1

INTRODUCTION

1.1 Motivation

As the world population reaches its 7 billions mark, the need for energy will also increase tremendously. In the last century, oil and gas as well as coal have been the main contributors for fulfilling the energy need. Nevertheless, several alternative routes have been explored and tapped to support the expanding energy demand. These include hydropower, solar, wind and geothermal which are deemed as promising renewable energy route.

It is projected that the global demand for energy will be more than double by 2050. This demand is equivalent to 30 trillion watts or 30 terawatts (TW) [1]. Coupled with the concern of global warming and the promotion of sustainable energy, a suitable renewable energy source is required to meet the rising global energy demand. Although renewable energy only accounts a small portion of the total energy supply, the installed renewable energy capacity has been advancing to a great scale between the year 2000 and 2009 [2]. One of the promising renewable energy sources is solar energy.

Solar energy is a good candidate for future energy supply due to its non-generation of green house gases particularly carbon dioxide (CO_2). Apart from that, it is the most abundant resource available to us. The energy from sunlight which hits the earth surface in one hour (4.3×10^{20} J) has more than enough energy that is needed for the global consumption in one year. Current energy consumption is estimated equivalent to 13 trillion watts or 13 terawatts (TW) [1].

In order to tap the abundance of sunlight energy, we need an efficient solar energy conversion system. There are currently three types of solar energy conversion system available: solar electricity, solar fuel and solar thermal system [1]. Solar electricity system covers the basic photovoltaic solar cells. Over the years, numerous research and developments have produced a few categories of photovoltaic technology, namely crystalline silicon, thin-film, concentrator, and excitonic and novel materials with high efficiency solar cells [3]. Each photovoltaic technology has its advantages and shortcomings. At the moment, multijunction cells have shown the highest efficiency as reported (Figure 1.1) [4].

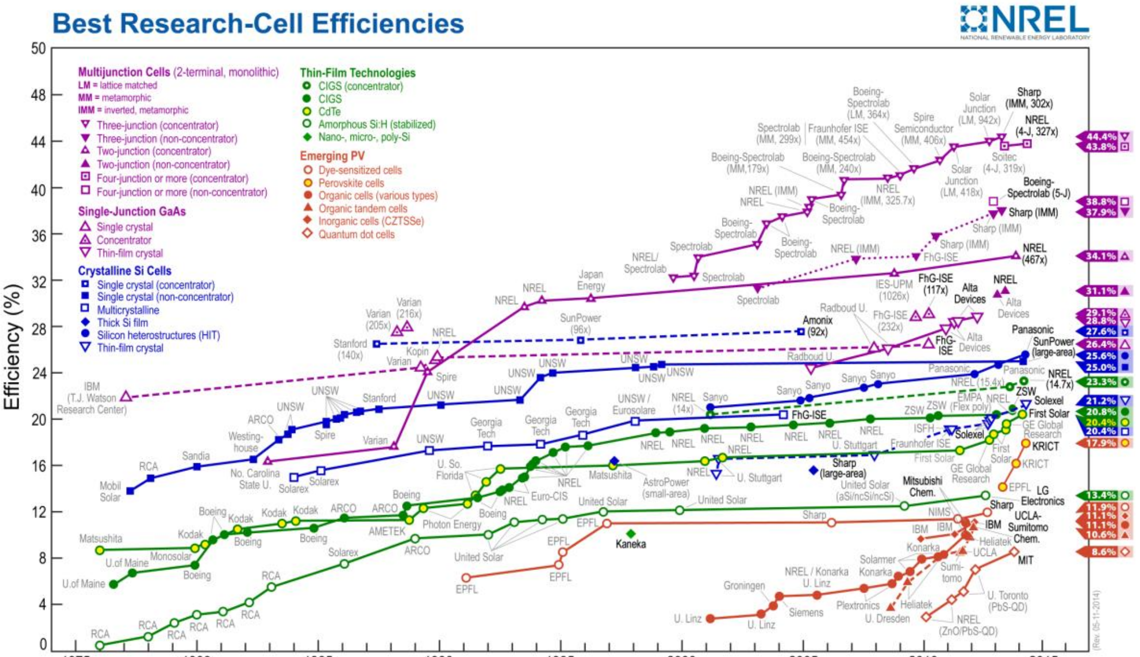

Figure 1.1. Best research-cell efficiencies [4].

By the year 2040, it is expected that solar energy would account up to 30% of the global energy supply [5]. However, this will not be materialized if the main challenges of solar cell systems are not addressed. Lower power cost (i.e. cost per power output, \$/Wp) is one of the major factors affecting the decision of switching to solar energy. The ultimate goal is to reduce the power cost to as low as \$0.40/Wp or at an energy cost of \$0.02/kWh [2]. Apart from that, higher efficiencies of solar cell systems will contribute positively to the overall system cost and energy payback times. It is suggested that excitonic and novel materials with high efficiency photovoltaic technologies have the edge of reaching this goal.

The hurdles described above have been addressed (although not entirely) with the introduction of dye-sensitized solar cell (DSSC) [6]. Since the discovery of this cell, numerous researches have been dedicated to develop and enhance the architecture of DSSC. This led to the development of quantum dot-sensitized solar cell (QDSSC), which have the potential of achieving higher efficiency with low fabrication cost [7]. It is even presented that solar cell employing quantum dots (QDs) can achieve a maximum theoretical conversion efficiency up to 66% [8]. However, at present the reported efficiencies of QDSSC are still low compared to mature silicon photovoltaic. Therefore, in-depth investigation and understanding of QDSSC are required for the development of this type of solar cell technology. This thesis will therefore, provide a basis for the development of high efficiency QDSSC. CdS and CdSe were selected to be used as sensitizers due to their excellent optical properties (see Chapter 2 for more details). CdS and CdSe QDSSCs have been highly reported in journals in recent years.

1.2 Objectives

This thesis makes a contribution to the optimization of QDSSC with CdS and CdSe QDs as sensitizers. The optimization study includes a focus on the configuration of the cell assembly, namely electrolyte and counter electrode towards an optimum cell performance. The major part of the work emphasizes on the optimization of QD sensitizers in the photoanode. The output is aimed to be a basis for developing CdS and CdSe QDSSCs.

As QDSSC does not work well with iodide-based electrolyte, it is crucial to review the alternative electrolyte to be used in the cell. Since CdS QDSSC has a reported suitable polysulfide liquid electrolyte, it is therefore timely to develop a similar polysulfide liquid electrolyte for CdSe QDSSC [9]. The outcome of this work is then able to complement to the existing CdSe QDSSC study.

Finally, in order to achieve higher efficiency, a different photoanode configuration study was carried out, particularly on the deposition layer of QD sensitizers and passivation layers. The aim is to find the best photoanode configuration for optimum cell performance. The result is expected to pave way for future development and enhancement work on QDSSC.

1.3 Overview

This thesis is divided into 9 main chapters. Most of the chapters are presented in journal article form. Some of the chapters have been published and some have been prepared for future submission. Chapter 2 has been published as "Jun, H.K., Careem, M.A., & Arof, A.K. (2013). Quantum dot-sensitized solar cells – perspective and recent developments: A review of Cd chalcogenide quantum dots as sensitizers. *Renewable and Sustainable Energy Reviews,* 22, 148-167". This chapter gives the detailed overview of QDSSC from optical, electrical and physical properties point of view. A brief introduction of the fabrication of QDs is included in this chapter.

Chapter 3 outlines the steps used to synthesize and characterize the QD sensitizers. Also described are the characterization methods for solar cell device which form the crucial part of the scientific research.

Chapter 4 has been published as "Jun, H.K., Careem, M.A., & Arof, A.K. (2014). Fabrication, characterization and optimization of CdS and CdSe quantum dot-sensitized solar cells with quantum dots prepared by successive ionic layer adsorption and reaction. *International Journal of Photoenergy,* Volume 2014, Article ID 939423, 14 pages". This work depicts the first step of the optimization study. CdS and CdSe QDs were fabricated via wet chemical process. The optimum parameters required to produce a high efficiency QDSSC are reported. Subsequently, the development of suitable polysulfide liquid electrolyte for CdSe QDSSC is described in Chapter 5. This chapter has been published as "Jun, H.K., Careem, M.A., & Arof, A.K. (2013). A suitable polysulfide electrolyte for CdSe quantum dot-sensitized solar cells. *International Journal of Photoenergy,* Volume 2013, Article ID 942139, 10 pages". Compatible counter electrode materials for CdS and CdSe QDSSC are presented in the following chapter where it has been published as "Jun, H.K., Careem, M.A., & Arof, A.K. (2014). Performances of some low-cost counter electrode materials in CdS and CdSe quantum dot-sensitized solar cells. *Nanoscale Research Letters,* 9, 69".

The study of QDs multilayered structure is reported in Chapter 7. In this chapter, optimization of the CdS and CdSe QDSSCs was further investigated by applying co-sensitization technique of both QD materials. Also included in this study is the effect of Zn chalcogenide layer as the passivation layer. Chapter 7 has been prepared for submission as "Jun, H.K., Careem, M.A., & Arof, A.K. Investigation of multilayered quantum dot-sensitized solar cells with different Zn chalcogenide passivation layers". Finally, high efficiency QDSSC is reported in Chapter 8. This work concluded the most effective technique used for the enhancement of solar cell performance. This chapter has been published as "Jun, H.K., Careem, M.A., & Arof, A.K. (2014). Efficiency improvement of CdS and CdSe quantum dot-sensitized solar cells by TiO_2 surface treatment. *Journal of Renewable and Sustainable Energy*, 6, 023107". Overall conclusions and future outlook are summarized in the final chapter, Chapter 9.

1.4 References

[1] Lewis, N.S., & Crabtree, G. (2005). *Basic research needs for solar energy utilization. In: 2005 Report on the Basic Energy sciences Workshop on Solar*

Energy Utilization. Retrieved from U.S. Department of Energy website: http://www.er.doe.gov/bes/reports/files/SEU_rpt.pdf

[2] U.S. Deparment of Energy (2010). *2009 Renewable Energy Data Book.* Washington, DC.

[3] Curtright, A.E., Morgan, M.G., & Keith, D.W. (2008). Expert assessments of future photovoltaic technologies. *Environmental Science and Technology,* 42, 9031-9038.

[4] *Research cell efficiency records (May 12, 2014)*. Retrieved May 12, 2014, from National Renewable Energy Laboratory website, http://www.nrel.gov/ncpv/images/efficiency_chart.jpg.

[5] Resch, R. (2007, June 1). The promise of solar energy: A low-carbon energy strategy for the 21st century. *UN Chronicle,* Vol. XLIV, No. 2. Retrieved from www.unchronicle.un.org/

[6] O'Regan, B., & Grätzel, M. (1991). A low-cost, high-efficiency solar cell based on dye-sensitized colloidal TiO_2 films. *Nature,* 353, 737-740.

[7] Grätzel, M. (2001). Photoelectrochemical cells. *Nature* 414, 338-344.

[8] *Innovation (June, 2010)*. Retrieved July 11, 2011 from National Renewable Energy Laboratory website: http://www.nrel.gov/innovation/pdfs/47571.pdf.

[9] Lee, Y.-L., & Chang, C.-H. (2008). Efficient polysulfide electrolyte for CdS quantum dot-sensitized solar cells. *Journal of Power Sources,* 185, 584-588.