A Compilation of Nanotechnology in Thin Film Solar Cell Devices

Nurul Amziah Md Yunus, Izhal Abdul Halin, Nasri Sulaiman, Noor Faezah Ismail, Nik Hasniza Nik Aman

Abstract**—**Nanotechnology has become the world attention in various applications including the solar cells devices due to the uniqueness and benefits of achieving low cost and better performances of devices. Recently, thin film solar cells such as Cadmium Telluride (CdTe), Copper-Indium-Gallium-diSelenide (CIGS), Copper-Zinc-Tin-Sulphide (CZTS), and Dye-Sensitized Solar Cells (DSSC) enhanced by nanotechnology have attracted much attention. Thus, a compilation of nanotechnology devices giving the progress in the solar cells has been presented. It is much related to nanoparticles or nanocrystallines, carbon nanotubes, and nanowires or nanorods structures.

Keywords**—**Nanotechnology, nanocrystalline, nanowires, carbon nanotubes, nanorods, thin film solar cells.

I. Introduction

NANOTECHNOLOGY is the new attractive technology involving the development in new length scale of range 1 to 100nm at the atomic, molecular or macromolecular levels in structures, devices, and systems that still provide good or even better performances and functions related to their small size [1]. Nanotechnology is now become world demand and interest. A lot of research and developments have been done in various fields including the solar cells devices. Recent developments in nanotechnology provide new exciting opportunities for further improvements in cell performance and cost reduction in manufacturing processes of the solar cells [2].

The use of nanotechnology in solar cells can boosts the cells performance because conventional solar cells cannot convert all the incoming light into usable energy due to some of the light can escape the cell into the air and lost as heat, not electricity [3]. These mean that the structures from nanotechnology products could absorb more sunlight [4].

Nanotechnology in solar cell devices can be based on nanostructured application, which could be classified in terms of nanocomposites, nanotubes, nanorods, nanoparticles and quantum dots, which are also being applied for various functions [5]. The advantages of the nanostructured solar cells are: can increase the effective optical path for absorption due to multiple reflections, thickness absorber layer can be reduced to avoid recombination losses because light generated electrons and holes need to travel over shorter path, and the band gap of various layers can be varied by varying the size of nanoparticles [6].

Nurul Amziah Md Yunus is with Micro and Nano Electronic Systems Unit (MiNES), Department of Electrical and Electronic Engineering and Advanced Material Synthesis and Fabrication (AMSF) Laboratory, Faculty of Engineering, Universiti Putra Malaysia, Serdang, Selangor, Malaysia (Corresponding author Phone: +603-89464368; Fax: +603-89466327; e-mail: amziah@upm.edu.my).

Izhal Abdul Halin and Nasri Sulaiman are with the Micro and Nano Electronic Systems Unit, Department of Electrical and Electronic Engineering, Faculty of Engineering, Universiti Putra Malaysia, Serdang, Selangor, Malaysia (e-mail: izhal@upm.edu.my, nasri_sulaiman@upm.edu.my).

Nik Hasniza Nik Aman and Noor Faezah Ismail are with the Universiti Putra Malaysia, Serdang, Selangor, Malaysia.

II. Nanotechnology in Thin Film Solar Cell

Recently, thin film solar cells enhanced by nanotechnology have attracted much attention [7]. Thin film solar cells which are towards achieving thinner solar cells thus, can be also related to nanotechnology. Nanoparticles or Nano crystalline structures are common nanotechnology that being deployed in thin film solar cells to reduce the size or thickness of solar cells. Besides, carbon nanotubes (CNT), are also potential nanotechnology device, where they have a good ability in light absorption, conductivity of continuous wave illumination, and high carrier mobility [8]. Another potential technology is the nanowires or nanorods, which are unique with nano-scaled block solar cells structures and being used to form the p-n junction that can increase the surface junction area-to-volume ratio thereby can increase conversion efficiency [9]. The advantages of nanowires solar cells are; they can improve band gap, reduce reflection, increase defect tolerance, great light trapping, facile strain relaxation, and reduce cost [10]. A few efforts have been done to employ the nanotechnology in the conventional solar cells. Below are some of the nanotechnologies developments in some of thin film solar cells.

A. Cadmium Telluride, CdTe

Singh, V. P. et al. [2] have studied on nanostructured of Cadmium sulfide, (CdS)-CdTe by developing nanocrytalline CdTe as an n-type window layer coated on to Indium-Tin-Oxide, (ITO)-coated glass as shown in Fig. 1. The nanocrystalline CdTe obtained an effective band gap which is 2.8eV higher than bulk CdTe (1.5eV) [11]. The increasing band gap of CdTe makes it as good candidate for electroluminescent display devices. Besides, the nanowires of CdS in the thin film CdS-CdTe solar cells are also being studied [12]. P Liu et al. have replaced traditional CdS window layer by nanowires of CdS embedded in an Aluminium Oxide, (Al_2O_3) matrix or free-standing (Fig. 2) and efficiency of 6.5% has been achieved. CdS nanowires are having potential to give higher values of open circuit voltage, fill factor, short circuit current density and power conversion efficiency.

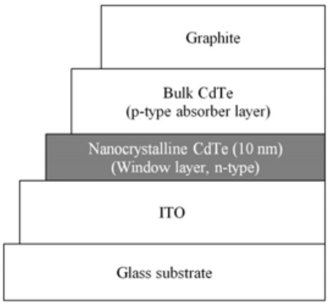

Fig. 1 Nanocrystalline development in CdTe Solar Cell [11]

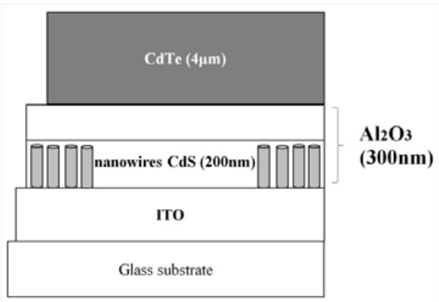

Fig. 2 Nanowires development in CdTe Solar cell [12]

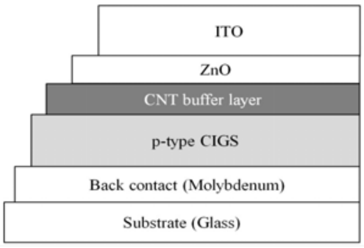

Fig. 3 Carbon Nanotubes (CNT) development in CIGS Solar Cell [8]

B. Copper-Indium-Gallium-diSelenide, Cu(In, Ga)Se$_2$ or CIGS

CIGS solar cell also not excluded from this nanotechnology developments. For example, Carbon nanotube, (CNT) is employed as alternative buffer layers for common buffer layer such as CdS due to the facts that Cd having a low band gap and it is a toxic material. Thus, much interest is towards fabrication of Cd-free buffer layer. The CNT is one of the suitable candidates for this purpose. Gorji and Houshmand have done a study on CNT application as buffer layer in CIGS thin film solar cells (Fig. 3) [8]. The benefit of this buffer layer is regarding on the thin structure, which does not disrupt the tunnel current. Besides, other types of buffer layer such as Indium Sulfide, In_2S_3 also being studied as buffer layer. A simulation of cell structure n-ZnO/i-ZnO/ In_2S_3/CIGS and the thickness of buffer layer (In_2S_3) and absorber layer (CIGS) are investigated to observe the impact on the cell performance [13]. Based on the cell performances, the optimum thickness for absorber layer is in the range of 2000nm to 3000nm and buffer layer between 40nm and 50nm. The nanometer scale of the buffer layer shows the prospect of reducing cost for materials and production. There is also nanowires technology employment on CIGS based thin film solar cells such as a study by [14] whereby they have fabricated CIGS nanowire arrays for application in solar cells.

C. Copper-Zinc-Tin-Sulphide, Cu_2ZnSnS_4 or CZTS

Nanotechnology for CZTS also has gain much interest such as in terms of nanowires and nanocrystalline structure for CZTS. The conventional CZTS solar cells have thickness of p-type CZTS layers in range of 1~2μm, but by deployment of nanocrystalline and nanowires of CZTS, it can achieved thickness as low as 500nm. Nanocrystalline CZTS as shown in Fig. 4 have resulted open circuit voltage of 220 mV, short-circuit current of 1.40 mA/cm^2, fill factor of 0.263 and a power conversion efficiency of 0.16% [15]. The efficiency is still in low range so more research can be done to improve the cell performances. Meanwhile, Wang et al. (2014) have successfully fabricated the CZTS nanowire arrays into Anodic Aluminium Oxide, (AAO) template by using two-step electroplating method as illustrated in Fig. 5. The diameter and average length of the resulted CZTS nanowires are 70 nm and 500 nm respectively [16].

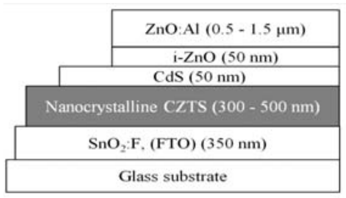

Fig. 4 Nanocrystalline development in CZTS solar cell [15]

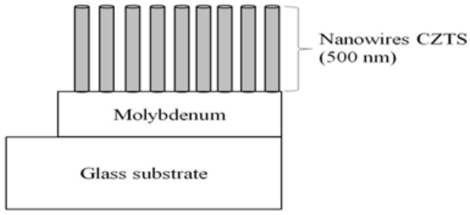

Fig. 5 Nanowires development in CZTS [16]

D. Dye Sensitized Solar Cells (DSSC)

DSSC is the first solar cell that directly utilized the nanoscale components for its performances [17]. DSSCs are alternative p-n junction photovoltaic device that convert visible light into electrical energy. It consists of nanocomposition, commonly titanium dioxide, (TiO_2) which also could be composed of one-dimensional nanotubes, nanorods, nanowires, and nanoparticles [18]. For example, a study has been done on the photoanode using the TiO_2 nanocompositions, the results show that the composition of TiO_2 nanoparticles (90%) incorporated with TiO_2 nanowires (10%) give more power conversion efficiency compared with pure nanoparticles or nanowires. This might be due to faster interfacials charge transfer and higher amount of dye adsorption [18]. Other study has been done regarding the grown of ZnO nanowires as the photo-electrode in DSSCs as shown in Fig. 6. In the study, the ZnO nanowires are assembled and characterized using optical and electrical measurement whereby the short circuit current densities of 1.3 mA cm^{-2} and overall power conversion efficiencies of 0.3% are achieved with 8 µm long nanowires. It is said that increasing the nanowire surface area by increasing their length allows more dye to be adsorbed and more light are harvested which will increase the current densities and overall efficiencies of DSSC [19]. Another prospective study has been done previously by [20] whereby they are comparing the DSSC with ZnO nanorods and without ZnO nanorods. It is found that the solar conversion efficiency of the DSSC with ZnO nanorods is increased by about 15% compared to that without ZnO nanorods. Besides, DSSCs are also widely being developed using Carbon Nanotube, (CNT). The CNTs can be used as electron transport network, which can be replacing the conventional platinum, Pt electrode. For example, a study has been done on CNTs with Titanium Nitride, (TiN) nanoparticles as counter-electrode materials in DSSC. TiN nanoparticles with a size of 5 – 10 nm are fabricated on the surface of the CNTs. TiN-CNTs are potential combination of electrode which is inexpensive and has shown comparable photovoltaic performance with the conventional Pt electrode [21].

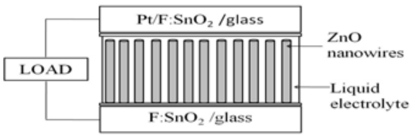

Fig. 6 Nanowires development in DSSC [19]

II. Compilation nanotechnology in Thin Film Solar Cells

A compilation of some valuable studies that have been done on nanotechnology in thin film solar cells are tabulated as shown in Tables I-III. Table I shows the performance parameters for nanoparticles or nanocrystalline of thin film solar cells. It can be seen that nano-ZnO structures in Al:ZnO and i-ZnO (AZO) in CIGS solar cells has good cell performance especially the high efficiency of 16.11% has been obtained. Meanwhile, the nanowires or nanorods structures of DSSC are widely being studied compared with other types of thin film solar cells as can be seen in Table II.

In terms of Carbon nanotube or nanotube structures, the CdTe and CIGS are among solar cells that showing potential in achieving good cell performances by using the CNT as shown in Table III.

III. Conclusion

The developments of nanotechnology in thin film solar cells are not only focusing on the nanoparticles or nanoscale based structures, but others technology such as nanowires, or nanorods, and Carbon Nanotube are prospect incorporation in the thin film solar cells to provide better cell performances. The nanotechnology in solar cells is expected to give high efficiency and based on the results obtained from few researches, more improvement can be done to achieve the expectation.

Besides, the ability to obtain higher band gap and successful of fabrications are also shown prospect of this technology in achieving the high efficiency. The ability of CNTs in replacing the buffer layers or electrode of solar cells is showing the potential of huge development in the solar cells in the future. Meanwhile, based on the various studies on DSSCs, it has shown that DSSCs are most potential of towards nanotechnology solar cells which is also have been utilized the nanotechnology since from the beginning of their developments. In short, much effort of researches and developments can be done for the realization of nanotechnology in thin film solar cells.

TABLE I
Performance Parameters for Nanocrystalline or Nanoparticles in Thin Film Solar Cells

Solar cells	Structures	Voc (mV)	Jsc (mA/cm^2)	FF (%)	Eff. (%)	Ref.
CdTe	SLG/ Cd_2SnO_4/$ZnSnO_x$/nano-CdS:O/CdTe	833.8	24.06	73.29	14.7	[22]
	ITO/nano CdTe/Al	520	17.56	56.39	5.15	[23]
CIGS	Nano- AZO/CdS/CIGS/Mo/glass	620	35.28	72.7	16.11	[24]
CZTS	Nano-CZTS/FTO/Glass	220	1.4	26.3	0.162	[15]
DSSC	Nano ZnO as electrode material	539	3.63	57	1.11	[25]
	Double-layered electrodes nano TiO_2 films	505	11.2	62.8	3.55	[26]
	Nano Pt electrode	750	16.5	64.6	7.96	[27]

TABLE II
Performance Parameters for Nanowires or Nanorods in Thin Film Solar Cells

Solar cells	Structures	Voc (mV)	Jsc (mA/cm^2)	FF (%)	Eff. (%)	Ref.
CdTe	Nanowires CdS embedded in Aluminium Oxide	705	25.3	36.4	6.5	[12]
CIGS	CIGS/CdS nanowires	430	30.06	47.0	6.18	[28]
	(Al, Ni)/AZO/iZnO/CdS/CIGS/ITO nanorod/glass	700	15.10	59.60	6.29	[29]
CZTS	ITO/ZnO/CdS/CZTS nanowires/Mo/glass	455	26.5	51.3	6.18	[30]
DSSC	ZnO nanorods	710	10.7	62	4.7	[31]
	TiO_2 nanorods	767	13.1	72.8	7.29	[32]
	TiO_2/ZnO nanorods	760	11.4	50	5.8	[20]
	10 % TiO_2 nanowire + 90% TiO_2 nanoparticles	550	8.0	52	2.27	[18]

TABLE III
PERFORMANCE PARAMETERS FOR NANOTUBE OR CARBON NANOTUBE IN THIN FILM SOLAR CELLS

Solar cells	Structures	Voc (mV)	Jsc (mA/cm^2)	FF (%)	Eff. (%)	Ref.
CdTe	SLG/ Cd_2SnO_4/$ZnSnO_x$/nano-CdS:O/CdTe/Cu_xTe/SWCNT (TCO)	818.1	22.25	68.18	12.4	[33]
CIGS	ITO/ZnO/CNT/CIGS/Mo/Glass	640	-29.0	56	10.4	[8]
CZTS	-	-	-	-	-	-
	TiN-CNT as counter-electrode	750	12.74	57	5.41	[21]
DSSC	MultiWalled CNT/TiO_2	720	8.82	73.17	4.62	[34]
	TiO_2 nanotubes/FTO glass	733	16.8	62	7.6	[35]

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