Ain Shams University
Faculty of Science
Chemistry Department

Preparation of Graphene and its derivatives for applications in Solar Cells

A Thesis in Chemistry

Submitted for the Degree of Doctor of Philosophy of Science in Chemistry

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M. Sc., Chemistry, 2012

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Abstract

Dye-sensitized solar cell (DSSC) is built with combining many components in order to convert the solar energy to electricity. One of the DSSC components is a metal oxide semiconductor which plays the role of electron transport layer (ETL). It receives electrons from photoexcited dyes attached on its surface and ensures the electron transfer to the back contact of the solar cell. Developing the metal oxide that fulfills the requirements as an ETL is one of the effort to increase the DSSC power conversion efficiency. The layer thickness was optimized to be three layers. The electrode made of 1 wt. % graphene (GR) and TiO_2 gives the highest photovoltaic efficiency 0.54 %. The electrode made of 1 wt. % GR-TiO_2 -5 wt. % ZrO_2 NF gives the highest photovoltaic efficiency 0. 19 %. The electrode made of 1 wt. % GR-TiO_2 -7 wt. % SnO_2 NF gives the highest photovoltaic efficiency 0.13 %. Titania nanofibers are more effective for increasing the power conversion efficiency than zirconia nanofibers and tin oxide nanofibers. TiO_2 NF > ZrO_2 NF > SnO_2 NF. The use of N3 dye instead of the expensive N719 as well as the carbon counter electrode instead of Pt will lower the cost of fabrication of the DSSCs. The formation of graphene sheets was first confirmed using transmission electron microscopy (TEM) and X-ray diffraction (XRD). All photoelectrodes are prepared by spin coating technique. The morphology of photoelectrodes has been characterized using scanning electron microscopy (SEM). The cell performances were obtained by measuring the I-V curves of the cells under calibrated illumination.

Keywords: Dye-sensitized solar cell, electron transport layer, photoelectrode, TiO_2, graphene, nanofibers.

Aim of the work

The aim of the current research is to advance the performance and lower the cost of manufacturing dye sensitized solar cells through the replacement of the different solar cell components: mainly the active layer by incorporation of graphene and different ratios of different metal oxides nanofibers. Based on the background in Chapter 1, one can see that graphene, a two dimensional carbon sheet, has attracted great interests due to its unique properties. To explore its practical applications, large-scale synthesis methods with controllable integration of individual graphene sheets to advanced multi-functional structures are essential. Chemical oxidation and reduction of graphite is considered to be a very promising approach due to its low cost, easy preparation and high yield. It has been applied to prepare graphene oxide solutions, graphene-based composite materials. Chemical oxidation and reduction of graphite method includes three steps: oxidation of graphite, exfoliation of graphite oxide into graphene oxide, and reduction of graphene oxide. The oxidation of graphite produces hydrophilic graphite oxide, which can be easily exfoliated into graphene oxide in solvents, and further reduced to graphene by chemical, thermal reduction approaches.

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List of the Important Abbreviations and Symbols

AM	Air Mass
CDA	Chenodeoxycholic Acid
CVD	Chemical Vapor Deposition
DSSC	Dye-sensitized Solar Cell
EDX	Energy Dispersive X-ray
E_F	Fermi Level
ETL	Electron Transport Layer
FF	Fill Factor
FTO	Flourine doped Tin Oxide
GO	Graphene Oxide
GQDs	Graphene Quantum Dots
GR	Graphene
GuT	Guanidinium Thiocyanate
HOMO	Highest Occupied Molecular Orbital
IPCE	Incident Photon-to-electron Conversion Efficiency
IR	Infrared Rays
ITO	Indium Tin Oxide
ITO/PEN	Indium Tin Oxide coated Polyethylene Naphthalate sheets
ITO/PET	Indium Tin Oxide Coated Polyethylene Terephthalate sheets
J_{sc}	Short Circuit Current density
LLCT	Ligand to Ligand Charge Transfer
LUMO	Lowest Unoccupied Molecular Orbital
MLLCT	Metal and Ligand to Ligand Charge Transfer
N3	cis-bis (isothiocyanato) bis (2-2-bipyridyl-4,4-dicarboxylato) ruthenium (II)
PCE	Power Conversion Efficiency
PEDOT	Poly(3,4-Ethylenedioxythiophene)
SAED	Selected Area Electron Diffraction
SEM	Scanning Electron Microscope
TBP	4-Tert-Butylpyridine
TCO	Transparent Conductive Oxide
TEM	Transmission Electron Microscope
XRD	X-Ray Diffraction
VB	Valence Band
V_{oc}	Open Circuit Voltage
η	Cell Efficiency

I. Introduction & Literature Review

I.1. Background

I.1.1. Solar Energy as an Alternative Renewable Energy

Energy is one of the primary needs of human life. Nowadays, the consumption of energy is increasing not only because the population increase, but also because many activities are going to be more and more energy dependent. Modern high technology era needs energy for various purposes including communication and transportation.

The fossil fuels, including coal, liquid fuels (oil/petroleum) and natural gas, are the major energy sources in the world that supplies 80% of the world energy demands (Asif & Muneer, 2007). Fig 1.1 displays the consumption of the fossil fuels from 1965 until 2030. This fig. shows that the demand increases with time. As non-renewable energy source, the fossil fuels have disadvantages of a limited availability. In their article, Shafiee and Topal have calculated that the oil, coal and gas stocks are only sufficient for about 40, 200 and 70 years, respectively if assumed that the world-consumption rate is constant as 2006’s rate (Shafiee & Topal, 2009).

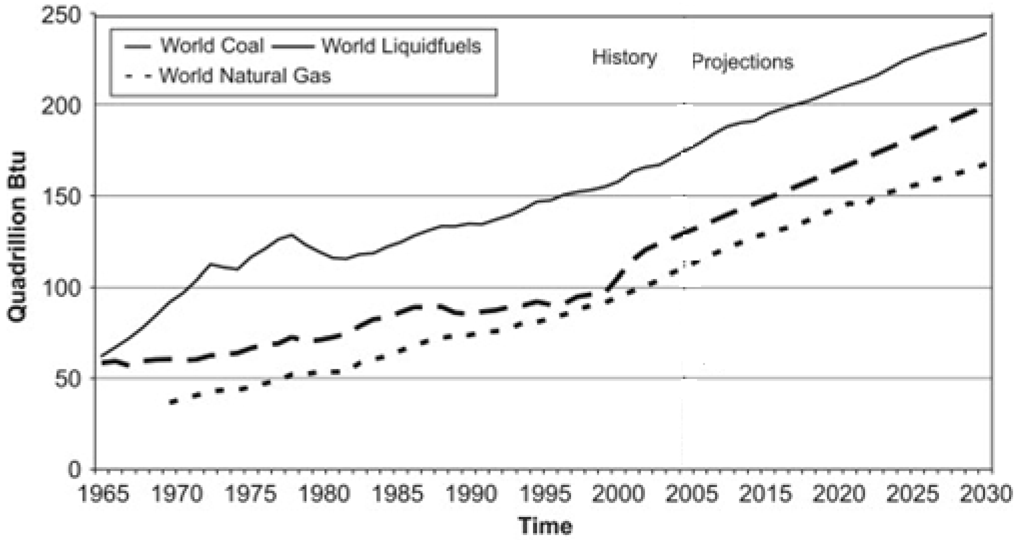

Fig. 1.1: Consumption of the fossil fuel in the world from 1965 to 2030, as an expectation (Shafiee and Topal, 2009)

Another disadvantage of the fossil fuels is their negative effect on the environment. Their combustion releases the greenhouse CO_2 gas in the atmosphere that provokes climate change and global warming (Steinberg, 1999).

The issue of the fossil fuels limited availability and the global warming effect has become a global problem and has been discussed for years. This situation has encouraged many researchers to exploit the renewable energy sources. There are many kinds of renewable energy that have potency to be used, such as: wind, solar, geothermal, hydrogen, hydroelectric or biomass energies(Jacobson & Delucchi, 2011a; Salameh, 2003). One of the potential sources of renewable energy is the solar energy. It meets three criteria as energy source which are sustainability, cleanness and low-risk (Kumar, Shrivastava, & Untawale, 2015; Surendra S. Yadav, 2015). These three criteria are important to maintain the energy system for a long term (Jacobson & Delucchi, 2011b). The availability of the solar