UNIVERSITY OF BAHRAIN

College of Science

Department of Physics

Green Synthesis, Characterization, and Application of Metallic Nanoparticles in Natural Dye-Sensitized Solar Cells

A Thesis Submitted in Partial Fulfillment of the Requirements for the Master of Science Degree in Applied Physics

Submitted by

Fatema Jaber Aljaboori

ID number: 20100847

Supervised by

Assistant Professor / Khalil Ebrahim Jasim

University of Bahrain

Associate Professor/ Fryad Zaki Henari

The Royal College of Surgeons in Ireland- Medical University of Bahrain

Kingdom of Bahrain

May, 2018

UNIVERSITY OF BAHRAIN

College of Science **Department of Physics**

Green Synthesis, Characterization, and Application of Metallic Nanoparticles in Natural Dye-Sensitized Solar Cells

A Thesis Submitted in Partial Fulfillment of the Requirements for the Master of Science Degree in Applied Physics

Submitted by

Fatema Jaber Aljaboori

ID number: 20100847

Supervised by

Assistant Professor / Khalil Ebrahim Jasim

University of Bahrain

Associate Professor/ Fryad Zaki Henari

The Royal College of Surgeons in Ireland- Medical University of Bahrain

Kingdom of Bahrain

May, 2018

University of Bahrain
Deanship of Graduate Studies
And scientific Research

جامعة البحرين
عمادة الدراسات العليا والبحث العلمي

Thesis Discussion Committee Decision

Student Name: Fatema Jaber Aljaboori	Student ID: 20100847
Department: **Physics**	College: **Science**
Program: **Masters in Applied Physics**	
Thesis Title: **Green Synthesis, Characterization, and Application of Metallic Nanoparticles in Natural Dye-Sensitized Solar Cells**	
Supervisor Name: **Dr Khalil Ebrahim Jasim**	Student GPA: Click here to enter text.

The Discussion Committee met on 14-Jun-18 In The Physics Department. Upon discussing the student whose details are stated above in public, the discussion committee recommends the following:

The student is awarded a grade A in the thesis subject.

☐ Without making any changes to the thesis.

☒ After making the modifications attached with this decision.

Discussion Committee Members Approval:

Name		Signature
1. Dr. Khalil Ebrahim Jasim	(Advisor)	Click here to enter text.
2. Dr. Aqeel Dakhel	(Internal Examiner)	Click here to enter text.
3. Pr. Dr. Shawqi Al-Dallal	(External Examiner)	Click here to enter text.

Approved at the University Council 6th meeting, 2013
In accordance with Decision No. 736/2013 dated 14/3/2013
Modified by University Council Decision No. 2043/2013 dated 20/11/2013.

ABSTRACT

In this study green synthesis of silver nanoparticles was accomplished using different natural dye extracts from various plant parts (e.g. Saffron, Salvia, Cinnamon, Gloves, and Pomegranate peels). Both the extracted natural dyes and the grown metallic nanoparticles were optically characterized using UV-visible spectroscopy as well as fluorescence spectroscopy. Also, Transmission Electron Microscopy (TEM) was used to image the grown metallic nanoparticles in order to determine their sizes distribution and shapes. Effects of dye extracts concentration, silver solutions concentration, and silver nanoparticles preparation conditions have been analyzed by studying the variations in absorbance and the characteristic wavelength of the Surface Plasmon Resonance peak (SPR) of silver nanoparticles. The green synthesis procedures of silver nanoparticles using natural dye extracts used in fabrication of dye sensitized solar cells (DSSCs) will be discussed. Operation principles, preparation, assembly and testing of the solar cells will be detailed. Electrical and optical characterization of the solar cells will be presented. It has been found that solar cell electrical parameters such as photocurrent and efficiency were improved in some cases depending on the source of the natural dye extract. Factors limiting cell efficiency will be discussed.

DEDICATION

To

My father and mother

To

My Husband Ali

To

My friends

To

All learning lovers

To

Bahrain

Fatema

2018

ACKNOWLEDGEMENT

I would like to express my sincere thanks and recognitions to my supervisor Dr. Khalil Ebrahim Jasim who gave me the opportunity to join his research activities, supported, guidance and continuous encouragements during this project. It was really a great and fantastic experience.

Also, I would like to extend my thanks and gratitude to:

- Dr. Fryad Zaki Henari (The Royal College of Surgeons in Ireland- Medical University of Bahrain), for accepting to co-supervise me, his guidance and help during the practical part of this project.

- Mrs. Fatima Al-Hanan (The Royal College of Surgeons in Ireland- Medical University of Bahrain), for her help in the lab and facilitating the needed chemicals.

Also, I would like to thank the Royal College of Surgeons in Ireland-Medical University of Bahrain for allowing me to work in their labs and help me a lot during the research work. Many thanks for Department of Physics faculty at the University of Bahrain for giving me the opportunity to do my MSc. studies and facilitating some of my lab work.

The kind support and encouragements I have received from my family were continuous and they deserve from me endless appreciations and thank you so much.

TABLE OF CONTENTS

Table of Contents

Defense committee's approval page ..... B

Abstract C

Dedication ..... D

Acknowledgement ..... E

Table of contents ..... F

List of Figures I

List of Tables ..... Q

Abbreviations ..... R

Chapter 1: Introduction 1

1.1 Introduction 2

1.2 Research Problem 3

1.3 Research Questions 5

1.4 Research Objectives 5

1.5 Research Significance 6

1.6 Research Setting 6

1.7 Definitions 7

Chapter 2: Dye-Sensitized Solar Cells (DSSC) 9

2.1 History 10

2.2 Types of solar cells 12

2.3 DSSCs materials and components 15

2.3.1 Two transparent conducting electrodes 16

2.3.2 Nanostructured wide band gap semiconducting layer 17

2.3.3 Dye molecule 20

2.3.4 The electrolyte 20

2.4 DSSCs operating principle 21

2.4.1 Photosynthesis 21
2.4.2 Working principle of DSSCs 25
2.5 Green synthesis of nanoparticles 27
2.6 Previous researches 30
2.7 DSSCs evaluation 32
2.8 DSSCs advantages and applications 34
2.8.1 DSSCs advantages 34
2.8.2 DSSCs application 36
CHAPTER 3: METHODOLOGY 38
3.1 Materials and equipment 39
3.2 Natural dyes extraction and characterization 43
3.2.1 Natural dyes extraction 43
3.2.2 Soxhlet Extractor 44
3.2.3 Immersing dyes 47
3.2.4 Natural dyes absorption spectra 49
3.2.5 Natural dyes fluorescence spectra 50
3.3 Synthesis and characterization of nanoparticles 51
3.3.1 Row materials preparation 51
3.3.2 Green synthesis of nanoparticles 52
3.3.3 Imaging Nanoparticles 58
3.3.4 Nanoparticles absorption spectra 58
3.3.5 Nanoparticles fluorescence spectra 59
3.4 Growth & characterization of TiO_2 nanoporous photo anode 60
3.4.1 Preparation of TiO_2 suspension 60
3.4.2 TiO_2 layer deposition and annealing 61
3.4.3 Staining Titanium dioxide layer with organic dyes 66
3.4.4 Catalyst coating 67

3.4.5 Plate anode XRD 68

3.4.6 Plate anode transmission 68

3.5 DSSCs fabrication & electrical characterization 69

3.5.1 Solar cell assembling 70

3.5.2 Current-voltage (I-V) characteristics 71

CHAPTER 4: RESULTS, DISSCUSSION AND RECOMMENDATIONS 73

4.1 Results and discussion 74

4.1.1 Group 1: Flowers 74

4.1.2 Group 2: Leaves 79

4.1.3 Group 3: Seeds 92

4.1.4 Group 4: Stem 101

4.1.5 Group 5: Fruits 112

4.1.6 Dye sensitized solar cells competing processes 124

4.2 Study Recommendations 128

REFERENCES 130

ملخص البحث 138

LIST OF FIGURES

Figures	Page number
Figure (1): (a) The French physicist Becquerel. (b) Diagram of apparatus described by Becquerel for photovoltaic effect.	12
Figure (2): Chart of best research efficiencies.	14
Figure (3): Main parts of dye-sensitized solar cell.	16
Figure (4): Use of digital multimeter to measure the resistance of conducting glasses.	17
Figure (5): X-ray diffraction measurement for TiO_2.	18
Figure (6): The anatase (a) crystal structure (b) color , The rutile (c) crystal structure (d) color.	19
Figure (7): Structure of chloroplast in plants.	22
Figure (8): (a) Image of chlorophyll pigment in chloroplast. (b) Chemical structure for chlorophyll pigment.	23
Figure (9): The process of photosynthesis in green plant.	24
Figure (10): Operation principle of dye sensitized solar cells.	26
Figure (11): Biological synthesis of nanoparticles using plant extracts.	29
Figure (12): (a) UV-vis spectra of the dye. (b) UV-vis spectra of FTO/TiO2, and FTO/TiO2/Ag-NPs with dye.	30
Figure (13): Photocurrent density–voltage (J –V) curves with and without Ag-NPs	31
Figure (14): Circuit diagram of how to obtain the short circuit current.	32
Figure (15): Circuit diagram of how to obtain the open circuit voltage.	33
Figure (16): Typical I-V characteristics of solar cell.	33
Figure (17): Some future application for DSSCs.	36
Figure (18): Effect of dye extraction method on the absorbance spectra.	43
Figure (19): Soxhlet apparatus for the extraction dyes from	44

solid samples	
Figure (20): Insertion of a solid sample inside the thimble.	43
Figure (21): Extraction of a dye (e.g. cinnamon) from a solid material using soxhlet extractor	45
Figure (22): Extracting dyes using immersion method	46
Figure (23): Filtering the prepared solutions.	47
Figure (24): Absorption of light by a sample of thickness d	47
Figure (25): Schematic representation of the spectrophotometer and image of the used Shimadzu spectrophotometer, model UV-1800.	48
Figure (26): Schematic representation and image of Spectro fluorophotometer and Shimadzu fluorophotometer, model RF-6000.	49
Figure (27): Silver nitride ($AgNO_3$) powder.	50
Figure (28): Silver nanoparticles formed after the addition of salvia leaf extract to silver nitride.	51
Figure (29): Silver nanoparticles formed after the addition of salvia leaf extract to silver nitride after different heating time.	52
Figure (30): Silver nanoparticles formed after the addition of gloves seeds extract to silver nitride.	53
Figure (31): Silver nanoparticles formed after the addition of gloves seeds extract to silver nitride with different heating time.	55
Figure (32): Transmission electron microscope (TEM).	56
Figure (33): UV-VIS spectra of synthesized AgNPs using cinnamon extract.	57
Figure (34): Preparing TiO_2 to make the suspension.	58
Figure (35): Preparation of the TiO_2 suspension in a mortar and pestle.	59
Figure (36): Checking conductive side using ohmmeter.	60
Figure (37): Fixing the glass plate on the table.	61
Figure (38): Spreading the TiO_2 suspension on the glass	62

plate.

Figure (39): Spin coating instrument 62

Figure (40): Rotation method for deposited TiO_2 on conductive glasses. 63

Figure (41): Annealing TiO_2 layer using: (a) hot air gun, (b) gas burner. 64

Figure (42): Coating the annealed TiO_2 layer with dye solution. 64

Figure (43): Coating the annealed TiO_2 layer with nanoparticles solution. 65

Figure (45): Coating the counter electrode with carbon catalyst layer (a) using a pencil lead and (b) using a candle flame. 65

Figure (46): Schematic representation of X-ray diffraction spectroscopy and Rigaku diffractometer. 66

Figure (47): Transmittance of the conductive electrode (clean glass) before deposition, coated with TiO_2 non-annealed, annealed and TiO_2 layer only. 67

Figure (48): Assembled dye sensitized solar cell. 68

Figure (49): Circuit used to measure the voltage-current characteristics, (a) illumination by sunlight, (b) using simulator. 69

Figure (50): Absorption spectrum of saffron extract dye. 71

Figure (51): Fluorescence spectrum of saffron extract dye excited with Ari one laser ($\lambda = 514$ nm at 6 mW). 73

Figure (52): I-V characteristics of saffron dye solar cell. 74

Figure (54): Synthesis of AgNPs by using saffron extract with different concentrations, a) Saffron extract, b) 5 ml solution of silver nitrate and 1ml saffron extract, c) 10 ml solution of silver nitrate and 1ml saffron extract, and d) 10 ml solution of silver nitrate and 3drops saffron extract. 75

Figure (55): Absorption spectra of synthesized AgNPs using different concentration of saffron extract. 76

Figure (56): Assembled solar cell using silver nanoparticles 76

with saffron extract dye.

Figure (57): Absorption and fluorescence spectra of salvia extract dye. 77

Figure (58): I-V characteristics for salvia dye sensitized solar cell. 79

Figure (59): AgNPs formed after the addition of salvia extract to silver nitrate and heat it for 10second. a: before heating; b: after heating. 80

Figure (60): Absorbance and fluorescence spectra of AgNPs. 81

Figure (61): Absorbance and fluorescence spectra of AuNPs solution. 82

Figure (62): Color change due to the concentration on synthesis of AgNPs by using silvia extract dye. a) Salvia extract dye, b) 10 ml AgNO3 + 1ml salvia, c) 5 ml AgNO3 + 1ml salvia, d) 1 ml AgNO3 + 10 ml salvia. 83

Figure (63): Effect of concentration of salvia extracted dye on formation of AgNPs. 84

Figure (64): Color change due to the microwave heating time on synthesis of AgNPs by using silvia extract dye. a) Salvia extract dye, b) 10 seconds, c) 15seconds, d) 20 seconds. 84

Figure (65): Effect of microwave heating time of salvia extract dye on AgNPs solution. 85

Figure (66): Stability of silver nanoparticles. 86

Figure (67): Size distribution histogram of AgNPs prepared using salvia extract. 87

Figure (68): I-V characteristics of Salvia extract dye and 88

AgNPs with salvia.

Figure (69): Deposition of TiO2 past on conductive glasses. a) Doctor blade method, b) Rotation method.	88
Figure (70): Absorption and fluorescence spectra of gloves extracted dye.	89
Figure (71): I-V characteristics for gloves dye sensitized solar cell.	91
Figure (72): AgNPs formed after the addition of gloves extract to silver nitrate and heat it for 10second. a: Gloves extract dye solution; b: AgNPs with gloves.	92
Figure (73): Absorbance and fluorescence spectra of AgNPs.	93
Figure (74): Absorbance and fluorescence spectra of AuNPs.	94
Figure (75): Color change due to variation of concentration on synthesis of AgNPs using gloves extract dye. a) Gloves extract dye, b) 10 ml AgNO3 + 1 ml gloves, c) 5 ml AgNO3 + 1 ml gloves, d) 1 ml AgNO3 + 5 ml gloves.	95
Figure (76): Effect of concentration of gloves extracted dye on formation of AgNPs.	96
Figure (77): Color change due to the microwave heating time on synthesis of AgNPs by using gloves extract dye. a) Gloves extract dye, b) 10 seconds, c) 15seconds, d)20 seconds.	96
Figure (78): Effect of microwave time heating of gloves extract dye on AgNPs.	97
Figure (79): I-V characteristics of Gloves extract dye and AgNPs with gloves.	98

Figure (80): Absorption and fluorescence spectra of cinnamon extracted dye.	99
Figure (81): I-V characteristics of cinnamon dye solar cell.	100
Figure (82): Formation of AgNPs after the addition of cinnamon extract to silver nitrate and heated for 10 seconds. a) before heating; b) after heating.	101
Figure (83): Absorbance and fluorescence spectra of AgNPs.	102
Figure (84): Color change due to variation of concentration on synthesis of AgNPs using cinnamon extracted dye. a) Cinnamon extract dye, b) 10 ml AgNO3 + 1 ml cinnamon, c) 5 ml AgNO3 + 1 ml cinnamon, d) 1 ml AgNO3 + 10 ml cinnamon.	103
Figure (85): Effect of variang concentration of cinnamon extracted dye on formatiojn of AgNPs.	104
Figure (86): Effect of varying concentration of cinnamon extracted dye on formantion AgNPs.	104
Figure (87): Color change due to the microwave heating time on synthesis of AgNPs by using cinnamon extract dye. a) Cinnamon extract dye, b) 10 seconds, c) 15seconds, d) 25 seconds, e) 30 seconds.	105
Figure (88): Effect of microwave time heating of cinnamon extract dye on AgNPs.	105
Figure (89): Stability of silver nanoparticles after being prepared.	106
Figure (90): (a) Size distribution histogram of AgNPs	106

reduced with cinnamon. (b) TEM image of silver nanoparticles synthesized using cinnamon	
Figure (91): I-V characteristics of Cinnamon extract dye and AgNPs with cinnamon.	107
Figure (92): Absorption spectra of pomegranate extracted dye.	108
Figure (93): I-V characteristics of pomegranate dye sensitized solar cell.	109
Figure (94): AgNPs formed after the addition of pomegranate extract to silver nitrate and heat it for 10 seconds. a) Pomegranate solution; b) Silver nitrate solution with pomegranate after heating.	111
Figure (95): Absorption spectra of AgNPs solution.	112
Figure (96): Color change due to the concentration on synthesis of AgNPs by using pomegranate extract dye. a) Pomegranate extract dye, b) 10 ml AgNO3 + 1 ml pomegranate, c) 5 ml AgNO3 + 1 ml pomegranate, d) 1 ml AgNO3 + 10 ml pomegranate.	113
Figure (97): Effect of pomegranate extracted dye concentration on AgNPs.	114
Figure (98): Effect of concentration of pomegranate extracted dye on AgNPs.	115
Figure (99): Effect of microwave time heating of pomegranate extract dye on AgNPs.	116

Figure (100): I-V characteristics of pomegranate extract dye and AgNPs reduced with pomegranate.	117
Figure (101): Absorption spectra of Syzygium cumin extract.	118
Figure (102): Color change due to varing concentration of syzgium cumin extract dye on synthesis of AgNPs. a) Syzgium cumin extract dye, b) 10 ml AgNO3 + 1 ml Syzgium cumin, c) 5 ml AgNO3 + 1 ml Syzgium cumin, d) 1 ml AgNO3 + 10 ml Syzgium cumin.	121
Figure (103): Effect of concentration of Syzgium cumin extracted dye on synthesis of AgNPs.	122
Figure (104): Illustration of the competing processes, no absorption of photon or no excitation of dye molecule.	123
Figure (105): Illustration of the competing processes, a generated photoelectron in the dye excited state return back to the ground state rather than being injection into the conduction band of TiO2 .	124
Figure (106): The injected electron recombines with electrolyte.	125
Figure (107): No capture of electrons.	125
Figure (108): Injected electron from dye gets captured by nanoparticles, broken red line.	127

LIST OF TABLES

Table	page numbers
Table (1): Types of solar cells	13
Table (2): Performance characteristics of DSSCs fabricated with different anodes under solar illumination of 100 $mWcm^{-2}$	32
Table (3): Comparison between silicon solar cell and dye sensitized solar cell	35
Table (4): Natural material used as source of dye extracts	39
Table (5): List of the materials used to fabricate DSSCs	40
Table (6): List of the systems and instruments used in characterization	41
Table (7): Concentrations used in synthesis of AgNPs	52
Table (8): Heating time used in synthesis of AgNPs	53
Table (9): Concentrations used in synthesis of AgNPs	54
Table (10): Heating time used in synthesis of AgNPs	55
Table (11): Saffron dye solar cell I-V parameters	75
Table (12): Salvia dye solar cell I-V parameters	80
Table (13): Salvia dye with AgNPs solar cell I-V parameters	90
Table (14): Gloves dye sensitized solar cell I-V parameters	93
Table (15): Gloves dye with AgNPs solar cell I-V parameters	99
Table (16): Cinnamon dye solar cell I-V parameters	101
Table (17): Cinnamon dye with AgNPs solar cell I-V parameters	110
Table (18): Pomegranate dye sensitized solar cell I-V parameters	112
Table (19): Pomegranate dye with AgNPs solar cell I-V parameters	118

ABBREVIATIONS

DSSCs	Dye sensitized solar cells
AgNPs	Silver nanoparticles
AuNPs	Gold nanoparticles
NPs	Nanoparticles
TEM	Transmission electron microscope
XRD	X-ray diffraction
SPR	Surface Plasmon Resonance
$\mathbf{I_{max}}$	Maximum current
$\mathbf{V_{max}}$	Maximum voltage
$\mathbf{I_{sc}}$	Short circuit current
$\mathbf{V_{oc}}$	Open circuit voltage
FF	Fill factor
A	Affected area
E	Radiation intensity
η	Cell efficiency

CHAPTER 1: INTRODUCTION

1.1 Introduction

1.2 Research Problem

1.3 Research Questions

1.4 Research Objectives

1.5 Research Significance

1.6 Research Setting

1.7 Definitions

1.1 Introduction

As a matter of fact, Earth's energy comes from the sun. Life on the earth depends on solar energy. Plants use sunlight to make food through the process of photosynthesis. Many countries are adopting solar energy as renewable energy source. They focus on solar energy due to huge amount of energy that is produced by harvesting solar radiation.

Solar cell is a device that converts energy of light into electrical energy through the action of photovoltaic. Photovoltaic cell when exposed to light generates electric current without being attached to any external voltage source. In 1883 the first genuine solar cell was built by Chales Fritts, who used junctions formed by coating selenium (a semiconductor) with an extremely thin layer of gold (Bellis, 2006). With further investigations new types of solar cells have been created as thin film solar cell, nano-crystalline solar cell, etc. The most common type of solar cell is the crystalline silicon solar cell. These solar cells considered as the first generation of solar cell. Crystalline silicon solar cells have high efficiency, long life and can be applied to almost any surface such as metal, glass or plastic (Pierro, 2011). On the other hand, silicon solar cells are more expensive and aged cells when decomposed produce harmful substances to the environment. With the development of science and the increase of research scientists turned towards producing green energy by using environmentally friendly and less expensive materials.

Dye sensitized solar cells (DSSCs) are a promising class of photovoltaic cells with the capability of generating green energy at low production cost, due to non-expensive equipment and safe materials required for fabrication. Furthermore, DSSCs are easier to manufacture (Jasim, K.E. 2011). In the late of 1960s it has been discovered that organic dyes can generate electricity at oxide electrodes in

electrochemical cells. From this discovery a new generation of solar cells, also known the Gratzel cell or the dye sensitized solar cell. The first DSSC were invented by Micheal Grätzel and Brain O'Regan in 1991. DSSC depends on the dye for producing electricity (O'Regan & Gratzel.1991). As a result of this invention many researchers got involved in this subject using different types of industrial or natural dyes in fabricating solar cells (Gleue, 2008 ; Jasim, 2011 ; Soutter, 2013 and Ananth, 2015).

1.2 Research Problem

Fossil fuels are the most common source for producing energy on earth. These fuels are the primary source of all the power generated in the world due to their affordability and high energy content. Petroleum, coal, natural gas and nuclear energy (some countries) are the most used sources to generate electric power. These sources are considered as non-renewable resources because they are limited or cannot be replaced as fast as they are consumed. Also, burning fossil fuels caused many environmental problems. Besides the environmental impact, the economic impact of non-renewable resources can also be very damaging. As the non-renewable energy sources waning, their cost will rise. Eventually, the price will hit a point that end users cannot afford. In fact, most of Earth's energy comes from the Sun. All life on the Earth depends on solar energy. Plants use sunlight to make food through the process of photosynthesis. Therefore, some countries tended to use sunlight as renewable energy sources. They focus on solar energy due to huge amount of energy that is produced by harvesting solar radiation. Which is one of the most uses of solar energy is in the fabrication of solar cell.

The main aim of this project is to investigate and fabricate Dye Sensitized Solar Cells (DSSCs) using both natural dye extracts and metallic nanoparticles such as silver and gold as sensitizers of a wide bandgap semiconductor photo anode. Examples of natural extracted dyes that will be used are: saffron, cinnamon, pomegranate, salvia officinalis, and clove. The Green synthesis method of metallic nanoparticles such as: silver and gold nanoparticles will be used. Both the extracted natural dyes and the grown metallic nanoparticles will be optically characterized using UV-visible spectroscopy and florescence spectroscopy. Also, Transmission Electron Microscope (TEM) will be used to image the grown metallic nanoparticles in order to determine their size distributions. X-ray diffraction (XRD) will be used to investigate the formation of nanostructured TiO_2 layer on the photoelectrode.

After understanding structure and operation principles of the Dye Sensitized Solar Cell (DSSC), a nanostructured wide band gap semiconductor material such as Titanium dioxide TiO_2 photoelectrode will be prepared since it acts as the photo anode of the assembled solar cell. The photoelectrode topology will be characterized using scanning electron microscopy (SEM) and X-ray diffraction (XRD) spectroscopy. After assembling a cell and testing it under standard illumination using a solar simulator, electrical parameters of the DSSCs such as short circuit current and open circuit voltage will be measured. Then, both the fill factor (FF) and power conversion efficiency (η) will be calculated and presented in tabular form. Moreover, solar cell photocurrent versus voltage (I-V characteristics) will be presented graphically (Fanis, 2007).

A similar approach will be followed with assembled solar cells sensitized with metallic nanoparticles alone as well as with natural dye extracts to investigate if there is any improvement in solar cell operation.

1.3 Research Questions

In this study, the following questions are discussed:

- What is dye-sensitized solar cells?
- What are the components of the dye sensitized solar cells?
- What is the operational principle of dye-sensitized solar cells?
- How to extract dyes?
- How to grown metallic nanoparticles?
- How to fabricate dye-sensitized solar cells?
- How to characterize the optical and electrical properties of the assembled solar cells?

1.4 Research Objectives

The main objectives of the study are:

- Synthesizing metallic nanoparticles using eco-friendly approach.
- Fabricating DSSCs.
- Characterizing optical and electrical properties of the fabricated solar cells.
- Developing prototype green solar cells (NDSSCs based on nanostructured materials).
- Initiate research activities in Bio-nanotechnology based materials and devices.
- Enhance natural dyes extracts database.

1.5 Research Significance

The non-renewable resources of energy like Petroleum and coal are limited and caused many environmental problems. Besides the environmental impact, they are of high cost. Therefore, some countries tended to use renewable energy sources which are low cost and environmental friendly. They focus on solar energy due to huge amount of energy that is produced by harvesting solar radiation. Fabrication of solar cell is one of the most important uses for solar energy.

Dye sensitized solar cell (DSSC) is one of the third generation of solar cells. This generation of cells has a low production cost, easier to manufacture and environment friendly. In DSSC dyes molecules are the sun light harvesting part of the cell from which electricity is generated. The working principle of the cell is such as the process of photosynthesis in plants. At the University of Bahrain researchers (Jasim et. al., 2009, 2011, 2012) have demonstrated the capability of natural dye extracts to sensitize wide band gap nanostructured semiconductor and generating electric energy. The present work will focus on learning DSSC principle, fabrication and evaluation. We shall adopt green chemistry approach to produce metallic nanoparticles such as silver or gold nanoparticles using different plants extract to use them as a sensitizer in DSSC in order to improve power conversion efficiency of solar cell. This work is one of the chapters in the research activities running at the University of Bahrain (Jasim, 2012 ; Jasim, 2011 ; Jasim et.al., 2012 ; Mirza, 2016).

1.6 Research Setting

There are many researches working on dye-sensitized solar cells. The subject of study covers a very wide range of topics. No single study

can cover all topics, so many topics are omitted, such as the effect of nanoporous layer materials change or electrolyte class. However, the main target of the study was achieved, that is to investigate the effect of some dyes collected from the environment and to use them in green synthesis of nanoparticles to improve the efficiency of solar cells.

The study constrained by many factors like missing of some tools such as scanning electron microscope (SEM) which is a major tool to evaluate the topology of the photo electrodes. This constrains doing further analysis of the topology of the formed nanostructured TiO_2 layer.

1.7 Definitions

- **Dye:** A substance used to color materials. It could be natural or synthetic
- **DSSCs:** Dye sensitized solar cells are a third generation photovoltaic (solar) cell that converts light into electrical energy. This new class of advanced solar cell can be likened to artificial photosynthesis due to the nature way in light energy absorption.
- **Green synthesis:** is Synthesis of Nanoparticles using plants parts. It is a green chemistry approach that interconnects nanotechnology and plant biotechnology.
- **Nanotechnology:** is the science and technology of small things, in particular things that are less than 100 nm in size.
- **Nano:** is SI prefix (one billionth). One nanometer is 10^{-9} meters or about 3 atoms long. For comparison, a human hair is about 60-80,000 nanometers in diameter .
- **Nanoparticles:** is a microscopic particle with at least one dimension less than 100 nm and behaves as a whole unit in terms of its transport and properties.
- **Photosynthesis:** is the process used by plants, algae and certain bacteria to harness energy from sunlight into chemical energy.

- **Spectrophotometer:** is an instrument that measures the amount of photons (the intensity of light) absorbed after it passes through sample solution.
- **Solar simulator:** is a device that provides illumination approximating natural sunlight. Also known as artificial sun.

CHAPTER 2: DYE-SENSITIZED SOLAR CELLS (DSSC)

2.1 History

2.2 Types of solar cells

2.3 DSSCs materials and components

2.4 DSSCs operation principle

2.5 Green synthesis nanoparticles

2.6 Previous research

2.7 DSSCs evaluation

2.8 DSSCs advantages

CHAPTER 2: DYE-SENSITIZED SOLAR CELLS (DSSC)

In this chapter, the history of solar cells and types of solar cells are exhibited. The materials and components used to fabricate dye sensitized solar cells (DSSCs) are demonstrated. Moreover, the operating principle of dye sensitized solar cells (DSSCs) is explained, beside more details about the dyes and metallic nanoparticles that have been used as sensitizers will be presented. We introduce a short review about results obtained in previous research papers and projects. Furthermore the method used to evaluate DSSCs is explained. Finally, advantages of DSSCs and some applications are mentioned.

2.1 History

In fact, most of Earth's energy comes from the Sun. All life on Earth depends on solar energy. The plants use sunlight to make food through the process of photosynthesis. Therefore, some countries tended to use sunlight as renewable energy sources. They focus on solar energy due to huge amount of energy that is produced by harvesting solar radiation.

One of the most important uses of solar energy is in fabrication solar cells.

A solar cell is a device that converts energy of light into electrical energy through the action of photovoltaic. The photovoltaic effect was observed in 1839 by French physicist Becquerel while experimenting with a solid electrode in an electrolyte solution. He observed that a voltage developed when light fell upon the electrode (see figure (1)). He arrived to the following result "when some materials are exposured to light, voltage or electric current is generated". From the principle of photovoltaic effect the solar cells were built. The photovoltaic effect is the basic physical process through which a solar cell converts sunlight into electricity. Photovoltaic cell when exposed to light generates electric current without being attached to any external voltage source. In 1883 the first genuine solar cell was built by Chales Fritts, who used junctions formed by coating selenium (a semiconductor) with an extremely thin layer of gold (Bellis, 2006). The silicon solar cell was invented by Russel Ohl in 1941. With further investigations new types of solar cells created as thin film solar cell, nano-crystalline solar cell, etc. The most common type of solar cell is the crystalline silicon solar cell. These solar cells considered as the first generation of solar cell and they have many advantages, but also they have some disadvantages. Crystalline silicon solar cells have high efficiency. Also, this kind of cells has long life and can be applied to almost any surface such as metal, glass or plastic. On the other hand, silicon solar cells are more expensive and need special laboratory to fabricate them. Also, pure silicon used in fabricating these cells should be very pure almost 99.99% purity. Aged cells can be decomposed and produce harmful substances to the environment.

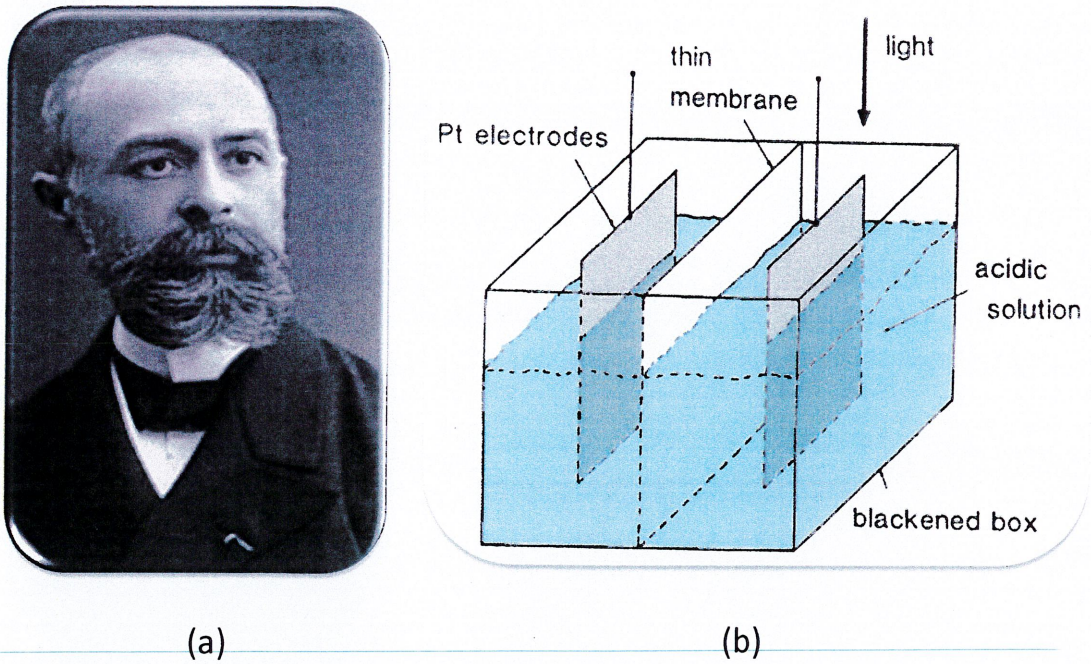


Figure (1): (a) The French physicist Becquerel. (b) Diagram of apparatus described by Becquerel for photovoltaic effect. (Michael W, 2004)

2.2 Types of solar cells

There are many different classes of solar cells, like crystalline solar cells, thin film solar cells and many other types of solar cells (see Figure (2)). There are three main types of semiconductor-based solar cells and are distinguished by the type of crystal used in them. They are monocrystalline, polycrystalline, or amorphous (thin film). In monocrystalline silicon cell the semiconducting material should be pure. Monocrystalline rods are extracted from melted silicon and then sawed into thin plotes, this production process guarantees a high level of efficiency. Monocrystalline solar cells are the most efficient as in absorbing sun light and converting it into electricity, but they are too expensive to make and to buy. The rate of efficiency of monocrystalline solar cells are 17%-22%. The most common type of photovoltaic solar

cells on markets today is poly crystalline solar cells. Polycrystalline solar cells consist of multiple amounts of smaller silicon crystals. They look like shattered glass. The polycrystalline solar cells are less efficient than monocrystalline and less expensive to produce. The rate of efficiency for polycrystalline cells is 14%-16%. The third type is amorphous solar cells and consists of thin film made from molten silicon. The amorphous solar cells have lower efficiency and cheapest to produce. One advantage of amorphous solar cells is they can continue charge while parts of solar panel cells are in shadow. The efficiency rating of amorphous solar cells is 7%-13%. (Andrew Sendy, 2016)

Table (1): Types of solar cells:

Type	Advantages	Disadvantages	Efficiency
Monocrystalline	• highest efficiency • long life span • more efficient in warm weather.	• too expensive	17% - 22%
Polycrystalline	• The process used to make polycrystalline silicon is simpler and cost less. • have slightly lower heat tolerance than monocrystalline solar panels.	• Lower space-efficiency. • have a less uniform look	14% - 16%

Amorphous	• Cheaper to manufacture than crystalline-based solar cells. • Can be made flexible. • High temperatures and shading have less impact on solar panel performance.	• Degrade faster than mono-crystalline and polycrystalline solar panels (shorter warranty). • Require a lot of space.	7% - 13%

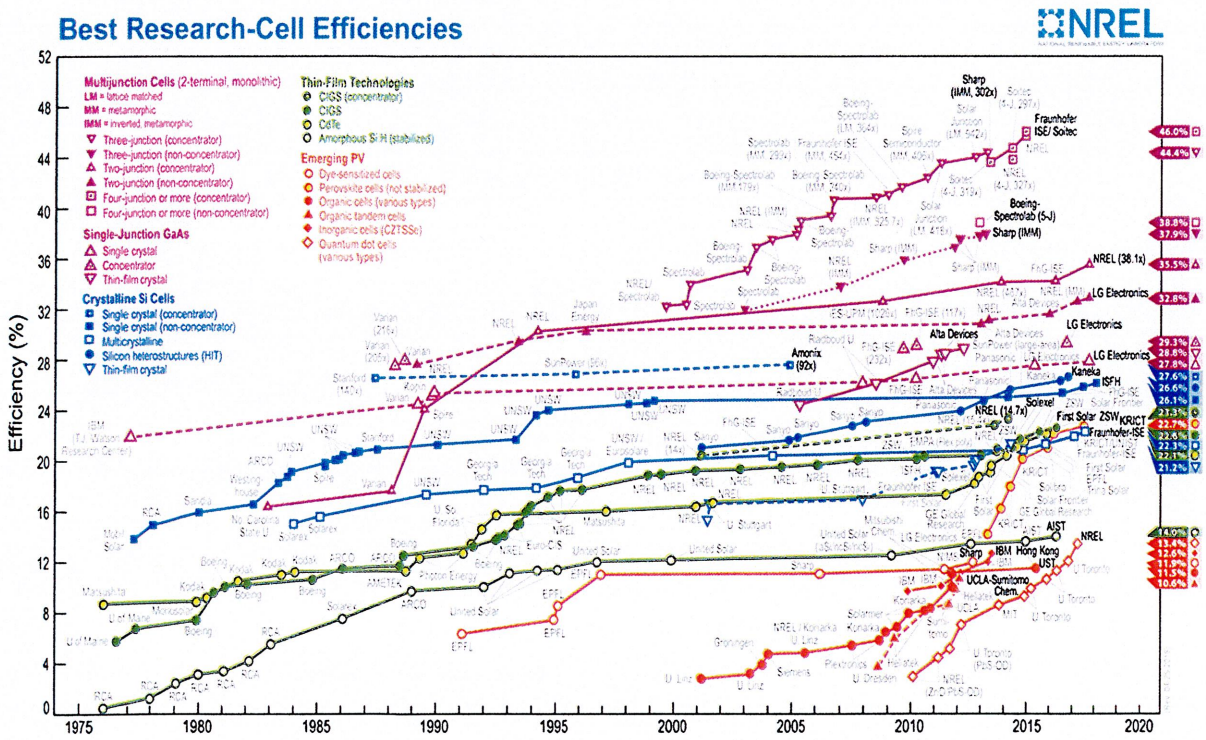


Figure (2): Chart of best research efficiencies. (NREL, 2018)

Crystalline silicon solar cells have high efficiency, long life and can be applied to almost any surface such as metal, glass or plastic (Pierro, 2011). On the other hand, silicon solar cells are more expensive and aged cells decompose and produce harmful substances to the environment. With the development of science and the increase of research, the

scientists turned towards producing green energy by using environmentally friendly and less expensive materials.

Dye sensitized solar cells (DSSCs) are classified as thin film amorphous solar cells. Dye sensitized solar cells (DSSCs) are a promising class of photovoltaic cells with the capability of generating green energy at low production cost, due to non-expensive equipment and safe materials required for fabrication. Furthermore, DSSCs are easier to manufacture (Jasim, K.E. 2011). In the late of 1960s it has been discovered that organic dyes can generate electricity at oxide electrodes in electrochemical cells. From this discovery a new generation of solar cells has been invented, namely the Gratzel cell or the dye sensitized solar cell. The first DSSC were invented by Micheal Grätzel and Brain O'Regan in 1991. DSSC depends on the dye for producing electricity (O'Regan & Gratzel.1991). As a result of this invention many researchers got involved in this subject using different types of industrial or natural dyes in fabricating solar cells (Gleue, 2008 ; Jasim, 2011 ; Soutter, 2013 and Ananth, 2015).

2.3 DSSCs materials and components

As illustrated in Figure (3), dye sensitized solar cell (DSSC) is made up of four main parts: two transparent conducting electrodes, nanostructured wide band gap semiconducting layer, dye molecules, and electrolyte.

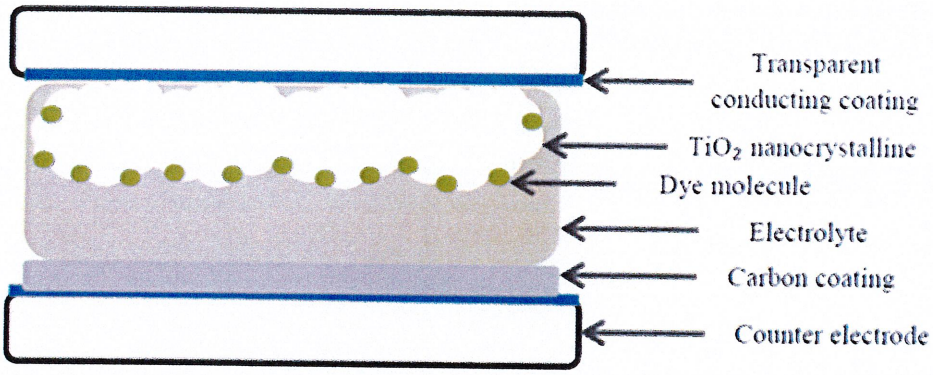


Figure (3): Main parts of dye-sensitized solar cell.

2.3.1 Two transparent conducting electrodes

In DSSC two pieces of conductive clear glass are used due to their low cost and high transparency. The glass pieces consist of two sides' conductive side and nonconductive side. The conductive side is coated with transparent conductive oxide (TCO). The transparent conducting electrode and counter electrode are coated with thin conduction film of fluorine-doped tin dioxide (SnO_2). To check the conductive side of the glasses an ohmmeter is used as shown in figure (4). Ohmmeter is a device to measure the resistance. The ohmmeter used to measure the resistance of the conductive side of glasses, it should have a value between 10 and 30 ohm (Fanis, 2007). The two pieces of glass are sandwiched together where the conductive sides face inside and each conductive side is coated by a different material. One conductive side coated by TiO_2 nanoparticles layer (transparent conducting electrode) and the other conductive side of the second glass (counter electrode) coated by graphite which acts as a catalyst. The main reason behind choosing carbon is because it is available, cheap and nontoxic.

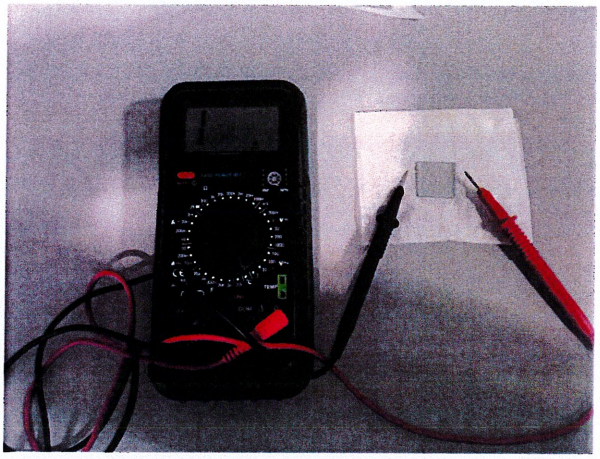


Figure (4): Using digital multimeter to measure the resistance of conducting glasses.

2.3.2 Nanostructured wide band gap semiconducting layer

This layer is the heart of the system of DSSC and is composed of nanometer sized particles which have been sintered together to allow the electronic conduction taking place. Researchers have been tested various semiconductor materials such as ZnO (Vittel, 2006), TiO_2 (Hosseini, 2013), and SnO_2 (Wanninayake, 2017). The material that has been chosen is titanium dioxide TiO_2 due to their high chemical stability and their resistance to photocorrosion. Old fashion cells are bulky semiconductor materials, such as Si, GaAs or CdS ans they get affected by light. In addition, poor stability of the photoelectrochemical cell was observed. So, nanostructured material has no change in mechanical, electrical or chemical properties. Another reason for choosing TiO_2 is not expensive and non-toxic. The titanium dioxide layer is used to attach dye molecules. The nanocrystalline TiO_2 particles size is allowed to absorbed more molecules of the dyes. A suspension of TiO_2 can be prepared following very easy steps that will be explained in detail. TiO_2 layer must be heated up to 450°C for 30minute to increase the surface area, where the volume

increases with decreasing the area due to volume- surface area ratio. The higher surface area allows adsorbing sensitizing dye with high concentration, and thus enhances light harvesting efficiency (Hara & Arakawa, 2003). To confirm the formation of nano-structured of TiO_2 layer scanning electron microscopy or X-ray diffraction is usually obtained. X-ray diffraction measurements are shown in figure (5), and confirms the formation of nanocrystalline TiO_2 particles by using analysis of the X-ray diffraction measurement.

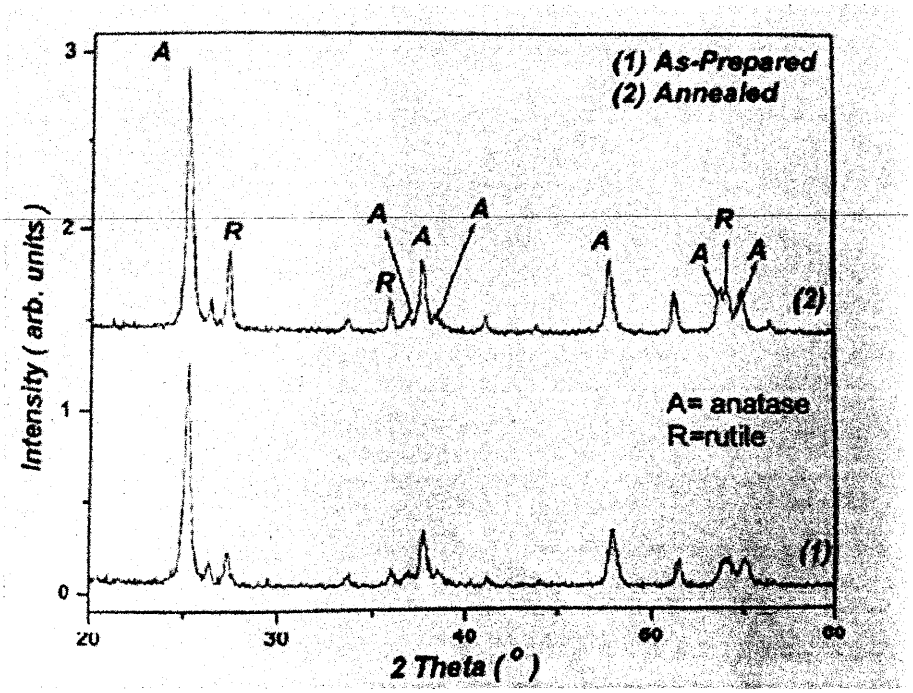


Figure (5): X-ray diffraction measurement for TiO_2.

Titanium dioxide has three forms rutile, anatase and brookite. shown in figure (6). Rutile is deep red while anatase is yellow to blue. Rutile has high refractive of index. It is also hard and has chemical resistant properties. Anatase is a type of polymorph which becomes a rutile when it is heated at about 915°C. Rutile has a higher absorbance property than anatase. Furthermore, the titanium dioxide plate annealed to have more rutile than anatase and thus improving the efficiency of the solar cell. (Celine, 2012)

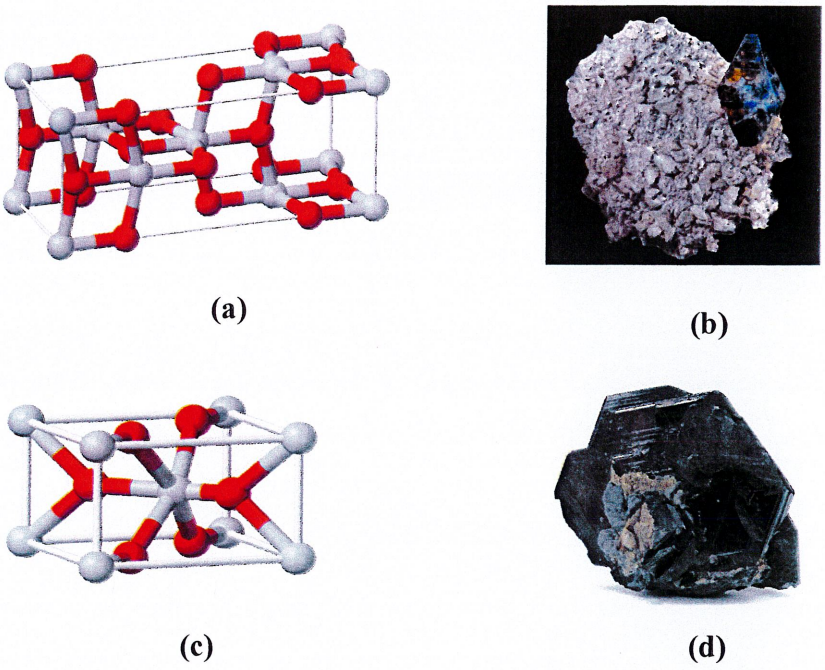


Figure (6): The anatase (a) crystal structure (b) color ("Anatase ", 2017), The rutile (c) crystal structure (d) color, ("Rutile", 2017).

The Titanium Dioxide (TiO_2) film deposited on conductive glasses using three different ways : doctor blade method, spin coating, and rotation method. Doctor blade method is rapid sweeping motion with the glass rod to coat the titanium diooxide suspension on the masked conductive glass plate. The second method which used is spin coating, in this method a small amount of caoting material (TiO_2) is applied on the center of conductive glass, then rotated at high speed in order to spread the coating TiO_2 by centrifugal force. While in the third method a small machine were built to achieve a uniform film. In this method a rotation motion is used to have uniform and good thickness of TiO_2 film. After that the conductive glass coated with TiO_2 is annealed to have rutile crystal structure (Wang et al., 2003).

2.3.3 Dye molecule

Dye molecules are used to sensitized wide band gap nanostructured photoelectrode by absorption of photons. Dye molecules absorbed to the surface of TiO_2 on the transparent conducting electrode. These used dyes in DSSC can be natural dyes or artificial dyes. There are many researches that have been done to find suitable dyes to act as sensitizers in order to increase DSSC efficiency. During the last decade huge number of papers were published using natural dyes, such as Egg purple plants, black rice, Jaboticaba, Anthocyanin, Henna, etc (Calogero, 2008 ; Matsubara, 2005 ; Hao, 2006 ; Polo, 2006 ; Wogcharee, 2007 ; Cramer et al, 2012; Jasim, 2012).In this experiment natural dyes are used like saffron, cinnamon, raspberry, Salvia officinalis, and clove, Plus metallic nanoparticles such as silver and gold. Each type of dyes absorb particular type of light, each dye absorbs certain wavelength range. To find out which wavelength ranges are absorbed by each dye, the absorbance spectrum was measured using spectrophotometer. Spectrophotometry is a device to measure how much a chemical substance absorbs light by measuring the intensity of light as a beam of light passes through sample solution. The basic principle is that each compound absorbs or transmits light over certain range of wavelength. Both the extracted natural dyes and the grown metallic nanoparticles will be optically characterized using UV-visible spectroscopy. Also, Transmission Electron Microscope (TEM) will be used to image the grown metallic nanoparticles in order to determine their sizes.

2.3.4 The electrolyte

The electrolyte used in the DSSC contains I^-/I_3^- redox ions. The electrolyte solution is used to capture the electrons at the counter

electrode (cathode) and transfers them back to the dye molecules to complete the electrical circuit. The electrolyte solution is made of mixtures of iodides such as LiI, NaI, KI. The reason behind using iodine redox electrolyte is because it gives the best performance and not interacts with TiO_2.

2.4 DSSCs operating principle

To understand the concept of dye sensitized solar cells we need to understand the process of photosynthesis in plants first.

2.4.1 Photosynthesis

Photosynthesis is a process used by plants and some organisms to convert energy of light, normally from the Sun, into chemical energy and storing it in the bonds of sugar. Plants need light, CO_2, H_2O and pigment to sustain this process. The process of photosynthesis takes place in the chloroplasts, specifically using chlorophyll which is the green pigment involved in photosynthesis. Chloroplast includes outer and inner membranes, stroma and thylakoids stacked in grana. (See Figure (7)) The chlorophyll looks green because it absorbs red and blue light and reflects the green light. However, from the energy absorbed from blue and red light the plants do photosynthesis. The green light is not used in photosynthesis. (Bassham and Lambers, 2017)

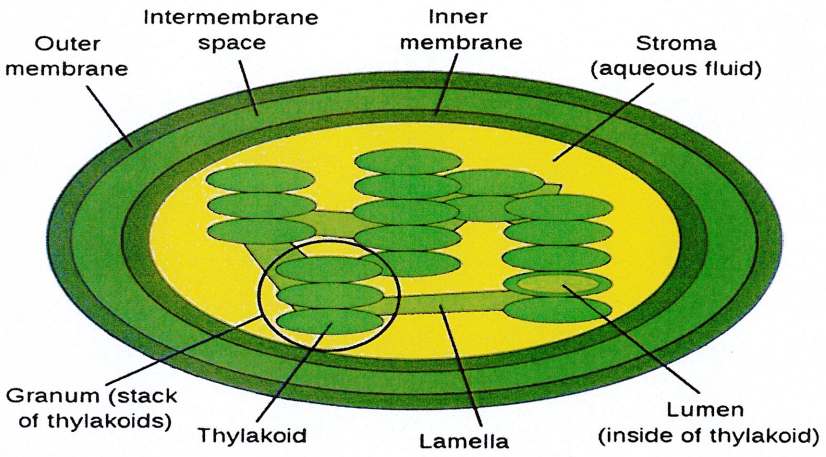
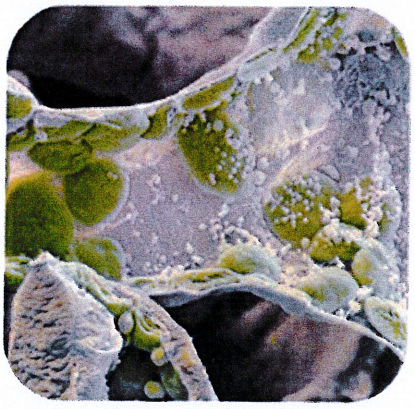


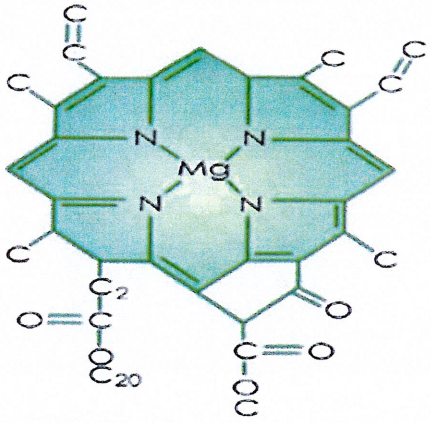
Figure (7): Structure of chloroplast in plants. (Arnold, 2009)

Photosynthesis consists of light reaction and dark reaction ("Photosynthesis", 2017). Photosynthesis light reaction happens in the thylakoid membrane. This chemical reaction must take place in the presence light. Chlorophyll and several coloured pigments absorb different color of light and pass its energy to the central chlorophyll molecule to do photosynthesis. The chemical structure of a chlorophyll molecule is a parphyrin, which consists of several fused rings of carbon and nitrogen with a magnesium ion at the center, See Figure (8).

$$carbon\ dioxide + water \xrightarrow{sun\ light} Oxygen + Sugar \qquad (1)$$



(a)



(b)

Figure (8): (a) Image of chlorophyll pigment in chloroplast. (b) Chemical structure for chlorophyll pigment. (Becker & Deamer.1991)

In the light reaction, one molecule of the pigment absorbs a photon and loses an electron. The lost electron passed to a modified form of chlorophyll called pheophytin which passes the electron to a quinone molecule, allowing the electron to flow down and leads to reduction of NADP and NADPH. The chlorophyll molecule recuperates the lost electron from a water molecule through a process called photolysis, which releases an oxygen (O_2) molecule. The overall equation for the light dependent reaction in green plants is:

$$2H_2O + 2NADP^+ + 3ADP + 3Pi \xrightarrow{sun\ light} 3NADPH + 2H^+ + 3ATP + O_2 \quad (2)$$

In the light independent or dark reaction, reaction takes place in the stroma within the chloroplast and converts carbon dioxide to sugar. This reaction doesn't need light but does need the products of light reaction (ATP and NADPH). The dark reaction involves a cycle called the Calvin cycle in which carbon dioxide and energy from ATP are used to make sugar. The enzyme RuBisCo captures carbon dioxide from the

atmosphere and in process that requires the formed NADPH and releases 3 carbon sugars which are combined later to form sucrose and starch. To be more specific, carbon fixation produces an intermediate product, which is converted to final carbohydrate products. The carbon skeltons produced by photosynthesis variously used to form other organic compounds such as the building material cellulose ("Photosynthesis", 2017). The overall equation for the light independent reaction in green plant is:

$$3CO_2 + 9ATP + 6NADPH + 6H^+ \rightarrow C_3H_6O_3 - phosphate + 9ADP + 8Pi + 6NADP^+ + 3H_2O \quad (3)$$

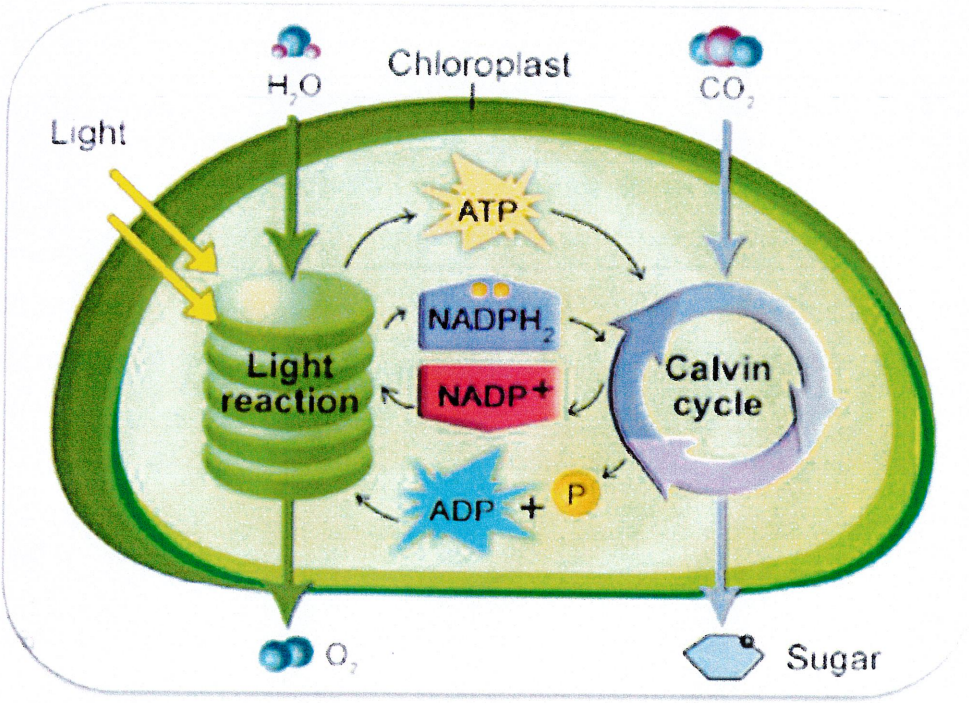


Figure (9): The process of photosynthesis in green plant. (Kurse, 2007)

After understanding the process of photosynthesis in plants we can move to dye sensitized solar cell which is working with the same principle of photosynthesis. In dye sensitized solar cell we have TiO_2 and electrolyte instead of water and carbon dioxide. Dye molecules replaced the chlorophyll in the plant. (Marchuk, 2000)

2.4.2 Working principle of DSSCs

Dye sensitized solar cell working as photosynthesis in plants. In DSSC we have titanium dioxide and graphite instead of water and carbon dioxide and dye molecules are represented as chlorophyll in photosynthesis. When photons fall on the solar cell, it is absorbed by the dye molecules as shown in Figure (10). (Jasim 2011)

1. **Excitation process:**

   The electrons in the dye molecules take this energy from photons and become excited. The dye molecules are excited from ground state S to the excited state S*.

$$S + photon \rightarrow S^* \qquad (4)$$

2. **Injection process:**

   The excited electron is injected into the conduction band of TiO_2 electrodes and caused oxidation for dye molecules.

$$S^* + TiO_2 \rightarrow S^+ + e^-_{TiO_2} \qquad (5)$$

3. **Energy generation:**

   Then the injected electrons transported to the counter electrode and transported through the external load. Via an external circuit, the injected electron reaches back surface contact (transparent counter electrode).

$$e^-_{TiO_2} + C.E. \rightarrow TiO_2 + e^-_{C.E.} + electrical\ energy \qquad (6)$$

4. Regeneration of dye:

The electrolyte solution captures the electrons at the transparent counter electrode and transfers them back to the dye molecules in order to complete the electrical circuit.

$$S^{+} + \frac{3}{2}I^{-} \rightarrow S + \frac{1}{2}I_3^{-} \qquad (7)$$

5. Electron recapture reaction:

$$\frac{1}{2}I_3^{-} + e_{C.E.}^{-} \rightarrow \frac{3}{2}I^{-} + C.E. \qquad (8)$$

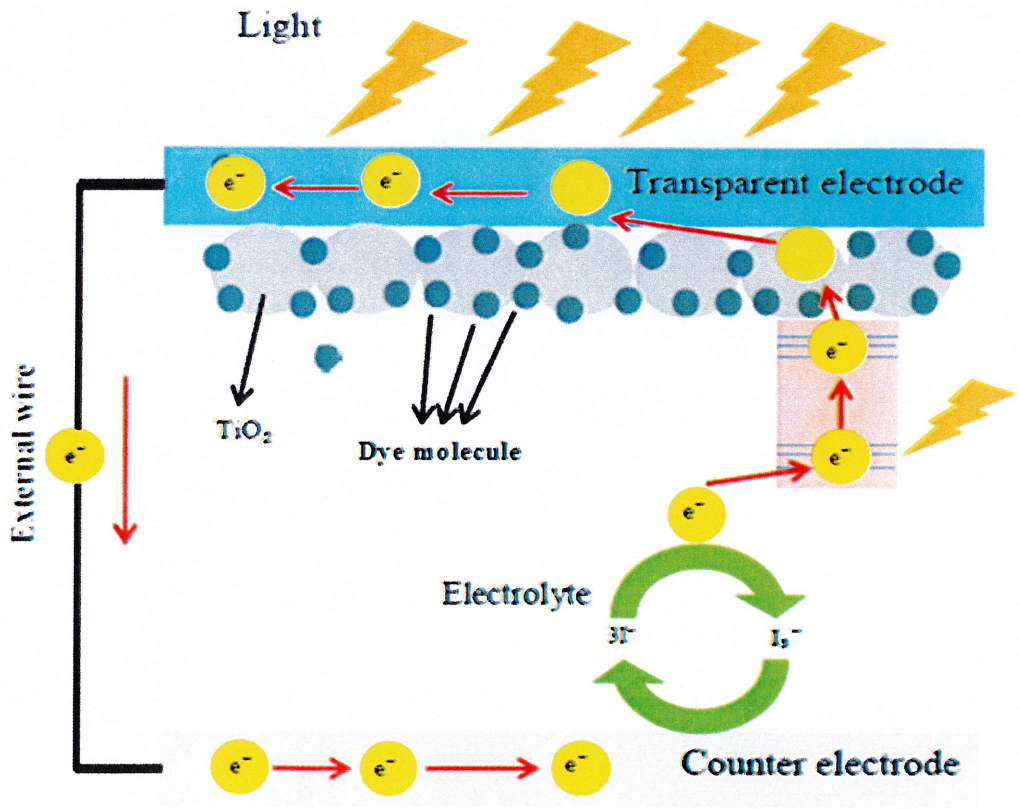


Figure (10): Operation principle of dye sensitized solar cells.

2.5 Green synthesis of nanoparticles

The efficiency of DSSC is low compared to that of silicon based PN junction photovoltaic cells; there are many researches that have been done to find suitable dyes to act as sensitizers in order to increase DSSC efficiency. During the last decade huge number of papers were published using natural dyes, such as Egg purple plants, black rice, Jaboticaba, Anthocyanin, Henna, etc (Calogero, 2008 ; Matsubara, 2005 ; Hao, 2006 ; Polo, 2006 ; Wogcharee, 2007 ; Cramer et al, 2012. Jasim, 2012). But achieved cell's efficiency was still low. Researchers have designed and tested various methods for enhancing conversion efficiency of DSSCs, such as use of ZnO as the semiconductor material in a DSSC instead of TiO_2 (Vittal, 2006); mixed few dye in the same cell (Hung, 2011), they found that the cell consisted of mixed dyes generated the highest power conversion efficiency of 2.3 %. However, despite various research groups and experiments, DSSC efficiency is still limited.

Recently scientists turned towards nanoparticles NPs because their structure and properties differ significantly from bulk material. NPs can have a broad absorption and fluorescence from the ultraviolet (UV) to the infrared (IR) depending on their size. As the size of NPs shrinks, their emission wavelength gets smaller and they gain more energy. " Since NP sizes can be tuned, scientists have been able to control their optical, electrical, magnetic, mechanical and chemical properties. For this reason, NPs have many applications in modern technology, specifically in light-emitting diodes, transistors, alternative energy, and biomedicine " (Sun et al, 2009). NPs have also been studied for photovoltaic applications and, specifically, dye-sensitized solar cells (DSSCs). Researchers found out that when dye is coupled with nanoparticles the photocurrent increased in DSSCs. By combining NPs with dyes, the DSSC could harvest more light

from the visible to infrared spectrum and thus be more efficient (Cramer et al, 2012).

Metallic nanoparticles (silver, gold, copper, zinc, palladium, titanium, nickel, indium etc) can be prepared by physical, chemical, or biological method (Iravani S. et al, 2014). However, in order to avoid toxic and echo unfriendly chemicals, biological based method or green synthesis approach is preferred by many researchers (Raveendran P. et al.,2003; Mohanpuria P. et al., 2008;). Beside, using safe and environmental friendly materials in green synthesis method, it is low cost, requires fewer preparation steps, and diversity of biological materials (ranging from micro-organisms to plants) that can be employed in the synthesis of non-metallic particles (Saifuddin N. et. al, 2009; Song J.Y et. al, 2009).

Different methods were used to find the cheapest and the easiest method for synthesizing gold and silver nanoparticles. Generally, nanoparticles are synthesized using a reduction method. A reducing agent is used to reduce silver and gold, (abdulwahab, 2016). In Green synthesis method, plants extract is used as reducing agents such as Saffron, Salvia, Gloves and Cinnamon, as shown in Figure (11). The nanoparticles could be synthesized rapidly by involvement of heat. General chemical reactions for gold and silver are given below:

$$Ag^{+} + reducing\ agent \rightarrow Ag^{0} \qquad (9)$$

$$Au^{+3} + 3e^{-} \rightarrow Au \qquad (10)$$

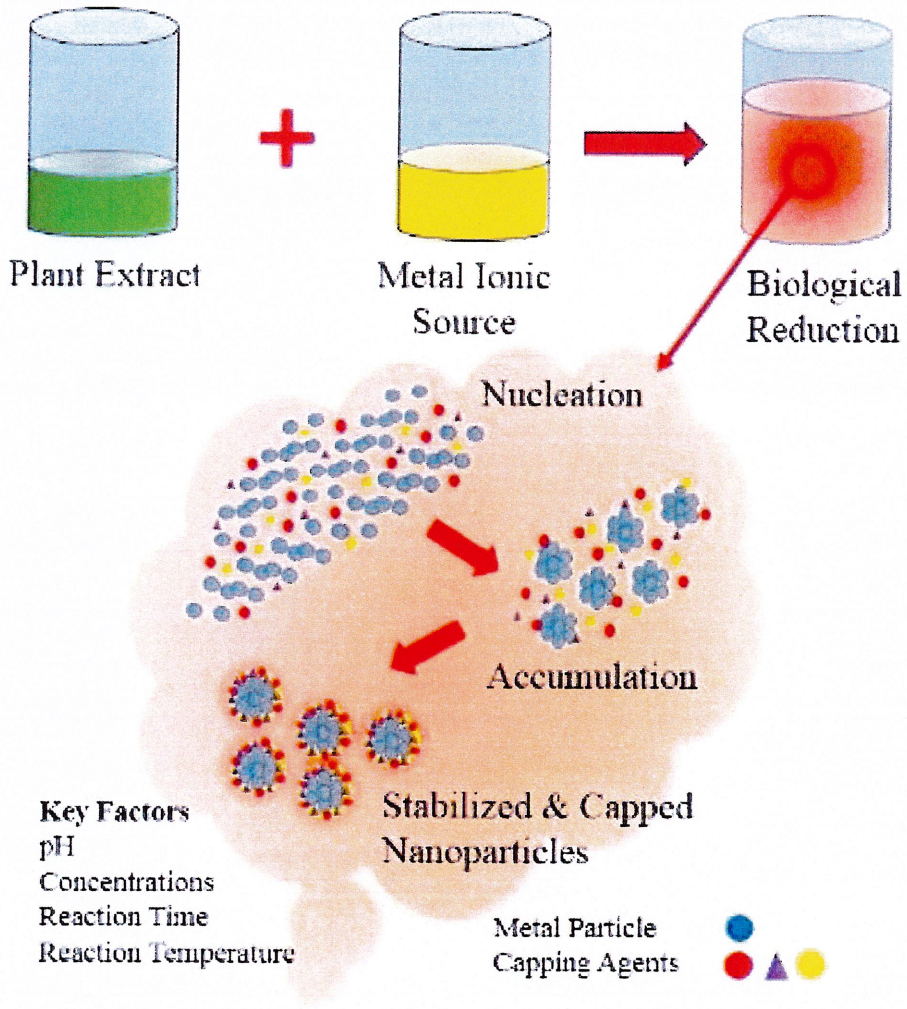


Figure (11): Biological synthesis of nanoparticles using plant extracts. (Shah et.al,2015)

Furthermore, conditions of synthesized nanoparticles can be changed by changing many factors such as, natural dye extract concentration, silver or gold solution concentration, microwave heating time period, and power of microwave heating. The nanoparticles solutions could be characterized using UV-visible spectroscopy and Transmission electron microscope (TEM). The UV-visible spectroscopy for measuring the transmission and absorption spectra of the nanoparticles solutions. While TEM used to quantify morphology and crystallographic information of samples.

2.6 Previous researches

As an example of visibility of using green synthesized silver nanoparticles in dye synthesizes solar cell, in 2016 a group of Nigerian scientists worked on DSSC (Eli et al, 2016). They tried to improve the performance of DSSC using silver nanoparticles (Ag-NPs); by using dye from Dried Hibiscus Sabdariffa flower and mix it with Ag-NPs in DSSC. The absorbance of optical property of the extracted dye solutions have been quantified by using UV-visible spectrophotometer. Figure (12) shows the absorbance of the dye and prepared Ag-NPs suspension with the dye within the wavelength range of 350-1000 nm.

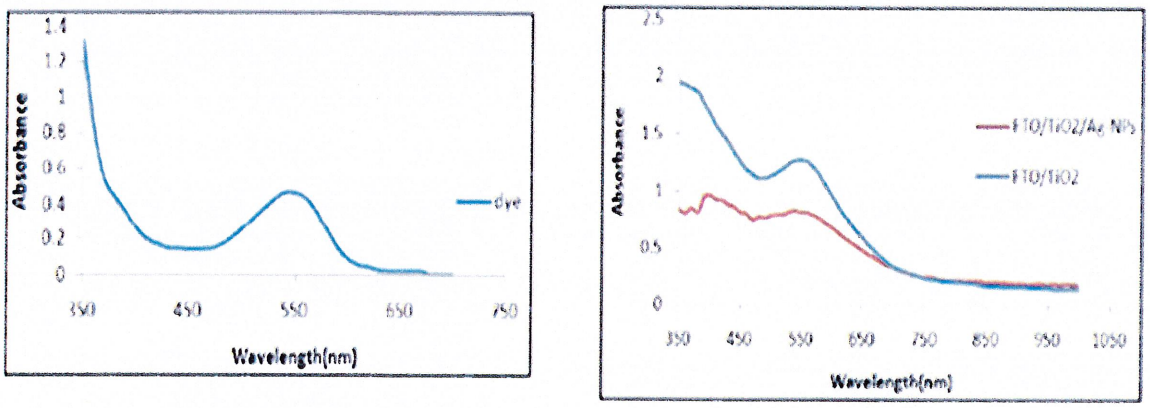


Figure (12): (a) UV-vis spectra of the dye. (b) UV-vis spectra of FTO/TiO_2, and FTO/TiO_2/Ag-NPs with dye (Eli et al, 2016).

The absorption peak of Hibiscus Sabdariffa dye was observed around 550 nm which indicated in Figure (12-a). While broad and strong enhancement is observed in the range of 370–650 nm with peaks at about 390 nm and 550 nm as shown in Figure (12-b) for Ag-NPs suspension with the dye. We can conclude that, the absorption of the entire visible region for the electrodes with Ag-NPs was stronger than that for the

electrodes without Ag-NPs. The current-voltage (*I-V*) characteristics was obtained using a keithley 2400 source meter under AM1.5 (100 mW/cm^2) illumination from a Newport A solar simulator. Figure (13) shows the photocurrent density–voltage (*J–V*) curves of the DSSCs with and without silver nanoparticles.

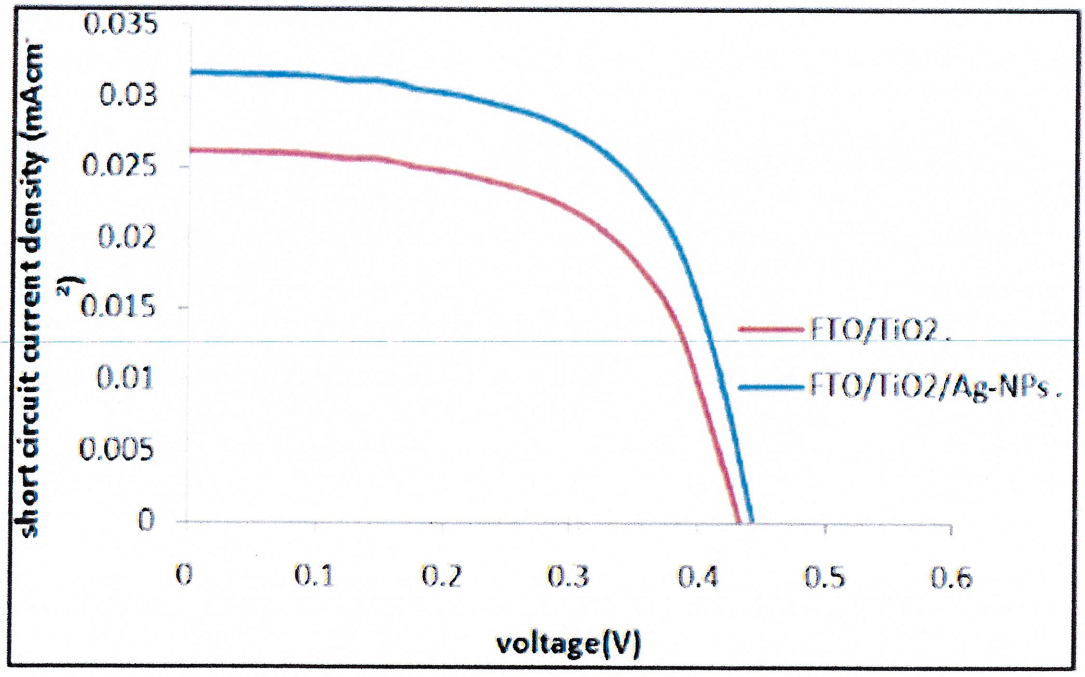


Figure (13): Photocurrent density–voltage (J –V) curves with and without Ag-NPs (Eli et al, 2016).

As a result, they found out that the modified Ag-NPs photo-anode shows a conversion efficiency of 0.00710% (see table (2)). " Which represents a 22% improvement in photocurrent over the photocurrent (0.0259 mA.cm^{-2}) of bare FTO without Ag-NPs " (Eli et al, 2016).

Table (2): Performance characteristics of DSSCs fabricated with different anodes under solar illumination of 100 mWcm^{-2}: (from Eli et al, 2016).

Sample	J_{sc} (mA.cm^{-2})	V_{oc} (V)	FF	η (%)
FTO/Ti O_2	0.0259	0.432	0.594	0.00670
FTO/Ti O_2/AgNPs	0.0316	0.442	0.507	0.00710

2.7 DSSCs evaluation

To characterize solar cell several important parameters are measured and calculated (see Figure (16)). Open circuit voltage (V_{OC}) and short circuit current (I_{SC}) are two most important characteristics of a solar cell. In short circuit, the charges are free to move through the circuit and no buildup of voltage is produced. (See Figure (14)). In the open circuit there is a charge build up on each side creating a voltage Voc. (See Figure (15)).

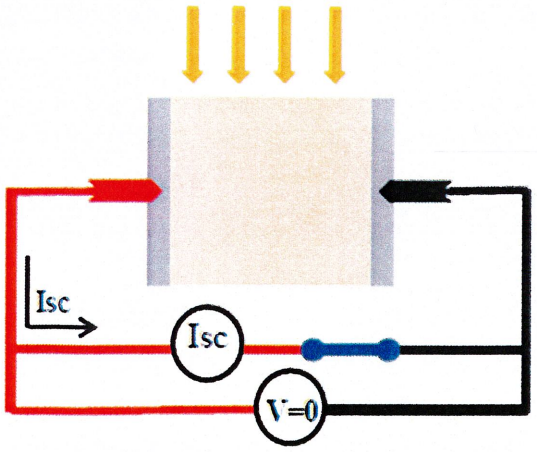


Figure (14): Circuit diagram of how to obtain the short circuit current.

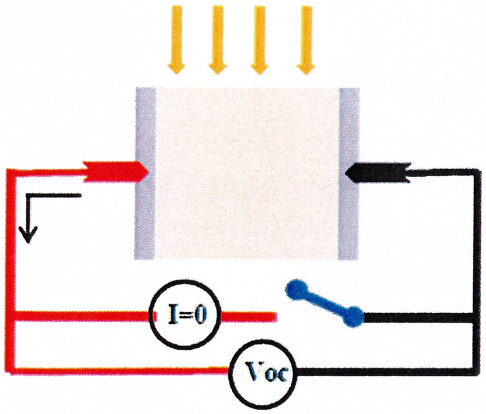


Figure (15): Circuit diagram of how to obtain the open circuit voltage.

The I-V characteristics for a cell can be drawn by measuring the voltage and the current at varied load. Figure (16) shows the ideal I-V characteristics for a cell.

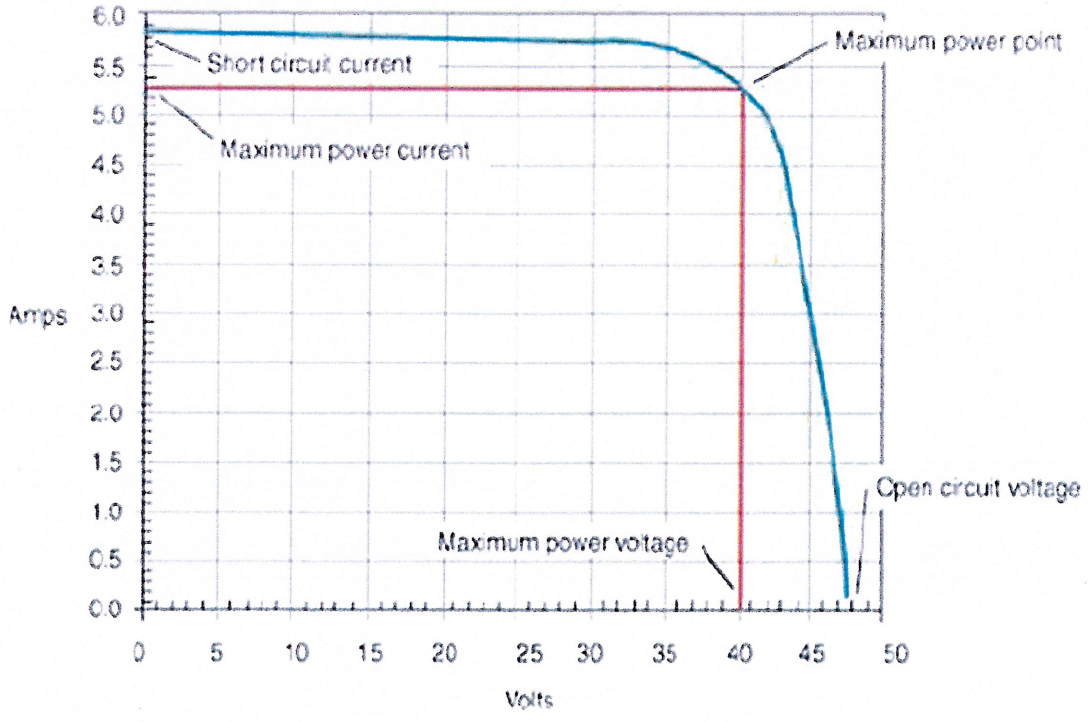


Figure (16): Typical I-V characteristics of solar cell. *(www.circuitcellar.com)*

The fill factor ff of solar cell is defined as the ratio of maximum voltage and maximum current to the open circuit voltage and short circuit current.

$$ff = \frac{I_{max}V_{max}}{I_{SC}V_{OC}} \qquad (11)$$

The efficiency for the cell can be calculated by using the following equation:

$$\eta = \frac{ff \times I_{SC} \times V_{OC}}{E \times A} \qquad (12)$$

The value of E which is radiation intensity is 1000W/m^2 and it is the solar constant. However, not all of that intensity is absorbed by the cell. only small amount can be absorbed through glass and TiO_2 layer. This amount of intensity can be measured by measuring the transmission of the glass. A represent the affected area. The efficiency of DSSC is too small, because of that is not all of the energy is absorbed by the dye molecules Typical efficiencies for DSSC is 10-12%. (Hettelsater et al., 2002)

2.8 DSSCs advantages and applications

2.8.1 DSSCs advantages

Dye sensitized solar cells are the most promising generation of solar cells. Dye sensitized solar cells have many advantages over previous generation of solar cells as detected in table (3).

Table (3): Comparison between silicon solar cell and dye sensitized solar cell:

	Silicon solar cells	**Dye sensitized solar cells**
Cost	High cost and expensive manufacture	Low cost and cheap manufacture
Life time	Long	Long
Component	Very pure silicon need special laboratories for preparation	Cheap and available materials
Color	Limited	Various
Efficiency	High	Normal
Environment impact	Harm the environment	Eco-friendly
Ability to work	- Can absorb only strong visible sunlight. - Can't work in cloudy weather or low light conditions (simply if there is no sunlight no generation of power).	- Can absorb diffused sunlight and fluorescent light. - Can work in cloudy weather and low light conditions. - Can work at wider angles and absorb most of available light.

DSSCs are inexpensive and easier to manufacture, which leads to shorter payback. This generation of cells has medium efficiencies even

under low and indirect light. DSSC work in cloudy weather and also work at wider angles which makes the cells absorb most of the available sunlight. Unlike other thin film cells, dye sensitized solar cells do not degrade in sunlight over time, which makes the cells last longer. DSSCs can be produced on a thin film, flexible robust, plastic substrate; also can apply to metal and glass substrate. Over all of these advantages, dye sensitized solar cells use inexpensive and eco-friendly material. Therefore, DSSCs are environmental friendly. (Soutter, 2013)

2.8.2 DSSCs application

Dye sensitized solar cells are inexpensive and eco-friendly, so they can be used instead of glass windows in covering buildings and provide electrical power to the whole building. Also, DSSCs can be designed in different colors and different materials; it can be flexible and put anywhere. Some of the future applications for dye sensitized solar cells in indoor or outdoor light power, calculators, gadgets and mobiles. DSSC can be design in colorful shapes and used as decorative element and source of power at the same time. (Costa, 2008)

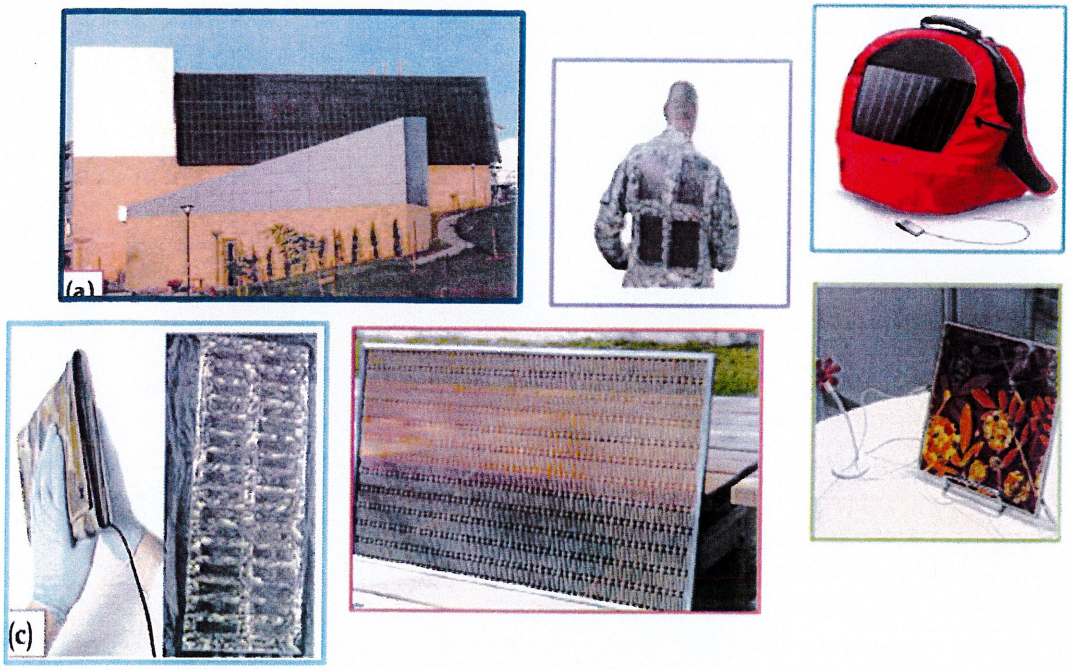


Figure (17): Some future application for DSSCs. (Costa, 2008)

CHAPTER 3: METHODOLOGY

3.1 Materials and equipment

3.2 Natural dyes extraction & characterization

3.2.1 Natural dyes extraction

3.2.2 Soxhlet Extractor

3.2.3 Immersing dyes

3.2.4 Natural dyes absorption spectra

3.2.5 Natural dyes fluorescence spectra

3.3 Synthesis of Nanoparticles & characterization

3.3.1 Row material preparation

3.3.2 Green synthesis of nanoparticles

3.3.3 Nanoparticles transmission

3.3.4 Nanoparticles absorption spectra

3.3.5 Nanoparticles fluorescence spectra

3.4 Growth & characterization of TiO_2 nanoporous photo anode

3.4.1 Preparation of TiO_2 suspension

3.4.2 TiO_2 layer deposition and annealing

3.4.3 Staining Titanium dioxide layer with organic dyes

3.4.4 Catalyst coating

3.4.5 Plate anode XRD.

3.4.6 Plate anode transmission

3.5 DSSCs fabrication & electrical characterization

3.5.1 Solar cell assembling

3.5.2 Current -voltage (I-V) characteristics

CHAPTER 3: METHODOLOGY

In this chapter the method used to prepare dye sensitized solar cells is presented. Six different dye extracts were used (Saffron, Cinnamon, Gloves, Salvia, Jumbo, and Pomegranate), and silver (Ag) nanoparticles. Firstly, methods of extraction of the dyes extract from raw materials are explained. In addition to extraction methods, characterization methods of these extracted dyes are stated. Secondly, methods for synthesis and characterization of nanoparticles are detailed. Thirdly, growth and characterization of TiO_2 nanoporous photo anode are presented. The plate anode characterizing techniques are characterized by X-ray diffraction in order to assure formation of TiO_2 nanostructured layer. Moreover, transmission spectra of the anode coated with TiO_2 to measure the amount of light transmitting through it is shown. Finally, dye sensitized solar cells fabrication and electrical characterization are shown in details. Both I-V characteristics and efficiency of fabricated cells are measured.

3.1 Materials and equipment

This research was based on the extraction of dyes from natural products and using these dyes to reduced silver nanoparticles. These dyes classified into five groups according to the plant parts as shown in Table 4. In Table 4, natural materials are classified into groups. The Arabic and English names are stated as well as images of the used materials.

Table 4: Natural material used as source of dye extracts:

Group	English name	Arabic name	Image
Flower	Saffron	زعفران	
Leaves	Salvia	الميرمية	
Seed	Gloves	قرنفل (مسمار)	
Stem	Cinnamon	قرفة (دارسين)	

Fruit	Pomegranate	رمان	
	Syzygium cumin	الجمبولان	

Materials used in fabrication of dye sensitized solar cells are shown in Table 5.

Table 5: List of the materials used to fabricate DSSCs:

Materials	Description	Characterizations
Conductive Glass (tin dioxide coated)	Transparent glass conductive layer Name: FTO	Dimension : 2.5 cm x 2.5 cm resistance 18-32 Ω
Colloidal titanium dioxide powder TiO_2	White powder	Formula: TiO_2
acetic acid	Transparent liquid	Formula: CH_3COOH Purity%: 99%
Iodide electrolyte	0.5M Potassium iodide mixed with 0.05M iodine in water-free ethylene	Formula : (I^-/I_3^-)
Ethanol	Transparent liquid	CH_3CH_2OH Purity%: 99%

deionizer water	Pure water (washing & solvent)	H_2O
Candle (graphite coating)	FTO-coated glass	Carbon layer
Surfactant	Dish detergent	Hydropholic and hydrophopic
Silver powder	Silver nanoparticles	Silver nitrate Furmula: $AgNO_3$
Gold powder	Gold nanopaticles	Gold (III) chloride trihydrate Furmula: $HAuCl_4.3H_2O$
Several laboratories tools	Pipette, Glass stirring rod , mortals , pestle , Petri dishes , tweezers, beakers, transparent tape, absorbent tissue paper, cotton swaps, Para films, filter papers, gloves, alligator clips, small Binder clips , glassware	

Table 6 shows the instruments used to characterize materials and data acquisition.

Table 6: List of the systems and instruments used in characterization:

Instruments and systems	Function	Specification
UV-VIS spectrophotometer	Absorbance spectra	UV-1800 Shimadzu UV spectrophotometer
UV-VIS spectrophotometer	transmittance spectra	UV-3101 Shimadzu UV spectrophotometer
Spectro fluorophotometer	Emmision spectra	RF-6000 Shimadzu spectro fluorophotometer
Diffractometor	XRD pattern	Rigaku powder diffractometer
Soxhlet set	Dye extraction	Chemistry setup
Solar Simulator	Solar Simulator	ABET Solar Simulator
digital multimeter	Measuring current, voltage, resistance	Manual
PH meter	Measuring PH level	

Microwave oven	Grow nanoparticles	Samsung microwave oven
Centrifuge	Spin coating Rotation motion is used to have uniform and good thickness of TiO_2 film	

3.2 Natural dyes extraction and characterization

3.2.1 Natural dyes extraction

In this project, six different dye extracts from assorted plant parts were used. These dyes were extracted through two different methods. The first method is the soxhlet extractor apparatus, while the second method is the immersion method. In the immersion method, the materials were immerse in a chosen solvent (distilled water). The effect of extraction method was checked by comparing the absorbance of the extracted dye. As shown in Figure (18), there was a relatively small difference in the absorbance level in the visible part of spectrum. Therefore, the immersion method is a sufficient and quick method of extraction.

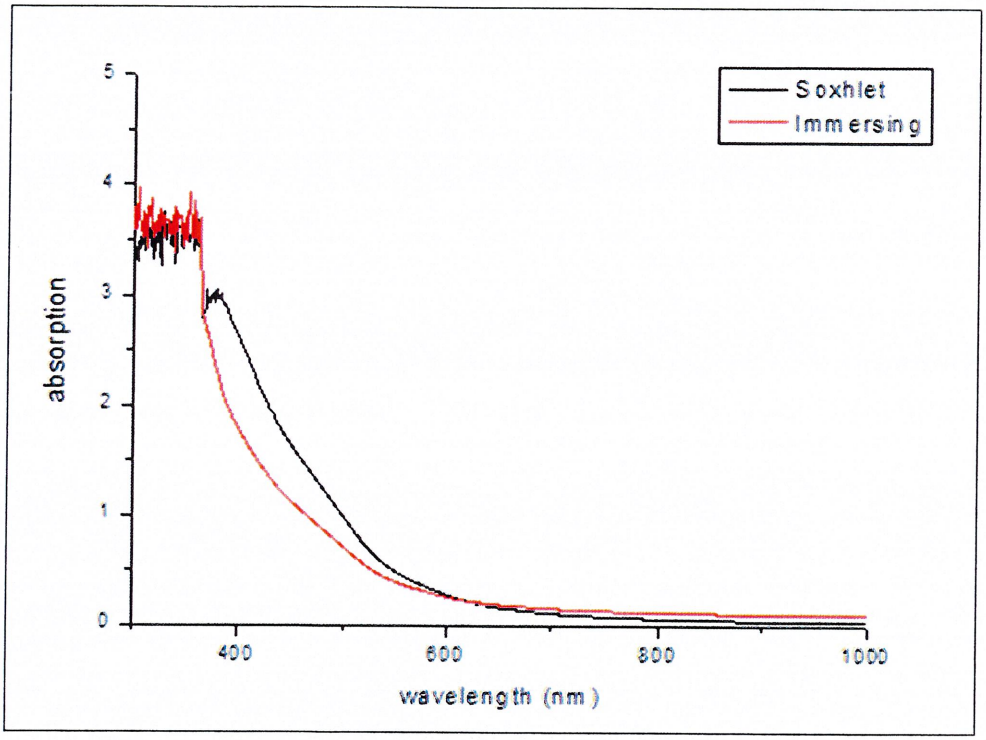


Figure (18): Effect of dye extraction method on the absorbance spectra.

3.2.2 Soxhlet Extractor

The first step is to extract dyes from plants and flowers; to extract the dye an apparatus called Soxhlet was used. Soxhlet is an apparatus use in dyes extraction or other materials with volatile solvent (such as ether, alcohol, or benzene). The Soxhlet consisting of a vertical glass cylindrical extraction tube that has both a siphon tube and a vapour tube, that is fitted at its upper end to a reflux condenser and at its lower end to a flask so that the solvent may be distilled from the flask into the condenser whence it flows back into the cylindrical tube and siphons over into the flask to be distilled again. According to the Soxhlet's procedure, dyes from solid material are extracted by repeated washing with solvent, distilled water, under reflux in special glassware. The basic procedure is by insertion a solid sample in a porous container and allowing condense solvent to

extract continuously. Figure (19) shows the basic component of Soxhlet apparatus.

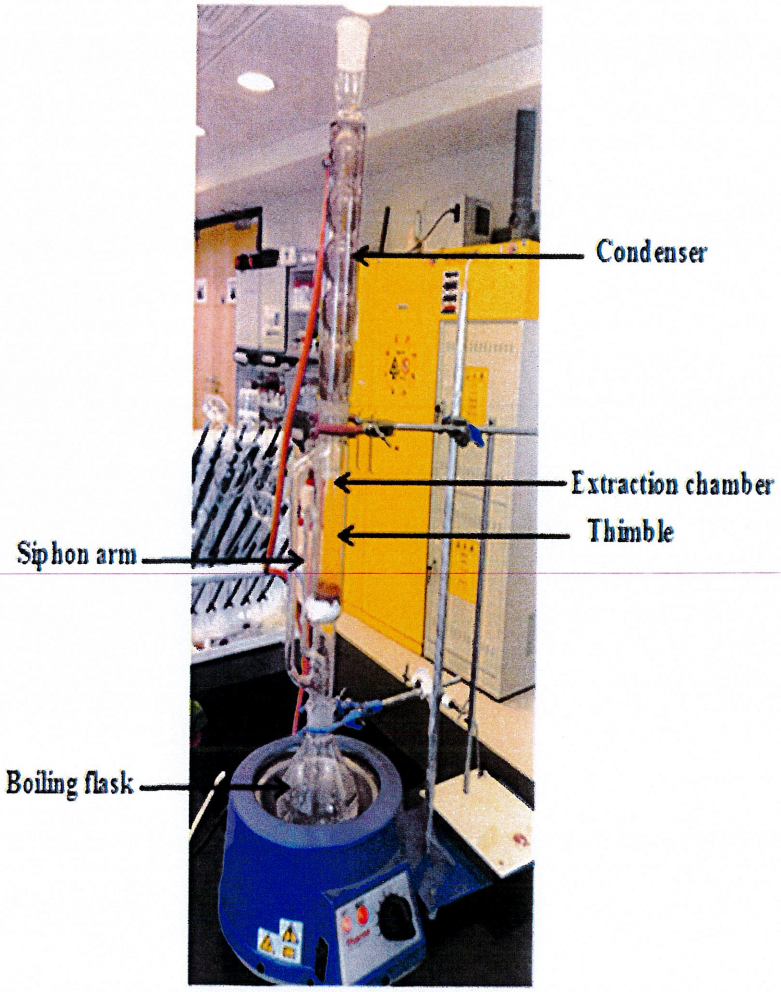


Figure (19): Soxhlet apparatus for the extraction dyes from solid samples.

1. A paper thimble was placed in an extractor chamber, and then the solid sample was placed inside it to insure that there is no fall of the solid material inside the liquid as shown in Figure (20).



Figure (20): Insertion of a solid sample inside the thimble.

2. The extractor chamber placed above a distillation flask containing an organic solvent and below a condenser. The solvent used is ethanol because it doesn't affect the chemical composition of the material and protect it from decomposition.
3. The flask is heated and the solvent partially evaporates and moves up into the condenser where it is converted into a liquid that trickles down into the extraction chamber containing the sample.
4. The solvent surrounding the samples were exceeds an upper level of an extractor siphon it overflows and trickles back down into the distillation flask. At the end of the multiple extraction process, which usually takes several hours the extractor is removed and the organic solvent is distilled out from the extracted solid.

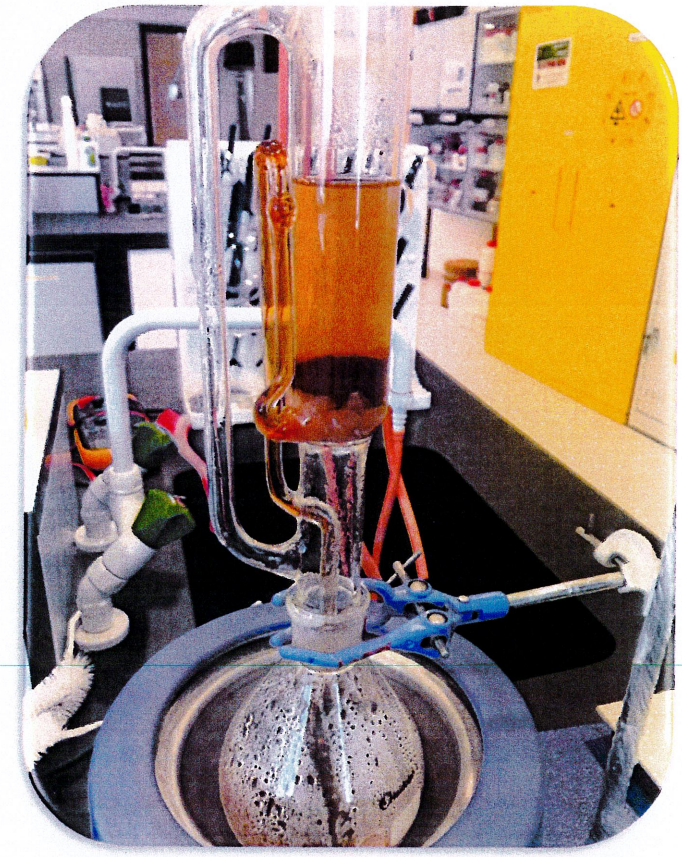


Figure (21): Extraction of a dye (e.g. cinnamon) from a solid material using soxhlet extractor.

5. The solutions of the dyes were placed in covered beakers and stored in cold place.

3.2.3 Immersing dyes

The second method was used to extract dyes is the immersion method. In immersion method materials were immersed in a chosen solvent (such as distilled water) for few hours or heated up until boiling. Immersion method is quite sufficient, easy and quicker method for dye extraction.

1. Particular amount of solid materials were weighted. The weight is measured in order to calculate the concentration of the prepared solution.
2. 100 ml of solvent such as distilled water was added to the solid material and kept for few hours or heated until it boils.

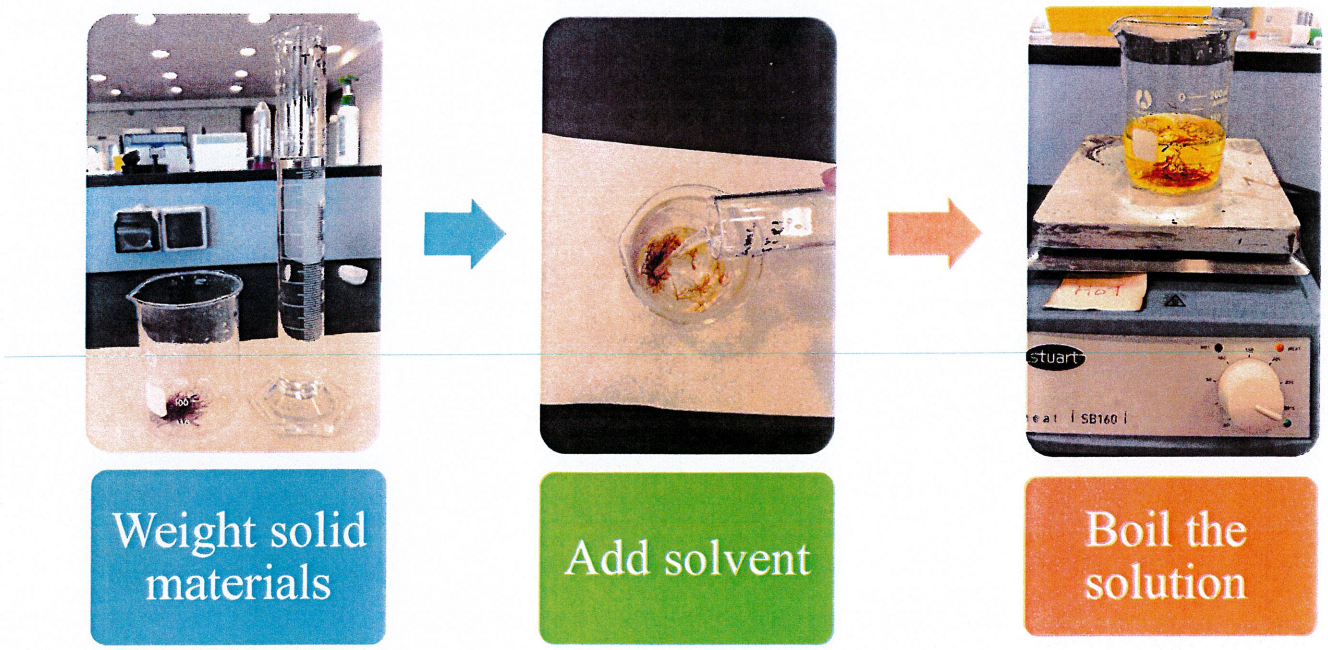


Figure (22): Extracting dyes using immersion method.

3. Finally, the solution was filtered and stored in covered beakers in cold place.

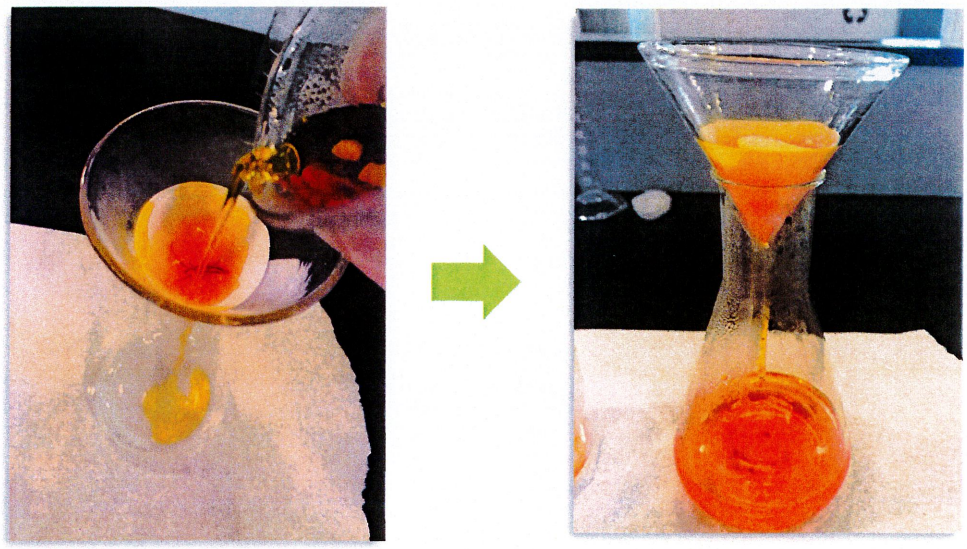


Figure (23): Filtering the prepared solutions.

3.2.4 Natural dyes absorption spectra

In this experiment natural dyes are used like saffron, cinnamon, raspberry, Salvia officinalis, and clove. Each type of dyes absorb particular type of light, each dye absorbs certain wavelength range. To find out which wavelength ranges are absorbed by each dye absorbance spectrum has been measured using spectrophotometer. Spectrophotometer is an instrument to measure how much a sample absorbs light by measuring the intensity of light as a beam of light passes through the sample solution. The basic principle is that each compound absorbs or transmits light over certain range of wavelength. The extracted natural dyes will be optically characterized using UV-visible dual beam spectrophotometer.

Absorbance measurements were performed using dual beam UV-VIS spectrophotometer (Shimadzu, model UV-1800). The absorbance (A) is defined as:

$$A = -\log_{10} \frac{I_\circ}{I_T} \qquad (13)$$

Where I_T is the intensity of light after it has transmitted through the sample and $I_\circ$ is initial light intensity. ("Absorbance", 2018)

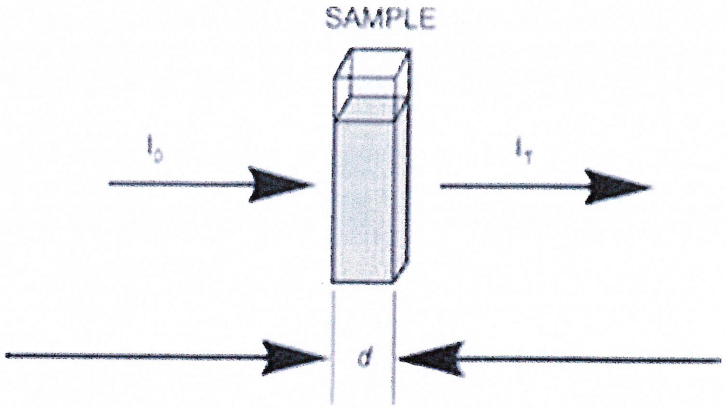


Figure (24): Absorption of light by a sample of thickness d. ("Absorption",2017)

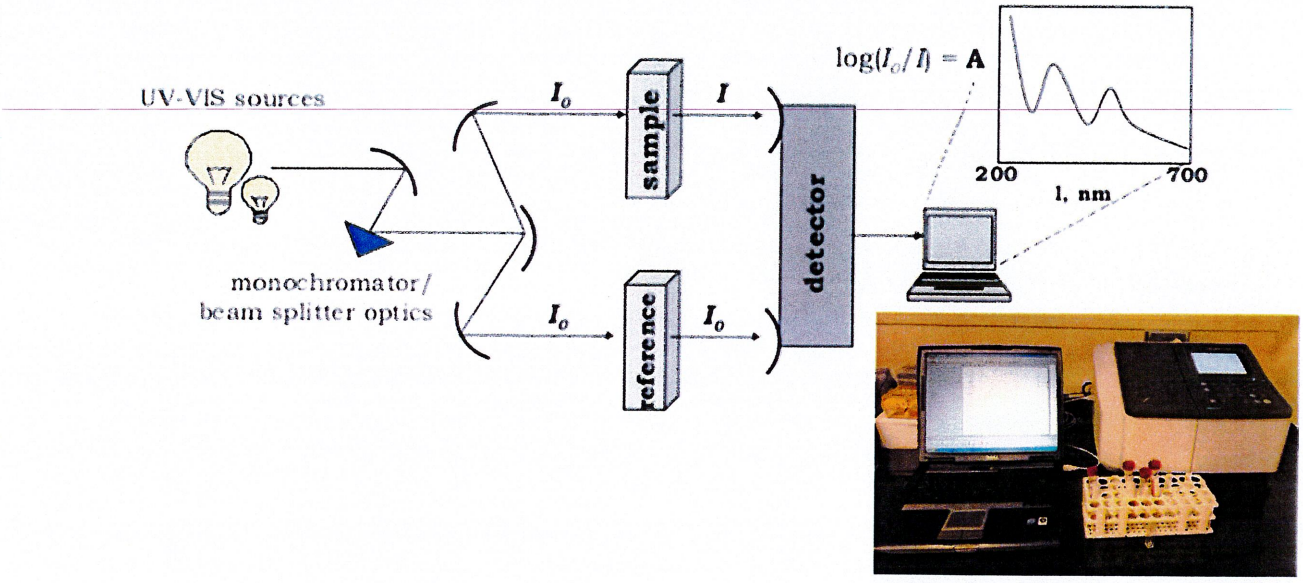


Figure (25): Schematic representation of the spectrophotometer and image of the used Shimadzu spectrophotometer, model UV-1800. ("UV-Visible spectroscopy", 2018)

3.2.5 Natural dyes fluorescence spectra

Fluorescence is the light given off by certain substances when it absorbs light. The florescence spectra reveals how efficient exited dyes molecule when relaxing to the ground state. Excited dye molecule emits

different photons, when the fluorescence light has longer wavelength than the absorbed one the fluorescence light is redshift and this is called Stokes shift. ("Fluorescence Spectroscopy", 2018)

In this study a Spectro fluorophotometer (Shimadzu spectro fluorophotometer, model RF-6000 (see Figure (26))) is used to measure the fluorescence spectra of each extracted dye.

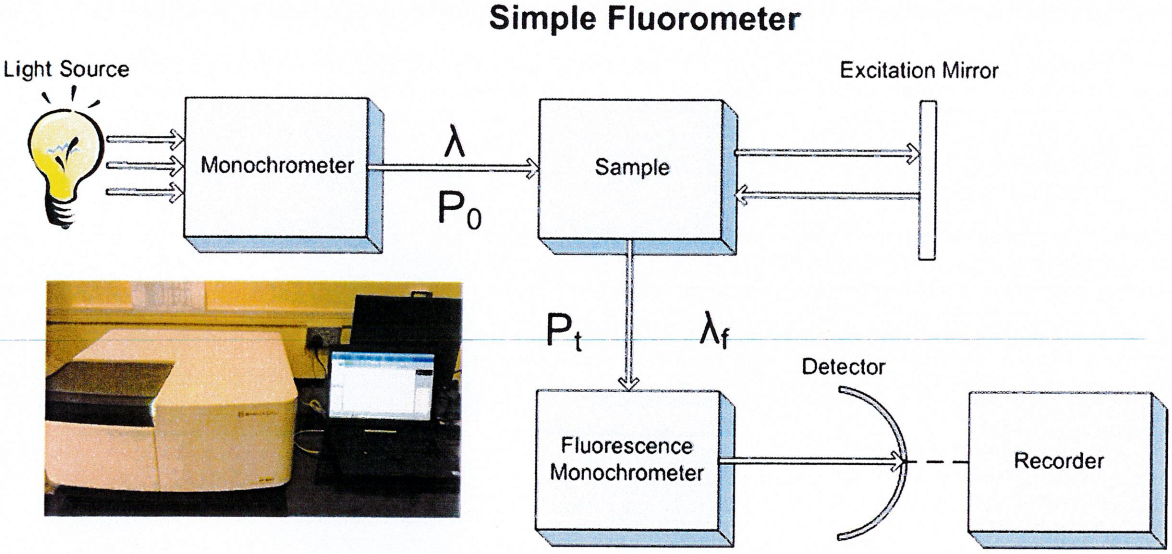


Figure (26): Schematic representation and image of Spectro fluorophotometer and Shimadzu fluorophotometer, model RF-6000. ("Electronic Spectroscopy",2018)

3.3 Synthesis and characterization of nanoparticles

3.3.1 Row materials preparation

Metallic nanoparticles can be prepared by physical, chemical, or biological method. However, in order to avoid toxic and nonecho unfriendly chemicals, biological based method or green synthesis is adopted in this study. Silver nanoparticles will be synthesized by taking specific amount (few miligrams) of row materials such as silver nitride

($AgNO_3$) powder and sock it in specified volume of solute such as distilled water (few milliliters) in order to prepare a 1-mM of $AgNO_3$ solution 42.1 mg of silver nitride ($AgNO_3$) powder was added to 100 ml of distilled water at room temperature.



Figure (27): Silver nitride ($AgNO_3$) powder.

3.3.2 Green synthesis of nanoparticles

Green synthesis of nanoparticles is safe, environmental friendly, low cost, and requires fewer preparation steps. Beside these advantages of green synthesis it is based on use of diversity of biological materials (ranging from micro-organisms to plants). In green synthesis method plants extract used as reducing agents such as saffron, salvia, gloves, cinnamon, pomegranate, and Syzygium cumin. Nanoparticles could be synthesized rapidly in association of heat. Furthermore, conditions of synthesized nanoparticles can be changed by changing many factors such

as, natural dye extract concentration, silver solution concentration, and heating (using microwave) time period or level of heating (using heater).

1. **Silver nanoparticles AgNPs using the leaf extract of salvia:**

The silver nanoparticles have been synthesized using leaf extract of salvia by changing two factors:

i. **Concentration:**

1. Different volume of $AgNO_3$ solution was added to different volume of salvia solution.
2. Solutions were placed in microwave oven for 10sec.
3. The optical properties of AgNPs were determined by using UV-VIS spectrophotometer.

Table 7: Concentrations used in synthesis of AgNPs.

$AgNO_3$ solution volume (ml)	Salvia solution volume (ml)	Heating period time (second)
10	1	10
5	1	10
1	10	10

As the salvia leaf extract is mixed with $AgNO_3$ solution, it started to change colour as shown in Figure (28). Solutions' colour change is visual evidence of the formation of silver nanoparticles AgNPs.

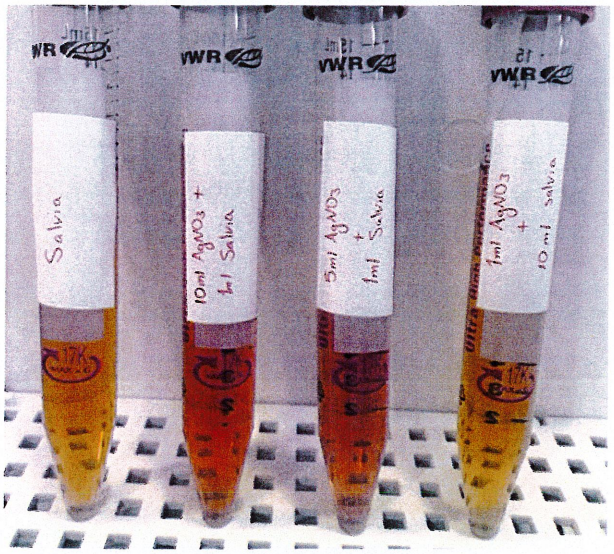


Figure (28): Silver nanoparticles formed after the addition of salvia leaf extract to silver nitride.

ii. **Microwave heating time period:**

1. Specific volume of $AgNO_3$ solution was added to specific volume of salvia solution.
2. The solutions were positioned in microwave oven for different time.
3. Absorbance of AgNPs samples were measured using UV-VIS spectrophotometer.
4. Solutions were saved and tested after different storage time periods.

Table 8: Heating time used in synthesis of AgNPs.

$AgNO_3$ solution volume (ml)	Salvia solution volume (ml)	Heating time (second)
5	1	10
5	1	15
5	1	20



Figure (29): Silver nanoparticles formed after the addition of salvia leaf extract to silver nitride after different heating time.

From Figure (29) as the salvia leaf extract was mixed with $AgNO_3$ solution with different heating time, it started to change the colour. The colour change in the solutions denotes the formation of silver nanoparticles AgNPs.

II. **Silver nanoparticles AgNPs using the seeds extract of gloves:**

Silver nanoparticles have been synthesized using seeds extract of gloves by changing two factors:

i. **Concentration:**

1. Different volumes of $AgNO_3$ solution were added to different volumes of gloves solution.
2. The solutions were placed in microwave oven for 10sec.
3. Absorbance of AgNPs were determined by using UV-VIS spectrophotometer.

Table 9: Concentrations used in synthesis of AgNPs.

$AgNO_3$ solution	Gloves solution	Heating time

volume (ml)	volume (ml)	(second)
10	1	10
5	1	10
1	5	10

As the gloves seeds extract was mixed with $AgNO_3$ solution, it started to accelerate the reduction of silver solution (Figure (30)). The colour change in the solutions denotes the formation of silver nanoparticles AgNPs.

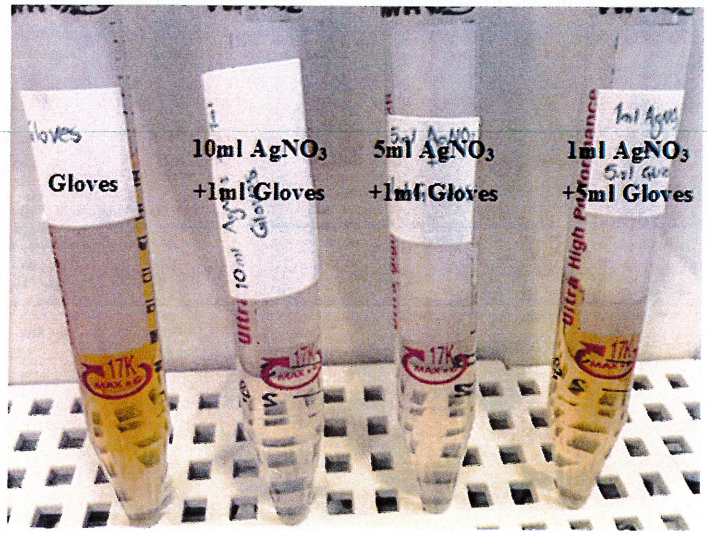


Figure (30): Silver nanoparticles formed after the addition of gloves seeds extract to silver nitride.

ii. **Microwave heating time period:**

1. Specific volume of $AgNO_3$ solution was added to a specific volume of salvia solution.
2. The solutions were positioned in microwave oven for different time.
3. Absorbance of AgNPs were determined by using UV-VIS spectrophotometer.

4. Solutions were saved and tested after different time periods.

Table 10: Heating time used in synthesis of AgNPs.

$AgNO_3$ solution volume (ml)	Gloves solution volume (ml)	Heating period time (second)
5	1	10
5	1	15
5	1	20

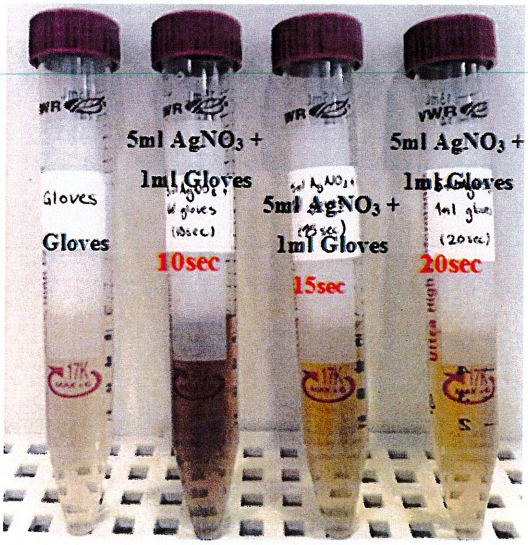


Figure (31): Silver nanoparticles formed after the addition of gloves seeds extract to silver nitride with different heating time.

As presented in Figure (31), as the gloves seeds extract was mixed with $AgNO_3$ solution with different heating time, it started to change the colour. The colour change in the solutions indicates the formation of silver nanoparticles AgNPs.

3.3.3 Imaging Nanoparticles

Nanoparticles solutions could be characterized using transmission electron microscope (TEM). TEM used to quantify morphology and crystallographic information of samples.

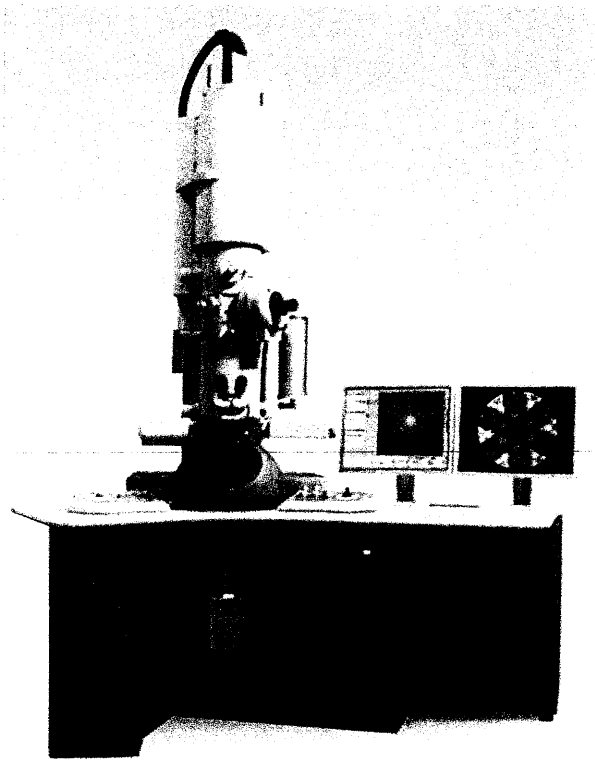


Figure (32): Transmission electron microscope (TEM). ("TEM", 2018)

3.3.4 Nanoparticles absorption spectra

Metallic nanoparticles have a property called Surface Plasmon Resonance (SPR). Plasmon is a quantum collective electron oscillation in a metal ("Plasmon", 2018). SPR is a property appears in some metal surface due to resonant oscillation of conduction electrons at the interface when incident light falls on them. This property appear clearly in gold, silver, and copper in visible light. Therefore, this property is responsible for changing material colours when particles attain nano size. When nanoparticle size is smaller than the incident light wavelength an optical phenomenon is generated called Localized Surface Plasmon Resonance

(LSPR), (Jussila, 2016). Surface plasmon resonance of silver or gold nanoparticles showed a peak in visible range corresponds to characteristic absorbance. The peak indicates formation of nanoparticles. As a result, the absorption spectra will be measured using UV-VIS spectroscopy to ensure the formation of nanoparticles. An example of that is presented in Figure (33). The surface plasmon resonance of AgNPs showed a peak centred near 450 nm at the UV-VIS spectra which corresponds to the absorbance of AgNPs. This peak indicates the reduction of silver nitride into AgNPs using cinnamon extracts.

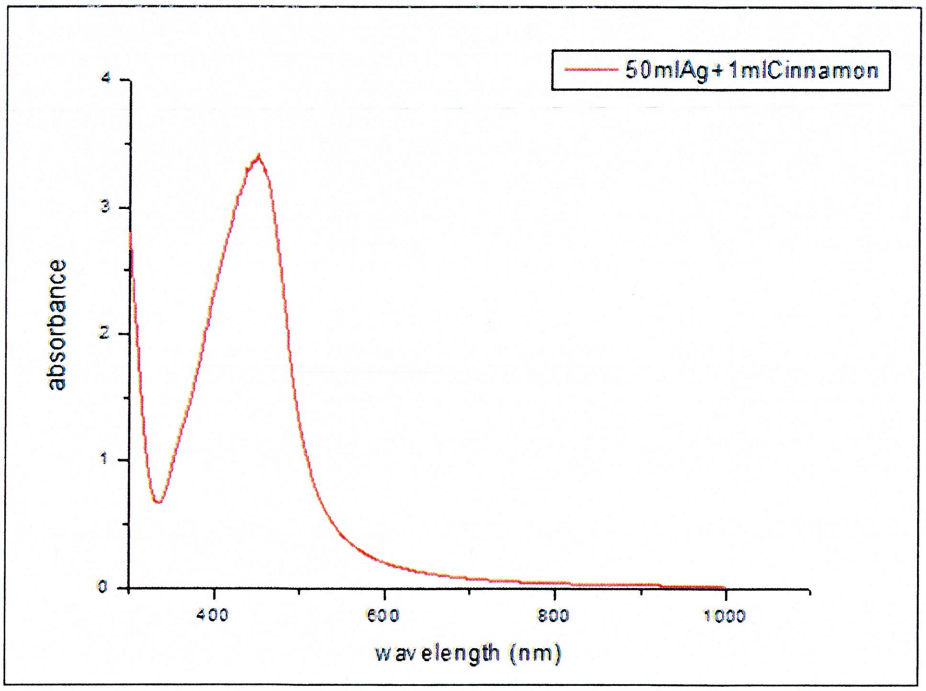


Figure (33): UV-VIS spectra of synthesized AgNPs using cinnamon extract.

3.3.5 Nanoparticles fluorescence spectra

In this study a Spectro fluorophotometer (see Figure (26)) - Shimadzu spectro fluorophotometer, model RF-6000 is used to measure fluorescence spectra of each metallic nanoparticle sample.

3.4 Growth & characterization of TiO_2 nanoporous photo anode

Nanostructured wide band gap semiconducting layer is the heart of the system of DSSC. In this study titanium dioxide TiO_2 is used as semiconductor material to attach dye molecules. A suspension of TiO_2 was prepared and characterized using X-ray diffraction spectroscopy.

3.4.1 Preparation of TiO_2 suspension

A suspension of TiO_2 can be prepared following very easy steps:

1. 6 grams of colloidal Degussa P25 TiO_2 powder is weighted.

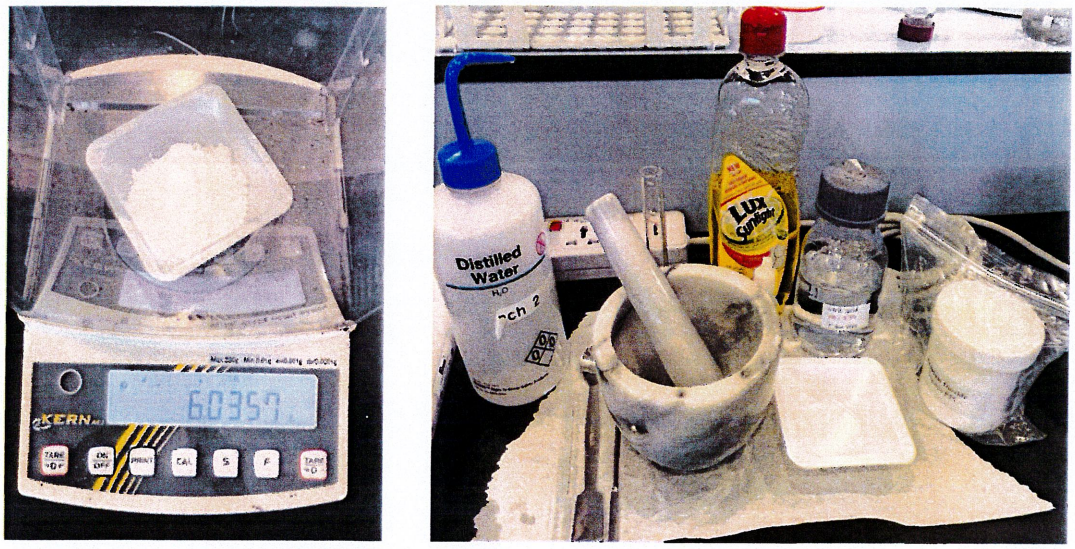


Figure (34): Preparing TiO_2 to make the suspension.

2. 9ml of nitric acid with PH around 3-4 is added to the 6 g of TiO_2 powder in a mortar and pestle while grinding. The nitric acid is added 1ml every time while grinding until have thick paint.
3. 1 ml of surfactant (soap) is added to 1ml of distilled water and added to the TiO_2 paste. This step allows the final suspension to more uniformly coat the glass plates. A spatula is used to return TiO_2 material to the center of the mortar.

4. The TiO_2 suspension became thick and ready for next step. If the suspension is liquid and too thin that means it is not good and can't absorb enough light in solar cell.
5. The TiO_2 suspension is stored in small capped bottle.

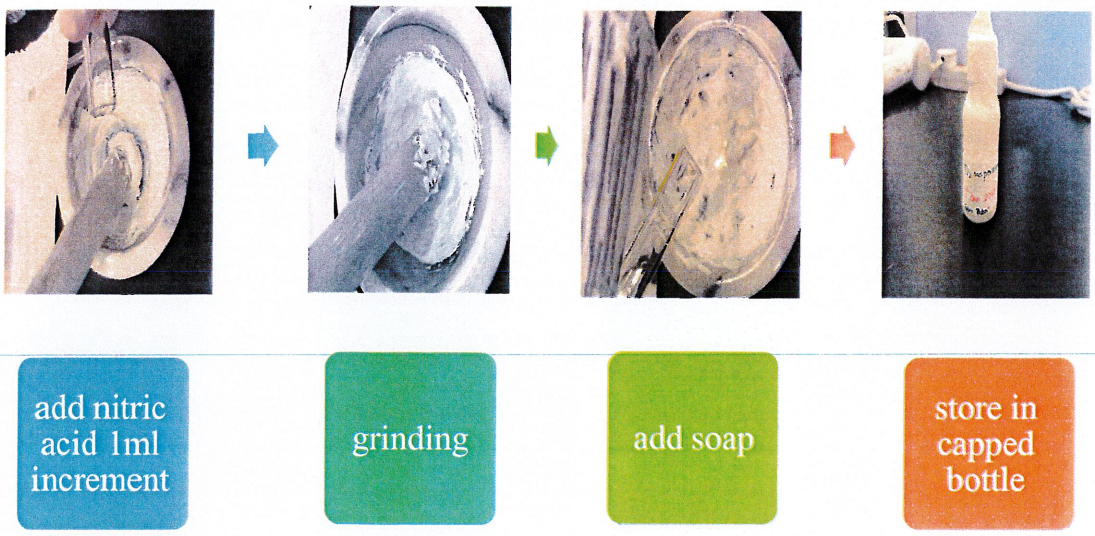


Figure (35): Preparation of the TiO_2 suspension in a mortar and pestle.

3.4.2 TiO_2 layer deposition and annealing

A Titanium Dioxide (TiO_2) film deposited on conductive glasses using three different ways: doctor blade method, spin coating, and rotation method.

I. **Doctor blade method:**

Doctor blade method is rapid sweeping motion with the glass rod to coat the titanium diooxide suspension on the masked conductive glass plate.

1. Two conductive glass plates are obtained and cleaned by rinsing them in ethanol. The two glasses were dried with soft tissue.
2. A multimeter set to ohms is used to check which side of the glass is conductive. Multumeter reading should be between 10-30 ohms for the conductive side.

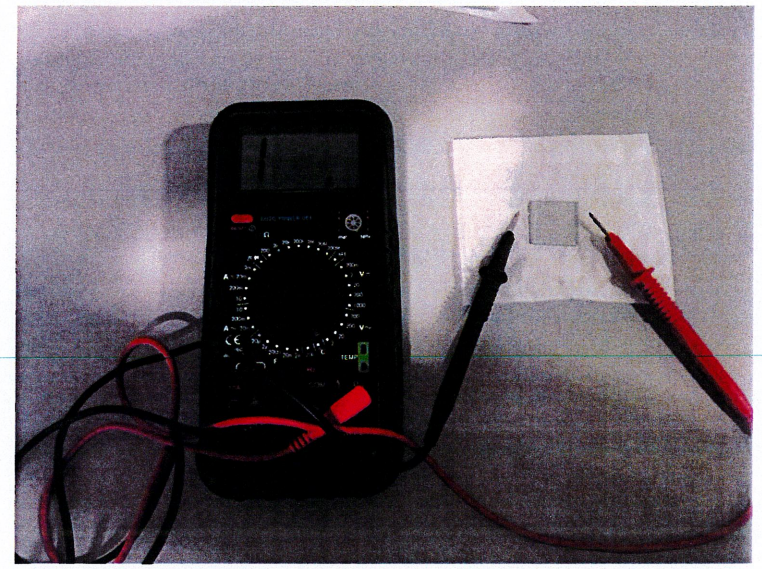


Figure (36): Checking conductive side using ohmmeter.

3. One glass plate is placed on a table where the conductive side faces up.
4. Pieces of scotch tape were applied on three edges of the glass plate as shown in Figure (37). The strip should not be more than 1mm wide in the edges. The three pieces of tape extend from the edge of the glass to the table in order to secure the plates to the table.

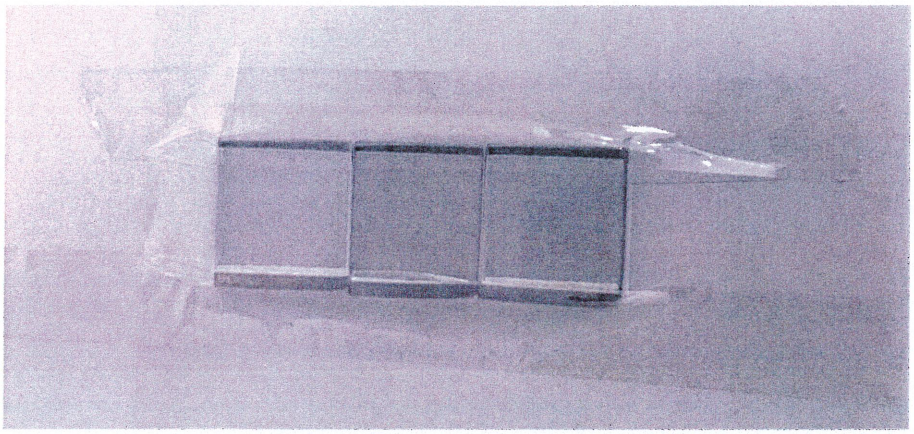


Figure (37): Fixing the glass plate on the table.

5. A thin line of the TiO_2 suspension is uniformly applied to the edge of the plate near the tape using the dropper bottle or a pipit.
6. A clean glass stirring rod is slid over the plate to spread the TiO_2 suspension. The most successful technique for achieving a uniform film is to use a rapid sweeping motion of the rod towards the bottom of the setup and then back over the film in the opposite direction until have uniform coating as shown in Figure (38).

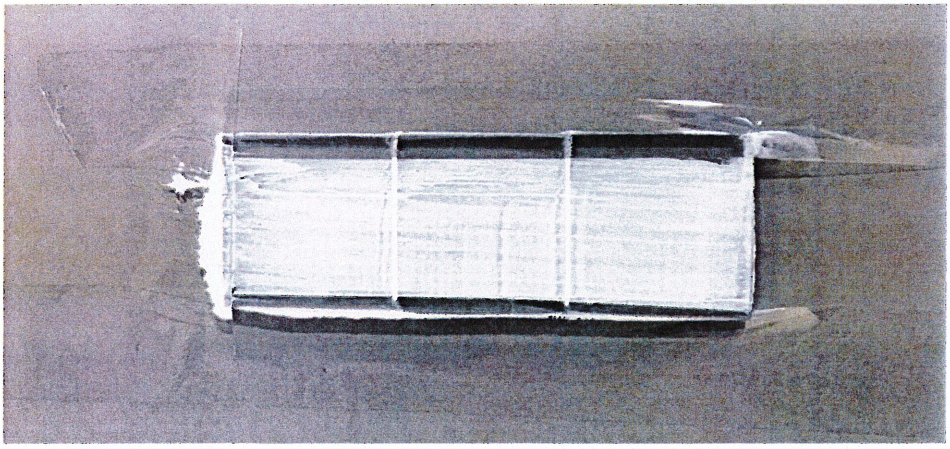


Figure (38): Spreading the TiO_2 suspension on the glass plate.

7. After deposition of the suspension, the tape is carefully removed.
8. The plate is placed in a petri dish with cover to allow the TiO_2 film to dry.

II. **Spin coating:**

In this method a small amount of caoting material (TiO_2) is applied on the center of conductive glass, then rotated at high speed in order to spread the coating TiO_2 by centrifugal force.

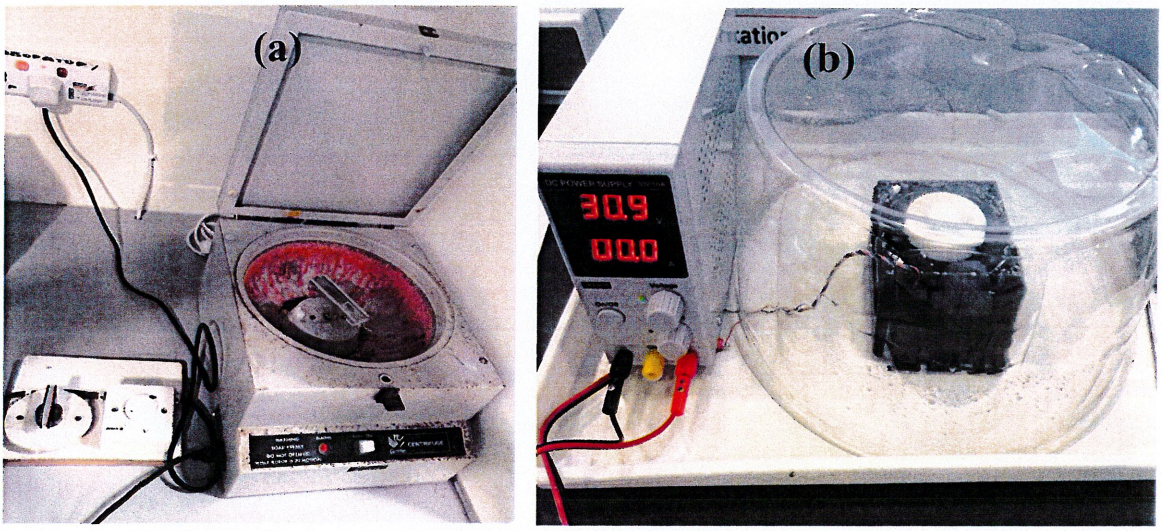


Figure (39): Spin coating instrument.

III. **Rotation method:**

In this method a small machine were built to achieve a uniform film. In this method a rotation motion is used to have uniform and good thickness of TiO_2 film.

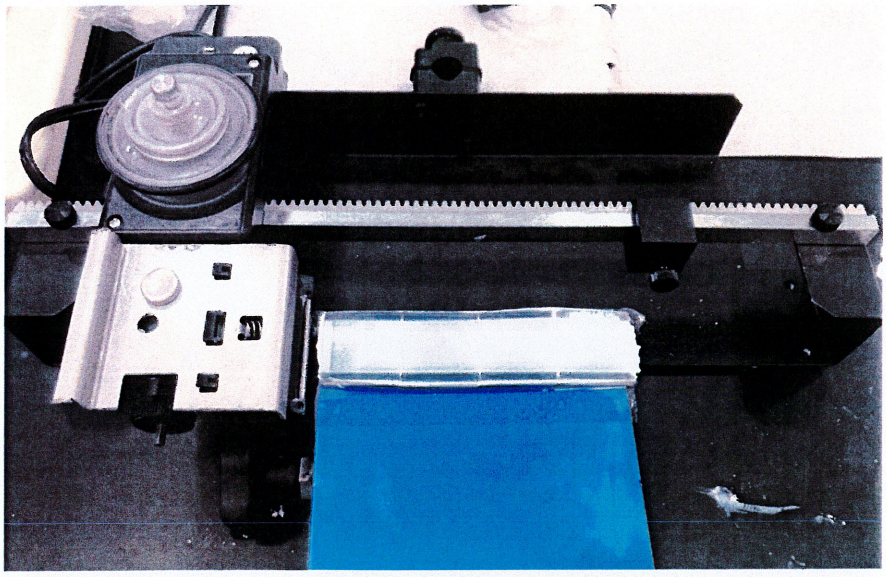


Figure (40): Rotation method for deposited TiO_2 on conductive glasses.

After that the dried TiO_2 film is anneal on the conductive glass by using a hot air gun or a gas burner. The TiO_2 film is placed on a ring stand on the gas burner for 15-20 minutes (see Figure (41)).

During heating the white color TiO_2 film become light brown and then back to white color. This step is important to create nanostructured TiO_2 layer in order to increase the surface area.

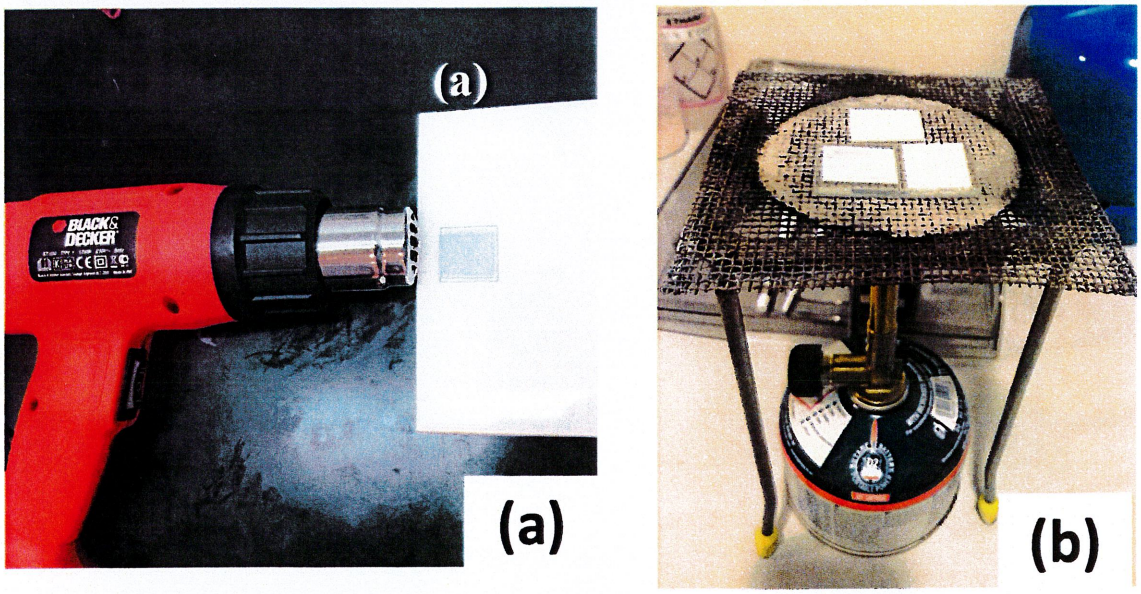


Figure (41): Annealing the TiO_2 layer using: (a) hot air gun, (b) gas burner.

3.4.3 Staining Titanium dioxide layer with organic dyes

Dye molecules and metallic nanoparticles loaded to the surface of TiO_2 on the transparent conducting electrode.

1. The TiO_2 layer was placed in a petri dish filled with a dye solution or nanoparticles solution where the TiO_2 coated layer face up. No specific time for this process but leave the plate in the dye solution until it get colored with the dye (see Figure (42)).
2. After removing the glass from the petri dish of the dye, the glass plate was washed with water and then with ethanol.
3. The TiO_2 layer is gently dried with soft tissue.

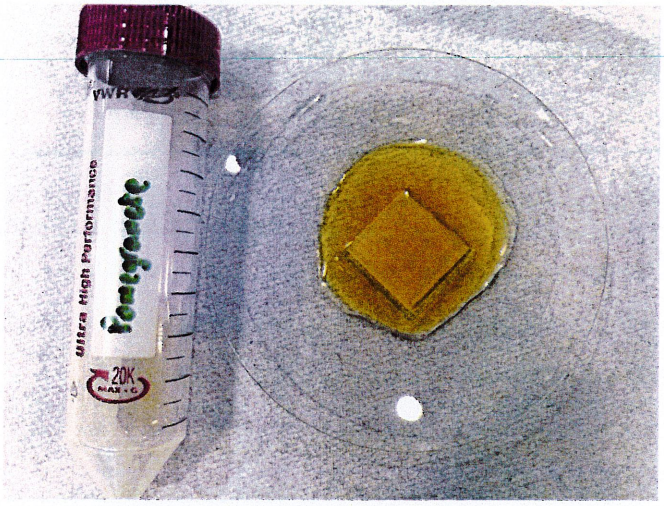


Figure (42): Coating the annealed TiO_2 layer with dye solution.

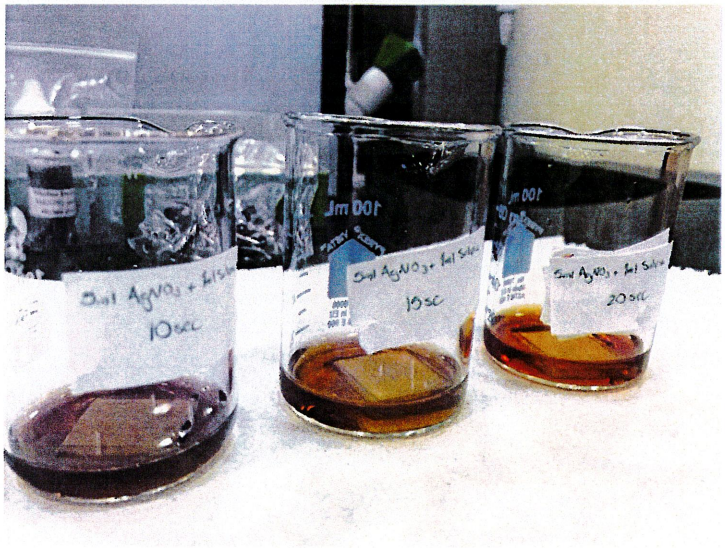


Figure (43): Coating the annealed TiO_2 layer with nanoparticles solution.

3.4.4 Catalyst coating

The DSSC consist of two pieces of conductive glass and each conductive side coated with different material. One conductive side is coated by TiO_2 layer (transparent conducting electrode) and the other conductive side of the second glass (counter electrode) is coated by graphite which acts as catalyst.

1. The other conductive glass plate is held with a tweezers.
2. A light carbon film is applied to the entire conductive side of the plate. This thin carbon layer serves as a catalyst for triiodide to iodide regeneration reaction in the solar cell.

There are many ways to cover the plate with carbon, one can use a soft pencil lead or a better performing can be deposited by holding the conductive side of the counter electrode with tweezers at a tip of a candle flame and move the plate back and forth to produce a thin and uniform coating as shown in Figure (45).

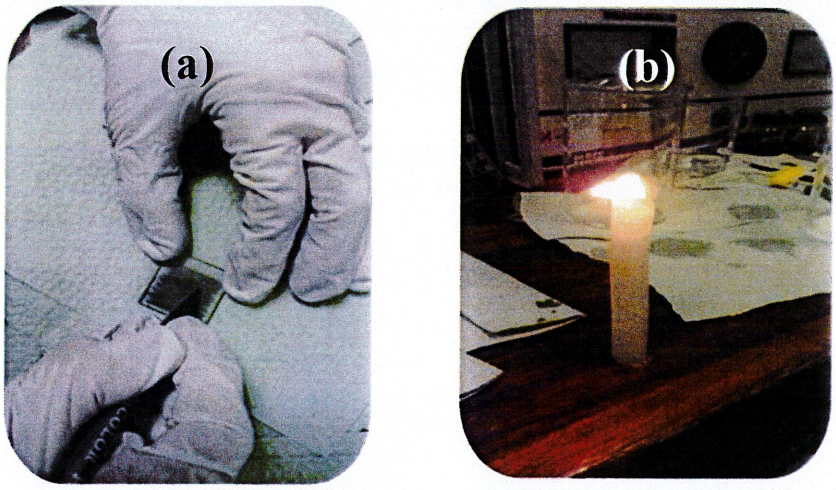


Figure (45): Coating the counter electrode with carbon catalyst layer (a) using a pencil lead and (b) using a candle flame.

3.4.5 Plate anode XRD

To confirm the formation of nanostructured TiO_2 layer, X-ray diffraction is performed. In this study X-ray diffraction spectroscopy (Rigaku diffractometer) was used for structural characterization.

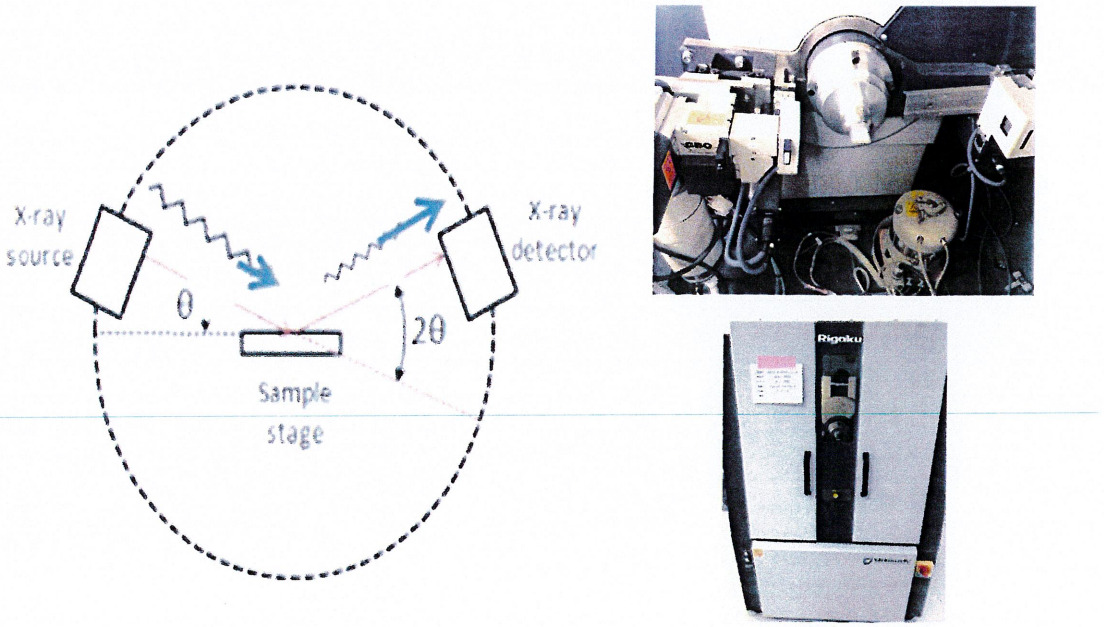


Figure (46): Schematic representation of X-ray diffraction spectroscopy and Rigaku diffractometer. ("X-ray", 2018)

3.4.6 Plate anode transmission

The transparency of the conductive electrode can be measured using dual beam UV-VIS spectrophotometer (Shimadzu, model UV-3101). The transparency level of the coated transparent conducting electrode is not flat100% over the visible spectrum and near infrared. Figure (47) shows the transparency of nanoporous deposited layer of TiO_2. The transmittance of conductive clean glass, before deposition of TiO_2 layer

(black curve) reaching about 70 % at wavelength 750 nm, non-annealed TiO_2 (red curve) about 8 %, after annealed (green curve) about 6 %, while the transparency of TiO_2 layer only (blue curve) is about 10%. Therefore, the efficiency of the tested solar cell only 10% of irradiance was considered.

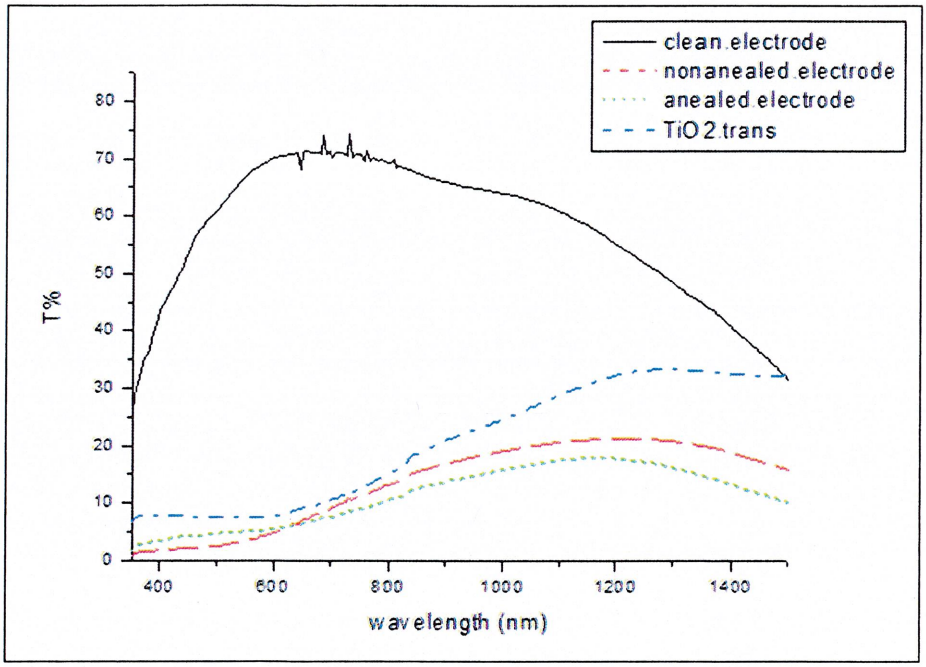


Figure (47): Transmittance of the conductive electrode (clean glass) before deposition, coated with TiO_2 non-annealed, annealed and TiO_2 layer only.

3.5 DSSCs fabrication & electrical characterization

DSSCs will be fabricated using Dr. blade method and then under 1 Sun illumination will be characterized by measuring short circuit current (I_{sc}), open circuit voltage (V_{oc}), plotting I-V characteristics. Also, Calculating fill factor of the solar cells (FF), power conversion efficiency (η).

3.5.1 Solar cell assembling

1. The TiO_2 layer is placed on a flat surface where the TiO_2 layer faces up.
2. The catalyst coated counter was placed on the top of the TiO_2 layer where the conductive sides of the two glasses are opposite together.
3. A space of 4-5mm was left between the two plates. This space is the contact points for the negative and positive electrodes. All TiO_2 layer is covered with carbon.
4. Two clips are placed on the longer edges to hold the plates together.
5. Potassium iodide mixed with iodine of 1 drop or 2 drops were added on one edge of the plates.

Opening and closing each side of the solar cell by releasing the binder clips to draw the liquid into the space between the electrodes.

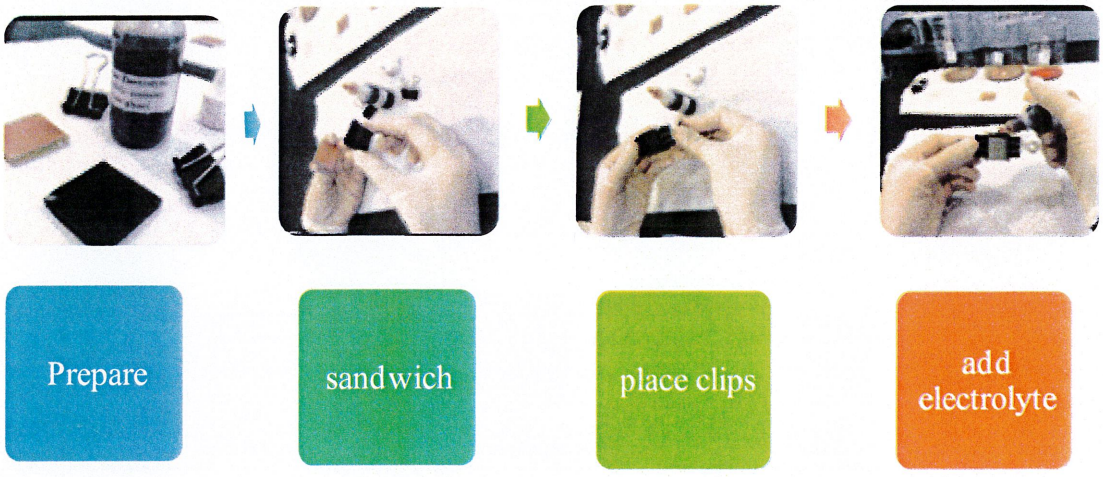


Figure (48): Assembling dye sensitized solar cell.

3.5.2 Current-voltage (I-V) characteristics

The completed solar cell can be taken outside and measured under illumination by sunlight or using simulator. Light enters the glass through the TiO_2 coated glass plate. Measurements can be taken using multimeter and voltmeter to determine the current and voltage for the cell.

1. The TiO_2 coated glass is attached with the black (-) wire of the meter where the TiO_2 coated glass is the negative electrode.
2. The counter electrode is attached to the red (+) wire of the meter where the carbon coated glass is the positive electrode.
3. The open circuit voltage is measured by connecting the solar cell directly to the voltmeter.
4. The short circuit current is measured by connecting the solar cell directly to the multimeter set to milliamperes.
5. The circuit where attached to a resistance, by changing the resistance the voltage and current was measured each time to graph the current-voltage characteristic for the solar cell.
6. The current-voltage curve was plotted by using the voltage and current reading.

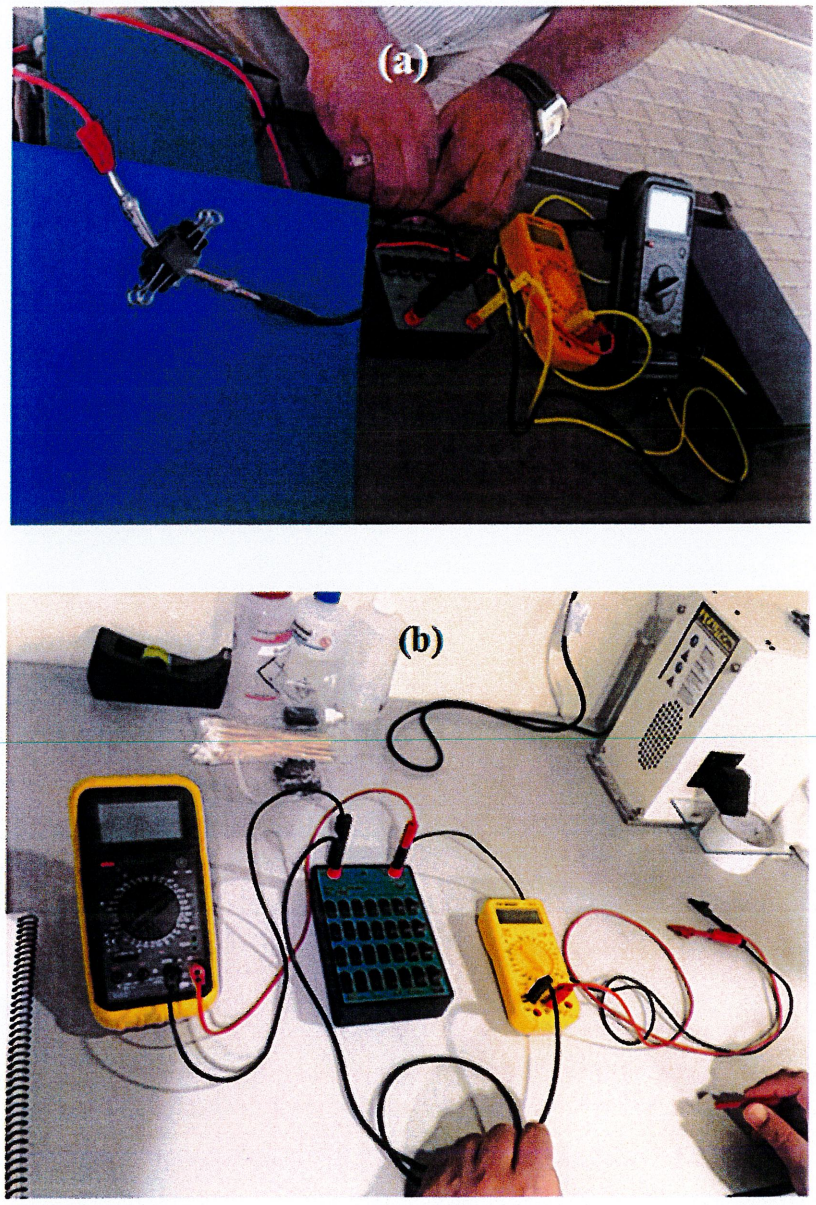


Figure (49): Electric circuit to measure the voltage-current characteristics, (a) illumination by direct sunlight, (b) using solar simulator.

CHAPTER 4: RESULTS, DISSCUSSION AND RECOMMENDATIONS

4.1 Results and discussion

4.1.1 Group 1: flowers

4.1.2 Group 2: leaves

4.1.3 Group 3: seeds

4.1.4 Group 4: stem

4.1.5 Group 5: fruits

4.1.6 Dye sensitized solar cells competing processes

4.2 Study Recommendations

4.1 Results and discussion

The main target of the study was to investigate some dyes extracted from natural materials found in the local environment, characterize their optical properties and then use them in green synthesis of nanoparticles. The grown nanoparticles will be loaded in nanostructured TiO_2 layer in order investigate their aptitude to improve the light conversion efficiency of the assembled solar cells. Our results confirm that cell electrical parameters such as photocurrent and power conversion efficiency were improved in some cases depending on the natural dye extract source. The results were classified into five groups according to dye type.

4.1.1 Group 1: Flowers

I. Saffron extracts dye:

i. The absorption and emission of the dye:

In this group one kind of flower was used. The Saffron (الزعفران) dye extract. The extracted dye was diluted with distilled water. Figures (50) present the absorption spectrum, while Figure (51) shows the florescence spectrum for Saffron extract dye.

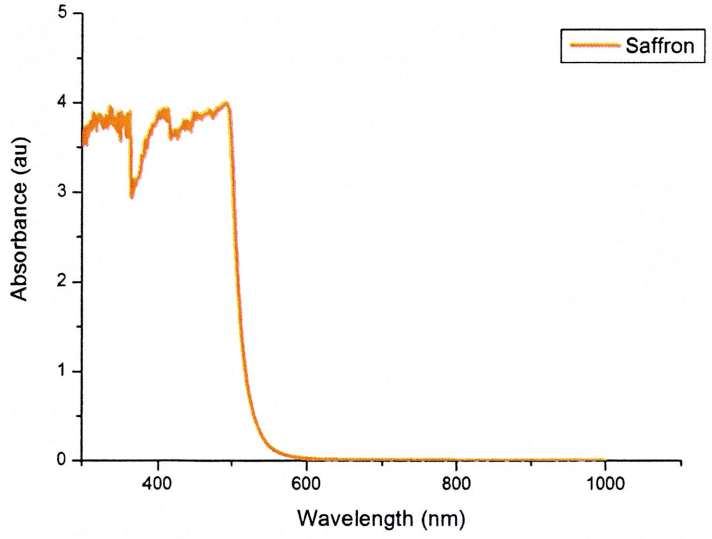


Figure (50): Absorption spectrum of saffron extracted dye.

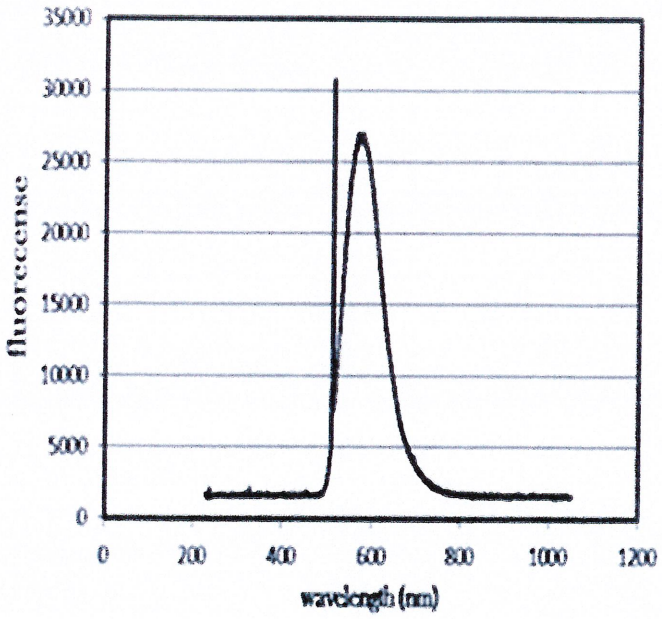


Figure (51): Fluorescence spectrum of saffron extracted dye excited with Argon laser (λ = 514 nm at 6 mW).

The spectroscopy graphs reveals that Saffron extract dye is an excellent absorber of most of the visible light and all ultraviolet light, but hardly absorbs photons of wavelengths beyond 800 nm. The fluorescence spectrum of the saffron extract is in the visible range with wavelength from 400-700nm. The florescence spectrum has a characteristic peak around λ = 600 nm this unfortunately indicates that this dye molecules have tendency to capture the photogenerated electrons to go for florescence emission rather than being easily injected into the nanostructured TiO_2 conduction band and hence resulted in solar cell with low power conversion efficiency as presented in table (11).

ii. I-V characteristics of a dye-sensitized solar cell:

As shown in Figure (52) and table (11), the saffron sensitized solar cell has an open circuit voltage V_{oc} = 0.348 V, short circuit current I_{sc} = 1.362 mA, fill factor FF = 26.3%, and power conversion efficiency η =

0.55%. We infer from the I-V characteristics that the cell has a quite large ohmic resistance. One research activity has been done using saffron extracted dye as natural sensitizer in dye sensitized solar cell, but their conversion efficiency is also almost same as what we got (η = 0.66%), (Hosseinpanahi, et.al, 2016). This small increase in efficiency they obtained may be due to optimization of the preparation method they used for both the transparent and counter electrode and hence better I-V characteristics.

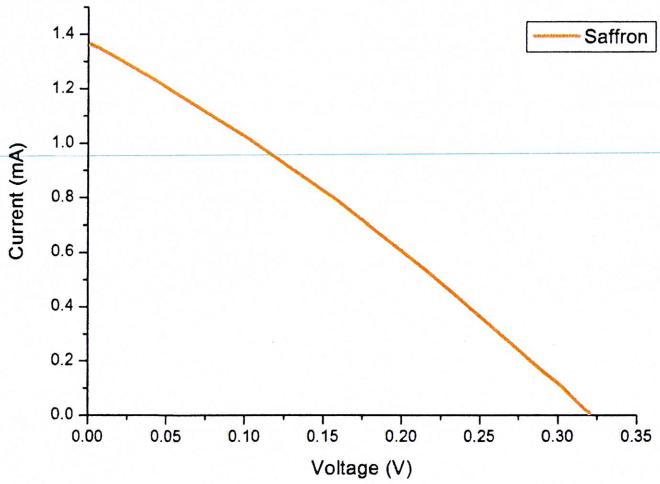


Figure (52): I-V characteristics of saffron dye solar cell.

Table (11): Saffron dye solar cell I-V parameters:

Extract source	V_{oc} (V)	I_{sc} (mA)	P_{max} (W/cm^2)	J_{max} (mA/cm^2)	FF (%)	η (%)
Saffron	**0.348**	**1.362**	**0.055**	**0.350**	**26.3**	**0.55**

II. Green synthesis of Silver nanoparticles (AgNPs) using Saffron extract dye:

i. Color change and the absorption of the Silver nanoparticles:

The saffron extract dye has been used in green synthesis of silver nanoparticles (AgNPs) with different concentration. Reduction of silver ions into AgNPs using saffron extract dye is confirmed by

observing the color change of solutions as shown in Figure (54). Figure (55) shows the absorption spectra of silver nanoparticles using saffron extract dye.

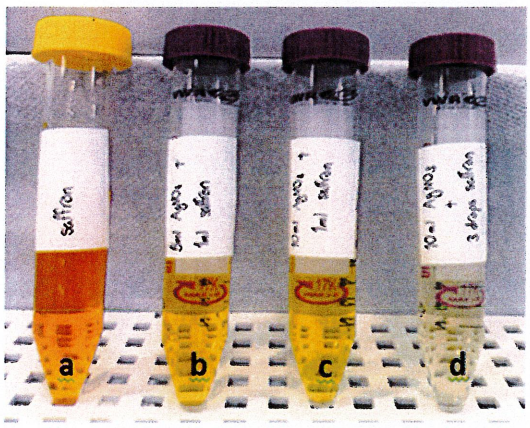


Figure (54): Synthesis of AgNPs by using saffron extract with different concentrations, a) Saffron extract, b) 5 ml solution of silver nitrate and 1ml saffron extract, c) 10 ml solution of silver nitrate and 1ml saffron extract, and d) 10 ml solution of silver nitrate and 3drops saffron extract.

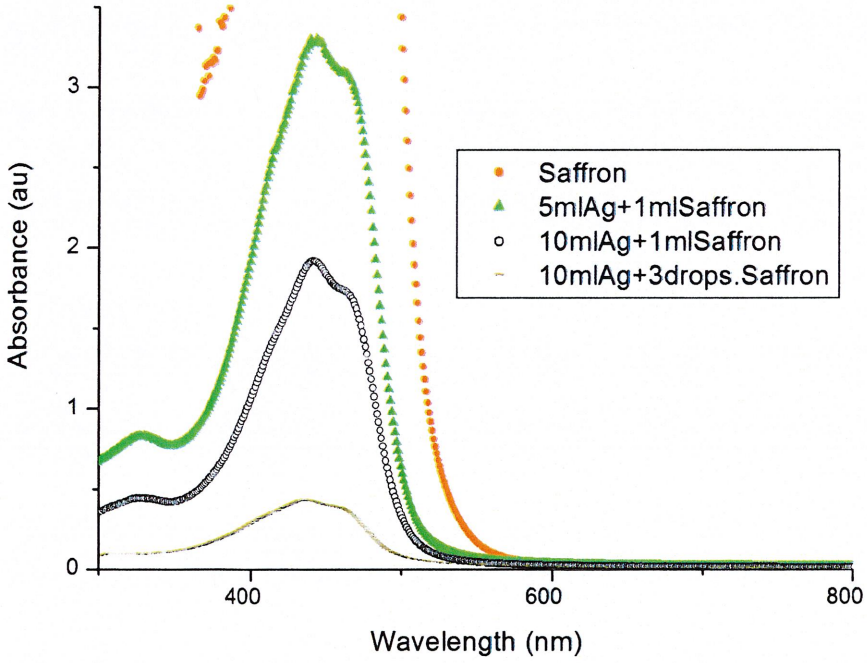


Figure (55): Absorption spectra of synthesized AgNPs using different concentration of saffron extract.

Reduction of silver ions into AgNPs using saffron extract was evidenced by color change of solutions from dark orange to light yellow due to excitation of surface plasmon vibrations in AgNPs as shown in Figure (54). The surface plasmon resonance of AgNPs showed a peak centred near λ = 450 nm for all three different concentrations at UV-VIS spectra which corresponds to the absorbance of AgNPs, Figure (55). This characteristic peak at 450 nm indicates the reduction of silver nitrate into AgNPs. There is an increase in absorbance levels as the amount of added Ag solution increases. However, no clear shift in the characteristic peak wavelength has been observed.

ii. I-V characteristics of dye-AgNPs sensitized solar cells:

The fabricated dye sensitized solar cells using silver nanoparticles with saffron extract dye are shown in Figure (56).



Figure (56): Assembled solar cell using silver nanoparticles with saffron extract dye.

When testing the cell and measuring the I-V characteristics for saffron with AgNPs in solar cell, it has been observed that the values of

current and voltage are not stable. They both, upon illumination of the cell from the solar simulator, start increasing till reaching certain maximum value and then drops very fast as if the case with discharging a capacitor. There are many reasons behind this behaviour and will be discussed later. Finally, we can conclude that Saffron with AgNPs is not suitable to be used in dye sensitized solar cells.

To our knowledge, there is no research activity published about synthesis of AgNPs using saffron extract and used in fabrication of dye sensitized solar cell. They use saffron extract was reported only in green synthesis of AgNPs in biomedical applications (Bagherzade; at.el, 2016).

4.1.2 Group 2: Leaves

1. Salvia extract dye:

i. The absorption and emission spectroscopy of the extracted dye:

In this group one kind of leaves was used. The Salvia (الميرمية) dye extract. The extracted dye was diluted with distilled water. Figure (57) present the absorption; and the florescence spectra for Salvia extract dye.

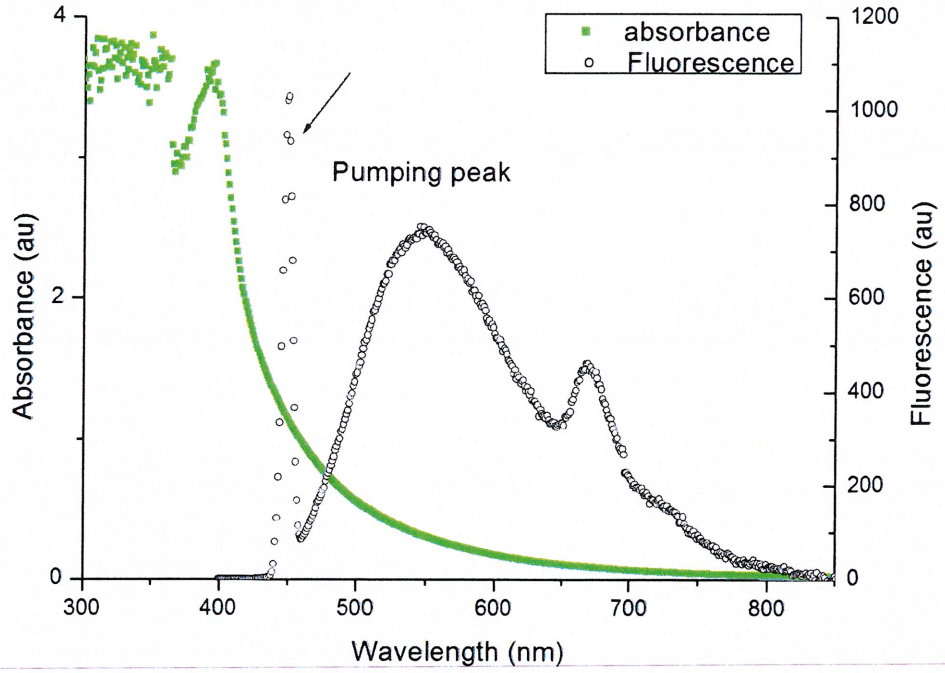


Figure (57): Absorption and fluorescence spectra of salvia extract dye.

The spectroscopy graphs reveals that Salvia extract dye absorbs most of the visible light and all ultraviolet light with one characteristic peak at about $\lambda = 400$ nm. Sample absorbance faded beyond 700 nm. The fluorescence of the salvia is in the visible range with wavelength from 400-700 nm. The florescence spectrum has two large peaks at 550 nm and 680 nm. Since it has broad and two florescence peaks, it is expected that assembled solar cell will attain poor conversion efficiency. This material dye molecules have high tendency to capture photogenerated electrons before being injected into the conduction band of the nanostructured TiO_2.

ii. I-V characteristics of dye sensitized solar cells:

As shown in Figure (58) and table (12), the salvia sensitized solar cell has open circuit voltage $V_{oc} = 0.344$ V, short circuit current $I_{sc} = 0.1$

mA, fill factor FF = 35.9%, and power conversion efficiency η = 0.055%. Salvia dye extract sensitized solar cell I-V characteristic shows better behavior than that of saffron cells. There are many research activities on Salvia dye sensitized solar cell, but most researchers reported even lower cell efficiency, 0.0017% (Mebrahtu, al.et, 2016) and 0.0513% (Menisa, al.et, 2014).

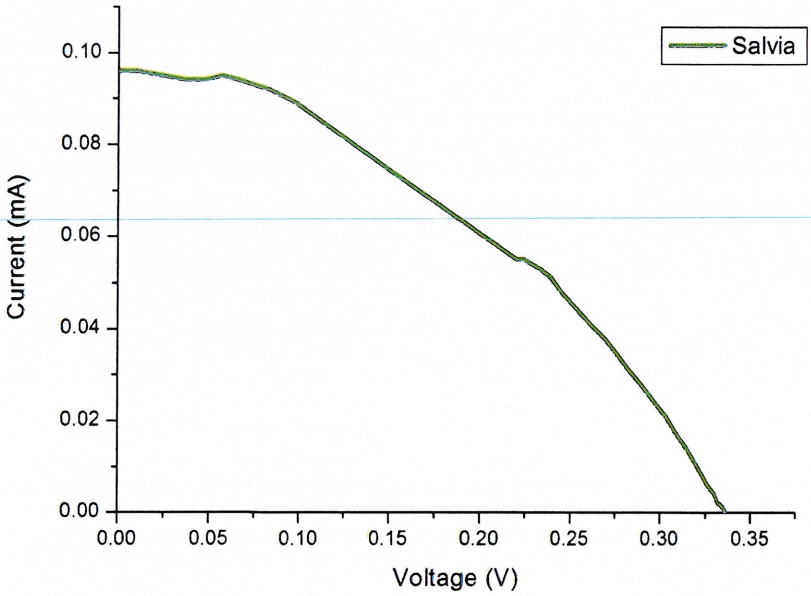


Figure (58): I-V characteristic for salvia dye sensitized solar cell.

Table (12): Salvia dye solar cell I-V parameters:

Extract source	V_{oc} (V)	I_{sc} (mA)	P_{max} (W/cm^2)	J_{max} (mA/cm^2)	FF (%)	η (%)
Salvia	0.344	0.100	0.0055	0.023	35.9	0.055

II. Green synthesis of Silver nanoparticles (AgNPs) using Salvia extracts dye:

i. Color change and absorption spectra of nanoparticles:

The salvia extract dye has been used in green synthesis of silver nanoparticles (AgNPs) by changing parameters like: plant extract concentration, silver solution concentration, and microwave heating time. Reduction of silver ions into AgNPs using salvia extract dye was confirmed by observing the color change of solutions as shown in figure (59). Figure (60) shows absorption and fluorescence spectra of AgNPs. As a trial for future work using gold nanoparticles reduction of gold ions into AuNPs using salvia extract dye is presented in Figure (61).

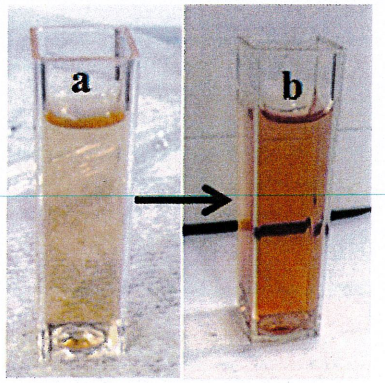


Figure (59): AgNPs formed after the addition of salvia extract to silver nitrate and heat it for 10 second. a) before heating; b) after heating.

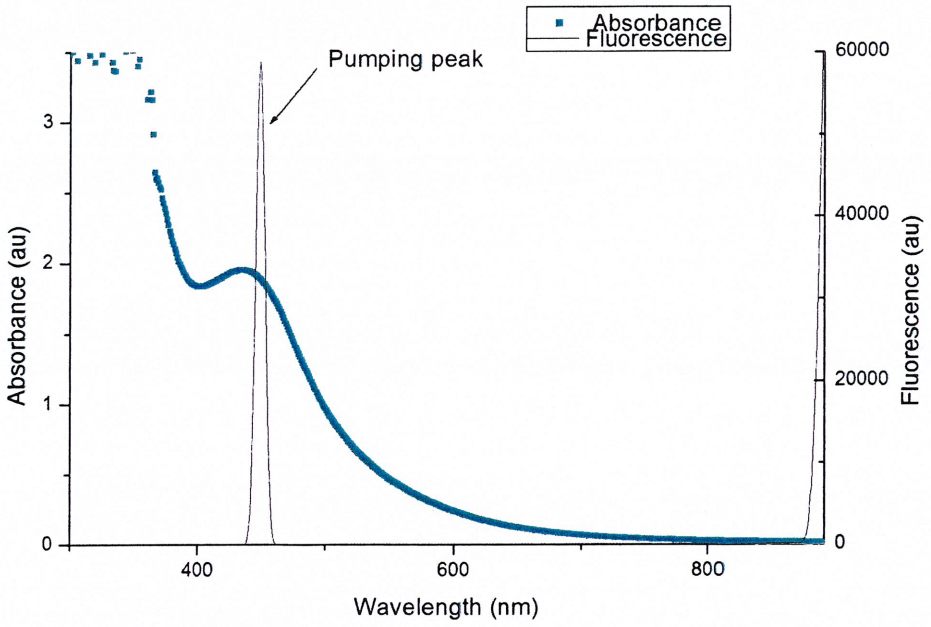


Figure (60): Absorbance and fluorescence spectra of AgNPs.

As the salvia extract was mixed with silver nitrate solution and heated up in microwave oven for 10 seconds, the color change from yellowish brown to brown as shown in Figure (59). The color change denotes the formation of silver nanoparticles AgNPs due to the excitation of surface plasmon vibrations in AgNPs. From the absorption spectrum (Figure (60)) a single absorption band was observed at $\lambda = 440$ nm which is a characteristics peak for the formation of nanoparticles. There is no fluorescence effect has been observed. Since fluorescence activity is weak, a quite good value of the cell conversion efficiency.

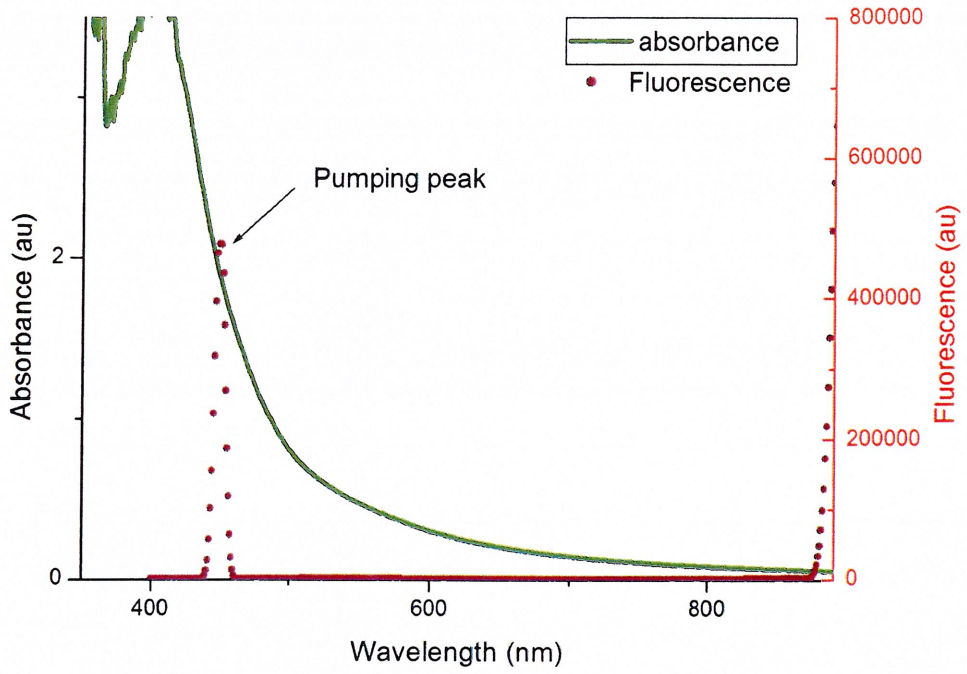


Figure (61): Absorbance and fluorescence spectra of AuNPs solution.

From the absorption spectrum (Figure (61)) it can be concluded that no absorbance band was observed for the gold nanoparticles and the solution absorb all visible light. The florescence spectrum shows very weak fluorescence activity.

Effect of salvia extract concentration, silver solution concentration and microwave heating time on the formation of silver nanoparticles has been analyzed after obtaining specifying the variations in absorbance and wavelength of Surface Plasmon Resonance (SPR) of silver nanoparticles as shown in Figures (62), (63), (64) and (65). Also, the stability of nanoparticles solutions was confirmed as shown in Figure (66).

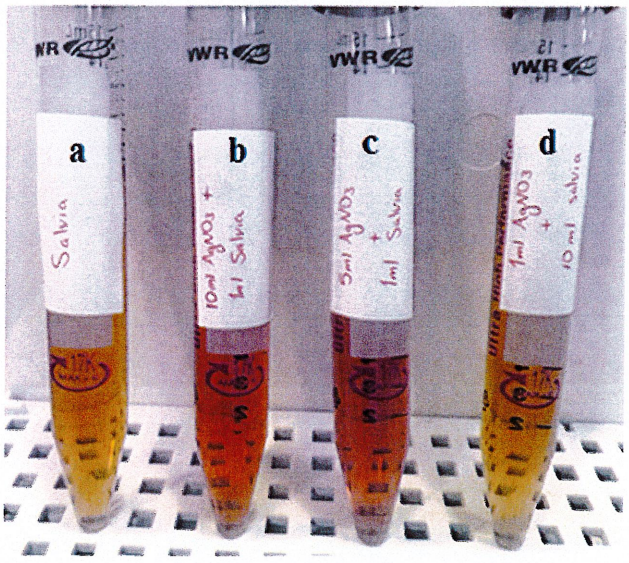


Figure (62): Color change due to the concentration on synthesis of AgNPs by using silvia extract dye. a) Salvia extract dye, b) 10 ml $AgNO_3$ + 1ml salvia, c) 5 ml $AgNO_3$ + 1ml salvia, d) 1 ml $AgNO_3$ + 10 ml salvia.

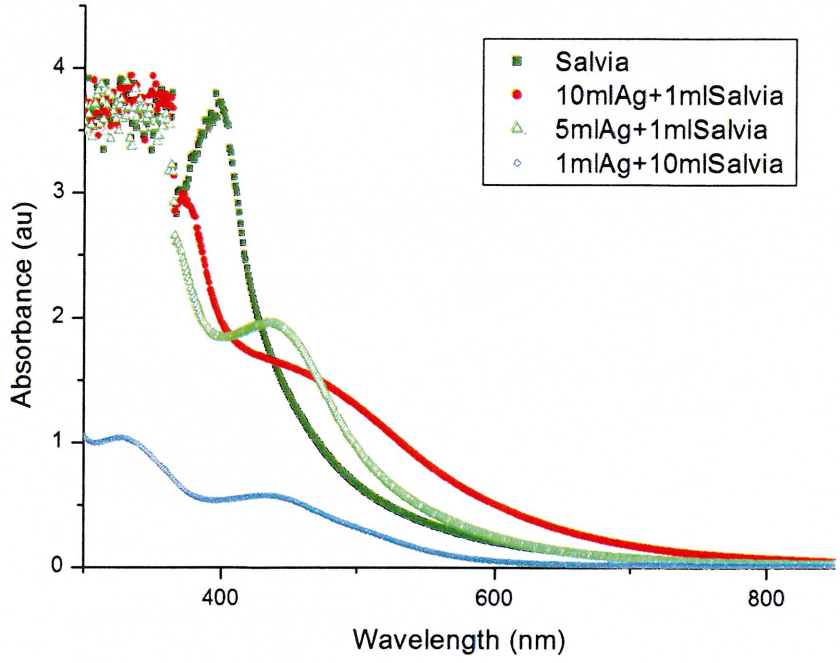


Figure (63): Effect of concentration of salvia extracted dye on formation of AgNPs.

Formation of silver nanoparticles by reduction of aqueous metal ions during exposure of microwave radiation to the salvia extract can be followed by UV-VIS spectroscopy. The appearance of brown color indicates formation of silver nanoparticles as shown in Figure (62). The

color formation is due to the surface plasmon vibration of the metal nanoparticles. There is a red shift in SPR band of silver nanoparticles with increasing concentration of salvia extract as shown in Figure (63). It was observed that absorbance increases as concentration of salvia extract increases which may due to higher reduction of silver nirtate into silver nanoparticles. In salvia there is better reduction at a concentration of 1ml of leaf extract for 5ml of silver nitrate solution which clearly appear at λ = 450nm.

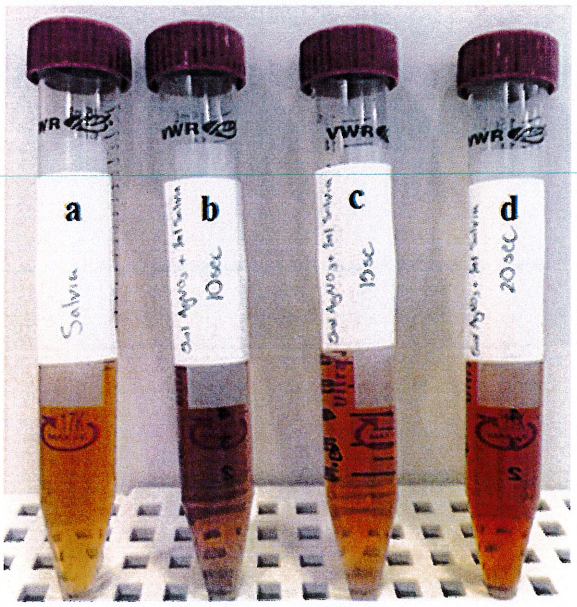


Figure (64): Color change due to the microwave heating time on synthesis of AgNPs by using silvia extract dye. a) Salvia extract dye, b) 10 seconds, c) 15seconds, d: 25 seconds.

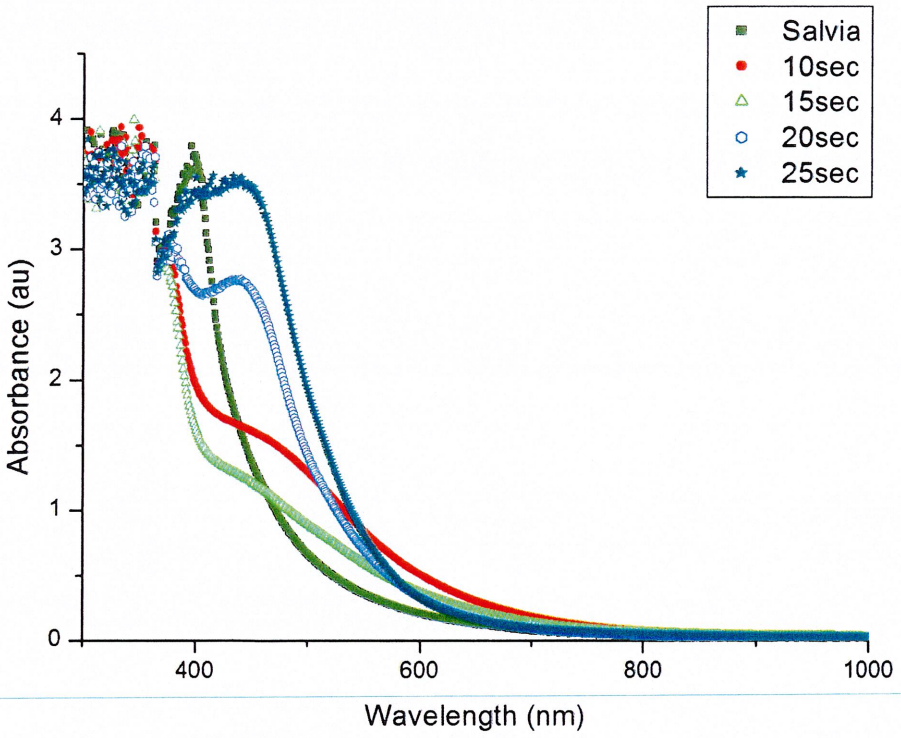


Figure (65): Effect of microwave heating time of salvia extract dye on AgNPs solution.

The effect of microwave heating time was investigated using silver nanoparticles synthesized at an optimum concentration of 1ml of salvia extract with 5ml of silver nitrate. There was an increase in absorbance level as heating time increased, and no shift in the peak wavelength observed as it is presented in Figure (65). The surface plasmon resonance of AgNPs showed a peak centered near λ = 450 nm in UV-VIS spectra which corresponds to the absorbance of AgNPs.

The capability of Salvia to stabilized silver nanoparticles was evaluated by measuring the absorption spectra of solutions at different period of time after it has been prepared.

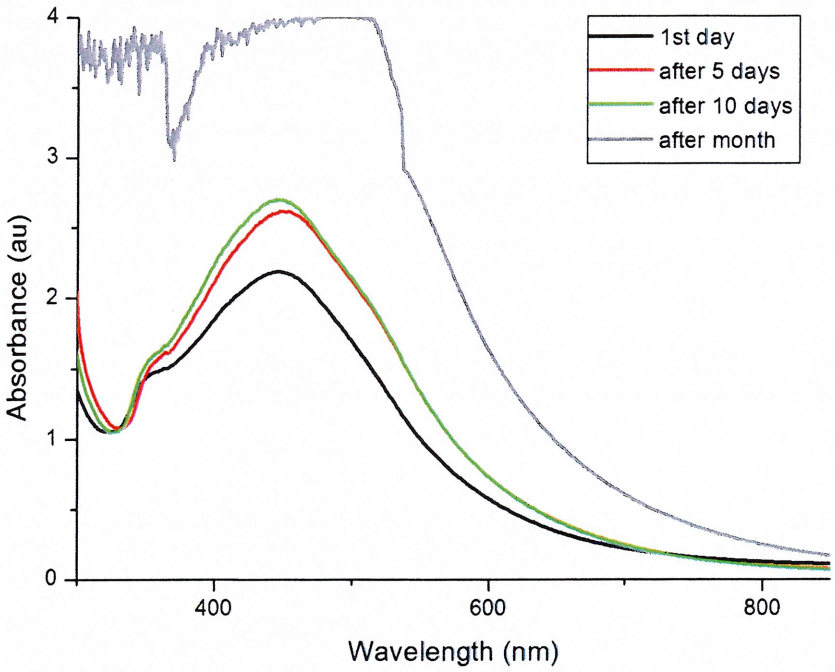


Figure (66): Stability of silver nanoparticles.

From Figure (66) it could be concluded that silver nanoparticles are stable in salvia solution for short period of time, then it start agglomerate and silver deposit is formed in the solution.

ii. TEM analysis:

Transmission electron microscopy (TEM) was performed to determine shapes and sizes of synthesized nanoparticles. Figure (67) shows the size distribution histogram of AgNPs with salvia. TEM analysis illustrated that AgNPs have sizes less that 8 nm.

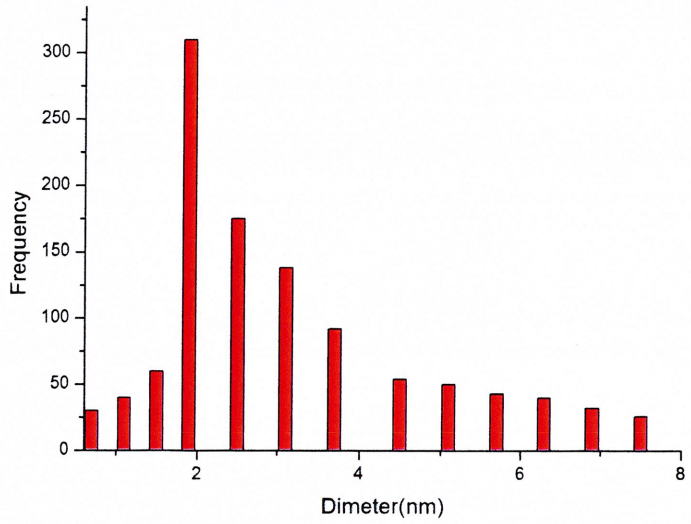


Figure (67): Size distribution histogram of AgNPs prepared using salvia extract.

iii. The I-V characteristics of dye-NPs sensitized solar cells:

Dye sensitized solar cell uses a dye to act as sensitizer in order to generate photocurrent. Figure (68) and table (13) show the I-V characteristics of fabricated salvia coupled with AgNPs sensitized solar cell.

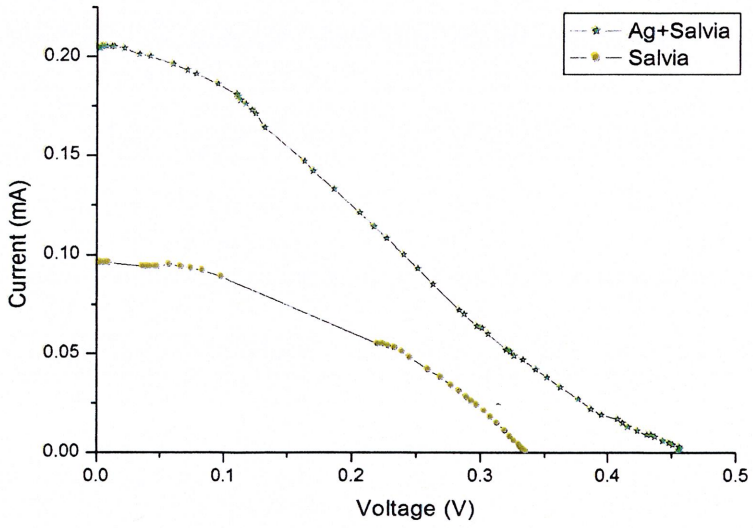


Figure (68): I-V characteristics of Salvia extract dye and AgNPs with salvia.

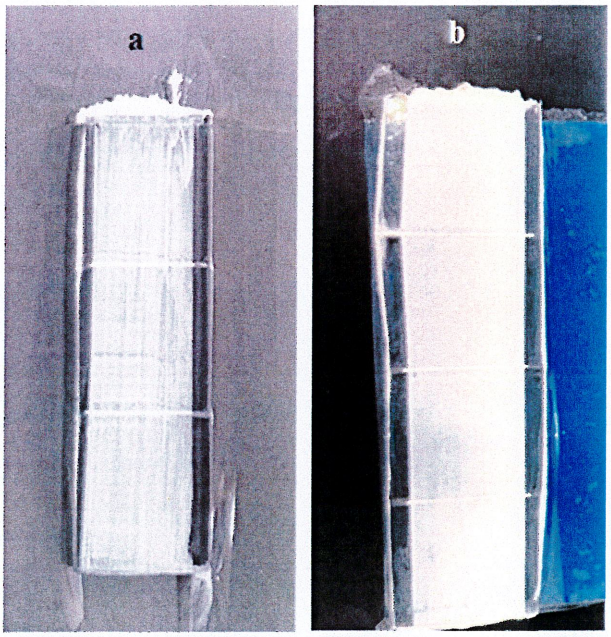


Figure (69): Deposition of TiO_2 past on conductive glasses. a) Doctor blade method, b) Rotation method.

The Titanium Dioxide (TiO_2) layer is deposited on conductive glasses by means of two different ways: doctor blade method, and rotation method as shown in Figure (69). In doctor blade method TiO_2 layer is not smooth and contains cracks which may hinder the photogenerated electrons from diffusing within the nanostructured layer . On the other hand, rotation method give smother layer of TiO_2 and a reduced amount of cracks. By comparing the two methods we can see that from table (13) rotation method improved cell performance compared to doctor blade method. For salvia extract dye solar cell has power conversion efficiency of 0.055% by means of doctor blade method, while it has 0.12% power conversion efficiency after using rotation method. Also, for dye coupled with AgNPs solar cell there was an improvement in efficiency, e.g. for 5 ml Ag + 1ml salvia heated for 15 sec attained power conversion efficiency of 0.012% when doctor blade method is used, while rotation method resulted in 0.042% of power conversion efficiency. By comparing salvia extract dye solar cell with

salvia coupled with AgNPs solar cell there was no improvement in performance of cells except in one case. In salvia extract dye solar cell using doctor blade method the attained power conversion efficiency is 0.055%, while the 5 ml Ag + 1 ml Salvia heated for 10 sec using doctor blade method too has power conversion efficiency of 0.11%, with improvement of 2% in the two cells. This result confirmed by means of absorption and fluorescence spectra of salvia coupled with AgNPs in Figures (61) and (63). There are many reasons behind this behavior and will be discussed later.

Table (13): Salvia dye with AgNPs solar cell I-V parameters:

Method of TiO_2 deposition	Sensitizer material(s)	Heating time (sec)	V_{oc} (V)	I_{sc} (mA)	P_{max} (W/cm^2)	J_{max} (mA/cm^2)	FF (%)	η (%)
Doctor blade	Salvia	-	0.344	0.100	0.0055	0.023	35.9	0.055
	5mlAg+1mlSalvia	10	0.332	0.200	0.011	0.053	37.5	0.11
	10mlAg+1mlSalvia	10	0.08	0.038	0.0001	0.003	10.5	$1.4*10^{-3}$
	1mlAg+10mlSalvia	10	0.283	0.100	0.0035	0.024	27.9	0.035
	5mlAg+1mlSalvia	15	0.272	0.046	0.0011	0.008	20.9	0.012
	5mlAg+1mlSalvia	20	0.046	0.044	0.0001	0.007	14.2	$1.28*10^{-3}$
Rotation method	Salvia	-	0.322	0.260	0.0119	0.089	32.2	0.12
	5mlAg+1mlSalvia	10	0.345	0.085	0.0037	0.02	28.4	0.037
	5mlAg+1mlSalvia	15	0.335	0.100	0.0041	0.026	28.2	0.042
	5mlAg+1mlSalvia	20	0.250	0.051	0.00130	0.012	24.1	0.0137

Up to our literature review, there is no research activity published about synthesis of AgNPs by means of salvia extract and being used in fabrication of dye sensitized solar cell. Salvia extract was only used in

green synthesis of AgNPs for biomedical applications, (Baghayeri, et.al, 2017; Daoud, et.al, 2015).

4.1.3 Group 3: Seeds

I. Gloves extract dyes:

iv. Absorption and fluorescence spectroscopy of the dye extract:

In this group one kind of seeds was used. The Gloves (القرنفل) dye extract. The extracted dye was diluted with distilled water. Figure (70) presents the absorption; and the florescence spectra for gloves extracted dye.

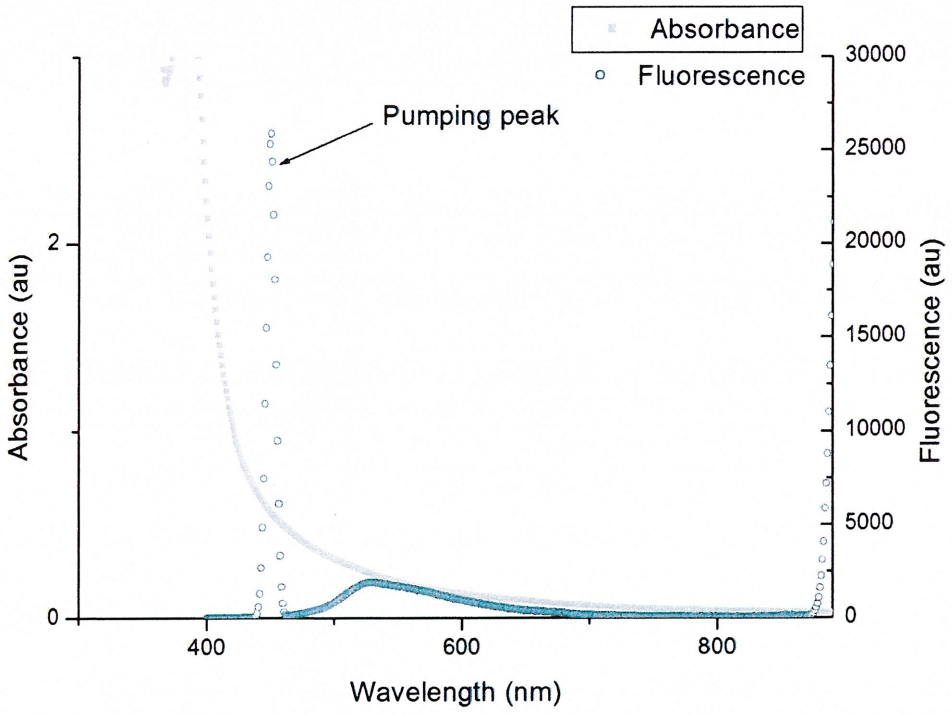


Figure (70): Absorption and fluorescence spectra of gloves extracted dye.

Figure (70) reveals that the gloves extracted dye strongly absorbs ultraviolet photons, but quite lower level of the visible light. The

fluorescence of the gloves is in the visible range with wavelength from 440-700 nm. The florescence spectrum has sharp broad peak at λ = 550 nm. Since it has high capacity to florescence in the visible part of the spectrum, the photogenerated electrons will find it easy assist dye molecule relaxation rather than being injected in the conduction band of the nanostructured TiO_2 layer and therefore, poor power conversion efficiency of the solar cell is expected.

i. I-V characteristics of dye sensitized solar cells:

As shown in Figure (71) and table (14), gloves sensitized solar cell has open circuit voltage V_{oc}= 0.297 V, short circuit current I_{sc}= 0.089 mA, fill factor FF = 33.9% and power conversion efficiency η = 0.039%. There is no research activities has been published about gloves dye sensitized solar cell.

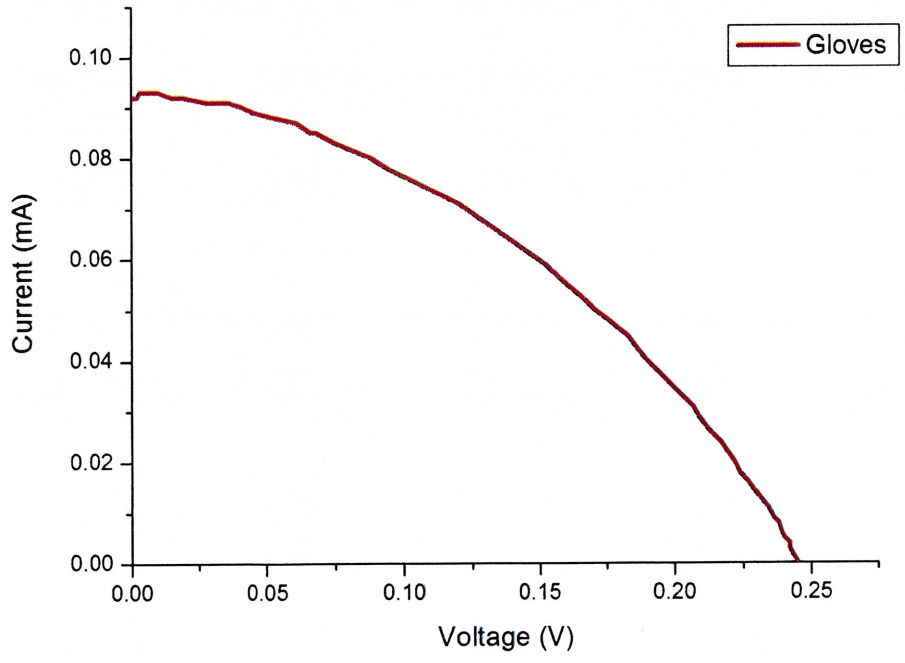


Figure (71): I-V characteristics for gloves dye sensitized solar cell.

Table (14): Gloves dye sensitized solar cell I-V parameters:

Extract source	V_{oc} (V)	I_{sc} (mA)	P_{max} (W/cm^2)	J_{max} (mA/cm^2)	FF (%)	η (%)
Gloves	**0.297**	**0.089**	**0.0039**	**0.026**	**33.9**	**0.039**

II. Green synthesis of silver nanoparticles (AgNPs) using gloves extracts dye:

i. Color change and absorption spectra of nanoparticles:

Gloves extract dye has been used in green synthesis of silver nanoparticles (AgNPs) by changing parameters like: plant extract concentration, silver solution concentration and microwave heating time. Reduction of silver ions into AgNPs using gloves extracted dye was confirmed by color change of solutions as shown in Figure (72). Figure (73) presents both the absorption and fluorescence spectra of AgNPs. While, reduction of gold ions into AuNPs using gloves extract dye is shown in Figure (74).

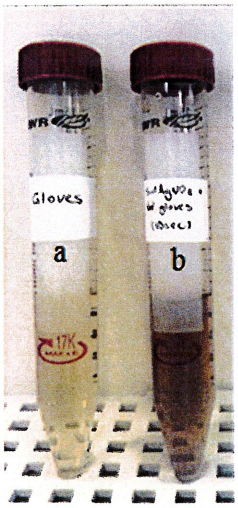


Figure (72): AgNPs formed after the addition of gloves extract to silver nitrate and heat it for 10 second. a) Gloves extract dye solution; b) AgNPs with gloves.

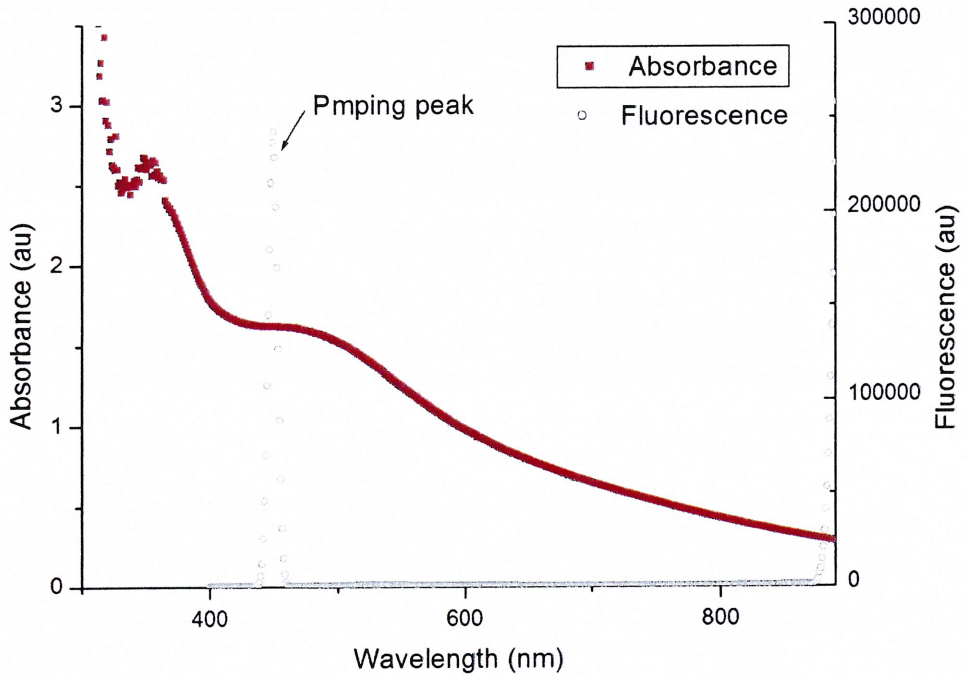


Figure (73): Absorbance and fluorescence spectra of AgNPs.

As the gloves extract was mixed with silver nitrate solution and heated up in microwave oven for 10 seconds, the color change from yellowish brown to brown as presented in Figure (72). Color change denotes the formation of silver nanoparticles AgNPs due to the excitation of surface plasmon vibrations in AgNPs. From the absorption spectra (Figure (73)) it can be seen that a single small absorbance band was observed around $\lambda = 500$ nm which is characteristics for the formation of small nanoparticles. The florescence spectrum shows weak fluorescence spectrum, such limited emission range may indicate that photogenerated electrons will have enough time to diffuse in the nanostructured layer and find higher chance to get injected in the conduction band of TiO_2, and hence fair power conversion efficiency could be achieved.

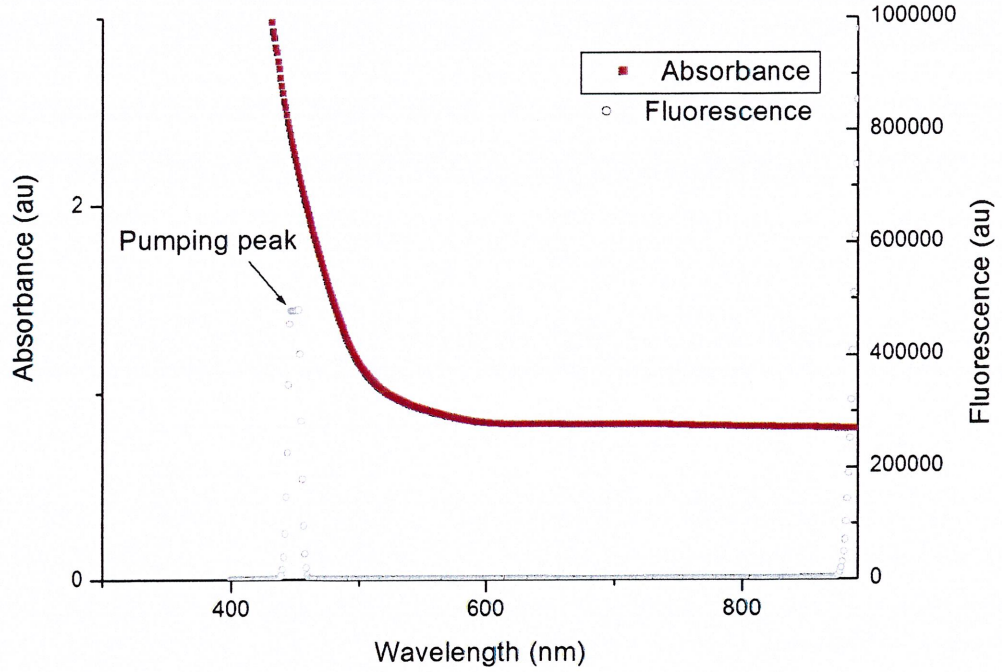


Figure (74): Absorbance and fluorescence spectra of AuNPs.

From the absorption spectra (Figure (74)) it can be seen that AuNPs shows no absorbance characteristics peak and the solution absorbs UV, visible and near infrared photons. The florescence is quite weak.

Effect of gloves extract concentration, silver solution concentration and microwave heating time on the formation absorbance and wavelength of Surface Plasmon Resonance (SPR) of silver nanoparticles are shown in Figures (75), (76), (77) and (78).

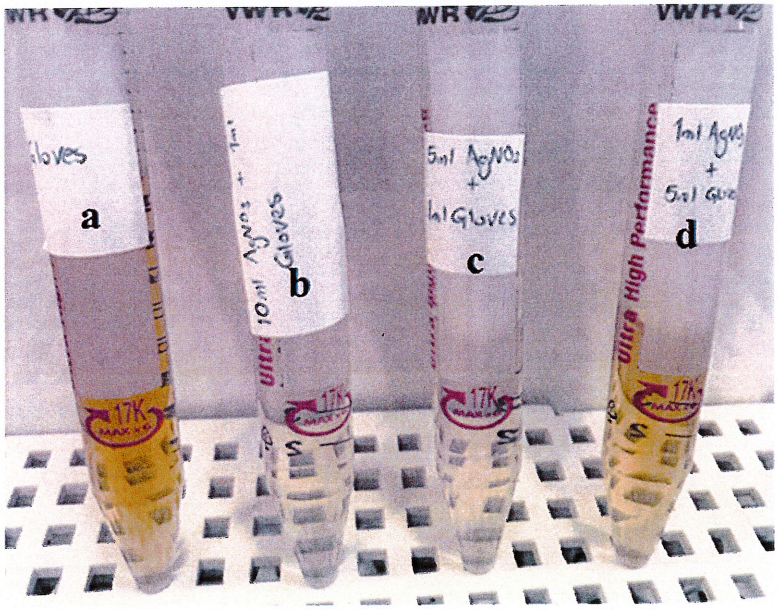


Figure (75): Color change due to variation of concentration on synthesis of AgNPs using gloves extract dye. a) Gloves extract dye, b) 10 ml $AgNO_3$ + 1 ml gloves, c) 5 ml $AgNO_3$ + 1 ml gloves, d) 1 ml $AgNO_3$ + 5 ml gloves.

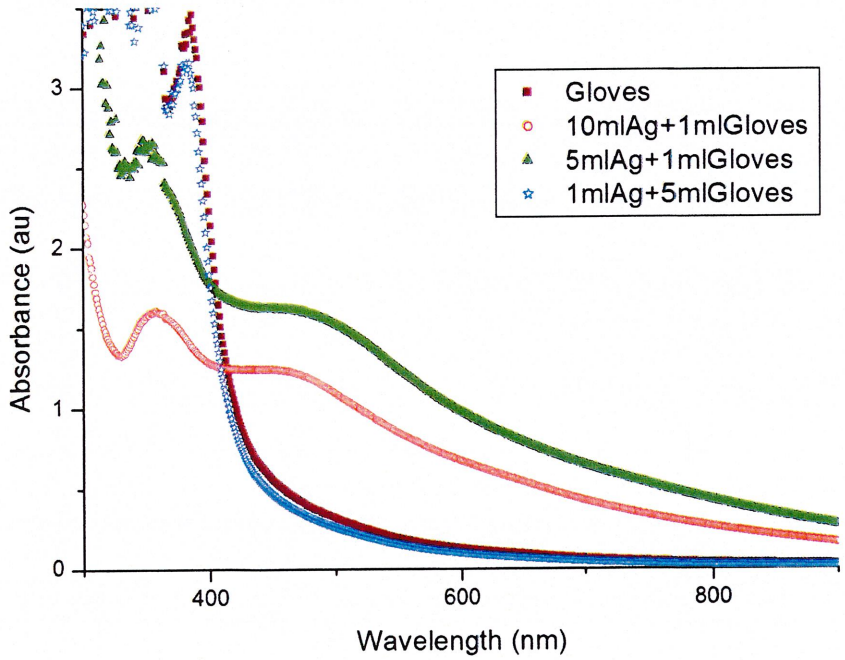


Figure (76): Effect of concentration of gloves extracted dye on formation of AgNPs.

Formation of silver nanoparticles by reduction of aqueous metal ions during exposure of microwave radiation to the gloves extract can be followed by UV-VIS spectroscopy. The color change indicates formation

of silver nanoparticles as shown in Figure (75). The color formation is due to the surface plasmon vibration of the metal nanoparticles. There was a blue shift in SPR band of silver nanoparticles with increasing concentration of gloves extract, see Figure (76). It was observed that absorbance increases as concentration of gloves extract increases this may be due to higher reduction of silver nirtate into silver nanoparticles. In gloves there is better reduction at a concentration of 1ml of leaf extract for 5 ml of silver nitrate solution which appear clearly around $\lambda = 500nm$.

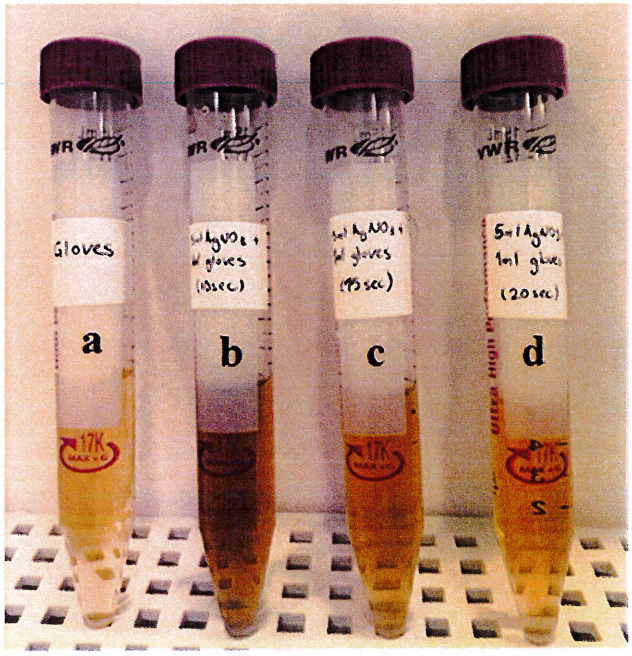


Figure (77): Color change due to the microwave heating time on synthesis of AgNPs by using gloves extract dye. a) Gloves extract dye, b) 10 seconds, c) 15seconds, d)20 seconds.

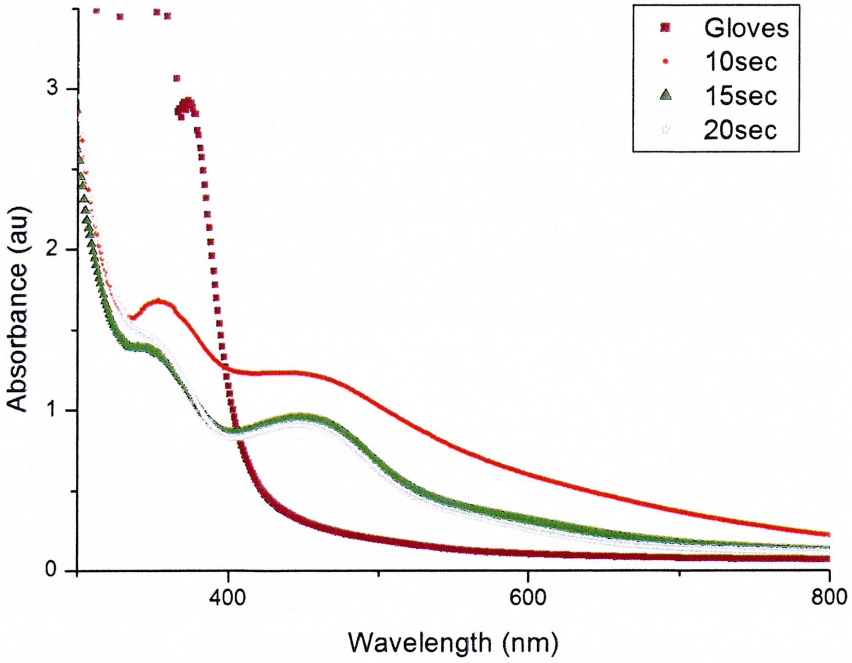


Figure (78): Effect of microwave time heating of gloves extract dye on AgNPs.

The effect of microwave heating time was tested on silver nanoparticles synthesized at an optimum concentration of 1ml of gloves extract with 5ml of silver nitrate. There was a decrease in intensity as heating time increases without any shift in the peak wavelength as shown in Figure (78). The surface plasmon resonance of AgNPs showed a peak centered near 450 nm at UV-VIS spectra which corresponds to the absorbance of AgNPs.

ii. I-V characteristics of dye-NPs sensitized solar cells:

Dye sensitized solar cell uses a dye to act as sensitizer for generating photocurrent. Figure (79) and table (15) showed the I-V characteristics of fabricated gloves coupled with AgNPs sensitized solar cell. By comparing gloves extract dye solar cell with gloves coupled with AgNPs solar cell there was no improvement in performance of cells. The gloves extracted dye solar cell has power conversion efficiency of 0.039%,

while 5ml Ag+ 1ml gloves heated for 10 sec has power conversion efficiency of $6.35*10^{-3}$%. There are many reasons behind this behavior and will be discussed at the end of this chapter. Therefore, one can conclude that gloves extracted dye is good reducer in green synthesis of silver nanoparticles, but it fails as being a good sensitizer. Up to date, there is no research activities have been published about green synthesis of silver nanoparticles using gloves extract dye.

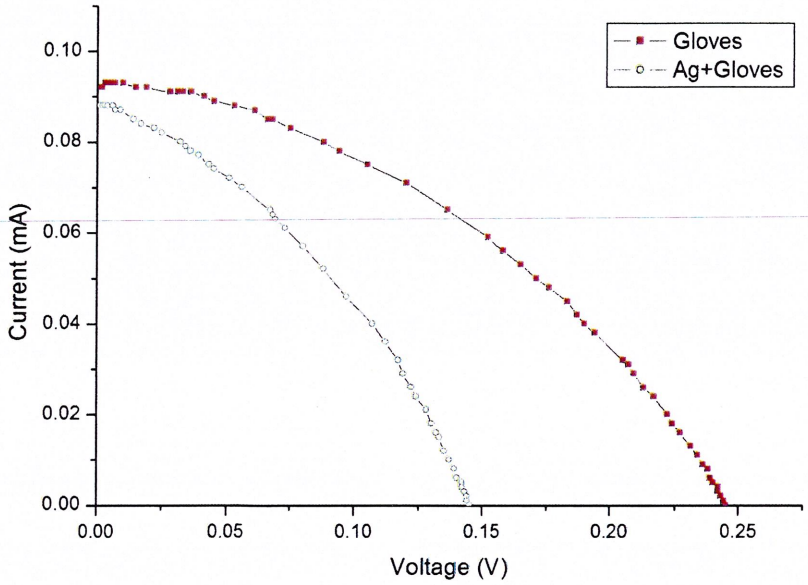


Figure (79): I-V characteristics of Gloves extract dye and AgNPs with gloves.

Table (15): Gloves dye with AgNPs solar cell I-V parameters:

Sensitizers	Heating time (sec)	V_{oc} (V)	I_{sc} (mA)	P_{max} (W/cm^2)	J_{max} (mA/cm^2)	FF (%)	η (%)
Gloves	-	0.297	0.089	0.0039	0.026	33.9	0.039
10mlAg+1mlGloves	10	0.209	0.035	0.0007	0.007	24.5	0.008
5mlAg+1mlGloves	10	0.205	0.025	0.0006	0.005	27.9	0.0064

1mlAg+5mlGloves	10	0.191	0.087	0.002	0.023	27.5	0.020
5mlAg+1mlGloves	15	0.177	0.033	0.0003	0.005	15.2	0.004
5mlAg+1mlGloves	20	0.273	0.037	0.0013	0.008	29.3	0.013

4.1.4 Group 4: Stem

I. Cinnamon extract dyes:

i. **Absorption and emission spectroscopy of the dye extract:**

In this group one kind of stem was used. The Cinnamon (القرفة) dye extract. The extracted dye was diluted using distilled water. Figures (80) present the absorption; and the florescence spectra for Cinnamon extract dye.

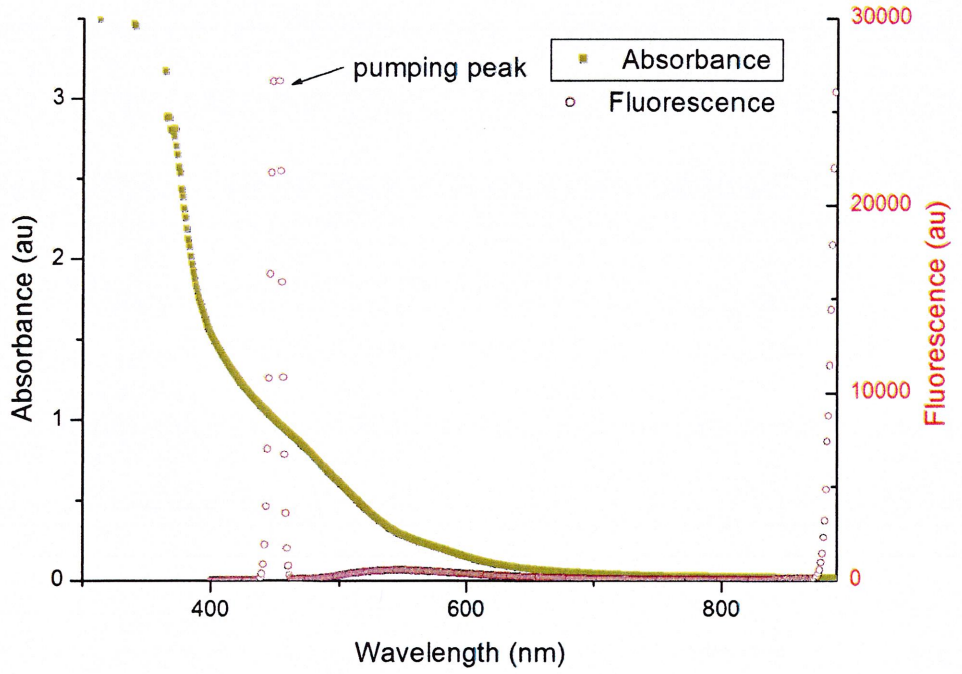


Figure (80): Absorption and fluorescence spectra of cinnamon extracted dye.

Figure (80) reveals that the cinnamon extracted dye strongly absorbs ultraviolet photons, but quite lower level of the visible light. Beyond 800 nm extract absorbance is very low. The fluorescence of the cinnamon is in the visible range with wavelength from 400-700 nm. The florescence spectrum has a broad small peak around 550 nm. Since it has small florescence peak, we expect fair power conversion efficiency for it as sensitizer in solar cell.

ii. I-V characteristics of dye sensitized solar cells:

As shown in Figure (81) and table (16), the cinnamon sensitized solar cell has open circuit voltage V_{oc} = 0.225 V, short circuit current I_{sc} = 0.048 mA, fill factor FF = 25.9% and power conversion efficiency η = 0.014%. As it could be seen in Figure (81), the cell has huge internal impedance. There is one research activity found on cinnamon dye sensitized solar cell. They obtained efficiency 0.75%. (Jung and Lee, 2013)

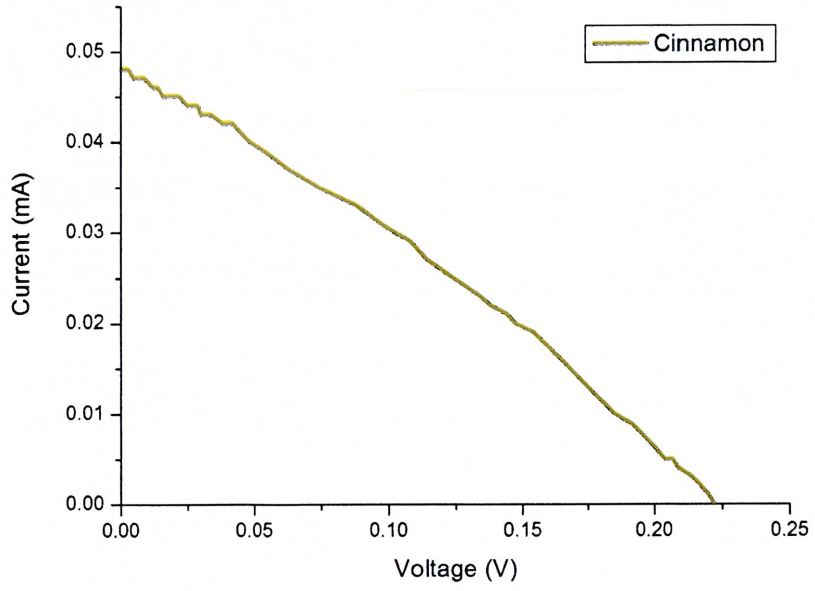


Figure (81): I-V characteristic of cinnamon dye solar cell.

Table (16): Cinnamon dye solar cell I-V parameters:

Extract source	V_{oc} (V)	I_{sc} (mA)	P_{max} (W/cm^2)	J_{max} (mA/cm^2)	FF (%)	η (%)
Cinnamon	0.225	0.048	0.0013	0.012	25.9	0.014

II. Green synthesis of silver nanoparticles (AgNPs) using cinnamon extracted dye:

i. Color change and absorption spectra of nanoparticles:

The Cinnamon extract dye has been used in green synthesis of silver nanoparticles (AgNPs) by changing parameters like: plant extract concentration, silver solution concentration, and microwave heating time. Reduction of silver ions into AgNPs using cinnamon extract dye was confirmed by the color change of solutions as shown in Figure (82). Figure (83) present the absorption and fluorescence spectra of AgNPs.

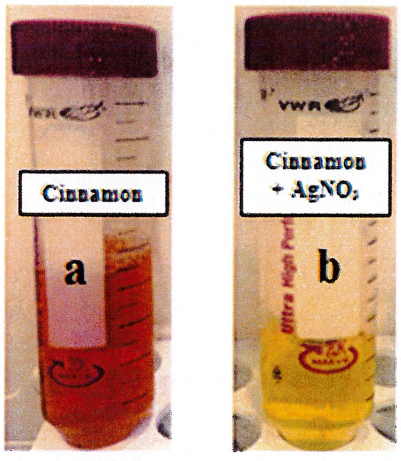


Figure (82): Formation of AgNPs after the addition of cinnamon extract to silver nitrate and heated for 10 seconds. a) before heating; b) after heating.

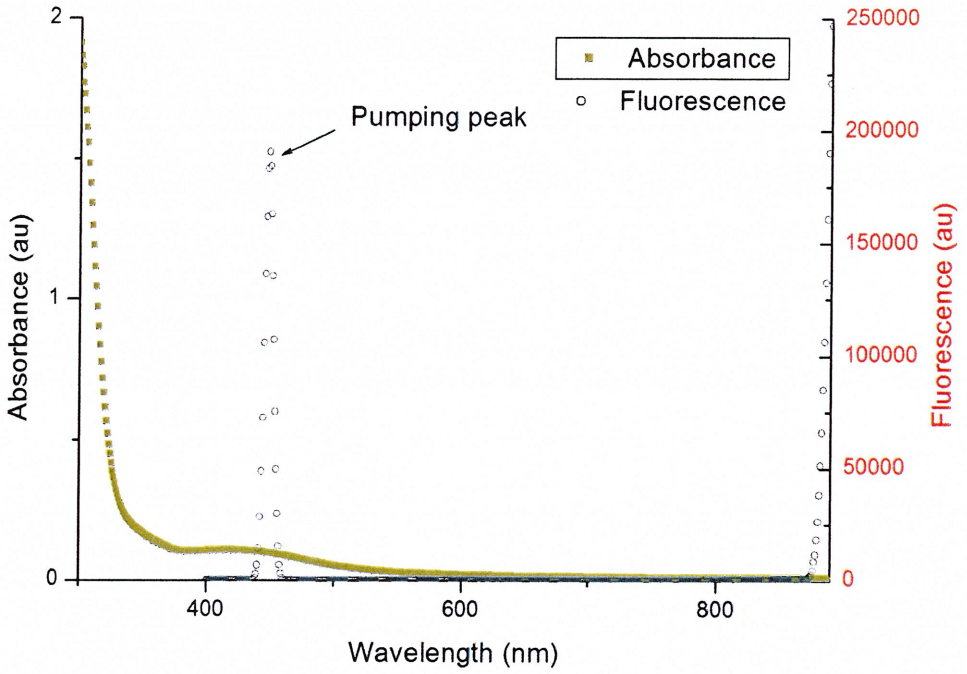


Figure (83): Absorbance and fluorescence spectra of AgNPs.

As the cinnamon extract was mixed with silver nitrate solution and heated up in microwave oven for 10 seconds, solution color changed from brown to yellow color as presented in figure (82). Color change denotes the formation of silver nanoparticles AgNPs due to the excitation of surface plasmon vibrations in AgNPs. From the absorption spectra (see Figure (83)) it can be seen that a small and broad absorbance band was centered at about $\lambda = 450$ nm which is characteristics for the formation of small nanoparticles. The florescence spectrum shows no fluorescence effect absorbed.

Effect of cinnamon extract concentration, silver solution concentration and microwave heating time on the formation of silver nanoparticles has been analyzed by studying the variations in absorbance and wavelength of Surface Plasmon Resonance (SPR) of silver nanoparticles, see Figures (84), (85), (86), (87) and (88). Also, the stability of nanoparticles solutions were studied, see Figure (89).

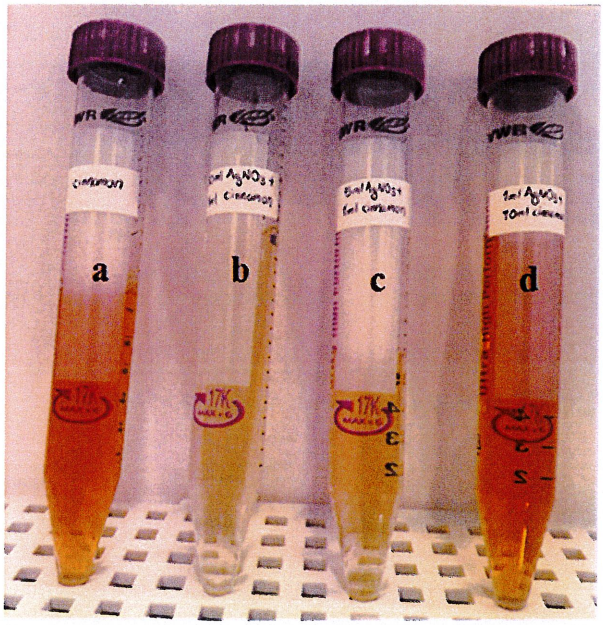


Figure (84): Color change due to variation of concentration on synthesis of AgNPs using cinnamon extracted dye. a) Cinnamon extract dye, b) 10 ml $AgNO_3$ + 1 ml cinnamon, c) 5 ml $AgNO_3$ + 1 ml cinnamon, d) 1 ml $AgNO_3$ + 10 ml cinnamon.

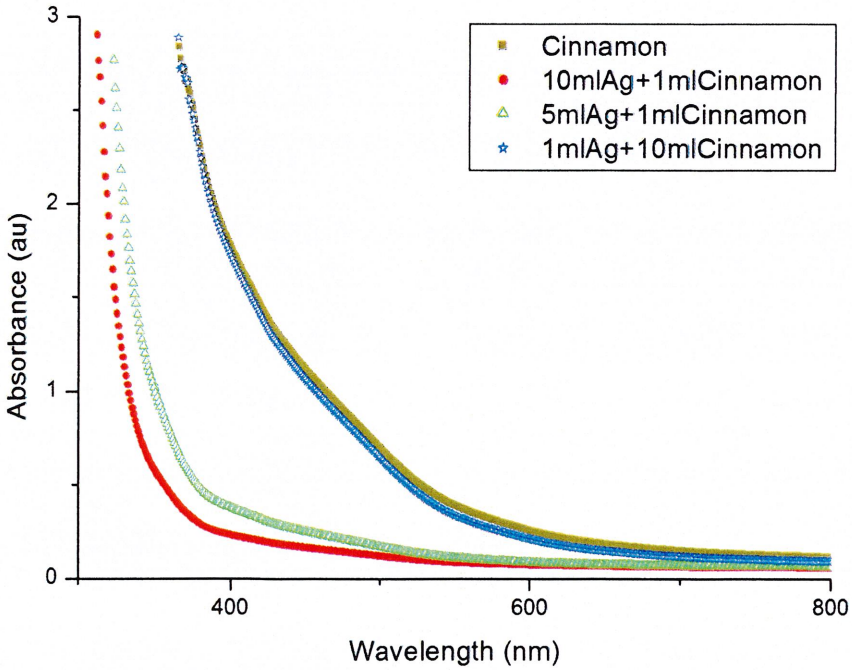


Figure (85): Effect of variang concentration of cinnamon extracted dye on formatiojn of AgNPs.

Formation of silver nanoparticles by reduction of aqueous metal ions during exposure of microwave radiation to the cinnamon extract can be quantified by the use of UV-VIS spectroscopy. Change of solution color proves the formation of silver nanoparticles as shown in Figure (84). Color formation is due to the surface plasmon vibration of the metal nanoparticles. There was no characteristic peak in the absorption spectra shown in Figure (85), as a result there is no formation of silver nanoparticles. It was observed that absorbance increases as concentration of cinnamon extract increases. Cinnamon dye extract solution has better reduction at a concentration of 1 ml of cinnamon extract for 50 ml of silver nitrate solution which clearly appear at 450 nm, see Figure (86).

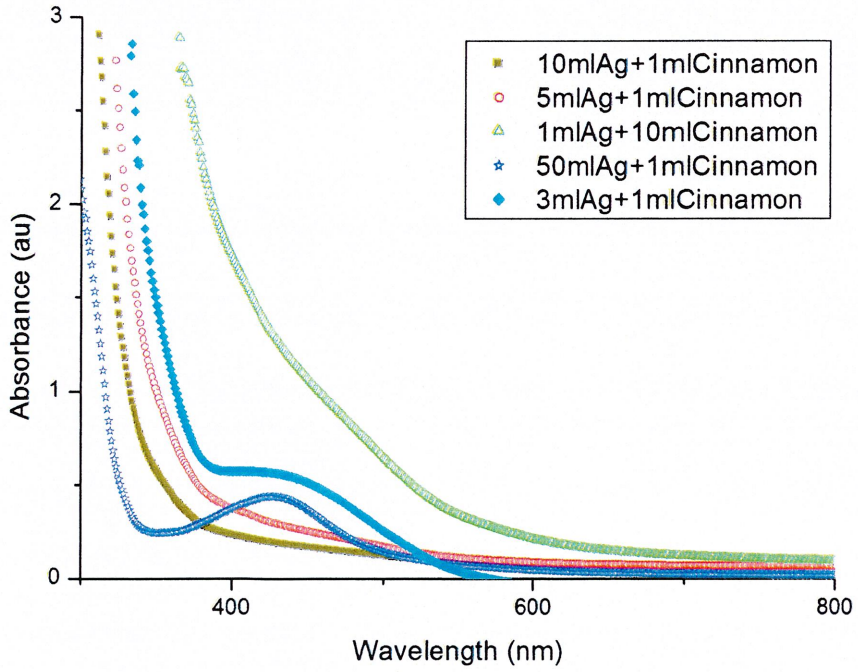


Figure (86): Effect of varing concentration of cinnamon extracted dye on formantion AgNPs.



Figure (87): Color change due to the microwave heating time on synthesis of AgNPs by using cinnamon extract dye. a) Cinnamon extract dye, b) 10 seconds, c) 15 seconds, d) 25 seconds, e) 30 seconds.

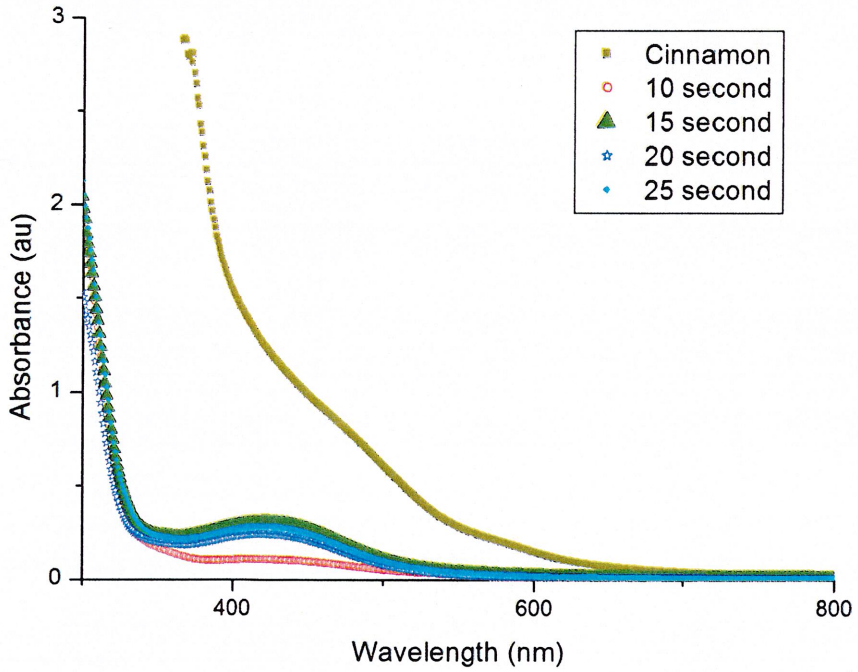


Figure (88): Effect of microwave time heating of cinnamon extract dye on AgNPs.

The effect of microwave heating time was obtained using silver nanoparticles synthesized at an optimum concentration of 1ml of cinnamon extract with 50 ml of silver nitrate. There was an increase in

intensity as heating time increases without any shift in the characteristic peak wavelength as shown in Figure (88). Surface plasmon resonance of AgNPs showed a characteristic peak centered near λ = 450 nm at UV-VIS spectra which corresponds to the absorbance of AgNPs.

The stability of cinnamon stabilized silver nanoparticles was evaluated by measuring the absorption spectra of the prepared solutions after different period of time, see Figure (89).

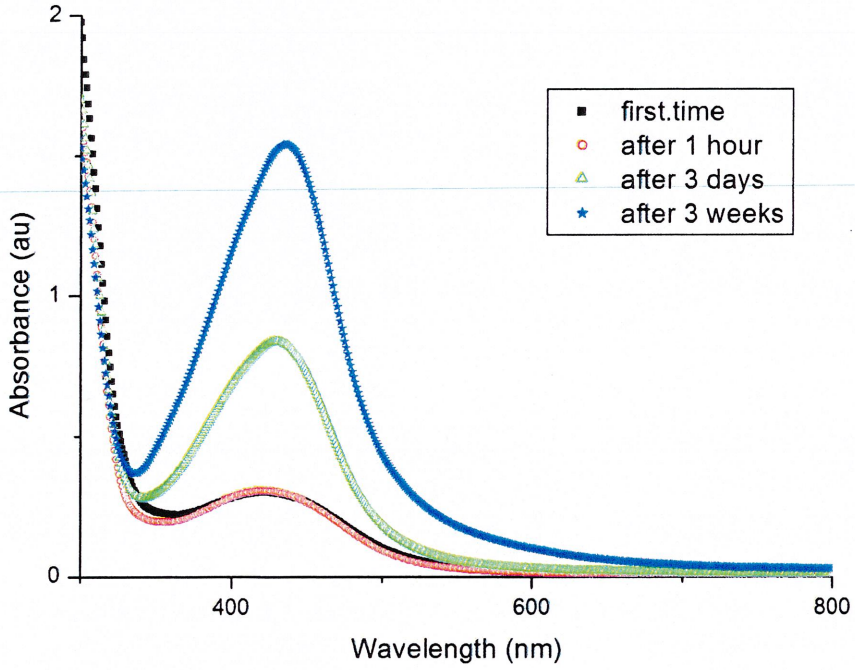


Figure (89): Stability of silver nanoparticles after being prepared.

From Figure (89), we can conclude that silver nanoparticles are stable in cinnamon solution for long period time. There was an increase in absorbance level as period of time increases without any shift in the characteristic SPR peak wavelength as shown in Figure (89). Surface plasmon resonance of AgNPs showed a peak centered near λ = 450 nm at the UV-VIS spectra which corresponds to the absorbance of AgNPs.

ii. TEM analysis:

Transmission electron microscopy (TEM) was performed to determine shapes and size distribution of synthesized nanoparticles. " The samples were prepared by dispersing a few drops of the solution on a copper grid and left to dry in room temperature. The size distribution of nanoparticles was analyzed using ImageJ 1.5j software. This was performed by converting pixels on the TEM images into nanometers by applying the scale of the image " (Abdulla, et.al, 2015). Figure (90) shows the size distribution histogram of AgNPs reduced with cinnamon. TEM analysis clearly illustrated that the shape of AgNPs is not spherical. It can be seen that the formed silver nanoparticles have narrow distribution with a high yield of size less than 20 nm.

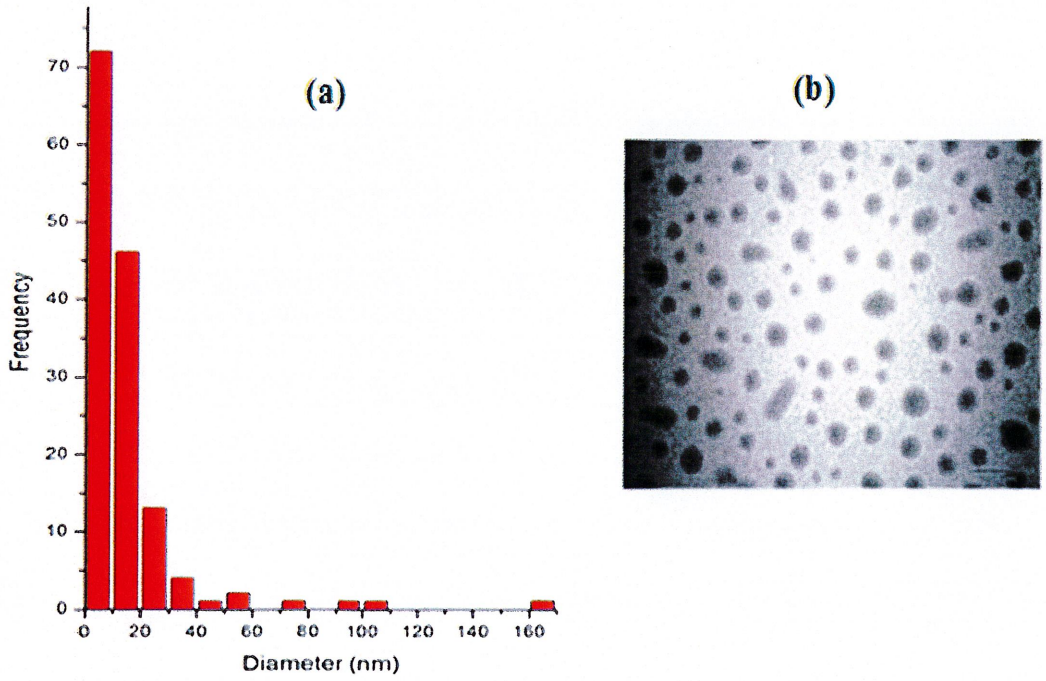


Figure (90): (a) Size distribution histogram of AgNPs reduced with cinnamon. (b) TEM image of silver nanoparticles synthesized using cinnamon, (Abdulla, et.al, 2015)

i. I-V characteristics of dye sensitized solar cells:

Dye sensitized solar cell uses a dye to act as sensitizer for generating photocurrent. Figure (91) and table (17) showed the I-V characteristics of fabricated cinnamon coupled with AgNPs sensitized solar cell. The Titanium Dioxide (TiO_2) nanostructured layer deposited on conductive glasses using two different ways: doctor blade method, and rotation method. By comparing the two methods we can see that from table (17) that the rotation method does not improved cell performance compared to doctor blade method, except for one case. For cinnamon extracted dye, solar cell has power conversion efficiency 0.014% by using doctor blade method, while it has 0.16% power conversion efficiency by using rotation method. Also, for dye coupled with AgNPs solar cell there was no improvement in efficiency, e.g. for 50 ml Ag+1 ml cinnamon heated for 25 seconds has power conversion efficiency 0.014% when doctor blade method is used, while rotation method resulted in $\eta = 0.0009\%$.

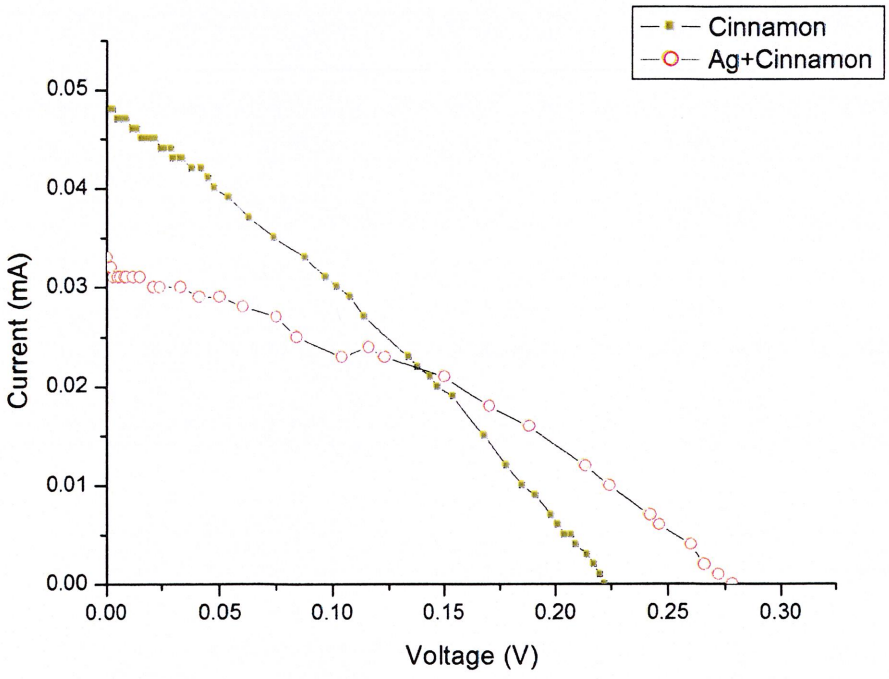


Figure (91): I-V characteristics of cinnamon extract dye and AgNPs with cinnamon.

By comparing cinnamon extract dye solar cells with cinnamon coupled with AgNPs solar cells there were no improvement in performance of cells. In cinnamon extract dye solar cell using doctor blade method it achieved power conversion efficiency of 0.014%, while 50 ml Ag + 1 ml cinnamon heated for 25 seconds using doctor blade method too has power conversion efficiency of 0.14%. There are many reasons behind this behavior and will be discussed in the end of the discussion section.

Table (17): Cinnamon dye with AgNPs solar cell I-V parameters:

Method of TiO_2 deposition	Sensitizer	Heating time (sec)	V_{oc} (V)	I_{sc} (mA)	P_{max} (W/cm^2)	J_{max} (mA/cm^2)	FF (%)	η (%)
Doctor blade	Cinnamon	-	0.252	0.048	0.0013	0.012	25.9	0.014
	50 ml Ag+ 1ml Cinnamon	10	0.125	0.033	0.0005	0.007	29.5	0.0054
	50mlAg+1ml Cinnamon	15	0.053	0.040	0.0001	0.007	14.4	0.0014
	50mlAg+1ml Cinnamon	20	0.200	0.040	0.0005	0.004	14.3	0.0051
	50 ml Ag+1 ml Cinnamon	25	0.234	0.037	0.0014	0.009	36.4	0.014
	50 ml Ag+1 ml Cinnamon	30	0.074	0.032	0.0001	0.005	17.2	0.0018
Rotation method	Cinnamon	-	0.346	0.037	0.0015	0.009	27.8	0.160
	50 ml Ag+1ml Cinnamon	10	0.202	0.013	0.0002	0.002	25.6	0.0030
	50 ml Ag+1 ml Cinnamon	15	0.248	0.010	0.0007	0.003	64.5	0.0071
	50 ml Ag+1 ml	20	0.222	0.009	0.0005	0.004	63.6	0.0056

Cinnamon							
50 ml Ag+1 ml Cinnamon	25	0.056	0.011	0.00009	0.003	33.0	0.0009

Up to ower knowledge, there is no research activity published on synthesis of AgNPs using cinnamon extract as a sensitizer for dye sensitized solar cells. They use cinnamon extract was reported only in green synthesis of AgNPs for biomedical applications, (Abdalla, et.al, 2015).

4.1.5 Group 5: Fruits

In this group two kinds of fruits were used. The Pomegranate (الرمان) and Syzygium cumin (الجمبولان) dye extracts. The extracted dyes were diluted using distilled water.

I. Pomegranate extracted dye:

i. Absorption spectroscopy of dye extracts:

Figures (92) present the absorption spectra for pomegranate extracted dye. Absorption spectroscopy graphs revealed that the pomegranate extracted dye solution absorbs UV, visible and NIR photons. However, absorbance level beyond 500 nm is much lower than that at 450 nm.

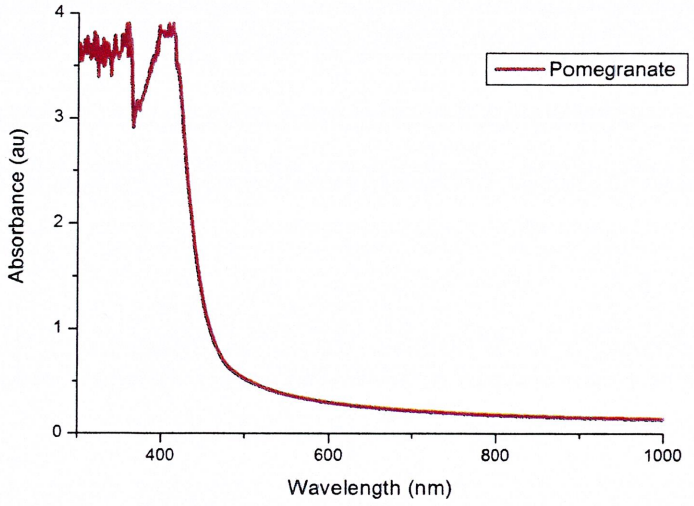


Figure (92): Absorption spectra of pomegranate extracted dye.

ii. I-V characteristics of dye sensitized solar cells:

As shown in Figure (93) and table (18), the pomegranate dye sensitized solar cell has open circuit voltage V_{oc} = 0.132 V, short circuit current I_{sc} = 0.133 mA, fill factor FF = 20.5% and power conversion efficiency η = 0.022%. There are many research activities found on pomegranate dye sensitized solar cell (Mirza, at.al, 2016; Ghann, et.al, 2017). The highest power conversion efficiency that has been obtained was 2%, mainly because they have used spin coating technique to deposit TiO_2. (Ghann, et.al, 2017)

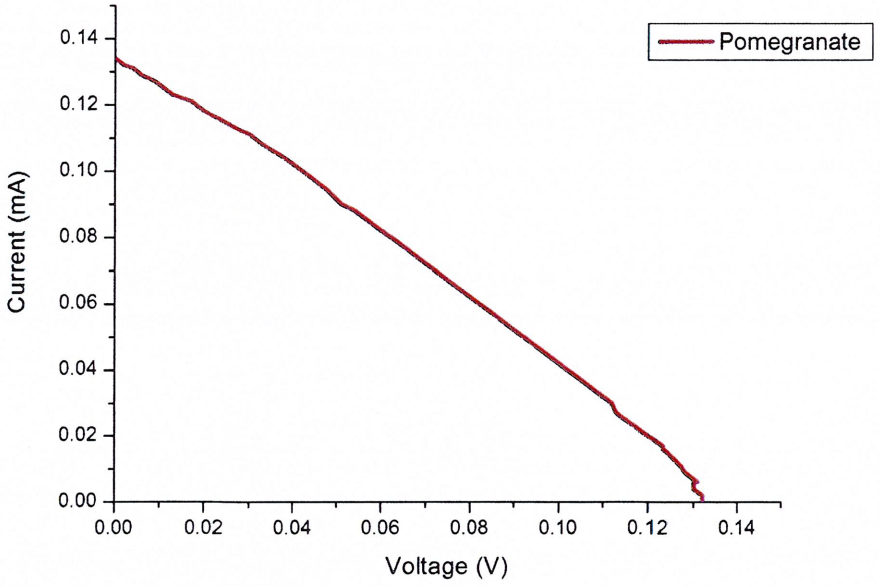


Figure (93): I-V characteristic of pomegranate dyesensitized solar cell.

Table (18): Pomegranate dye sensitized solar cell I-V parameters:

Sensitizer source	V_{oc} (V)	I_{sc} (mA)	P_{max} (W/cm^2)	J_{max} (mA/cm^2)	FF (%)	η (%)
Pomegranate	**0.132**	**0.133**	**0.0022**	**0.029**	**20.5**	**0.022**

II. Green synthesis of silver nanoparticles (AgNPs) using pomegranate extracts dye:

i. Color change and absorption spectra of nanoparticles:

The pomegranate extract dye has been used in green synthesis of silver nanoparticles (AgNPs) by changing parameters like: plant extract concentration, silver solution concentration, and microwave heating time. Reduction of silver ions into AgNPs using pomegranate peel extract dye was recognized by the color change of solutions as shown in figure (94). Figure (95) presents the absorption spectra of AgNPs.

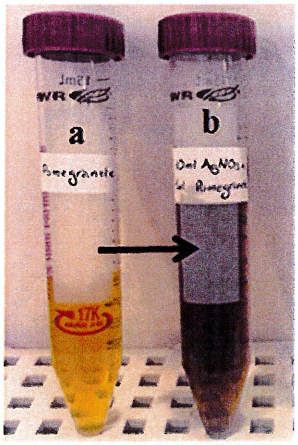


Figure (94): AgNPs formed after the addition of pomegranate extract to silver nitrate and heat it for 10 seconds. a) Pomegranate solution; b) Silver nitrate solution with pomegranate after heating.

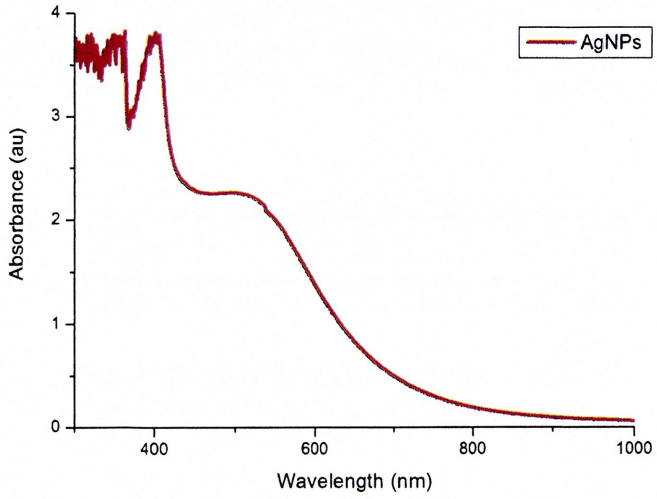


Figure (95): Absorption spectra of AgNPs solution.

As the pomegranate extract was mixed with silver nitrate solution and heated up in microwave oven for 10 seconds, the color change from yellow to brown as shown in Figure (94). Solution color change denotes the formation of silver nanoparticles AgNPs due to the excitation of surface plasmon vibrations in AgNPs. From the absorption spectra

(Figure (95)) it can be seen that a wide absorbance band centered at λ = 450 nm which is characteristics for the formation of small nanoparticles.

Effects of pomegranate extract concentration, silver solution concentration and microwave heating time on the formation of silver nanoparticles have been analyzed via studying variations in absorbance and wavelength of Surface Plasmon Resonance (SPR) of silver nanoparticles as presented in Figures (96), (97), (98) and (99).

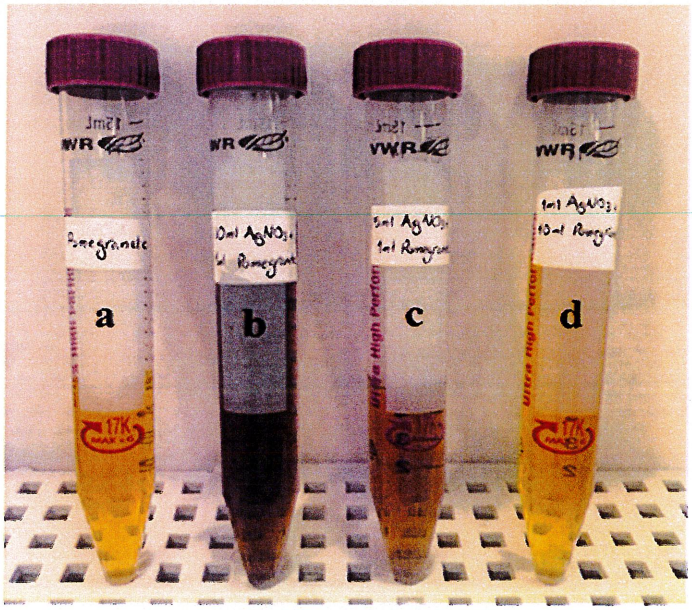


Figure (96): Color change due to the concentration on synthesis of AgNPs by using pomegranate extract dye. a) Pomegranate extract dye, b) 10 ml $AgNO_3$ + 1 ml pomegranate, c) 5 ml $AgNO_3$ + 1 ml pomegranate, d) 1 ml $AgNO_3$ + 10 ml pomegranate.

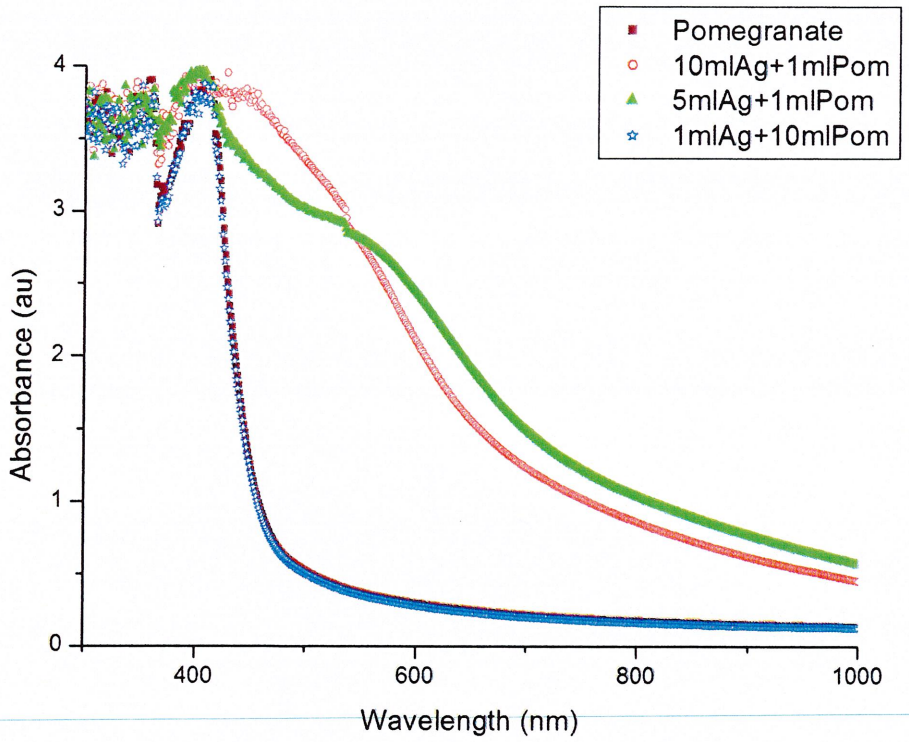


Figure (97): Effect of pomegranate extracted dye concentration on AgNPs.

Formation of silver nanoparticles by reduction of aqueous metal ions during exposure of microwave radiation to the pomegranate extract can be followed by UV-VIS spectroscopy. The color change should indicates formation of silver nanoparticles as shown in Figure (96). The color formation is due to the surface plasmon vibration of the metal nanoparticles. There was no characteristic peaks apearing in the absorption spectra shown in Figure (97), except with concentration of 5 ml of $AgNO_3$ + 1 ml pomegranate. It was observed that absorbance increases as concentration of pomegranate extract increases. In pomegranate there is better reduction at a concentration of 1-ml of pomegranate extract for 20 ml of silver nitrate solution which clearly appear at $\lambda = 450$ nm, as shown in Figure (98).

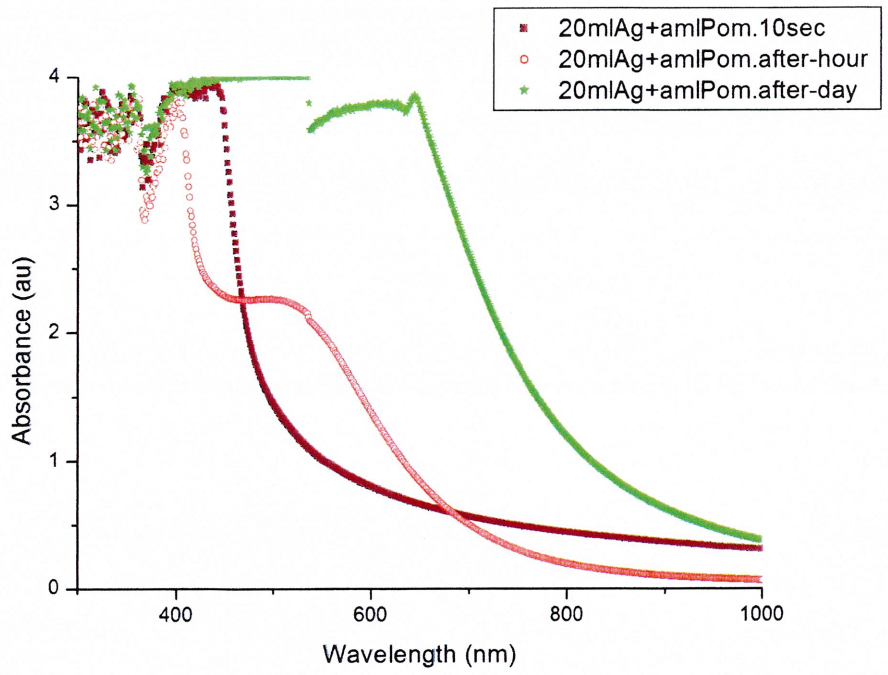


Figure (98): Effect of pomegranate extracted dye concentration on AgNPs.

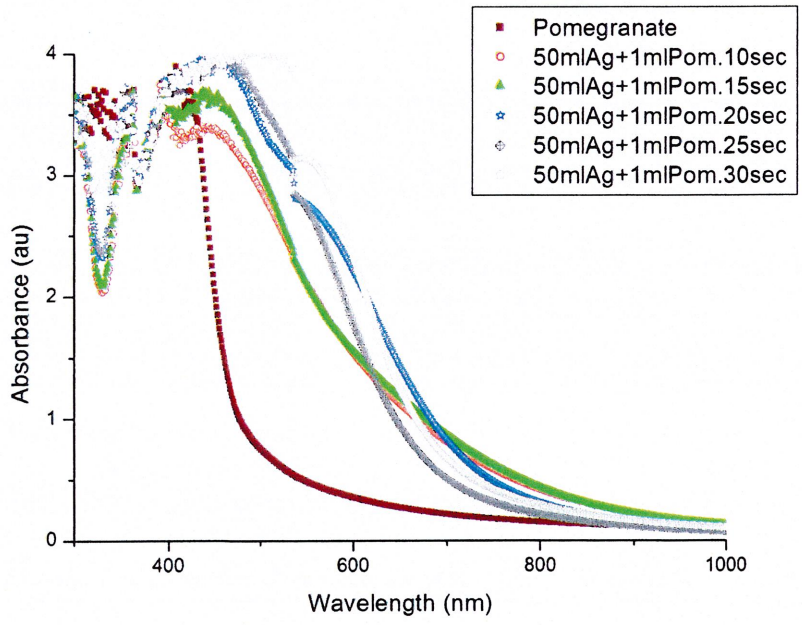


Figure (99): Effect of microwave time heating of pomegranate extract dye on AgNPs.

The effects of microwave heating time was investigated using silver nanoparticles synthesized at an optimum concentration of 1-ml of pomegranate extract with 50 ml of silver nitrate. There was an increase in

absorbance level as heating time increases without any shift in the peak wavelength position as shown in Figure (99). The surface plasmon resonance of AgNPs showed a characteristic peak centered near λ = 450 nm at UV-VIS spectra which corresponds to the absorbance of AgNPs.

ii. I-V characteristics of dye-NPs sensitized solar cells:

Dye sensitized solar cell uses a dye to act as sensitizer for generating photocurrent. Figure (100) and table (19) show the I-V characteristics of fabricated pomegranate coupled with AgNPs sensitized solar cell. The Titanium Dioxide (TiO_2) film deposited on conductive glasses using two different ways: doctor blade method, and rotation method. By comparing the two methods we can see that from table (19) rotation method improved cell performance compared to doctor blade method.

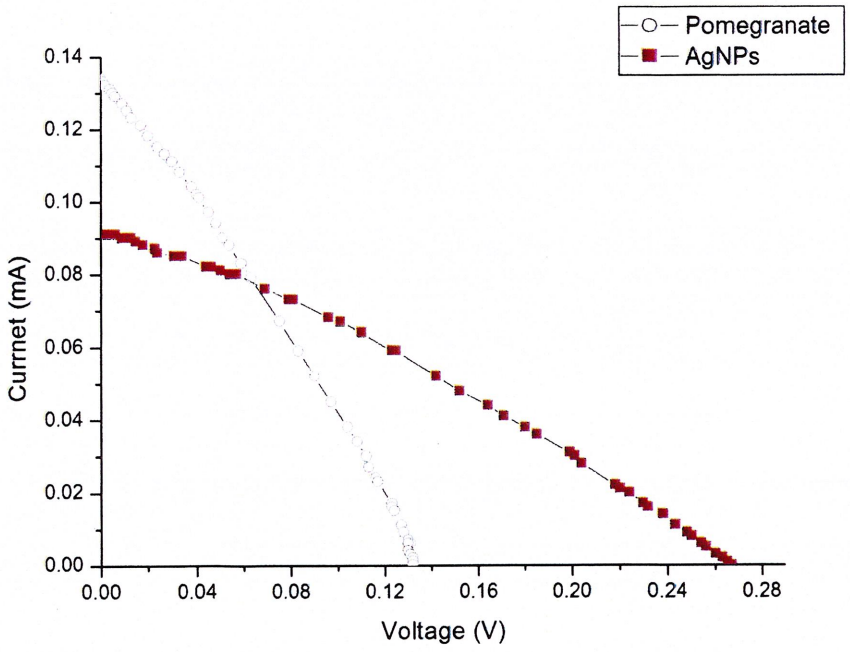


Figure (100): I-V characteristics of pomegranate extract dye and AgNPs reduced with pomegranate.

For pomegranate extracted dye solar cell achieved power conversion efficiency of 0.022% when using doctor blade method, while it achieved 0.11% of power conversion efficiency by using rotation method. Also, for dye coupled with AgNPs solar cell there was improvement in efficiency.

Table (19): Pomegranate dye with AgNPs solar cell I-V parameters:

Method of TiO_2 deposition	Sensitizer	Heating time (sec)	V_{oc} (V)	I_{sc} (mA)	P_{max} (W/cm^2)	J_{max} (mA/cm^2)	FF (%)	η (%)
Doctor blade	Pomegranate	-	**0.184**	**0.133**	**0.0022**	**0.029**	**20.5**	**0.022**
	10mlAg+1mlPomegranate	**10**	**0.276**	**0.105**	**0.0032**	**0.023**	**25.5**	**0.033**
	20mlAg+1mlPomegranate	**10**	**0.278**	**0.093**	**0.0038**	**0.026**	**33.6**	**0.04**
Rotation method	Pomegranate	-	**0.421**	**0.174**	**0.0109**	**0.048**	**33.7**	**0.11**
	5mlAg+1mlPomegranate	**10**	**0.320**	**0.100**	**0.0041**	**0.025**	**28.8**	**0.041**
	1mlAg+10mlPomegranate	**10**	**0.18**	**0.126**	**0.0021**	**0.031**	**21.6**	**0.022**
	1mlAg+10mlPomegranate	**15**	**0.215**	**0.282**	**0.0085**	**0.073**	**31.8**	**0.086**

By comparing Pomegranate extract dye solar cell with pomegranate coupled with AgNPs solar cell there was improvement in performance of cells. In pomegranate extract dye solar cell using doctor blade method has efficiency 0.022%, while 20 ml Ag + 1ml pomegranate heated for 10 seconds using doctor blade method too has efficiency 0.04%. There are many reasons behind this behavior that will be discussed in the end of the discussion.

We found no research activity reporting synthesis of AgNPs to be used in fabrication of dye sensitized solar cells. Pomegranate extract has been used only in green synthesis of AgNPs for biomedical applications, (Shanmugavadivu, et.al, 2014).

III. Syzygium cumin extracted dye:

Figures (101) present the absorption spectra for Syzygium cumin extract dye. Absorbance spectrum reveals that the Syzygium cumin extract dye strongly absorbs UV part of the electromagnetic spectrum. However it has low absorbance for most of the visible and NIR part of the electromagnetic spectrum.

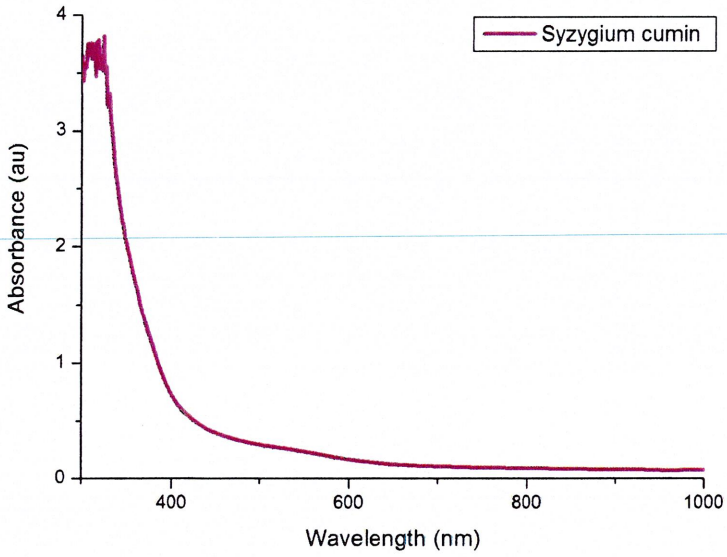


Figure (101): Absorption spectra of Syzygium cumin extract.

When testing the cell and measuring the I-V characteristics for Syzygium cumin in solar cell we note that the photocurrent and voltage levels are not stabilizes they reach some maximum value and then deteriorate quickly like discharging a capacitor. There are many reasons behind this behaviour and will be discussed at the end of the discussion part. Finally, conclude that Syzygium cumin dye extract is not a suitable sensitizer to be used in a dye sensitized solar cells.

IV. Green synthesis of silver nanoparticles (AgNPs) using Syzgium cumin extracts dye:

i. Color change and absorption spectra of nanoparticles:

The Syzgium cumin extract dye has been used in green synthesis of silver nanoparticles (AgNPs) by changing parameters like: plant extract concentration, silver solution concentration, and microwave heating time. Reduction of silver ions into AgNPs using Syzgium cumin extract dye was observed via the change of solutions color as presented in Figure (102). Figure (103) shows the absorption spectra of AgNPs.

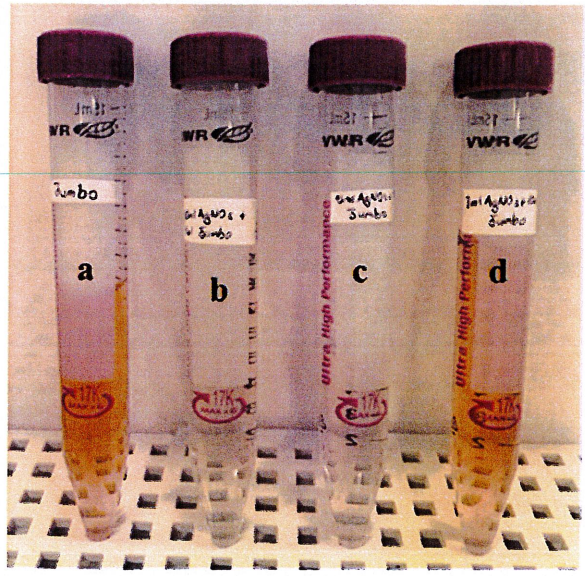


Figure (102): Color change due to varing concentration of syzgium cumin extract dye on synthesis of AgNPs. a) Syzgium cumin extract dye, b) 10 ml $AgNO_3$ + 1 ml Syzgium cumin, c) 5 ml $AgNO_3$ + 1 ml Syzgium cumin, d) 1 ml $AgNO_3$ + 10 ml Syzgium cumin.

As the Syzgium cumin extract was mixed with silver nitrate solution and heated up in microwave oven for 10 seconds, its color does not change as shown in Figure (102). Therefore, it be concluded that there is slim chance of formation of silver nanoparticles AgNPs. The broad characteristic peak a bears in the spectra shown in Figure (103) supports this conclusion.

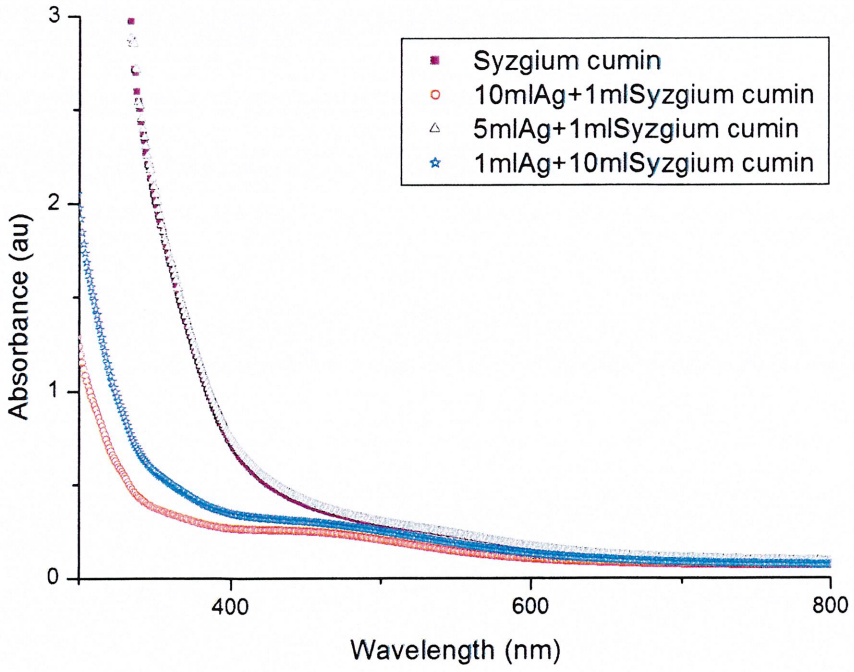


Figure (103): Effect of concentration of Syzgium cumin extracted dye on synthesis of AgNPs.

Even when testing the assembled solar cells and measuring the I-V characteristics for Syzgium cumin with AgNPs in solar cell, it has been noted that the values of photocurrent and voltage are not stable. They reached some maximum value and then diminished very quickly like discharging a capacitor. There are many reasons behind this behavior and will be discussed in section 4.1.6. Finally, it could be concluded that Syzgium cumin with AgNPs does not work as proper sensitizer in solar cells as well as in green synthesis of nanoparticles.

Up to date there is no research activity reporting synthesis of AgNPs using Syzgium cumin extract for fabrication of dye sensitized solar cell or green synthesis of silver nanoparticles.

4.1.6 Dye sensitized solar cells competing processes

Dye sensitized solar cell (DSSC) is fabricated using four main parts: two transparent conducting electrodes, nanostructured wide band gap semiconducting layer, sensitizer (dye molecules), and electrolyte. Therefore, the injected photoelectrons have long path to go through after they become generated from the molecules before get transported out as electric current through an external load. Each injected photoelectron is be exposed to many barriers during its journey in the cell's parts which can affect the performance of dye sensitized solar cells. Many researchers investigated these barriers or efficiency limiting factors, (Hara & Arakawa, 2003; Jasim, 2011; Mohamed,et.al, 2016; Selvaraj, et.al, 2018).

At the beginning of the photoelectron generation process, photons fall on a solar cell. The incident photons are not fully absorbed by dye molecule to get converted to electric energy. The absorbed photons depend on the chemical nature of the dye that will define and limit the spectral absorbance range of dye molecule. Each type of dye absorbs different range of electromagnetic radiation . Due to that, the dye molecule may not efficiently absorbs photons or get excited, as illustrated in Figure (104).

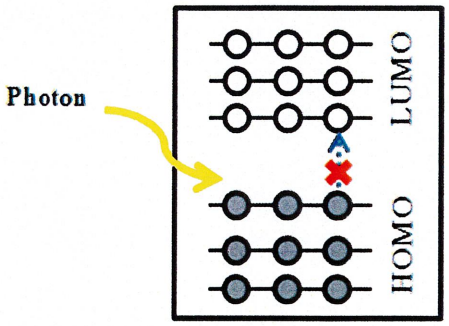


Figure (104): Illustration of the competing processes, no absorption of photon or no excitation of dye molecule.

In case photons of prober energy get absorbed by a molecule, it will transfer an electron from the highest occupied molecular orbit (HOMO) to lowest unoccupied orbit (LUMO). Then, if lucky the excited electron get injected into the conduction band of TiO_2 electrodes. This results in what is known as oxidation of dye molecule. But some time, the excited electron relax and returns back to ground state (no injection), as illustrated in Figure (105).

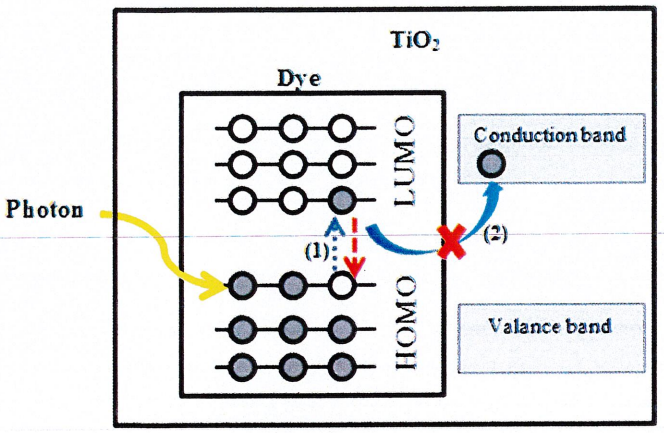


Figure (105): Illustration of the competing processes, a generated photoelectron in the dye excited state return back to the ground state rather than being injection into the conduction band of TiO_2 .

After that, the injected electrons transported to the counter electrode and transported through the external load. The injected electrons in the TiO_2 conduction band might go to the electrolyte rather than the working electrode, due to many reasons, such as TiO_2 thickness. As the thickness increased the electron will have very long path to pass through and probability of recombine dyes with electrolyte increased as illustrated in Figure (106). (Selvaraj, et.al, 2018)

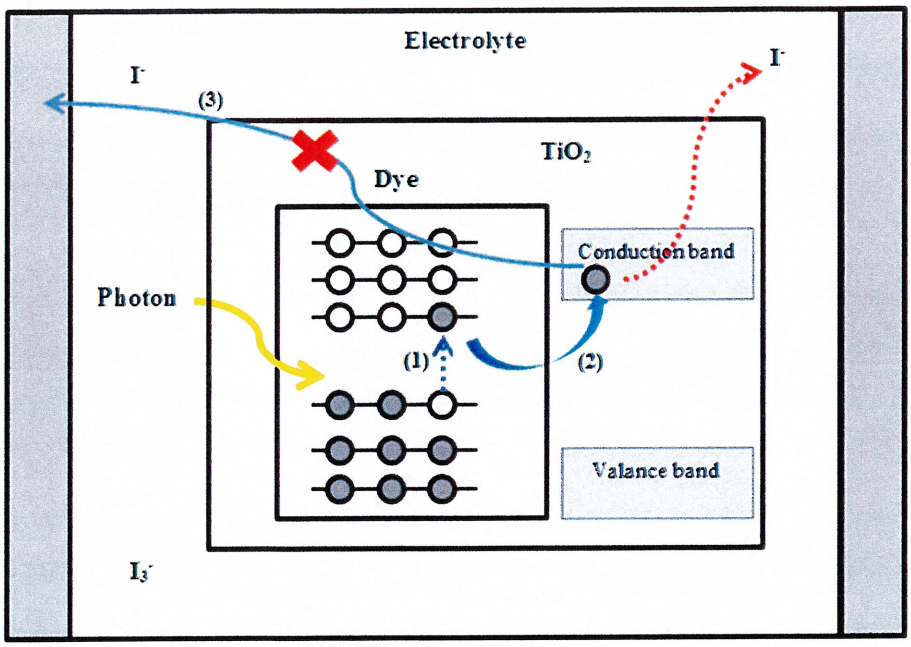


Figure (106): The injected electron recombines with electrolyte.

Finally, the electrolyte solution captures the electrons at the transparent counter electrode and transfers them back to the dye molecules in order to complete the electrical circuit. But in some cases the injected electrons get lost and couldn't capture by electrolyte, as illustrated in Figure (107).

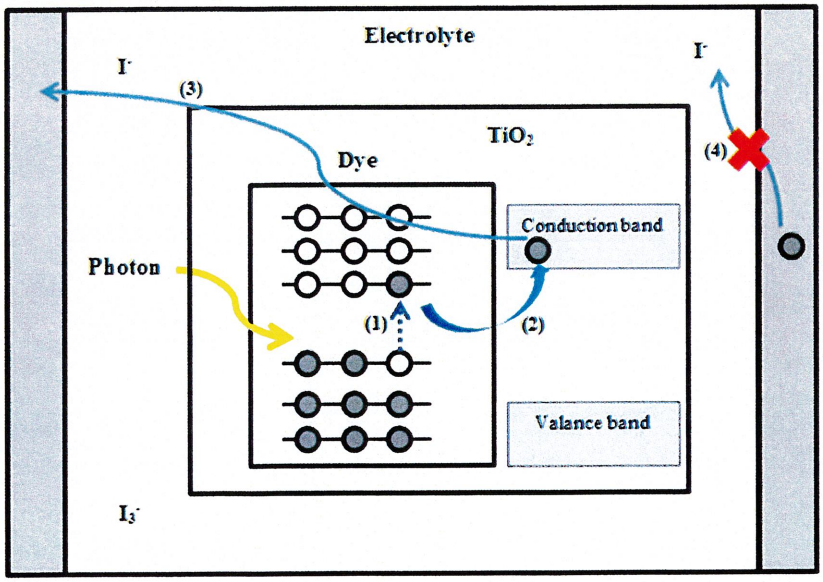


Figure (107): No capture of electrons.

The generated electrons in dye sensitizer face many competing processes which can limit or reduce solar cell performance. Also, there are many factors that can affect performance of the solar cell, such as, TiO_2 layer thickness, TiO_2 layer cracks, annealing temperature of TiO_2 layer, testing (operating) temperature where the concentrated sunlight generates high temperature due to high light intensity (Selvaraj, et.al, 2018). To study factors affecting dye sensitized solar cell further work is required to investigate them.

Capacitance, electric resistance, and nature of media forming the cell are limiting processes which photogenerated electron are encountering in dye sensitized solar cell. For dye coupled with nanoparticles solar cells, the same factors can face them as well as another factors. In dye coupled with nanoparticles electrons injected from both dye molecule and nanoparticles. This process should increase photocurrent, and thus leading to have a better performance of solar cell. But as we see from previous results the efficiency of coupled solar cell in most cases was not improved that much. The main cause of that problem may be attributed to capture of the photogenerated electrons in dye molecule by nanoparticles, and hence reduction of photocurrent as illustrated in Figure (108).

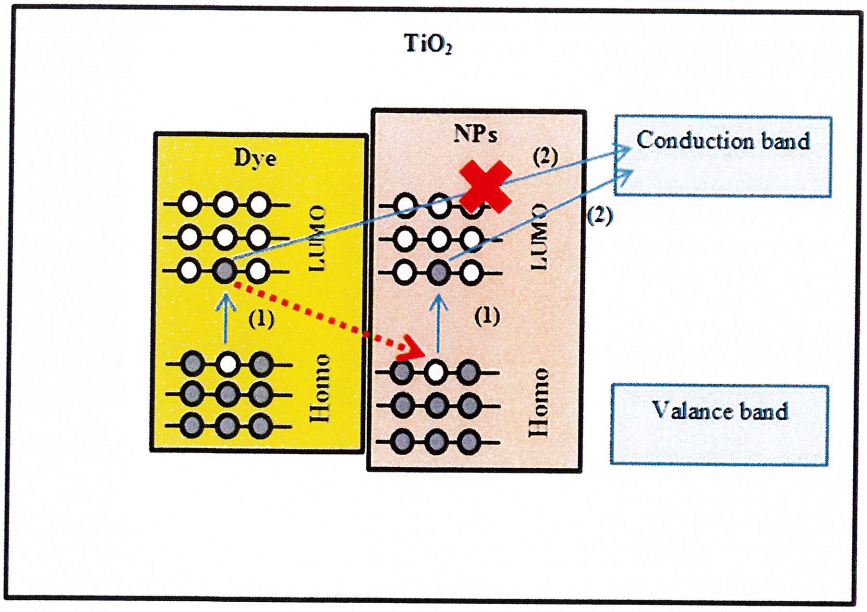


Figure (108): Injected electron from dye get captured by nanoparticles, broken red line.

4.2 Study Recommendations

For further work and better performance of dye sensitized solar cell, the following suggestions are proposed:

1- Investigate each factor affecting dye sensitized solar cells operation or performance such as solvent choice, extraction temperature, immersing times, dyes concentration and solvent PH.

2- Replacing the manual way of data acquisition with computer aided to have more organized and faster data acquisition processes.

3- Replacing doctor blade or rotation method with better or automated method for TiO_2 deposition, for example, screen printing method (Kunugi, et.al, 2013; Haryanto, et.al, 2014), and spin coating (Hosseini, et.al, 2013).

4- Trying another TiO_2 preparation methods such as: sol-gel method (Hosseini, et.al, 2013; Hayashi, et.al, 2011; Menisa, et.al, 2014).

5- Replacing TiO_2 with another wide bandgap semiconductor like zinc oxide (ZnO) (chang, et.al, 2012) or use nanocomposite such as ($ZnO-TiO_2-Fe_2O_3$) (Mebrahtu, et.al, 2017).

6- Developing a new TiO_2/graphene/TiO_2 sandwich structure for photoelectrodes by inserting thin layer of graphene into the traditional TiO_2 photoelectrode layer, making it a double layer (Chen, et.al, 2014).

7- Prepare electrolyte solution with different solvents and different potassium iodide (KI) & iodine (I_2) concentration to improve performance of dye sensitized solar cell. (Gu, et.al, 2017)

8- Replacing the redox electrolyte solution with polymer electrolytes (Rokesh, et.al, 2015)

9- Replacing the solid thick glass conductive electrodes with thin high transparent flexible ones.

10- Investigating other kinds of metallic nanoparticles and quantum dots as co-sensitizers.

REFERENCES

- Abdulwahab, Fatema. (2016). Detection of Glucose Based on Gold & Silver Nanoparticles using Z-scan Technique (MSc). Royal College of Surgeons in Ireland.

- Abdalla, Khalid H., Al- Hannan, Fatima, Alghamdi, Ali, & Z. Henari, Fryad. (2015). Green Synthesis of Silver Nanoparticles using Cinnamon (Cinnamomum cassia), Characterization and Antibacterial Activity.

- *International Journal of Science and Research (IJSR)*. Vol. 6, Issue 6, pp.965-971.

- Absorbance. (2017). Slideshare. Retrieved 24 December 2017, from https://www.slideshare.net/IvyLeeSensoRx/beerlambert-lawvitro-photon-absorbance-or-transmittance-p49-1418

- Absorption. (2017). andor. Retrieved 24 December 2017, from http://www.andor.com/learning-academy/absorption-transmission-reflection-spectroscopy-an-introduction-to-absorption-transmission-reflection-spectroscopy

- Ananth, S., Vivek, P., Saravana Kumar, G., & Murugakoothan, P. (2015). Performance of Caesalpinia sappan heartwood extract as photo sensitizer for dye sensitized solar cells. *Spectrochimica Acta Part A: Molecular And Biomolecular Spectroscopy*, 137, 345-350.

- Anatase. (2016). Wikipedia. Retrieved 24 December 2017, from https://en.wikipedia.org/wiki/Rutile

- Andrew , Sendy. (2017). Pros and Cons of Monocrystalline vs Polycrystalline solar panels. Retrieved from: https://www.solarreviews.com/blog/pros-and-cons-of-monocrystalline-vs-polycrystalline-solar-panels

- Arnold, Paul. (2009). Guide to Plant Cell Structures: The Chloroplast. Retrieved 24 December 2017, from : https://www.brighthub.com/science/genetics/articles/24560.aspx

- Baghayeri, Mehdi, Mahdavi, Behnam, Abadi, Zahra, & Farhadi, Samaneh. (2017). Green synthesis of silver nanoparticles using water extract of Salvia leriifolia: Antibacterial studies and applications as catalysts in the

electrochemical detection of nitrite. *Applied Organometallic Chemistry.* Vol,32 , pp.e4057.

- Bagherzade, Ghodsieh, Tavakoli, Maryam, & Namaei, Mohammad. (2016). Green synthesis of silver nanoparticles using eqeous extract of saffron wastages and its antibacterial activity against six bacteria. *Asian Pacific Journal of tropical biomedicine.* Vol, 7(3), pp.227-233.

- Becker, W.M. and D.W. Deamer.(1991). The World of the Cell. 2nd ed. Redwood City, California. Available from: http://www.differencebetween.net/science/chemistry-science/differences-between-rutile-and-anatase-titanium-dioxide/

- Bellis, Mary. (2006). History of solar cells. Retrieved May28, 2017. Available from: http://www.investopedia.com/terms/n/nonrenewableresource.asp

- Calogero, G.; and Marco, G.D. (2008). Red Sicilian orange and purple eggplant as natural sensitizers for dye-sensitized solar cells. *Solar Energy Materials & Solar Cells* (vol 92, pp 1341-1346).

- Celine. (2012). Differences between Rutile and Anatase Titanium dioxide. [online]. Available from: http://www.differencebetween.net/science/chemistry-science/differences-between-rutile-and-anatase-titanium-dioxide/

- Chang, Wei-chen, Cheng, Yao-Yi, Yu, Wan-Chin, Yao, Yih-Chun, Lee, Chai-Hau, & Ko, Hung-Han. (2012). Enhancing performance of ZnO dye-sensitized solar cells by incorporation of multiwalled carbon nanotubes. [online]. From: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3320520/

- Chen, Lung-Chien, Hsu, Chih-Hung, Chan, Po-Shun, Zhang, Xiuyu, & Huang, Cing-Jhih. (2014). Improving the performance of dye-sensitized solar cells with TiO_2/graphene/TiO_2 sandwich structure. [online]. From: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4127667/

- Costa, Christen. (2008). Sony unveils solar lamps shades. [online]. Available from: http://www.gudgetreview.com

- Cramer, Hailey E.; Griep,Mark H.; and Karna ,Shashi P. (2012). Synthesis, Characterization, and Application of Gold Nanoparticles in Green Nanochemistry Dye-Sensitized Solar Cells. *Washington: U.S. Army Research Laboratory.*

- Daoud, Shahdl, Alqahtani, Mona A. M., Alkhalifah, Dalal H. M., Elobeid, Mudawi M., & Mohammed, Afrah E. (2015). Biosynthesis of silver nanoparticles using salvia officinalis extract and assessment of their antibacterial activity. *International Journal of Current Research*. Vol. 7, Issue, 10, pp.21548-21552

- Electronic Spectroscopy. (2018). Chemistry.LiberTexts. Retrieved 3 January 2018, from https://chem.libretexts.org/Core/Physical_and_Theoretical_Chemistry/Spectroscopy/Electronic_Spectroscopy/Electronic_Spectroscopy%3A_Application

- Eli, D., Onimisi, M.Y., Abdu, S.G., Gyuk, P.M., and Jonathan, E. (2016). Enhanced Performance of a Dye sensitized solar cell using silver nanoparticles modified photoanode. *Journal of scientific research & reports*, article no. JSRP24439. Nigeria.

- Fanis, Linda. (2007). Nanocrystalline Solar Cell Kit. Madison. University of Wisconsin Broad of Regents.

- Fluorescence Spectroscopy. (2018). University of Cyprus. Biomedical Imaging and Applied Optics. Retrieved 3 January 2018, from http://www.eng.ucy.ac.cy/cpitris/courses/ECE477/presentations/English/08.%20Fluorescence%20Spectroscopy.pdf

- Ghann, William, Kang, Hyeonggon, Sheikh, Tajbik, Yadav, Sunil, Chavez-Gel, Tulio, Nesbitt, Fred, & Uddin, Jamal. (2017). Fabrication, Optimization and Characterization of Natural Dye Sensitized Solar Cell. [online].From: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5270247/

- Gleue, Alan D. (2008). Dye-sensitized solar cell. Retrieved May28, 2017. Available from: http://teachers.usd497.org/agleue/index.html

- Gu, Peng, Yang, Dingyu, Zhu, Xinghua, Sun, Hui, Wangyang, Peihua, Li, Jitao, & Tian, Haibo. (2017). Influence of electrolyte proportion on the performance of dye-sensitized solar cells. *American Institute of Physics*.

- Hao, S.; Wu, J.; Huang, Y.; and Lin, J. (2006). Natural Dyes as Photosensitizer for Dye-Sensitized Solar Cell. *Solar energy* (vol.80, pp 209-214). Elsevier.

- Hara, K., & Arakawa, H. (2003). Dye-sensitized Solar Cells, In A. Luque and S. Hegedus, (Ed.) Handbook of Photovoltaic Science and Engineering, pp. 663-700, John Wiley & Sons, Ltd.

- Haryanto, Ditia Allindira, Landuma, Suarni, & Purwanto, Agus. (2014). Fabrication of Dye-sensitized Solar Cell (DSSC) Using Annato Seeds (Bixa orellana Linn). Indonesia.

- Hayashi, Hiroaki, Shintani, Yasushi, Tsurummaki, Hiroshi, Shiratsuchi, Ryuichi, & Hayase, Shuzi. (2011). The application of Ti precursor solutions to dye sensitized solar cells. *Kyushu institute of technology*. Japan. Vol. 79, pp.807-809.

- Hettelsater, Dawn. Zhang, Yan and Shakouri, Ali. (2002). Solar cells. University of California at Santa Cruz. USA.

- Hosseini, A., icli, K. C., & Güllü, H. H. (2013). Preparation and characterization of porous TiO2 thin films by sol-gel method for Extremely Thin Absorber-ETA solar cell applications. *Turkish Journal of Science & Technology*. Volume 8(2), pp.69-79.

- Hosseinpanahi, Kambiz, Abbaspour, Mohammad, Feizy, Javad, & Golzarian, Mahmood. (2016). Dye-Sensitized Solar Cell Using Saffron Petal Extract as a Novel Natural Sensitizer. Ferdowsi University of Mashhad. Iran

- Hung, Tien Tsan. (2011). Dye-sensitized solar cells based on Novel mixed dyes. Advanced Materials Research (vol.383, pp 5501-5515). Retrieved May30, 2017. From scientific.net website: https://www.scientific.net/AMR.383-390.5510

- Iravani S., Korbekandi H., Mirmohammadi S.V., Zolfaghari B. (2014). Synthesis of silver nanoparticles: chemical, physical and biological methods. Res Pharm Sci.;Vol.9(6), pp.385-406. Review.

- Jasim, K., & Hassan, A. (2009). Nanocrystalline TiO_2 based natural dye sensitised solar cells. *International Journal Nanomanufacturing*.Vol.4(1/2/3/4), pp.242–247.

- Jasim, K., Al Dallal, S., & Hassan, A. (2011). Natural dye-sensitised photovoltaic cell based on nanoporous TiO_2. *International Journal of Nanoparticles*. Vol.4(4), pp.359-368.

- Jasim, K. (2011). Natural Dye-Sensitized Solar Cell Based On Nanocrystalline TiO2. *Journal of Sains Mallaysiana*.Vol. 41(8), pp.1011–1016.

- Jasim, K., Al-Dallal, S., & Hassan, A. (2012). Henna (Lawsonia inermis L.) Dye-Sensitized Nanocrystalline Titania Solar Cell. *Journal of Nanotechnology*, 2012, 1-6.

- Jung, Onyu, & Lee, Sang-Soo. (2013). Preparation of Dye Sensitized Solar Cell Using Coumarin Dyes Extracted from Plants. Korean chemical engineering research.

- Jussila, Henr, Yang, He, Granqvist, Niko, & Sun, Zhipei (2016). "Surface plasmon resonance for characterization of large-area atomic-layer graphene film". Optica. 3 (2): 151

- Kunugi, Yoshihito, Shimoyama, Yuki, & Umeza, Shinjiro. (2013). Fabricated of dye-sensitized solar cells using electrostatic inkjet printing. *Journal of photopolymer science and technology*. Vol.26, pp. 383-385.

- Kurse, Sarah. (2007). The process of photosynthesis. [online]. Available from: http://bioweb.uwlax.edu/bio203/2011/kruse_sara/author.htm
- Lambers, Hans, Bassham, James. (2017). Photosynthesis. Retrieved from: https://www.britannica.com/science/photosynthesis

- Matsubara, T.; Ichikawa, Y.; Aramki, K.; and Katagiri, A. (2005). The use of xylenol orange in a dye-sensitizer solar cell. *Solar Energy Materials &Solar Cells* (vol 85, pp 269-275).

- Mebrahtu, Chalachew, Taddesse, Abi M., Goro, Girma, & Yohannes, Teketel. (2016). Natural pigment sensitized solar cells based on ZnO-TiO_2-Fe_2O_3 nanocomposite in quasi-solid state electrolyte system. *Chemical Society of Ethiopia*.Vol, 31(2), pp.263-279.

- Menisa, Leta, Mengesha, Abi Tadesse, Gonfa, Girma Goro, & Anshebo, Taketel Yohannes. (2014). *Chemistry and Materials Research*. Vol,6, pp.126-133. Ethiopia

- Michael W. Davidson, (2004). Alexandre Edmond Becquerel. Molecular expression. Available from: http://micro.magnet.fsu.edu/optics/timeline/people/becquerel.html

- Mirza, Najla., & Jasim, K. (2016). Green Solar Cells: Natural Dye Extracts Sensitized Solar Cells Based on Nanoporous TiO2 (Msc). University of Bahrain.

- Mohamed, Ahmed A., & Selim, Yehia. (2016). Factors Affect Dye Sensitized Solar Cells performance. *Renewable Energy and Sustainable Development (RESD).* Vol. 3, Issue. 1, pp.83-86.

- Mohanpuria P., Rana N.K., Yadav S.K. (2008). Biosynthesis of nanoparticles: technological concepts and future applications. J Nanopart Res.10, pp.507–517

- NREL. (2018). Best research efficiencies. National renewable energy laboratory. From: https://www.nrel.gov/

- O'regan B, and Gratzel,M. (1991). A low cost, high-efficiency solar cell based on dye-sensitized colloidal TiO_2 films. *Nature* (vol 353, pp. 733-739)

- Photosynthesis. (2017). Chemistry for biologists. Retrieved 24 December 2017, from http://www.rsc.org/Education/Teachers/Resources/cfb/Photosynthesis.htm

- Pierro, R.E. (2011). Pros and cons of difference types of solar cells. [online]. Available from: http://www.pierrosolar.com/why/about-solar-panels/types

- Plasmon. (2014). The free dictionary. Retrieved 4 January 2018, from https://www.thefreedictionary.com/plasmon

- Polo, A.S.; and Iha, Murakami. (2006). Blue sensitizers for solar cells: natural dyes from Calafate and Jaboticaba. Sol. Energy Mater. Sol. Cells (vol 90, pp1936)

- Raveendran P., Fu J., and Wallen S.L. (2003). Completely "green" synthesis and stabilization of metal nanoparticles. J Am Chem Soc. 125(46), pp 13940-1.

- Rokesh, Karuppannan, Anandan, Sambandam. (2015). Polymer Electrolytes in Dye Sensitized Solar Cells. *Material Focus*. Vol.4, pp.262-271.
- Rutile. (2016). Wikipedia. Retrieved 24 December 2017, from https://en.wikipedia.org/wiki/Rutile

- Saifuddin N., Wong C.W., Nur Yasumira A.A. (2009). Rapid biosynthesis of silver nanoparticles using culture supernatant of bacteria with microwave irradiation. *E-Journal of Chemistry*. Vol. 6, pp 61–70.

- Selvaraj, Prabhakaran, Baig, Hasan, Mallick, Tapas K., Siviter, Jonathan, Montecucco, Andrea, Li, Wen, Paul, Manosh, Sweet, Tracy, Gao, Min, Knox, Andrew R., & Sundaram, Senthilarasu. (2018). Enhancing the efficiency of transparent dye-sensitized solar cells using

- concentrated light. *Solar Energy Materials and Solar Cells*. pp.29-34.

- Shah, Monaliben, Fawcett , Derek, Sharma, Shashi, Suraj, Tripathy Kumar, & Poinern, Gérrard Eddy Jai . (2015). Green Synthesis of Metallic Nanoparticles via Biological Entities. *Materials MDPI*. Switzerland

- Shanmugavadivu, M., Kuppusamy, Selvam, & Ranjithkumar, R.(2014). Synthesis of Pomegranate Peel Extract Mediated Silver Nanoparticles and its Antibacterial Activity. American Journal of Advanced Drug Delivery. Vol.2, pp.174-182.

- Song J.Y, and Kim BS. (2009). Rapid biological synthesis of silver nanoparticles using plant leaf extracts. *Bioprocess Biosyst Eng*. Vol.32(1), pp.79-84.

- Soutter, Will. (2013). What is a dye sensitized solar cell. [online]. Available from: http://www.azonano.com/article.aspx?ArticleID=3175

- Srikar, Sista Kameswara, Giri, Deen Dayal, Pal, Dan Bahadur, Mishra, Pradeep Kumar, & Upadhyay, Siddh Nath.(2016). Green Synthesis of Silver Nanoparticles: A

- Review. Green and Sustainable Chemistry. Vol.6, pp.34-56

- Sun, K.; Vasudev, M.; Jung, H. S.; Yang, J.; Kar, A.; Li, Y.; Reinhardt, K.; Snee, P.; Stroscio, M.; and Dutta, M.(2009). Applications of Colloidal Quantum Dots. *Microelectronics Journal*.Vol. 40, pp.644–649.

- TEM. (2013). Microscopy and analysis. Retrieved 4 January 2018, from https://microscopy-analysis.com/editorials/editorial-listings/fei-launches-tecnai-femto-ultrafast-transmission-electron-microscope
- UV-Visible spectroscopy. (2014). Slideshare. Retrieved 3 January 2018, from https://www.slideshare.net/krishslide/uv-visible-spectroscopy-39462942

- Vittal, R.; Chuan Ho, Kuo. (2016). Zinc oxide based dye sensitized solar cells. Renewable and sustainable energy reviews (vol.70, pp 920-935). Taiwan: National Taiwan University.

- Wanninayake, W.M.N.M.B., Premartne, K., & Rajapakse, R.M.G. (2017). Photovoltaic performance of SnO2/CaCO3-based dye-sensitized solar cells co-sensitized using metal-free organic dyes. *Journal of Photochemistry and Photobiology A: Chemistry*. Volume346, pp541-547.

- Wang, P., Zakeeruddin, S., Comte, P., Charvet, R., Humphry-Baker, R., & Grätzel, M. (2003). Enhance the Performance of Dye-Sensitized Solar Cells by Co-grafting Amphiphilic Sensitizer and Hexadecylmalonic Acid on TiO_2 Nanocrystals. *The Journal Of Physical Chemistry B*. Vol,107(51), pp.14336-14341.

- Wongcharee, K.; Meeyoo, V.; and Chavadej, S. (2007). Dye-sensitized solar cell using natural dyes extracted from rosella and blue pea flowers. Sol. Energy Mater. Sol. Cells (vol 91, pp566)

- X-ray. (2016). Slideshare. Retrieved 4 January 2018, from https://www.slideshare.net/christophsontag/spectroscopy-xrd

- Yasmin, Akbar, Ramesh, Kumaraswamy, & Rajeshkumar. (2014). Optimization and stabilization of gold nanoparticles by using herbal plant extract with microwave heating. *Nano Convergence*. India

ملخص البحث

الخلايا الشمسية المستحثة بالصبغيات الطبيعية هي نوع من أنواع الخلايا الشمسية الحديثة، تندرج ضمن الجيل الثالث للخلايا الشمسية، فهي خلايا شمسية ذات تكلفة منخفضة وكفاءة جيدة بالإضافة لكونها صديقة للبيئة، في الخلايا الشمسية المستحثة بالصبغيات الطبيعية، تكون الصبغيات هي المصدر الرئيسي للطاقة فهي التي تمتص الفوتونات وتحولها إلى طاقة كهربائية. هناك العديد من الأبحاث المتعلقة بهذا النوع من الخلايا الشمسية ومحاولة تحسين أدائها.

عندما تسقط الفوتونات (الأشعة الشمسية) على الخلية الشمسية فإن الصبغيات تقوم بامتصاصها، مما يؤدي لتأكسد جزيئات الصبغيات، فتنتقل الالكترونات من جزيئات الصبغيات إلى التركيب النانوي لثاني أكسيد التيتانيوم ومن ثم تعبر من خلاله إلى القطب السالب للخلية الشمسية مما يؤدي إلى نشوء تيار وفرق جهد كهربائيان في الحمل الكهربائي.

في هذه الأطروحة تم التركيز على دراسة تركيب الخلايا الشمسية المستحثة بالصبغيات الطبيعية، ومحاولة تحسين أداءها عن طريق دمجها مع جسيمات نانوية من الفضة للحصول على كفاءة أكبر. تم حضير العديد من الخلايا الشمسية باستخدام الصبغيات طبيعية، هذا بالإضافة إلى تحضير جسيمات نانوية بطريقة آمنة بيئيا وسهلة التحضير باستخدام الصبغيات الطبيعية واستخدامها في تلك الخلايا الشمسية. وقد تمت دراسة و تقييم الصبغيات والمواد النانوية بواسطة عدة طرق، منها قياس أطياف الامتصاص والفلورة، وأيضا تم دمج هذه الصبغيات وجسيمات الفضة النانوية داخل الخلايا الشمسية. وكما تم اختبار بنية الأقطاب بواسطة المجهر الالكتروني والأشعة السينية ، وفي الختام تم القيام بالقياسات الكهربائية المعتمدة لتحديد كفاءة الخلية الشمسية المصنعة.

حضرت الخلايا الشمسية المستحثة بالصبغيات الطبيعية والخلايا الشمسية النانوية المدمجة بالصبغيات الطبيعية باستخدام ثاني اكسيد التيتانيوم كطبقة شبة موصلة مع ست صبغيات طبيعية مستخلصة من بتلات الزعفران، وأوراق الميرمية، و أعواد القرفة، وبذور القرنفل، بالإضافة إلى قشور ثمر الرمان و ثمر الجمبولان، من خلال البحث وجد أن أوراق الميرمية وأعواد القرفة هي صبغيات ممتازة في تحضير المواد النانوية، كما أنها ساهمت بتحسين كفاءة الخلايا بشكل مقبول، ووجد أن أفضل كفاءة للخلايا الشمسية التي تم تصنيعها كانت لتلك التي حوت صبغيات لمستخلص أوراق الميرمية وجسيمات الفضة النانوية حيث بلغت 0.11% بينما أفضل عامل ملأ (FF) كان من نصيب أعواد القرفة ومادة الفضة النانوية بنسبة 64.5% .

كشفت قياساتنا التجريبية أن بعض الصبغيات المستخلصة من بتلات الزعفران، أوراق الميرمية، و أعواد القرفة، وبذور القرنفل، بالإضافة إلى قشور ثمر الرمان هي مصدر ممتاز لتحضير الجسيمات النانوية واستخدامها في العديد من التطبيقات. كما أن لبعضها القابلية لتكون مصدر واعد لصبغيات مستخلصة فاعلة في الخلايا الشمسية المستحثة بالصبغيات الطبيعية.

جامعة البحرين

كلية العلوم

قسم الفيزياء



تحضير واختبار وتطبيقات الجسيمات المعدنية النانوية في الخلايا الشمسية المستحثة بالصبغيات الطبيعية

أطروحة مقدمة كجزء من متطلبات الحصول على درجة الماجستير

في الفيزياء التطبيقية

إعـــــــداد

فاطمه جابر الجبوري

الرقم الجامعي: 20100847

إشـــــــراف

د.خليل إبراهيم جاسم / أستاذ مساعد

جامعة البحرين

د. فرياد زكي هنارى / أستاذ مشارك في الفيزياء

جامعة البحرين الطبية

مملكة البحرين

مايو 2018