Dye sensitized solar cell based on TiO$_2$ sensitized with DN-F01/Ag

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Abstract. This research reports the performance of DSSC solar cells that have been fabricated by modification of Ag metal doping with varying concentrations. The sample was deposited by spin coating method and characterized using UV-Vis spectrophotometer to obtain gap energy, FESEM characterization to see sample’s morphology, IPCE, and solar simulator to show performance of DSSC solar cell. The TiO$_2$ / DN-F01 / Ag working electrode layer has a gap energy of 1.95 eV which value is smaller than the pure TiO$_2$ layer and TiO$_2$ / DN-F01 which value is 3.15 eV and 2.3 eV respectively. The results show the greatest efficiency found in Ag doped dye solar cell samples with Ag mass of 0.0172 gr. This result was influenced by Ag metal which has good light absorption ability, extends TiO$_2$ response to visible light, and charge recombination.

1. Introduction

Dye sensitized solar cell (DSSC) as a form of renewable energy that is a promising alternative energy for the future continues to get the most attention from researchers. Various methods and experiments are being carried out to get the best performance from DSSC solar cells. Modifications to the constituent components of DSSC solar cells became a breakthrough made by researchers such as photoanode modifications [1-2], dye modifications [3-4]; modification of counter electrodes [5-6]; and electrolyte modification [7-8].

Each component of the DSSC solar cell has an important role in the process of converting solar energy into electrical energy. Therefore, the selection of material for the components of the DSSC needs to be considered to get the best performance. One form of modification made by researchers in the working electrodes is to add metal materials to semiconductors such as metal Cr, Zr, Ni, Fe, Cu, Ag [9-14], etc. Adding the right metal material can increase the absorption of light from the UV light region to the visible light region, reduce electron recombination, and increase efficiency [15]. The most commonly used semiconductor material for the working electrode components is TiO$_2$ because of its abundant availability, its non-toxicity, stable, and easily prepared [16]. Dye as a photoelectron producer on DSSC has a major influence on the electronic output of solar cells. Dye / TiO$_2$ interface is a bridge between dye and conductive substrate to accelerate electron transmission [17].

In this research, the working electrode components of DSSC solar cells has immersed with DN-F01 dye which modification by adding Ag solution into the dye. Ag belongs to the noble metal group
which has high electrical conductivity, good physical chemical properties, low Fermi energy levels and is able to utilize light with a longer wavelength to produce electrons to move the charging carrier and can facilitate the transfer of electrons between interfaces with improve the performance of solar cells [18]. Several studies have shown that the addition of Ag to the working electrode or semiconductor layer can increase the efficiency of DSSC solar cells. Research by Omar and Hartomy shows that Ag doping on the TiO$_2$ semiconductor loaded on the Pt-carbon ball shifts the position of the bottom absorption edge toward the longer wavelength and reduces band gap energy to absorb energy from most visible light [19].

2. Experiment

The experiment method of this research is spin coating method to deposit TiO$_2$ solution on the FTO conductive substrate at a speed of 1000 rpm and annealed using a carbotile furnace at a temperature of 450$^\circ$C. Ethanol solvent is used in this study to dissolve TiO$_2$ paste, dye, and Ag powder. The dye used is dye DN-F01 with a concentration of 0.01 M (Y) with Ag as much as 0.0172 gr (Ag 1); 0.172 gr (Ag 2); and 1.72 gr (Ag 3). The working electrode consisted of platinum paste dripped on the FTO conductive substrate and annealed using a carbotile furnace at a temperature of 450$^\circ$C. Veloron nitrile, Butyl pyridine / TBP, Iodolyte AN 50, Guanidine Thiocynate, DMPII were used as materials for electrolyte production. The characterization carried out in this study are the FESEM test to see the morphology of the layers of pure TiO$_2$, TiO$_2$ / dye, and TiO$_2$ / dye / Ag; Optical characterization using a UV-Vis spectrophotometer Shimadzu UV-1800; DSSC solar cell performance tests using portable solar simulators; and the Incident Photon to Current Conversion Efficiency (IPCE) test.

3. Results and Discussion

Figure 1 is a characterization of FESEM from pure TiO$_2$, TiO$_2$ / dye, and TiO$_2$ / dye / Ag layers. The results obtained at a magnification of 50,000 x images show the morphology of the surface layers of pure TiO$_2$, TiO$_2$ / dye, and TiO$_2$ / dye / Ag. The surface of the TiO$_2$ / dye layer in Figure 1 (b) is clearer and the TiO$_2$ stacks are more than the pure TiO$_2$ surface layer in Figure 1 (a), in addition there are lumps on the TiO$_2$ / dye surface. For Figure 1 (c) the surface layer of the TiO$_2$ / dye / Ag sample looks like a coral with clearer particle spheres.

Fabricated DSSC solar cells are tested using a portable solar simulator. Four samples were tested, namely sample Y using DN-F01 concentration of 0.01 M without doping Ag; Ag 1 sample used DN-F01 0.01 M concentration doped with Ag solution with an Ag mass of 0.0172 gr; Ag 2 sample used DN-F01 concentration of 0.01 M doped with Ag solution with an Ag mass of 0.172 gr; and Ag 3 samples using DN-F01 0.01 M concentration doped with Ag solution with an Ag mass of 1.72 gr. The results of the DSSC solar cell performance test can be seen in Table 1 and the efficiency of the characteristics of the Jsc-V curve in Figure 2 which shows the measurement results of 2.76% efficiency for sample Y; 3.62% for Ag 1 samples; 1.71% for Ag 2 samples; and 0.55% for Ag 3 samples. The results show that Ag 1 samples with Ag addition of 0.0172 gr in the dye obtained the greatest efficiency. While for Ag 2 and Ag 3 samples decreased efficiency along with the addition of the mass of Ag doped at DN-F01 which value is smaller than the efficiency of sample Y without doping Ag.

| Sample | I$_{sc}$ x 10$^{-3}$ (A) | J$_{sc}$ (mA/cm$^2$) | V$_{oc}$ (volt) | V$_{max}$ (volt) | I$_{max}$ x 10$^{-3}$ (A) | FF | Efficiency (%) |
|--------|--------------------------|----------------------|---------------|-----------------|------------------------|----|----------------|
| Y      | 2.98                     | 6.14                 | 0.79          | 0.55            | 2.44                   | 0.56 | 2.76           |
| Ag 1   | 5.10                     | 10.25                | 0.77          | 0.50            | 3.58                   | 0.48 | 3.62           |
| Ag 2   | 2.37                     | 4.75                 | 0.77          | 0.49            | 1.69                   | 0.45 | 1.71           |
| Ag 3   | 0.82                     | 1.64                 | 0.71          | 0.51            | 0.52                   | 0.45 | 0.55           |
The results of research conducted by Wang et al who obtained the best DSSC performance on a modified TiO$_2$ Ag 0.5 wt% with variations of Ag 0 wt%, 0.5 wt%; 1 wt%; 1.5 wt%; the more Ag added, the efficiency of the sample decreases [20]. Research by Usha et al on the modification of TiO$_2$ doping Ag with variations of Ag 1%, 2%, and 3% obtained an increase in efficiency of 4% compared to layers that were not doped with Ag with a concentration of Ag addition of 1%. The conductivity of TiO$_2$ increases with increasing Ag concentration, but higher Ag concentrations may not produce cash flow because the recombination rate increases due to direct contact of electrolytes which penetrate through the porous particulate TiO$_2$ structure with the lower layers [21]. while research by Sun et al revealed that in addition to Ag concentration, the thickness of TiO$_2$ also affects the efficiency of DSSC
solar cells. TiO$_2$ which is not thick enough can only lead to the phenomenon of leakage so that the ability of electron transmission is reduced and causes low efficiency [22].

Figure 3 presents the IPCE values for each sample. IPCE is used to determine the efficiency of light conversion on DSSC and in this study obtained an IPCE value of 80% for sample Y in the wavelength range of 300-500 nm, 67% for Ag 1 samples in the wavelength range of 430-550 nm, 14% for samples Ag 2 in the wavelength range of 300-500 nm, and 10% for Ag samples in the wavelength range of 300-500 nm. From Figure 3 it can be seen that samples Y, Ag 2, and Ag 3 absorb light at a wavelength of 300-500 nm, while the Ag 1 sample experiences a slight shift in wavelength absorbing light at a wavelength of 430-550 nm. The increase in IPCE values in the Ag 1 sample occurred around the wavelength region of 500 nm. The increase in IPCE at a wavelength of 500-550 nm is associated with high dye adsorption that is affected by a large surface [23]. A high IPCE value indicates that the electron transfer process from the dye to the semiconductor conduction band occurs effectively and the transfer of electrons from the I$^- \text{to the dye is effectively oxidized}$ [24].

Figure 3. The IPCE spectra of DSSC sensitized with dye solution Y, Ag 1, Ag 2, and Ag 3

Figure 4. $(\alpha h\nu)^{1/2}$ as a function of photon energy for pure TiO$_2$, TiO$_2$/DN-F01, TiO$_2$/DN-F01/Ag

Figure 4 is a graph of the estimated band gap value of the TiO$_2$, TiO$_2$/DN-F01, TiO$_2$/DN-F01/Ag layers. From the picture it can be seen the estimated value of pure TiO$_2$ layer in the present work is 3.15 eV which value is almost close to the gap value of the anatase phase TiO$_2$ band gap in general.
which is confirmed at 3.2 eV. The TiO\textsubscript{2} / DN-F01 layer has band gap energy of 2.3 eV which value is smaller than pure TiO\textsubscript{2}. The small band gap value of the TiO\textsubscript{2} / DN-F01 layer compared to the pure TiO\textsubscript{2} layer indicates that dye DN-F01 can be used as a sensitizer to absorb photons and accelerate the transfer of electrons from the valence band to the conduction band. Meanwhile for the TiO\textsubscript{2} / DN-F01 / Ag layer the band gap value is 1.95 eV smaller than the pure band gap value of TiO\textsubscript{2} and TiO\textsubscript{2} / DN-F01 layers. The small band gap energy can speed up the electron transfer process so that it can improve the performance of DSSC solar cells. Ag added to the sample may be responsible for visible light-induced photocatalytic degradation by increasing electron photogeneration and hole separation as well as charge migration, which allows electrons and holes to take part in the overall photocatalytic reaction. In addition, Ag has good light absorption ability, extending TiO\textsubscript{2}’s response to visible light [25].

4. Conclusion
Modification of dye DN-F01/Ag can precisely increase the efficiency of DSSC solar cells. High Ag conductivity has an effect on increasing electron transfer which can improve DSSC performance. The addition of Ag on DSSC solar cells can reduce charge recombination and respond to light over the wavelength range of visible light. Although Ag has many advantages, its use in large numbers of DSSC solar cells can reduce the efficiency of solar cells. For this reason, research is needed regarding the proper concentration of Ag as a dopant in DSSC solar cells. In addition to the amount of metal concentration, TiO\textsubscript{2} thickness, temperature, and electrode deposition methods are factors that need to be considered to improve the performance of DSSC solar cells.

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