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Preparation and Characterization of TiO_2-SiO_2 Sol-Gel Anti Reflection Coatings on Multi Crystalline Silicon Solar Cell

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Abstract*— Nano scale TiO_2 and TiO_2–SiO_2 mixed solutions have been prepared using sol-gel process and are deposited on multi crystalline silicon solar cell by spray process. Subsequent annealing is carried out to obtain amorphous crystalline structure of TiO_2 and to form crack free and homogeneous coating of TiO_2–SiO_2 mixed layer. The coated cells are characterized by scanning electron microscopy (SEM), Fourier transform infrared (FTIR) spectroscopy and Energy dispersive X-ray Spectroscopy (EDS). Electrical parameters are estimated to observe the enhancement of conversion efficiencies of the coated cells. Results obtained shows that the cell coated with mixed solution of TiO_2–SiO_2 gives better performance than the cell coated with TiO_2 solution. It is due to the introduction of SiO_2 particles during the synthesis of TiO_2 which enhances the optical and electrical properties of the thin film coat of the compound solution. Subsequent annealing after the coatings helps in forming homogeneous layer with reduced cracks on the surface and increased conversion efficiency of the multi crystalline silicon solar cell.

***Key words* — Multi crystalline silicon solar cell, Sol-Gel, TiO_2, TiO_2-SiO_2.**

I. INTRODUCTION

Thin film photovoltaics have become the mainstream of solar power production. Over decades solar panels/modules are manufactured by using single or mono crystalline (c-Si), ribbon (ribbon-Si), amorphous (a-Si) and poly or Multi crystalline silica (mc-Si) solar cells [1]. mc-Si solar cells have been dominating the market due to low cost of production compared to mono crystalline cells. Crystalline silica cells reflect 36% of the incident irradiation which can be reduced to about 11% by texturing the top surface of the cell. The losses can be further reduced to near zero by coating the top surface with suitable anti reflection (AR) coating. Mono crystalline cells are textured by etching in alkaline solutions but mc-Si cells require different kinds of texturisation methods. Non contact type lacer texturisation is preferred for mc-Si solar cells because of its many advantages [2-4].

Sol-gel process requires simple and less expensive equipment compared to conventional vacuum process like PECVD, CVD, PVD etc. Alcohols are used in the sol-gel technique to form bonds of metal-oxygen-metal which will end up in gel after hydrolysis and condensation.

There are various methods like electron beam evaporation, sputtering, pulsed laser deposition spinning, dipping and spraying that are used to prepare the AR coatings on the mc-si solar cells. The refractive indices and layer thicknesses can be tuned to the desired levels by changing the process parameters of the sol-gel synthesis, as the proper choices of the refractive indices and layer thickness influence the performance of the cell. Selection of the material for AR coating depends on many factors. Titanium dioxide with large value of refractive index (2.0-2.3) with over 90% transparency over the spectral range of 320 to 6000nm is preferred material for AR thin film coatings. It has excellent chemical and mechanical properties and desirable optical properties. The type of crystal structure obtained by the sol-gel prepared thin film layers depends on the process conditions and subsequent annealing temperatures [5-9].

Anti reflection coatings reduces the reflection losses and increases the transmittance and absorbance of the mc-Si silicon solar cell. Solar cells are subjected to many loss mechanisms that can be compensated by suitable AR coatings on the top surface of the cell. AR coating on the top surface of the cell improves the conversion efficiency and the life time of the cell by maximizing the photo generation current within the cell substrate. There are number of expensive and conventional vacuum processes like Plasma enhanced chemical vapor deposition (PECVD), Reactive sputtering (RF), Chemical vapor deposition (CVD), Physical vapor deposition (PVD) etc., to prepare the AR coatings. At least a single layer anti reflection (SLAR) coating on the top surface of the mc-Si solar cell becomes necessary to reduce reflection losses. Many researchers are experimented double layer AR (DLAR) coating and binary AR coatings and studied the surface morphology of these thin films coated on different substrates. Few researchers are extended their studies to investigate the effect of these layers on the optical properties of the coated substrate. However studies on 156 x 56 mm, mc-Si solar cells coated with mixed solutions of TiO_2-SiO_2 to estimate the electrical parameters are scarce in literature. Sol-gel spray coating is demonstrated in this study to obtain TiO_2 and TiO_2-SiO_2 layers on the mc-Si silicon solar cells [10-13].

II. MATERIAL METHODS

A. *Synthesis of TiO_2 and TiO_2-SiO_2 solutions:*

TiO_2, TiO_2-SiO_2 thin films were prepared by sol-gel spray coating technique. Titanium tetra iso propoxide (TTIP), and Tetra ethoxy silane (TEOS) as a precursors is purchased from Sigma Aldrich. Absolute isopropyl alcohol was used as a solvent and hydrochloric acid as a catalyst. TiO_2 and TiO_2-SiO_2 anti reflection solutions was sonicated vigorously in a ultra sonicator for 1 hour. The volume ratio of iso propyl

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alcohol, TTIP, HCl (2M) is experimented and optimized to 18.6 ml:1.3 ml:0.04 ml for TiO_2 solution; Iso propyl alcohol, TTIP/TEOS, HCl (2M) optimized to 18.6 ml:1.3 ml/0.21 ml:0.04 ml for TiO_2-SiO_2 solution[14].The solution obtained was sprayed on the mc-Si silicon solar cell using fine spray pilot gun. Before the spray the cell was treated with diluted HF solution (1:10) to remove the unwanted contaminations on the cell surface and washed with double distilled and deionized water and ethanol then dried for 10 min at 120°C. The sprayed TiO_2, TiO_2-SiO_2 solutions on the cell surface are subsequently annealed at 350°C to obtain homogeneous amorphous structure. Different kinds of thin films were prepared by changing the parameters of the sol-gel synthesis process and the coated films heat treated and tested for optimizing the desired results. The flow chart of Sol-gel synthesis of TiO_2 and TiO_2-SiO_2 solutions is schematically represented in Fig. 1.

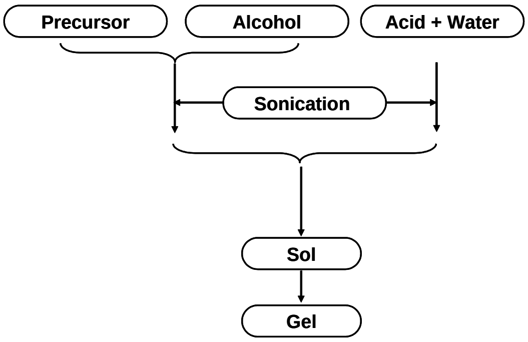

Figure 1: Flow-chart of synthesis of TiO_2, TiO_2-SiO_2 solutions.

III. RESULT AND DISCUSSION

Fig. 2 shows the SEM images of plain, TiO_2 coated and TiO_2-SiO_2 mixed solution coated mc-Si solar cells. Fig. 2a shows the surface morphology of the uncoated cell treated with diluted HF for the removal of unwanted materials on the top surface of the cell. Fig. 2b shows the SEM image of the TiO_2 coated cell. The cell is subjected to thermal annealing up to 350°C to allow the TiO_2 micro structure to adhere firmly to the crystalline silica substrate. The process has to be undertaken before the formation of gel. Many cracks are observed in the SEM image of TiO_2 coated cell as shown in Fig. 2b. There are various reasons for the cracks to be formed. Surface roughness of the silica substrate, difference in coefficient of thermal expansion of the film and substrate, increased layer thickness, brittleness of the film deposited and insufficient annealing temperatures. These cracks can be effectively reduced by selecting suitable coating materials like TiO_2 and SiO_2 which are compatible to the silica substrate. Another way to reduce the cracks is to gradually increase and decrease the annealing temperatures to avoid thermal shocks. The lattice mismatch due to difference in coefficient of thermal expansion can be controlled by varying the volume ratios of the sol-gel preparations to alter the viscosity of the final solutions. Coating thickness can also be controlled by varying the process parameters and pressure of the spray gun.

In case of DLAR, these initial cracks are useful for proper adhesion of the second layer. Fig. 2c shows the SEM image of the TiO_2-SiO_2 mixed solution in which a relatively homogeneous and crack free surface morphology can be observed. It is due to the penetration of silica in to the microstructure of the TiO_2 particle. Mixing ratio of the TiO_2 and SiO_2 is crucial in obtaining a homogeneous and crack free surface. Mixing silicon dioxide influences the crystallization of the titanium dioxide particles and reorients the refractive index to an optimum value, improving the optical properties of the final thin layer coat. The enhanced performance of the cell coated with mixed solution is attributed to the tailored refractive index of the final coat due to the combined effect of the phase separation, removal of organic component and crystal structure transition of the mixed solution coating.

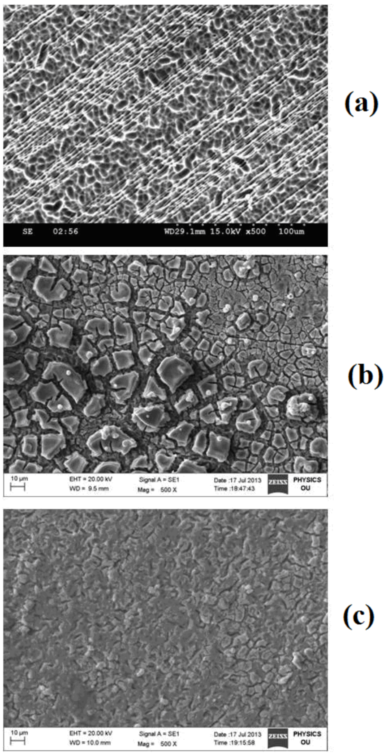

Figure2: SEM micrographs and EDS spectra of (A) TiO_2 coated MC Silica solar cell, (C) TiO_2-SiO_2 coated MC Si Solar cell.

Fig. 3 shows FTIR spectra of TiO_2 and TiO_2-SiO_2 coatings annealed at 350°C. Fig. 3a shows the IR spectra of TiO_2 .Ti-O-Ti peak at 586 cm^{-1}. Stronger absorption peak of TiO_2 is observed at 1451 cm^{-1}. The other peaks at 1635 cm^{-1} and 3419 cm^{-1} are attributed to the OH stretching vibration of different OH species and to absorbed molecular water content. These alkoxide groups can be eliminated with higher annealing temperatures. Fig. 3b shows the IR spectra of TiO_2-SiO_2 mixed coating. Ti-O-Ti bonding is observed at 586 cm^{-1} where phase separation process is initiated. Si-O-Si bonding is observed at 1104 cm^{-1} and alkoxide OH peaks are at 1620 cm^{-1} and 3415 cm^{-1} are observed. SiO_2 bonding at 803 cm^{-1} is attributed to stretching vibrations of SiO and Si-O-Ti groups. After high thermal annealing TiO_2-SiO_2 phase separation together with TiO_2 crystallization decrease the oxygen deficiency of SiO_2 and results in a blue shift of the Si-O-Si vibration peak.

The micro analysis of the prepared thin film coatings are studied by Energy-dispersive X-ray spectroscopy (EDS) . Fig. 4a shows the EDS spectra of the thin film sol-gel TiO_2 layer.

TiO_2 Peaks are observed at 0.5 and 4.5 keV which confirms the presence of titanium dioxide. Fig. 4b shows the EDS spectra of mixed solution coating where in similar TiO_2 peaks are observed. SiO_2 peaks are observed at 2.0 keV to confirm the presence of SiO_2. It is observed that the mixed solution coatings exhibits regular and homogeneous surface morphology as the TiO_2 particles are covered by SiO_2 particles at the micro level.

Electrical parameters like open circuit voltage (*Voc*) , short circuit current (*Isc*), Fill factor (*FF*) and conversion efficiency (η) are obtained at 1.5 air mass solar spectrum under one sun irradiation at standard conditions using solar simulator. The experimental values are tabulated in table (1). Corresponding *IV* curves are plotted in Fig. 5.

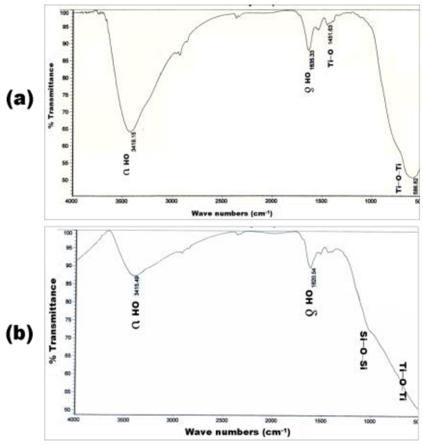

Figure 3: FT-IR characterization of TiO_2, TiO_2-SiO_2 thin film coated mc-Si solar cells.

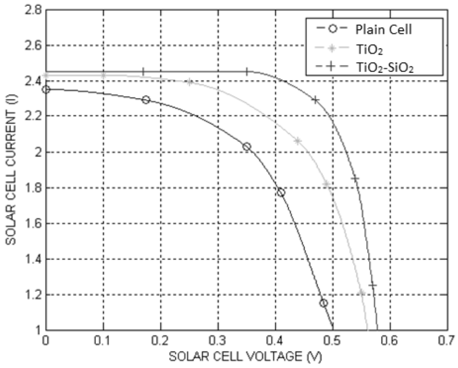

Figure 5: *I-V* characteristics of Plain TiO_2, TiO_2-SiO_2 mc-Si solar cell.

Table 1: *I-V* characteristics of plain and TiO_2, TiO_2-SiO_2 coated mc-Si solar cell.

Solar Cell	V_{oc} (*V*)	I_{sc} (*Amp*)	*FF* (%)	η (%)
Plain cell	0.6	2.35	56	10.39
TiO_2 coated cell	0.6	2.43	63	11.72
TiO_2-SiO_2 coated cell	0.6	2.45	78	14.55

IV. CONCLUSION

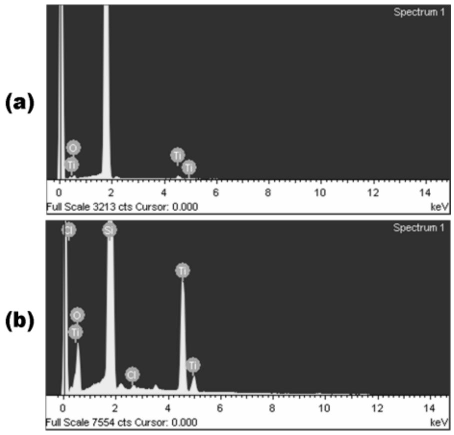

Figure 4: EDS characterization of TiO_2 (a), TiO_2-SiO_2 (b) thin film coated mc-Si solar cells

This study presents simple and inexpensive sol-gel process to prepare effective AR coatings to coat on the mc-Si silicon solar cell for reducing the reflection losses. The conversion efficiency of uncoated cell is estimated to be 10.39% , the cell coated with TiO_2 solution to be 11.72% and the cell coated with TiO_2-SiO_2 mixed solution is 14.55%. The enhancement in efficiency of the mixed solution coated cell over the plain cell is 40%. The increment in conversion efficiency is due to the increased fill factor achieved by re-orienting the structural and optical properties of the top surface of the cell substrate by coating it with TiO_2-SiO_2 nano materials. In the future this study can be extended to other types of nano materials to optimize and enhance the conversion efficiency of the mc-Si solar cell.

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