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Dye sensitized solar cells: From genesis to recent drifts

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ABSTRACT

Of late, photovoltaics have achieved enormous growth as sustainable energy source. It is witnessed that solar cells being the renewable and pollution free source of electrical energy can easily replace the traditional fossil fuels. This communication overviewed the basic role of various components of dye sensitized solar cells (DSSCs) and the use of nanomaterials to enhance their efficiency. Furthermore, recent trends and future prospects of DSSCs are emphasized.

1. Need of photovoltaics

In this century, the energy and the fuel crises are certainly the major global concerns. With modernization the energy demand is exponentially escalating day by day. The fossil fuels resources are rapidly depleting and many nations worldwide have no other option but to raise the domestic oil prices. Thus, there is a critical need of sustainable energy resources. Solar energy being environmental friendly is the novel alternative with unlimited potential to tackle this problem [1,2]. The clean, abundant, and renewable nature of solar energy is prospective for the diversification of the energy supply, improvement of the air quality, reduction of the fossil fuels dependence, and economic growth [3,4]. Besides, photovoltaics (PVs) have demonstrated the potential to solving the problem of climate change [5]. Research revealed that by covering 0.1% of the Earth's surface with solar cells having efficiency of 10% would gratify the present requirements globally [6]. Currently, the cost of major solar energy systems are more than the energy options like grid electricity available to consumers. Therefore, the cost and efficiency of solar systems need substantial improvement in order to compete in the energy markets [7].

2. Types of photovoltaics

The PV devices that convert the solar energy into electricity are called solar cells, which have undergone three generations so far [8]. The existing PV market consists of wafer-based silicon (Si) and varieties of thin-film technologies. In the first-generation (1G) PV, the production is dominated by single-junction solar cells based on Si wafers including single crystalline Si (c-Si) and multi-crystalline Si (mc-Si). Despite much progress 1G PV costs around US$4/W, which is still roughly four times more expensive for truly competitive commercial fabrication. The 1G technology is comprised of these types of single-junction and silicon-wafer devices.

In the second-generation (2G) PV, efforts are made towards the reduction of $/W by removing the unnecessary material from the cost equation and using thin-film devices. The 2G technology involves single-junction devices that exploit less material but maintain the efficiencies of 1G PV. The 2G solar cells employ amorphous-Si (a-Si), $CuIn(Ga)Se_2$ (CIGS), CdTe/CdS(CdTe) or polycrystalline-Si (p-Si) deposited on low-cost substrates such as glass. These technologies are greatly promising because CdTe, CIGS and a-Si absorb the solar irradiation much more efficiently than c-Si or mc-Si and use only 1–10 mm of active material. Moreover, poor material reproducibility and lack of uniformity over large areas creates a gap between lab efficiencies (above) and the best module efficiencies of 10.7% for CdTe and 13.4% for CIGS. Actually, PVs based on CdTe and CIGS are slow to scale up. Eventually, even 2G technology progressively reduces the active material cost with thinner films and low-cost substrate but higher efficiency need to be maintained to achieve $/W cost-reduction. Thus, third-generation (3G) PV devices has emerged in its own right as future solution.

The 3G solar cells exceed the limits of single-junction devices and lead to ultra-high efficiency for the same production costs of 1G/2G PV, driving down the $/W [9]. Yet, the 3G solar cells still exhibit relatively low efficiencies despite the use of nanostructures in their fabrication. Conversely, the 1G and 2G solar cells based on conventional semiconductor materials display conversion efficiencies as much as 20–

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30%. However, the 3G solar cells have announced countless particularities superior to the 1G and 2G PVs. This supremacy of 3G PV is majorly attributed to their compatibility with flexible substrates and low cost of materials as well as manufacturing [8]. The nanostructured solar cells are advantageous due to the incorporation of new physical mechanisms, which allow to attain an efficiency greater than that of a single-junction solar cell. Nanostructured solar cells offer several notable benefits including the capability to exceed single-junction solar cell efficiency by implementing new concepts, the ability to overcome practical limitations in existing devices such as tailoring the material properties or using nanostructures to overcome constraints related to lattice matching, and the prospect for low-cost solar cell structures using self-assembled nanostructures [10].

The development of dye-sensitized photo electrochemical solar cells (PESCs) is an eventual alternative to the conventional Si based solar cell technology. PESCs having large surface area of nanoparticles are advantageous to increasing the light harvesting capacity and maximizing the number of dye molecules, thereby broaden the spectral response of these cells [11]. The emergence of 3G solar cells based on nanocrystalline and conducting polymers films dominates over the inorganic solid-state junction devices by recommending the prospect of very low cost fabrication thus makes market entry easy. By replacing the contacting phase to the semiconductor by an electrolyte, liquid, gel or solid a PEC cell can be formed. Thus, it becomes possible to quit completely from the traditional solid-state junction device [12]. Fig. 1 illustrates the evolution of world-record efficiencies of laboratory cells. Particularly, the Si cell efficiency can be divided into four stages, with each stage corresponding to new solutions in technology or cell structure [10]. Despite all such advancements in PV technology the tradeoff among cost lowering and efficiency enhancement remain challenging.

3. Cost effectiveness of DSSCs

Presently, the mainstream solar cells are silicon-based because of their high stability and energy conversion efficiency. The big challenge is to reduce the cost of solar panels to promote the extent to which PV generation is used in the future. The c-Si solar cells are widely used despite their fluctuating cost factor and poor energy conversion efficiency. However, the development of non-Si compound semiconductors faces few essential problems including resource depletion and long term toxicity [14]. Although PV cells are attractive due to low-carbon energy supply but remain expensive relative to other technologies. Greatly enhanced penetration of solar cells into global energy markets requires an expansion from designs of high efficiency devices to those that can deliver considerably lower cost per kilowatt hour.

In the past few decades, incredible research efforts have been dedicated to dye-sensitized solar cells (DSSCs) owing to their cost-effectiveness and resource-unlimited attributes [15]. It is worth noting that the current state-of-the-art DSSCs have efficiencies that rival their solid-state counterparts because the initial argument for DSSCs is very convincing. Another advantage of DSSCs is that they can operate well in lowlight conditions [16]. On top, the key materials of DSSCs manufacturing are more environmentally affable and energy-saving than conventional Si technology [14,17,18]. The c-Si wafer technology would not be able to meet the low-cost targets, whereas thin-film technologies offer a foreseeable viable alternative [10]. The organic solar cells owing to their lightweight and flexibility are meritorious than conventional c-Si PVs. Nevertheless, DSSCs are most efficient and cost-effective than all the organic solar cells [19,20].

DSSCs fabrication being devoid of any vacuum process can very easily produce low cost panels in open air. By using the dye both colored and transparent cells can be produced. Flexible thin films solar cells can be formed by aggregates of fine particles of photoelectric conversion materials. Besides, plastic substrates can be used to reduce the weight of solar cells and panel. These prominent advantages allow DSSCs to be installed in locations where appearance is important and other solar cells are hardly applicable. For instance, at the glass panes, the inner and outer walls of a building, the sunroof and outer panels of an automobile, and the cover of a cellular phone [14]. In short, DSSCs are exceptional as compared with almost all other types of solar cells because every task including electron and hole transport as well as light absorption is controlled by different materials in the cell [21]. Unlike to the p-n junction type solar cell, in DSSC the strict requirement of high

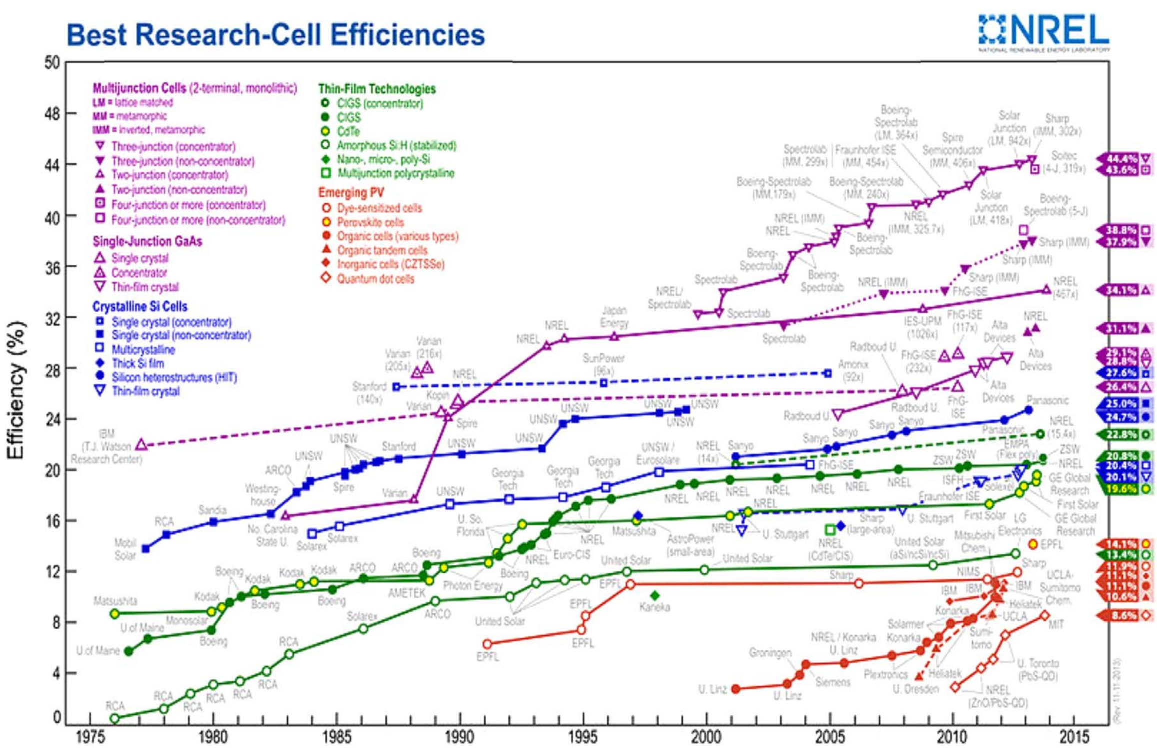

Fig. 1. Evolution of the conversion efficiencies of various types of PV cells [13].