PJSRR (2015) 1(1): 67-81

Pertanika Journal of Scholarly Research Reviews
http://www.pjsrr.edu.my/

Quantum Dot-sensitized Solar Cell Based on nano-TiO_2 Electrodes

Wardatun Nadrah, MOHD AMIN[1, a] Zulkarnain, ZAINAL[1,2, b *]
Zainal Abidin, TALIB[3, c] Hong Ngee, LIM[1, 4, d] and Sook Keng, CHANG[2,e]
[1]Department of Chemistry, Faculty of Science, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia
[2]Material Synthesis and Characterization Laboratory, Institute of Advanced Technology, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia
[3]Department of Physic, Faculty of Science, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia
[4]Functional Device Laboratory, Institute of Advanced Technology, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia
[a]wardatunnadrah@gmail.com, [b]zulkar@upm.edu.my, [c]zainalat@upm.edu.my,
[d]hongngee@upm.edu.my

Abstract - Quantum dots-sensitized solar cell (QDSSC) is one of the third generation solar cell that is the most promising low cost, easy to manufacture and highly efficient solar cell. Compared to Dye-sensitized solar cell (DSSC), quantum dots (QDs) of QDSSC has a narrow bandgap and possess excellent properties such as tunable band gaps, strong light absorption and high multiple electron generation. Titanium dioxide or titania (TiO_2) is an oxides semiconductor material that is frequently used as a photoanode in this photovoltaic system due to high stability under visible light illumination. TiO_2 is also known as a good photocatalyst and an excellent choice in environmental purification. The efficiencies of electron injection and light harvesting in QDSSC are affected by the nature, size morphology, and quantity of this nanomaterial. In this review, the concept and principles of the QDSSCs are reviewed. The preparation and fabrication method ofTiO_2 electrode in QDSSC are also discussed. It is worthwhile to know the architecture of TiO_2 in order to enhance the efficiency of QDSSC.

Keywords: Quantum dots-sensitized solar cell, titanium dioxide, quantum dots

Introduction

Sunlight continued to be harvested by technologies up to the early years of the industrial revolution. Since then, the temperature has risen by 0.6°C because of the global activities which cause the greenhouse effect whereby the quantity of carbon dioxide increases and eventually causing global warming (Du, Li, Brown, Peng, & Shuai, 2014; El Chaar, Lamont, & El Zein, 2011; Gong, Liang, & Sumathy, 2012). In recent years, renewable energy has attracted high interest due to these factors. As an alternative source of energy, the sun sends high quantities of light energy to the surface of the earth (Selinsky, Ding, Faber, Wright, & Jin, 2013). It is also completely renewable and definitely an abundant resource with rapidly declining conversion cost (Jun, Careem, & Arof, 2014). The energy provided by the sun for our planet is 10,000 times more than world demand whereby 10 % of the efficiency of the solar cell would fulfil global needs (Kouhnavard et al., 2014). A broad range of solar cell research is currently underway and they include dye-sensitized solar cell (Abdullah & Rusop, 2014), organic solar cell (Halim, 2012), silicon solar cell (Halim, 2012) and heterojunction solar cell (Church, Muthuswamy, Zhai, Kauzlarich, & Carter, 2013; Guo, Shen, Wu, & Ma, 2012).

The photovoltaic technology (PV) is a highly potential candidate for an alternative or renewable source of energy in the current market. PV can be classified into first, second and third generation solar cell. Solar cells based on silicon wafer, so-called first generation technology solar cell, make up the most number of solar cells present in the market and can reach as high a 27% solar cell efficiency (Green, 2002).Meanwhile solar cell utilized with inorganic film is the second generation solar cell which is cheaper to produce but has less than 14% solar cell efficiency (Jun, Careem, & Arof, 2013). Chronologically, the invention of the third-generation solar cell is to decrease cost by significantly increasing efficiencies as high as above 30% and at the same time maintain the economic and environmental cost advantage (Conibeer, 2007). Figure 1 shows the PV production per square meter against the efficiency of solar cell and the cost unit power.

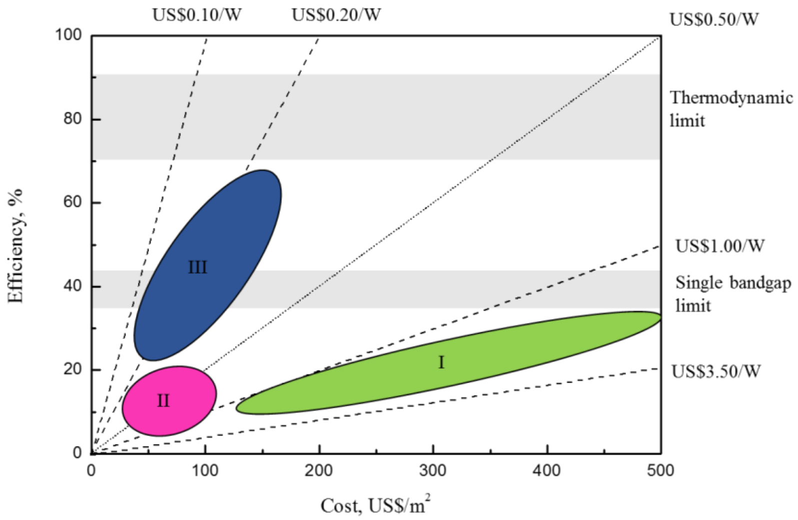

Figure 1: Efficiency and cost projection for first (I), second (II) and third generation (III) (wafer-based, thin films, and advanced thin film, respectively)

Dye-sensitized solar cell (DSSCs) is the first third generation which has attracted much attention due to low fabrication cost and high efficiency, flexibility in colour, shape and transparency (Golobostanfard & Abdizadeh, 2014). However QDSSCs is the further improvement of dye-sensitized solar cell (DSSCs) in boosting the overall efficiency by coupling synthesized inorganic quantum dots (QDs) semiconducting materials as sensitizers (Prabakar, Minkyu, Inyoung, & Heeje, 2010).QDSSC based on semiconductor nanocrystal has attracted attention as an alternative to DSSCs owing to their great stability, good absorption over wider wavelength range and multiple exciton generation leading to the production of power efficiencies (Z) that are much higher than DSSC (Xu, Zou, Yu, & Zhi, 2013; Yang, Chen, Roy, & Chang, 2011). All these unique characteristics of the QDSSC have raised high interest among researchers in renewable energy research field.

Despite all of these good characteristics of QDSSCs, the power conversion efficiency is still not as impressive as DSSCs mainly due to several reasons such as bad charges separation, less efficient photo excited electrons and unsuitable sensitizers (Li, Yu, Liu, & Sun, 2015). The electrode also plays a critically important role in contributing to the high efficiency of the QDSSC performance. Photo anode with high strong light scattering, efficient electron transport, high QD loading and quick electrolyte is of great importance to the QDSSC system (Zhou et al., 2014). The unique textural and structural characteristic of nanostructured material such as TiO_2, SnO_2 and ZnO has attracted much interest in the past decade(Malekshahi Byranvanda, 2013). The unique textural and structural characteristics are particle size distribution, specific surface area, morphology, crystallinity and crystal structure (Hu et al., 2014). This review paper is focused on TiO_2 as an electrode in QDSSC.

During the past decade, TiO_2 has become one of the most popular electrode materials and different methods apply to photovoltaic application and QDSSC specifically. In addition TiO_2 is an eco-friendly commercial product and has been known to be effective and is of great value(Liao et al., 2012). TiO_2 is a semiconductor with wide band gap known to be n-type. It has three crystalline phases which are anatase (tetragonal), rutile (tetragonal) and brookite (orthorhombic).The most stable phase is rutile TiO_2 whereby anatase and brookite TiO2 are metastable and they can be converted into rutile phase at high temperature that is, around 750°C (Wang, He, Lai, & Fan, 2014). Single crystal anatase is reported to be more effective than rutile phase in photovoltaic application (Bet-moushoul, Mansourpanah, Farhadi, & Tabatabaei, 2016).

Basic principle of QDSSC

QDSSCs have similar configuration with DSSCs and the only difference is that QDSSCs uses inorganic semiconductor quantum dots (QDs) as light absorbing material instead of molecular dyes, onto the surface of a thin film of nano-TiO_2 electrode that acts as a working electrode (Song et al., 2014). Similar to DSSCs, in QDSSCs, excitons are formed in quantum dots whereby the charge separation occurs in the QD molecule layer upon the photoexcitation as electrons are injected from the QD excited state into the conduction band of the nano-TiO_2 and that eventually produces a photovoltaic effect as shown in figure 2.

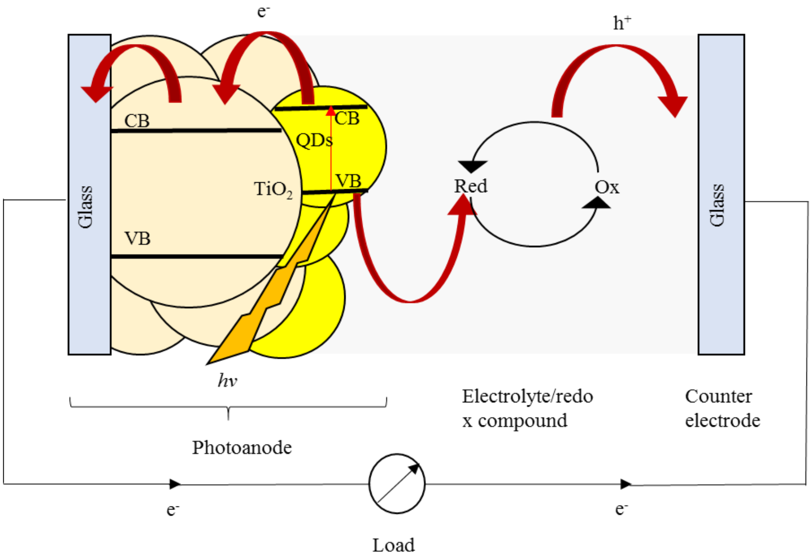

Figure 2: Operating principle of QDSSC

QDs is restored through electron donation from the frequently used polysulfide electrolyte, which consist of (S^{2-}/S_x^{2-}) the redox system. The oxidized QD is then restored (hole is filled with electron) when it is reduced by S^{2-} from the electrolyte and in turn it is oxidized into S_x^{2-} that diffuses to the counter electrode.

$$S^{2-} + 2^{h+} \rightarrow S \qquad (1)$$

$$S + S_{x-1}^{2-} \rightarrow S_x^{2-} \quad (x = 2 - 5) \qquad (2)$$

The oxidized group S_x^{2-} are reduced to S^{2-} occur on the counter electrode.

$$S_x^{2-} + 2e^{-} \rightarrow S_{x-1}^{2-} + S^{2-} \qquad (3)$$

In the electrolytes, voltage is generated in the Fermi levels between the electron in the photo electrode and the redox potential of I^{-}/I_3^{-} .I^{-} ion reduced to I_3^{-} at the counter electrode whereby platinum and carbon based materials coated on the substrate (Guo, Shen, Wu, Wang, et al., 2012; Lee & Chang, 2008; Yu, Lia, Qiu, Kuang, & Su, 2011). The efficiency of the solar cell can be determined by the equation below:

$$\eta = \frac{(J_{SC}\times V_{OC}\times FF)}{P_{in}}, \tag{4}$$

where J_{SC} is the short circuit photocurrent density, V_{OC} is the open circuit voltage, FF is the fill factor and P_{in} is the power intensity of the incident light. The J_{SC},V_{OC} and FF values can be calculated from the direct current density-voltage (J-V) curves.

TiO_2 as an electrode

The excellent properties of TiO_2such as good chemical stability, low cost production, high corrosion resistance, non-toxicity, high photocatalytic activities and good charge transport properties play an important role in the performance of QDSSC (Barbe et al., 1997; Kong, Chang, & Jang, 2014; Ou & Lo, 2007). TiO_2 nanostructure such as nanoparticles(Balis, Dracopoulos, Bourikas, & Lianos, 2013; Chen, Chappel, Diamant, & Zaban, 2001; Ito et al., 2007; Jung, Kim, Kim, Choi, & Ahn, 2012; Kongkan, Tvrdy, Takechi, Kuno, & Kamat, 2008; Zaban, Mic´ic, Gregg, & Nozik, 1998; Zhang et al., 2009), nanotubes (Chen et al., 2009), nanorods (Gonfa et al., 2014), nanowires (Nikhil, Thomas, Amulya, Mohan Raj, & Kumaresan, 2014; Sun et al., 2012) and nanoflower (Yu, Li, Liu, Cheng, & Sun, 2014b) have been widely recognised as excellent photo anodes in QDSSC. The size of the TiO_2 building units, apparently in nanometer scale, highly influences the performance of QDSSC (Kavitha, Gopinathan, & Pandi, 2013). Table 1 shows the example of QDSSC and the solar cell efficiency performance based on nano- TiO_2 as an electrode.

Table 1: Example of QDSSC and the solar cell efficiency performance based on nano-TiO_2 as an electrode.

TiO2	Sensitizer	Counter electrode	Efficiency	Reference
TiO_2 nanoparticle	$CuInS_2$	Cu_2S	1.05%	(Gong et al., 2012)
TiO_2 sol	CdSe	Cu_2S/CNT	1.05%	(Golobostanfard & Abdizadeh, 2014)
TiO_2 nanoparticle	CdSe	Pt	3.65%	(Prabakar et al., 2010)
TiO_2 nanotube	$CdSe_xTe_1$-$_x$	Pt	0.588%	(Xu et al., 2013)
TiO_2 beads	CdS/CdSe	Cu_2S	4.33%	(Zhou et al., 2014)
TiO_2 nanoparticle	CdSe	Pt	2.23%	(Song et al., 2014)
TiO_2 nanoparticle	CdS	Pt	1.15%	(Lee & Chang, 2008)
Mesoporous spherical TiO_2 powder	CdS/CdSe	Pt	0.29%/0.34 %	(Kong et al., 2014)
TiO_2 sol gel	InP	Pt	-	(Zaba, Mic´ic´, Gregg, & Nozik, 1998)
TiO_2 nanoparticle	ZnS, CdS, CdSe	Pt, CoS, CuS	2.7%	(Balis et al., 2013)
TNT/TNP	CdSe		-	(Kongkanand, Tvrdy, Takechi, Kuno, & Kamat, 2007)
TNP	CdS	Pt	-	(Jung et al., 2012)
TiO_2 nanoparticle	CISe	Cu_2S	4.3%	(Yang et al., 2013)
TiO_2 nanoparticle	CdS/CdSe/ZnS	NiS	2.97%	(Kim et al., 2014)

TiO_2 nanoparticle	CdS	Cu_2S	2.15%	(Zhou et al., 2013)

Table 1: Example of QDSSC and the solar cell efficiency performance based on nano-TiO_2 as an electrode (*continued*).

TiO2	Sensitizer	Counter electrode	Efficiency	Reference
TiO_2 nanoparticle	CdS/CdSe	Pt/Cu_2S/Graphite/ Carbon soot/ Reduced Graphene Oxide (RGO)	1.2%	(Jun, Careem, & Arof, 2014)
TiO_2 nanoparticle	$SnSe_2$	-	0.12%	(Yu et al., 2012)
TiO_2 nanoparticle	SnS	Pt	<0.1%	(Miyauchi, 2011)
TiO_2 nanosheet	CdS	Pt/CuS	1.95%	(Li et al., 2014)
TiO_2 nanoparticle	Ag_2Se	Pt	3.6%	(Tubtimtae, Lee, & Wang, 2011)
TiO_2 nanoparticle	CdS	NiS	3.6%	(Li, Yang, Zhang, Zhang, & Li, 2014)
TiO_2 nanorod	CdS/PbS	Pt	2.0%	(Jiao, Zhou, Zhou, & Wu, 2013)
TiO_2 nanoparticle	$CuInS_2$	Cu_2S	1.85%	(Peng, Liu, Shu, Chen, & Chen, 2013)
TiO_2 nanodendrite array	$CuInS_2$	Cu_2S	1.26%	(Peng, Liu, Zhao, et al., 2013)
TiO_2 nanoparticle	CdS/CdSe	Brass plate	0.45%	(Shen et al., 2015)
TiO_2 hollow sphere	CdS/N719	Pt	4.66%	(Cui et al., 2015)
TiO_2 nanowire	PbSe	-	-	(Győri, Kónya, & Kukovecz, 2015)
TiO_2 nanoparticle	CdS	CoS2/Pt	2.27%	(Punnoose, Kim, Srinivasa Rao, & Pavan Kumar, 2015)
TiO_2 nanotube	$CdS_{0.54}Se_{0.46}$	Pt	-	(Gakhar, Smith, Misra, & Chidambaram, 2015)
TiO_2 nanoparticle	CdS_xSe_{1-x}/ Mn-CdS	$Cu_{1.8}$/CuS	3.26%	(Li et al., 2015)
TiO_2 nanoparticle	CdS/CdSe/ZnS	NiS	3.03%	(Gopi, Srinivasa Rao, Kim, Punnoose, & Kim, 2015)
TiO_2 nanorods arrays	CdSe/Mn-CdS	$Cu_{1.8}S$/CuS	2.40%	(Yu, Li, Liu, Cheng, & Sun, 2014a)

Preparation of TiO_2 as an electrode in QDSSC

In QDSSC, TiO_2 nanoparticles (example like commercial P25 nanoparticles) have been extensively studied as a photoanode due to their special characteristics as mentioned before (Zhou et al., 2014).Anatase, rutile and brookite are the three crystalline form of TiO_2 whereby anatase is the most preferable in solar energy conversion. This is due to the ability to avoid charge recombination and efficient electron transport in photoanode (Byranvana, Bazarganb, & Kharat, 2012). In recent years, a lot of research have gone into preparing TiO_2among them are in achieving low cost production and making them easily reproducible by using a simple method which is eventually imperative for the industrial manufacture of QDSSC (Zhang et al., 2009).The methods in preparing TiO_2 such as the hydrothermal method (Gopinathan, & Pandi, 2008; Vijayalakshmi & Rajendran, 2012; Wu et al., 2013), the sol gel method (Behnajady & Eskandarloo, 2013; Guo, Liu, Hong, & Jiang, 2005; Sabataitytė, Oja, Lenzmann, Volobujeva, & Krunks, 2006) and anodization (Tang et al., 2008) have been studied extensively in order to produce excellent characteristics of TiO_2 as a photoelectrode.

Sol-gel method

The sol-gel method for TiO_2 synthesis is a very useful tool for photo-induced molecular reaction due to the special variables such as particle size, incident light, phase composition and convenient preparation method (Karami, 2010). Titanium (IV) isopropoxide (TIPP) is usually used as a starting material in this method(Manoharan & Venkatachalam, 2015; Zeng, Chen, Su, Li, & Feng, 2014). The mixture will undergo an aging period and it is kept in the oven to obtain the colloidal solution (Zeng et al., 2014). Next the solution is dried and calcined to get TiO_2 nanocrystal powder (Hu, Tang, He, Lin, & Chen, 2014; Laranjo et al., 2014; Zhu, Zhang, Gao, & Cao, 2000). Figure 3 shows TiO2 nanoparticles prepared by the sol gel method at different levels of concentration.

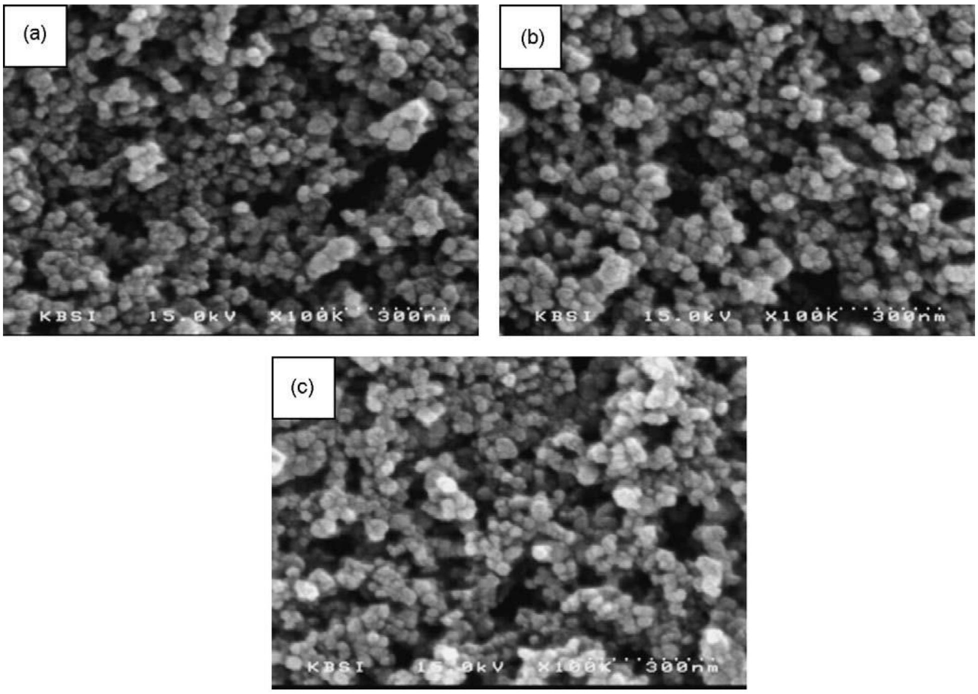

Figure 3: SEM surface images of three different kinds of TiO_2 concentrations of (a) 17 wt.%, (b) 20 wt.%, and (c) 24 wt.% films on the SnO2:F glass after sintering process(Lee et al., 2009).

Hydrothermal method

Hydrothermal method is one of the most popular methods to prepare TiO_2 nanostructure. Other than TiO_2 nanoparticle, other nanostructures such as nanotube and nanorod can also be synthesized via the hyrothermal method (Lee, Lee, Rhee, & Park, 2014). One of the suggested methods is TIPP where it is mixed and stirred with nitric acid, ethanol and distilled water through the sol-gel method. The product produced from the sol-gel method will undergo hydrothermal treatment in the teflon-lined autoclave to produce TiO_2 powder and the powder will receive further treatment for calcination to achieve the desired size and crystallinity (Manoharan & Venkatachalam, 2015). Figure 4 shows SEM images of TiO_2 nanorod arrays formed by the hydrothermal method by optimization of the seed layer.

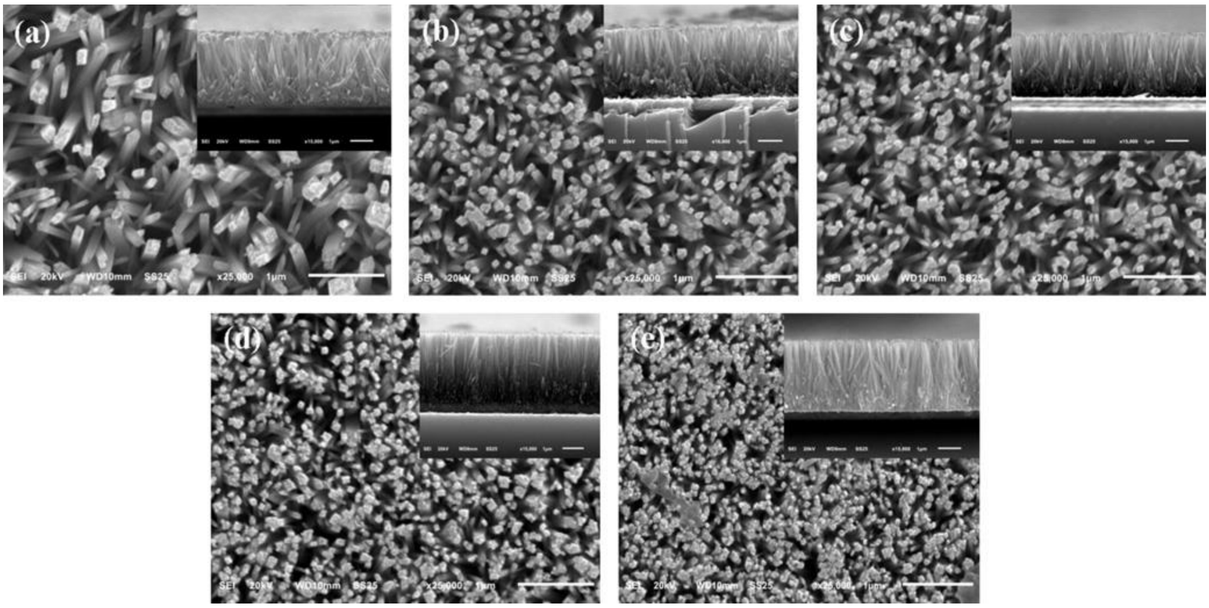

Figure 4: SEM images of TiO_2nanorod arrays grown by hydrothermal method on (a) bare FTO, (b) FTO immersed in 0.05 M $TiCl_4$ solution, (c) FTO immersed in 0.1 M $TiCl_4$ solution, (d) FTO immersed in0.15 M $TiCl_4$ solution, (e) FTO immersed in 0.2 M $TiCl_4$ solution, respectively (Wang et al., 2013)

Electrochemical method

The Electrochemical method is an impressive technology to develop the nanotube or nanoporous layer as an electrode especially in QDSSC. TiO_2 nanotube can be formed by an anodization of the titanium whose capability is strongly influenced by the variation of parameters. The quality and ability of TiO_2 nanotubes also depends on their very own properties such as crystallite size, morphology and the lattice strain. Yulian Zhang et al.,(2015)reported the frequent used of ammonium fluoride (NH_4F) as an electrolyte and indicated that high NH_4F concentration is beneficial to the growth of ribs around the nanotubes. Figure 5 shows the FESEM images of surface morphologies and cross-section of TNTs obtained in electrolytes with different NH_4F concentrations. Meanwhile, Munirathinam, Pydimukkala, Ramaswamy, & Neelakantan (2015) reported on the development of TiO_2 nanotubes by the anodization process using the two electrode system whereby titanium was used as anode and a stainless steel plate as a cathode at a specific distance. In this research, two different electrolytes which are hydrofluoric acid, HF (acidic medium) and sodium sulfate, Na_2SO_4 (neutral) were used and then followed by annealing at 450^{o}C for 2h. The result clearly indicated nanotubes formed from the neutral bath are four times longer than the ones synthesized from the acidic bath.

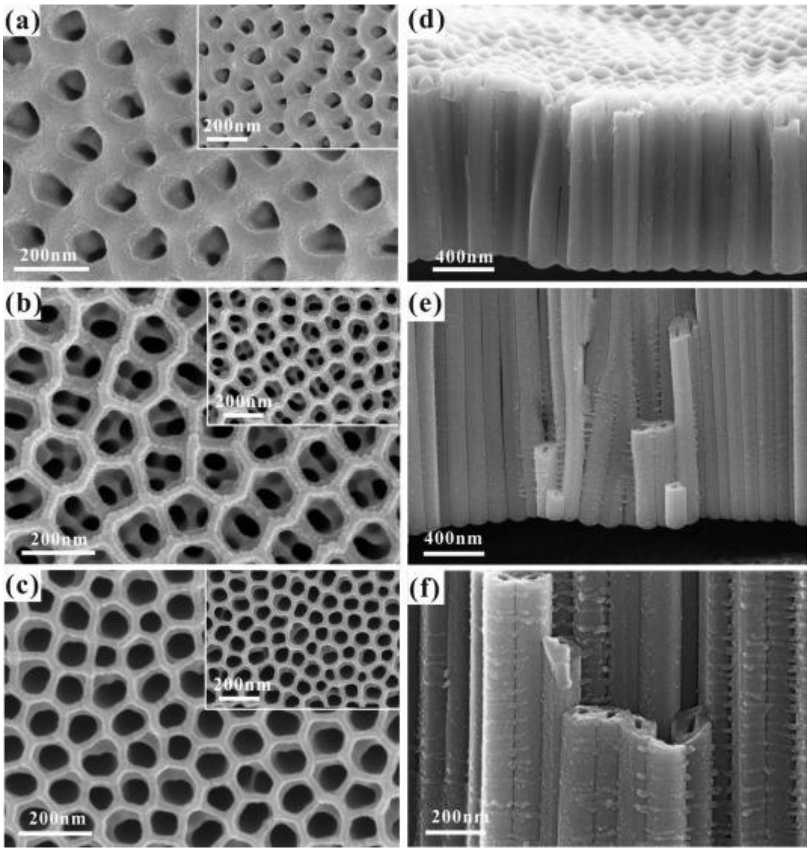

Figure 5: FESEM images of surface morphologies and cross-section of TNTs obtained in electrolytes with NH_4F concentrations of (a) (d) 0.2 wt%, (b) (e) 0.4 wt%, (c) (f) 0.6 wt%, respectively (Zhang et al., 2015)

Approach in improving TiO_2photoanode in QDSSCs

Although QDSSC raised tremendously high attention among researchers in order to improve solar cell performance, energy conversion efficiency remains under 10% as reported in figure 1. A lot of work has been done in the approach to improve QDSSC. One of the important approaches to increase the energy conversion efficiency yield is the architecture of the photoanodes. This is because photoanode material like TiO_2 has wide band gap (3.20 eV for anatase and 3.02 eV for rutile TiO_2) that limit its usage at UV light region(Maheswari & Venkatachalam, 2015). Other than that, optimal nanoparticle interconnection and pores size can control the charge carrier transport to ensure an efficient electrolyte penetration (Yacoubi, Samet, Bennaceur, Lamouchi, & Chtourou, 2015).

Among studies that have been done recently are doping TiO_2 electrode with Ni (Maheswari & Venkatachalam, 2015), Au (Liu et al., 2014), Co (Brigham, Achey, & Meyer, 2014; C. Wang et al., 2014), Fe (Wang et al., 2014) and Mn (Wang et al., 2014). Doping TiO_2 with impurities dopants will broaden the use of the PV to the visible region and at the same time provide a good surface for the deposition of QDs (Maheswari & Venkatachalam, 2015; Yacoubi et al., 2015). The dopants also act as a light harvesting material which means the light will be scattered and trapped in order to increase the effective path length of incident light of the absorption of the semiconductor (Liu et al., 2014). Some dopant like Fe have been reported as having the ability to increase charge carrier density of TiO_2 leading to good carrier transportation and separation and relatively long electron lifetime(Wang et al., 2014).

Beside dopants, surface modification also play an important role in order to avoid or reduce recombination of excited electron whereby it is a major problem in QDSSC(Kim et al., 2012). $TiCl_4$is usually applied on the substrate at multiple times of immersion, followed by annealing at 450^{o}C for 30 min before depositing TiO_2 paste (Kim et al., 2012). Nevertheless, $TiCl_4$ treatment decreases average pore size whereby it can lower the recombination and increase the current (Guo et al., 2014). Recently, a study focused on the treatment of TiO_2 hydrolysed by hydrochloric acid (HCl) in preparation of $TiCl_4$ stock solution has been reported for the synthesis of nanosized crystalline TiO_2 (Lee & Yang, 2005). The result from this study showed that the brookite phase was transformed to the rutile phase with increase reaction time, while through a heat treatment, it was transformed to rutile via anatase phase (Lee & Yang, 2005).

Previously, there were so many efforts made to optimize TiO_2 structures to enhance QDSSC performance. The first effort made was by creating large pore size distribution of TiO_2 to make the loading process of quantum dots much easier due to the small size of quantum dots (Salant et al., 2012). Secondly, the surface area of TiO_2 was increased in order to increase quantum dots loading. Moreover, high surface area of photoanaode may improve the quantum dots coverage and retard unnecessary interface recombination (Song et al., 2012). Thirdly, an additional layer of coating was also added to improve the electron transport path in order to enhance the QDSSC performance. However, previous researches reported that an additional layer of TiO_2 can hardly balance the required qualities of TiO_2 (Wu et al., 2015). Therefore, further studies on optimization of TiO_2 should be done to meet the demand in QDSSC. For example, Wu et al. (2015) designed a multi-dimension titanium dioxide made up of mesoporous nanoribbons consisting of oriented aligned nanocrystal. This impressive development resulted in increased surface area of TiO_2 that led to a high photocurrent efficiency of 4.15%. Meanwhile, in another study an attempt has been done by doping TiO_2 nanocrystal with two dimensional graphene in order to improve the photovoltaic performance owing to the graphene unique characteristics such as good thermal conductivity, good mobility charge carriers and specific surface area (Chen, Tuo, Rao, & Zhou, 2014). The incorporation of graphene with TiO_2 increase the photocurrent efficiency by 37% compared to the pure TiO_2 and eventually increased the QDSSC performance.

Conclusions and future directions

The review on TiO_2 as a working electrode in QDSSC demonstrated high potential inorder to increase energy conversion efficiency in a novel QDSSC system. The study of photoanode configuration is critically important because the significance can be of high impact particularly in providing high QD loading, strong light scattering, quick electrolyte diffusion and efficient electron transport (Zhou et al., 2014). Different nanocrystal structure such as nanotubes, nanorods and nanowire have been developed whereby particular control is given to recombination and this eventually improves PV performance. Currently, a lot of studies are focused on developing low cost high ability nanocrystal material for PV application and this will no doubt raise its potential when developed and applied in the academia and industry. The low cost nanocrystal material used make the current price of QDSSC cheaper than DSSC ($3/Wp–$4/Wp) and silicon solar cell ($3/Wp) (Kalowekamo & Baker, 2009). Future work should be focused on improving the solar cell efficiency as mentioned in this review paper. Many modifications on QDSSC have been developed however, they are still in their early stages and many other new developments can be done in order to improve the efficiency, robustness and potential of the thin-film-type material. No doubt, as the understanding of the topic continues, more possible ideas can be conceived to improve QDSSC potential.

References

Abdullah, M. H., & Rusop, M. (2014). Improved performance of dye-sensitized solar cell with a specially tailored TiO_2 compact layer prepared by RF magnetron sputtering. *Journal of Alloys and Compounds*, *600*, 60-66. doi: 10.1016/j.jallcom.2014.01.139

Atomsa Gonfa, B., Zhao, H., Li, J., Qiu, J., Saidani, M., Zhang, S., & Ma, D. (2014). Air-processed depleted bulk heterojunction solar cells based on PbS/CdS core–shell quantum dots and TiO_2 nanorod arrays. *Solar Energy Materials and Solar Cells*, *124*, 67-74. doi: 10.1016/j.solmat.2014.01.037

Balis, N., Dracopoulos, V., Bourikas, K., & Lianos, P. (2013). Quantum dot sensitized solar cells based on an optimized combination of ZnS, CdS and CdSe with CoS and CuS counter electrodes. *Electrochimica Acta, 91*, 246-252. doi: 10.1016/j.electacta.2013.01.004

Barbe, C. J., Arendse, F., Comte, P., Jirousek, M., Lenzmann, F., Shklover, V., & Gra¨tzel, M. (1997). Nanocrystalline Titanium Oxide Electrodes for Photovoltaic Applications. *J. Am. Ceram. Soc, 20(12)*, 3157-3171.

Behnajady, M. A., & Eskandarloo, H. (2013). Preparation of TiO_2 nanoparticles by the sol–gel method under different pH conditions and modeling of photocatalytic activity by artificial neural network. *Research on Chemical Intermediates*. doi: 10.1007/s11164-013-1327-5

Bet-moushoul, E., Mansourpanah, Y., Farhadi, K., & Tabatabaei, M. (2016). TiO_2 nanocomposite based polymeric membranes: A review on performance improvement for various applications in chemical engineering processes. *Chemical Engineering Journal*, *283*, 29-46. doi: 10.1016/j.cej.2015.06.124

Brigham, E. C., Achey, D., & Meyer, G. J. (2014). Excited state electron transfer from cobalt coordination compounds anchored to TiO_2. *Polyhedron, 82*, 181-190. doi: 10.1016/j.poly.2014.07.023

Byranvana, M. M., Bazarganb, M. H., & Kharat, A. N. (2012). *The Method For Preparing Anatase Titania Nanoparticles: Application to Flexible Dye Sensitized Solar Cells.* Paper presented at the Proceedings of the 4th International Conference on Nanostructures (ICNS4), Kish Island, I.R. Iran.

Chen, L., Tuo, L., Rao, J., & Zhou, X. (2014). TiO_2 doped with different ratios of graphene and optimized application in CdS/CdSe quantum dot-sensitized solar cells. *Materials Letters*, *124,* 161-164. doi: 10.1016/j.matlet.2014.03.062

Chen, P., Brillet, J., Bala, H., Wang, P., Zakeeruddin, S. M., & Grätzel, M. (2009). Solid-state dye-sensitized solar cells using TiO_2 nanotube arrays on FTO glass. *Journal of Materials Chemistry*, *19*(30), 5325. doi: 10.1039/b905196a

Chen, S. G., Chappel, S., Diamant, Y., & Zaban, A. (2001). Preparation of Nb_2O_5 Coated TiO_2 Nanoporous Electrodes and Their Application in Dye-Sensitized Solar Cells. *Chem. Mater.*, *13*, 4629-4634.

Church, C. P., Muthuswamy, E., Zhai, G., Kauzlarich, S. M., & Carter, S. A. (2013). Quantum dot Ge/TiO2 heterojunction photoconductor fabrication and performance. *Applied Physics Letters*, *103*(22), 223506. doi: 10.1063/1.4826916

Conibeer, G. (2007). Third-generation photovoltaics. *Materials Today*, *10*(11), 42-50. doi: 10.1016/s1369-7021(07)70278-x

Cui, C., Qiu, Y., Zhao, J., Lu, B., Hu, H., Yang, Y., & Li, X. (2015). A comparative study on the quantum-dot-sensitized, dye-sensitized and co-sensitized solar cells based on hollow spheres embedded porous TiO_2 photoanodes. *Electrochimica Acta*, *173*, 551-558. doi: 10.1016/j.electacta.2015.05.100

Du, H., Li, N., Brown, M. A., Peng, Y., & Shuai, Y. (2014). A bibliographic analysis of recent solar energy literatures: The expansion and evolution of a research field. *Renewable Energy, 66,* 696-706. doi: 10.1016/j.renene.2014.01.018

El Chaar, L., lamont, L. A., & El Zein, N. (2011). Review of photovoltaic technologies. *Renewable and Sustainable Energy Reviews*, *15*(5), 2165-2175. doi: 10.1016/j.rser.2011.01.004

Gakhar, R., Smith, Y. R., Misra, M., & Chidambaram, D. (2015). Photoelectric performance of TiO_2 nanotube array photoelectrodes sensitized with CdS0.54Se0.46 quantum dots. *Applied Surface Science, 355*, 1279-1288. doi: 10.1016/j.apsusc.2015.07.169

Golobostanfard, M. R., & Abdizadeh, H. (2014). Tandem structured quantum dot/rod sensitized solar cell based on solvothermal synthesized CdSe quantum dots and rods. *Journal of Power Sources, 256*, 102-109. doi: 10.1016/j.jpowsour.2014.01.055

Gong, J., Liang, J., & Sumathy, K. (2012). Review on dye-sensitized solar cells (DSSCs): Fundamental concepts and novel materials. *Renewable and Sustainable Energy Reviews, 16*(8), 5848-5860. doi: 10.1016/j.rser.2012.04.044

Gopi, C. V. V. M., Srinivasa Rao, S., Kim, S.-K., Punnoose, D., & Kim, H.-J. (2015). Highly effective nickel sulfide counter electrode catalyst prepared by optimal hydrothermal treatment for quantum dot-sensitized solar cells. *Journal of Power Sources, 275*, 547-556. doi: 10.1016/j.jpowsour.2014.11.038

Green, M. A. (2002). Third generation photovoltaics: solar cells for 2020 and beyond. *Physica E, 14*, 65-70.

Guo, B., Liu, Z., Hong, L., & Jiang, H. (2005). Sol gel derived photocatalytic porous TiO_2 thin films. *Surface and Coatings Technology, 198*(1-3), 24-29. doi: 10.1016/j.surfcoat.2004.10.055

Guo, K., Liu, Z., Zhou, C., Han, J., Zhao, Y., Liu, Z., & Zhang, J. (2014). Fabrication of TiO_2 nano-branched arrays/Cu_2S composite structure and its photoelectric performance. *Applied Catalysis B: Environmental, 154-155*, 27-35. doi: 10.1016/j.apcatb.2014.02.004

Guo, W., Shen, Y., Wu, M., & Ma, T. (2012). Highly efficient inorganic-organic heterojunction solar cells based on SnS-sensitized spherical TiO2 electrodes. *Chem Commun (Camb), 48*(49), 6133-6135. doi: 10.1039/c2cc31903a

Guo, W., Shen, Y., Wu, M., Wang, L., Wang, L., & Ma, T. (2012). SnS-quantum dot solar cells using novel TiC counter electrode and organic redox couples. *Chemistry, 18*(25), 7862-7868. doi: 10.1002/chem.201103904

Győri, Z., Kónya, Z., & Kukovecz, Á. (2015). Visible light activation photocatalytic performance of PbSe quantum dot sensitized TiO_2 Nanowires. *Applied Catalysis B: Environmental, 179*, 583-588. doi: 10.1016/j.apcatb.2015.05.056

Halim, M. (2012). Harnessing Sun’s Energy with Quantum Dots Based Next Generation Solar Cell. *Nanomaterials, 3*(1), 22-47. doi: 10.3390/nano3010022

Hu, B., Tang, Q., He, B., Lin, L., & Chen, H. (2014). Mesoporous TiO_2 anodes for efficient dye-sensitized solar cells: An efficiency of 9.86% under one sun illumination. *Journal of Power Sources, 267*, 445-451. doi: 10.1016/j.jpowsour.2014.05.119

Hu, C., Lu, T., Chen, F., Zhang, R., Lian, C., Zheng, S., & Duo, S. (2014). Enhancement of photocatalytic performance of TiO_2 produced by an alcohothermal approach through inclusion of water. *Materials Research Bulletin, 53*, 42-48. doi: 10.1016/j.materresbull.2014.01.034

Ito, S., Chen, P., Comte, P., Nazeeruddin, M. K., Liska, P., Péchy, P., & Grätzel, M. (2007). Fabrication of screen-printing pastes from TiO_2 powders for dye-sensitised solar cells. *Progress in Photovoltaics: Research and Applications, 15*(7), 603-612. doi: 10.1002/pip.768

Jiao, J., Zhou, Z.-J., Zhou, W.-H., & Wu, S.-X. (2013). CdS and PbS quantum dots co-sensitized TiO_2 nanorod arrays with improved performance for solar cells application. *Materials Science in Semiconductor Processing, 16*(2), 435-440. doi: 10.1016/j.mssp.2012.08.009

Jun, H. K., Careem, M. A., & Arof, A. K. (2013). Quantum dot-sensitized solar cells—perspective and recent developments: A review of Cd chalcogenide quantum dots as sensitizers. *Renewable and Sustainable Energy Reviews, 22*, 148-167. doi: 10.1016/j.rser.2013.01.030

Jun, H. K., Careem, M. A., & Arof, A. K. (2014). Fabrication, Characterization, and Optimization of CdS and CdSe Quantum Dot-Sensitized Solar Cells with Quantum Dots Prepared by Successive Ionic Layer Adsorption and Reaction. *International Journal of Photoenergy, 2014*, 1-14. doi: 10.1155/2014/939423

Jun, H. K., Careem, M. A., & Arof, A. K. (2014). Performances of some low-cost counter electrode materials in CdS and CdSe quantum dot-sensitized solar cells. *Nanoscale Research Letters, 9(16)*, 1-7.

Jung, S. W., Kim, J.-H., Kim, H., Choi, C.-J., & Ahn, K.-S. (2012). ZnS overlayer on in situ chemical bath deposited CdS quantum dot-assembled TiO_2 films for quantum dot-sensitized solar cells. *Current Applied Physics, 12*(6), 1459-1464. doi: 10.1016/j.cap.2012.04.012

Kalowekamo, J., & Baker, E. (2009). Estimating the manufacturing cost of purely organic solar cells. *Solar Energy, 83*(8), 1224-1231. doi: 10.1016/j.solener.2009.02.003

Karami, A. (2010). Synthesis of TiO_2 Nano Powder by the Sol-Gel Method and Its Use as a Photocatalyst. *J. Iran. Chem. Soc., 7*, 154-160.

Kavitha, M., C.Gopinathan, & P.Pandi. (2008). Synthesis and Characterization of TiO_2 Nanopowders in Hydrothermal and Sol-Gel Method. *International Journal of Advancements in Research & Technology, 2*, 102-108.

Kavitha, M., C.Gopinathan, & P.Pandi. (2013). Synthesis and Characterization of TiO_2 Nanopowders in Hydrothermal and Sol-Gel Method. *International Journal of Advancements in Research & Technology, 2*(4), 102-108.

Kim, H.-J., Kim, D.-J., Rao, S. S., Savariraj, A. D., Soo-Kyoung, K., Son, M.-K., & Prabakar, K. (2014). Highly efficient solution processed nanorice structured NiS counter electrode for quantum dot sensitized solar cells. *Electrochimica Acta, 127*, 427-432. doi: 10.1016/j.electacta.2014.02.019

Kim, J., Choi, H., Nahm, C., Kim, C., Nam, S., Kang, S., & Park, B. (2012). The role of a $TiCl_4$ treatment on the performance of CdS quantum-dot-sensitized solar cells. *Journal of Power Sources, 220*, 108-113. doi: 10.1016/j.jpowsour.2012.07.133

Kong, E.-H., Chang, Y.-J., & Jang, H. M. (2014). Quantum dot-sensitized mesoporous spherical TiO_2 paste with cyclic calcination for photoelectrochemical cells. *Electrochimica Acta, 132*, 98-102. doi: 10.1016/j.electacta.2014.03.122

Kongkan, A., Tvrdy, K., Takechi, K., Kuno, M., & Kamat, P. V. (2008). Quantum Dot Solar Cells. Tuning Photoresponse through Size and Shape Control of CdSe-TiO2 Architecture. *J. AM. CHEM. SOC., 130*, 4007-4015.

Kongkanand, A., Tvrdy, K., Takechi, K., Kuno, M., & Kamat, P. V. (2007). Quantum Dot Solar Cells. Tuning Photoresponse through Size and Shape Control of CdSe-TiO2 Architecture. *J. AM. CHEM. SOC., 130*, 4007-4016.

Kouhnavard, M., Ikeda, S., Ludin, N. A., Ahmad Khairudin, N. B., Ghaffari, B. V., Mat-Teridi, M. A., & Sopian, K. (2014). A review of semiconductor materials as sensitizers for quantum dot-sensitized solar cells. *Renewable and Sustainable Energy Reviews, 37*, 397-407. doi: 10.1016/j.rser.2014.05.023

Laranjo, M. T., Ricardi, N. C., Arenas, L. T., Benvenutti, E. V., de Oliveira, M. C., Santos, M. J. L., & Costa, T. M. H. (2014). TiO_2 and TiO_2/SiO_2 nanoparticles obtained by sol–gel method and applied on dye sensitized solar cells. *Journal of Sol-Gel Science and Technology, 72*(2), 273-281. doi: 10.1007/s10971-014-3341-5

Lee, D.-S., Lee, S.-Y., Rhee, K. Y., & Park, S.-J. (2014). Effect of hydrothermal temperature on photocatalytic properties of TiO_2 nanotubes. *Current Applied Physics, 14*(3), 415-420. doi: 10.1016/j.cap.2013.12.018

Lee, J.-K., Jeong, B.-H., Jang, S.-I., Kim, Y.-G., Jang, Y.-W., Lee, S.-B., & Kim, M.-R. (2009). Preparations of TiO_2 pastes and its application to light-scattering layer for dye-sensitized solar cells. *Journal of Industrial and Engineering Chemistry, 15*(5), 724-729. doi: 10.1016/j.jiec.2009.09.053

Lee, J. H., & Yang, Y. S. (2005). Effect of HCl concentration and reaction time on the change in the crystalline state of TiO_2 prepared from aqueous $TiCl_4$ solution by precipitation. *Journal of the European Ceramic Society, 25*(16), 3573-3578. doi: 10.1016/j.jeurceramsoc.2004.09.024

Lee, Y.-L., & Chang, C.-H. (2008). Efficient polysulfide electrolyte for CdS quantum dot-sensitized solar cells. *Journal of Power Sources, 185*(1), 584-588. doi: 10.1016/j.jpowsour.2008.07.014

Li, L., Yang, X., Zhang, W., Zhang, H., & Li, X. (2014). Boron and sulfur co-doped TiO_2 nanofilm as effective photoanode for high efficiency CdS quantum-dot-sensitized solar cells. *Journal of Power Sources, 272*, 508-512. doi: 10.1016/j.jpowsour.2014.08.116

Li, S., Chen, Z., Li, T., Gao, H., Wei, C., Li, W., & Zhang, W. (2014). Vertical nanosheet-structured ZnO/TiO_2 photoelectrodes for highly efficient CdS quantum dot sensitized solar cells. *Electrochimica Acta, 127*, 362-368. doi: 10.1016/j.electacta.2014.02.042

Li, Z., Yu, L., Liu, Y., & Sun, S. (2015). Efficient quantum dot-sensitized solar cell based on $CdS_xSe_{1-x}/Mn\text{-}CdS/TiO_2$ nanotube array electrode. *Electrochimica Acta, 153*, 200-209. doi: 10.1016/j.electacta.2014.11.197

Liao, Y., Que, W., Jia, Q., He, Y., Zhang, J., & Zhong, P. (2012). Controllable synthesis of brookite/anatase/rutile TiO_2 nanocomposites and single-crystalline rutile nanorods array. *Journal of Materials Chemistry, 22*(16), 7937. doi: 10.1039/c2jm16628c

Liu, A., Ren, Q., Zhao, M., Xu, T., Yuan, M., Zhao, T., & Tang, W. (2014). Photovoltaic performance enhancement of CdS quantum dot-sensitized TiO_2 photoanodes with plasmonic gold nanoparticles. *Journal of Alloys and Compounds, 589*, 218-225. doi: 10.1016/j.jallcom.2013.11.106

M. Malekshahi Byranvanda, A. N. K., L. Fatholahib, & Z. Malekshahi Beiranvandc. (2013). A Review on Synthesis of Nano-TiO_2 via Different Methods. *JNS, 3*, 1-9.

Maheswari, D., & Venkatachalam, P. (2015). Enhancing the performance of dye-sensitized solar cells based on organic dye sensitized TiO_2 nanoparticles/nanowires composite photoanodes with ionic liquid electrolyte. *Measurement, 60*, 146-154. doi: 10.1016/j.measurement.2014.10.016

Manoharan, K., & Venkatachalam, P. (2015). Photoelectrochemical performance of dye sensitized solar cells based on aluminum-doped titanium dioxide structures. *Materials Science in Semiconductor Processing, 30*, 208-217. doi: 10.1016/j.mssp.2014.08.012

Miyauchi, M. (2011). Tailoring of SnS quantum dots in mesoporous media for efficient photoelectrochemical device. *Chemical Physics Letters, 514*(1-3), 151-155. doi: 10.1016/j.cplett.2011.08.064

Munirathinam, B., Pydimukkala, H., Ramaswamy, N., & Neelakantan, L. (2015). Influence of crystallite size and surface morphology on electrochemical properties of annealed TiO_2 nanotubes. *Applied Surface Science, 355*, 1245-1253. doi: 10.1016/j.apsusc.2015.08.017

Nikhil, A., Thomas, D. A., Amulya, S., Mohan Raj, S., & Kumaresan, D. (2014). Synthesis, characterization, and comparative study of CdSe–TiO_2 nanowires and CdSe–TiO_2 nanoparticles. *Solar Energy, 106*, 109-117. doi: 10.1016/j.solener.2014.01.034

Ou, H., & Lo, S. (2007). Review of titania nanotubes synthesized via the hydrothermal treatment: Fabrication, modification, and application. *Separation and Purification Technology, 58*(1), 179-191. doi: 10.1016/j.seppur.2007.07.017

Peng, Z., Liu, Y., Shu, W., Chen, K., & Chen, W. (2013). Efficiency enhancement of $CuInS_2$ quantum dot sensitized TiO_2 photo-anodes for solar cell applications. *Chemical Physics Letters, 586*, 85-90. doi: 10.1016/j.cplett.2013.08.109

Peng, Z., Liu, Y., Zhao, Y., Shu, W., Chen, K., Bao, Q., & Chen, W. (2013). Efficiency enhancement of TiO_2 nanodendrite array electrodes in CuInS2 quantum dot sensitized solar cells. *Electrochimica Acta, 111*, 755-761. doi: 10.1016/j.electacta.2013.08.054

Prabakar, K., Minkyu, S., Inyoung, S., & Heeje, K. (2010). CdSe quantum dots co-sensitized TiO_2photoelectrodes: particle size dependent properties. *Journal of Physics D: Applied Physics, 43*(1), 012002. doi: 10.1088/0022-3727/43/1/012002

Punnoose, D., Kim, H.-J., Srinivasa Rao, S., & Pavan Kumar, C. S. S. (2015). Cobalt sulfide counter electrode using hydrothermal method for quantum dot-sensitized solar cells. *Journal of Electroanalytical Chemistry, 750*, 19-26. doi: 10.1016/j.jelechem.2015.05.003

Sabataitytė, J., Oja, I., Lenzmann, F., Volobujeva, O., & Krunks, M. (2006). Characterization of nanoporous TiO_2 films prepared by sol–gel method. *Comptes Rendus Chimie, 9*(5-6), 708-712. doi: 10.1016/j.crci.2005.05.019

Salant, A., Shalom, M., Tachan, Z., Buhbut, S., Zaban, A., & Banin, U. (2012). Quantum rod-sensitized solar cell: nanocrystal shape effect on the photovoltaic properties. *Nano Lett, 12*(4), 2095-2100. doi: 10.1021/nl300356e

Selinsky, R. S., Ding, Q., Faber, M. S., Wright, J. C., & Jin, S. (2013). Quantum dot nanoscale heterostructures for solar energy conversion. *Chem Soc Rev, 42*(7), 2963-2985. doi: 10.1039/c2cs35374a

Shen, C., Tong, H., Gao, W., Yuan, S., Chen, G., & Yang, Y. (2015). Effects of anode structures and fabrication methods on cell efficiencies of CdS/CdSe quantum dot co-sensitized solar cells. *Journal of Alloys and Compounds, 644*, 205-210. doi: 10.1016/j.jallcom.2015.04.188

Song, X., Wang, M., Shi, Y., Deng, J., Yang, Z., & Yao, X. (2012). In situ hydrothermal growth of CdSe(S) nanocrystals on mesoporous TiO_2 films for quantum dot-sensitized solar cells. *Electrochimica Acta, 81*, 260-267. doi: 10.1016/j.electacta.2012.07.015

Song, X., Wang, M., Xing, T., Deng, J., Ding, J., Yang, Z., & Zhang, X. (2014). Fabrication of micro/nano-composite porous TiO_2 electrodes for quantum dot-sensitized solar cells. *Journal of Power Sources, 253*, 17-26. doi: 10.1016/j.jpowsour.2013.12.033

Sun, P., Zhang, X., Liu, X., Wang, L., Wang, C., Yang, J., & Liu, Y. (2012). Growth of single-crystalline rutile TiO_2 nanowire array on titanate nanosheet film for dye-sensitized solar cells. *Journal of Materials Chemistry, 22*(13), 6389. doi: 10.1039/c2jm16695j

Tang, Y., Tao, J., Zhang, Y., Wu, T., Tao, H., & Bao, Z. (2008). Preparation and Characterization of TiO_2 Nanotube Arrays via Anodization of Titanium Films Deposited on FTO Conducting Glass at Room Temperature. *Acta Phys. -Chim. Sin., 24(12)*, 2191-2197.

Tubtimtae, A., Lee, M.-W., & Wang, G.-J. (2011). Ag2Se quantum-dot sensitized solar cells for full solar spectrum light harvesting. *Journal of Power Sources, 196*(15), 6603-6608. doi: 10.1016/j.jpowsour.2011.03.074

Vijayalakshmi, R., & Rajendran, V. (2012). Synthesis and characterization of nano-TiO_2 via different methods. *Archives of Applied Science Research, 4(2)*, 1183-1190.

Wang, C., Chen, Z., Jin, H., Cao, C., Li, J., & Mi, Z. (2014). Enhancing visible-light photoelectrochemical water splitting through transition-metal doped TiO_2nanorod arrays. *J. Mater. Chem. A, 2*(42), 17820-17827. doi: 10.1039/c4ta04254a

Wang, J., Zhang, T., Wang, D., Pan, R., Wang, Q., & Xia, H. (2013). Improved morphology and photovoltaic performance in TiO_2 nanorod arrays based dye sensitized solar cells by using a seed layer. *Journal of Alloys and Compounds, 551*, 82-87. doi: 10.1016/j.jallcom.2012.09.113

Wang, Y., He, Y., Lai, Q., & Fan, M. (2014). Review of the progress in preparing nano TiO_2: an important environmental engineering material. *J Environ Sci (China), 26*(11), 2139-2177. doi: 10.1016/j.jes.2014.09.023

Wu, D., He, J., Zhang, S., Cao, K., Gao, Z., Xu, F., & Jiang, K. (2015). Multi-dimensional titanium dioxide with desirable structural qualities for enhanced performance in quantum-dot sensitized solar cells. *Journal of Power Sources, 282*, 202-210. doi: 10.1016/j.jpowsour.2015.02.062

Wu, W. Q., Lei, B. X., Rao, H. S., Xu, Y. F., Wang, Y. F., Su, C. Y., & Kuang, D. B. (2013). Hydrothermal fabrication of hierarchically anatase TiO_2 nanowire arrays on FTO glass for dye-sensitized solar cells. *Sci Rep, 3*, 1352. doi: 10.1038/srep01352

Xu, T., Zou, F., Yu, Y., & Zhi, J. (2013). Synthesis and characterization of CdSexTe1−x sensitized TiO_2 solar cell with enhanced photovoltaic properties. *Materials Letters, 96*, 8-11. doi: 10.1016/j.matlet.2012.12.089

Yacoubi, B., Samet, L., Bennaceur, J., Lamouchi, A., & Chtourou, R. (2015). Properties of transition metal doped-titania electrodes: Impact on efficiency of amorphous and nanocrystalline dye-sensitized solar cells. *Materials Science in Semiconductor Processing, 30*, 361-367. doi: 10.1016/j.mssp.2014.10.035

Yang, J., Kim, J. Y., Yu, J. H., Ahn, T. Y., Lee, H., Choi, T. S., & Hyeon, T. (2013). Copper-indium-selenide quantum dot-sensitized solar cells. *Phys Chem Chem Phys, 15*(47), 20517-20525. doi: 10.1039/c3cp54270j

Yang, Z., Chen, C. Y., Roy, P., & Chang, H. T. (2011). Quantum dot-sensitized solar cells incorporating nanomaterials. *Chem Commun (Camb), 47*(34), 9561-9571. doi: 10.1039/c1cc11317h

Yu, L., Li, Z., Liu, Y., Cheng, F., & Sun, S. (2014a). Enhanced photoelectrochemical performance of CdSe/Mn-CdS/TiO_2 nanorod arrays solar cell. *Applied Surface Science, 309*, 255-262. doi: 10.1016/j.apsusc.2014.05.023

Yu, L., Li, Z., Liu, Y., Cheng, F., & Sun, S. (2014b). Mn-doped CdS quantum dots sensitized hierarchical TiO_2 flower-rod for solar cell application. *Applied Surface Science, 305*, 359-365. doi: 10.1016/j.apsusc.2014.03.090

Yu, X.-Y., Lia, J.-Y., Qiu, K.-Q., Kuang, D.-B., & Su, C.-Y. (2011). Dynamic Study of Highly Efficient CdS/CdSe Quantum Dot-Sensitized Solar Cells Fabricated by Electrodeposition. *ASC NANO, 5*, 9494-9500.

Yu, X., Zhu, J., Zhang, Y., Weng, J., Hu, L., & Dai, S. (2012). SnSe2 quantum dot sensitized solar cells prepared employing molecular metal chalcogenide as precursors. *Chem Commun (Camb), 48*(27), 3324-3326. doi: 10.1039/c2cc17081g

Zaba, A., Mic´ic´, O. I., Gregg, B. A., & Nozik, A. J. (1998). Photosensitization of Nanoporous TiO_2 Electrodes with InP Quantum Dots. *Langmuir, 14*, 3153-3156.

Zaban, A., Mic´ic, O. I., Gregg, B. A., & Nozik, A. J. (1998). Photosensitization of Nanoporous TiO_2 Electrodes with InP Quantum Dots. *Langmuir, 14*, 3153-3156.

Zeng, T., Chen, Y., Su, X., Li, Y., & Feng, Q. (2014). Hydrothermal steam induced crystallization synthesis of anatase TiO_2 nanoparticles with high photovoltaic response. *Materials Letters, 119*, 43-46. doi: 10.1016/j.matlet.2013.12.100

Zhang, Y., Fan, H., Ding, X., Yan, Q., Wang, L., & Ma, W. (2015). Simulation of anodizing current-time curves and morphology evolution of TiO2 nanotubes anodized in electrolytes with different NH_4F concentrations. *Electrochimica Acta, 176*, 1083-1091. doi: 10.1016/j.electacta.2015.07.110

Zhang, Y., Wu, L., Xie, E., Duan, H., Han, W., & Zhao, J. (2009). A simple method to prepare uniform-size nanoparticle TiO_2 electrodes for dye-sensitized solar cells. *Journal of Power Sources*, *189*(2), 1256-1263. doi: 10.1016/j.jpowsour.2009.01.023

Zhou, R., Zhang, Q., Tian, J., Myers, D., Yin, M., & Cao, G. (2013). Influence of Cationic Precursors on CdS Quantum-Dot-Sensitized Solar Cell Prepared by Successive Ionic Layer Adsorption and Reaction. *The Journal of Physical Chemistry C, 117*(51), 26948-26956. doi: 10.1021/jp410615b

Zhou, R., Zhang, Q., Uchaker, E., Yang, L., Yin, N., Chen, Y., & Cao, G. (2014). Photoanodes with mesoporous TiO_2 beads and nanoparticles for enhanced performance of CdS/CdSe quantum dot co-sensitized solar cells. *Electrochimica Acta, 135*, 284-292. doi: 10.1016/j.electacta.2014.05.021

Zhu, Y., Zhang, L., Gao, C., & Cao, L. (2000). The synthesis of nanosized TiO2 powder using a sol-gel method with $TiCl_4$ as a precursor. *Journal of Materials Science, 35*, 4049-4054.