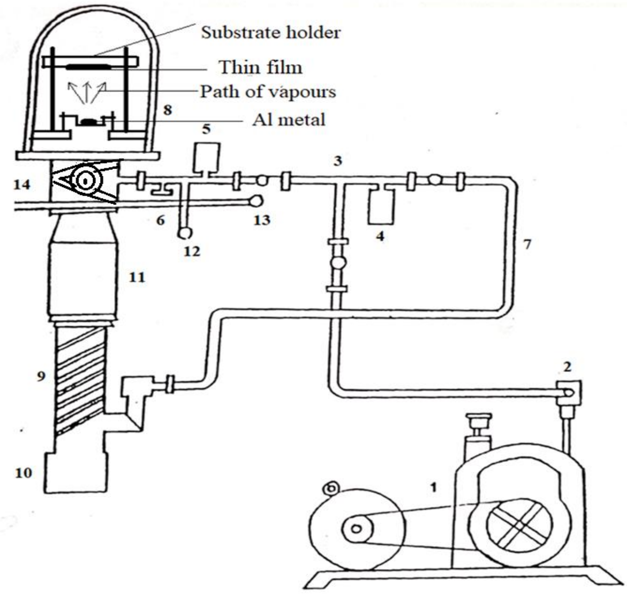
III. METHODS

Resistive thermal evaporation unit shown in fig.2 was used to deposit Al films on glass substrates. Aluminum thin films with thickness 0.0165 μm, 0.0620 μm, 0.1068 μm and 0.1564 μm were deposited in chamber with pressure approximately 2×10^{-6} mbar. Tungsten coil was used to evaporate the high purity Al metal. Glass substrates were cleaned using distilled water, then by ethanol in ultrasonic bath and finally with the low pressure glow discharge. The thicknesses of the films were controlled during deposition by a quartz crystal and thickness measured by DTM thickness monitor model 101. The deposition LT (Low-Tension) current for all thickness of thin films was taken about 40-50A. The deposition rate in all thickness of the films was about 10 A°/sec. The rotary pump reduced pressure from atmospheric to 0.001 mbar then the diffusion pump was started for the further reduction in pressure. The diffusion pump decreased the pressure from 0.001 mbar to $2\text{x}10^{-6}$ mbar. The desired thickness of the films was obtained on glass substrates and they were taken for resistance measurement.

The prepared Al thin film is placed inside the four probe set up. The outer pins are connected to the current source and the inner pins are connected to the voltage source.

Initial adjustments and observations:

(i) Switch on DMV-001 and adjust zero on the panel at 10 mV range, with the zero adjustment knob
(ii) Switch on CCS-01 and set the current at zero and then again check the reading of DMV-001 and adjust zero if required
(iii) Now, increase the current gradually in CCS – 01 from 10 to 200 mA in steps of 10 mA and note down the corresponding voltage from DMV – 001. From the current and voltage values, the sheet resistance can be calculated using equation (2) and electrical conductivity can be obtained by equation (4).



1. Rotary Pump
2. Magnetic isolation valve
3. Butterfly valve
4. Pirani gauge I
5. Pirani gauge II
6. Pinning gauge
7. Backing line
8. Glass or metal bell jar
9. Diffusion pump
10. Diffusion pump heater
11. Liquid air trap
12. Air admittance valve
13. Needle valve
14. Baffle valve

Figure 2: Resistive thermal evaporation unit for deposition of Al thin films

IV. RESULTS AND DISCUSSION

The variation of electrical resistivity with films thickness is shown in figure.3. It shows that with increase in film thickness, the resistivity decreases. Figure 4 shows the plot of conductivity as a function of film thickness. Fig.5 shows the sheet resistance variation with film thickness. The resistivity of pure Aluminum is 2.65x10-8 Ω.m and the resistivity of thin films is more than that of bulk which is evident from table I. The results obtained in the present work are of the same order reported in the literature [12]. High resistivity values in thin films can be attributed to fabrication process in which lattice defects, grain boundaries, impurities and uneven surfaces occur. These characteristics become predominant when the films are very thin and result in increase in the resistivity.

A grain boundary constitutes a significant obstacle along the motion of the electrons. This is because the crystal lattice orientation with respect to the wave vector of the incoming electron is different on both sides of the grain boundary [13]. So, the electron should unavoidably undergo an appreciable scattering event when impinging on a grain boundary. Therefore, the smaller the grain size, the more grain boundaries are present in a crystalline material and, then, the larger is the resistivity. Interconnect lines are predominantly produced via atom by- atom deposition processes such as sputtering, evaporation or electro deposition. On the other hand, it has long been known that such deposits typically exhibit an average lateral grain size in the submicron range [14]. Thus, a significant resistivity contribution may also arise due to the large amount of grain boundaries as a consequence of the small grain size in these thin films. The small grains are present more in low thickness films which results in more scattering and hence low electrical conductivity [15,16]. Table 1 shows the results of average electrical resistivity, average electrical conductivity and average sheet resistance which were determined for aluminum thin films of different thicknesses.

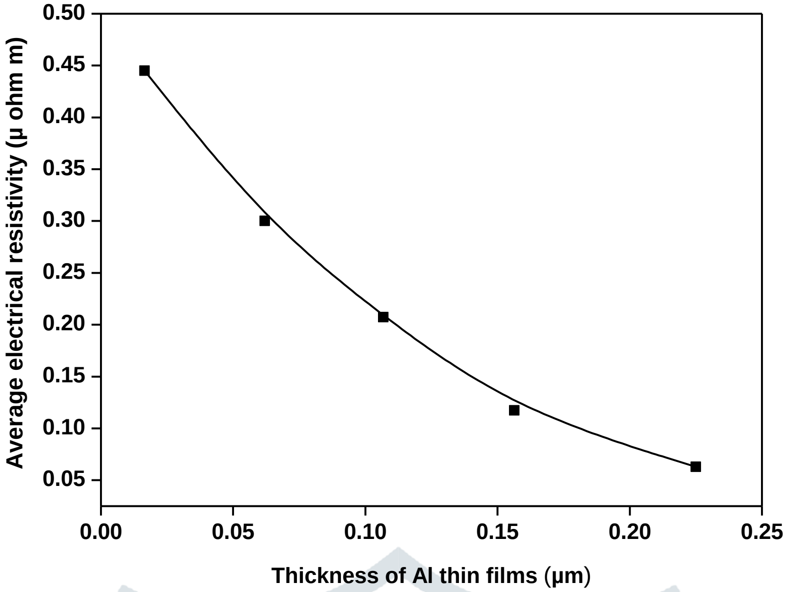


Figure 3: Variation of average electrical resistivity (ρ) with thickness of Al thin films

Unlike the properties of bulk materials, the resistivity, conductivity and sheet resistance in the thin film depends on several factors such as rate of deposition, thickness, temperature and grain boundaries [17-19].

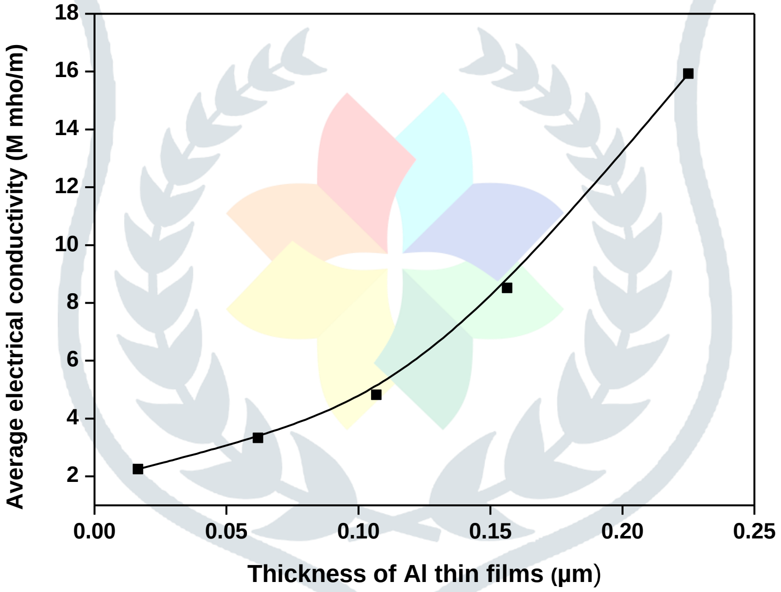


Figure 4: Variation of average electrical conductivity (σ) with thickness of Al thin films

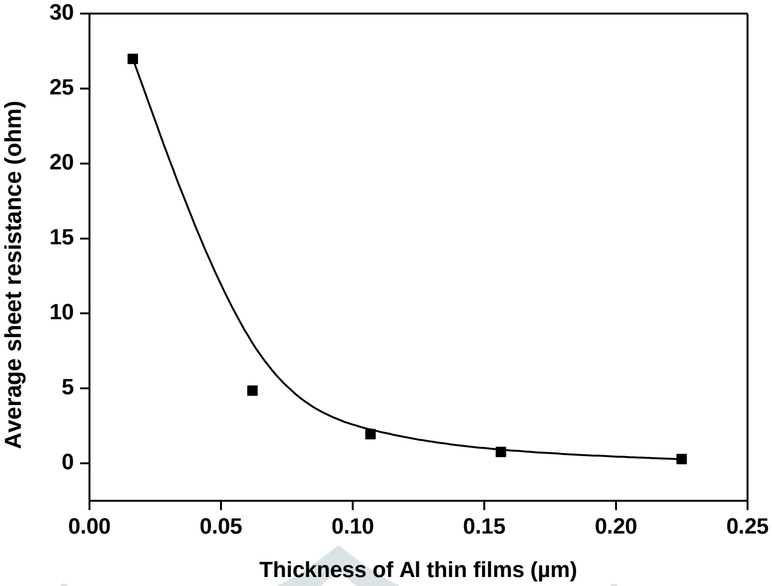


Figure 5: Variation of average sheet resistance (R_s) with thickness of Al thin films.

Table.1. Average electrical resistivity, electrical conductivity, sheet resistance and thickness of Al thin films

Sl.No	Al thin film samples	Thickness of Al thin films t (μm)	Average electrical resistivity ρ (10^{-6}Ωm)	Average electrical conductivity σ (10^{6} mho/m)	Average sheet resistance R_s(Ω)
1	Sample1	0.0165	0.4448	2.2475	26.9603
2	Sample 2	0.0620	0.3001	3.3322	4.8403
3	Sample 3	0.1068	0.2073	4.8229	1.9414
4	Sample 4	0.1564	0.1173	8.5186	0.7502
5	Sample 5	0.2250	0.0628	15.9235	0.2791

As the thickness of the film decreases, the electron collisions with surfaces become important [20]. Such confinement effect due to film thickness is clearly observed on Al thin films whose electrical resistivity values are higher than bulk. Aluminum usually presents a native oxide film (Al_2O_3) when exposed to atmospheric pressure, which changes substantially its surface properties. As can be seen in figures 3 - 5, measured ρ, σ and R_s values show variation with film thickness

V. CONCLUSION

Investigation has been carried out cautiously to know the thickness dependence of electrical conductivity of thermally evaporated Al thin films with thickness 0.0165 μm, 0.0620 μm, 0.1068 μm ,0.1564 μm and 0.2250 μm deposited on glass substrates. From this study it is concluded that the electrical conductivity of Al thin films strongly depends on film thickness.

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REFERENCES

[1] C C. Cheng, CC. Lee, J Opt. Quant. Electron. **28,** 1583 (1996).
[2] L.J. Chen, Minerals, Metals & Materials Society, 57 (9) 24(2005)
[3] S. Ishihara, T. Hirao, Thin Solid Films. **155,** 325 (1987).
[4] M. A. Green, Solar Cells: Operating Principles, Technology, and System Applications: Prentice-Hall 1982.
[5] J . Muller, B. Rech , J. Springer, M .Vanecek, Solar Energy. **77,** 917 (2004).
[6] J. Nelson, The Physics of Solar Cells, Imperial College Press 2003.
[7] A.S.H. Makhlouf, in Nanocoatings and Ultra-Thin Films, 2011.
[8] K. Wijekoon , H. Mungekar , M. Stewart , P. Kumar , J. Franklin, M. Agrawal , K. Rapolu, Y. Fei , Z.Yi , A. Chan , M. Vellaikal , L. Xuesong , D. Kochhar, Z. Lin , D. Tanner, V. Dabeer H. Ponnekanti , IEEE 38th Photovoltaic Specialists Conference (PVSC) ,June 3-8th, Texas. USA 2012
[9] P. K. Shetty, N. D. Theodore, J. Ren, J. Menendez, H.C. Kim, E. Misra, J. W. Mayer, T.L. Alford, Materials letters. **59,** 872 (2005).
[10] W. E. Beadle, J.C.C Tsai, and R.D. Plummer, integrated R.D. Plummer quick Reference manual for Silicon.Integrated circuit Technology, Wiley, New York 1985

[11] Charles A. Bishop, Process Diagnostics and Coating Characteristics in Vacuum Deposition onto Webs, Films and Foils (Second Edition), 2011

[12] A. F. Mayadas, R. Feder, and R. Rosenberg, Resistivity and Structure of Evaporated Aluminum Films, journal of Vacuum Science and Technology. **6,** 690 (1969).

[13] J.M. Ziman, Electrons and Phonons, Ch. VI, Clarendon Press, Oxford 1960.

[14] A.F. Mayadas, R. Feder, R. Rosenberg, Resistivity and Structure of Evaporated Aluminium Films. J. Vac.Sci. Technol. **6,** 690 (1969)

[15] Q. G. Zhang, X. Zhang, and B. Y. Cao, Influence of grain boundary scattering on the electrical properties of platinum nano films, Appl. Phys. Lett. **89,** 114102 (2006).

[16] Sawsan Abdul Zahra, Effect of grain size on the electrical conduction mechanism for aluminium doped CdS thin films, Journal of Electron Devices. **17,** (2013) 1494-1499**.**

[17] Oliva A I, Aviles F& Ceh O, Physical properties of AU and AL thin films measured by resistive heating, Surface Review and Letters 12, (2005) 101- 106.

[18] I. Bakonyia, Accounting for the resistivity contribution of grain boundaries in metals: critical analysis of reported experimental and theoretical data for Ni and Cu, Eur. Phys. J. Plus. **136**:**410** (2021) 34-48.

[19] Hanna Bishara, Matteo Ghidelli and Gerhard Dehm, Approaches to Measure the Resistivity of Grain Boundaries in Metals with High Sensitivity and Spatial Resolution: A Case Study Employing Cu, ACS Applied Electronic Materials2, Issue**7** (2020) 2049-2056.

[20] Guowen Ding, César Clavero, Daniel Schweigert, and Minh Le, AIP Advances **5** (2015) 117234.