A Historical Review on the Efficiency of Perovskite Solar Cells

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Abstract

Our dependency on the nonrenewable energy resources is increasing day by day, whereas the resources are scares. Therefore, it is the present need of humankind to look at some another sources of energies so that our future generation can also use the less available resources. Looking at renewable sources of energies, the most effective and abundant energy resource is solar energy. There are various generation of solar cells but among them 3rd generation solar cell shows greater efficiencies. One of most popular technology from 3rd generation solar cell is perovskite solar cell which has shown a tremendous increase in the efficiency in a decade period. Cost of fabrication is also very low and also it shows tremendous efficiency and various other properties. There is a stability issue related to perovskite solar cell which when reduced completely can make these solar cells a very good alternative for commercialization purposes as compared to Silicon Solar cell. Several obstacles need to be handled before it can be entered in the market of photovoltaics. Inspite of high PCE the instability of perovskite should be addressed and also it should be fabricated at lower processing temperature.

Keywords. Perovskite Solar Cell, Power Conversion efficiency, Open Circuit Voltage, Current Density.

1. INTRODUCTION

As the industrialization is growing day by day, and the fact that fossil fuels are nonrenewable sources of energy which pollute our environment and demand is increasing at very high rate, therefore this has put a pressure on humans to develop some sources which can be capable of meeting our demand. Fossil fuels has an adverse effect on the environment therefore to reduce this, people are seeking clean renewable energies to replace fossil fuels [1]. Basically, our energy resources are categorized as renewable resources of energy and nonrenewable resources of energy. As our population is tremendously increasing therefore use of nonrenewable resources are increasing very rapidly. If we keep on consuming the nonrenewable energy resources at the same rate, then our future generation might not use it because they are on the verge of extinction. Therefore, among the various renewable energy resources we need to look at which energy resources are easily available and can be useful for providing a large amount of energy. Among various renewable energy resources solar energy is one the important source because it provides us a very large amount of energy continuously throughout the year. Sun is a very enormous source of energy and we are currently unavailable to use its energy properly. There are various technologies available for the generation of solar energy [2]. One of the most advanced and popular technique which researchers have found in previous decade is Perovskite solar cell which requires easy laboratory preparation methods and on the other hand it is very cost effective technology [3]. The increase in efficiency, fill factor, Open circuit Voltage, Current density, etc. has taken place very rapidly. As compared to Silicon solar cell in which the efficiency of 25% has reached in 60 years whereas it only took 10 years to reach to that level. Therefore, it plays a major role in generation of electricity in the upcoming years which will provide a great support in decreasing the use of nonrenewable energy resources which produces a lot of pollution and also, they are very scarcely available resources.

2. GENERATIONS OF SOLAR CELL

Different Generations of solar cells are shown in Figure 1. There are 3 generations of solar cell. Since the development of first solar cell a large number of researches started on solar cell and as the time progresses 3 generations are developed which have different advantages as well as disadvantages

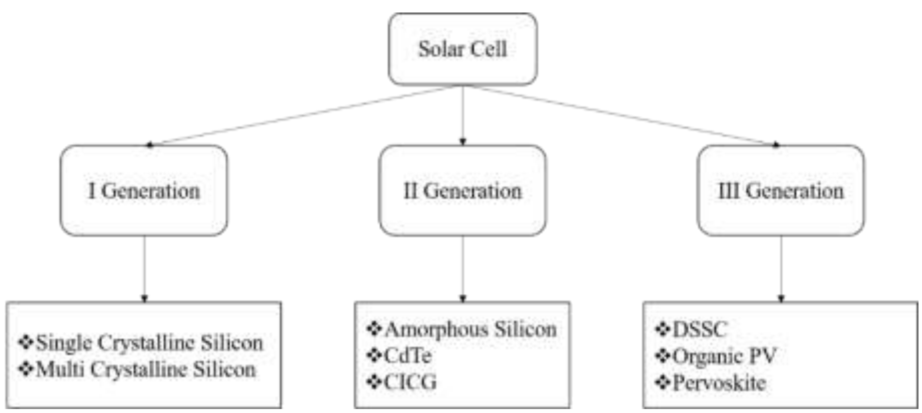

Figure 1. Generations of Solar Cell

2.1 First generation

These are based on Silicon wafers and it is playing a vital role in the photovoltaic market. Mostly these solar cells are made of crystalline silicon which can be either single-crystal or poly-crystal silicon wafers having a high purity. Although these have an efficiency in the range of 20 % but they have a disadvantage that for the large scale production the manufacturing cost rises to very high level and also its method of production has a poor impact on environment.

2.2 Second Generation

These are based on thin film technology. A very thin film of active material is deposited on the substrate. Due to this reason the use of active material is reduced and also it helps in decreasing the weight and making the cell more flexible. Some of the active materials used are Cadmium Telluride (CdTe) or Copper Indium Gallium Selenide (CIGS). The efficiency of second generation solar cells is around 20 % but it still faces the difficulty of production at large scale and also the availability of the Te, In, and Ga is difficult.

2.3 Third Generation

These are the latest technology solar cells that aims at producing the solar cells which has a great efficiency and also it can be manufactured at low cost. Various efforts are made on this technology so that it can be used for industrial purposes which can solve the problem very easily since they are of low cost with a great efficiency. Organic solar cells, quantum dots solar cells, dye-sensitized solar cells (DSSCs), perovskite solar cells are some of the examples of third generation solar cell. As we can see from Figure 2 that the third generation solar cells are showing a great efficiency as well as the cost of the solar cells are also very less as compared to other generations. Therefore, various measures are taken by researchers to increase the efficiency and making low cost solar cells [4]. Perovskite solar cells are one of those types of solar cells that had taken a very rapid growth and the efficiency of these solar cells are increased in the upcoming years also.

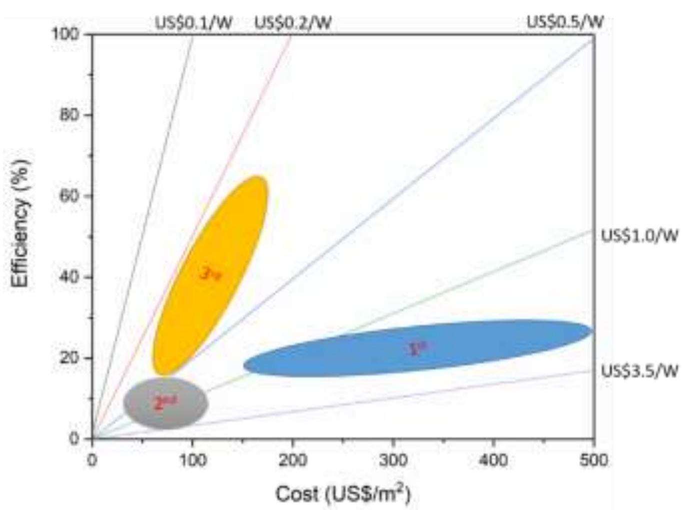

Figure 2. Efficiency and Cost Comparison of different Generations of Solar Cell[6]

3. PEROVSKITE

In 1939 Gustav Rose found this mineral in Ural mountain, Russia. Lev Alekseevich Perovski, a mineralogist had done the research and hence was named as 'Perovskite'. Mitzi et al. reviewed the optoelectronic properties of the perovskites in 1991 [5]. The report shows that the perovskites has strong excitation properties and therefore may be used in LEDs, transistors and solar cell. The process of Photovoltaic generation was firstly being observed in this material by Kojima et al. in 2009 [6]. First use of perovskite material in solar cells application was by using it as a liquid sensitizer in DSSC architecture [7]. Since first use of perovskite in solar cells, the efficiency of perovskite solar cells has increased from 3.81% to 25.8 %.

4. STRUCTURE OF PEROVSKITE

Compounds with perovskite structure have a chemical formula of ABX_3, where an A Cation is present at the eight corners of the cubic cell and the B Cation is present at the body center, surrounded by six X Anions (located at the face center), forming a BX6 octahedron [8]. Some of the examples of cation and anion are shown in Figure3.

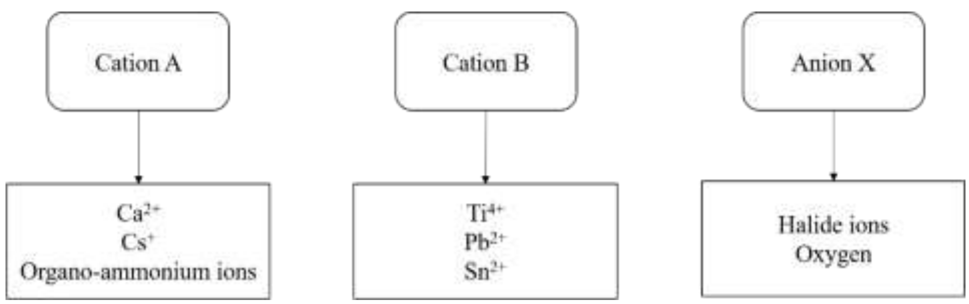

Figure 3. Examples of Cation and Anion

5. PEROVSKITE SOLAR CELL

Perovskite Solar cell was firstly developed in 2009 by Kojima et al. At the time of its development its model was taken from DSSC Structure with a slight modification in it. But due to the presence of liquid electrolyte it could not work for longer duration. [9].Therefore, after many years of hard work the PCE of perovskite solar cells is increased from 3.51 % to 25.8 %. The researchers working in the area of DSSC and Organic solar cells are mostly influenced by this technology because PSC consist of similar structure and components. [10]

5.1 Major Components of Perovskite Solar Cell

There are 4 major components of the Perovskite Solar cell as shown in Figure4. Main component of perovskite cells consists of absorber layer which is generally made up of MaPbX3, FaPbX3 and various others. Electron transport layer is generally made of TiO2, ZnO, Al2O3 [11]. Hole transport layer is generally made up of Spiro-OMetad, Pedot etc. and metal electrode is made up of silver or gold layer. [12]

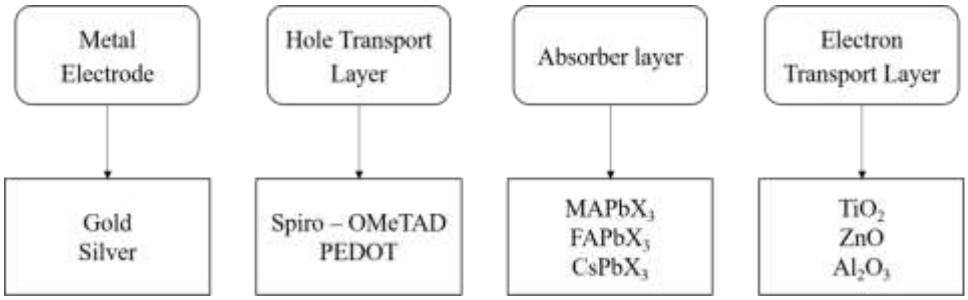

Figure 4. Components of Perovskite Solar Cell [8]

The Configuration of Solar cell is shown in Figure **Error! No text of specified style in document.**. Various components of the Perovskite Solar cells such as metal Cathode, Hole Transport Layer, Perovskite Layer, Electron transport Layer, FTO glass are shown.

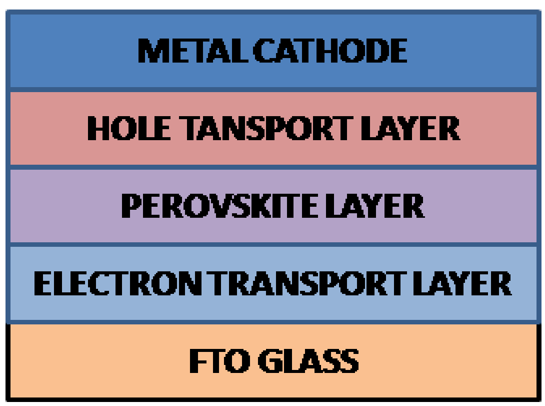

Figure **Error! No text of specified style in document.**. Structure of perovskite solar cell [12]

6. PROGRESS IN PEROVSKITE SOLAR CELLS

Kojima et al. discovered a new type of solar cell by doing some modifications in DSSC structure. The results obtained was great and they obtained the efficiency of 3.51%. The perovskite was used as a liquid sensitizer, but due to the presence of liquid electrolyte, the system was extremely unstable and it could not work for longer duration. The device configuration which was used was (Pt-FTO/Electrolyte solution/$CH_3NH_3PbI_3$/TiO2) [9].Park et al. make use of quantum dots of nano-crystalline material and used dye-sensitized method which in turn increases the cell efficiency from 3.8% to 6.54% and they found that still the device performs for only 10 min.

This is because of the dissolution of quantum dots in the electrolyte. Due to instability by liquid electrolytes, this architecture does not meet the expectation. The device configuration which was used is Pt/Liquid Electolyte/ $CH_3NH_3PbI_3$ (QD) / TiO2/FTO [13]. Kim et al. solve this problem of liquid electrolytes by developing solid-state Photovoltaic Solar cell. The Spiro-OMeTAD has been used as a HTL and hence the efficiency increased to 9.7%. The device configuration which was used is Au/spiroOMeTAD/ $CH_3NH_3PbI_3$/mTiO2/FTO. Due to this a tremendous change occured in the field of the PSCs which increases the PCE and also raised the stability. [14]. Also, in the same year Lee et al. developed a device efficiency of 10.9% with the open-circuit voltage higher than 1.1 V. [15]. Burschka et al. found the efficiency of 15% with the help of 2-step sequential deposition technique by making it in planar architecture. This is done through the sequential deposition method in which they firstly deposited PbI_2 layer and then deposition of CH_3NH_3I.The device configuration which was used is Au/spiroMeOTAD/TiO2/ $CH_3NH_3PbI_3$/Glass [16]. Im et al. manufactured solar cells with two-step solution processing in which MAPbI3 is used. Due to the regulated size of the MAPbI3 cuboid, which allowed good light harvesting and increased charge transportation, high performance is achieved. The solar cell's efficiency is therefore increased to 17.01 %. The device configuration which was used is Au/spiroMeOTAD/TiO2/CH3NH3PbI3/Glass [17]. A technique in which Yang et al. deposited improved quality FAPbI3 film with (1 1 1) crystallographic orientation, uniform, dense and large microstructures was developed. In place of $CH_3NH_3PbI_3$, they used FAPbI3 and achieved 20.2 % efficiency. The device configuration which was used is Au/PTAA/Perovskite/(bl/m-TiO2)/FTO [18]. Li et al. fabricated a perovskite film which has uniform morphology as well as crystalline behavior. They used VASP in which FA0.81MA0.15PbI2.51Br0.45 was used as an absorber layer. Due to this reason PCE of 20.5% was achieved. The device configuration which was used is Au/Spiro-OMeTAD/Perovskite/m-TiO2/ bl-TiO2/ FTO [19]. Bi et al. have reported a new technique to manufacture perovskite film in the same year and improved electronic properties due to polymer usage. Growth and nucleation processes are increased by the use of poly methyl methacrylate (PMMA) and 21.6 % efficiency. The device configuration used was Au/Spiro-OMeTAD/Perovskite/m-TiO2/ Perovskite/bl-TiO2/ FTO [20]. Many cations, such as FA and mixed halide anion, were used as an absorber layer by Yang et al. By adding iodide solutions to the organic cation solution, they reduce the concentration of deep-level defect states. This enables to reach uptoPCE of 22.1% for small scale and 19.7% in 1 cm^2cell.The device configuration which was used is FTO/TiO2/m-TiO2/perovskite composite layer/perovskite upper layer/PTAA/Au [21]. The Chinese Academy of Sciences researchers developed a solar cell device which has shown a great efficiency of 23.3%. Jung et al. developed a solar cell made of P3HT as a hole transport layer. In this a thin layer of halide perovskite is deposited which have very high bandgap. The PSC of the device came out to be 22.7%. The device configuration which was used is FTO/d-TiO2/mp-TiO2/NBH/P3HT/Au [22]. This type of perovskite solar cell is developed by Mingyu. Jeong et al. using isomeric HTM instead of normal HTM and therefore due to this reason the efficiency is increased upto 24.82%. Spiro-OMetad was used as hole transport material. Also, the stability of solar cell was increased upto a great extent [23]. Min et. al created an interlayer between SnO_2ETL and perovskite layers to minimize interfacial defects. This interlayer enhances charge extraction and transport from perovskite layer and efficiency is also maintained to about 90 % after 500 hours of light exposure [24].

6.1 Improvement in the Power Conversion Efficiency of PSC

As we can see from the Figure **Error! No text of specified style in document.** that the efficiency of PSC started from 3.8% in 2009 and in a very less amount of time the efficiency has come a long way to 25.8 %.This change occurs by developing various changes in the device configuration and by changing the materials required in the fabrication techniques of PSC [24]..In 2009 when it was firstly used by kojima et al. then the PCE was coming to be 3.8%. kojima fabricated their device by using DSSC structure but it doesn't have much stability therefore park et al. uses quantum dots so the efficiency is increased to 6.54%.Kim et al. solve this problem of liquid electrolytes by developing solid-state Photovoltaic Solar cell and the increased efficiency is found 9.7%.by changing the carrier transport material the efficiency is increased and also as the time progresses many researchers who have made their contributions and now the PSC stands at 25.8 %. The life of solar cell is increasing and in near future there is a scope of much more enhancement in the efficiency.

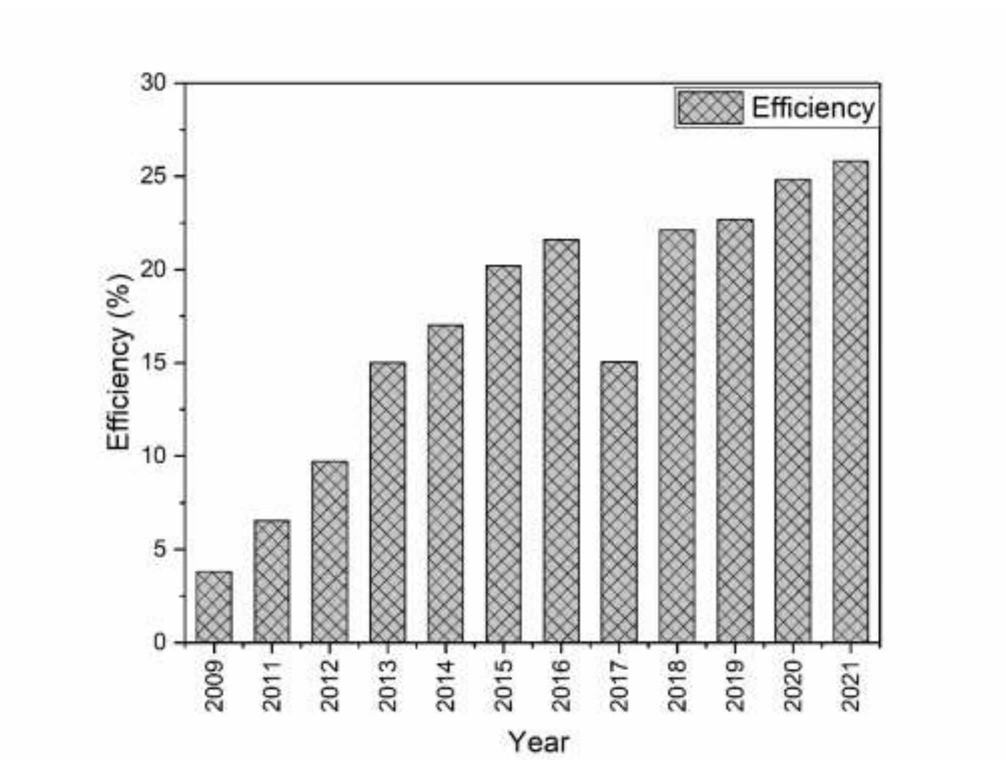

Figure **Error! No text of specified style in document.**. Power Conversion Efficiency

6.2 Improvement in the Fill Factor of PSC

The ratio of actual maximum available power to the product of the open circuit voltage and short circuit current is known as the fill factor. In assessing efficiency, this is a key parameter. The Fill Factor is a measure of the I-V curve's "squareness”. As it is clear from the Figure 7 that the increase in the fill factor in case of perovskite solar cell is upto a great extent in the last decade.

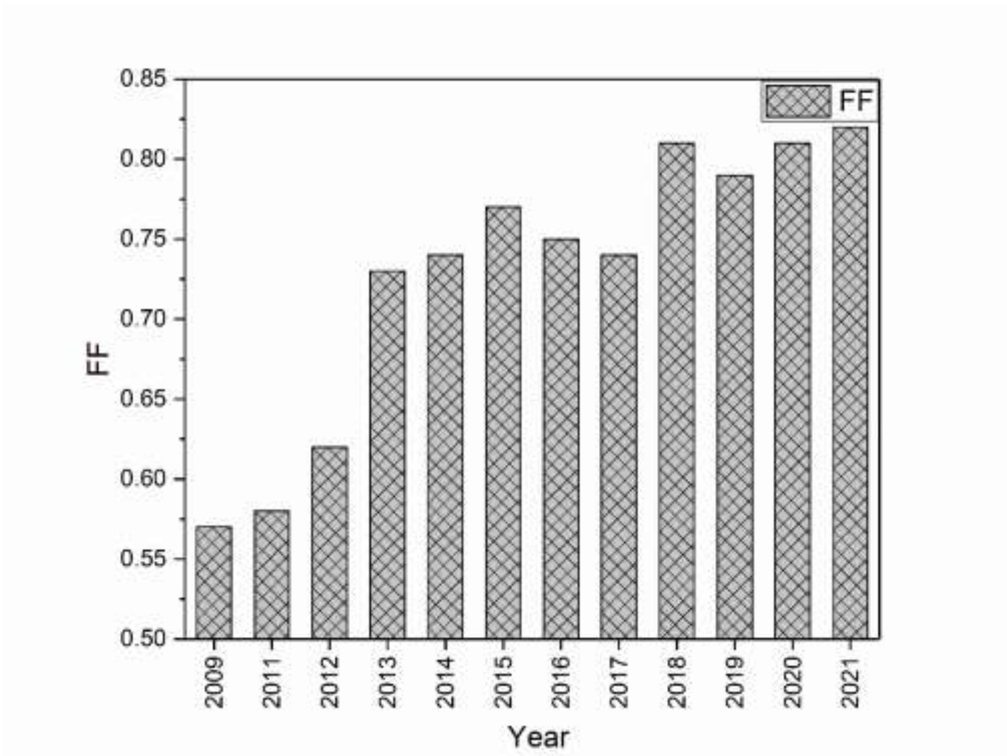

Figure 7. Increase in Fill Factor

6.3 Improvement in the Open Circuit Voltage of PSC

Open-circuit voltage is the electrical potential difference between two terminals of a device, when disconnected from any circuit. This is achieved if there is no attached external load and no external electric current flows between the terminals as well. From the year of development of PSC and till now there has been a continuous growth in the open circuit voltage because researchers are doing various modifications in the material and the fabrication techniques of the PSCs [25]. The growth rate is so fast that PSC has made a great impact in the field of solar energy and the number of researchers related to PSC is increased rapidly. It is shown in Figure8.

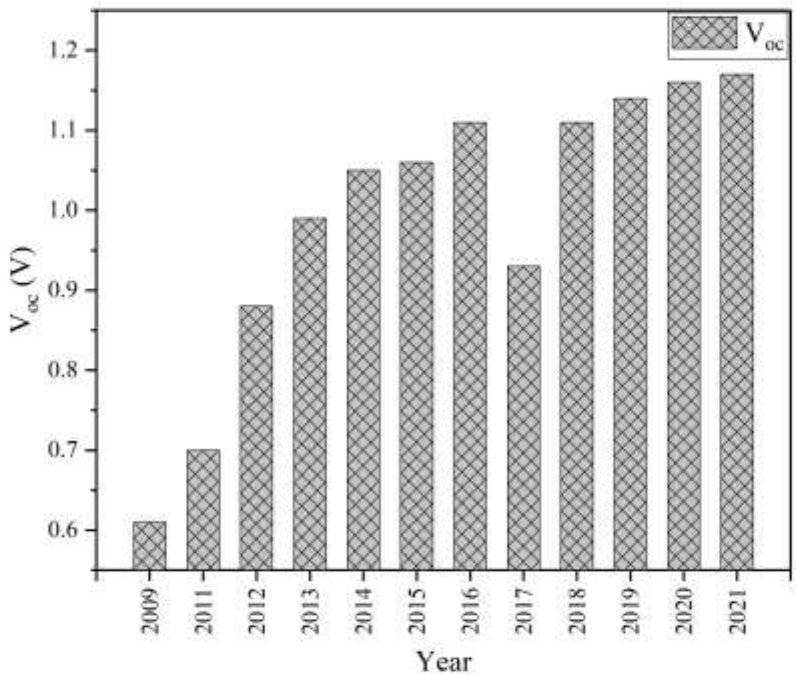

Figure 8. Improvement in Open circuit Voltage

6.4 Improvement in the Current Density of PSC

Current density is the amount of charge per unit time that flows through a unit area of a chosen cross section. A continuous growth in the current density is seen. In 2009 at the time of PSC development it was 11 mA/cm2 and now it has reached to 25.7 mA/cm2. Current density plays a important role in case of solar cells applications [26]. This increase in the current density of the perovskite solar cells make this solar cell a very advantageous for various solar energy applications. It is shown in Figure 99.

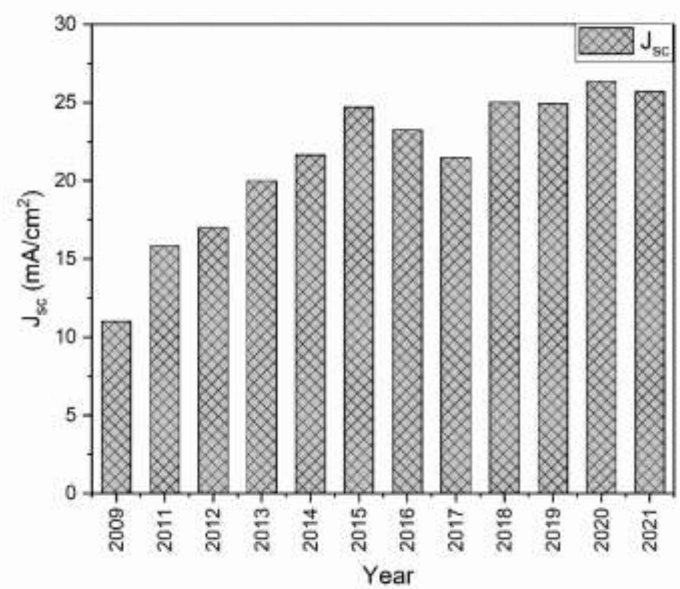

Figure 9. Improvement in Current Density

7. CONCLUSION

Renewable Resources of energy are capable of producing a large amount of power because its availability is very large and throughout the year. The only reason for a lesser consumption of these resources is that we are not having a great technology so that we can fulfill our needs from these renewable energy sources. Whereas many steps are taken in the recent years for enhancing the use of these resources. Perovskite solar cells shows a great result in producing the energy from the sun via photovoltaic effect. There is a tremendous increase in the efficiency, fill factor, open circuit voltage, current density etc. by changing the configuration of the device. The development was so quick that it gained interest of lot of researchers and various other methods were adopted in order to increase its performance. If some stability related issues are solved in the upcoming years then it can prove out to be one of the greatest techniques which can be used for commercialization purposes.

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