Effect of RF/DC Magnetron Sputtering Process Parameters for Improving Efficiency of Solar PV Cell

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Abstract. The biggest disadvantage of solar cells is that it has low solar power conversion efficiency typically 14%. So as to improve the power conversion performance, several attempts was made by researchers and once such technique is to reduce the reflection by providing textures on the solar cells. This texture will reduce the reflectance and thereby increase the solar power conversion efficiency. In this work, an investigational study was conducted to improve an energy efficiency of solar PV cells. Here Cu, Ag, Al was deposited for metallization purpose at specific places by using RF and DC magnetron sputtering process. The input parameters such as power, deposition time and substratum temperature were optimized during the sputtering process and the corresponding coating thickness, optical properties and surface topography were investigated. The coating thickness and surface roughness were increased as power increased from 15W to 45W. Average surface roughness (Ra) of 6nm and was obtained at the optimum power of 45W and deposition rate of 5-7 mins. The surface morphology and topography was characterized by using SEM and AFM which shows uniform coating with spherical shaped with densely packed nanostructures with increase in grain size were observed and elemental composition were confirmed by using EDAX. The absorption and reflection were investigated by using UV-VIS-NIR spectrometer indicates that the optical absorption increased from 1.2% to 1.68% at the wavelength range from 250 to 314nm. The reflection was reduced from 13.4% to 3.67% and the conversion efficiency was increased from 14.22% to 16.63%. This paper reports the complete experimental details, results and analysis.

Keywords: Solar PV cell; Magnetron sputtering; Nano coatings; Nano materials; Solar Efficiency.

1. Introduction

A solar cell is a solid state semiconductor device it can convert light energy into electrical energy based on the principle of photovoltaic effect. When compare to the other readily available energy sources conversion of electricity was more expensive. Yet, thin film sunlight based solar cell is cheap and could utilize environmentally friendly power vitality which is accessible abundant and give sun oriented power. The thin film metallic coating has been carried out with the process like electro
deposition, chemical deposition, thermal oxidation, spray pyrolysis and magnetron sputtering. Contrast with electro and chemical deposition method, magnetron sputtering gotten significant consideration since it has less ecological contamination and it is utilized for high space deposition with comparatively high deposition rate will be achieved [1]. This methodology is well appropriate for depositing oxides, nitrides, and carbides for surface protection and used as optical film [2]. Over 10.2% efficiency has been accomplished in Cu$_2$ZnSn(S,Se)$_4$ flimsy film which is which is manufactured by utilizing magnetron sputtering process [3]. Since copper and silver exhibit good properties like high thermal conductivity, low electrical resistivity and good antibacterial agent so the Metallization of copper and silver to the silicon wafer can improve the overall performance of the solar cell [4,5]. Aluminium films generally utilized in numerous application like optical layers, dielectric layers, electronic seals and insurance coatings in light of the fantastic warm, electrical, mechanical and concoction properties [6]. The properties of the film including its thickness is depend upon the input parameters employed in magnetron sputtering such as power, deposition time, argon/oxygen flow rate, base pressure, temperature. The vacuum degree plays the major effect on tungsten-rhenium adherence towards the alumina ceramic substrate have been demonstrated at optimized combination of argon flow rate 30sccm, power 400W and vacuum of $0.7 \times 10^{-6}$ torr [7]. The impact of oxygen fractional weight and substrate temperature can improve the stoichiometry of the film [8]. The affidavit time can modify the morphology of the structure because of variety in the molecule measure appropriation. Longer statement indicates diminish the surface coefficient and shorter affidavit time gives the film unpredictable grains with high harshness [9]. The normal surface roughness and the power of the film get expanded with increment surface temperature 200 to 300$^0$C and decrease of Ar has harmed the crystallinity yet produce smooth surface and thick morphology [10]. The aim of this work is to developing Nano coating on solar PV cell by using RF/DC magnetron sputtering unit and to study the impact of process parameters in material properties and enactment of solar cell.

2. Experiment
The substrate utilized in this research was multicrystalline solar Photovoltaic cell of 0.5v capacity. For trialling it was turned into size of 20 x 40mm. Surface cleaning is essential to achieve efficient coating to avoid contaminations. First the surface was washed with acetone and then rinses with distilled water and ethanol. The sputtering unit and vacuum chamber shows in figure 1. The target materials of 50mm diameter and 20mm thickness Cu, Ag, Al (99.99%) was purchased from HHV, Bangalore as cathode material was placed at a distance of 4cm from the substrate, metallization of Cu, Ag, Al were performed by varying the input parameters that are employed in the sputtering process such as power, deposition time and substrate temperature are tabulated in table 1. The cathode materials were pre - sputtered before deposition of about 5minutes to dispose of any defilement on its surface. All the coating process was performed at a constant base pressure of $3 \times 10^{-6}$ mbar at argon (99.999%) rate of 10sccm in the vacuum chamber.

| Experiments | Power (W) | Deposition Time (Minutes) | Temperature (Degree Celsius) |
|-------------|-----------|--------------------------|----------------------------|
| 1           | 15        | 3                        | 100                        |
| 2           | 15        | 5                        | 200                        |
| 3           | 15        | 7                        | 300                        |
| 4           | 30        | 3                        | 200                        |
| 5           | 30        | 5                        | 300                        |
| 6           | 30        | 7                        | 100                        |
| 7           | 45        | 3                        | 300                        |
| 8           | 45        | 5                        | 100                        |
| 9           | 45        | 7                        | 200                        |
Coating properties such as thickness and the surface roughness was measured by using STYLUS PROFILOMETER. The grain size and the cross sectional view was measured by FEI Quanta FEG 200 HRSEM and elemental composition were confirmed by EDX. An optical property such as absorption and reflection was measured by UV visible spectrophotometer (Model – UV-3600 plus) with wavelength range from 200 to 2500nm. I-V characteristics were studied by using class AAA solar simulator - ORIEL SYSTEM.

3. Results and discussion
3.1. Coating properties
Figure 2(a) & (b). indicate the graphical representation of coating thickness and surface roughness against process parameters involved in sputtering process and their values are tabulated in table 2. The process parameters are influencing the coating properties. When the power is increasing the coating thickness and surface roughness is also increasing. As power increases the energy available to eject atoms from target increases and hence more number of atoms will be ejected and gathered on to the substrate [11]. So the maximum surface roughness was obtained as 6nm at the power of 45W. Amount of roughness can create texture on to the surface of the substrate.

| Experiments | Power (W) | Deposition Time (minutes) | Temperature (Degree Celsius) | Coating thickness (nm) | Surface roughness Ra (nm) |
|-------------|-----------|---------------------------|-----------------------------|------------------------|--------------------------|
| 1           | 15        | 3                         | 100                         | 49.640                 | 1.33                     |
| 2           | 15        | 5                         | 200                         | 70.466                 | 2.37                     |
| 3           | 15        | 7                         | 300                         | 61.359                 | 3.19                     |
| 4           | 30        | 3                         | 200                         | 150.620                | 2.55                     |
| 5           | 30        | 5                         | 300                         | 138.286                | 2.99                     |
| 6           | 30        | 7                         | 100                         | 160.079                | 5.01                     |
| 7           | 45        | 3                         | 300                         | 310.670                | 5.03                     |
| 8           | 45        | 5                         | 100                         | 227.415                | 5.90                     |
| 9           | 45        | 7                         | 200                         | 203.500                | 6.76                     |
3.2. Surface morphology

The surface morphology of Cu, Ag, and Al coated samples with different magnifications of 1\(\mu\)m, 2\(\mu\)m, 400nm and 500nm shown in figure 3(a), (b) & (C). The image shows non-uniformly distributed surface under 15w and 30W. From Fig. 3(c) at 45W spherical shape nanostructure morphology with densely packed throughout the surface with increase in grain size from 80nm to 150nm respectively. Coalescence of atoms was observed due to increase in anode temperature [12].

Figure 2. Shows the graphical representation of (a) coating thickness, (b) surface roughness

Figure 3. Shows the SEM image of the samples (a) 15W, (b) 30W & (c) 45W
3.3. Surface topography
From the Fig. 4(a) & (b) shows the surface topography which indicates that the surface has many spikes which confirms the surface is not smooth and also shows the variation in the surface with less inter grain space due to increase the sputtering power [13]. This rougher surface can create more reflection and bounce back into the surface thereby increase the output power of the PV cell.

![Figure 4. Shows the AFM image of the (a) sample 6 & (b) sample 8](image)

3.4. Optical properties
The absorption spectra of the coated and non-coated samples are presented in the figure 5(a), (b), (c) & (d). The absorbance of non-coated solar PV cell was about 1.22% in the wavelength of 280nm. After metallization the absorption was increased to 1.56% for the sample 1 and 1.61% for sample 6 in the wavelength shifted to 320nm and the maximum absorption of 1.68% was observed at sample 8 in the wavelength range of 312nm so the optimum combination of process parameters maintained at 45W and 5 mins of deposition. figure (e), (f), (g) & (h). shows the reflection spectra, it shows the reflection of 23% for non-coated sample and the reflection was decreased to 13.4% in the wavelength range of 360nm for the sample 1 at 15W and 5.4% of reflection for sample 6. For sample 8 we observed that the reflection reduced to 3.67% in shifted wavelength range of 270nm at 45W. Since at 45W the amount of deposition of Nano particles was more compare to the 15W and 30W such that less amount of photons was reflected back due to multiple reflection with cu, Ag, & Al Nano particles.
Figure 5. Shows the absorption spectra of (a) sample 1-3, (b) sample 4-6, (c) sample 7-9 and reflection spectra of (e) reference cell, (f) sample 1, (g) sample 6, (h) sample 8

3.5 I-V characteristics

The performance of multicrystalline solar cell without coating (Reference sample) and the maximum absorption sample were measured and the outcomes are potted in the table 3. And the corresponding I-V curve is presented in figure 6(a) & (b). From the table 3, the electrical properties such as $V_{oc}$ and $P_{max}$ are slightly increased to 0.6283 volts and 133.11mW compare to the reference cell respectively. The fill factor of the coated sample is 73.57% compared to 67.04% of the reference cell which leads to increase of 23% efficiency. Since the sample 8 has maximum absorption of 1.68% which shows the maximum efficiency.
Figure 6. I-V characteristics of (a) reference cell & (b) sample 8

Table 3. Electrical Properties of Reference and Coated Sample

| Sample no  | Open circuit voltage \( V_{oc} \) (V) | Short circuit current \( I_{sc} \) (A) | Max voltage \( V_{max} \) (V) | Short circuit current density \( J_{sc} \) (A/cm²) | Max Power \( P_{max} \) (mW) | Fill Factor (%) | Efficiency (%) |
|------------|---------------------------------------|--------------------------------------|-------------------------------|----------------------------------|-------------------------------|-----------------|---------------|
| Reference cell | 0.5877                              | 0.2887                               | 0.4534                        | 36.09                            | 113.88                        | 67.04           | 14.22         |
| Sample 8   | 0.6283                              | 0.2879                               | 0.2712                        | 35.99                            | 133.11                        | 73.57           | 16.63         |

4. Conclusion
Copper, silver and aluminium was deposited by using Magnetron sputtering process and the input parameters were varied as well as the optimum combination was found to be 45W, 5mins and 100°C. The coating properties were analysed by using stylus Proflimeter that shows the coating thickness and surface roughness was increased with increase in power and deposition time and the maximum roughness of about 6nm. SEM and AFM images show the Spherical shape with tightly packed nanostructure due to increase substrate temperature. Optical properties were characterized by using UV spectrometer which shows the maximum absorption of 1.68% and reflection reduced to 3.67% and I-V measurement shows 14% of increased efficiency.

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