Novel Technologies To Improve Efficiency And Performance Of Solar PV Cells – A Review

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Abstract

Global environmental concerns and the escalating demand for energy, coupled with steady progress in renewable energy technologies, are opening up new opportunities for utilization of renewable energy resources. Solar energy is the most abundant, inexhaustible and clean of all the renewable energy resources till date. The power from sun intercepted by the earth is about 1.8×10^{11} MW, which is many times larger than the present rate of all the energy consumption. Photovoltaic technology is one of the finest ways to harness the solar power. Solar photovoltaic technology is one of the renewable technologies, which has a potential to shape a clean, reliable, scalable and affordable electricity system for the future. This article provides a comprehensive review of various novel recent technologies to enhance the efficiency and performance of solar photovoltaic cells.

1. Introduction

Everyday sun sends out tremendous amount of energy in the form of heat and radiations called solar energy. Solar energy is a limitless source of energy which is available at no cost [1,2]. The major benefit of solar energy over other conventional power generators is that the sunlight can be directly harvested into solar energy with the use of small and tiny photovoltaic (PV) solar cells [3,4]. The Sun is assumed as a big spherical gaseous cloud made up of hydrogen and helium atoms. This big spherical gaseous cloud is mainly composed of several hydrogen nuclei combining to form helium energy with the emission of energy from the fusion of the hydrogen nuclei in inner core of the Sun via nuclear fusion[5].

$$ {}^{2}_{1}H + {}^{2}_{1}H \rightarrow {}^{3}_{2}He + {}^{1}_{0}n + 3.27 \text{ MeV} $$

$$ {}^{2}_{1}H + {}^{3}_{1}H \rightarrow {}^{4}_{2}He + {}^{1}_{0}n + 17.59 \text{ MeV} $$

During this process of fusion, four hydrogen atoms combine to form one helium atom with a loss of mass which is radiated as thermal energy [1] [4-5]. This radiant energy produced by fusion reactions is free from any pollutant, gases, or other reaction by-product. This is why it is the major driving force of all the clean energy technology, in view of the climatic disturbance caused by the emission of carbon from the fossil fuels deposits. One of the biggest advantages of solar energy is that it is free reachable to common people and available in abundant supply compared to that of the price of various fossil fuels and oils in the past decade [1-7]. Moreover, solar energy requires considerably lower manpower expenses over conventional energy production technology. Though the solar energy is freely available everywhere, there is still an initial expenditure on the equipments for harvesting this radiant energy by developing solar cells, panels and modules [8]. These small and tiny solar cells produce no noise during their operation. On the other hand, the big power pumping devices produce unbearable sound pollution, and therefore they are very disturbing to the society [6-8]. Nowadays, due to the decreasing amount of renewable energy resources, the per watt cost of solar energy device has become more important in the last decade, and is definitely set to become economical in the coming years and grow as better technology in terms of both cost and applications [9,10]. In spite of numerous advantages, this energy has few limitations too. Firstly, solar energy doesn’t radiate at night. Secondly, the solar energy is almost not constant all the time. There must be plenty of sunlight available to generate electrical energy from a solar PV device [7, 10, and 11]. Moreover, apart from daily fluctuations in the intensity of radiant energy, the solar energy is hindered to reach the earth during bad climatic conditions. For example, the amount of sunlight reaching the earth’s surface depends on location, time as well as weather as it falls during winter season as compared to the summer, and the Sun’s radiation is less intense [10] [11]. To overcome these demerits of this technology, solar energy must be stored elsewhere at night and the highly efficient solar cells and modules needs to be developed.

There have been an enormous amount of research activities to harvest the Sun’s energy effectively by developing solar cells/panels with high conversion efficiencies. The photovoltaic conversion efficiency is referred to the efficiency of solar PV modules, and is defined as the fraction of Sun’s energy that can be converted into electricity. Solar panels are a huge collection of tiny solar cells arranged in a definite geometrical shape to produce a given amount of power supply. The storage of solar power is still has not been achieved successfully. Currently the radiation efficiency of solar panel is up to

22% [11]. There are many solar photovoltaic batteries
available which are usually more expensive and bulky. These are more suitable for small scale or household solar needs compared to large solar plants [12,13].

2. High efficiency PV materials and new material technologies

2.1 Crystalline silicon (c-Si)

According to Bruton (2002), silicon is one of the most dominating materials in solar PV technology. The first generation PV modules were manufactured from crystalline structure of silicon. However, this technology is not obsolete but it is constantly under R&D phase. After the invention of bipolar transistor in 1948, a semiconductor era was evolved, in which there was a rapid progression on silicon solar cell, which raised the efficiency up to 15%. Thereafter in second stage in 1970, due to achievements of microelectronic technology, silicon solar cell efficiency reached to 17%, and after that in 1980s and 2000+, the cell efficiency has almost reached to 25% (Green et al., 2001). The University of New South Wales, demonstrated the efficiency of 24.7% of silicon solar cells from Passivated Emitter, Rear Locally (PERL) on Flat Zone (FZ) silicon substrate and another 24.5% efficiency based on Passivated Emitter, Rear Totally (PERT) diffused silicon solar cells fabricated on Magnetically Confined Czochralski (MCZ) substrates (Zhao et al., 2011). Crystalline silicon is the traditional cell material for solar modules and has maintained at least 80% of market share of worldwide production of PV modules. To date, crystalline silicon has achieved highest module efficiency under Standard Test Conditions.

2.2 Monocrystalline.

Monocrystalline material is widely used because of its high efficiency level as compared to multi-crystalline. Zhao et al. (1998) reported the honeycomb textured monocrystalline solar cells, with an efficiency of 24.4%. However, it is essential to note that module efficiency is always lower than the cell efficiency. However, the leading company is SunPower Corporation (2015) (US17) of USA by manufacturing the modules with an efficiency of 20.4% (range of 20.0%-20.9% efficiency) and it was measured by National Renewable Energy Laboratory (NREL) (2015).

2.3 Multi-crystalline or poly crystalline.

Zhao et al. (1998) reported the honeycomb textured solar cells, with an efficiency of 9.8% for multi-crystalline. Multi-crystalline solar modules are cheaper to manufacture, they are preferred more in market. However, they are less efficient as compared to monocrystalline solar modules. The highest commercial module efficiency is 16.9% from Neo Solar Power Corporation (T10) from Taiwan, whereas the maximum efficiency of monocrystalline is 20.4%. Hence, research is currently underway to bring multi-crystalline technology compatible with monocrystalline technology (Becker et al., 2011).

2.4 Thin film technology

Thin film is an alternative technology, which uses less or no silicon in the manufacturing process. The more in depth review of amorphous and crystalline thin film silicon solar cell is

done by Roedern (2003) and in the initial phases of development of thin film solar cells, 10.7% efficiency was demonstrated by Yamamoto et al. (2001).

2.5 Cadmium telluride (CdTe)/cadmium sulphide (CdS).

Cadmium telluride solar cells are formed from cadmium and tellurium. Because of its ideal band gap of 1.45 eV, and longer stability (Boer, 2011), it is one of the promising materials in thin film technology. There are several remarkable results reported by Compaan (2004), Schock and Pfisterer (2011), Razykov et al. (2004) and an efficiency of 10.6% and 11.2% was obtained on thin film 0.55- and 1-mm-thick CdTe by Nowshad et al. (2001). In addition, CdTe on plastic foil with an efficiency of 11.4% is reported by Upadhayaya et al. (2007). In general, 15% to 16% cell efficiency has been obtained by Britt and Ferekides (1993), Aramoto et al. (1997) and Wu et al. (2001). In July 2011, First Solar (2011) company sets the world record of 17.3% cell efficiency, which was confirmed by NREL.

3. Enhancing efficiency with antireflection coating

Antireflection coating (ARC) of surfaces is of great interest in many applications and in several research fields like optics and optoelectronics. The usual targets of applications range from military applications to display panels, solar cells, and optical lenses [14,15]. Antireflection layers are needed when two adjacent materials have different refractive indices, thus leading to unwanted Fresnel's reflections from their interfaces. The most common method to suppress the reflection is to coat the surface with a thin l μm having a suitable refractive index and an optimized thickness. However, it is well known that many factors, electrical or optical, limit solar cell efficiency. Enhancing the efficiency of a given solar cell could be approached by using a good cell design and trying to have minimum reflectance on its surface by using ARC techniques [16-18]. ARCs have become one of the key issues in the mass production of silicon solar cells. They are generally examined by a computer system prior to using them on the solar cell surface to ensure that they enhance the solar energy transmitted to the cell, thus increasing its efficiency.

4. Enhancing efficiency by Photon up conversion.

Photon upconversion (UC) provides a means to circumvent transmission loss by converting two sub-band-gap photons into one above-band-gap photon, where the PV cell has high light responsivity. This technology enables us to break the Shockley–Queisser limit of a single-junction PV cell (about 31% for non-concentrated sunlight irradiation for a semiconductor material with an optimized band-gap of around 1.35 eV) by transforming the solar spectrum [19]. Indeed, Trupke et al. demonstrated through a detailed balance model that modification of the solar spectrum with an up-converter could elevate the upper theoretical efficiency limit of a single-junction crystalline silicon PV cell to be as high as 40.2% under non-concentrated sunlight irradiation [20].

5. Use of nano structured glasses.

The cover glass constitutes approximately 25% of the silicon thin film (Si) modules [21] and approximately 10–15% of the crystalline Si modules [22]. Therefore, the improvement of the cover glass becomes essential to reduce costs. In this context, there are two means of acting on glass to reduce costs. The first would be the reduction of costs in the manufacture of glass and the second, an increase in the transmission of sunlight through the glass, since a 5% increase in solar transmittance could result in an improvement of up to 10% in the efficiency of the solar module [23]. Current solar glasses transmit about 90% of incident light, due to loss of absorption and reflection, unless coated with some coating. In this case, it is possible to achieve transmissions >98%. The regular coatings are typically SiO2, Si2N3 or MgF2 porous films [24]. However, these coatings do not usually have a high hydrophobicity that would give them the ability to self-clean, and therefore would require maintenance. Self-cleaning liners are a way to achieve reduced maintenance. One of the most frequently used liners to obtain self-cleaning surfaces is the TiO2 [25,26]. However, these coatings have a higher refractive index than the glass of the substrate that increases the reflectivity. The self-cleaning surface technology is often related to the lotus flower effect [27], where the contact angle of the water is key. In this context, two relevant low-cost and scalable techniques are spray coating (commercial products are already disposable such as SurfaShield G by NanoPhos S.A) and dip-coating [28]. In order to use self-cleaning coatings with a similar index of refraction, nanostructuration of the solar glass is presented as a good option to improve both the transmission of sunlight and the ability to self-clean (hydrophobic) or prevent fogging (hydrophilic). By altering the roughness of the surface at the nanoscale, it is possible to create hydrophilic surfaces [29] that prevent fog or to create hydrophobic surfaces [30] that have a self-cleaning effect.

6. Conclusion :

Various methods to enhance the efficiency of solar PV cells have been reviewed. Advanced materials show improved efficiency about 24%. Further improvement in efficiency can be attained by coating antireflection and dispersing nano structured materials up to 40% increase.

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