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A review on Semiconductor nanoparticles in Photovoltaic cells

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Abstract

An increasing demand of electricity coupled with the environmental concerns and tremendous growth in renewable energy technologies have triggered new openings in different renewable energy usage. Among all, solar energy possess the maximum availability, less conversion losses and maintenance cost and the ease of use. Use of solar photovoltaic technology is the prime method to harness the solar energy. In recent years solar cell has undergone awesome growth as sustainable supply of energy. The history of photovoltaic cells begins within the nineteenth decade once it was discovered that the sunlight generates feasible current. Photovoltaic cells are renewable, pollution free supply of current which may replace traditional fossil fuels. The requirement to expand and utilize large-scale, profitable, renewable resource is increasing progressively. Recently solar cells with supported particles having nano range, merging with semiconducting polymers have achieved sensible power conversion efficiencies.

Keywords: *s*emiconductor nanoparticle, photovoltaic cell, $CuInGaSe_2$, Cu_2FeSnS_4

1. Introduction

Renewable energy is globally regarded as a vital requirement. Solar cells or photovoltaic cells convert the power of the sun into electricity. Traditional solar cells are referred to as photovoltaic cells. Silicon is the semiconducting material generally used in solar cell. When sunlight strikes solar cells they take up energy in the form of photons. This consumed energy emits electrons inside the silicon allowing them to drift and current of electrons is generated which is regarded as power.

Traditional solar cells have major drawbacks. They are able to gain efficiencies around 10% only and thus has a costly production value. Inefficiency cannot be avoided using silicon cells. The approaching photons need to have proper energy known as optical gap energy to emit an electron. If the photon contains higher energy than the optical gap energy then the additional power will be squandered as heat. This outcome records the lack of around 70% of the energy from radiation that strikes the cell.

Introducing nanotechnology into the films indicates unique promise to strengthen performance and decrease overall price. Many nanostructured materials are being investigated for their ability towards applications in photovoltaic cells. The brand new photo catalysts allow us to utilize light, to power beneficial chemical reactions. When light is used instead of petroleum products in order to carry out certain reactions this will help to ease dependence on non-renewable energy source and decrease intake of energy and emission of CO_2. Traditional semiconductor photo catalysts, has been considerably investigated. As photo catalysts have a huge optical gap, photo catalysis can occur when ultraviolet light is assimilated.

Solar energy conversion is the conversion of natural light into power without any heat engine to intervene. The biggest benefit of solar cells is in their production of energy from microwatts to megawatts. Thus it is utilized for water pumping, energy supply, photovoltaic domestic structures, etc. With this sort of enormous cluster of utilizations the call for photovoltaic is growing every year.

Photovoltaic is a particular area of science and innovation deals with conversion of natural light into power. Photovoltaic was a standout amongst the most inventive and ecologically amicable innovations. Photovoltaic frameworks are described by effortlessness of establishment and can be utilized both in industry and in households.

2.1 Working principle of photovoltaic cells

The conversion of solar energy into electrical energy was discovered by a French physicist Alexander E. Becquerel in 1839. A high-purity silicon were used for constructing photovoltaic cell. PN junction formed acts as a potential barrier. Charge carriers were formed when light falls on it and goes to different directions. Holes go to the semiconductor P and electrons to the semiconductor N. At the junction, voltage is generated. The electrical charges formed were having infinite life and the voltage formed at the PN junction are constant. The junction where the photon strikes acts as a stable electric cell.

2.2 Semiconductor Nanoparticles

Semiconductor nanoparticles are prepared from various compounds. They are classified as IV-VI, III-V, II-VI nanocrystals. They are classified based on which periodic group the element belongs to ie, CdSe, ZnS comes under II-VI semiconductor and GaAs, InP to III-V semiconductors.

3 Semiconductor nanostructure based solar cell

Cha et al. synthesised $CuInGaSe_2$ (CIGS) by using hydrazine solvents via sonochemical method under controlled conditions [1]. The solvent used is toxic. Hence an alternative way of preparation of CIGS nanoparticle which is easy and simple is by using less toxic chemicals. Scientists have used aqueous metal salt precursors and selenourea [2] for the synthesis of CIGS nanoparticle (NP) under ambient conditions. To achieve a single phase crystalline CIGS NPs the metal salt precursor's composition and ultra-sonication parameters were optimized [3]. The sample was characterised using XRD, XRF, UV-visible-NIR spectrophotometer and SEM. With various ultra-sonication durations different phases were formed and analysed using XRD. The elemental composition was measured using EDS.

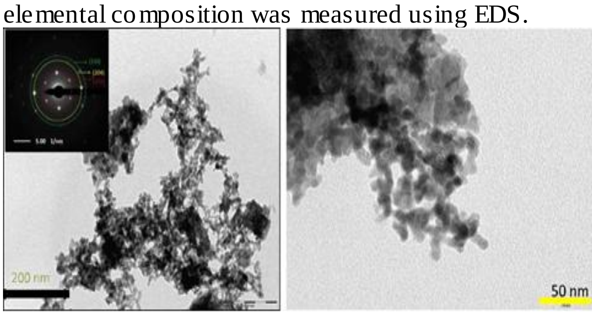

Fig.1 (a) TEM image (b) HM-TEM after ultrasonication [6]

Particle size was analyzed using TEM. It was found that the average particle size was about 20-30nm which is higher than the size which is calculated using XRD. It was probably due to agglomeration of nanoparticles. The main application of CIGS NPs is in photovoltaic cells. The CIGS NPs were synthesized by spray casting on coated Cadmium Sulphide/ Al:ZnO/ soda lime glass at 120°C. The voltage was 0.437V with 50% of a fill factor. The efficiency of photovoltaic cell was found to be 0.16%. A high resistance is showed by CIGS layer due to its smaller crystallite size [4]. Modification in size of the crystals is possible by conventional selenization at about 475°C and 500°C [5] and it produces photo conversion efficiency around 2.62% and 5.17% [6].

Due to excellent band gap [7], high absorption coefficient [8] and reduced toxicity [9], Sb_2S_3 is suitable for photovoltaic cell. Wei Wang et al [10] reported hybrid solar cells from Sb_2S_3. The FTIR spectra are depicted in Figure 2. Sb_2S_3 NPs doped with 1-dodecanethiol (DT) [11] via hot injection method [12] and applied in hybrid solar cells. Oleic Acid (OA) [13-16] was used as a capping agent to regulate the size of the NPs. It prevented the separation of charges and transportation of charges present in thin film. 1-dodecanethiol is used as surfactant. The energy gap was found to be 2.02eV [17] and 1.65eV [18] for unannealed and annealed samples respectively. The unannealed sample was found to be in amorphous phase and annealed one in crystalline phase [19]. Sb_2S_3 cells capped with both oleic acid and DT [20] were compared to check the photovoltaic properties.

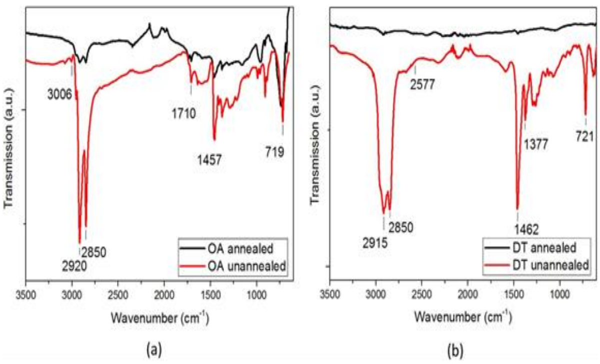

Fig. 2 FTIR of (a) Oleic Acid and (b) 1-dodecanethiol capped Sb_2S_3 nanoparticles before annealing (black) and (red) after annealing. [10]

DT capped Sb_2S_3 cells shows higher V_{oc} and J_{sc} [21] value compared with OA capped cells and this indicate that charge separation and transport of charges are done effectively [22].

Carbon nanotubes are extensively used in solar cells. The optical transitions and diameter of the single walled carbon nanotubes (SWCNT) are determined using chiral index [23]. The selected SWCNT should have good optical gaps in order to expand the light absorption among solar cells. For a single walled carbon nanotubes having one nanometer diameter, it absorbs light from IR, visible, and ultraviolet regions [24]. A diameter of 0.69-0.76nm will trap light in the near infrared and visible regions. Diameter ranging from 1.01-1.47nm traps light from near IR resulting in potential sunlight harvesting up to 19% [25,26]. A planar solar cell having 7nm thick film shows 2%-

3% light trapping capacity [27]. The strength of inter tube interactions depends on the method of synthesis, mainly by wrapping of polymer or by using aqueous capping agent methods [28]. Considering the single walled carbon nanotubes wrapped with polymer the residue gets left over on the walls even in the last cell [29]. Although various methods have emerged to separate the polymer, Lohrman et al. [30] first studied the width drop off in bulk heterojunction with a width of about 1.2nm.

Tang et al. [31] synthesized the bulk heterojunction cells with single walled carbon nanotubes with C_{60} wrapped in graphene oxide. To calculate the electric field intensity, transfer matrix [32] calculations are used by Guillot and his group [33]. The diameter of SWCNT from 0.7 to 1.8nm shows that it is in polychiral dispersions [34]. Louie [35] proposed the lower unoccupied molecular orbital of C_{60} to be -4.05eV. Based on the calculations, the solar cells with larger width [36] does not set apart the excitons with C_{60}. It shows the internal quantum efficiency of 10% [37]. Pfohl et al. [38] studied solar cells with different compositions in order to find out which nanotube is lasting. The optical gap increases as the dielectric constant decreases [39]. This is observed in solar cells by differentiating with red shift vs that calculated in solution [40-42]. The red shift is 6meV for a single walled carbon nanotube wrapped with polymer and 42meV for the tubes not containing the polymer [43]. Crochet et al. [44] proposed that for the segregated group of SWCNT not containing polymer, the shift is not completely observed and ultimately causes delocalised excitons in the valence band (VB) and conduction band (CB). Another method was proposed by Bernard et al. [45] for bulk heterojunction solar cells by inculcating graphene oxide. Examining the spectrum containing lower energy, the current increases [46, 47]. C_{70} can be used instead of C_{60} [48]. Charge carriers can be formed by using different acceptors for various NT band gap and width. According to Misty et al., C_{60} gets electrons from nanotubes at a rate of 120femto seconds [49].

Due to small optical gap energy and large absorption coefficient copper based chalcogenides are used in solar cells [50]. Among this, $CuIn_xGa_{1-x}Se_2$ [51-54] is the most prominent among solar cells but In and Ga elements are scarce and expensive. At the same time solar cells containing CdTe showed a power conversion efficiency of 22% [55] but due to the presence of Cd it is not found to be effective to use. Therefore to replace Ga, In and Cd the scientists introduced CZTS (Cu_2ZnSnS_4) [56] and CZTSe ($Cu_2ZnSnSe_2$) [57]. This showed a power conversion efficiency of around 33%. This were not found to be successful because the kestrite phase of CZTS showed a number of 2^o and 3^o phases [58] due to the similarity in size of zinc and copper. Later Cu_2FeSnS_4 (CFTS) was found to be an alternative for CZTS and showed a very good band gap and absorption coefficient [59, 60]. Iron increases the conversion of solar to electricity and increases the conductivity. Crystal quality was improved by annealing [61]. CFTS was synthesized using various techniques such as solvothermal, hydrothermal, microwave, reflux and hot injection [62]. Ha et al. [63] synthesized CFTS/Au nanostructures and showed an enhanced hydrogen production of 126% and 241% [64] compared to the CFTS nanoparticles. For the first time Ali et al. [65] synthesized templating assisted CFTS nanotubes using microwave method. Guan et al. [66] reported a flower like CFTS nanoparticle. Wang et al. [67] synthesized the nanoparticles using thioacetamide for sulphur source. The obtained nanoparticles were found to be 5nm. Luo et al. [68] used mixed solvent for the synthesis of nanoparticle using microwave method [69]. For the removal of dyes from contaminant water, Ali et al. [70] used porous CFTS.

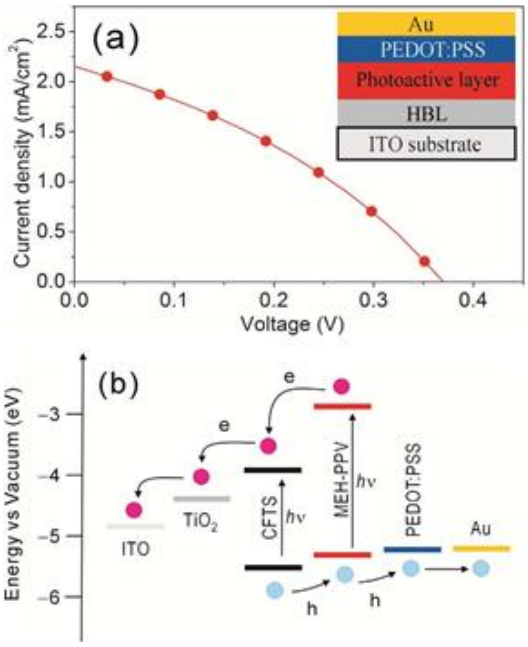

Fig.3 (a) Graph on current density and (b) MEH-PPV/CFTS solar cells band level alignment. [71]

Dong et al. [71] synthesized CFTS nanoparticles using solvothermal method. The materials used were thiourea, sulphur precursor, 1-octadecanamine and ethanol [72-74] as a surfactant. The nanoparticles formed were non stoichiometric [75]. In the presence of ethanol, thiourea showed less reactivity and indicates lesser amount of iron and sulphur in CFTS crystals [76]. Nowadays CFTS is used in polymer based photovoltaic cells as electron acceptors [77]. The solar cell showed a power conversion efficiency of around 0.29% after illumination [78-81]. The fill factor, short circuit current and V_{oc} was found to be 34.5%, 2.15mA/cm^2 and 0.4V [82] respectively. This is a new way for a hybrid polymer based solar cell to utilize CFTS nano crystals as an electron acceptor material [83].

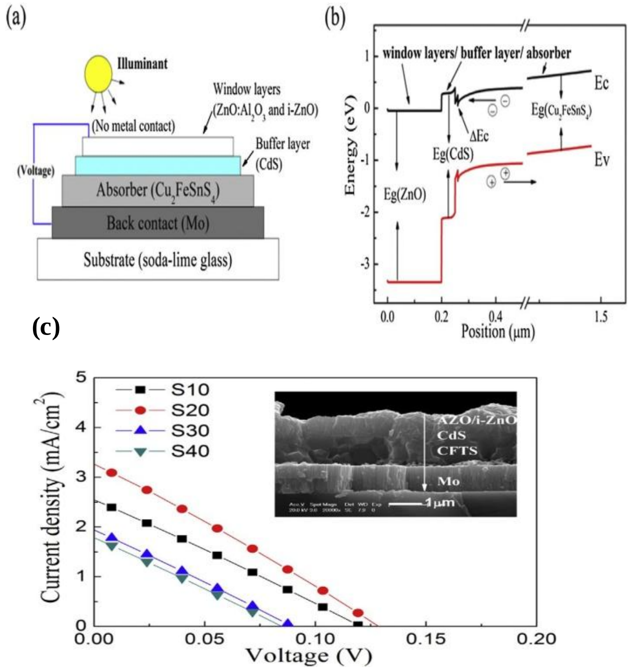

Fig.4 (a) Diagram of CFTS based solar cell (b) band alignment (c) current density Vs voltage. [84]

By sputtering of metallic layers on sulphurisation Meng et al. [84] synthesized CFTS based photovoltaic device. The optical gap increased from 1.42 to 1.47eV as the temperature is lowered. The observed J_{sc} and V_{oc} were 3.25mA/cm^2 and 1.30mV respectively [85-87].

Guan et al. [88] synthesized CFTS using chemical method. The band gap of the formed CFTS thin film was 1.2eV [89]. Adelifard et al. [90] added a large amount of S in order to minimise the oxidation. Meng et al. [91] used post sulphurisation and RF-magnetron sputtering for depositing CFTS on molybdenum coated glass. For an effective conversion of solar energy they used Cu poor [92] and Fe rich compositions [93]. Solar cell was prepare via rapid thermal annealing sulfurization [94]. Glass/CdS/CFTS/i-ZnO/Mo/AZO structured CFTS based solar cells were fabricated [95]. It showed a fill factor of about 26% and V_{oc} to be 110mV [96].
Wang et al. [97] synthesized SnO_2 nanocrystallites using hydrothermal method. It offered better properties and can be used for a large scale production [98, 99]. Characterization was done by XRD, FE-SEM, TEM. SnO_2 is also used in dye sensitized solar cells as photoanodes [100]. Nanocrystallites shows highest power conversion efficiency of about 4.21%. High purity nanocrystallites are obtained as products.

4. Conclusions

Sunlight based power has been created as a standout amongst the inexhaustible wellsprings of power. The complete nanostructure based solar cells have performed interesting development because of exceptional advancement of nanostructure synthesis strategies and device fabrication strategies. Solar energy is an alternative for petroleum and fossil fuels. Inspite of the fact that the strategies of using solar power are simple yet require a green and solid solar material. More than 60% of the sunlight can be converted into electricity using a semiconductor quantum dot. There are various challenges for the enterprise consisting of quality infrastructure, universal attention and reducing the price of manufacturing.

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