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Synthesis of TiO_2 and ZnO Nano-Particle films and their effect on Performance of Silicon Solar Cells

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Abstract

Titanium dioxide (TiO_2) nano-particles and films were prepared by the sol-gel method and zinc oxide (ZnO) films were synthesized by rf sputtering method. The results of investigation of un-coated and TiO_2 and ZnO nano-particle films coated monocrystalline silicon solar cells are presented. The investigation of current – voltage characteristics to determine electrical properties of monocrystalline silicon solar cells was carried out after annealing the samples at different temperatures. The fill factor varied with the annealing temperature and nano-particle films deposited on the solar cell. The light absorption is affected by the morphological changes on the surface of the solar cell. The use of metal oxide nano-particles on the surface of silicon solar cells enhanced the performance of solar cell.

Keywords: TiO_2, ZnO, thin films, nano-particles, sol-gel, silicon solar cell.

Introduction

Solar power technology has become a replacement for extinguishing fossil fuels and large electric grids. Solar cells are made of semiconducting material, usually silicon. Silicon being abundant in nature, less expensive and highly stable finds application in various devices of semiconductor technology and especially solar cells. But these cells manufactured so far are of low efficiency because of poor light emission and absorption. Hence production of electricity at large scale has become very expensive. Silicon-based solar cells have weak absorption to long-wavelength photons near the band gap[1] (1.1 eV).Since a large fraction of the AM1.5 solar spectrum falls into this region (0.7 µm–1.1 µm) where silicon is unable to absorb light, trapping long-wavelength photons has become a challenge to thin-film silicon solar cells. Recent advancement in nanotechnology has increased absorption of light through various methods.

Pioneer work by Manal Midhath Abdullah[2] in enhancing photocurrent, by depositing gold nanoparticles of diameter 20.09 to 41.07 nm, over solar cell and later annealing to 200°C showed that the fill factor of bare Si solar cell 0.5388 is increased to 0.629 resulting in the improvement of the photocurrent and hence enhanced absorption of the photoactive due to the high electromagnetic field strength in the vicinity of the excited surface plasmon. Under solar spectrum AM1.5, the transmittance of Ag nano-particles with radius of 160 nm were found to be equivalent to that of the usual textured antireflection coating over solar cells, and its effects are found to be better than that of the planar antireflection film are highlighted in the reports of Chen Feng-Xiang et al[3]. As studied by Valeria Marrocco et al[4] light absorption in a solar cell can be increased by scattering silver nano-particles which were arranged in a periodic pattern placing on the top of amorphous layer. Different geometry of metal nano-particles, back and forward scattering and Si thickness were analyzed which revealed that the thickness of the substrate has huge influence on the back-scattering, when the nano-particles have corners. Another similar work done in this regard is photon injection into the silicon solar cell which is maximized with the help of anti reflection coatings given to the silicon surface is found to balance the mismatch in refractive index between air and silicon. Path length enhancement is observed by the work of Santanu Maity et al[5] due to absorption inside the cell by obliquely incident light and also multiple reflections inside the cell. Path length enhancement is observed due to the properties of silver nano-particles deposited on the top of the solar cell. For size of nano-particle in the range of less than 50nm reduction in the efficiency was also observed. By depositing Au nano-particles over amorphous silicon film an enhancement in short-circuit current density and energy conversion efficiency are observed which were achieved via improved transmission of electromagnetic radiation from the forward scattering by surface plasmon polariton modes[6]. For Au nano particle density of ~$3.7X10^8$ cm^{-2}, an 8.1% increase in short-circuit current density and an 8.3% increase in energy conversion efficiency are observed.

Work done by Robert Bywalez et al[7] demonstrates one of the methods to form stable dispersion of medium-sized silicon nano-particles by thermally induced grafting of acrylic acid to the surface of nano-particles. The measurements such as X-ray photoelectron spectroscopy and diffuse reflectance infrared Fourier spectroscopy were carried out to confirm the covalent attachment on the silicon nano-particles. Dynamic light scattering and Zeta-potential measurements, showed no signs of degradation for months which proved the stability of the dispersion.

In this paper we report the increase in fill factor of the bare solar cell after being coated with TiO_2 nano-particles and annealed to 50°C, whereas the same when annealed to 100°C showed decrease in fill factor. Sol-gel TiO_2 nano-particle coated on silicon solar cell gave a contradictory result to that of previous one.

Material and Methods

The silicon solar cell (un-coated) were procured from BHEL and connected to the circuit consisting of a battery, ammeter, voltmeter and resistance box as shown in figure 1. The open circuit voltage and short circuit current were measured and recorded. The resistance has been varied and the current and voltage values were recorded and the I-V characteristics have been plotted and determined their efficiency and fill factor. The blue color portion of the solar cell is the negative terminal and behind the solar cell is the positive terminal. A wire was soldered to one of the parallel metal coating on the blue colored portion of the solar cell and then another wire to either of the parallel metal lines behind the solar cell. These two wires were connected to the positive and negative terminals indicated on the solar kit. The short-circuit current and the open-circuit voltage are the maximum current and voltage respectively from a solar cell. However, at both of these operating points, the power from the solar cell is zero. The "fill factor" (FF), is a parameter which, in conjunction with V_{oc} and I_{sc}, determines the maximum power from a solar cell. The FF is defined as the ratio of the maximum power from the solar cell to the product of V_{oc} and I_{sc}. Graphically, the FF is a measure of the area of the rectangle by the area of the I-V curve. The FF is illustrated below.

$$\text{Fill factor (FF)} = \frac{\text{Area of rectangle}}{\text{Area of curve}}$$

The efficiency is the most commonly used parameter to compare the performance of one solar cell to another. Efficiency is defined as the ratio of energy output from the solar cell to input energy from the sun (In this experiment, it is the lamp of 200W). In addition to reflecting the performance of the solar cell itself, the efficiency depends on the spectrum and intensity of the incident light and the temperature of the solar cell. Therefore, conditions under which efficiency is measured must be carefully controlled in order to compare the performance of one device to another. The efficiency of a solar cell is determined as the fraction of incident power which is converted to electricity and is defined as,

$$\eta = \frac{I_m * V_m}{E * area\ of\ the\ cell}$$

Where E is the power of the light incident on solar cell (this experiment is done under laboratory conditions. Hence we have replaced sun by a bulb of 200W).

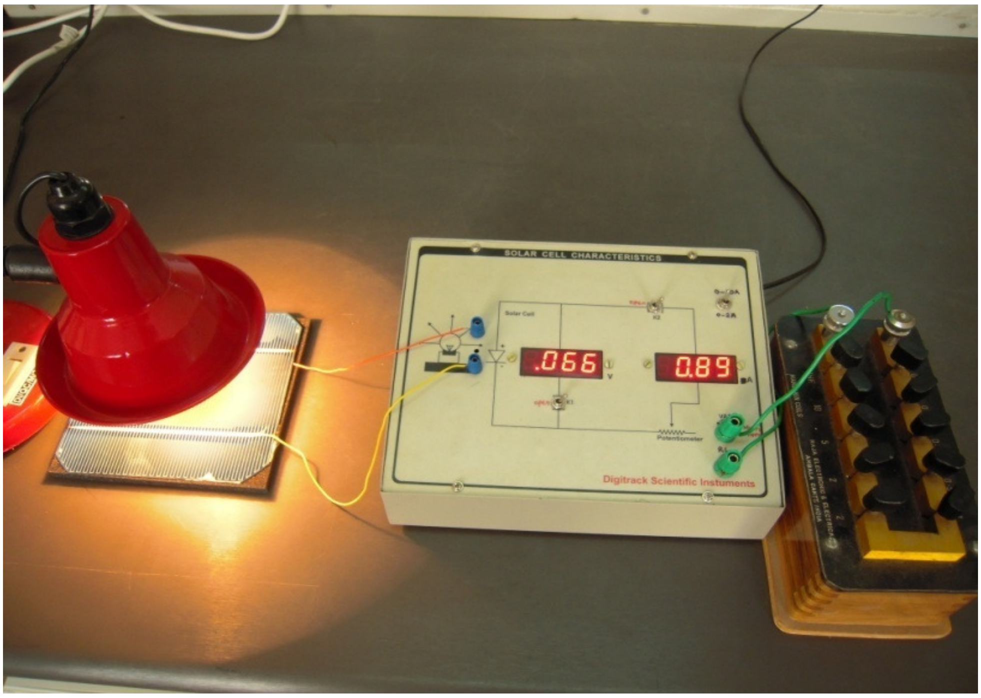

Figure -1
Apparatus used for silicon solar cell operation

The solar cell was coated with ZnO film by radio frequency (RF) sputtering. Like direct current (DC) sputtering, this technique involves running an energetic wave through an inert gas to create positive ions. The target material (ZnO), which ultimately becomes the thin film coating, is struck by these ions and broken up into a fine spray that covers the substrate (solar cell) as a thin film. TiO_2 nano-particles were synthesized by the sol-gel method[8,9]. Titanium tetraisopropoxide and absolute ethanol were mixed in a beaker with the volume ratio of 1: 9 and 0.1 ml of concentrated HCl was added and stirred for 30 min to get a homogeneous clear solution (sol). A part of that sol was used to make TiO_2 film on silicon solar cell. The remaining sol was stirred constantly on a hot plate maintaining a temperature of 60°C for 2 hr. The precipitate obtained was filtered and dried at 80°C for 2hr. Then the resultant solid was annealed at 400°C to obtain anatase phase of TiO_2[10]. The flow chart for the preparation of TiO_2 nano-particles is shown in figure-2.

0.5 g of TiO_2 nano-particles was mixed with 10 ml of water. This mixture was coated uniformly on the solar cell using a glass rod. The solar cell was kept in an oven and annealed at 50^0C for 1 hr. Another solar cell coated the same way was kept in an oven and annealed at 100^0C. The electrical measurements were done the same way as for uncoated solar cell. TiO_2 sol-gel film is coated on the solar cell using a glass rod. The solar cell was kept in an oven and annealed at 50 ^{0}C and 100^0C for 1h. Measurements are done in the same way as for the uncoated solar cell. The un-coated, ZnO film, TiO_2 nano-particles and TiO_2 film coated solar cells are shown in figure-3.

Results and Discussion

Figure 4a and b show the SEM image of the un-coated solar cell and ZnO film coated solar cell at RT, respectively. The un-coated solar cell is featureless and crack free without any pores where as the ZnO film coated solar cell is uniform and less porous type and some agglomerations were also observed. Figure 4c and d show the SEM images of TiO_2 nano-particles coated solar cell annealed at 50^0C and TiO_2 film coated solar cell annealed at 100^0C, annealed for 1 hr in air, respectively. The TiO_2 nano-particles coated solar cell shows more porous granular structure with agglomeration of nano-particles. The SEM image of TiO_2 film coated solar cell shows layer like arrangement of film with irregular and non-uniform deposition. The film showed amorphous nature without any grains.

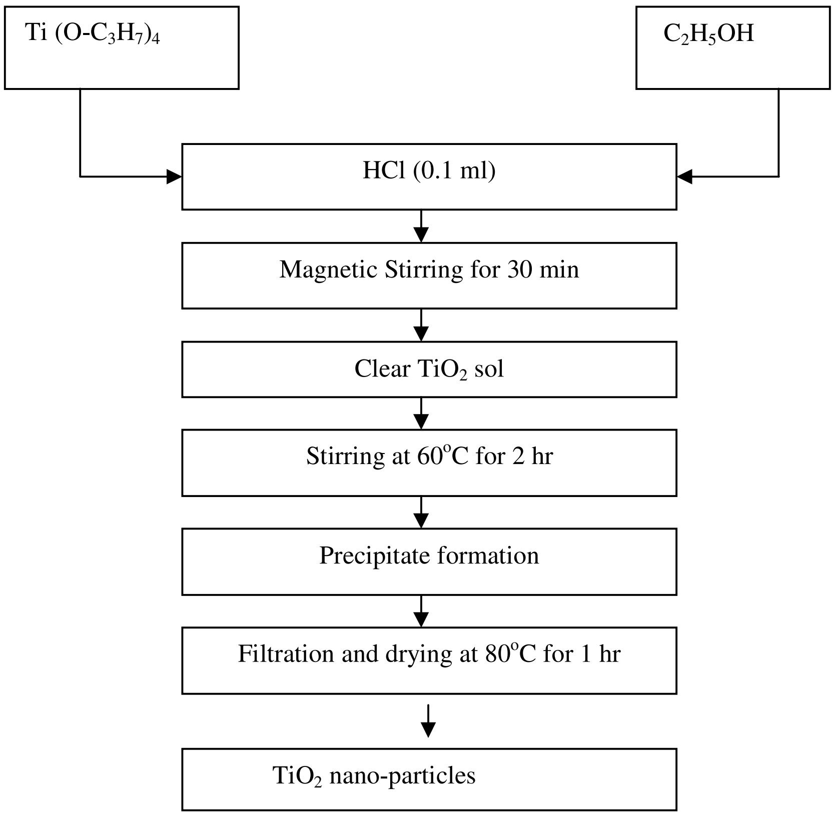

Figure- 2
Flow chart for the preparation of TiO_2 nano-particles

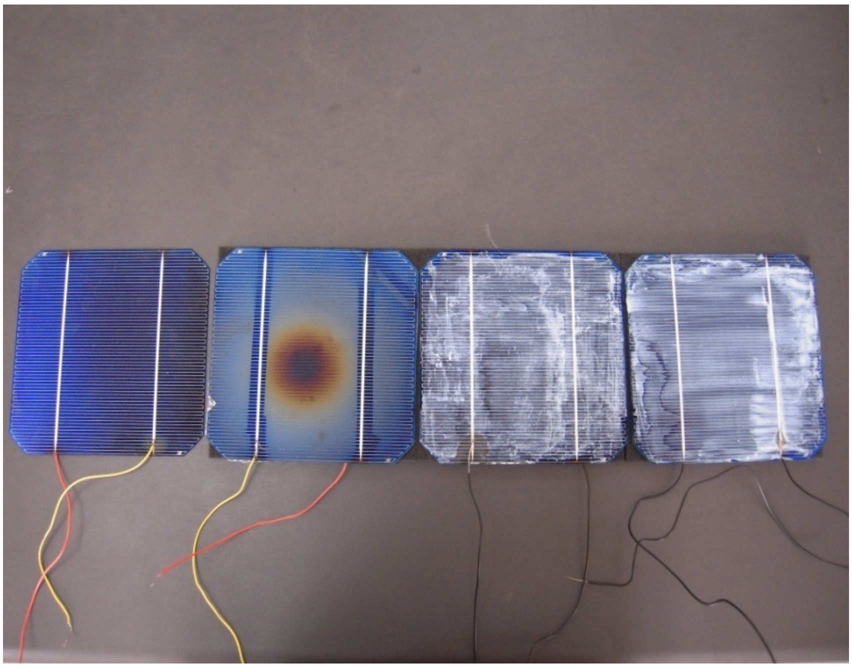

Figure-3
(a) Un-coated solar cell, (b) ZnO film coated on solar cell by RF sputtering, (c) TiO_2 nano-particles coated on solar cell annealed at 50 ^{0} C (d) TiO_2 nano-particles coated on solar cell annealed at 100 ^{0} C for 1hr

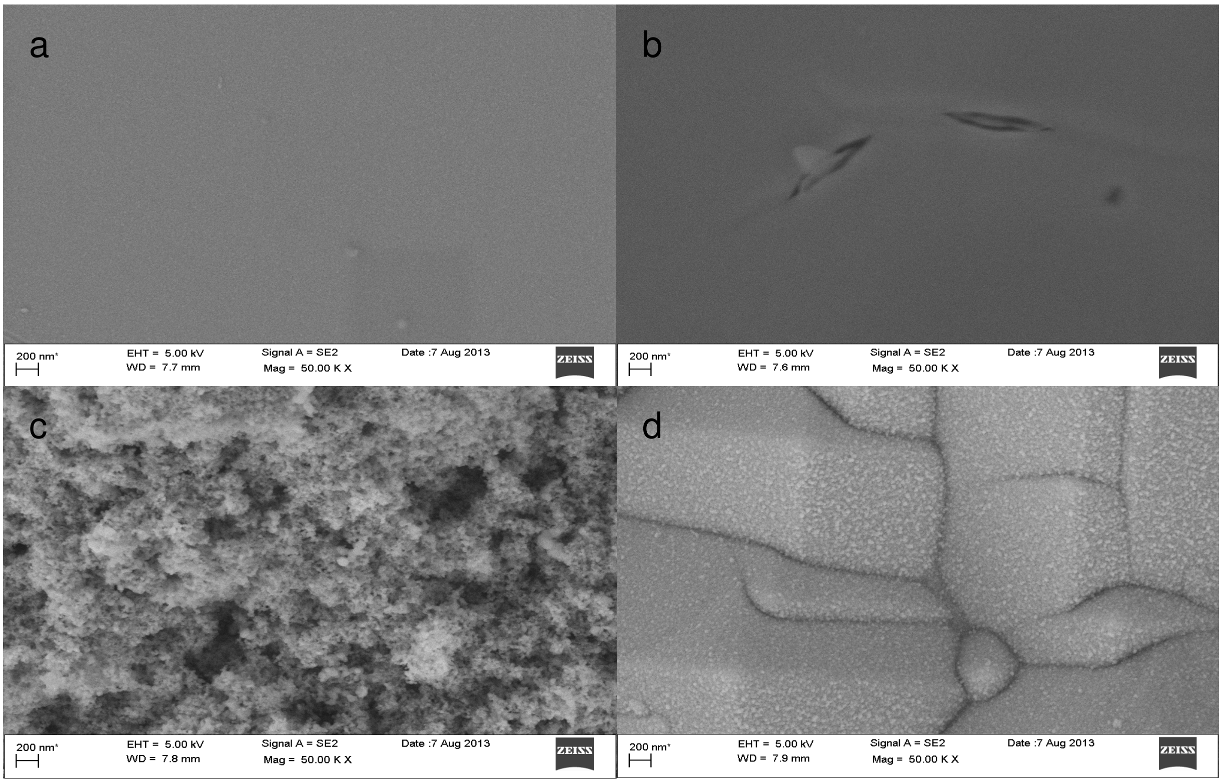

Figure-4
SEM images of (a) Un-coated solar cell, (b) ZnO film coated at RT,
(c) TiO_2 nano-particles coated solar cell annealed at 50^0 C and
(d) TiO_2 film coated solar cell annealed at 100^0C for 1 hr in air

The current-voltage (I-V) characteristics of un-coated and coated solar cells are plotted and the graphs obtained are shown in figure-5. The graph shows that the open circuit voltage, short circuit current and efficiency varied for solar cells coated with different nano-particles. In this study TiO_2 film coated solar cell annealed at 100^0C shows maximum FF of 53, as compared to the FF of 42 for solar cell coated with TiO_2 film annealed at 50^0C, whereas the solar cell coated with TiO_2 nano-particles and annealed at 50^0C has FF of 50 as compared to 36 for solar cell coated with TiO_2 nano-particles and annealed at 100^0C. The solar cell coated with zinc oxide nano-particles by RF sputtering method without annealing shows a fill factor of 36. The open circuit voltage, short circuit current and FF of all the solar cells are listed in table1. The TiO_2 film coated solar cell annealed at 50^0C has high value of open circuit voltage (0.577 V) and short circuit current (3.91 A) among all the six cells.

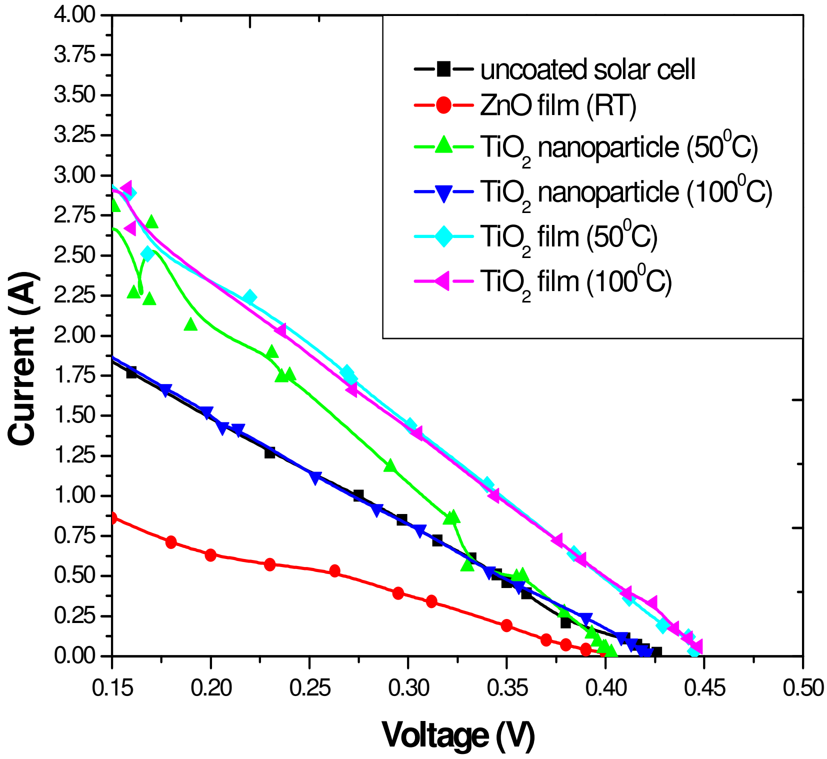

Figure- 5
I-V characteristics of (a) un-coated solar cell, (b) ZnO film coated at RT (c) TiO_2 nano-particles coated and annealed at 50^0C, (d) TiO_2 nano-particles coated and annealed at 100^0C, (e) TiO_2 film coated and annealed at 50^0C and (f) TiO_2 film coated and annealed at 100^0C for 1 hr

Table-1
Electrical properties of nano-particle films coated silicon solar cells

Sl. No.	Solar cell (coated/uncoated)	Open circuit voltage (V)	Short circuit current (A)	Fill factor (FF)
1	Finished solar cell without any nano-particles	0.54	1.64	42
2	ZnO film coated solar cell by RF Sputtering without annealing	0.46	1.4	38
3	TiO_2 nano-particles coated solar cell annealed at 50 ^0C for 1 hr	0.53	3.33	50
4	TiO_2 nano-particles coated solar cell annealed at 100 ^0C for 1 hr	0.529	2.30	36
5	TiO_2 film coated solar cell annealed at 50 ^0C for 1 hr	0.577	3.91	42
6	TiO_2 film coated solar cell annealed at 100 ^0C for 1 hr	0.549	3.35	53

Conclusion

The optical absorption on the surface of the solar cell enhanced with the modification of surface morphology using nano-particle films. This study suggests that the nano-particle films coated on silicon solar cell have an ability to change the efficiency of the solar cells. The solar cells coating with various other metal oxide nano-particles and annealing at different temperatures to improve their efficiency is the further scope of this research work.

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