UNIVERSITI PUTRA MALAYSIA

# *EFFECT OF CARBON QUANTUM AND GRAPHENE QUANTUM DOTS ON EFFICIENCY OF DYE-SENSITIZED SOLAR CELLS*

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ITMA 2021 13

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By

**NAZALEA YAZMIN BINTI MUHAMMAD**

**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science**

**February 2020**

## DEDICATION

**This thesis is dedicated to my beloved parents, family members and friends for their endless love, supports and encouragement <3**

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

**EFFECT OF CARBON QUANTUM AND GRAPHENE QUANTUM DOTS ON EFFICIENCY OF DYE-SENSITIZED SOLAR CELLS**

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**February 2020**

**Chairman : Mohd Nazim Mohtar, PhD**
**Institute : Advanced Technology**

Dye Sensitize Solar Cell (DSSC) is a photo electrochemical cell that has a comparative mechanism as photosynthesis in nature with effective electron separation, enabling the cell to perform well under overcast condition. In any case, unfortunate recombination response of generated electrons with oxidized species has limited the advancement of high performing DSSC. The recombination process can be limited by integrating photoanode film with a thickness smaller than electron diffusion length. However, a very thin photoanode film has low capability to confine light and anchor dye molecules. This study aims to improve the performance of DSSC through applying advanced material, Graphene Quantum Dots (GQDs) and Carbon Quantum Dots (CQDs) in the photoanode. Both known to have high electron mobility and high surface area with good photoluminescence properties make it a right decision to choose it as enhancer for DSSC. Photoanode was immersed in the enhancer solution in a series of adsorption time. This is to identify the optimum adsorption time for the enhancer. It has been observed that adsorption of GQDs of 48 hours achieved the highest efficiency, which is at 4.53%. Besides that, the value of short circuit current ($J_{SC}$), open circuit voltage ($V_{OC}$) and fill factor (FF) is 12.26 mA cm$^{-2}$, 0.72 V, 0.55 sequentially. Meanwhile, the adsorption time of CQDs reached the highest efficiency, which is at 3.50% also at 48 hours. In addition, the value of short circuit current ($J_{SC}$), open circuit voltage ($V_{OC}$) and fill factor (FF) is 10.01 mA cm$^{-2}$, 0.68 V, 0.51 consequently. Both enhancers have been observed to successfully enhance the efficiency and performance of the cell with conventional DSSC fabricated in this laboratory.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

**KESAN TITIK KUANTUM KARBON DAN KUANTUM GRAPHENE PADA KECEKAPAN SEL SURIA PEKA PEWARNA**

Oleh

**NAZALEA YAZMIN BINTI MUHAMMAD**

**Februari 2020**

**Pengerusi : Mohd Nazim Mohtar, PhD**
**Institut : Teknologi Maju**

Sel Suria Peka Pewarna (DSSC) adalah sel elektrokimia foto yang mempunyai perbandingan mekanisme sebagaimana sifat fotosintesis dengan pemisahan elektron yang berkesan, membolehkan sel berfungsi dengan baik di bawah keadaan mendung. Walau bagaimanapun, proses penggabungan di antara elektron dengan spesis teroksida menghalang pembangunan DSSC berkecekapan dengan tinggi. Proses penggabungan semula dapat dikurangkan dengan menggunakan filem anod foto yang lebih nipis berbanding panjang keperesapan elektron. Tetapi, filem anod foto yang nipis tidak mampu memerangkap cahaya dan menyerap pewarna secara optimum. Kajian ini bertujuan untuk meningkatkan prestasi DSSC melalui penggunaan bahan canggih, Graphene Quantum Dots (GQDs) dan Carbon Quantum Dots (CQDs) dalam anod foto. Kedua-duanya diketahui memiliki mobiliti elektron yang tinggi dan kawasan permukaan yang tinggi dengan sifat foto pendarcahayaan yang baik, menjadikannya keputusan yang tepat untuk memilihnya sebagai penggalak untuk DSSC. Anod foto telah direndam dalam larutan penggalak pada beberapa siri masa penjerapan. Ini adalah untuk mengenal pasti masa penjerapan optimum untuk penggalak. Telah diperhatikan bahawa penjerapan GQDs selama 48 jam mencapai kecekapan tertinggi, iaitu pada 4.53%. Sementara itu, masa penjerapan CQDs mencapai kecekapan tertinggi, iaitu 3.50% juga pada 48 jam. Kedua-dua penggalak telah diperhatikan untuk meningkatkan kecekapan dan prestasi sel dengan DSSC konvensional yan direka di makmal ini.

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First, praise to The Almighty, on whom ultimately, we depend for guidance and sustenance. With His blessing, we can make this thesis finished.

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I hereby confirm that:
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Signature: ________________________
Name of Member of Supervisory Committee: Dr. Muhammad Mahyiddin bin Ramli

## TABLE OF CONTENTS

## LIST OF TABLES

## LIST OF FIGURES

## LIST OF ABBREVIATIONS

| | |
|---|---|
| % | Percentage |
| ˚C | Degree Celsius |
| u | Micro |
| *A* | Ampere |
| AM | Air mass density |
| C | carbon |
| Ca | Calcium |
| CB | Conduction band |
| CdTe | Cadmium Telluride |
| CE | Counter electrode |
| $CH_4$ | Methane |
| CIS | Copper Indium Selenide |
| CISG | Copper Indium Gallium Selenide |
| $CO_2$ | Carbon dioxide |
| CQDs | Carbon Quantum Dots |
| DSSC | Dye Sensitized Solar Cell |
| $E_0$ | Standard potential |
| $E_{2g}$ | Double generation Raman active optical vibration |
| *Ec* | Energy of conduction band |
| $E_{CB}$ | Energy of conduction band |
| EDS | Energy-dispersive X-ray spectroscopy |

| | |
|---|---|
| $E_F$ | Fermi level in dark conditions |
| $eV$ | Electron volt |
| ex | Excitation |
| ET | Electron transfer |
| FF | Fill Factor |
| FTO | Fluorine-doped Tin Oxide |
| GHG | Greenhouse Gas |
| GQDs | Graphene Quantum Dots |
| $H_2O$ | Water vapor |
| HOMO | Highest occupied molecular orbital |
| HRTEM | High Resolution Transmission Electron |
| $I$ | Current |
| $I$ | Iodide |
| IPA | Isopropyl Alcohol |
| $Isc$ | Short circuit current |
| $I$-$V$ | Current - Voltage |
| $J$ | Current density |
| $Jmax$ | Current density at maximum power point |
| $Jsc$ | Current density at short circuit conditions |
| $J$-$V$ | Current Density – Voltage |
| $K$ | Kelvin |
| $k_B$ | Boltzman constant |

| | |
|---|---|
| LUMO | Lowest unoccupied molecular orbital |
| M | Molar |
| $\eta$ | Efficiency |
| $N_2O$ | Nitrous Oxide |
| Na | Sodium |
| NHE | Normal Hydrogen Electrode |
| $O_2$ | Oxygen |
| $O_3$ | Ozone |
| $P$ | Power |
| PCE | Power Conversion Efficiency |
| PL | Photoluminescence |
| Pt | Platinum |
| PV | Photovoltaic |
| QDs | Quantum Dots |
| RGO | Reduced Graphene Oxide |
| *rpm* | Revolution per minute |
| Ru | Ruthenium |
| SEM | Scanning Electron Microscopy |
| Si | Silicon |
| $TiCl_4$ | Titanium Tetrachloride |
| $TiO_2$ | Titanium Dioxide |
| UHV | Ultra High Vacuum |

| | |
|---|---|
| UV | Ultraviolet |
| UV-Vis | Ultraviolet Visible Spectroscopy |
| $V$ | Voltage |
| $V_{max}$ | Voltage at maximum power point |
| $V_{oc}$ | Open Circuit Voltage |
| $W$ | Watt |
| WE | Working electrode |
| $\theta$ | Degree |
| $\lambda$ | Wavelength |
| $\lambda_{ex}$ | Excitation wavelength |

## CHAPTER 1

## INTRODUCTION

Humankind needs energy for stay living. Besides the energy in our food are necessary to sustain our body and make it function (100 W), it also believed that 30 times more energy is utilized on average to make our life progressively comfortable. Energy is defined as the capacity for doing work reported by (N. Hicks, 1998). It may exist in potential, kinetic, thermal, electrical, chemical, nuclear, or other various forms. An energy can do a transition was form one energy to another energy. For example, sunlight was used in solar cells to convert the light energy into an electrical energy described by (D. Gielen et al., 2019). Meanwhile, wind turbine blades capture the wind energy and turn it into mechanical energy. There are nine major areas of energy resources, which fall into two categories. There are nonrenewable and renewable energy. Nonrenewable energy resources, like natural gas, coal, nuclear, and oil are available in limited supplies reported by (BT. Mambu, 2018). This is usually due to the long time it takes for them to renew. On the other hand, renewable resources are replenished naturally, and over relatively short period explained by (BT. Mambu, 2018). The five major renewable energy resources are biomass, solar, geothermal wind, and hydro. Table 1.1 shows the difference between renewable energy and nonrenewable energy.

**Table 1.1 : Differences of renewable and nonrenewable energy**

| Description | Nonrenewable Energy | Renewable Energy |
|---|---|---|
| Mode of harnessing | Surface and underground mining | Solar panel, hydro dam, wind vane, geothermal plants, waste to energy plants |
| Usage | Raw materials and energy | Raw materials and energy |
| Components and derivations | Recycling challenge and increased geothermal gradient | None |
| Estimated time to replenish | Million's years | Non-exhaustible |
| World consumption | >7,000 trillion tons per year | 20,000 – 50,000 million tons per year |

(Source: B T. Mambu, 2018)

The solar cell effect discovered by the French scientist Edmond Becquerel in 1839 after observing two electrodes attached to a solid or liquid system (E. Becquerel, 1839) producing electrical potential between electrodes. He purposed that; this method is the basic concept to convert solar light radiation into electrical energy. This is because; one simple reason is that the Earth receives 1.2 x 1017 *W* insolation or 3 x 1024 *J* energy per year from the Sun.

This means it only covering 0.13% of the Earth's surface with solar cells with an efficiency of 10% that would satisfy our present needs by (M. Grätzel, 2001).

Solar power generation has emerged as one of the most rapidly growing renewable sources of electricity reported by (D. Gielen et al., 2019). Electrical power sector consumption of fossil fuel was at the lowest level since 1994 due the increasing of renewable energy usage such as solar energy. Solar energy production does not require fossil fuels, in this way less reliant on this limited and expensive natural resource compared to non-renewable energy. Although there is variability in the amount and timing of sunlight over the day, season and year, a properly sized and configured system can be intended to be exceptionally reliable while providing long-term up to 30-40 years. Besides that, it also environmentally friendly and it requires minimal maintenance requirements. Solar power production generates electricity with a constrained impact on the environment as compared to other forms of electricity production.

The usage of solar cells keeps increasing day by day. Countries that have the highest installed capacity of solar PV power mostly are from Europe. Germany and Italy are in top two followed by Spain, France, Belgium and Czech Republic in sixth, seventh, eighth and tenth accordingly. Australian is in top ninth while Asia, which are China and Japan are in top third and fifth. Between them is United State of America by (A. Almerini, 2019). At the top, Germany has by far the highest capacity of solar photovoltaic power (PV) in the world at 32.4 GW (31%) at the end of 2012 reported by (A. Almerini, 2019). Germany's solar panels generated about 23 TW/h (terawatt hours) of electricity in 2012, which is impressive, but still only covers 3% of the country's total electricity consumption. Market analysts believe this number will increase to 25% before 2050. Germany aims for a total capacity of 66 GW by 2030 with an annual growth of 2.5 - 3.5 GW stated by (A. Almerini, 2019). Other countries in Europe have also started to implement similar incentives: Italy added more than 3.4 GW of solar PV capacity in 2012 by (A. Almerini, 2019). Spain, France, UK, Greece and Bulgaria were also started the same initiatives. The U.S. places number four on the list with a total solar PV capacity of 7.8 GW, right behind China at 8.3 GW. The California Solar Initiative is at the forefront of the development. California, as of June 2013, has close to 1.6 GW of solar power described by (A. Almerini, 2019). South America such as New Mexico and Colorado also started to follow same steps as the North America stated by (A. Almerini, 2019). Meanwhile in Malaysia, solar panel manufacturing is the third world manufacturer after China and Taiwan and the government is committed to reduce its Greenhouse Gas (GHG) by 45% by 2030 reported by (WSW. Abdullah et al., 2019). Government is investing a huge impact in order to develop and promote this solar cell technology. Figure 1.1 shows the revolution of solar cells in industry and the prediction of solar cell growth around the world.

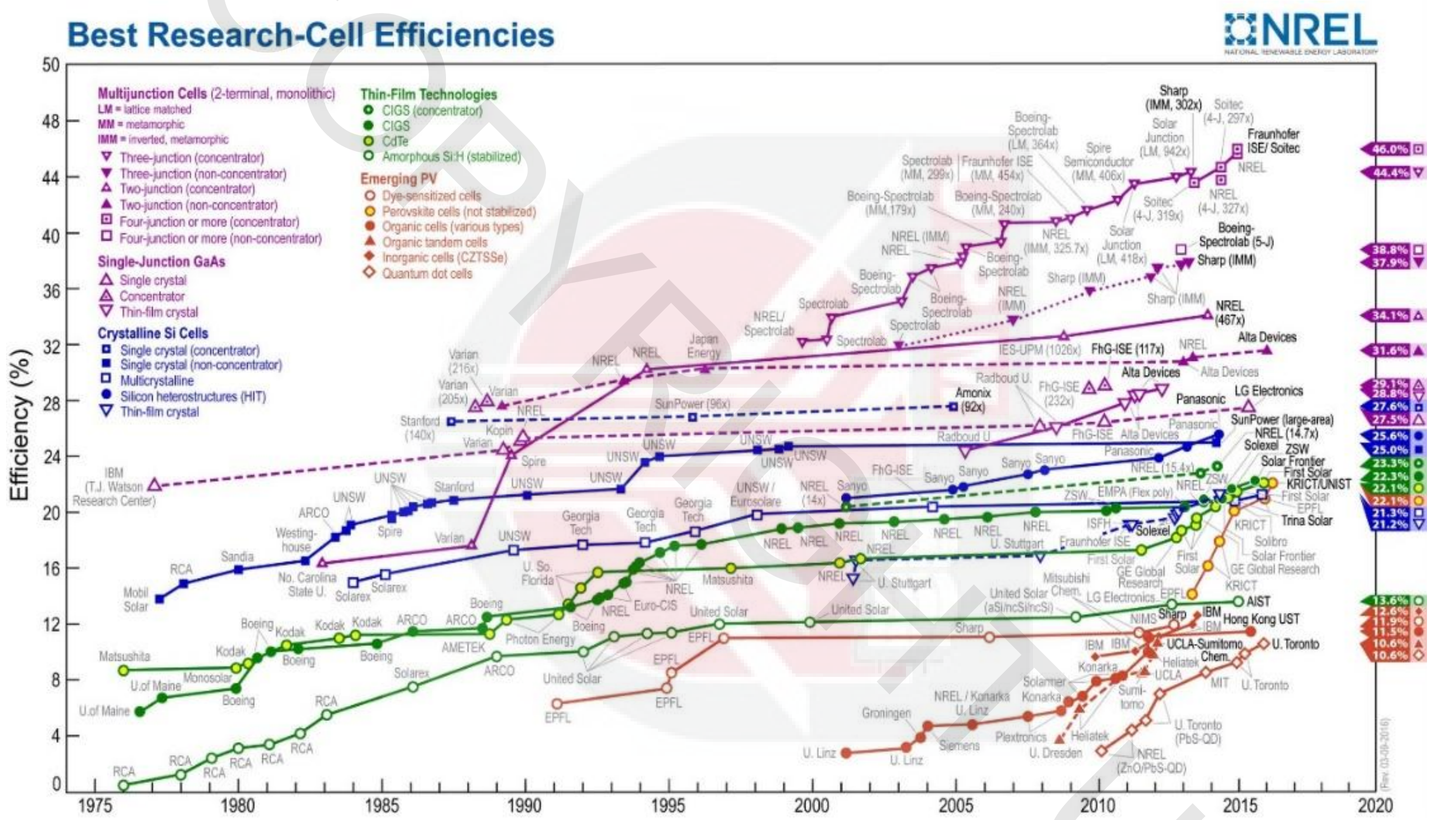


**Figure 1.1 : Solar cell industry revolution**
(Source: https://www.nrel.gov/pv/cell-efficiency.html)

## 1.1 Solar cell generation

Renewable energy technologies are clean sources of energy because it gives low environmental impact than conventional energy technologies such as global warming and improve public health reported by (PR. Epstein et al., 2011). Renewable energy will not run out, while the conventional energy is limited and it will eventually dwindle, becoming excessively costly or becoming harm to the environment. There are many types of renewable energy such as wind and solar energy. Solar Cells technology is one of the promising photonic devices that can convert light energy into electrical energy without releasing carbon dioxide, which leads to global warming. Until today, solar cells have gone through three generations since Bequerel discovered it in 1839. The first generation of solar cells is made from crystalline silicon. The silicon solar cells have high efficiency up to 25%, but it complicated and expensive to fabrication stated by (S. Chinnusamy et al., 2018) and (Zijian Xia, 2010). The second generation was developed using thin film and it can convert 22% from the sunlight energy to electrical energy, but it has toxicity and limited by the Shockley-Queisser limit described by (Y.Xu, T.Gong & JN. Munday, 2015). The Shockley-Queisser limit describes the maximum solar energy conversion efficiency achievable for a particular material and it is the standard by which new photovoltaic cell. In contrast with the first generation, second generation solar cell are more flexible, lightweight and aesthetically pleasing solar innovations which can be rolled out on roofing or other surfaces by (M. Pagliaro, G. Palmisano & R. Ciriminna, 2008). 86% of the current solar market was dominated by the first generation solar photovoltaic with the highest recorded efficiency of 24.7% for a laboratory cell and about 15% for solar panels reported by (T. M. Razykov et al., 2011) which is much higher compared to the second-generation solar technology. However, the first-generation solar cells demand high purity silicon (Si) thus requires high-level semiconductor technology and very capital-intensive.

The third generation was created to overcome the toxicity in second generation and aiming to produce low-cost solar cells. On top of that, it also designed to overcome the drawback of current solar cell technology and emerged as a new technology soon. This technology is still in the research phase and generally comprises of non-semiconductor technologies (polymer-based cells and biomimetic), dye-sensitized solar cells (DSSC), quantum dot technologies, hot-carrier cells, tandem/multi-junction cells, and up-conversion technologies reported by (G. F. Brown & J. Wu, 2009). The advantage of the third generations over other generation is that they offer very high possibilities for improving parameters such as charge generation, separation, molecular mass, band gap, molecular energy levels, rigidity, and molecule-to-molecule interactions stated by (G. F. Brown & J. Wu, 2009). Besides that, material used are more flexible (substrates) and have lower production cost with almost 30-40% compared to the previous two generation. Between all these three generations, dye sensitized solar cells (DSSC) attracts great research interest due to ease of fabrication with low manufacturing cost, environmentally friendly components and significant performance under diffuse light condition. Table 1.2 shows the generation of solar cell from the first generation to the third generation.

**Table 1.2 : Generation of solar cell.**

| Generation | 1st generation | 2nd generation | 3rd generation |
|---|---|---|---|
| Types | • Single Crystal Solar Cells<br>• Multi Crystal Solar Cells | • Si thin film solar cells<br>• mc-Si solar cells<br>• CdTe solar cells<br>• CIS & CIGS solar cells | • Nanocrystal based solar cells<br>• Polymer based solar cells<br>• Dye sensitized solar cells<br>• Concentrated solar cells. |
| Advantages | It has high conversion efficiency | • It has high absorption co-efficient<br>• It can occupy both vacuum and non-vacuum process.<br>• Lower cost in comparison of Si based solar cell.<br>• Low-cost substrate | • Raw materials are easy to find<br>• Easier fabrication process rather than other two technology<br>• Cost is minimal |
| Disadvantages | • High cost<br>• Fabrication process is complex. | • Environment contamination starts from fabrication process.<br>• Materials are hard to find. | • Liquid electrolyte (low temperature)<br>• High cost, Ru (dye) and Pt (electrode) |

(Source: M. T. Kibria et al., 2014)

## 1.2 Dye sensitized solar cell

The third generation is a dye-sensitized solar cell (DSSC) which is based on the concept of photosensitization of wide band-gap mesoporous oxide semiconductors reported by (AN. Zulkifili et al., 2015). It consists of two electrodes (working electrode and counter electrode), photosensitizer, nanostructured wide bandgap semiconductor layer, and electrolyte. Transparent electrode is used in DSSC to allow light to penetrate to it. In previous work, Fluorine-doped Tin Oxide has been used as the electrodes stated by (NFM. Sharif et al., 2019). DSSC needs photosensitizer to absorb light and the subsequent electron-transfer reactions, and its quality. The photosensitizer is divided into two categories, which are synthetic dye and natural dye. The natural dye can be obtained from flower and fruit, which makes it a low-cost dye. It has been reported at previous work, a natural dye cannot reach a high efficiency, which leads to the production of synthetic dye by (T. Oku et al., 2011). To achieve high efficiency, Ruthenium complex dye (N719 dye) is widely used as synthetic dye while Protoporphyrin IX (PPIX), Xylenol Orange (XO) and Rose Bengal (RB) are examples of natural dyes that commonly used for photosensitizer reported by (T. Oku et al., 2011), (P. E. Marchezi et al., 2016) and (X. Guo et al., 2017). The selection of photosensitizer is important because it is one of the factors that will determine the power conversion efficiency (PCE) produced by the DSSCs.

The efficiency of a standard DSSC cannot be increase anymore, therefore a few researchers have investigated about methods that they can applied to enhance the efficiency of DSSC. Previous work has investigated the uses of quantum dots as photosensitizer in DSSCs reported by (X. Guo et al., 2017). Size-tuned optical response, efficient multiple carrier generations, and low cost are beneficial properties of quantum dots such that makes them attractive for Dye-Sensitized Solar Cells (DSSCs) devices by (S. Paolo et al., 2016). However, from the previous studies, quantum dots that are composed of toxic metals, such as cadmium and lead, which would pose serious problems for large-scale device applications by (S. Paolo et al., 2016). In contrast, the 10-nm quantum dots made of graphene and carbon that have fabricated before this, do not have the same hazardous nature, yet they have similar electronic properties. Most importantly, quantum dots have a high charge carrier mobility, which means that it can increase the speed of transporting charges to the electrodes, reducing current losses and improving solar cell efficiency. Adding carbon-based quantum dots as photosensitizer into DSSCs have proved to have a better efficiency compared to the traditional DSSC stated by (T. Oku et al., 2011). This work has implications for inexpensive and efficient solar cells and the potential advantages are lightweight, flexible, cost-effective, large area processing and multipurpose use, which make it suitable to be used as a photosensitizer in DSSCs.

In this work, Graphene Quantum Dots (GQDs) and Carbon Quantum Dots (CQDs) has studied as carbon-based quantum dots to be added as enhancer for DSSC. Graphene is known as a single atomic layer of graphite that has attracted the interest of researchers because of their interesting optical and electronic properties. Its act as a conductive material because it has zero-bandgap semiconductor. It is a single layer of carbon packed in a hexagonal lattice with a carbon-carbon distance of 0.142 nm. It representative of whole class of 2D materials as the first two-dimensional crystalline material (Novoselov et al. 2005). Meanwhile, the quantum dot is a nanometer-sized object, where excitons are confined in all three spatial dimensions (M. Bacon et al. 2014). The diameter of the quantum dots must be in the range of 3-20 nm (Hanjun et al. 2013). Therefore, GQDs are small graphene fragments but multi-layer formations containing up to 10 layers of reduced graphene oxide (RGO) from 10 to 60 nm in size (M. Bacon et al. 2014), where electronic transport is confined in all three spatial dimensions and cause a quantum size effect. Due to its unique properties such as low toxicity, pronounced quantum confinement, effect chemical stability and stable photoluminescence, GQDs is known as a unique material for biological, electronic, biomedical, optoelectronics, energy and environmental applications (Hanjun et al 2013). The GQDs are becoming a multifunction material for its unique optical, electronic, and photoelectric properties convince by the edge effect and quantum confinement effect.

Meanwhile for CQDs, were first discovered accidentally during the purification of single-walled carbon nanotubes by (Xu et al., 2004). This discovery triggered extensive studies to utilize the fluorescence properties of CQDs. The CQDs emit bright fluorescence, which can gradually tune from blue to red continuously, almost covering the completely visible spectrum by (X. Song et al., 2019). Many progresses have achieved in the synthesis, properties and applications of CQDs by (Wang, Youfu Hu & Aihuo et al., 2014). As a new class of fluorescent carbon nanomaterials, CQDs own an attractive property of high stability, environmental friendliness, good conductivity, simple synthetic routes, and low toxicity as well as comparable optical properties to quantum dots by (Chan et al., 2002). CQDs have been extensively investigated especially due to their strong and tunable fluorescence emission properties by (Lim et al., 2015), which suitable for various applications such as catalysis, biomedicine, optoelectronic, solar cell and sensing.

These both quantum dots, GQDs and CQDs have unique properties such as stable photoluminescence and low toxicity. Their unique properties make them suitable to use as solar cell, optoelectronic and sensing application.

## 1.3 Problem statement

1. Applying Graphene Quantum Dots (GQDs) and Carbon Quantum Dots (CQDs) as enhancer to dye sensitized solar cell is a new challenge. Previous work, GQDs and CQDs are applied in DSSC without adding Ruthenium in photoanode but it does not achieve high efficiency. Although the properties are suitable for DSSCs, but we still do not know is it suitable to be apply as an enhancer to DSSC.

2. Previous work of enhancer has done before, but the method of applying enhancer in DSSC is still questionable. There are a few methods such as immersing method, mixing method, doping method and coating method. Therefore, we are trying to identify the best method in applying GQDs that can provide high efficiency of DSSC including the adsorption time of enhancer.

3. There are no consistent results from previous work, which state the performance differences of DSSCs with the presence of enhancer in photoanode (with and without GQDs and CQDs). Therefore, we will characterize both quantum dots and compare it.

## 1.4 Research objective

1. To study the effect of GQDs and CQDs adsorption time towards the efficiency.

2. To compare the performance of GQDs and CQDs used in photoanode with the conventional DSSC.

3. To characterize the material (GQDs and CQDs) used as an enhancer in photoanode by using UV-Vis, Raman Spectroscopy, HRTEM, SEM and EDS.

## 1.5 Scope of work

This study is divided into three different sections. The first section focuses on the material used as an enhancer for the DSSC, which are GQDs and CQDs. In this section, GQDs purchased from Sigma Aldrich was used. Meanwhile, the CQDs, we obtained it from Harvest$^{TM}$. The material has been characterized for its physical properties by using Scanning Electron Microscopy (SEM), and High-Resolution Transmission Electron Microscopy (HRTEM). The quality properties were characterized by using Raman Spectroscopy, and Energy-dispersive X-ray spectroscopy (EDS). Lastly, Ultraviolet Visible Spectroscopy (UV-Vis) was used to characterize the optical properties.

Section two focuses on the method of applying enhancer in DSSC. There are several methods that can we used to help increase the efficiency of enhancer in DSSC. Absorption and adsorption methods are applied in this section. The efficiency of DSSC is observed to effect of different methods towards the performance of DSSC. On top of that, adsorption time of the enhancer also varied, to observe the impact to the performance of photoanode. The different adsorption time will affect the thickness of photoanode. Therefore, the thickness of photoanode is measured by using SEM.

Section three emphasizes the improvement of light harvesting efficiency and dye absorption capability of photoanode. As of section two, two material approaches were implemented as an enhancer for the DSSC. The performance of the DSSC was measured by using Solar Simulator with the intensity of 1000 W/m$^2$. The efficiency of the DSSC was compared between the material ad time adsorption. After that, the results will be compared with the conventional DSSC (without enhancer).

## 1.6 Outline of the thesis

This thesis is arranged in five chapters. The first chapter is an introductory chapter, which gives an overview of the renewable energy and non-renewable energy. It also overviews the generation of solar cell solar and usage of solar cell as the potential source of renewable energy specifically DSSC as a promising third generation solar technology. This chapter also covers the background of the research study, problem statement, objective as well as scope of the work.

Chapter 2 establishes the review of literature related to this study. It includes the explanation of solar cell. Then, it also included the explanation about DSSC and the operating principle of DSSC and performance evaluation through J-V characteristic. On top of that, it also explained about GQDs, CQDs, and the properties that make it possible as an enhancer for DSSC. Besides, the chapter also discussed the previous research attempting to improve the efficiency by adding enhancer inside the photoanode.

Chapter 3 describes the methodology designed to tackle the problem statement and to achieve the objectives of this research study. This chapter explains the procedure in preparing photoelectrode paste, fabrication of dye-sensitized solar cell, characterization procedures to study the physical, optical, and quality properties of the prepared photoelectrode material and the performance analysis of solar cells.

Chapter 4 shows the outcomes of from chapter 3. This chapter discussed the result thoroughly to establish the suitable enhancers, method of applying the enhancer and the performance of the DSSC added enhancer.

Chapter 5 concludes the observation and finding of this research study. This chapter also highlights the novelty, contribution of the research study and recommendation of future research directions that can further improve the performance of a DSSC.

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