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REVIEW

A review on solar cells from Si-single crystals to porous materials and quantum dots

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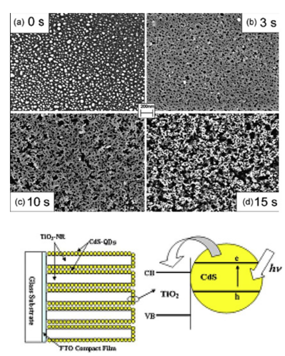
GRAPHICAL ABSTRACT



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ABSTRACT

Solar energy conversion to electricity through photovoltaics or to useful fuel through photoelectrochemical cells was still a main task for research groups and developments sectors. In this article we are reviewing the development of the different generations of solar cells. The fabrication of solar cells has passed through a large number of improvement steps considering the technological and economic aspects. The first generation solar cells were based on Si wafers, mainly single crystals. Permanent researches on cost reduction and improved solar cell efficiency have led to the marketing of solar modules having 12–16% solar conversion efficiency. Application of polycrystalline Si and other forms of Si have reduced the cost but on the expense of the solar

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conversion efficiency. The second generation solar cells were based on thin film technology. Thin films of amorphous Si, CIS (copper–indium–selenide) and t-Si were employed. Solar conversion efficiencies of about 12% have been achieved with a remarkable cost reduction. The third generation solar cells are based on nano-crystals and nano-porous materials. An advanced photovoltaic cell, originally developed for satellites with solar conversion efficiency of 37.3%, based on concentration of the solar spectrum up to 400 suns was developed. It is based on extremely thin concentration cells. New sensitizer or semiconductor systems are necessary to broaden the photo-response in solar spectrum. Hybrids of solar and conventional devices may provide an interim benefit in seeking economically valuable devices. New quantum dot solar cells based on CdSe–TiO_2 architecture have been developed.

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Fig. 1 Solar system based on Si-single crystals.

Introduction

It is now a half century of research where solar energy conversion was taking a major interest of many researchers worldwide. Photovoltaic cells, where the solar spectrum can be converted directly to electricity or photoelectrochemical cells in which the solar energy can be converted to chemical energy have attracted many research groups [1–6]. In the under terrestrial applications, solar cells based on Si have been used and still heavily in use for solar energy conversion. The technology was based on p–n junction or a Schottky barrier that enables the use of the photovoltaic characteristics of the suitable semiconductor i.e. Si [7–18].

The first generation solar cells are based on Si wafers, beginning with Si-single crystals and the use of bulk polycrystalline Si wafers. These cells are now marketed and produce solar conversion efficiencies between 12% and 16% according to the manufacturing procedures and wafer quality [19]. In Fig. 1, one of the collections of solar modules that were used for the production of electricity in separate areas is presented. The energy storage was based on lead–acid batteries.

High cost and the sophisticated technological steps have led to use polycrystalline Si instead of the single crystal wafers, of course, on the expense of the solar conversion efficiency. Continuous research has led to the development of the second generation solar cells.

The second generation solar cells are based on thin film technology in which different materials like amorphous silicon, a-Si, cadmium indium selenide, CIS, or thin silicon films on indium tin oxide, t-Si were produced. In contrast to the Si-wafer technology, thin layer solar cells provide potentials for cost reduction in the manufacturing process due to materials savings, low temperature processes integrated cell insulation and high automation level in series production. Further advantage is the use of flexible substrates, a property that gives a good chance for these cells as second generation solar cells to take more part in the energy conversion sector, and opens new application fields such as the integration into textiles. Material combinations of Cu/In/Ga/Se what is called (CIGS-cells) as well as III/V semiconductors like GaAs are applied and solar conversion efficiencies up to 20% were reported [16,20–25]. Unfortunately, thin film solar cells represent difficult module technology, limited stability and have a small market share (≅12% of the total photovoltaic market). In Fig. 2 the different types of materials marketed for thin film solar cells are presented.

It is clear that thin crystalline Si films of about 2.5 μm thickness represent the most used material [26]. Cadmium telluride and amorphous Si and other thin film materials are also good candidates [27–30]. Modules of the second generation solar cells have been also marketed but they did not gain the success of the first generation solar cells, due to technological problems and module stability [31]. Losses due to polycrystallinity of thin films were investigated. It was reported that there were no clear dominant losses for Cu(In, Ga)Se_2 or CdTe solar cells and it was suggested to incorporate impurities into the absorber like Na in both Cu(In, Ga)Se_2 and CdTe and to use anti-reflection coatings. Significant problems must be solved prior to large scale development of polycrystalline thin