Inexpensive solar cell using TiO$_2$/coffee composite as photon absorbing material

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Abstract. Solar cell using TiO$_2$/coffee composite as photon absorbing material has been successfully fabricated. A suspension of TiO$_2$/coffee was dropped on Fluorine Tin Oxide substrate which was previously heated on a hotplate with temperature of 100 °C. The fraction of coffee was varied from 10, 20, 30, 40, and 50 %, compared to the mass of TiO$_2$. PVA-LiOH electrolyte polymer was functionalized as the hole transport medium. The highest efficiency of 0.76 % was achieved with 40% of coffee fraction. The solar cell is promising to be developed in the future due to the easy method and cheap materials used.

1. Introduction

Currently, the hope of the world in possession of cheap solar cell devices is increasing continuously. This condition feeds the research into the manufacture of solar cells comprising inexpensive materials, a convenient and necessarily easy process and ready to be adopted to mass production. Great efforts have been done to produce these types of solar cells starting from the first generation of bulk silicon solar cells [1,2], followed by the second generation of thin-film solar cells [3,4], and the third generation of organic solar cells [5,6]. The thin-film solar cell appeared as the solution to the high cost of silicon production since it consumed a thick layer and high purity of silicon [7,8]. The organic solar cell was then developed to largely overcome the shortcomings of its previous generation which was caused by the high cost of encapsulation and furthermore, the toxic materials involved [9]. Each development has been carried out mainly for obtaining much easier method of fabrication, much cheaper materials used, and much more comparable efficiency than the present applied solar cell especially silicon based solar cell.

Dye-sensitized solar cell (DSSC) is a type of organic solar cell that has been mostly developed by researchers over the last decade. The structure of this solar cell is comprised of a dye as photon absorber and titanium dioxide (TiO$_2$) as transport medium of electron injected by the dye to move towards transparent conducting electrode [10,11]. Since the efficiency of the solar cell is still relatively small compared to the most commercial-silicon-based solar cells, it is in need to find a new structure of solar cell made with much cheaper materials and easier method.

Further development of solar cell using much cheaper materials and much easier fabrication method than DSSC is a challenge. A new structure of solar cell replacing most of all materials used in DSSC
has been proposed. The solar cell is comprised of TiO$_2$ as the photon absorbing material, metal particles as the mean of transporting the electron out to the front electrode (FTO), PVA-LiOH electrolyte polymer as the medium for transporting positive charge, and aluminium as counter electrode [12,13]. Technical anatase TiO$_2$, which also can be used as photocatalytic and antibacterial activity material [14-18], is very cheap. Another materials such as PVA-LiOH and aluminium sheet are also inexpensive, and the processes involved in fabricating this solar cell module are simple. Since the lifetime of electron-hole pair in TiO$_2$ is quite short, which is typically in order of $n s$, the deposition of copper particle among TiO$_2$ particle is aimed to dissociate electron-hole pairs freely and inhibit electron-hole recombination through producing high Schottky barrier at the metal-semiconductor junction that accommodated electron capture [12,13].

Since TiO$_2$ has limited absorption range of solar spectrum, further development was carried out using graphite powder to have a wider absorption of solar spectrum and ultimately increased the current of the cell [19]. Although graphite is commonly used as counter electrode [20-22], the presence of graphite powder has successfully improved the performance of the solar cell through higher current resulted [19].

Due to the limited availability of graphite as mined materials, using another carbon-based material replacing graphite is challenging, especially from renewable materials. Coffee powder is a promising material to be combined with TiO$_2$ in absorbing the solar spectrum since it has a narrow bandgap of 2.59 eV [23], capable of absorbing the solar spectrum until the visible region. In addition, it is a renewable material, reasonably cheap, and massively planted in many places around the world.

In the present study, combined materials of large bandgap titanium dioxide (TiO$_2$) with material of small bandgap (coffee) in order to get higher current is reported. The function of TiO$_2$ as a large bandgap material-in absorbing high energy of photons and producing high V$_{oc}$ will be supported by the role of coffee in absorbing low energy of photons and increasing I$_{sc}$ of the solar cell. Optimum composition is studied by varying the coffee fraction. High I$_{sc}$ and V$_{oc}$ would simultaneously improve the efficiency of the solar cell. The effect of using coffee in various different fractions are observed in I-V characterization.

2. Material and Experiment

2.1. Materials

Anatase TiO$_2$ technical grade was purchased from Bratachem Indonesia. Coffee powder was obtained from local production in Bandung. Fluorine tin doped oxide (FTO) was procured from Solaronix Switzerland. LiOH was purchased from Chemical Kanto Japan. Polyvinyl alcohol (PVA) was purchased from Bratachem Indonesia. Aqua mineral water was acquired from local stall in Bandung. The solar cell performance was measured using current-voltage (IV) counter (Keithley 617) under xenon lamp illumination at intensity of 300 W/m$^2$. The intensity of illumination was measured using the Newport 841-PE energy/power meter model.

2.2. Preparation of solar cell.

A 5 g of TiO$_2$ powder was stirred homogeneously in 12 mL of mineral water (Aqua, Indonesia) for 15 minutes. Subsequently, a coffee powder was added to the suspension with the amount of 10% up to 50% to the amount of TiO$_2$ powder. The suspension of TiO$_2$ and coffee was then stirred for 30 minutes. Meanwhile, FTO (fluorine doped tin oxide) transparent electrode was heated on a hot plate at 100$^\circ$ C for 30 minutes. The suspension was then dropped onto the FTO surface using a small spatula surface and was distributed evenly on the FTO surface. To make the TiO$_2$/coffee particles well attached on the surface of FTO, the film was then heated further at 200$^\circ$ C for 2 hours.

Separately, 0.38 g of LiOH was dissolved in 20 ml mineral water for 15 minutes. A 1.8 g of polyvinyl alcohol (PVA) was then added to the solution and heated at 100$^\circ$ C for 60 minutes to form an electrolyte polymer gel. The solar cell module was constructed by sandwiching the electrolyte polymer between film and aluminium electrode. The detailed description of the solar cell structure is illustrated at Figure 1.
The efficiency ($\eta$) and the fill factor of the solar cell were calculated based on the equation below:

$$\eta = \frac{I_{sc}V_{oc}FF}{P_{in}} \times 100\%$$  \hspace{1cm} \text{(1)}$$

$$FF = \frac{I_{m}V_{m}}{I_{sc}V_{oc}}$$  \hspace{1cm} \text{(2)}$$

Where $I_{sc}$ is the short circuit current, $V_{oc}$ is the open voltage, FF is the fill factor, $P_{in}$ is the power of light, $I_{m}$ and $V_{m}$ are the current and voltage that produce the maximum power.

For each coffee fraction, four samples were measured to obtain the I-V characteristics. Since the efficiencies obtained from I-V characterization for each coffee fractions are almost the same, only one data was listed to represent the four data obtained.

3. Result and Discussion

Figure 1 describes the proposed mechanism of photo-current of the developed solar cell. After absorbing the photons, electrons in the valence band of TiO$_2$ and coffee will be excited to the conduction band where accumulated electrons located on the conduction band of TiO$_2$ will directly flow to the conduction band of coffee due to the lower band gap of coffee particles and finally arrived at FTO. The electrons located on the conduction band of coffee will directly move to FTO. As the ion minerals filled the voids of particles of absorber materials act as holes’ scavengers, the holes will be easily captured and converted into positive ions. The movement of ions to the electrolyte polymer will be easy since they are located deep inside the film.

![Figure 1](image)

**Figure 1.** Schematic diagram of TiO$_2$/coffee solar cell.

Figure 2 shows the I-V curve of TiO$_2$ based solar cell containing different fractions of coffee powder. The corresponding parameters obtained from each fraction are summarized in Table 1. It is clearly shown that the presence of coffee powder in the TiO$_2$ solar cell has increased the $I_{sc}$, compared to the $I_{sc}$ of TiO$_2$-based solar cell (0.99 mA). An $I_{sc}$ of 1.39 mA was observed when the fraction of coffee was 10% and continued to increase up to coffee fraction of 40% (1.7 mA). However, when the coffee fraction surpassed 40%, the $I_{sc}$ decreased to 1.35 mA for the coffee fraction of 50%.
The increase of $I_{sc}$ after inserting small bandgap materials was theoretically calculated by Soga [24]. $I_{sc}$ strongly depends on the absorption characteristics of the active material [24], in which $I_{sc}$ is higher when larger number of electron-hole pairs can be generated or more photons can be absorbed. Therefore, it is highly suggested that the active material in the solar cell should have a small bandgap to increase $I_{sc}$. The increase of $I_{sc}$ was also followed by the increase of $V_{oc}$ from 0.23 V, without coffee, to 0.78 V, when the fraction of coffee was 40 %. The increase of $I_{sc}$ and $V_{oc}$ boosted the efficiency of the solar cell from 0.32 %, without coffee, to 0.76 %, when the fraction of coffee was 40 %. It is predicted that this is the optimum amount of a combination of small and large bandgap materials in achieving highest efficiency. The function of small bandgap materials in producing high $I_{sc}$ and large bandgap materials in achieving high $V_{oc}$ is immensely confirmed in the present study [25, 26].

### Table 1. The parameters obtained from I-V measurement for TiO$_2$ based solar cell containing different fractions of coffee powder.

| Coffee fractions (%) | $I_{sc}$ (mA) | $V_{oc}$ (V) | FF | Efficiency (%) |
|----------------------|---------------|--------------|----|----------------|
| 0                    | 0.99          | 0.23         | 0.35 | 0.32           |
| 10                   | 1.39          | 0.33         | 0.28 | 0.46           |
| 20                   | 1.48          | 0.68         | 0.15 | 0.54           |
| 30                   | 1.56          | 0.78         | 0.18 | 0.71           |
| 40                   | 1.70          | 1.02         | 0.13 | 0.76           |
| 50                   | 1.35          | 0.90         | 0.16 | 0.65           |

Several researches have reported the same attempt of employing small and large bandgap materials in a solar cell. Peet et al succeeded in improving the cell efficiency by using combined small and large bandgap materials [27]. An efficiency of 10.6 % was successfully achieved by You et al., who combined small and large bandgap materials in a polymer solar cell [28]. Employing small bandgap material to support main absorbing material was also carried out by Kim et al., and the work succeeded in improving the efficiency of a plastic-based solar cell [28]. Although the efficiency of the developed
solar cell in this study is much lower than those of solar cells, it is possible to be further developed in the future since it used much cheaper materials and easier method.

4. Conclusion
We have successfully fabricated inexpensive solar cell using TiO$_2$/coffee composite as photon absorbing material. Combination of small bandgap material (coffee) and large bandgap material (TiO$_2$) in producing high $I_{sc}$ and $V_{oc}$ has remarkably boosted the efficiency of the solar cell. The highest efficiency of 0.76 % with $I_{sc}$ of 1.70 mA and $V_{oc}$ of 1.02 V was achieved when the fraction of coffee of 40 % was used. Since easy method and cheap materials were applied in this work, this solar cell is promising to be developed in the future.

5. References
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