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Experimental Study of Electrical and Optical Characterization of Aluminum Thin Film Deposited by Physical Vapor Deposition (PVD) Technique on Glass Substrates.

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Abstract: Uniform *Al* thin films were deposited by physical vapor deposition (PVD) technique on glass substrates. The electrical resistivity and reflectance of the films as a function of film thickness and wavelength of light were studied. These parameters have been measured by four-point probe method and UV-Visible Spectrophotometer. The electrical resistivity was obtained by the measurement of current (in mA) and voltage (in mV) through the probe. The results showed that resistivity of the film decreases linearly with the film thickness in the range of the thickness studied. In optical measurement, we have studied mainly reflectance as a function of wavelength of light used. For most of the *Al* samples, reflectance was seen as thickness dependent and it was seen minimum at ultraviolet region, high and almost found to be constant from visible to infrared region. The reflectance of almost *Al* samples have increased with increased in thickness of films.

Keywords Aluminum thin film, electrical resistivity and conductivity, sheet resistance,reflectance and transmittance.

1. Introduction

The new tendencies of miniaturization of electrochemical components are causing a revolution in the materials field. Particularly, materials with thin films geometry deposited on thick substrates present physical properties that can be more relevant than for bulk[1,2]. There are several physical properties that change depending on the film thickness and kind of material. Some thin film semiconductors present electrical and optical properties that depend on the thickness of the deposited films. Metals tend to increase their electrical resistivity (ρ) and sheet resistance (R_s) when thickness decreases between the mean free path and certain coalescence limits. It means that the electrical conductivity(σ) of metals thin films increase with the increase in thickness of thin films and remains almost constant at bulk state for particular metals[3,4]. Due to amazing results of thin films, the actual demand of micro -devices used as micro-sensors to control or to measure certain physical parameters for specific applications is increasing[5]. These efforts follow two basic objectives: to increase the range of use and the capacity of the devices, as well as to reduce the device size and to increase the materials quality[6]. There are different physical properties that can be studied in a known material in order to obtain a possible new behavior[7]. In this work, a study of electrical and optical properties of *Al* thin films deposited by PVD technique on glass substrates is described[8]. The importance and role of the metallic film-substrate geometry as well as the methodology used to obtain some electrical properties have been explained. The obtained results may be of great interest due to the direct application in the microelectronic industry. Physical vapor deposition of aluminum thin films is used to create electrical paths in several applications and micro-system. PVD aluminum thin films should exhibit a metallic luster, however thin films in the exhibit a milky appearance. This milky white appearance could be due to the formation of alumina as the film is deposited, or to the surface roughness of the deposited film[9-11]. The electrical and optical properties of metallic thin films and their applications in several fields have been studied in many research papers[12-16].

2. Materials and Methods

2.1 Experimental: The Hind High Vacuum box coater model BC 300 was used to deposit *Al* films on glass substrates. Aluminum thin films with different thickness ranging from 0.148μm to 0.225 μm were deposited in chamber with pressure approximately 2×10^{-6} mbar. Samples were washed and cleaned with distilled water then by ethanol in ultrasonic bath and finally with the low pressure glow discharge. The thickness of the films were controlled during deposition by a quartz crystal and thickness measured by DTM thickness monitor model 101[8].

The deposition LT (Low-Tension) current for all thickness of thin films was taken about 40-50 A[8]. The deposition rate in all experiments was about 10 A^o/sec and films thickness ranged between 0.148μm and 0.225 μm. The rotary pump reduced pressure from atmospheric to 0.001 mbar then diffusion pump was started for the further reduction in pressure. Then diffusion pump decreased the pressure from 0.001 mbar to 2×10^{-6} mbar (1 mbar = 100 Pa = 0.76 Torr.). The desired thickness of the film was obtained deposited on glass substrates within one minute[8]. Finally, all deposited samples have been taken for electrical and optical properties measurement by using four–point probe method and UV-Visible Spectrophotometer technique respectively[17].

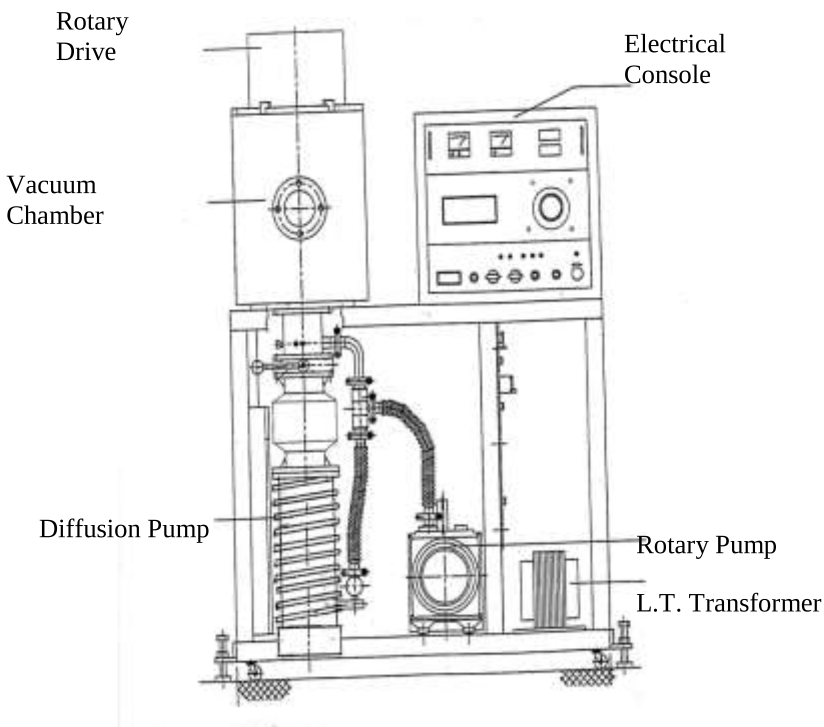

Figure 1. Hind High Vacuum Box Coater Model BC- 300 for deposition of thin films

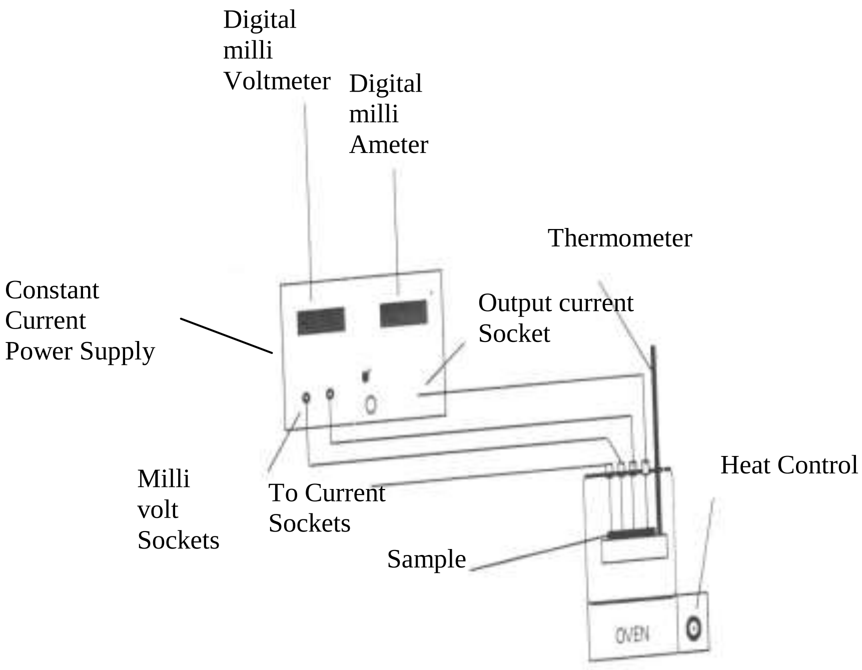

Figure 2: Schematic diagram of four-point probe for measurement of ρof thin films.

2.2 Theory: (Electrical Characterization of *Al* Thin Films):The four point probes are placed collinearly with equal spacing between them on the sample. The current is passed through the two outer probes and the potential is measured between the two inner probes. The errors due to electrical contacts are absent because the current and voltage leads are separate. This is a widely used technique to measure the electrical resistivity by superficial contact. This technique is mainly used in the semiconductor industry, research and manufacturing field.
Generally, the resistivity of *Ge* semiconductor crystal is given by Eq. (2.1)

(2.1) $$\rho = (V/I) \times 2\pi s ,$$

where V is the voltage in mV, I is the current in mA and s is the spacing betweentwo point electrode and here $s = 1.5$ mm. But in case of thin metallic films, the electrical resistivity (ρ) of the film, whose length is much longer than its thickness d can be obtained by formula as expressed in (2.2)[8].

$$(2.2)\qquad \begin{cases} \rho = \dfrac{\pi VD}{I \ln 2}, \\ \rho \approx 4.532\left(\dfrac{Vd}{I}\right), \end{cases}$$

where V is the drop potential measured among the internal electrodes and I is the current in mA and $d =$ thickness of thin film. The electrical conductivity of the films can be obtained by

$$(2.3)\qquad \sigma = \frac{1}{\rho}.$$

Knowing the values of ρ and thickness of thin films, the sheet resistance can be determined according to Eq. (2.4)

$$(2.4)\qquad R_s = \frac{\rho}{d}.$$

(Optical Characterization of *Al* Thin Films):UV-Visible Spectrophotometer is used for the determination of the transmittance of the depositedfilms. Ultraviolet and visible (UV-VIS) absorption spectroscopy is the measurement of the attenuation of a beam of light after it passes through a sample or after reflectionfrom a sample surface. The relationship between the energy absorbed in anelectronic transition with the frequency υ and wavelength λ of theradiation producing the transition is[17]

$$(2.5)\qquad \Delta E = h\nu = \frac{hc}{\lambda},$$

where, h is Planck's constant, c is the velocity of light and ΔE is the energy absorbed inan electronic transition in a molecule from a low-energy state (ground state) to a highenergy state (excited state). Aconvenient expression, which relates the absorbance with the path length that theradiation travels within the system and the concentration of the species, can be derivedfrom the Lambert-Beer law and is given as

$$(2.6)\qquad A = a : b : c,$$

where A is measured absorbance, a is the absorptivity, b is the path length and c isthe concentration of the modules.
Optical properties of thin films are somewhat different from those of the respective bulk materials. The observed values of refractive indices are highly lower and the extinction coefficients are higher than the optical constants of the bulk materials. The resulting thin film properties are strongly influenced by the deposition method and selected deposition conditions.

The quality of the transparent region depends strongly on the material itself, especially on its stoichiometry and impurity, which may cause absorption. The transparency of the thin films is often slightly lower than that of bulk materials and is strongly related to the deposition conditions. A reason for the increased extinction of the films is the true absorption induced by the small deviations from stoichiomerty or by contamination. Another reason is the light scattering induced by surface and volume imperfections such as surface roughness, internal grain boundaries, and density fluctuation soriginating from crystalinity, porous microstructure, pinholes, cracks etc.The contribution of light scattering and optical losses can be given by[17]

(2.7) $$R+T+L=1,$$

or

(2.8) $$R+T+L=100\%$$

and

$$L=A+S\ .$$

For aluminum thin films, coating surfaces are almost shining so there is less absorption and low transmission. So, $\left(R+T+A\right)=1$

(2.9) $$\left(R+A\right)=\left(1-T\right)$$

(2.10) $$R=\left(100-T\right)\%\ .$$

$L=\left(A+S\right)$ is loss, A is absorption, S is scattering, R is reflectance, T is the transmittance. For *Al* coated surface of substrates, value of A is very low (highly reflecting surface). So $(R + A)$ is approximately equal to R for *Al* thin films and S can be neglected due to closed source system.

3. Results and discussion

The variation of electrical resistivity with films thickness is shown in Fig. 3. It shows that with increase of thickness of *Al* thin films, the resistivity decreases. Fig. 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. These values obtained for the thin films differ from the bulk values. Thus, the electrical resistivity, conductivity and sheet resistance of aluminum thin films were measured and compared with bulk value[8]. Fig. 6 and Fig. 8 show the plot of % transmittance versus wavelength (nm) of light. The transmittance increased from 250 nm to 320 nm and decreased from 320 nm to 600 nm and almost remains constant from 600 nm to 1000 nm. Fig. 7, Fig.9 also show the plot of % reflectance versus wavelength (nm) of light. The reflectance is minimum at wavelength 300 nm to 320 nm. The reflectance increased beyond 320 nm and almost remains constant from 350 nm to 1000 nm. For most of the samples, average electrical resistivity, average electrical conductivity, average sheet resistance, transmittance, reflectance have been seen as thickness dependent in this research work.

The below mentioned optical figures show representative curves of reflectivity and transmittance of vacuum deposited aluminum thin films for thicknesses 0.1483 micron, 0.1650 micron, 0.19 micron, 0.2150 micron and 0.225 micron. The films were deposited on glass substrates.

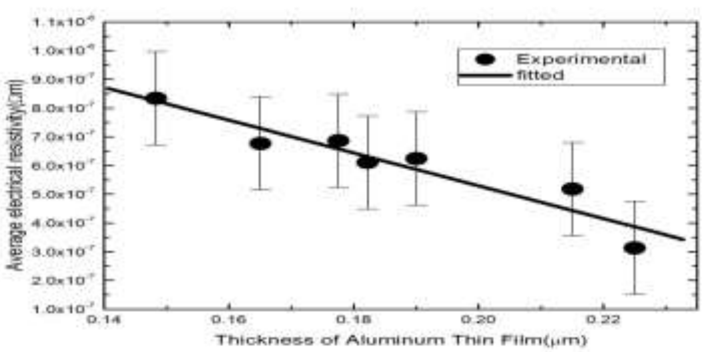

Figure 3. Average electrical resistivity as a function of thickness of *Al* thin film sample

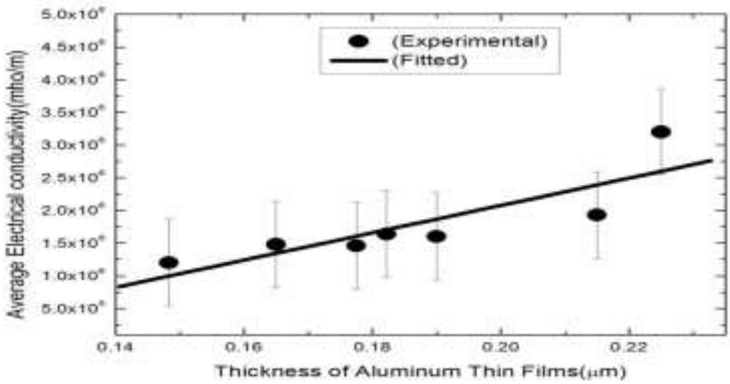

Figure 4. Average electrical conductivity as function of thickness of *Al* thin film sample

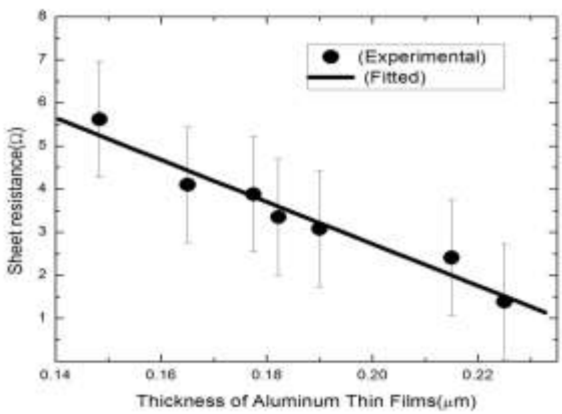

Figure 5. Average sheet resistance as a function of thickness of *Al* thin film sample

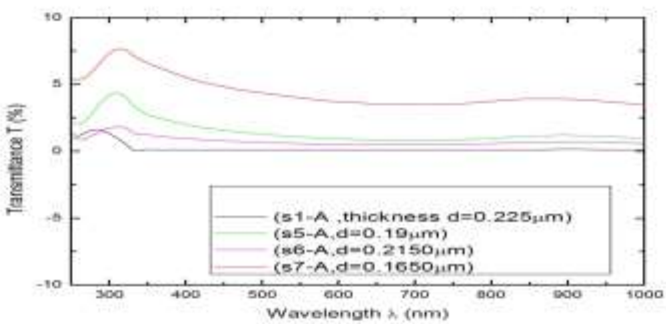

Figure 6. Transmittance as a function of wavelength of *Al* thin film for sample A

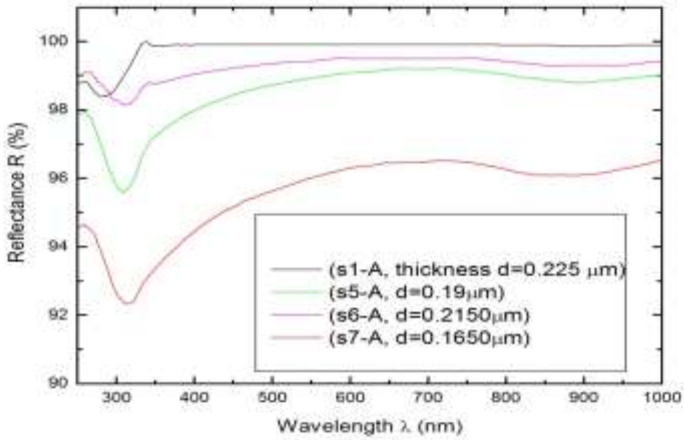

Figure 7. Reflectance as a function of wavelength of *Al* thin film for sample A

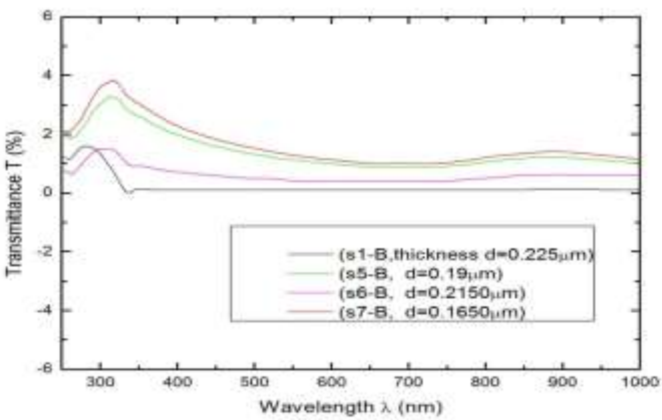

Figure 8. Transmittance as a function of wavelength of *Al* thin film for sample B

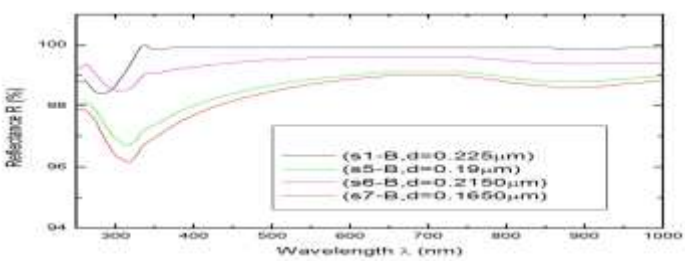

Figure 9. Reflectance as a function of wavelength of *Al* thin film for sample B

Figure 10. Transparent parts indicate glass substrates and white parts indicate coated *Al* thin films.

We measured the transmittance (T) of each film of known thickness, utilizing UV-Visible Spectrophotometer and reflectivity (R) was derived as: $R+A+T=1$ or, $R+A+T=100\%$ or, $R=(100-T)\%$. Here, we assumed the absorbance of the film with respect to reflectance was negligible. We can see clearly that with increasing wavelength (decreasing photon energy) the reflectivity of the film increases rapidly from wavelength approximately 320 nm to 400 nm reaching upto98% at later wavelength and saturates thereafter. This trend is consistent with measured curve of aluminum. As mentioned above, we also investigated thickness dependent of R and T for various thicknesses between 0.1483 micron and 0.225 micron. However, we could not observe any clear evidence of any dependency somewhere for all *Al* samples. As our films thicknesses are in the order of micrometer, one most plausible reason could be that the films are already representing a bulk property. In order to observe thickness dependence clearly, probably, we may need to investigate for film thicknesses in the order of nanometer scale. To avoid more noises, the all optical part of figures were smoothed by 40 points of window in origin 8.0 software. After smoothed of whole optical figures,each layer of reflectance and transmittance was seen less noisey. Actually, more noises in optical part of figures were introduced due to instrumental, sample ageing and contamination errors[17].

Unlike the properties of bulk materials, the resistivity, conductivity and sheet resistance of the thin film depends on several factors such as rate of deposition, thickness, temperature and grain boundaries between others. As the thickness of the film decreases, the collision of electrons 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 (Al_2O_3) when exposed to atmospheric pressure, which changes substantially its surface properties [16]. We can be seen that the measured ρ, σ, R_s, reflectance and transmittance values show variation with thickness of thin films. The measurements of average voltage, average current, average electrical resistivity, average electrical conductivity, average sheet resistance, reflectance and transmittance of *Al* samples have slightly changed after nine months from the first measurements due to the oxidation of samples and shining effect[17]. The analysis and behavior of the oxide layer in aluminum films require a more detailed study and will be the subject of another work [8].

4. Conclusions

This work has studied the electrical and optical properties of *Al* thin films with thickness between 0.1483μm to 0.225 μm deposited on glass substrates. The techniques to characterize metallic thin films and to measure electrical and optical properties as a function of thickness are discussed. The electrical resistivity measured on *Al* thin films is larger than those measured in bulk. The reflectance of *Al* thin films measured is very high and is thickness dependent for most of the samples used in this work. Due to high reflectance of *Al* thin films, it can be used for different purposes in micro-electronic devices and it can also be used as mirrors. The present study will be extended in future to investigate the thermal and mechanical properties.

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