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Effect of Surface Area on The Performance of Dye-Sensitized Solar Cell

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Abstract
The quantity of dye loaded on TiO_2 film plays a very important role on the performance of DSSC as it directly determines the number of charges generated within the solar cell, therefore it needs to be measured and optimized to avoid recombination because of aggregation of molecules on the titania surface. In this study, TiO_2 is modified to increase its surface area using ball milling process. The bandgap energy of the modified titania is reduced from 3.3 eV to 2.8 eV after the ball milling, additionally, pure size of semiconductor is also increased from 5 nm to 20 nm which resulted in the increase of dye loading of the semiconductor.
Keywords: Titania, semiconductor, band gap, ball milling.

Introduction
Enhancement of photoanode materials based on semiconductor oxides, especially titanium dioxide (TiO_2) has the potential to significantly boost the overall efficiency of a dye-sensitized solar cell (DSSC). However, the electron transport dynamics in this type of semiconductor material is characterized with high electron–hole recombination which lower the overall solar cell performance (Samaila *et al.,* 2016).

Among the most important components of DSSC, TiO_2 film plays a dual role in dye anchorage and charge carrier transport which are key factors that determine the performance of DSSC. Over the past decade, significant efforts have been made to improve the efficiency of the solar cell through the modification of the TiO_2 which include enhancement of light absorption efficiency of the photoanode by increasing the surface area of the TiO_2 film, which offers sufficient room for dye loading as well as visible light absorption. Similarly, the electron injection efficiency was improved by adjusting the conduction band edge of the semiconductor to match the lower unoccupied molecular orbital (LUMO) of the sensitizing dye (Jose *et al.,* 2009). Another strategy was used is to increase the charge collection efficiency through the improvement of the electron transport or lifetime (Gao *et al.,* 2016).

This research is designed to enhance power conversion efficiency of dye-sensitized solar cell through improvement of semiconductor particle size for optimum dye loading and light absorption as well as carrier transport in the photoanode.

Materials and Methods
Dye molecules were detached from the surface of TiO_2 by dipping the dye adsorbed photoanode into 3 M of sodium hydroxide solution KOH for 12 hours to ensure a complete detachment of the dye on the TiO_2 surface, then a UV-Vis data of that solution was taken using a UV-Vis spectrophotometer.

The surface area and pore distribution for the doped titania particles were measured by Brunauer, Emmett, and Teller (BET) technique. A higher surface area is needed for the semiconductor material for optimum dye uptake. Large particle is associated with small pore size and minimum surface for dye loading while small sized particle will have sufficient surface area for maximum dye attachment. Automated gas adsorption machine (BEL, Japan, Inc.) was used for the measurement.

The amount of dye loaded on a TiO_2 film was quantitatively calculated using Equation 1.

$$A = \varepsilon cl \tag{1}$$

where *A* is the absorbance, ε is the Molar extinction coefficient (14 x 103 M^{-1} cm^{-1} for N719 dye), l is the cell length (generally 1 cm) and c is the concentration of dye in solution.

To determine the porosity of the TiO_2, the surface area and pore distribution measurements based on the Brunauer, Emmett and Teller (BET) method were carried out.

Results and Discussion

A type IV adsorption-desorption isotherms is clearly observed in Figure1(a) which, according to the IUPAC classification system represents a mesoporous material with a hysteresis loop of type H_2, indicating that the material has good pore connectivity (Guo *et al.,* 2011). The pore size distribution is found to be within the range from 5 nm to 20 nm as shown in Figure1(b). These numerous pores provide vacant site for dye uptake. Light harvesting in nanoparticle-based film is usually higher than that of a flat junction because the surface area for the nanoparticle is also a thousand times greater than the bulk material surface. This ensures a maximum dye attachment on the monolayer of the semiconductor material.

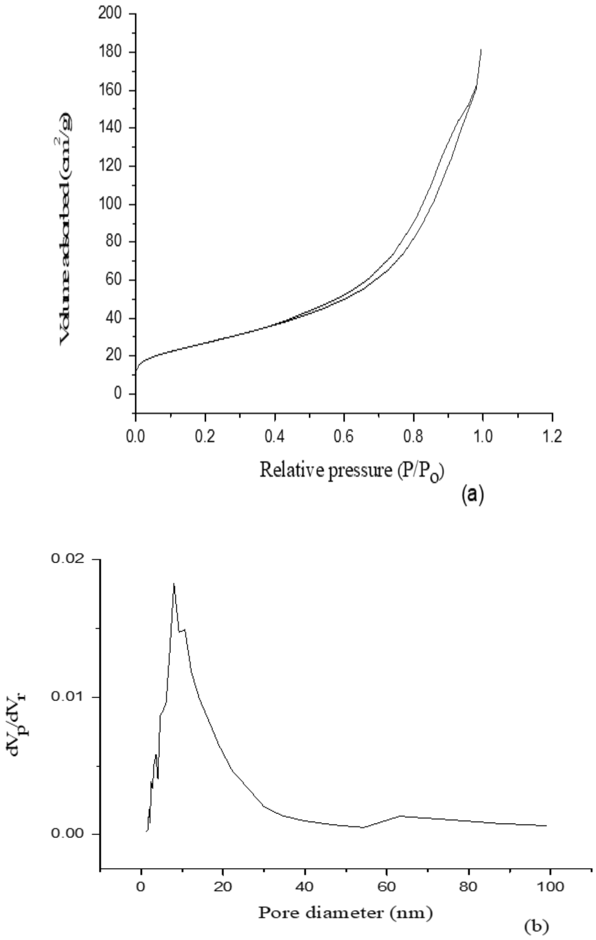

Figure 1 (a) N_2 adsorption-desorption isotherms for TiO_2 power sample, (b) Pore size distribution curve for milled TiO_2 powder.

The effect of milling time on the surface area of samples prepared under different milling time was also investigate. The relationship between the particle size and milling time is plotted in Figure 2. The plot also presents the amount of dye loaded on the solar cell device prepared with TiO_2 powder synthesized under different milling time. For both the surface area and dye uptake results, it is evident that milling time has influenced the surface area expansion of the TiO_2 which was responsible for high dye loading ability of the TiO_2 photoanode based device.

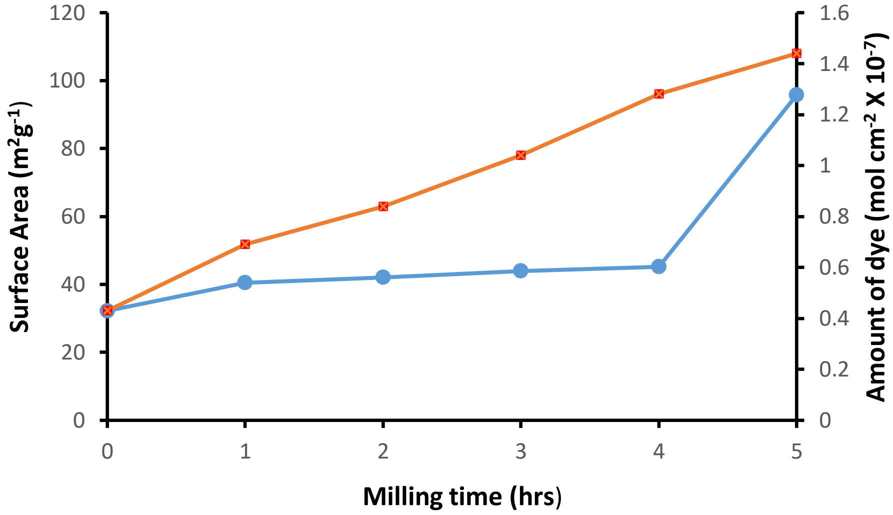

Figure 2 Relationship between surface area, dye loading and milling time of TiO_2 prepared using ball milling technique.

Light-harvesting in the nanoparticle-based film is usually higher than that of a flat junction because the surface area for the nanoparticle is also a thousand times greater than the bulk material surface (Lim, 2014). This ensures a maximum dye attachment on the monolayer of the semiconductor material.

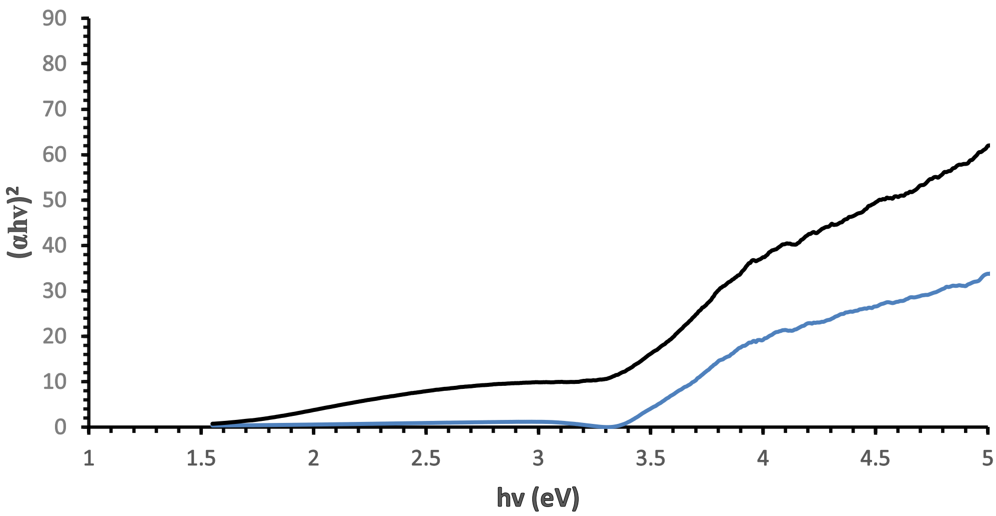

Figure 3: Tauc plot a TiO_2 and milled TiO_2

Figure 3 represents a curve of (αhv) ^{2} versus photo energy (hv). The extrapolation of the linear point of the curve gives the band gap energy of the respective samples. From the plot it is shown that the band gap energy of un-milled TiO_2 is traced at 3.3 eV. Expectedly, a reduction in band gap energy for the milled TiO_2 was observed at 3.28 eV and will continue to drop as the milling time increased. This reduction of band edge is attributed to the expansion of the titania surface which acts as acceptors thereby reducing in band gap energy value (Ravidhas *et al.,* 2015).

Conclusion

The study has clearly shown that the light absorption of a dye-sensitized solar cell can be effectively enhanced by increasing the particle size of the titania semiconductor as the bandgap is reduced from 3.3eV to 3.28eV which will allow more photon absorption, also ball milling technique can be employed to achieved the increase of the particle size.

Acknowledgement

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