

# Effect of Crystal Growth Inhibitors on Efficiency Enhancement of Dye-Sensitized Solar Cell

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**Abstract**— The present research work was aimed to construct and analyze the performance of the organic dye-sensitized solar cell (DSSC) with different types of crystal growth inhibitors. The characteristic behaviors (I-V curves) of these solar cells were studied for different amounts (mol%) of two crystal growth inhibitors, i.e., 1-ethyl-3-methyl-imidazolium chloride (EMICI) and 1-butyl-3-methyl-imidazolium iodide (BMII) were added to SiC. It had been found that EMICI and BMII crystal growth inhibitors show the highest efficiency at contents of 134 mol% and 78 mol%, respectively. Moreover, BMII crystal growth inhibitor shows 10 times higher efficiency than that of EMICI crystal growth inhibitor. The dependency of I-V curves for different thicknesses ( $\mu\text{m}$ ) of  $\text{Fe}_2\text{O}_3$  and SiC on the indium tin oxide (ITO) glass was also studied and it was found that  $\text{Fe}_2\text{O}_3$  and SiC at a thickness of 10  $\mu\text{m}$  and 9  $\mu\text{m}$ , respectively, show the highest efficiency with the BMII crystal growth inhibitor.

**Keywords**— DSSC, EMICI, BMII, Indium tin oxide, Ruthenium-polypyridine dye,  $\text{Fe}_2\text{O}_3$ , SiC.

## 1 INTRODUCTION

Organic dye-sensitized solar cells (DSSCs) are a third-generation technology in the area of photovoltaics. They are classified as a type of thin-film solar cell, meaning that they require only a small amount of material per cell compared to the first-generation solar cells, making the DSSCs lighter and more physically resilient than their first-generation counterparts. They use a process similar to photosynthesis to produce electrical energy, making them an example of biomimicry. Organic DSSCs are a promising technology because they are inexpensive and resilient, making them ideal for large and small scale applications. However, they have lower efficiencies than most other types of solar cells, so they require more space than other types of solar cells to produce the same amount of electric energy. This disadvantage is offset by their low cost, greater resilience, and flexibility [1].

Since the early twentieth century, the most commonly researched types of solar cells were the crystalline silicon solar cells, which were generally very efficient but costly and difficult to produce. Due to the problems of high cost and difficulty in production with crystalline silicon cells, researchers developed cheaper but less efficient thin-film cells. DSSCs are one of the most promising types of thin-film solar cells [2].

DSSCs were invented by Michael Grätzel in 1991, who won the Millennium Technology Prize [3] in 2010 for his work in the area of DSSCs. Since their invention, a great deal of work has been done to optimize the performance of DSSCs, such as finding their optimum parameters, the most cost efficient dyes, doping with various elements to improve dye functioning, and running cells in tandem to improve the efficiency. The research work done on DSSCs will likely increase their

effectiveness while lowering their cost, making them a strong competitor to traditional crystalline silicon cells in the near future [1]. Also, DSSCs do not lose effectiveness at high temperatures unlike the traditional crystalline silicon cells, making them ideal for hotter environments [4]. The only major technical problem currently affecting the DSSCs is their lack of chemical stability over time, which has slowed their commercial growth and application. Much work is being done regarding this issue, and it is likely to become less of a problem in the near future.

An organic DSSC is similar to all other forms of solar cells in general functioning, as it absorbs sunlight to release electrons that provides electrical energy as shown in Fig. 1. The composition of DSSCs is unique from other types of photovoltaic cells in the use of a network of porous titanium dioxide ( $\text{TiO}_2$ ) nanoparticles covered with photosensitive dye, usually ruthenium-polypyridine dye [5] or some kind of organic dye. The  $\text{TiO}_2$  acts as the anode and is separated from a platinum cathode by an electrolyte solution, typically iodide. When light strikes the dye, electrons are released and transported by the  $\text{TiO}_2$ 's conduction band, creating a voltage difference between the two sides similar to a battery. When the anode and cathode are connected, an electric current is generated between the cathode and the anode due to the voltage difference between the two. As long as the anode and cathode are connected and the cell is active, the voltage difference and current generate electric power, which can be used or fed into the existing grid. After reaching the cathode side of the cell, the electrons pass through the electrolyte solution to the anode to replenish the dye and prepare it to absorb more sunlight [6].

The overall conversion efficiency of DSSCs is usually around 5-11%, which is lower than most other solar technology due to the poorer absorption of light by most common dyes compared to crystalline silicon. However, DSSCs are quite efficient on the quantum level, as electrons released by the dye

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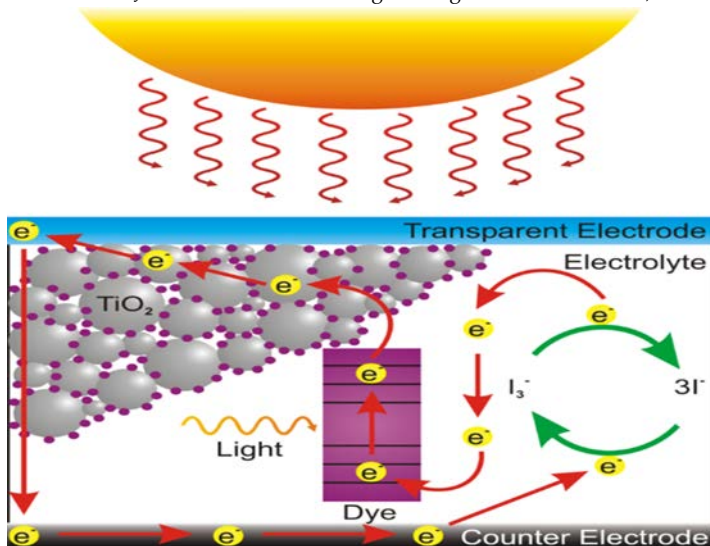


Fig. 1. Organic DSSC.

are usually absorbed by  $\text{TiO}_2$  and converted to useful energy. In practical applications, this fact means that generally when the dye emits an electron, it will be usable as energy instead of wasted recombination with the dye. Most other solar technologies have lower quantum efficiencies, so their energetic electrons are more likely to be wasted than DSSCs [7].

This research work was intended first to construct and obtain the performance of the organic DSSC using two crystal growth inhibitors [1-ethyl-3-methyl-imidazolium chloride (EMICl) and 1-butyl-3-methyl-imidazolium iodide (BMII)] when added to SiC at different amounts (mol%) and second to show the dependency of I-V curves for different thicknesses ( $\mu\text{m}$ ) of  $\text{Fe}_2\text{O}_3$  and SiC on the indium tin oxide (ITO) glass.

## 2 CONSTRUCTION

In case of the original Grätzel design, the cell has three primary parts. On the top is a transparent anode made of fluoride-doped tin dioxide ( $\text{SnO}_2:\text{F}$ ) deposited on the back of a (typically glass) plate. On the back of this conductive plate is a thin layer of  $\text{TiO}_2$ , which forms into a highly porous structure with an extremely high surface area.  $\text{TiO}_2$  only absorbs a small fraction of the solar photons [those in the ultraviolet (UV)] [8]. The plate is then immersed in a mixture of a photosensitive ruthenium-polypyridine dye (also called molecular sensitizers) and a solvent as given in Fig. 2. After soaking the film in the dye solution, a thin layer of the dye is left covalently bonded to the surface of the  $\text{TiO}_2$ . A separate plate is then made with a thin layer of the iodide electrolyte spread over a conductive sheet, typically platinum metal. The two plates are then joined and sealed together to prevent the electrolyte from leaking [9].

## 3 OPERATION

Sunlight enters into the cell through the transparent  $\text{SnO}_2:\text{F}$  top contact, striking the dye on the surface of the  $\text{TiO}_2$ . Photons striking the dye with enough energy to be absorbed create an excited state of the dye from which an electron can be "injected" directly into the conduction band of the  $\text{TiO}_2$ . From

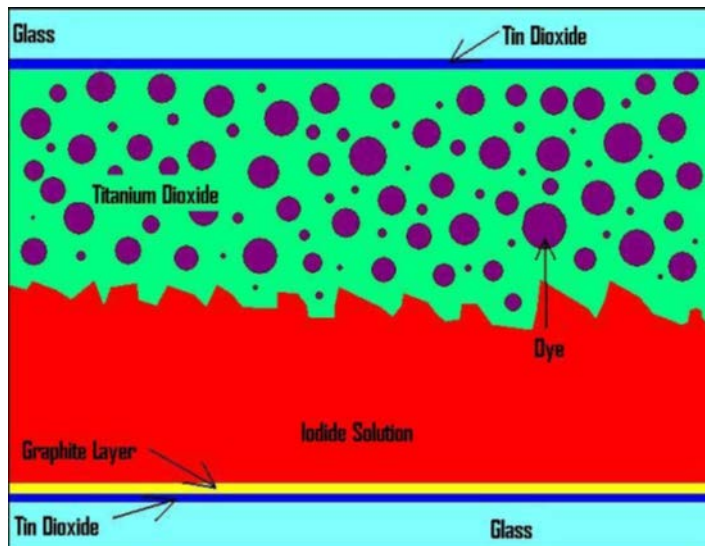
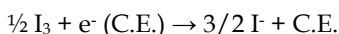
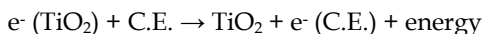
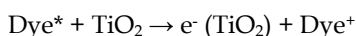
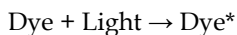


Fig. 2. Deposition layers on the typical glass plate.

there, it moves by diffusion (as a result of an electron concentration gradient) to the clear anode on the top.

Meanwhile, the dye molecule has lost an electron and the molecule will decompose if another electron is not provided. The dye strips one from iodide in the electrolyte below the  $\text{TiO}_2$ , oxidizing it into tri-iodide. This reaction occurs quite quickly compared to the time that it takes for the injected electron to recombine with the oxidized dye molecule, preventing this recombination reaction that would effectively short circuit the solar cell. The tri-iodide then recovers its missing electron by mechanically diffusing to the bottom of the cell, where the counter electrode reintroduces the electrons after flowing through the external circuit as represented in Fig. 3.

For simplicity, the incident light excites electrons within the dye, giving them enough energy to travel in the conduction band of the  $\text{TiO}_2$ . The electrons flow through the  $\text{TiO}_2$  onto the electrode through an electric circuit and then to the counter electrode. The electrolyte carries electrons back to the dye from the counter electrode.



where, C.E. is the counter electrode and  $\text{Dye}^*$  indicates an excited state of the dye.

## 4 MATERIALS AND METHODS

During the experiment,  $\text{Fe}_2\text{O}_3$ , SiC, ethanol, EMICl, and BMII were collected and used without further purification. All the films were prepared on ITO-coated glass that has a resistance of 8-12  $\Omega$ . In a beaker, 0.12 g of  $\text{Fe}_2\text{O}_3$  was mixed with 100 ml of ethanol, followed by sonication for 5 min. For the films of different thicknesses, different amounts of the  $\text{Fe}_2\text{O}_3$  were dropped on an ITO glass put on a hot plate heated at 120°C. The films were then calcinated at 500°C under air atmosphere

for 1 h. 30 mg of SiC was smashed in a mortar, followed by the addition of EMICl and BMII in desired amounts. After the addition of ethanol, the mixture was sonicated for 5 min. Different amounts of SiC with a crystal growth inhibitor were dropped on the  $\text{Fe}_2\text{O}_3$  film and ITO glass put on a hot plate heated at  $120^\circ\text{C}$ . The above two films were clipped in a way that the  $\text{Fe}_2\text{O}_3$  and SiC layers were sandwiched between the two ITO glass supports. The I-V curves were analyzed by an I-V curve analyzer. The incident photon to photocurrent conversion efficiency (IPCE) was measured with a solar cell evaluation system. A xenon lamp was used as the light source.

Different amounts of EMICl as a crystal growth inhibitor were added to SiC. The I-V characteristics curve of DSSCs for 147 mol%, 134 mol%, 120 mol%, and 27 mol% of EMICl as a crystal growth inhibitor is given in Fig. 4, which shows that the organic solar cells with EMICl have the highest efficiency at content of 134 mol% when added to SiC.

Again, different amounts of BMII as a crystal growth inhibitor were added to SiC. The I-V characteristics curve of DSSCs for 39 mol%, 58 mol%, 78 mol%, 97 mol%, and 116 mol% of BMII as a crystal growth inhibitor is given in Fig. 5, which shows that the organic solar cells with BMII have the highest efficiency at content of 78 mol% when added to SiC.

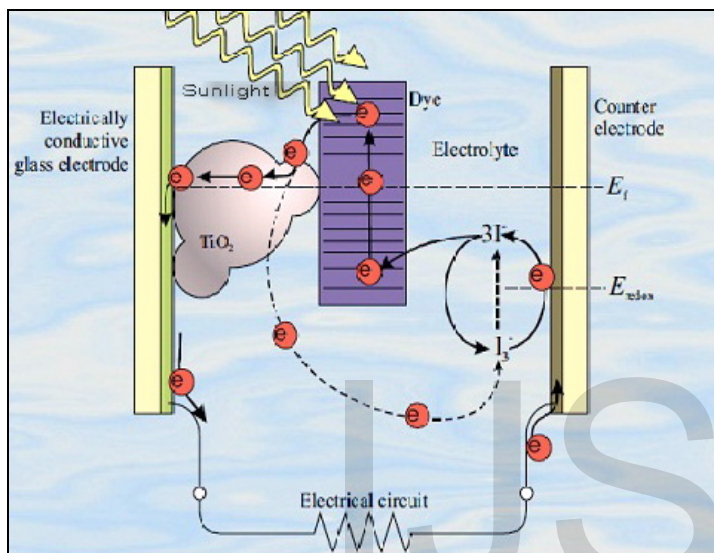


Fig. 3. Schematic diagram of the energy flow in organic solar cell.

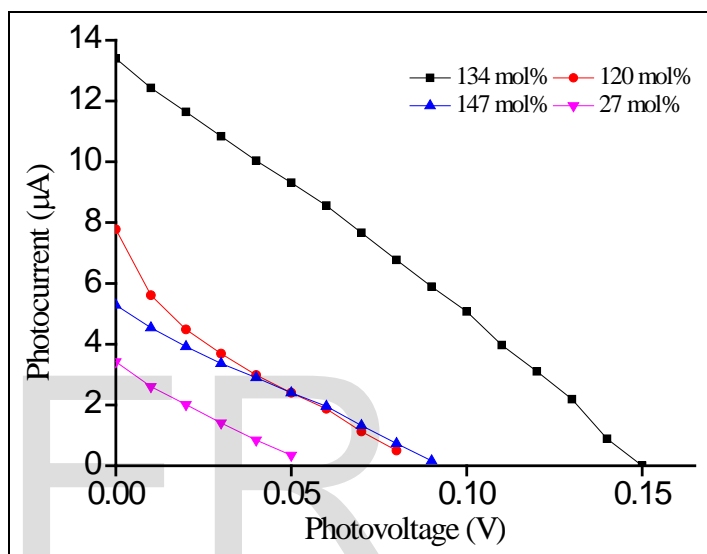


Fig. 4. I-V Characteristic curves for different amounts (mol%) of EMICl added to SiC.

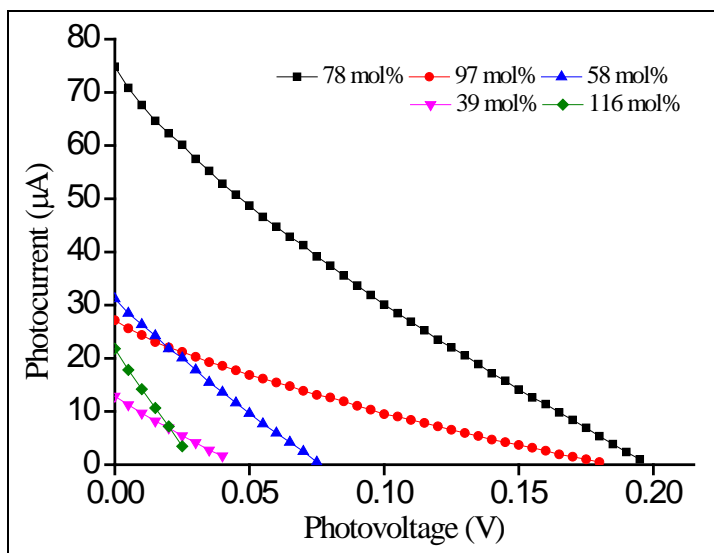


Fig. 5. I-V Characteristic curves for different amounts (mol%) of BMII added to SiC.

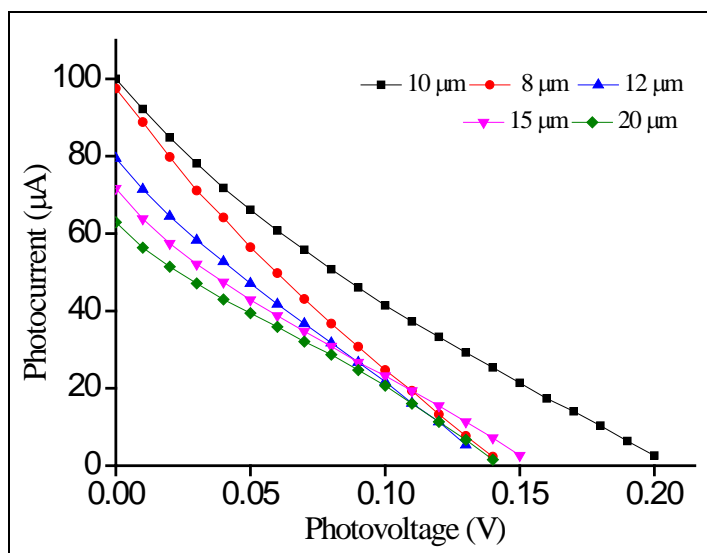


Fig. 6. I-V Characteristic curves for different thicknesses ( $\mu\text{m}$ ) of  $\text{Fe}_2\text{O}_3$  on the ITO glass.

## 5 RESULTS AND DISCUSSION



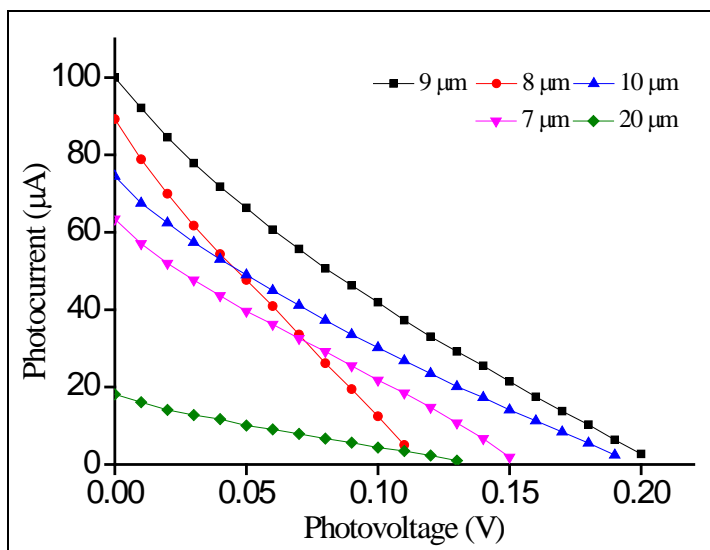


Fig. 7. I-V Characteristic curves for different thicknesses ( $\mu\text{m}$ ) of SiC on the ITO glass.

From Fig. 4 and Fig. 5, it can be marked that BMII showed 10 times higher efficiency than that of EMICl. Moreover, it had found that BMII was liquid in room temperature, whereas the melting point of EMICl was  $84^\circ\text{C}$ . It has been reported by Konno et al. in 2002 [10] that the crystal growth inhibitors having a lower melting point show a higher efficiency. Again, the performance of a crystal growth inhibitor depended on its viscosity and ionic conductivity. The viscosity and ionic conductivity of BMII were higher than that of EMICl.

It was reported by Suzuki et al. in 2003 [11] that the electrochemical activity of a semiconductor oxide depends on the size, surface area, and resistance of the films. The sheet resistance of an electrode has an effect on the internal resistance of a solar cell and consequently influences the fill factor of the cell and its conversion efficiency. For the optimization of solar cell efficiency, the thickness of the  $\text{Fe}_2\text{O}_3$  and SiC colloidal solution on the ITO glass was used. It has been seen that the photocurrent increases with increasing thickness of the  $\text{Fe}_2\text{O}_3$  films. This was due to an increase in the amount of absorbed light with an increase in the film thickness. An increasing thickness led to an increasing loss of injected electrons due to recombination in the electron transfer process in  $\text{Fe}_2\text{O}_3$  nanoparticles and increasing series resistance of the cell, resulting in a decrease in the photo-voltage [12].

$\text{Fe}_2\text{O}_3$  films of different thicknesses were dropped on the ITO glass. The I-V characteristics curves for 8  $\mu\text{m}$ , 10  $\mu\text{m}$ , 12  $\mu\text{m}$ , 15  $\mu\text{m}$ , and 20  $\mu\text{m}$  thickness of  $\text{Fe}_2\text{O}_3$  are represented in Fig. 6. Again, the films of different thicknesses of SiC were dropped on the ITO glass; the I-V curves are depicted in Fig. 7 for 7  $\mu\text{m}$ , 8  $\mu\text{m}$ , 9  $\mu\text{m}$ , 10  $\mu\text{m}$ , and 20  $\mu\text{m}$  thickness of SiC. It was found that the  $\text{Fe}_2\text{O}_3$  at a thickness of 10  $\mu\text{m}$  and SiC at a thickness of 9  $\mu\text{m}$ , respectively, in Fig. 6 and Fig. 7 showed the highest efficiency with the BMII crystal growth inhibitor.

The incident IPCE curve of the DSSC is shown in Fig. 8. We saw that the films had the absorption edges in the visible range at around 580 nm. However, it showed that the strong

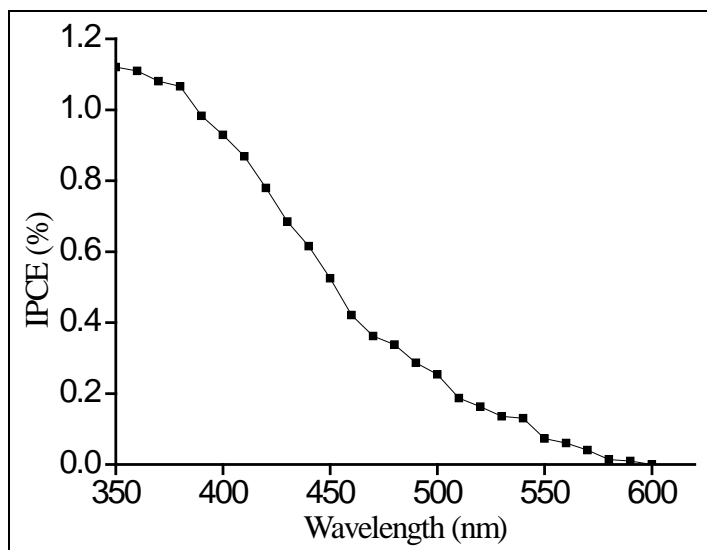


Fig. 8. The IPCE curve of this solar cell.

absorption was also in the UV range. It was seen that the photon to current conversion occurs due to the light absorption by the  $\text{Fe}_2\text{O}_3$  film. This solar cell can convert visible light in the region 350-400 nm into photocurrent. The maximum IPCE reached 1.1% at 350 nm, which was very low compared to DSSC. However, further research is required to increase the IPCE and efficiency of the  $\text{Fe}_2\text{O}_3$  film solar cells.

## 6 CONCLUSION

From the results of the present research work, it can be concluded that SiC films are applicable in the organic DSSC based on the  $\text{Fe}_2\text{O}_3$  film. Addition of crystal growth inhibitors to SiC gives a higher efficiency than that of SiC alone. The thickness of  $\text{Fe}_2\text{O}_3$  and SiC films has considerable effect on the efficiency of DSSCs. BMII showed 10 times higher efficiency than that of EMICl as the crystal growth inhibitor.

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