COMPUTATIONAL PROCESS DESIGN, OPTIMIZATION AND GROWTH OF ZINC OXIDE NANOSTRUCTURES ON GRAPHENE BY ULTRASONIC SPRAY PYROLYSIS

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DEDICATION

To the Soul of my uncle,
To my beloved mother and father,
To Safy, Dalia and Xiyan,
To my blessed country: Egypt.

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ABSTRACT

Computational process design, optimization, growth, characterization and computational analysis of zinc oxide (ZnO) nanostructures grown on graphene using zinc acetylacetonate ($Zn(acac)_2$) in the presence of hydrogen by ultrasonic spray pyrolysis were performed systematically. The dissociation of Zn ions from vapour-phase $Zn(acac)_2$ and its adsorption onto graphene oxide were studied using quantum mechanics approach involving the use of Density Functional Theory (DFT). The reaction energies were calculated, and the proposed reaction mechanism was well supported by a simulation of infrared properties. Next, Response Surface Methodology (RSM) was used to model and optimize the pyrolysis parameters by evaluating the nanostructure density, size and shape factor. The evolution of ZnO structures was well explained confirming that RSM is a reliable tool for the modelling and optimization of the pyrolysis parameters and prediction of nanostructure sizes and shapes. Finally, a computational analysis of the measured optical and charge transport properties of the grown nanostructures, i.e. Nanosphere Clusters (NSCs), Nanorods (NRs) and Nanowires (NWs) were developed. The calculated absorbance spectra based on the time-dependent DFT showed very close similarity with the measured behaviours. The atomic models and energy level diagrams were developed and discussed to explain the structural defects and band gap. As a conclusion it was found that the induced stress in the ZnO NSCs is the cause of gap narrowing between the energy levels. ZnO NWs and NRs showed homogeneous distribution of the Lowest Unoccupied Molecular Orbitals (LUMO) and Highest Occupied Molecular Orbitals (HOMO) orbitals all over the entire heterostructure which results to the reduction of the band gap. The calculated band gaps are confirmed to be in a good agreement with the experimental results. The electrical models and electrostatic potential maps were able to calculate the electron life time and to explain the mobility and diffusion behaviours of the grown nanostructures, respectively.

ABSTRAK

Proses reka bentuk secara pengkomputeran, pengoptimuman, pertumbuhan, pencirian dan analisis secara pengkomputeran telah dijalankan secara sistematik bagi pertumbuhan struktur nano zink oksida (ZnO) pada grafin menggunakan zink asetilasetonat (Zn(acac)$_2$) dengan kehadiran hidrogen oleh teknik semburan pirolisis ultrasonik. Pemisahan ion Zn dari fasa wap Zn(acac)$_2$ dan penjerapannya pada grafin oksida dikaji menggunakan pendekatan mekanik kuantum melibatkan penggunaan Teori Fungsi Ketumpatan (DFT).Tenaga tindakbalas telah dikira dan mekanisma tindakbalas yang dicadangkan telah disokong baik oleh simulasi sifat-sifat inframerah. Seterusnya, Kaedah Tindakbalas Permukaan (RSM) digunakan untuk memodelkan dan mengoptimumkan parameter pirolisis dengan menilai ketumpatan, saiz dan faktor bentuk nanostruktur. Evolusi struktur ZnO telah diterangkan sebaiknya mengesahkan bahawa RSM adalah alat yang dipercayai untuk pemodelan dan pengopmimuman parameter pirolisis dan anggaran saiz dan bentuk nanostruktur. Akhirnya, analisis pengkomputeran bagi sifat optik dan pengangkutan zarah bercas yang dikira bagi pertumbuhan nanostruktur seperti Kluster Nanosfera (NSCs), Nanorod (NRs) dan Nanowayar (NWs) telah dibangunkan. Spektra penyerapan yang dikira berdasarkan pada penggantungan masa DFT menunjukkan persamaan yang sangat dekat dengan perilaku yang dikira. Model atom dan gambar rajah aras tenaga telah dibangunkan dan dibincangkan untuk menerangkan kecacatan struktur dan jurang jalur. Sebagai konklusi didapati bahawa, tekanan teraruh di dalam NSCs ZnO adalah disebabkan jurang yang semakin sempit antara aras tenaga. NWs dan NRs ZnO menunjukkan pengedaran homogen bagi Orbital Terendah tidak Dihuni Molekul (LUMO) dan Orbital Tertinggi Dihuni Molekul (HOMO) pada seluruh heterostruktur yang mengakibatkan pengurangan pada jurang jalur. Jurang jalur yang dikira adalah disahkan berada dalam persetujuan yang baik dengan keputusan eksperimen. Model elektrik dan peta potentsi elektrostatik masing-masing boleh dibangunkan untuk mengira jangka hayat elektron dan untuk menerangkan pergerakan dan perilaku penyebaran bagi pertumbuhan nanostruktur.

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LIST OF ABBREVIATIONS

1D	-	One dimensional
2D	-	Two dimensional
Au	-	Gold
CMOS	-	Complementary metal-oxide semiconductor
CNT	-	Carbon nanotube
Cu	-	Copper
CVD	-	Chemical vapour deposition
DI	-	Deionized
DLE	-	Deep level emission
EDX	-	Energy dispersive X-ray
FESEM	-	Field emission scanning electron microscope
FWHM	-	Full width half maximum
GaAs	-	Gallium arsenide
GaN	-	Gallium nitride
Ge	-	Germanium
GOI	-	Ge-on-insulator
He-Cd	-	Helium-cadmium
HMTA	-	Hexamethylenetetramine
i-SOC	-	Intelligent technology system-on-chip
LED	-	Light emitting diode
ML	-	Multilayer
MOVPE	-	Metal organic vapour phase epitaxy
NBE	-	Near band edge
O_2	-	Oxygen
OH^-	-	Hydroxide
PL	-	Photoluminescence
Pt	-	Platinum

RT	-	Room temperature
Si	-	Silicon
SiC	-	Silicon carbide
Si-LSIs	-	Silicon-large scale integrated circuits
SiO_2	-	Silicon dioxide
SL	-	Single layer
ST	-	Set temperature
TEM	-	Transmission electron microscope
ULSIs	-	Ultra large scale integrated circuits
UV	-	Ultraviolet
XRD	-	X-ray diffraction
Zn	-	Zinc
$Zn(NO_3)_2.6H_2O$	-	Zinc nitrate hydroxide
ZnO	-	Zinc oxide

LIST OF SYMBOLS

a	-	Basic vector of the triangular Bravais lattice
$Å$	-	Angstroms, 1Å = 1 x 10^{-10} m
b	-	Regression coefficient
$°C$	-	Degree Celsius
cm	-	Centimetre
cm^2/Vs	-	Square centimeter per volt second
d_P	-	atomized spray droplet size
e	-	Statistical fitting error
eV	-	Electron volt
$E_{XC}(\rho)$	-	Exchange-correlation energy functional
GHz	-	Gigahertz
I_N	-	Power surface intensity of sonicator
M	-	Molarity of precursor solution
$mAh\ g^{-1}$	-	Mili amper hour per gram
nm	-	Naonometre
m^2/g	-	Square metre per gram
mA/cm^2	-	Miliampere per square centimetre
meV	-	Mili-electron volt
ms^{-1}	-	Metre per second
mW	-	Miliwatt
n	-	An integer 1, 2, 3 (usually equal to 1)
N	-	Corresponding number of carbon chain
nm	-	Nanometre
Oh	-	Ohnesorge number
Q	-	Liquid precursor flow rate
r	-	Nanostructure size (radius)
r_i	-	Distance between charged particle and atom center

S_t	-	Stokes number
t	-	Injection time
T	-	Substrate temperature
U	-	Carrier gas flow rate
Wac	-	Width for armchair
W/mK	-	Watt per metre per Kelvin
wt%	-	Weight percent ratio
Wzz	-	Width for zigzag
χ	-	Independent parameters
y_i	-	Taylor's function response
Zn^{2+}	-	Zinc dication
α	-	Significance level
ψ_I	-	Slater tensor of orthonormal orbitals
$\psi_{i\sigma}$	-	Occupied spin orbitals
δ	-	Lattice vector
ε_p	-	Electrostatic potential
φ	-	Nanostructure shape factor
φ_i	-	Basis set function
λ	-	Wavelength in angstroms
μm	-	Micrometre
v_{ext}	-	External nuclear potential
θ	-	Diffraction angle in degrees
ρ	-	Droplet density
ρ^{spin}	-	Spin density
ρ^{α}	-	Electron density formed by electrons of α spin
ρ^{β}	-	Electron density formed by electrons of β spin
σ	-	Surface tension
ζ	-	Nanowire density

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CHAPTER 1

INTRODUCTION

1.1 Research Background and Motivation

According to the Moore's law, the capability of silicon-large scale integrated circuits (Si-LSIs) was improved over the last three decades by increasing the population of transistors on the substrate [1, 2]. The most recent processors contain over a billion transistors. A remarkable enhancement for the efficiency of the ultra large scale integrated circuits (ULSIs) was achieved by following a scaling-up routine for the silicon (Si) transistor. However, further enhancement of the efficency of the LSIs turn out to be more complicated as a result of the transistors contraction (which is attributed to physical limitations) [3].

Advanced heterogeneous integration on Si platform has recently attracted great attention towards the understanding of a so-called "More than Moore" technology. This approach is mainly devoted to the growth of high quality elements (i.e. germanium (Ge) [4, 5]) and semiconductors based compounds such as gallium arsenide (GaAs) [6-8], gallium nitride (GaN) [9-12] and silicon carbide (SiC) [13], as well as metal oxides (i.e. zinc oxide (ZnO) [14, 15] and carbon based materials such as graphene [13, 16, 17] and carbon nanotube (CNT) [18-20] on Si platform. In fact, the cointegration of such materials led to the present ULSIs with ultra-high speed complementary metal-oxide semiconductor (CMOS) transistors [20, 21] in addition to various kinds of functional devices as optical devices [22-24], photodetectors [25-27], sensors and solar batteries [28]. Thus, such Si based intelligent system-on-chip (i-SoC) is considered to be promising.

The Si based system-on-chip technology is considered as a new generation technology. This is ascribed to its ability to present more capable and practical routes of development of electronic devices. An insulator that electronically isolates the functional materials from the Si substrate found to be essential for producing electronic devices. In accordance to this context, various researches reported the growth of high quality Ge-on-insulator (GOI) [29, 30], graphene-on-insulator [31-33], GaAs-on-insulator [8, 33-35], SiC-on-insulator [36-38] and ZnO-on-insulator structures [39]. Figure 1.1 illustrates the evolution of the Si based nano-electronics device. The integration of devices on Si platform in the way shown in figure was reported to improve the functionality, the quality and the efficiency of the device system.

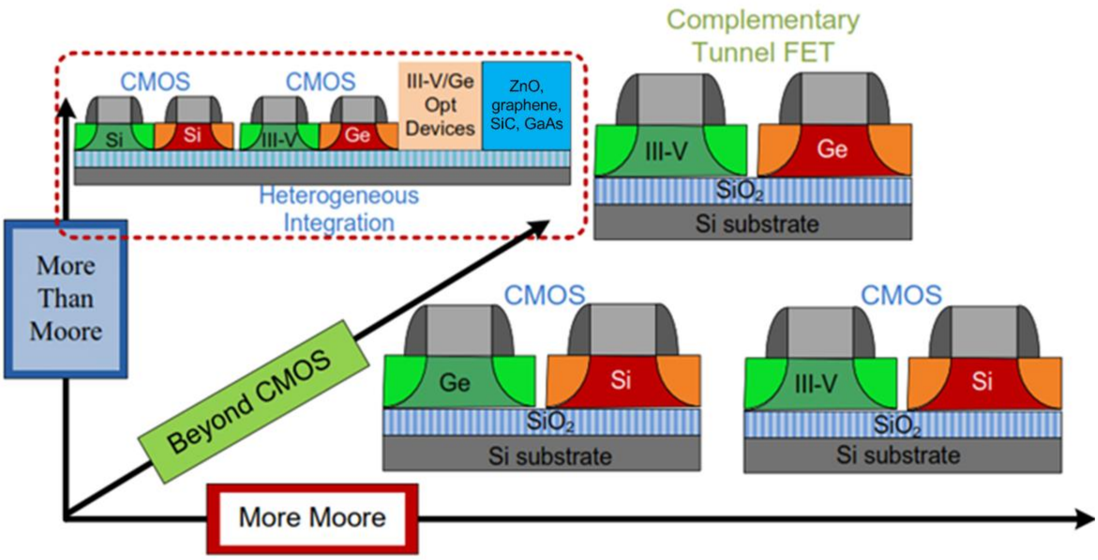

Figure 1.1 Evolution of Si-based nanoelectronics [40, 41]

Modern electronic devices are much depending on transparent conductive thin films (TCFs). Many applications are currently using TCFs such as field emission displays, sensors, thin film transistors solar cells, touch panels, electrostatic dissipation, and transparent electrodes for optoelectronic devices [42]. In fact, the development of alternative materials for such applications is taking place. For instance, the optically transparent and electrically conductive material Indium-Tin-Oxide (ITO) exhibits a sheet resistance and light transmittance that is meeting the standard requirement. However, ITO is not maintaining sufficient flexure stiffness.

Researchers have succeeded in preparing TCFs with single-walled carbon nanotubes (SWCNT) [43-45].

Recently, graphene nanosheets (GNS) were discovered, which can be obtained by the reduction of graphene oxide (GO). Two-dimensional (2D) sheet of sp2-hybrized carbons known as graphene has attracted great attention because of its exceptional optical, electrical, chemical and mechanical properties that imposes promising ability for developing new generation of functional nanomaterials for various applications [1-3]. A lot of research on graphene has stimulated the development of high-quality graphene for optoelectronic devices [1]. An ideal monolayer of graphene has an excellent light transmittance and conductivity at room temperature. Such optoelectronic properties suggest graphene as a promising material for flexible transparent conductor [3]. Lately, various methods were reported for growing graphene for large area production. Chemical vapour deposition (CVD) is the most used method for preparing high quality large-area monolayer graphene. Such method can control thickness of deposited layers for possible application as transparent conductors. Generally, GNS are found to be more conductive, flexible and less expensive than ITO or SWCNTs for transparent electrode applications [2].

Concerning the targeted applications, there have been huge exerted efforts to control and modify the properties of graphene through various functionalization routes [46-49]. The combination of various types of materials can lead to development of new generations of materials that have tailored properties suitable for new optoelectronic applications, which is beyond the ability of the individual materials. Thus decorating two-dimensional (2D) graphene with one-dimensional (1D) semiconductor nanostructure phase can result in a three-dimensional (3D) multifunctional conductor. It was reported in different studies the preparation of 1D-2D hybrid architectures (HAs) composed of regular arrays of nanorods such as zinc oxide, silver, platinum, palladium and gold formed on graphene layers. The 1D-2D HAs exhibited outstanding electrical conductivity, optical transparency, and mechanical flexibility, comparable to those of graphene. There are few studies that compare the effect of the metallic nano-rods material on the property of the multifunctional conductor [46-49].

Nanowires as prolonged nanostructures have privileges over other nanostructures. For instance, their electrical transport properties are much better than those of nanoparticles because of the extended transport surface area of nanowires. Besides, the optical reflectance of the nanorods is less than thin films thus, significantly their absorption of light increases, which is particularly interesting for photovoltaic and photon-induced hydrophillicity applications [50, 51]. Furthermore, much research has been conducted for developing semiconducting material/graphene hybrid structures either by vapour-phase [52-54] or liquid-phase techniques [55-57]. Since the past few decades, ZnO nanostructures have been thoroughly considered in many works for optoelectronic and photovoltaic device applications [58-61]. Recently, it has been reported that ZnO/graphene hybrid nanostructure has excellent potential to be used for transparent flexible electrical and optical devices, including flexible photovoltaics, displays, and light emitters [62-64].

1.2 Problem Statement

Majority of literatures are reporting on ZnO/graphene hybrid structures focus on the discussion of the structural morphologies [48]. Very few researches focused on the optimization of the process parameters [65, 66]. In fact, there is no report on the statistical modelling and subsequent optimization of the growth of ZnO nanowires on graphene using ultrasonic spray pyrolysis (UASP). Most of experimental design in such field is based on single factor design that leads to data waste, excessive precursor consumption and longer growth time in addition to lack of reproducibility upon scaling-up reactions. Thus, the effect of process parameters on the grown structures are not yet clear, for instance, the effect of the process parameters on ZnO density, shape and size of grains is not clearly reported. Furthermore, the ultrasonic assisted spray pyrolysis is mentioned mostly in articles for film deposition, however very scarce articles targeted the process ability for depositing other ZnO nanostructures. Thus, there is a need to clarify the capability of the process to deposit other categories of ZnO nanostructures such as quantum dot, nanowires and any other possible structures.

In order to suit graphene for optoelectronic devices, research works have been carried out to develop graphene based materials hybrid with semiconducting structures through various processes such as vapour-phase [52-54] or liquid-phase deposition techniques [55-57]. The vapour-phase deposition of ZnO using β-diketonates such as acetylacetonate as the Zn precursor was reported as a promising route to grow ZnO nanostructures [67, 68]. However, most studies on ZnO/graphene hybrid structures have focused on their structural morphologies and electronic properties [69], whereas few have paid attention to the reaction mechanisms of the semiconducting species at reaction sites on the graphene surface [65, 70]. There is no report to date on the reaction mechanisms of the vapour-phase deposited ZnO onto graphene utilizing acetylacetonate as a Zn source. In the current research, the possible reaction mechanisms that take place during the deposition of ZnO on graphene based substrates are investigated.

In this study, the growth of ZnO nanowires onto graphene as insulator using a low-temperature ultrasonic assisted spray pyrolysis technique was done. It is a simple and potentially industrially scalable process due to the abundance and stability of the precursors, and the low maintenance and set-up costs involved in scaling-up the process. Besides, it allows the deposition of homogeneous metal oxide phases, endowed with excellent physical properties for several applications. In addition, this work aimed to investigate the capability of the ultrasonic assisted spray pyrolysis for the deposition of every possible ZnO structure on graphene layer. Statistical modelling was used in correlation to multi-factorial experimental design to investigate the impact of the parameters of the process on the density, size and shape of the grown ZnO.

The injection of zinc acetylacetonate in the presence of either alcohol or hydrogen was studied, which are the main deposition routes using spray pyrolysis as found in literature [71, 72]. Quantum chemistry calculation approach is used to identify the most favoured route from the point of view of reaction kinetics taking in consideration the reduction of deposition temperature. Finally, various characterization techniques such as energy dispersive X-ray spectroscopy (EDX), fourier transform infrared spectroscopy (FTIR), field emission electron microscopy (FESEM) and energy dispersive spectroscopy (EDS) were used to investigate the structures morphology. Photoluminescence (PL) measurements, UV/Visible spectroscopy and electrochemical impedance (EIS) were used in combination with density functional theory calculations (DFT) (in the excited state of matter) to investigate the optoelectronic properties of the synthesized hybrid material.

1.3 Objectives of the Study

The objective of the present study is to prepare and characterize graphene based heterogeneous material hybrid with different ZnO nanostructures (mainly nanowires) for optoelectronic applications using ultrasonic assisted spray pyrolysis from liquid precursors. The objective can be divided into the following sub-objectives:

1. To propose growth mechanism using quantum chemistry calculation approach.
2. To design and construct a homemade ultrasonic assisted spray pyrolysis system.
3. To grow ZnO nanowires onto graphene layer and investigate the capability of the process to grow other ZnO nanostructures on graphene layer.
4. To optimize the deposition parameters and develop a statistical model to predict the growth rates and reaction kinetics using response surface method (RSM).

5. To investigate the optical and charge transport properties of the obtained structures using analytical and materials research aspects.

1.4 Scope of the Study

To achieve the objective of this study, the work was performed in three phases; i) Identify the favoured route for deposition of ZnO nanostructures on graphene layer from point of view of reaction kinetics using quantum chemistry approach, ii) grow ZnO nanowires on graphene layer, iii) Optimize the process of growth of ZnO nanostructures on graphene layer and iv) characterize the obtained samples. Figure 1.2 presents a flow chart summarizing the scope of this study. The details of the scope of the present study cover the following stages:

1. Preparation of deposition mixtures of various precursors-solvents mixing ratios.
2. Deposition of ZnO nanostructures on graphene layers under various reaction conditions.
3. Establishing the effects of deposition conditions on the ZnO growth rates and reaction kinetics.
4. Optimization of the growth reaction parameters using RSM.
5. Determination of various opto-electerical properties of the prepared conductor as well as investigating its morphology.

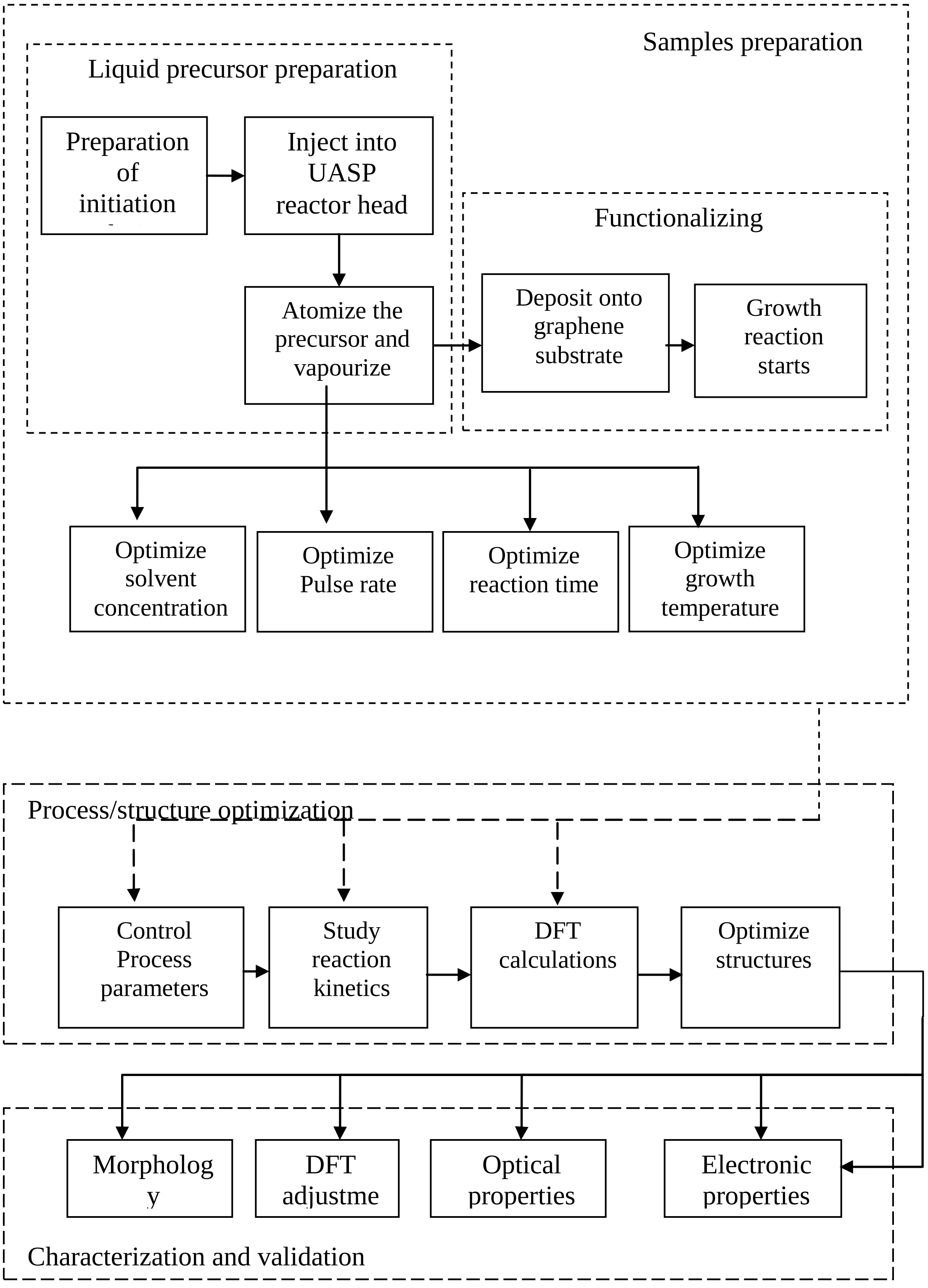

Figure 1.2 Flow chart summarizing the scope of work

1.5 Contribution of the Present Work

The main contribution of the present study can be divided into 3 major parts. The first part comprises of verifying the ability of the UASP process to deposit various ZnO nanostructures on SL graphene at relatively low substrate temperatures (134 – 355 °C) as well as establishing the growth rates and kinetics for all obtained structures using statistical tools. On the other hand, the second part of the contribution is identifying the favoured reaction pathway and the optimized geometries of transitions, intermediates and products by investigating the chemistry of possible pyrolysis routes and its corresponding reaction mechanisms using quantum chemistry approach. Lastly, the last part of the contributions is attributed to the exploration of optical properties of the ZnO/graphene hybrid structures as well as establishing the transport mechanisms of the charged particles through the obtained structures.

1.6 Overview of Thesis Organization

This thesis is structured on 6 chapters. First chapter highlights the overview of the research background and motivation of the past and current work on the growth of ZnO nanostructures on graphene. Besides, the research objectives and scopes are also included. Second chapter includes the overview of the main properties of ZnO and graphene. Furthermore, a brief description about the methods reported for growing ZnO on the graphene is included. Various research works on the impact of the morphology of different ZnO nanostructure on the optoelectronic properties of ZnO/graphene heterogeneous materials are briefly presented in chapter 2. The function of graphene as a buffer layer is also highlighted. Moreover, an overview of the use of ultrasonic assisted spray pyrolysis process to grow ZnO nanostructures on graphene is also included. Finally, the potential applications of ZnO on the graphene regarding the development of optoelectronic devices are also discussed in this chapter.

The third chapter of this thesis contains a brief discussion about the properties of the substrates used in this study. The group of materials, chemicals and equipment used throughout the entire research work are also listed in this chapter. The density functional theory approach in addition to other quantum chemistry calculations is discussed and the possible reaction mechanism of pyrolysis is presented as well. Furthermore, the aspects of multi factorial experimental design were presented, where RSM experimental design approach is followed. Finally, the ultrasonic assisted pyrolysis process is discussed in relation to reactor design and the main process parameters are clarified as well.

The fourth chapter of the thesis presents the results of the DFT study of the dissociation mechanisms of either zinc ions (Zn^{2+}) or ZnO from vapour-phase zinc acetylacetonate, $Zn(C_5H_7O_2)_2$ and its adsorption onto graphen layer. Moreover, the gas-phase reactions followed during the deposition of zinc oxide on graphene to produce ZnO/graphene composite had been investigated using two different routes. The energies of reactants, transition states and products were calculated and the reaction mechanisms were presented also.

The fifth chapter of this thesis includes a discussion about the experimental design and the results of the RSM modelling. The impact of the process parameters on the nanostructures density, size and shape is thoroughly discussed. The growth rates and reaction kinetics are also presented in this chapter. Furthermore, the structural morphology of ZnO nanostructures is systematically characterized. The involved growth mechanism is studied and described.

The sixth chapter of this thesis includes the discussion about the optoelectronic properties of the grown structures. UV/Visible spectra as well as PL spectra were presented in addition to DFT results to investigate the optical properties of the grown structures. Moreover, EIS results in correlation to quantum chemistry calculations of the electrostatic potential were presented to explain the electronic behaviour of the grown structures. Finally, the seventh chapter of this thesis includes conclusive remarks in addition to the contributions of present work and discussion about future research work and possible study extensions.

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APPENDIX A

Publications Related to this work

1. **Amgad Ahmed Ali Ibrahim**, Abdul Manaf Hashim, "Density Functional Theory Study of Atomic Layer Deposition of Zinc Oxide on Graphene", *Nanoscale Res Lett,* 2015. 10:299. (Impact Factor 2014: 2.781, ISI Thomson Reuters Indexed)
2. **Amgad Ahmed Ali Ibrahim**, Abdul Manaf Hashim, "Statistical modelling and optimization of the growth of ultra-thin zinc oxide nanorods on graphene using ultrasonic spray pyrolysis", *Nanoscale Res Lett,* 2015. Accepted. (Impact Factor 2014: 2.781, ISI Thomson Reuters Indexed)
3. **Amgad Ahmed Ali Ibrahim,** Abdul Manaf Hashim, "Evolution of ZnO nanowires based bird of paradise flower meso-structure: synthesis and optoelectronic properties", *Nanoscale Res Lett,* 2015. Accepted. (Impact Factor 2014: 2.781, ISI Thomson Reuters Indexed)
4. **Amgad Ahmed Ali Ibrahim,** Abdul Manaf Hashim, "Computational analysis of the optical and charge transport properties of ultrasonic spray pyrolysis grown zinc oxide/graphene hybrid structures", *Nanoscale Res Lett,* 2015. Accepted. (Impact Factor 2014: 2.781, ISI Thomson Reuters Indexed)

Publications Related to other work

1. Freddawati Rashiddy Wong, **Amgad Ahmed Ali Ibrahim**, Kanji Yasui, Abdul Manaf Hashim, "Seed/Catalyst-Free Growth of Gallium-Based Compound Materials on Graphene on Insulator by Electrochemical Deposition at Room Temperature", *Nanoscale Res Lett,* 2015. 10:223. (Impact Factor 2014: 2.781, ISI Thomson Reuters Indexed).

2. Mohamed Mahmoud Nasef, Amgad Ahmed Ali Ibrahim, Hamidani Saidi, Arshad Ahmad, "Modelling and optimization aspects of radiation induced grafting of 4-vinylpyridene onto partially fluorinated films", Rad Phys Chem, 2015. 94:1. (Impact Factor 2014: 1.38, ISI Thomson Reuters Indexed).

International Conferences

Main research

1. **Amgad Ahmed Ali Ibrahim**, and Abdul Manaf Hashim, "act of Density Functional Theory as a Tool for Process Design and Pre-Characterization of ZnO Growth on Graphene", *8th International conference on materials for advanced technology ICMAT,* 28 June -3 July 2015, Singapore.

2. **Amgad Ahmed Ali Ibrahim**, and Abdul Manaf Hashim, "Growth of Zinc Oxide Nanostructures on Graphene by Ultrasonic Assisted Spray Pyrolysis and Its Modelling", *8th International conference on materials for advanced technology ICMAT*, 28 June -3 July 2015, Singapore.

3. **Amgad Ahmed Ali Ibrahim**, and Abdul Manaf Hashim, "Growth of Zinc Oxide Nanostructures on Graphene by Ultrasonic Assisted Spray Pyrolysis and Its Modelling", *27th Regional Conference on Solid State Science and Technology RCSSST27,* 20-22 December 2013, Kota Kinabalu, Malaysia.