CHAPTER X
CONCLUSIONS AND RECOMMENDATIONS

10.1 Conclusions

The red cabbage dye was found to be the most suitable natural sensitizer in this work. In order to enhance DSSC performances, dye additives were added. It is found that the 4-(chloromethyl) benzoylchloride aided to increase the short circuit current, while decreases the open circuit voltage and fill factor. The opposite effects were observed with the 4-chloro-2,5-difluorobenzoic acid. The different in surface polarities of CTAB modified Na-bentonite and purified Na-bentonite were investigated to explore their roles as energy barriers or light scattering centers in an semiconductor TiO_2 electrode. The CTAB-modified bentonite was more suitable to make a composite with the P25 TiO_2 whereas the purified Na-bentonite was more suitable to make a composite with the sol-gel TiO_2 to obtain a homogeneous film and high cell performance. Even though overall performances of DSSCs decreased with increasing bentonite content in the electrode film, they increased when a sol-gel TiO_2/purified Na-bentonite scattering layer was applied on the sol-gel TiO_2 electrode. The electrophoretic deposition technique provides a good cell efficincy with purified Na-bentonite loading of 3.1 mole%Si in composite films. The best photovoltaic properties, J_{sc}, V_{oc}, FF, and η of this cell are 2.1 mA/cm^2, 0.55 V, 0.72, and 0.83%, respectively.

The incorperation of CTAB modified Na-bentonite in liquid electrolyte as a gelator render a high cell performance. The starting and optimal contents to form gel and render the best cell performance are 20 wt.% in Z646 liquid electrolyte and 13 wt.% in Z655 ionic liquid electrolyte. Compared to the cell with liquid electrolyte or standard cell, the V_{oc} is higher but J_{sc} and fill factor are lower. The maximum cell performances of this cell with synthetic dye, Z 907 are 11.7 mA/ cm^2(J_{sc}), 0.77 V (V_{oc}), 0.65 (FF), and 5.9% (η). Meanwhile, the commercial synthetic laponite with non-modified surface, the compared gelator provide higher V_{oc} and lower in J_{sc} compared to those of the standard cell. Nevertheless, the stability of cell with laponite is deteriorated extremly under light soaking and thermal stressing. This implies that high content of non-modified clay in liquid electrolyte is harmful to the DSSC stability during the usage. Compared to the synthetic laponite, purified Na-bentonite is not able to gel liquid electrolyte itself. However, the aerogel of purified Na-bentonite covered with polymethyl acrylate can be a good gelator. The optimal weight ratio of bentonite and polymer and the composite content in liquid electrolyte are 10:90 and 10 wt.%, respectively because at this content the gel render the maximum diffusion conductivity. The photovoltaic properties of the cell with this composite as gelator are 7.8 mA/ cm^2(J_{sc}), 0.66 V (V_{oc}), 0.67 (FF), and 3.41% (ŋ).

10.2 Recommendations

It is interesting to characterize the natural dyes in more details to explain clearly the dye properties that affect to the cell efficiency since this will help us to understand more their nature and to discover the solutions which make natural dyes efficient and economical besides environmentally friendly sensitizers. There are a few studies in deeply detail of natural dyes (Kay, 1994) since this is probably not worth for the funding due to their very low efficiency. However, both natural dyes and sun light are abundant and clean. This is a great inspiration to carry forward the research of natural dyes.

Apart from the wide band gap energy, an efficient dye should has a match in its excitation state against conduction band of semiconductor, and its oxidation state match to redox potential of electrolyte since these refer to the ability of photo-charge generation, charge separation, and oxidized dye reduction efficiency. To observe these the electrochemical characterizations of dye are needed. For instance, cyclic voltammetry is general technique to determine the oxidation and reduction state of dyes, or electrochemical impedance spectroscopy (EIS) is useful to compare the recombination rate or electron life time of DSSCs with different dyes (Jang *et al.*, 2009).

The TiO_2/clay composite for photoanode developed by our laboratory is still needed to be improved because the large aggregates appear in the composite. The reduction size of nanoclay particle is an idea since its geometry is not expected to retard the charge transportation along the film thickness. This influence could be simply investigated by measuring sheet resistance of the thin film electrodes via four-point probe measuring system as used for typical semiconductor (Sarah *et al.*, 2010). The mean particle size and particle size distribution of sol-gel TiO_2 at various purified Na-bentonite contents should be investigated, as clay may alter the pH of sol and then affect the particle size of TiO_2, additionally influencing the specific surface area of the composites. Moreover, the change in surface polarity could contribute to segregate of particles, and simultaneously could disperse the clay particles in electrophoretic media. The CTAB modified bentonite is an interesting one even it need low polar solvent and high charging in the system. However, a technique used to eliminate char residual on the clay surface at the calcination temperature of semiconductor is necessity.

The CTAB modified Na-bentonite is a good geletor when its content reaches the optimization between gel formation point and good dispersion. Even though drawback of synthetic laponite is low cell stability, its smaller particle size gives better fill factor. Thus if laponite can be modified its surface with a proper surfactant, this will enhance clay dispersion and cell stability along with higher cell performance. Meanwhile, purified Na-bentonite, inability to solidify liquid electrolyte itself, can provide gel formation at low clay content and low energy for dispersion in form of aerogel structure which support polymethyl acrylate. The latest cell of this composite as gelator exhibits high efficiency, comparable to the standard cell. This is a promising system that is worth to develop further. There are several approaches to investigate, for instance, various kinds of polymer with medium or high dielectric constant synthesized via soap-free emulsion polymerization (i.e. polymethyl methacrylate, polystyrene, polycrylonitrile, their copolymer, and etc.), the grinding aerogel composite in nanosize in order to obtain nano-exfoliated bentonite/polymer and use in powder form, the technique to synthesis exfoliated polymer/clay nanocomposite via soap-free emulsion polymerization (Choi *et al.*, 2001; Lee *et al.*, 2008b; Tu *et al.*, 2008). The two latter cases will provide the nanocomposite in which clay particles segregate and disperse well. This would contribute more gel formation efficiency at lower clay content and less ion diffusion problem due to less clay aggregation.