Low Temperature Conductivity Behaviour for Multilayered Thin Films

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Abstract
By using electron beam gun and thermal evaporation techniques in the vacuum range 6 x 10^-5 mbar (V.R. Technology Bangalore Make). The pure materials of 99.99% purity of Cobalt and aluminium multilayers films were produced on glass substrates at room temperature in the following multilayered [Co10Å/Al10Å]N where N= 1, 3, 6, 9 and 12 labeled as (CA1, CA2, CA3, CA4 and CA5). The low temperature (4.2K to 300K) resistance of these samples was measured by using four probe method at UGC-DAE Consortium Indore later resistivity and conductivity calculated and temperature co-efficient of resistance (TCR), residual resistivity ratio (RRR) and activation energy (Ea) were also calculated. The resistivity behavior shown that the resistivity is increased with increasing the n value it means it increased with increasing number of layers. The data belonging to metallic region has been analyzed using the conventional power law’s it is for the first time that a set of multilayered films in the present configurations have been explored for resistivity at low temperature.

Keywords: thin films, multilayers, TCR


1. Introduction

The fundamental problem in Solid State Physics has attracted the attention of researchers for over a century. A central issue is how the surface of the structure affects electrical transport, when one or more of the dimensions characterizing the structure are comparable to smaller than the mean free path of the charge carriers in the bulk. The residual resistivity ratio (RRR) is used as a screening tool to determine the cumulative Superconductive quality of a thin film. The RRR is a direct measure of the mean free path and quality of the film that is affected by scattering center, Structural defects. Charged impurities in the lattice are a major scattering center and affect RRR. Impurities are not easily controlled in experiments, often are influential in minute concentrations at cryogenic temperatures, and can originate from many sources proceeding during and after deposition. Strong efforts have been undertaken on the controlled growth of textured and epitaxial thin films of half metallic ferromagnetic CrO2 since there is an intensive demand of highly spin-polarized ferromagnetic materials for magneto electronic devices [1,2]. The temperature dependence of the resistivity has been studied for several metallic thin films [3,4,5,6]. Where, the cross-sectional area or the thickness was determined by physical characterization methods. Typically, an increase of the TCR has been observed for bulk metals. For thin films, the situation is more diverse and both bulk-like [7,8], as well as higher-than-bulk [6,9] and lower-than-bulk TCR values [5] have been observed.

2. Experimental Methodology

We planned to grow a film of materials of cobalt and aluminium in the following viz. The multilayered films (Co/Al) were prepared using electron beam gun and thermal evaporation techniques at a pressure 6X10^-5 mbar at room temperature on glass substrates in a standard V.R. technologies make coating unit it consists a two thermal evaporation and one four source electron beam gun. Four materials can be evaporated at a time without breaking the vacuum from electron beam gun and two materials can be evaporated at a time without breaking the vacuum by thermal evaporating source, i.e total six materials can be evaporated in this system without breaking the vacuum. The pure elements were procured from M/S Alfa-Aeser, USA. Cobalt layers deposited by evaporating from a molybdenum crucible using electron beam gun technique, whereas aluminium layers were deposited by using tungsten boats and helical by thermal evaporating source. The thickness of the layers was measured during the deposition using quartz crystal thickness monitor. After the preparation the films were kept for 24 hours in the same vacuum. The electrical resistivity were measured by following four probe methods two for voltages and two...
for current in an oxford makes instruments resistivity setup in the temperature range 4.2K to 300K at IUC Indore. While preparing the samples rate of evaporation was mentioned for all the samples are 2Å/s this was also observed by the crystal thickness monitor. The samples are [CO(10Å)/Al(10Å)]N N=3,6,9,12and 15Named as CA1, CA2, CA3, CA4 and CA5.

3. Analysis (Results) and Discussions

3.1. Electrical Resistance

The resistivity of the films increased with temperature of their interest as shown in Figure 1, for the films and named as CA1, CA2, CA3, CA4 and CA5. The room temperature (300K) resistivity ρ, was less by three or four orders of magnitude than the bulk may be due to increasing of the layer thickness. Also observed that the resistivity is increased with thickness of the layers in the range 9.5X10^-6 to 3.5 X 10^-2 (Ωm). The variation of ρ with temperature T is shown in Figure 1. The resistivity increased slowly with increasing temperature. The spin as well as lattice waves get excited as the temperature is increased which results in the enhanced electron-phonon scatterings. These caused increase of total resistivity.

The residual resistivity ratio RRR of the films has been estimated as $\text{RRR}=\left(\frac{R_{300K}}{R_{300K}}\right)\times100$ and shown in Table 1. These values may be due to the enhanced electron-electron, interfacial, grain boundary. For metals, TCR is the parameter which confirms relationship between electrical resistance and temperature. The temperature coefficient of resistance (TCR) has been determined in the temperature range 80K to 300K as $\text{TCR}=\frac{(\text{d}\rho/\text{d}T)}{\rho}$ where $\rho$ is room temperature resistivity and the TCR values are in the range of $10^{-3}(K^{-1})$ tabulated in Table 1. The resistance of bulk metals usually increases monotonically with temperature due to increasing electron-phonon and electron-electron scattering, [10] and their TCR is therefore positive. It is observed that TCR values are decreasing with increasing number of layers.

As per the conductivity expression, $\sigma=\sigma_0 \exp(E_a/K_BT)$ the plots of ln (σ) versus (1000/T) were sketched and shown in Figure 2. Here, $E_a$ stands for activation energy for dc conduction. The $E_a$ for each film has been determined by fitting least square linear lines in the temperature range 200 to 300K and obtained values are tabulated in Table 1.

<table>
<thead>
<tr>
<th>Sample No</th>
<th>RRR (300 to 300K)</th>
<th>TCR (K^-1)</th>
<th>Activation energy, $E_a$ (eV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CA1</td>
<td>1.22 X10^-1</td>
<td>4.02 X10^-3</td>
<td>2.53 X10^-1</td>
</tr>
<tr>
<td>CA2</td>
<td>2.17 X10^-1</td>
<td>3.19 X10^-3</td>
<td>1.89 X10^-1</td>
</tr>
<tr>
<td>CA3</td>
<td>5.57 X10^-1</td>
<td>1.89 X10^-5</td>
<td>1.15 X10^-1</td>
</tr>
<tr>
<td>CA4</td>
<td>5.17 X10^-1</td>
<td>1.87 X10^-5</td>
<td>1.07 X10^-1</td>
</tr>
<tr>
<td>CA5</td>
<td>5.72 X10^-1</td>
<td>1.74 X10^-5</td>
<td>9.49 X10^-1</td>
</tr>
</tbody>
</table>

Table 1. Residual resistivity ratio, RRR, Temperature coefficient of resistance, TCR and Activation energy, $E_a$.

Figure 1. Plots of Resistivity, $\rho$, versus temperature, $T$, of CA1 (a), CA2 (b), CA3 (c), CA4 (d) and CA5 (e) films in the temperature range 5 to 300K. And all in a single plot (F)
In Figure 1, it has been observed that the resistivity of the films was measured from liquid helium temperature to room temperature. The resistivity of each film is linear in the entire temperature range of 50–300 K and the fitting parameters are shown in Table 2. The temperature dependence of resistivity has been considered by dividing the entire temperature range into two intervals that is \( T = 5 \) to 50K and \( T = 50 \) to 300 K the power laws of the type \( \rho(T) = A + B^n \) has been fit to the data in the temperature range 50 to 300K (Figure 3) From Figure 1, it is observed that the resistivity is decreased with increasing temperature in films that is semiconductor to metallic transition between 40 to 50K respectively (this range of date will be published in later). Therefore we have analyzed 50 to 300 K data using the power law’s in the temperature range 50 to 300K (Figure 3) the best fit coefficients have been extracted in the temperature ranges and shown in Table 2. The exponent \( n \) was found to be one in all the films establishing a linear relation between resistivity and temperature in the temperature range 50 to 300K. The coefficients A and B are found to be in the orders of \( 10^{-2} \) to \( 10^{-6} \) Ωm. The electron phonon s-d scattering \[9,11\] \( T^3 \) term called block willson term begins has been said to dominate over the electron-magnon \( T^n \) term. Value infers that the interfaces between the layers and the magnetic layers thickness also affect the temperature dependence of resistivity in addition to the contributions from electron-phonon-magnon scatterings.

Table 2. Fitting parameters A, B, and \( n \) values in the temperature range 50 to 300K.

<table>
<thead>
<tr>
<th>Sample No</th>
<th>( n )</th>
<th>( B )</th>
<th>( A )</th>
</tr>
</thead>
<tbody>
<tr>
<td>CA1</td>
<td>1</td>
<td>8.78 \times 10^{-7}</td>
<td>4.00 \times 10^{-3}</td>
</tr>
<tr>
<td>CA2</td>
<td>1</td>
<td>1.06 \times 10^{-4}</td>
<td>1.62 \times 10^{-3}</td>
</tr>
<tr>
<td>CA3</td>
<td>1</td>
<td>6.02 \times 10^{-5}</td>
<td>1.34 \times 10^{-2}</td>
</tr>
<tr>
<td>CA4</td>
<td>1</td>
<td>6.67 \times 10^{-5}</td>
<td>1.40 \times 10^{-2}</td>
</tr>
<tr>
<td>CA5</td>
<td>1</td>
<td>6.26 \times 10^{-5}</td>
<td>1.72 \times 10^{-2}</td>
</tr>
</tbody>
</table>

Figure 2. The plots of \( \ln(\sigma) \) versus \((1/T)\) of CA1, CA2, CA3, CA4 and CA5 films. The solid lines Drawn are the least square linear fits to the data in the temperature range 200 to 300K

Figure 3. Plot of resistivity, \( \rho \) versus Temperature, \( T \) in the temperature range 50 to 300K of CA1, CA2, CA3, CA4 and CA5 films
4. Conclusion

We have studied the temperature dependence of resistance of CO/Al multilayered films with number of layers. The overall temperature behavior of resistance from 300 K to 5 K can be analyzed; the structural properties of the thin film undoubtedly contribute greatly to RRR values. The residual resistivity ratio RRR obtained in the temperature range 30 to 300K and Temperature coefficient of resistance TCR were worked out in the temperature range 80 to 300K, and the high temperature activation energy were calculated in the temperature range 200 to 300K. Weak localization of electrons and the electron–electron interaction effects at low temperatures resistance. Strongly suggesting free electron-like conduction processes in thin films. This work demonstrates that high metallic conduction can be readily achieved in these systems. Semi classical calculations showed that the TCR differs from bulk values due to surface roughness which contributes to scattering to the total resistivity for metallic thin films, in the relevant thickness range, with grain sizes comparable to the film thickness, the semi classical model finds that grain boundary scattering typically dominates and the TCR is bulk-like. Temperature dependent resistivity of these multilayered films is evidently connected to electron-phonon scattering.

In CO/Al multilayered films small change in the resistivity is because of small bridge layers between cobalt and aluminium layers similar type of interpretation, however, Here, a tunnel mechanism or short metallic nano bridges are discussed in literature. Probably, the bridges can be represented by a chain of single atoms. Arguments for such a mechanism can be derived from field effect measurements. The charging of the metal atoms influences their conductance as well as the tunneling probability of the electrons. The dominating parameter is the distance between the atoms which provides a smooth transition from tunneling to contact regime [12]. Less importance must be attributed to the chemical interaction of the atoms with the underlying glass substrate because of the consistence of the results obtained for nickel and copper.

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References