



Impact of porous SiC-doped PVA based LDS layer on electrical parameters of Si solar cells

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ABSTRACT

Nowadays, the advanced photon management is regarded as an area of intensive research investment. Ever since the most widely used commercial photovoltaic cells are fabricated with single gap semiconductors like silicon, photon management has offered opportunities to make better use of the photons, both inside and outside the single junction window. In this study, the impact of new down shifting layer on the photoelectrical parameters of silicon based solar cell was studied. An effort to enhance the photovoltaic performance of textured silicon solar cells through the application of porous SiC particles-doped polyvinyl alcohol (PVA) layers using the spin-coating technique, is reported. Current-voltage curves under artificial illumination were used to confirm the contribution of LDS (SiC-PVA) thin layers. Experiment results revealed that LDS based on SiC particles which were etched in HF/K₂S₂O₈ solution at T = 80 °C under UV light of 254 nm exhibited the best solar cell photoelectrical parameters due to its strong photoluminescence.

1. Introduction

One of the most studied attempts to make better use of the photons is the introduction of luminescent down-shifting (LDS) materials on the top of the silicon solar cells [1–3]. This type of coating absorbs high energy photons and reemits lower energy photons which are more favorable to the solar cells. Although the number of photons after the down-shifting may decrease, it is still possible to increase the output current of the solar cells by LDS due to the better spectral response of those reemitted longer wavelength photons [4]. The downshifter consists of a luminescent layer composed of chromophors embedded in a transparent matrix that is optically coupled to the solar cell. Ideal luminescent down shifting material should exhibit; a wide absorption band in the range of enhancement, high absorption coefficient, narrow emission band in the peak conversion efficiency region of the photo-active material, good separation between absorption and emission bands, and low cost [5].

The most frequently used host materials for the luminescent species are inorganic crystalline materials such as SiO₂ [6], Al₂O₃ [7] and CaF₂ [8]. Among many materials, polymers have found application in the PV industry as matrix for luminescent species. Very different

polymer properties are required for DC layers such as: a high barrier to water and oxygen, photostable, optical transparency in the UV and visible domain, easy to apply and environmentally friendly processing. Having said this, these properties have to be preserved in use conditions under sunlight heating exposure (85 °C).

Studied polymeric materials such as poly methyl methacrylate PMMA and ethyl vinyl acetate (EVA) [9] exhibited high transparency in the UV-Visible region of the solar spectrum, an adequate resistance to heat and humidity variations, and a high mechanical resistance [10]. They also provide a very good host environment for inorganic and organic dye molecules [11]. Recently, poly (vinyl alcohol) (PVA) based soft gels with luminescent properties were investigated [12]. Poly vinyl alcohol (PVA) is a semi-crystalline polymer that is water soluble and completely biodegradable, and has attractive traits such as hydrophilicity, chemical resistance, emulsifying, adhesivity and excellent film forming capability [13]. As PMMA, PVA is extensively used in optical devices owing to its high transparency in the UV-visible spectral range, its oxygen barrier effect and its good dissolubility in many organic solvents and water [14] to form gels. Recently, highly transparent PVA gels, prepared from Dimethyl sulfoxide-water mixtures, were reported [15,16]. PVA gels, consisting of network structure of crystalline

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and amorphous regions, are very interesting complex materials. The amorphous regions consist of long flexible chains that connect these junctions [17,18], while crystalline regions, the aggregation of ordered polymer sequences, act as junction points.

In practice, the degree of polymerization of PVA (of formula $[\text{CH}_2\text{CH}(\text{OH})]_n$ with « n » being the number of monomer mers in a macromolecule) is related to the degree of hydrolysis (each monomer contains one OH group) and both affect its solubility. It is well known that when the degree of polymerization of PVA increases, its molecular weight increases. It has been shown that, at a given temperature, the solubility of PVA decreases with increasing molecular weight [19–21]. The main factor to control when preparing PVA/fillers based suspensions is their stability, ensuring that the suspensions have the ability to last longer as possible before deposition of the composites thin films. Mendizabal et al. have discussed in their study the stability of the PVA based suspensions as function of degree of hydrolysis and polymerization and deduced that: (a) PVAs with a high degree of hydrolysis ($> 96\%$), regardless of their degree of polymerization, do not form good suspensions. The suspensions coalesce in less than 2 min, (b) Partially hydrolyzed (88% OH) PVAs of small degree of polymerization (low molecular weight $< 70\,000$) yield very stable suspensions, even after 24 h, the suspensions do not coalesce, (c) Partially hydrolyzed (88% OH) PVAs of high degree of polymerization (high molecular weight $> 70\,000$) yield less stable suspensions (12–44 min) than do PVAs of the same degree of hydrolysis but smaller molecular weights [22]. In consequence, the water solubility of PVA essentially depends upon degree of hydrolysis. PVA with 87–89% OH have high degree of solubility, even in cold water, but for the complete dissolution heating to 85 °C is required.

The distribution of OH groups in either side to backbone depends also on the degree of polymerization of PVA. Three distinct PVA configurations can be generated when $n \geq 3$: isotactic (i-PVA), syndiotactic (s-PVA) and atactic (a-PVA). All the three configurations co-exist, in general, with s-PVA as the prominent phase (as much as 62% content). It seems that, under favorable conditions, the sequential distribution of OH groups in either side to backbone in s-PVA can be explored to design a regular interchain bridging in a layer structure. The distribution of OH groups in opposite sides in alternate sites to backbone facilitates a regular H-bonding between the adjacent chains. A small s-PVA molecule in this particular conformer structure, offers many free OH groups in the backbone after the interchain bridging by H-bonding between adjacent chains. The OH groups in this specific structure are supposed to confer H bonding functionality to planarize the polymer backbone in a specific conformer which seems influence the PL property of PVA [23].

We will expose, through the present work and based on our previous investigations [24,25], the possible application of a new down shifting layer based on SiC-PVA composite thin films, trying by this, to enhance the light conversion efficiency of single crystalline silicon solar cells.

2. Experimental part

In our investigations, Czochralski grown B-doped mc-Si wafers (as cut) with low resistivity and (100) orientation were used to manufacture the solar cells. A 7 μm Silicon carbide micropowder was employed and subjected to etching process to produce luminescent porous SiC powder by mean of photo-assisted electroless etching as described in Refs. [24,25]. PVA, having an average molar weight of 17000 g/mol and 88% OH was used as received. The chemicals used for the pyramidal texturing were sodium carbonate anhydrous (Na_2CO_3) and sodium hydroxide (NaOH) with a purity $\geq 99\%$ in pellets. The chemicals were solved in 18 M Ω cm deionised water.

2.1. Solar cell processing

Within the wafer-based manufacturing technology, basic step is

texturing of the substrate. Indeed, texturing is important to decrease the front reflectance of the cell and to improve the light trapping in order to increase the generated current. We followed a modified Marrero's Method [26], in which, $\text{Na}_2\text{CO}_3/\text{NaHCO}_3$ was used as texturing solution to texture (100) Cz Si wafers, to fabricate solar cells. For purpose of comparison, we employed NaOH based solution besides Na_2CO_3 one to carry out the anisotropic etching of crystalline silicon wafers. The influence of the textured surface, especially, the surface resulting from the Na_2CO_3 texturation method on different solar cell processing steps was studied. The parameters of the reaction in this case were found optimum as following: 20 wt% Na_2CO_3 and deionized water at 95 °C, during 20 min to achieve minimum reflection.

2.2. LDS layer elaboration

The elaboration of the porous SiC micropowder and their incorporation in PVA matrix to perform the SiC/PVA composite thin films were detailed in our previous reports [24,25]. We note that the porous SiC micropowders, used in the present study, were chosen on the base of their photoluminescence properties, it means that, those which demonstrated the best PL intensity were selected to the LDS investigations. We will just specify the etching conditions followed in the present study to prepare the porous SiC micropowder and their corresponding thin films. Thus, PVA thin film were obtained by dissolving PVA powder in deionized water to form PVA gel which is spin coated on the substrate and annealed at 100 °C for 10–15 min [24]. PVA/SiC(I) were prepared, firstly, by etching SiC powder in HF/K2S2O8 under UV light with 254 nm during 40 min at room temperature, followed by its incorporation in PVA gel to form the composite thin film as PVA thin film. PVA/SiC(II) were prepared like as PVA/SiC(I) but at $T = 80$ °C. All the prepared LDS layers were deposited by spin coating method.

A typical spin process consists of a dispense step in which the composite fluid is deposited onto the substrate surface, a high-speed spin step to thin the fluid, and a drying step to eliminate excess solvents from the resulting film.

Two common methods of dispense are Static dispense, and Dynamic dispense. Static dispense is simply depositing a small puddle of fluid on the center of the substrate. This can range from 1 to 10 ml depending on the viscosity of the fluid and the size of the substrate to be coated. Higher viscosity and/or larger substrates typically require a larger puddle to ensure full coverage of the substrate during the high-speed spin step. Dynamic dispense is the process of dispensing while the substrate is turning at low speed. After the dispense step it is common to accelerate to a relatively high speed to thin the composite fluid to near its final desired thickness. Typical spin speeds for this step range from 1000 to 6000 RPM, again depending on the properties of the composite fluid as well as the substrate. This step can take from 10 s to several minutes. A separate drying step is usually added after the high speed spin step to further dry the film without substantially thinning it (Scheme 1).

Final film thickness and other properties depend on the nature of the composite fluid (viscosity, percent fillers, surface tension, etc.) and the parameters chosen for the spin process. Factors such as final rotational speed, acceleration contribute to how the properties of coated films are defined. The combination of spin speed and time defines generally the final film thickness.

In our work, we have chosen the static dispense step to deposit the composite fluid. Thin films of pure PVA, PVA mixed with 10% by weight of porous SiC microparticles (etched in different conditions) were prepared by spin coating. The deposition parameters were: Rotation speed $\omega = 1000$ tr/min, Acceleration $a = 500$ tr. min/s, total rotation time $t = 120$ s. The prepared samples were dried in Oven at 363K and kept in air tight container.

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