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Electrical Properties of Indium Doped Alumina (Al_2O_3) Thin Films

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Abstract

To know the electrical properties of any materials is very important for practical application of that material. In this paper I have tried to find out the proper electrical properties of Indium doped Alumina (Al_2O_3) for practical application of this Alumina. For this purpose all thin films are deposited on glass substrate by electron beam evaporation technique at a pressure of about 1.5 x 10-6 torr and at temperature of 307K. The thickness of Indium doped Al_2O_3 films (25%w, 30%w and 40% w of In_2O_3) range from 68 nm to 183 nm. For 25% In_2O_3 doped alumina the conductivity at room temperature is 24.10mho/cm, for 30% In_2O_3 doped alumina this value is 82.99mho/cm and for 40% In_2O_3 doped alumina this is 129.10mho/cm. The resistivity and sheet resistance decrease with the increase of doping concentration that means the conductivity increases with doping concentration.

Keywords*: thin film, indium, alumina, conductivity, concentration.*

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1. Introduction

Aluminum oxide (Al_2O_3) is one of the most popular electrical insulating materials since it has high electrical breakdown field, larger bandgap, and high dielectric constant. In particular, Al_2O_3 films having thicknesses in the range of 50–300 nm are interesting for preparing the gate insulators in thin film field effect transistors (FETs). Fabrication of Al_2O_3 thin films can be done by dc or RF magnetron sputtering of either an Al target in Al : O_2 mixtures (reactive sputtering) [1-4], or by sputtering of an Al_2O_3 target in pure Al, or Al : O_2 mixtures [4-12]. Optimization of the dielectric properties, in particular the electrical resistivity and electrical breakdown fields of Al_2O_3 films fabricated by magnetron sputtering was one of the most important point of investigations in the last year. However, Dielectric constants (ε) and breakdown fields were often used to describe the electrical properties of thin sputtered Al_2O_3 films [6, 8–10, 12]. Current voltage (I–V) curves were only reported in exceptional cases [3-5], [7, 11]. Nevertheless, researchers have the highest level of interest to those curves as they contain information about the electrical conduction mechanisms leading to unwanted leakage currents, e.g., across the gate insulator in a FET structure, and may contain information on the mechanism of the electrical breakdown and the statistical analysis of the breakdown fields [9]. In the present paper, we have tried to explain the the variations of resistivity, conductivity and sheet resistance with respect to the variations of doping concentration in detail. Our prime concern is to demonstrate the influence of the sputter parameters and to acquire insight in the origin of the leakage currents as well as their dependency on the dielectric break down fields. Atomic force microscopy data of the surface morphology will be reported along with the electrical measurements.

In_2O_3 is a semiconducting material which has a direct band gap of about 3.6 eV [13] and an indirect band gap of approximately 2.6 eV [14]. Generally, it is a yellow powder but it can be prepared as a thin film which has the property of transparency in the visible spectrum. In general, the films are n-type semiconductors due to a consequence of deviations from stoiechiometric composition, excess indium atoms or oxygen vacancies act as donors. The material properties which are often described in the literature are considerably different from each other. One important reason behind this is that there are lots of differences in the conditions of preparation and consequently the oxidation state of the samples is also different. It has become a difficult task to understand the conduction mechanism in indium oxide thin films because of its complicated crystal structure (80 atoms in an In_2O_3 unit cell [15]).

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"Thin Films" can be defined as a thin layer of solid material which is formed on a solid substrate having a thickness of that magnitude which is comparable with mean free path of the conduction electrons of solid material. Its value can vary from material to material. In most of the cases, a film having a thickness below a few micrometers can be regarded as thin. The thin film technology is an important branch of physics where the characteristics of different metals, semiconductors and insulators are investigated in the form of thin film [16]. Most of the electronics equipments in the modern world are the contributions of thin film technology. The increasing demands of microelectronics in science and technology have greatly stimulated after the invention of thin film and due to the expansion has been made on different kinds of thin films. Systematic study of semi-conducting films has been continued for more than fifty years. Primarily, semi conductor films like Si, Ge etc. were studied. The Si and Ge technology is now well established [17]. Now, attention has been given to the study of compound semiconductor mainly on the oxide semiconductors (like Alumina). The most commonly used method to prepare the thin films is the thermal evaporation technique where the atoms are condensed from vapor phase onto a substrate. Solid material starts to vaporize when it is heated to a sufficiently high temperature. One or more phase transformations are required to achieve the deposition of films and the study of the thermodynamics and kinetics of these phase transformation exposes the formation of thin films [18].

2. Deposition Mechanism

Vacuum evaporation is one kind of deposition technique which is used to deposit a variety of materials by means of heating a source material under vacuum until it starts to evaporate or sublime. In order to form a film, we need to deposit or condense that evaporator onto a substrate surface. The material which is used as a source melts into a liquid and subsequently starts to evaporate into a gaseous vapor or sublimes. Evaporation takes place in a vacuum if the mean free path of atoms in the evaporate material in that vacuum space is much longer than the distance from the source to the substrate. The Hertz-Knudsen equation is used to express the rate of deposition.

$$\frac{\partial N}{\partial t}\frac{1}{A} = \frac{\propto(p"-p)}{\sqrt{2\pi mkT}} \tag{1}$$

$\partial N/\partial t$ = deposition rate from a source with surface area A
α = coefficient of evaporation
m = molecular weight of the evaporate
k = Boltzmann's constant
T = temperature
p"= vapor pressure at the evaporate surface
p = hydrostatic pressure acting on the source's surface [19]

Vacuum evaporation is renowned as a low-energy process because it requires very little kinetic energy to condense the deposited material onto the substrate. Moreover, the film deposition is almost strictly line of sight since the vapor condenses onto the open surfaces identical to it and does not coat edges perpendicular to the source [20]. Film deposition thickness depends on the quantity or rate of generated vapor material and the distance from the source to the substrate. Rates greatly rely on the substrate to source geometry as well as the deposition rate which can vary in case of large substrates due to its strong function of distance. The variation in deposition rate because of position relative to the source can be found by Knudsen's cosine law, $\cos\theta/r^2$, where r is the radial distance from the source and θ is the angle between that radial vector and the normal to the receiving surface. The variation of thickness on a coated surface which is centered at a distance, h below or above a source can be expressed by the following equation:

$$\frac{t_x}{t_0} = \left[\left(1+\frac{x}{h}\right)^2\right]^{-3/2} \tag{2}$$

Where,

t_o = thickness at the center of the coated surface directly above or below the source.
t_x = thickness of deposition at some distance, x from the center of the coated surface.

The source can be treated as a point source if the sources are very small in comparison to the source to substrate distance (h). Then, the equation can be written as:

$$t_x = t_o \quad (3)$$

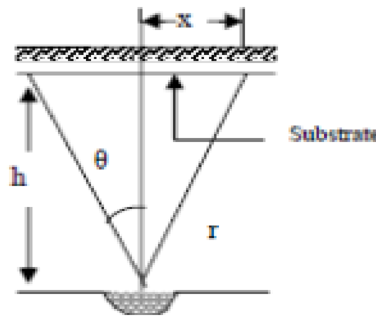

Figure 1. Schematic illustration of thickness [21]

3. Results and Analysis

Figure 2 and 3 shows the variation of resistivity and conductivity with different doping concentration of In_2O_3 respectively at 307 K. It is found from the graphs that the resistivity decreases with increasing the doping concentration and the conductivity increases with the increase of doping concentration. The variation of sheet resistance with different doping concentration of In_2O_3 is shown in Figure 4. The sheet resistance also decreases with the increase of doping concentration. All the data are given in table below.

Table 1. Data for variation of resistivity, conductivity and sheet resistance with doping concentration

Doping concentration in mole percent(%)	Resistivity in (ohm-cm)/1000	Conductivity in(mho/cm)	Sheet resistance in (ohm). 1000
25	43.12	24.10	4.15
30	11.99	82.99	0.99
40	7.69	129.10	0.70

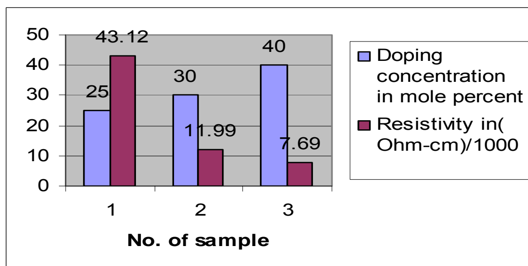

Figure 2. Variation of resistivity with doping concentration of In_2O_3 doped Al_2O_3 thin film

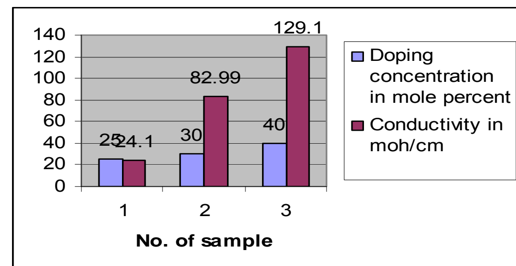

Figure 3. Variation of conductivity with doping concentration of In_2O_3 doped Al_2O_3 thin film

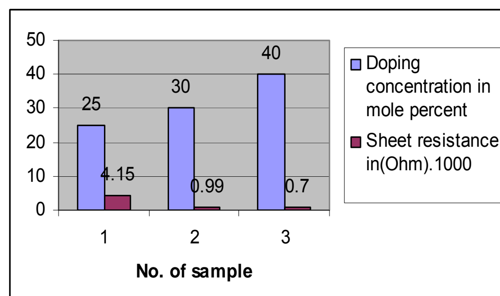

Figure 4. Variation of Sheet Resistance with doping concentration of In_2O_3 doped Al_2O_3 thin film

4. Conclusion

In this paper work we found that the conductivity of Al_2O_3 increases with the increases of Indium doping concentration. On the other hand, the resistivity and the sheet resistance decrease with the increases of Indium doping concentration.

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