Effect of temperature and deposition rate on the surface morphology of thin Al metal films on glass substrate: Application in Solar Cell

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Abstract. Thin Al films with thickness around 300nm are grown on glass substrate by thermal evaporation technique. The temperature of the substrate has varied in between 250°C - 300°C and the deposition rates are varied in the range of 0.5nm/s to 3nm/s. During the evaporation process, the vacuum level as lower as 10⁻⁵ Pa is maintained. The surface morphology/roughness of the thin films are studied using Scanning Electron Microscopy (SEM) technique. SEM images have shown that the surface roughness increases with the increasing deposition rate. The mean grain size of the metallic films on glass substrate increases from 25nm to 60nm (approx.) with the increasing deposition rate. In addition to that, the study reveals increasing substrate temperature will increase the average surface roughness.

1. Introduction

Since the pioneer development of Thin Film Solar Cell in the late 1970s, it is widely available in large module and vehicular charging systems. Thin-film solar panel is made up of an assembly of thin-film solar cells. These solar panels convert solar energy to electrical energy by using the principle of the photovoltaic effect. Each thin-film solar cell is made up of several layers of photon-absorbing materials. These layers can be up to 300 - 350 times smaller than the layers of standard silicon panels. They are very thin materials ranging from 0.22 nm to 1.22 nm. Thin film solar panels are very lightweight and flexible materials. Thin-film solar panels require a larger area for installation so they can be installed in institutional and commercial buildings with large rooftops/open spaces. The thin film solar panels are considered to be cheaper than traditional photovoltaic panels but it deals with the problem of less efficiency. The layers of the thin film solar can be deposited using Physical Vapour Deposition Process [1]. Physical vapor deposition (PVD) describes a variety of vacuum deposition methods [2] which can be used to produce thin films and coatings. PVD is characterized by a process in which the material goes from a condensed phase to a vapour phase and then back to a thin film condensed phase. Physical Vapour Deposition techniques such as evaporation and sputtering are often used to deposit Al films. The main advantage of PVD process are its high deposition rates and its developed process technology. PVD methods usually involve high
temperature steps during the deposition process, recently [3] low temperature deposition of Al film has been reported. One of the drawbacks of using Aluminium is that at relatively low temperatures it has very serious issue of surface roughness. They began to form hillocks at low processing temperature [4]. The hillocks formation depends on thickness and temperature. The hillock formation can cause shorts and failures to devices. It is necessary to prevent such hillock formation to avoid such failures of devices. The basic goal of this study is to view surface roughness as a function of deposition rate [5]. Lowering the deposition rate will reduce the surface roughness of the prepared thin films which will increase the efficiency of the thin film solar cell.

This will be novel experiment for the future development of low cost metallic thin film Solar cell. Al thin films on glass substrate have immense application possibilities in microelectronics and it is the basic building block of low cost solar cell development. Due to its excellent reflectance and adherence property, Al thin films on glass substrate could be used for increasing the efficiency of solar cell in optoelectronic industries [6]. This has prompted the authors to study the surface morphology of thin Al films, produced by thermal evaporation technique, on low-cost glass surface. The surface properties of thin films critically depend upon substrate temperature, deposition rate and vacuum level within the chamber. Out of these deposition rate is one of the most important parameters that influences the surface quality and in turn the device performances. The reduction of surface roughness reduces the chance of carrier recombination and defect density. Thus, the leakage current reduces significantly and the device performance enhances. Aluminium films grown on quartz substrate by thermal evaporation were studied by Semaltianoset. al. [7].

It was found that RMS roughness of the Al films increased from 3.2nm to 5nm for an increase of deposition from 0.2nm/s to 1.5nm/s. Higo et. al. [8] reported no change in the surface morphology of 200nm thick Al film for an increased deposition rate from 0.5 nm/s to 2 nm/s. In this paper, the author will study the surface roughness/morphology of Al metal films grown on glass substrate. The surface morphology analysis would be carried out based on SEM results. The thickness of the samples is given by the quartz crystal monitoring system and is correlated using Ellipsometry technique.

2. Experimental Technique

Thermal evaporation and vacuum coating technique equipped with diffusion pumping system is used in the present study. The thickness of the metallic film and deposition rate are monitored by in built Quartz Crystal Monitoring System. Al films of around 300nm are deposited initially on unheated glass substrate and gradually the substrate temperature is varied. Source Aluminium has placed into a crucible inside the system. The Aluminium is heated inside the vacuum chamber taking to some vapour pressure. Inside the vacuum, even a relatively low vapour pressure is sufficient to raise the vapour cloud in the chamber. This evaporated material now constitutes a vapour stream, which transverses the chamber and hits the substrate, sticking it as a coating or film.

3. Results and Discussion

The nature of the substrate, the substrate temperature, deposition rate and the contamination and presence of defects on the surface will affect the growth, structure and properties of the deposited aluminum films. Here, the deposition rate is varied to examine the changes of the growth of the grainy surface of the films.

When the atoms reach the surface of the substrate, a thin film is formed. Thermal evaporation technique which is one type of physical vapour deposition is used to deposit Al films on the glass substrate. The deposition rate has been varied for various samples. As a result, the deposition rate has
a critical influence on the film growth process. The grain size has been estimated from the SEM images and is shown in the Table 1.

Table 1. Grain Size as a function of Deposition rate (estimated from SEM images) grown on the surface of the glass substrate.

| Deposition Rate, nm/s | Grain Growth Size in nm |
|-----------------------|-------------------------|
| 0.2 ± 0.05            | 28                      |
| 0.5 ± 0.02            | 32                      |
| 1.5 ± 0.15            | 42                      |
| 2.5 ± 0.25            | 70                      |

As can be seen from the data presented, the grain size increases significantly as the deposition rate has been increased from 0.1 nm/s to 2.5 nm/s. The roughness of the film correlates with the grain size of these films. For low rates, the grain size is smaller and for higher rates the grain size increases.

The dependence of grain size on the deposition rate can be explained by Semaltianos[9] for thin evaporated Al films on quartz. The process of surface diffusion of atoms and nucleation and coalescence of metal clusters during deposition explains this formation. The Al atoms arriving onto the substrate surface can diffuse along the surface and form clusters which can in turn contribute to the formation of grains. At low temperature and deposition rates, the surface diffusion of Al atoms and formation of grainy surface is not prominent. The number of Al atoms arriving onto the surface per unit time is higher at higher deposition rates. As a result, the number of nuclei formed on the surface is higher which leads to the formation of bigger grains. Gases such as oxygen are considered to affect the growth of individual grains[10]. The adsorbed oxygen which accumulates on the surface can suppress the growth process. At a given temperature and pressure, the concentration of gas atoms on the surface decreases with the increase in the deposition rate from 0.1 nm/s to 2.5 nm/s. As a result, the increase of the deposition rate within the stated range significantly influences the gas atoms on the grain growth and allow the formation of bigger grains.

SEM imaging of Al glass films reveals the morphology and surface roughness for different deposition rate and substrate temperature. Figure 1 shows the SEM images of thermal evaporated Al thin films on glass substrates for deposition rates varying within 0.2 nm/s to 2.5 nm/s. Top view images are captured with SEM device for better contrast. In all the four cases, grainy surface and voids are observed. Metallic films produced at 0.2 nm/s deposition rate results in comparatively smoother surface morphology. The grains are mostly spherical or oval shaped and uniform in size. For higher deposition rate of 2.5 nm/s hillocks/outgrowth are observed. The density of hillocks is proportional to rate of deposition. The grain size in nanometre is estimated from SEM image and shown in Figure 2. It is shown that grain size increases with deposition rate. Moreover, the surface roughness increases with increase in deposition rate.
Figure 1. SEM images of thin Al films grown on glass substrate at different deposition rates: (a) 0.2nm/s, (b) 0.5nm/s, (c) 1.5nm/s (d) 2.5nm/s.

Figure 2. Range of grain sizes (estimated from SEM images) of thin Al films evaporated on glass substrate as a function of deposition rate

The thickness of some of the samples was correlated using Spectroscopic ellipsometric technique [11]. Further, the ellipsometric study has revealed that the thickness of sample 1 is around 300 nm and that for sample 2 is around 450nm. This is at par with the observation we found from the Quartz crystal monitoring unit embedded in the vacuum coating unit. The Spectroscopic ellipsometric observation are shown in Figure 3 respectively for 300nm and 450nm metallic film on glass substrate.

Figure 3. Ellipsometric observation respectively for a) 300nm and b) 450nm metallic film on glass substrate.
4. Conclusion

The study has focussed on the low cost and high efficient metallic film development on glass substrate as an application in thin film Solar cell. The surface morphology/roughness are studied through SEM analysis. Dependence of grain size and roughness on the deposition rates are extensively studied. SEM imaging of the as prepared films reveals the grainy structure, with the grain size being dependent on the deposition rate. The films produced at higher deposition rates exhibit outgrowth/hillocks the density of which increases with deposition rates. The characteristic feature of island growth on the surface are also explained in terms of substrate temperature, growth rate, condition of vacuum inside the chamber. This is a novel experiment for future development of high efficiency metallic thin film solar cell. The study will be extremely useful for optoelectronic industries.

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