

Electrical Characterization of Aluminum (Al) Thin Films

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Abstract. his paper deals with the preparation of aluminum (Al) thin films on glass substrate by thermal evaporation method. The electrical conductivity of the prepared thin films as a function of film thickness was systematically investigated. The electrical conductivity was obtained by the measurement of current and voltage through four-point probe. This study shows that electrical conductivity increases linearly with film thickness in the range of thickness studied in this work.

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1. INTRODUCTION

Aluminum (Al) is the most abundant metal in the earths crust and is the third most abundant element after oxygen (O_2) and silicon (Si). It is silvery white in color, shows high electrical and thermal conductivity and has a melting point of 660^0C. Al has been widely used for various applications. Al films evaporated on substrates 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 infrared (IR) regions [1]. Besides, Al is widely used in the microelectronics technology as Ohmic contacts, Schottky barrier contacts, gate electrodes and also as interconnects [2].

Al also finds its application in the fabrication of thin film transistors (TFTs), photo detectors, solar cells and many other devices [3]. In the fabrication of solar cells, Al is heavily used as back contacts 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 thin film solar cell, high reflectance property of the 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

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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 (660^0C), thermal evaporation appears to be good enough for its deposition. In addition, thermal evaporation is the simplest and the most 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 films 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 have attracted interests of many parties in photo voltaic (PV) and other related fields due to their reasonable temperature resistance, flexibility, light-weight, low-cost properties [9].

2. THEORY

The sheet resistance Rs is given by

$$Rs = \left(\frac{V}{I}\right) k \tag{1}$$

Where Rs 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 $\rho = R_s x t(\mu\Omega - cm)$ 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

$$k = \frac{\pi}{ln2} = 4.53$$

Thus, sheet resistance,

$$R_s = 4.53 \left(\frac{V}{I}\right) \quad (2)$$

Resistivity

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

and conductivity

$$\sigma = \frac{1}{\rho} \quad (4)$$

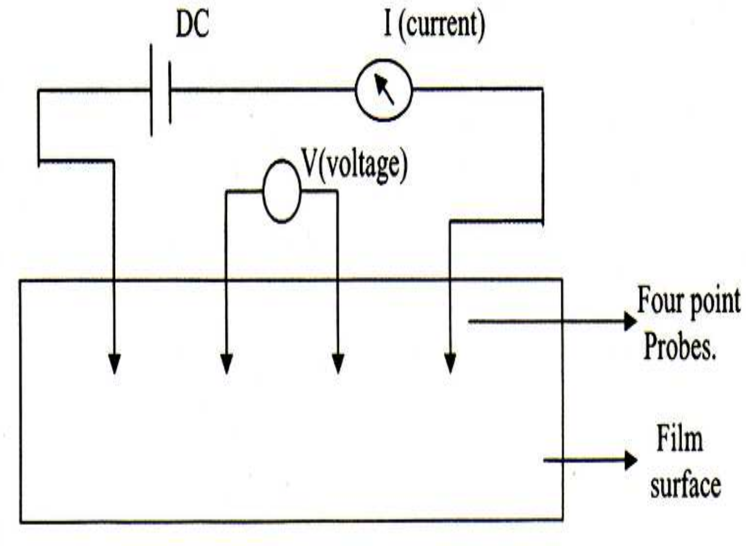

Figure 1. Four-Probe Technique

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.

3. EXPERIMENTAL

Three source modified activated reactive 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 $210 - 6\bar{m}$. 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^0/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 $0.001barm$ to $2x10^{-6}\bar{m}$. The desired thickness of the films were obtained on glass substrates and they were taken for resistance measurement.

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

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:

1. Switch on DMV-001 and adjust zero on the panel at $10mV$ range, with the zero adjustment knob
2. Switch on $CCS - 01$ and set the current at zero and then again check the reading of $DMV -$

001 and adjust zero if required

3. Now increase the current gradually in $CCS01$ from 10 to $200mA$ in steps of $10mA$ and note down the corresponding voltage from $DMV001$. From the current and voltage values, the sheet resistance can be calculated using equation (2) and electrical conductivity can be obtained by equation (4).

4. RESULTS AND DISCUSSION

The variation of electrical resistivity with films thickness is shown in Fig.3. It shows that with increase in thickness of Al thin films, the resistivity decreases. Figure 4 shows the plot of conductivity as a function of film thickness. Similarly, sheet resistance decreases when films thickness increases as shown in Fig. 5. The resistivity of pure aluminum is $2.65x10^{-8}\Omega\dot{m}$ and the resistivity of thin films is more than that of bulk which is evident from Table I. 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.

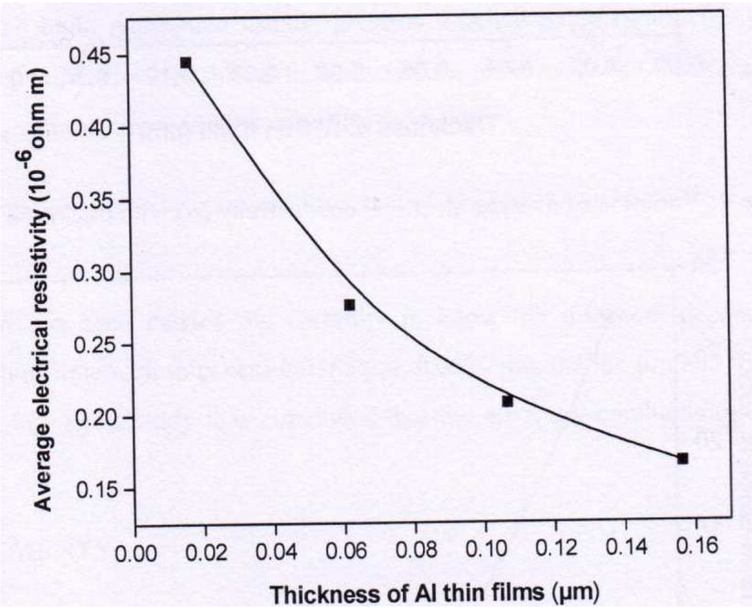

Figure 3. Variation of average electrical resistivity (ρ) with thickness of Al thin films

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 [12].

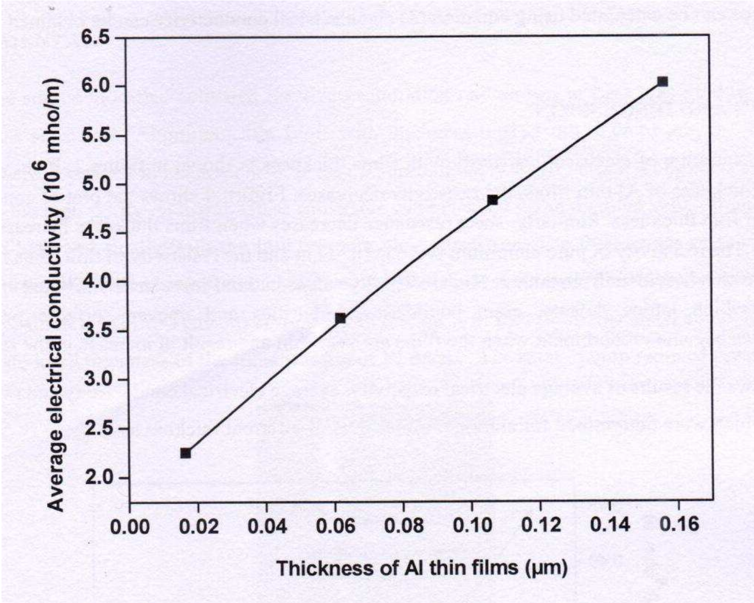

Figure 4. Variation of average electrical conductivity (ρ) with thickness of Al thin films

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.

As the thickness of the film decreases, the electron collisions with surfaces become important. 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 (Al2O3) when exposed to atmospheric pressure, which changes substantially its surface properties. As can be seen in figures 3 - 5, measured , and Rs values show variation with film thickness.

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

Sl. No.	Al thin films samples	Thickness of Al thin films $t(\mu m)$	Average electrical resistivity $\rho(10^{-6}\Omega m)$	Average electrical conductivity σ $(10^{-6}mho/m)$	Average sheet resistance $R_s(\Omega)$
1	Sample 1	0.0165	0.4448	2.2475	26.9603
2	Sample 2	0.0620	0.2761	3.6212	3.6467
3	Sample 3	0.1068	0.2073	7.8229	1.9414
4	Sample 4	0.1564	0.1661	6.018	1.062

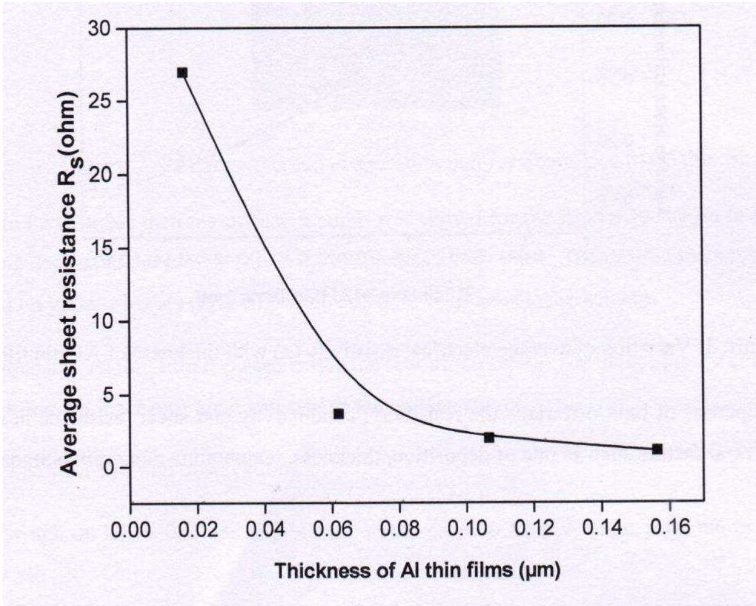

Figure 5. Variation of average sheet resistance (R_s) with thickness of Al thin films

5. CONCLUSION

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

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References

[1] CC. Cheng and CC. Lee, J Opt. Quant. Electron 28, 1583 (1996).

[2] G .Civrac, S. Msolli , J. Alexis, O. Dalverny, and H.Schneider, Electronics Letters 46, 791 (2010).

[3] S. Ishihara and 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 and M. Vanecek, Solar Energy 77, 917 (2004).

[6] J. Nelson, The Physics of Solar Cells, Imperial College Press (2003).

[7] M.L. Green, R.A. Levy, R.G. Nuzzo, and E.Coleman,Thin Solid Films 114, 367 (1984).

[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, and V.DabeerH. Ponnekanti, IEEE 38th Photovoltaic Specialists Conference (PVSC), June 3-8-th 2012, Texas.USA.

[9] P.K. Shetty, N.D.Theodore, J. Ren, J. Menendez, H.C. Kim, E. Misra, J.W. Mayer, and 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, NewYork, 1985.

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

[12] A.I. Oliva, F. Aviles, and O. Ceh, Physical properties of AU and AL thin films measured by resistive heating, Surface Review and Letters, Vol.12, No.1(2005),101- 106, World Scientific Publishing Company.