Unstable cell efficiency in CdS quantum dot sensitized solar cell using low cost lugols iodine aqueous electrolyte

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1. Introduction

Due to increasing energy demands in the human society alternative sources of energy must be found from the natural ways and among the various natural sources for garnering energy from the Sun is most important and reliable [1]. Required electricity were taken from sunlight by through various ways such as photovoltaics (PV), thin film solar cells, quantum dot cells, concentrating PV and thermal solar power stations [2,3]. In this method, in practical term Quantum dot sensitized solar cells (QDSSCs) is one of the next generation photovoltaic devices to producing electricity from sunlight for, because of high efficiency with low cost [4]. The efficiency of QDSSCs is still lower compare to Dye Sensitized solar cells (DSSCs); because of the electron recombination process was take place inside of TiO2/QD/electrolyte [3]. In recent years, most of the researchers have done so far increasing the efficiency of QDSSCs, but not yet reached up to required level. The components for fabrication of QDSSCs such as, semiconductor nanomaterial (TiO2, ZnO) on transparent conducting glass (FTO, ITO glass slide), sensitizing layer (Quantum dots), electrolyte (polysulfide) and counter electrode (Pt, Carbon and Cu2S) are used usually [4]. Electrolyte is responsible for charge carrier transport between the electrodes (anode/cathode) [5]. The prominent role extent to play of electrolyte is similar in case of QDSSCs, DSSCs, capacitors, supercapacitor and fuel cell etc., it is working as a charge transportation medium to form ions in between the electrodes.

In QDSSCs, most often polysulfide redox couples (S2-/Sn2-) are used as an electrolyte to achieve acceptable photo to current conversion efficiencies (CCE) [6]. Lugol's iodine is an iodine solution which contains potassium iodide with iodine water, and it was first made by Jean lugol. In a drop of Lugol's iodine have two parts, one is potassium iodide and remaining is iodine in water. It is also called strong iodine solution, markodine and iodine-potassium iodide (I2KI) [9]. In medical field lugol's iodine was used for oral

**A B S T R A C T**

We have designed and synthesis rutile TiO2 rod like nanoflower on the FTO glass by one step hydrothermal method operating at 150 °C for 15 h. The lower concentration of CdS Quantum dots was deposited on the surface of TiO2 through chemical bath deposition (CBD) method. The samples were characterized x-ray diffraction pattern (XRD), Scanning electron microscopy (SEM) and UV–Vis absorption studies. In this work lugols iodine was used as an aqueous electrolyte between FTO/TiO2/CdS photoanode and Cu2S as counter electrode respectively. The result of photo conversion efficiency (PCE) is decreased from 0.13 to 0.033%, this may be the reason photo degradation and corrosion were happened in CdS.

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Selection and peer-review under responsibility of the scientific committee of the NANOSMATAFRICA-2018.

Keywords:
CdS QDs
Lugol's iodine
Cu2S counter electrode
Unstable cell efficiency
cancer diagnosis [7]. The Lugol’s iodine solution has redox potential to produce I-/I3- redox couple and it was reported by Waldermarr Gottardi and M. Troye et al., [8,9]. In the present report, rutile TiO2 grow of both rod-like microflowers and nanoparticles simultaneously on FTO glass slide by one-step hydrothermal method consecutively to deposit semiconducting CdS nanocrystal on TiO2 surface and Cu2S on FTO film using CBD process. Furthermore, to study the photocurrent density–photovoltage (J-V) performance of fabricated CdS QDSSC with aqueous Lugol’s iodine were tested as an electrolyte.

2. Experimental section

Chemicals of analytical grades were used directly used without any purification and also the process deionized water were used as solvent. TiO2 thin film was grown-up on the conducting surface of FTO glass slide (F: SnO2: Surface resistivity) by using one-step hydrothermal synthesis method. In typical synthesis process, 15 ml of water (H2O) was mixed with 15 ml of Hydrochloric acid (HCl) with continuously stirred for 10 min. After that, 1.5 ml of tetrabutyl titanate [Ti(CH2CH2CH2CH3)4] was added and it undergoes continuous stirring for few min. The 1.5 × 1.5 cm2 of FTO glass slide was washed with equal volume of methanol-acetone solution. The well cleaned FTO glass slide was transfer in Teflon coated autoclave and proceeds with hydrothermal condition at 150 °C for 15 h. The synthesized glass slide was taken out, rinsed with deionized water, calcined at 400 °C for 10 min and called as FTO/TiO2 glass slide. The fabricated FTO/TiO2 glass slide was subject into CdS QD’s coating by chemical bath deposition (CBD) process [10].

In this immersing process, firstly dipped into 0.1 M of Cd(NO3)2-4H2O (Cadmium nitrate tetrahydrate) methanol solution for 3 min, rinsing with methanol, and then immersing into methanol water (1:1 ratio) mixed solvent of 0.1 M of Na2S·xH2O (Sodium hydrate) solution for 3 min, and again rinsing with methanol-water (1:1 ratio) solution. The two-step immersing process is defined as one CBD cycle, repeated this procedure for 5 times and then, finally annealing at 70 °C for 30 min and it was named as FTO/TiO2/CdS glass slide. For counter electrode preparation, the well cleaned another FTO glass slide was taken and dipped into 0.1 M of Cu(NO3)2·3H2O (cupric nitrate trihydrate) aqueous solution, rinsing with ethanol, and then dipped into 0.1 M of [Na2S·xH2O] aqueous solution, once again rinsed into ethanol solution and finally dried by dryer. The above typical steps are considered as one cycle of CBD. This process was repeated for 3 times and finally annealing at 70 °C for 1 h in an oven [11]. During the solar cell fabrication process, CdS deposited FTO/TiO2 glass slide and another Cu2S deposited FTO as a counter electrode was merged using scotch tap with binder clip. The intermediate between the two electrodes are filled with few drops of aqueous lugol’s iodine (SRL).

In the electrolyte preparation, 1 ml of lugol’s iodine was added with 10 ml of deionized water (concentration of about 0.02 M of I2 and 0.006 M of KI2 approximately) was used as a redox electrolyte [8,9]. The active area of the cell region is 0.25 cm2. The crystal structure of as prepared photoanodes was carryout by using X-ray Diffraction (XRD, PANalytical X’pert Pro) equipped with Cu kx radiation 1.5406 Å. The surface morphology of as-prepared films was studied by using scanning electron microscopy (SEM, VEGA 3 TESCAN) with energy dispersive X-ray (EDX, Bruker) spectrometer. An absorption study was taken over by UV–Vis-NIR spectrophotometer (Ocean optics HR 2000). The photocurrent–photovoltage (J-V) performance was investigated by using Precision Source/Measure meter (Agilent, Model: B2901A) under an illumination of one sun solar simulator purchased from Royal Enterprises Chennai (Model: 100L).

3. Results and discussion

3.1. XRD studies

The X-ray diffraction patterns of FTO/TiO2 and FTO/TiO2/CdS on glass slides as shown in the Fig. 1(a-b). The diffraction peaks for FTO/TiO2 glass slide was located at 27.5°, 36.0°, 54.4°, 62.9°, 65.5° and 69.9°, and corresponding to the plane of index is (1 1 0), (1 0 1), (2 1 1), (0 0 2), (2 2 1) and (1 1 2) as shown in the Fig. 1(a). Therefore, the XRD pattern matches the JCPDS file (Card No: 65-0192), which confirms the tetragonal rutile phase [13]. The FTO/TiO2/Cds glass a slide show that, there is minor CdS a peak is also presented, it may be due to lower concentration. Further it is noticed that the observable small shift was arrived with reduced change in the intensity as shown in Fig. 2.

3.2. SEM and EDX analysis

The scanning electron microscopic (SEM) image and EDX spectra of FTO/TiO2/CdS glass slide as shown in Fig. 3(a-c). From SEM
micrograph, confirms that TiO₂ was grown as rod-like nanoflowers and nanoparticles simultaneously on the surface of FTO glass plate in Fig. 2(a). Therefore, the TiO₂ nanoparticles were developed uniformly on the FTO glass slide with diameter about ~190 nm and the novel rod-like nanoflowers were also explored almost uniformly on the FTO glass slide with diameter ~750 nm and length ~4.25 μm. The ratio between diameter and length of the rod shows that a high aspect growth was obtained. Fig. 3(b-c), shows the elemental details of FTO/TiO₂/CdS glass slide with different region were analyzed by EDX. The atomic weight percentage (%) compositional details of Ti, O, Cd and S of FTO glass slide have 37.76, 62.10, 0.08 and 0.06% and similarly on rod-like microflowers have 25.94, 73.88, 0.11 and 0.07%. EDX studies confirmed that high atomic concentration of TiO₂ and less percentage of CdS composition was obtained [16]. This was good agreement with XRD result.

3.3. Optical studies

Fig. 4, shows the optical absorption spectra of FTO/TiO₂ and FTO/TiO₂/CdS glass slide with the wavelength range between 375 and 650 nm. In FTO/TiO₂ glass slide, a broad absorption band was observed in UV region with absorption edge is about 409.2 nm and corresponding to bandgap energy is 3.00 eV and it almost equal to bulk rutile bandgap of 3.02 eV [12]. The red shift was observed in FTO/TiO₂/CdS glass slide and it comes under visible region because the deposition of CdS on surface of TiO₂, the absorption edge is 515 nm with corresponding to bandgap is 2.4 eV. From the above absorption study reviles, the FTO/TiO₂/CdS glass slide have more sensitive in visible region, compare to FTO/TiO₂ glass slide.

3.4. Photocurrent to photovoltage (J-V) studies

The typical photocurrent to photovoltage (J-V) characteristics curve of FTO/TiO₂/CdS with Cu₂S as a counter electrode under one sun solar simulator as shown in Fig. 5. In this solar cell fabrication process, 1 ml of novel lugol’s iodine in 10 ml water was used as an electrolyte. The summarization of CdS sensitized solar cell various parameters are given in the Table 1. The output of the CdS sensitized solar cell of open circuit voltage (Voc), short circuit current density (Jsc), fill factor (FF) and power conversion efficiency...
of cell are 0.53 V, 0.57 mA/cm², 0.44 and 0.13% respectively. After 60 min, the efficiency is decreased from 0.13 to 0.033%, this may be the reason photo degradation and corrosion were happened in CdS [13,14]. In lugol’s iodine solution, the molar iodine (I2) combined with potassium iodide (KI) to form triiodide ion (I^3-) at 25 °C [9] and the lugol’s iodine in water have redox potential [8]. So, from this investigation, it can be concluded that lugol’s iodine is the best low cost (I-/I^3-) redox electrolyte for dye sensitized solar cells (DSSCs) [15,16–18].

4. Conclusion

The TiO₂ was successfully grown as both rod-like nanoflowers and nanoparticles simultaneously on FTO glass slide by one-step synthesized route and characterized. The fabricated FTO/TiO₂/CdS solar cell with novel lugol’s iodine aqueous electrolyte, have efficiency was decreased within 60 min due to photo degradation and corrosion of CdS crystals. In novel lugol’s iodine, Iodide/triiodide (I-/I^3-) redox couple was incorporated apparently, so this electrolyte is most probably suitable for DSSCs application.

Table 1

<table>
<thead>
<tr>
<th></th>
<th>Jsc (mA/cm²)</th>
<th>Voc (V)</th>
<th>Fill Factor</th>
<th>Efficiency (%)</th>
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<tr>
<td>ND1</td>
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<td>0.57</td>
<td>44</td>
<td>0.19</td>
</tr>
<tr>
<td>ND2</td>
<td>1.16</td>
<td>0.27</td>
<td>40</td>
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Fig. 5. J-V curve of CdS QDs sensitized solar cell with lugol’s iodine aqueous electrolyte.

CRediT authorship contribution statement

R. Vignesh: Conceptualization, Data curation, Formal analysis, Project administration. B. Arjun kumar: Investigation, Methodology, Resources, Software. A. Muthuvinayagam: Data curation, Methodology, Formal analysis, Funding acquisition. T. Elangovan: Methodology, Data curation. K. Kaviyarasu: Visualization. G. Theophil Anand: Formal analysis, Software, Writing - review & editing. G. Ramalingam: Supervision, Validation, Writing - original draft, Writing - review & editing, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

Corresponding author (Dr. G. Ramalingam) acknowledges full support from DST-SERB(EEQ/2016/00198) and the instrumentation facility used form RUSA 2.0 grant No.F.24-51/2014-U, Policy (TNMulti-Gen), MHRD-SPARC(2019/890) Govt. of India projects.

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