UNIVERSITI PUTRA MALAYSIA

PHYSICAL PROPERTIES OF ZnSe AND CdSe SEMICONDUCTOR NANOPARTICLES SYNTHESIZED BY THERMAL TREATMENT AND GAMMA IRRADIATION ROUTES

AESHAH NIZAR SALEM

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By

AESHAH NIZAR SALEM

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Doctor of Philosophy

December 2016

DEDICATIONS

To my mother and father,

--- and ---

My lovely husband Salman,

My sisters and brothers,

For their great patience and encouragement

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the Degree of Doctor of Philosophy

PHYSICAL PROPERTIES OF ZnSe AND CdSe SEMICONDUCTOR NANOPARTICLES SYNTHESIZED BY THERMAL TREATMENT AND GAMMA IRRADIATION ROUTES

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December 2016

Chairman : Professor Elias Saion, PhD
Faculty : Science

Several methods have been utilized previously to synthesize metal chalcogenide nanoparticles with enhanced chemical and physical properties. However, most of these methods have used a complicated procedure, longer reaction times, and employed toxic reagents of expensive materials. Current study employed two physical methods, the thermal treatment to synthesis pure ZnSe and CdSe semiconductor nanoparticles and their $(Cd_{0.5}Zn_{0.5})Se$ nanocomposite under a constant N_2 gas flow. Gamma radiation method was used to prepare pure ZnSe and CdSe semiconductor nanoparticles.

For the first method, an aqueous solutions of metal nitrate at different concentrations were mixed with 2 g of PVP, ethylenediamine(en) as a solvent of Se and deionized water as a solvent were prepared at calcination temperatures of 450-700°C. The samples were characterized by TGA, FTIR, EDX, XRD, TEM, and UV-Vis. FTIR analysis results confirmed the removal of organic matters and the presence of semiconductor nanoparticles at calcination temperatures 450-700°C. The elemental composition of the samples obtained by EDX spectroscopy has further evidence that the formation of ZnSe and CdSe nanoparticles and their nanocomposites. It was found that the phase formations of ZnSe and CdSe nanoparticles were cubic and hexagonal face-centered, respectively. The TEM images confirmed the increment of particle size from 12 to 26 nm for ZnSe and from 6 to 37 nm for CdSe and as well as from 12 to 24 nm for $(Cd_{0.5}Zn_{0.5})Se$ nanocomposites due to elevated calcination temperature and material concentration. The particle size of nanocrystals was also determined from XRD spectra. The estimated average sizes in the range 10.5-24 nm for ZnSe, 6-33 nm for CdSe nanoparticles and 10.5-25 nm for $(Cd_{0.5}Zn_{0.5})Se$ nanocomposites. While the optical properties were measured using UV-Vis spectrometer and the band gap ranged (3.956-4.158), (2.31-3.69) and (2.24-3.71) eV for ZnSe, CdSe and $(Cd_{0.5}Zn_{0.5})Se$ nanostructures, respectively.

ZnSe and CdSe semiconductor nanoparticles were also synthesized using a single-step radiolytic approach in aqueous solution containing metal sulfite were mixed with 2 g of PVP, ethylenediamine(en), deionized water, and IPA alcohol under irradiation with Co-60 gamma rays at dose of 120 kGy. The hydrate electrons created in water are responsible for the formation of CdSe and ZnSe nanoparticles. The final samples were characterized by EDX, XRD, TEM, and UV-Vis. The X-ray powder diffraction patterns reveal successful hexagonal crystal structure for both CdSe and ZnSe nanoparticles, with the average crystallite sizes of 16.3 and 10.7 nm, respectively. The EDX was used to confirm the stoichiometric elemental composition of Zn, Cd and Se in the samples. The TEM micrograph shows that CdSe and ZnSe nanoparticles are spherical in shape, with an average diameter of 17.3 and 11.2 nm, respectively. The optical band gaps determined from UV-Visible absorption spectra are between 2.87 and 3.58 eV for the CdSe and ZnSe nanoparticles, respectively.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Doktor Falsafah

CIRI FIZIKAL NANOPARTIKEL SEMIKONDUKTOR ZnSe DAN CdSe DISINTISIS DENGAN KAEDAH RAWATAN HABA DAN SINARAN GAMA

Oleh

AESHAH NIZAR SALEM

Disember 2016

Pengerusi : Profesor Elias Saion, PhD
Fakulti : Sains

Beberapa kaedah telah digunakan sebelum ini untuk mensintesis logam nanopartikel chalcogenide yang dipertingkatkan dan ciri-ciri fizikal dan kimianya. Walau bagaimanapun, kebanyakan kaedah-kaedah ini telah menggunakan prosedur yang rumit, masa tindak balas lebih lama, dan menggunakan bahan reagen toksik yang mahal. Kajian ini menggunakan dua kaedah fizikal iaitu rawatan haba untuk sintesis nanopartikel semikonduktor tulin ZnSe dan CdSe serta nanokomposit (Cd0.5Zn0.5)Se di bawah aliran gas N2 yang berterusan. Kaedah sinaran Gamma telah juga digunakan untuk menyediakan nanopartikel semikonduktor tulin ZnSe dan CdSe.

Bagi kaedah pertama, satu larutan akueus nitrat logam pada kepekatan yang berbeza telah bercampur dengan 2 g PVP, ethylenediamine (en) sebagai pelopor Se dan air ternyahion sebagai pelarut dan disediakan pada suhu pengkalsinan 450-700 °C. Sampel telah dicirikan menggunakan TGA, FTIR, EDX, XRD, TEM dan UV-Vis. Keputusan analisis FTIR mengesahkan penyingkiran bahan organik dan kehadiran nanopartikel semikonduktor pada suhu pengkalsinan 450-700 ° C. Komposisi unsur sampel yang diperolehi oleh spektroskopi EDX mempunyai bukti bahawa pembentukan nanopartikel ZnSe dan CdSe dan nanokomposit mereka. Ia telah mendapati bahawa pembentukan fasa nanopartikel ZnSe dan CdSe adalah padu dan heksagon berpusat muka, masing-masing. Imej-imej TEM mengesahkan peningkatan saiz zarah dari 12 kepada 26 nm untuk ZnSe dan dari 6 kepada 37 nm untuk CdSe dan juga dari 12 hingga 24 nm untuk nanokomposit $(Cd_{0.5}Zn_{0.5})$ Se disebabkan oleh suhu pengkalsinan yang tinggi dan kepekatan bahan. Saiz zarah nanokristal telah juga ditentukan dari spektrum XRD. Saiz purata dianggarkan dalam nm dalam julat 10.5-24 untuk nanopartikel ZnSe, 6-33 nm untuk nanopartikel CdSe dan 10.5-25 nm untuk nanocomposites (Cd0.5Zn0.5)Se. Walaupun ciri-ciri optik diukur dengan menggunakan spektrometer UV-Vis dan julat jalur adalah di antara (3.956-4.158), (2.31-3.69) dan (2.24-3.71) eV untuk semi konduktur ZnSe, CdSe dan nanokomposit (Cd0.5Zn0.5) Se, masing-masing.

Nanopartikel semikonduktor ZnSe dan CdSe juga disintesis menggunakan pendekatan radiolytic radiasi dalam satu langkah menggunakan larutan akueus yang mengandungi logam sulfit yang telah bercampur dengan 2 g PVP, ethylenediamine (en), air ternyahion, dan alkohol IPA di bawah sinaran gama sumber Co-60 pada dos 120 kGy. Elektron hidrat yang tercipta di dalam air adalah bertanggungjawab untuk pembentukan nanopartikel CdSe dan ZnSe. Sampel akhir telah dicirikan menggunakan EDX, XRD, TEM dan UV-Vis. Corak serbuk pembelauan X-ray mendedahkan struktur kristal heksagon berjaya untuk kedua-dua nanopartikel CdSe dan ZnSe, dengan saiz purata kristal 16.3 dan 10.7 nm, masing-masing. The EDX telah digunakan untuk mengesahkan komposisi unsur stoikiometri Zn, Cd dan Se dalam sampel. Mikrograf TEM menunjukkan bahawa nanopartikel CdSe dan ZnSe adalah berbentuk bulat, dengan diameter purata 17.3 dan 11.2 nm, masing-masing. Jurang jalur optik ditentukan daripada spektrum penyerapan UV-nyata adalah di antara 2.87 dan 3.58 eV bagi nanopartikel CdSe dan ZnSe, masing-masing.

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Last but not least, I would like to thank the staff and lecturers of Universiti Putra Malaysia for their continuous help throughout my study. Thank You.

I certify that a Thesis Examination Committee has met on 22 December 2016 to conduct the final examination of Soheil Roknideilami on his thesis entitled "Solar Tracking System Utilizing Sun Position Sensor with Precision Angle Control" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

Members of the Thesis Examination Committee were as follows:

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Date: 28 February 2017

This thesis was submitted to the Senate of the Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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Declaration by graduate student

I hereby confirm that:

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- this thesis has not been submitted previously or concurrently for any other degree at any institutions;
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This is to confirm that:

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Name of Chairman of Supervisory Committee: Professor Dr. Elias Saion

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Name of Member of Supervisory Committee: Professor Dr. Abdul Halim Shaari

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Signature: ______________________
Name of Member of Supervisory Committee: Professor Dr. Shahidan Radiman

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LIST OF ABBREVIATIONS

K.M	Kubelka-Munk
DI	Deionized water
NPs	Nanoparticles
NCs	Nanocomposites
SEM	Scanning electron microscopy
Nm	Nanometre
eV	Electron volte
θ	Bragg angle
h	Hour
min	Minutes
E_g	Optical band gap
^oC	Degree Celsius
λ Wavelength	Wavelength
D	Diameter
T	Transmittance
Λν	Energy
B	FWHM
ZnSe	Zinc selenide
CdSe	Cadmium selenide
Å	Lattice parameter
EDX	Energy dispersive X-Ray
TEM	Transmission electron microscopy
FTIR	Fourier transforms infrared spectroscopy
XRD	X-ray diffraction
TGA	Thermo gravimetric analysis

CHAPTER 1

INTRODUCTION

1.1 Introduction

In 1959, the American physics professor and Nobel laureate Richard Feynman proposed a ground-breaking foundation of nanoscience and nanotechnology in his lecture “There is Plenty of Room at the Bottom” (Feynman, 1959). Nowadays, it forms the fundamental of new science and engineering from the basic sciences of physics and chemistry to their applications in materials science, electronics, biology, medicine, pharmaceutical and many engineering fields. There are a variety of definitions of nanoscience and nanotechnology. In general, nanoscience is the study of physical and chemical phenomenon exhibited by nanomaterials, while nanotechnology involves the design, production, characterization, and applications of nanomaterials (Saini *et al*., 2010). Materials at the nanoscale dimension (1-100 nm) are known as nanomaterials, which are distinctly different from their atom or molecule and bulk counterparts. Nanomaterials possess increased surface-to-volume ratio in such a way that the surface atoms become dominant and so their three-dimensional quantum confinement electrons (Boles *et al*., 2016). The most studied nanomaterials are metal nanoparticles and semiconductor nanoparticles. The surface electrons regulate the quantum effects that influence the non-linear optical property of semiconductor nanoparticles in electro-optical devices and the chemical property of metal nanoparticles in catalysis.

This thesis encompasses the synthesis and characterization of Group II-IV semiconductor nanoparticles, in particular ZnSe and CdSe nanoparticles. They can be synthesized by a variety of methods including hydrothermal, chemical, sonar-chemicals, microwave, micro emulsion, and sol-gel (Aiken and Finke, 1999). The thermal treatment method has been used to prepare several oxide nanomaterials in our laboratory, such as metals ferrite nanoparticles (Nasri *et al*., 2010), ZnO and CdO nanoparticles (Al-Hada *et al*., 2016), ZrO_2 nanocrystalline (Keiteb *et al*., 2016) and thermo luminescence nanomaterials (Erfani *et al*., 2014). The motivation in the the present study is to synthesis ZnSe and CdSe semiconductor nanoparticles using thermal treatment method by removing oxygen to get the pure material. This technique is relatively simple and environmentally friendly as no toxic material is discharged into the common drainage system.

1.2 Nanomaterials

Ancient civilizations used metal nanoparticles for their brilliant colors, and they can be found in the coloured glass windows of the epic times, and yet, they continue to attract considerable attention today (Zhong *et al*., 2010). Nanoparticles exhibit size-dependent properties such as the tuning of absorption energy with particle size, a blue shift of absorption onset, and an enhancement of photo-catalytic activities with a decrease in particle size (Saion *et al*., 2013). Semiconductor nanomaterials have elicited renewed interest to researchers due to their capacity to synthesis high quality and large area nanoparticles with extraordinary optical, magnetic, electric and catalytic device applications, along with their improved physical properties like mechanical hardness, thermal stability or chemical passivity (Nalwa 1999; Garibe *et al*., 2011). Furthermore, studies of such particles provide an opportunity to observe, control and modify the relationship between physical properties (size and shape) for a given chemical compound (Duan *et al*., 2015).

Bulk material may be classified as a conductor, an insulator, or a semiconductor depending on the energy band structure as a consequence of electronic energy level mixing as many atoms are brought together to form a solid crystal. The valence band is filled with the orbital electrons while the conduction band is empty or partially filled with the conduction electrons. Insulators have a wide band gap so that electrons cannot be promoted from the valence band to the conduction band. On the other hand, semiconductors have a narrow band gap that allows excitation of electrons to the conduction band from the valence band. As the number of atoms are reduced, semiconductor nanomaterials have electronic structure deviated from the continuous electronic structure where their charge carriers are partially confined in their discrete energy levels, a phenomenon known as the quantum confinement effect. Figure 1.1 shows the electronic energy states of band structure of conductor, insulator, semiconductor, semiconductor nanocrystal, and molecule.

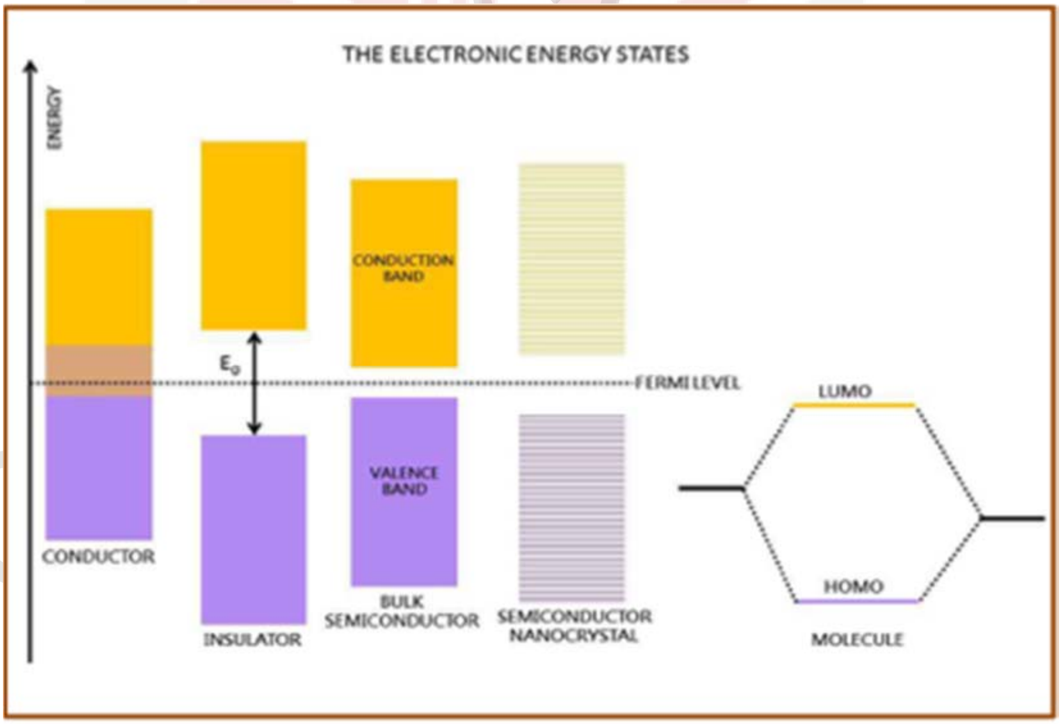

Figure 1.1 : Electronic energy states of band structure of conductor, insulator, semiconductor, semiconductor nanocrystal, and molecule (Sattler *et al*., 2011)

Nanomaterials can be in the form of particles or dots, rods or wires, wells or flowers, etc. as long as one of the dimensions is less than 100 nm. The density of states provides information on the electronic states availability at energy level of the particular dimension (Hornyak *et al*., 2008; Sattler *et al*., 2011). Figure 1.2 shows the density states of 3D structure of bulk material, and of 2D nanostructure of quantum well, 1D nanostructure of quantum wire, and 0D nanostructure of quantum dot. A high value for the density of states represents a high number for the energetic states ready to be occupied by electrons. If there are no available states for occupation in an energetic level of the nanostructure, the value for the density of states will be zero. The semiconductor nanomaterials that have strong quantum confinement effect are called quantum dots where the band gap increases with decreasing particle size. Consequently, the physical and chemical properties of semiconductor nanomaterials depend on particle size and chemical composition.

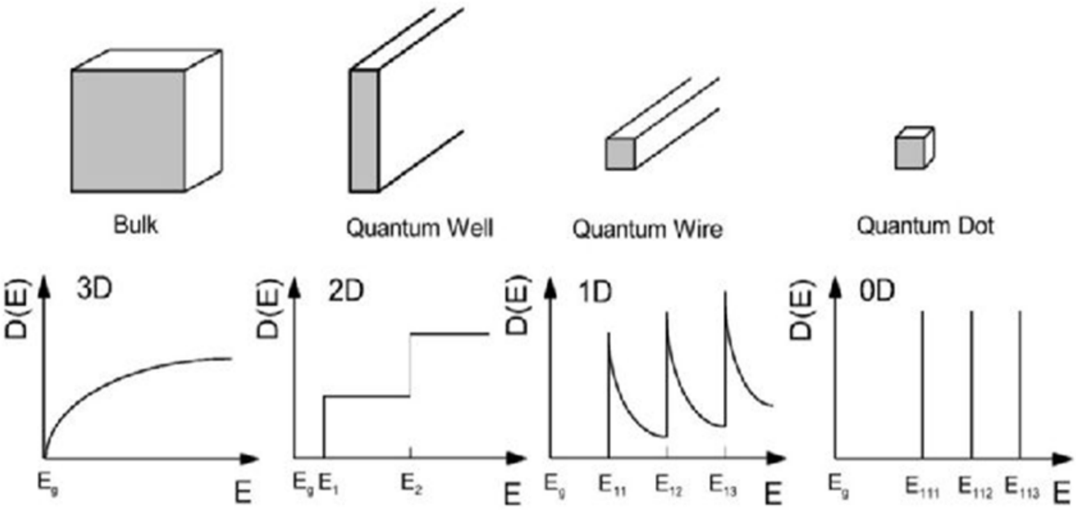

Figure 1.2 : Density states of 3D bulk material, 2D nanostructure of quantum well, 1D nanostructure of quantum wire, and 0D nanostructure of quantum dot (Suresh *et al*., 2013)

1.3 Semiconductor Quantum Dots

The semiconductor quantum dots (QDs) may be classified into group III-V and group II-VI nanoparticles, which both have a direct band gap (Sattler *et al*., 2011). Group III-V consists of the combination of group III metals (B, Al, Ga, In, or Tl) and group V non-metals (N, P, As, Sb or Bi), for examples InP, GaP, GaN, and GaAs QDs. Group II-VI consists of the combination of metals of group II (Zn or Cd) and non-metals of group VI (O, S, Se, or Te). For examples ZnS, ZnSe, CdO, CdS, CdSe, and CdTe are p-type semiconductor QDs and ZnO and ZnTe are n-type semiconductors. They possess tetrahedral bonding geometry of wurtzite or zinc blende structure at room temperature, with their unit cell has both ionic and covalent bonding contributions. Structure of individual quantum dots depend on growth mechanism, pressure, and temperature applied.

Group II–VI semiconductor QDs have attracted considerable attention due to its applications in solar cells, light-emitting diodes, diode lasers emitting blue light, photo-detectors and full color display (Suresh *et al*.,2013). Zinc selenium (ZnSe) QD is an intrinsic semiconductor of n-type. It has wide band gap (bulk band gap 2.7 eV at room temperature) and significantly large binding energy (21 meV) (Zhu *et al*., 2000). ZnSe structure can possess structure of wurzite (hexagonal) or sphalerite (cubic) at room temperature and is an attractive host for the formation of doped nanocrystals (Norman *et al*., 2003) On other hand, cadmium selenide (CdSe) ODs possess structure of wurzite (hexagonal), sphalerite (cubic), or rock-salt (cubic) depending on the temperature. The sphalerite CdSe structure is unstable at about 130 °C and converts to the wurtzite at 700 °C. At high pressure rock-salt structure is observed.

1.4 Problem Statement

Semiconductor nanostructures materials can be prepared by various methods like, hydrothermal, electrochemical, combustion, sol-gel, microwaves, micro-emulsions and many other chemical routs. In order to obtain materials of novel physical and chemical properties, the preparation of ZnSe and CdSe nanoparticles through different methods has become an essential focus of the related research and development (Hui *et al* 2004; Naseri *et al* 2011). In thermal treatment method the calcination process takes place in air or in a constant oxygen gas flow, is a common feature in the thermal treatment method. Therefore, oxygen in air is the main problem in the synthesis of metal chalcogenides such as ZnSe and CdSe QDs. Nevertheless, in the present fabrication of ZnSe and CdSe semiconductor nanoparticles, our problem was to remove oxygen during calcination process by applying a constant nitrogen gas flow, which otherwise the synthesized ZnSe and CdSe semiconductor nanoparticles will be contaminated with ZnO or CdO nanoparticles. At the same time the single-step radiolytic approach in gamma irradiation route will be tried out where the oxygen is removed by purging nitrogen gas into the reactant solution immediately prior to gamma irradiation.

1.5 Significance of study

Metal chalcogenides semiconductor nanoparticles and nanocomposites are attractive subjects of continuous scientific interest and have been deeply investigated in materials sciences, due to their physical-chemical properties that have wide range of applications. In particular, ZnSe and CdSe QDs are commonly used in solar cells, light-emitting diodes, diode lasers emitting blue light, photo-detectors and full color display, catalysis, chemical and biological sensors and many more applications.

In this study, two synthesis methods have been utilized for fabrication ZnSe, CdSe and CdZnSe nanostructures. The first route is thermal-treatment method, where an aqueous solution containing metal nitrates, poly (vinyl pyrrolidone), and deionized water undergone heat treatment to remove organic components. The second route is by gamma irradiation where the formed hydrated electrons become important in chemical reaction to form CdSe and ZnSe nanoparticles in water.

1.6 Scope of the Study

Among other metal semiconductor nanoparticles, ZnSe and CdSe nanostructure materials are ideal subjects that have been deeply investigated by researchers due to their impressive physical and chemical properties and their wide range of applications such as sensor, solar cell. The nanomaterial synthesis requires the use of a device or process that fulfills the following conditions: particle size control, size distribution, shape, crystal structure and composition distribution, less impurities, control of agglomeration, higher mass production, and lower costs. In particular, ZnSe and CdSe nanoparticles are commonly used in electronic devices, sensors, light emitting, optics, telecommunication, solar cell, medical and many more applications.

The methodology described above of achieving the synthesis of ZnSe and CdSe nano-particles by using single step radiolytic gamma irradiation and thermal treatment, presents a necessary limitation to the scope of the study. In addition to this, the study takes into consideration the morphological, structural and optical characteristics of the nanomaterials under investigation.

1.7 Research Objectives

The main objectives of the study are:

1. To produce pure ZnSe and CdSe semiconductor nanoparticles and Zn-CdSe nanocomposites by using thermal-treatment method.
2. To study the effect of calcination temperature and metal precursor concentration on the morphology, structural and optical properties of ZnSe and CdSe nanoparticles and Zn-CdSe nanocomposites
3. To produce ZnSe and CdSe nanoparticles by gamma-radiolytic route at dose of 120 kGy.
4. To study the morphology, structural and optical properties of gamma irradiation synthesized CdSe and ZnSe nanoparticles.

1.8 Thesis Layout

This thesis is comprised of five chapters. Chapter 1 briefly elaborate on the background of nanoscience and nanotechnology, semiconductor nanoparticles, problem statements, research objectives and finally the scope of the study.

Chapter 2 presents an overview of previous works carried out by other researchers including current and past literatures in terms of the background materials and method for the preparation and characterization of semiconductor nanoparticle materials along with their related applications. Chapter 3 considers the theoretical background of the research, looking in details at the material structure, Bragg's Law and optical properties. Chapter 4 discusses the methodology of the research, the utilized materials and sample preparation expressed in significant detail. In addition, this chapter provides the morphological, structural, and optical characterisations of the samples based on XRD, TEM, SEM, EDX, TGA, DTG, FTIR, UV-Visible spectroscopy and PL analyses. Results and discussion of the study on the obtained ZnSe CdSe and Zn-CdSe semiconductor nanomaterials on the morphological, structural, and optical characterisations are presented in Chapter 5. Finally, Chapter 6 provides the conclusion of the study based the structural and optical properties of the nanomaterials and the recommendations for future research.

Nanoparticles materials

REFERENCES

AChimovičová, M. et al.," Characterization of mechanochemically synthesized ZnSe in a laboratory and an industrial mill". *Solid State Ionics.* (2011) 192.1: 632-637.

Aiken, John D.; Finke, Richard G. A" review of modern transition-metal nanoclusters: their synthesis, characterization, and applications in catalysis". *Journal of Molecular Catalysis A: Chemical*. (1999) 145.1: 1-44.

Akhtar, Javeed et al., "A greener route to photoelectrochemically active PbS nanoparticles". *Journal of Materials Chemistry* (2010) 20.12: 2336-2344.

AL-habashi, Ramadan Masoud. "Electromagnetic Characterization Of Sm-Yig And Sm-Yig-Pvdf Composites Prepared Using Modified Conventional Mixing Oxide Technique". (2009). PhD Thesis. Universiti Putra Malaysia.

Al-hada, Naif Mohammed et al., "A facile thermal-treatment route to synthesize ZnO nanosheets and effect of calcination temperature". *PloS one* (2014) 9.8: 103134.

AL-hada, Naif Mohammed et al., "A facile thermal-treatment route to synthesize the semiconductor CdO nanoparticles and effect of calcination. Materials Science in Semiconductor Processing". (2014) 26: 460-466.

AL-hada, Naif Mohammed et al., "Structural, morphological and optical behaviour of PVP capped binary (ZnO) 0.4 (CdO) 0.6 nanoparticles synthesised by a facile thermal route". *Materials Science in Semiconductor Processing*(2016) 53: 56-65

Amiri, Gholam Reza; Fatahian, Soheil; Mahmoudi, Somayeh. "Preparation and optical properties assessment of CdSe quantum dots" (2013).

Behboudnia, M.; Aziziane kalandaragh, Y. "Synthesis and characterization of CdSe semiconductor nanoparticles by ultrasonic irradiation". *Materials Science and Engineering: B* (2007) 138.1: 65-68.

Bhagavannarayana, G. et al., Structural, optical and electrical properties of ZnSe semiconductor nanoparticles. Chalcogenide Letters, 2011, 8.7: 435-440.

Bhargava, Richa et al., "Variation in structural, optical and magnetic properties of Zn 1− x Cr x O (x= 0.0, 0.10, 0.15, and 0.20) nanoparticles: role of dopant concentration on non-saturation of magnetization". *Materials Chemistry and Physics*(2011) 125.3: 664-671.

Boldt, Klaus et al., "Electronic structure engineering in ZnSe/CdS type-II nanoparticles by interface alloying". *The Journal of Physical Chemistry C* (2014) 118.24: 13276-13284.

Boles, Michael A. et al., "The surface science of nanocrystals Nature materials" (2016)15.2: 141-153.

Brus, Louis. "Chemical approaches to semiconductor nanocrystals" *Journal of Physics and Chemistry of Solids* (1998) 59.4: 459-465.

Buscemi, Fabrizio et al., "Electrical bistability in amorphous semiconductors: A basic analytical theory". *Applied Physics Letters* (2014) 104.2: 022101.

Caglar, Mujdat et al., "Temperature dependence of the optical band gap and electrical conductivity of sol–gel derived undoped and Li-doped ZnO films". *Applied Surface Science* (2010) 256.16: 4966-4971.

Campelo, Juan M. et al., "Sustainable preparation of supported metal nanoparticles and their applications in catalysis". *ChemSusChem* (2009) 2.1: 18-45.

Cao, Wanqing; Hunt, Arlon J. "Photoluminescence of chemically vapor deposited Si on silica aerogels". *Applied physics letters* (1994) 64.18: 2376-2378.

Chate, P. A. et al., "Synthesis and characterization of cubic cadmium selenide by chemical route". *Journal of Alloys and Compounds*(2013) 552: 40-43.

Choi, Sang-Hyun, Hongju Song, Il Kyu Park, Jun-Ho Yum, Seok-Soon Kim, Seonghoon Lee, and Yung-Eun Sung. "Synthesis of size-controlled CdSe quantum dots and characterization of CdSe–conjugated polymer blends for hybrid solar cells." Journal of Photochemistry and Photobiology A: Chemistry 179, no. 1 (2006): 135-141.

Choi, Shin-Jung et al., "Electrochemical preparation of cadmium selenide nanoparticles by the use of molecular templates". *Journal of the Electrochemical Society* (2001) 148.9: C569-C573.

Cullity, B. D. 1978. "Elements of X-Ray Diffraction 2nd". *London*: Addison-Wesley.

Das, Bikas C.; Batabyal, Sudip K.; PAL, Amlan J. "A bit per particle: electrostatic assembly of CdSe quantum dots as memory elements". *Advanced materials* (2007) 19.23: 4172-4176.

Deng, Da-Wei; YU, Jun-Sheng; Pan, Yi. "Water-soluble CdSe and CdSe/CdS nanocrystals: a greener synthetic route". *Journal of colloid and interface science* (2006) 299.1: 225-232.

Deo, Soumya R. et al., "Structural, morphological and optical studies on chemically deposited nanocrystalline CdZnSe thin films". *Journal of Saudi Chemical Society* (2014) 18.4: 327-339.

Deshpande, M. P. et al., "Study on nanoparticles of ZnSe synthesized by chemical method and their characterization". *Journal of Nano-and ElectronicPhysics*(2011) 3.1: 193.

Ding, Ling et al., Microwave-assisted synthesis of L-glutathione capped ZnSe QDs and its interaction with BSA by spectroscopy. Journal of Luminescence, 2013, 142: 167-172.

Duan, Yu-lu et al., Preparation and characterization of ZnSe/CdSe core-shell microspheres. Transactions of Nonferrous Metals Society of China, 2015, 25.5: 1559-1567.

Eitan Oksenberg,Ronit Popovitz-Biro,Katya Rechav,Ernesto Joselevich. ZnSe Nanowires: Guided Growth of Horizontal ZnSe Nanowires and their Integration into High-Performance Blue–UV Photodetectors. Advanced Materials, 2015, 27: 3973.

Erfani Haghiri, Maryam et al., Thermoluminescence Properties of Nanostructured Calcium Borate as a Sensitive Radiation Dosimeter for High Radiation Doses. In: Advanced Materials Research. Trans Tech Publications, 2014. p. 189-194.

Feng, Bo et al., ZnSe nanoparticles of different sizes: Optical and photocatalytic properties. Materials Science in Semiconductor Processing, 2014, 27: 865-872.

Ferro, R.; Rodríguez, J. A. Study of some optical properties of CdO: F thin films. Physica Status Solidi B Basic Research, 2000, 220.1: 299-304.

Feynman, R. "There's Plenty of Room at the Bottom. Speech given at American." In Physical Society Meeting, California Institute of Technology, December. Retrieved from: http://nanoparticles. org/pdf/Feynman.pdf(accessed on 10/11/2014). 1959.

Focsha, A. A. et al., Properties of semiconductor scintillators and combined detectors of ionizing radiation based on ZnSe (Te, O)/pZnTe–nCdSe structures. Optical materials, 2002, 19.1: 213-217.

Fojtik, Anton; Henglein, Arnim. Luminescent colloidal silicon particles. Chemical Physics Letters, 1994, 221.5-6: 363-367.

Gene, Salahudeen A. et al., Structural, optical, and magnetic characterization of spinel zinc chromite nanocrystallines synthesised by thermal treatment method. Journal of Nanomaterials, 2014, 2014: 15.

Gerion, Daniele et al., Synthesis and properties of biocompatible water-soluble silica-coated CdSe/ZnS semiconductor quantum dots. The Journal of Physical Chemistry B, 2001, 105.37: 8861-8871.

Gharibe, Soodabe; Afshar, Shahrara; Vafayi, Leila. Development of a hydrothermal method to synthesize spherical ZnSe nanoparticles: Appropriate templates for hollow nanostructures. Bulletin of the Chemical Society of Ethiopia, 2014, 28.1: 37-44.

Gharibe, Soodabe; Afshar, Shahrara; Vafayi, Leila. Synthesis and characterization of porous hollow silica nanoparticles using znse core as template for drug delivery application. African Journal of Pharmacy and Pharmacology, 2011, 5.20: 2265-2271.

GLasbrenner, J. K.; Žutić, I.; Mazin, I. I. Theory of Mn-doped II-II-V semiconductors. Physical Review B, 2014, 90.14: 140403.

Gonçalves, Luis FFF et al., One-pot synthesis of CdS nanoparticles exhibiting quantum size effect prepared within a sol–gel derived ureasilicate matrix. Optical Materials, 2013, 36.2: 186-190.

Goswami, Biplab; Pal, Sougata; Sarkar, Pranab. A theoretical study on the electronic structure of ZnSe/ZnS and ZnS/ZnSe core/shell nanoparticles. The Journal of Physical Chemistry C, 2008, 112.31: 11630-11636.

Guleria, Apurav et al., Tuning of photoluminescence in cadmium selenide nanoparticles grown in CTAB based quaternary water-in-oil microemulsions. Journal of Luminescence, 2012, 132.3: 652-658.

Gur, Ilan et al., Air-stable all-inorganic nanocrystal solar cells processed from solution. Science, 2005, 310.5747: 462-465.

Hamizi, Nor Aliya, Ch'ng Shiau Ying, and Mohd Rafie Johan. "Synthesis with Different Se Concentrations and Optical Studies of CdSe Quantum Dots via Inverse Micelle Technique." International Journal of Electrochemical Science 7, no. 5 (2012): 4727-4734.

Hegazy, Maroof A., and Afaf M. Abd El-Hameed. "Characterization of CdSe-nanocrystals used in semiconductors for aerospace applications: Production and optical properties." NRIAG Journal of Astronomy and Geophysics 3, no. 1 (2014): 82-87.

Heine, J. R. et al., Synthesis of CdSe quantum dot–ZnS matrix thin films via electrospray organometallic chemical vapor deposition. Journal of crystal growth, 1998, 195.1: 564-568.

Hines, Margaret A., and Philippe Guyot-Sionnest. "Synthesis and characterization of strongly luminescing ZnS-capped CdSe nanocrystals." The Journal of Physical Chemistry 100, no. 2 (1996): 468-471.

Hoefelmeyer, James D., Krisztian Niesz, Gabor A. Somorjai, and T. Don Tilley. "Radial anisotropic growth of rhodium nanoparticles." Nano letters 5, no. 3 (2005): 435-438.

Hornyak, Gabor L. et al., *Introduction to nanoscience*. CRC press, 2008.

Hornyak, Gabor L. et al., Introduction to nanoscience. CRC press, 2008.

Hu, Zeng-Wen et al., A general chemical transformation route to two-dimensional mesoporous metal selenide nanomaterials by acidification of a ZnSe–amine lamellar hybrid at room temperature. Chemical Science, 2016.

Hui-Zhi, An; Qing, Zhao; WEI-MIN, Du. Raman spectra of ZnSe nanoparticles synthesized by thermal evaporation method. Chinese Physics, 2004, 13.10: 1753.

Hutagalung, Sabar D.; Loo, Siaw C. Zinc selenide (ZnSe) nanoparticles prepared by sol-gel method. In: 2007 7th IEEE Conference on Nanotechnology (IEEE NANO). IEEE, 2007. p. 930-933.

Huynh, Wendy U. et al., Controlling the morphology of nanocrystal–polymer composites for solar cells. Advanced Functional Materials, 2003, 13.1: 73-79.

Jang, Ho Seong et al., White Light-Emitting Diodes with Excellent Color Rendering Based on Organically Capped CdSe Quantum Dots and Sr3SiO5: Ce3+, Li+ Phosphors. Advanced Materials, 2008, 20.14: 2696-2702.

Jeong, Seung Yol et al., Photocurrent of CdSe nanocrystals on single-walled carbon nanotube-field effect transistor. Applied physics letters, 2008, 92.24: 243103-243103.

Jiang, Xuchuan et al., Direct synthesis of Se@ CdSe nanocables and CdSe nanotubes by reacting cadmium salts with Se nanowires. Advanced Materials, 2003, 15.20: 1740-1743.

Jiang, Yang et al., Photoresponse Properties of CdSe Single-Nanoribbon Photodetectors. Advanced Functional Materials, 2007, 17.11: 1795-1800.

Kausalya, J. Anne; Joseph, V.; Krishnakumar, S. Synthesis of cadmium selenide nanoparticles by wet chemical method. Elixir Appl Chem, 2013, 55: 13036-8.

Keiteb, Aysar Sabah et al., A Modified Thermal Treatment Method for the Up-Scalable Synthesis of Size-Controlled Nanocrystalline Titania. *Applied Sciences*, 2016, 6.10: 295.

Kharazmi, Alireza et al., Structural, optical and thermal properties of PVA/CdS nanocomposites synthesized by radiolytic method. Radiation Physics and Chemistry, 2014, 97: 212-216.

Kharazmi, Alireza et al., Structural, optical, opto-thermal and thermal properties of ZnS–PVA nanofluids synthesized through a radiolytic approach. Beilstein journal of nanotechnology, 2015, 6.1: 529-536.

Kim, Ki Eun et al., Enhancement in the performance of dye-sensitized solar cells containing ZnO-covered TiO_2 electrodes prepared by thermal chemical vapor deposition. Solar Energy Materials and Solar Cells, 2007, 91.4: 366-370.

Kittel, Charles. "Introduction to Solid State Physics". *University of Pennsylvania Law Review*. (2005) 154.3: 477.

Klaus D. Sattler (2011). Handbook of Nanophysics: Nanoparticles and Quantum Dots. CRC Press, London, New York. pp 6-1 CRC Press, London, New York.

Klein, Oskar. Quantum theory and five-dimensional relativity theory. The Oskar Klein Memorial Lectures: 1988-1999, 1, 69-82.

Kraus, R. M. et al., "Room-temperature exciton storage in elongated semiconductor nanocrystals". *Physical review letters*. (2007) 98.1: 017401.

Kravets, V. G. et al., "Plasmonic blackbody: Strong absorption of light by metal nanoparticles embedded in a dielectric matrix". *Physical Review B*. (2010) 81.16: 165401.

Kristl, Matjaž, *et al*. "A sonochemical method for the preparation of cadmium sulfide and cadmium selenide nanoparticles in aqueous solutions Ultrasonics sonochemistry".(2010) 17.5: 916-922.

Kumar, Pushpendra et al., ZnSe/ZnSe: Ag nanoparticles: synthesis, characterizations, optical and raman studies. *Journal of nanoscience and nanotechnology* (2013) 13.1: 377-383.

Kumar, Vijay; Rajaram, P.; Goswami, Y. C. "Sol gel synthesis of SnO 2/CdSe nanocomposites and their optical structural and morphological characterizations. Optik". *International Journal for Light and Electron Optics* (2016) 127.5: 2490-2494.

Kung, Sheng-Chin et al., "20 μs photocurrent response from lithographically patterned nanocrystalline cadmium selenide nanowires". *Nano letters*. (2010) 10.4: 1481-1485.

Laha, Suman Kumar; Mukherjee, Moumita. "Physics Based Modeling of Intrinsic Material Parameters of III-V Nitride Semiconductors: Elevated Temperature Effects. GaN" (2014) 10: 3.

Li, Fushan et al., "Memory effect of nonvolatile bistable devices based on CdSe/ZnS nanoparticles sandwiched between C60 layers". *Applied Physics Letters*. (2007) 91.16: 162109-162109.

Li, Hong-liang et al.," A novel ultrasound-assisted approach to the synthesis of CdSe and CdS nanoparticles". *Journal of Solid State Chemistry* (2003) 172.1: 102-110.

Li, Liang et al., "Single-crystalline CdS nanobelts for excellent field-emitters and ultrahigh quantum-efficiency photodetectors". *Advanced Materials*. (2010) 22.29: 3161-3165.

Li, Y. C. et al., "High-yield fabrication and electrochemical characterization of tetrapodal CdSe, CdTe, and CdSexTe1–x nanocrystals". *Advanced Functional Materials*. (2006) 16.13: 1705-1716.

Littau, K. A. et al., "A luminescent silicon nanocrystal colloid via a high-temperature aerosol reaction". *The Journal of Physical Chemistry* (1993) 97.6: 1224-1230.

Liu, Huilin; Fang, Guozhen; Wang, Shuo. "Molecularly imprinted optosensing material based on hydrophobic CdSe quantum dots via a reverse microemulsion for specific recognition of ractopamine:. *Biosensors and Bioelectronics* (2014) 55: 127-132.

Lu, Jun et al., "Study of the dissolution behavior of selenium and tellurium in different solvents—a novel route to Se, Te tubular bulk single crystals". *Journal of Materials Chemistry* (2002) 12.9: 2755-2761.

M. Nirmal, B.O. Dabbousi, M.G. Bawendi, J.J. Macklin, J.K. Trautman,T.D. Hattis, L.E. Brus. Fluorescence intermittency in single cadmium selenide nanocrystals. Nature, 1996, 383 (6603): 802–804.

Mahmoud, Mahmoud A.; Narayanan, Radha; EL-sayed, Mostafa A. "Enhancing colloidal metallic nanocatalysis: sharp edges and corners for solid nanoparticles and cage effect for hollow ones". *Accounts of chemical research* (2013) 46.8: 1795-1805.

Mekis, Ivo et al., "One-pot synthesis of highly luminescent CdSe/CdS core-shell nanocrystals via organometallic and "greener" chemical approaches". *The Journal of Physical Chemistry B* (2003) 107.30: 7454-7462.

Menke, E. J. et al., "Lithographically patterned nanowire electrodeposition". *Nature materials* (2006) 5.11: 914-919.

Mollaamin, F.; Gharibe, S.; Monajjemi, M. Synthesis of various nano and micro ZnSe morphologies by using hydrothermal method. International Journal of Physical Sciences. (2011) 6.6: 1496-1500.

Mosalam, Farag Marzouk Marea. "Effect of Gamma Radiation on the Microbial Synthesis of Metal Nanoparticles." PhD diss., Al-Azhar University (2013).

Moshi, Mainen J.; Otieno, Donald F.; Weisheit, Anke. Ethnomedicine of the Kagera Region, north western Tanzania. Part 3: plants used in traditional medicine in Kikuku village, Muleba District. Journal of ethnobiology and ethnomedicine, (2012) 8.1: 1.

Muthumari, S., G. Devi, P. Revathi, R. Vijayalakshmi, and C. Sanjeeviraja. "Structural Investigation of Zinc Selenide Thin Films." Journal of Applied Sciences 12, no. 16 (2012): 1722.

Nagaraju,Ganganagappa;Chandrappa,GujjarahalliThimmanna. "Surfactant assisted hydrothermal synthesis of CdSe nanostructural materials". *Journal of Materials Science and Technology*. (2012) 28.6: 495-499.

Nalwa, Hari Singh, ed. "Handbook of Nanostructured Materials and Nanotechnology, Five-Volume Set". Academic Press (1999).

Naseri, Mahmoud Goodarz; Saion, Elias B. "Crystalization in spinel ferrite nanoparticles". *In Advances in Crystallization Processes* .(2012) 349-380.

Naseri, Mahmoud Goodarz; Saion, Elias B.; Ahangar, Hossein Abbastabar. "Preparation and Characterization of NiCoFerrite Nanoparticles by Thermal Method". In: Computer Research and Development, (2010) Second International Conference on. IEEE, (2010). p. 597-601.

Norman, Geoffrey R.; Sloan, Jeff A.; "Wyrwich, Kathleen W. Interpretation of changes in health-related quality of life" *the remarkable universality of half a standard deviation. Medical care* (2003) 41.5: 582-592.

Norman, Thaddeus J. et al., "Optical and surface structural properties of Mn2+-doped ZnSe nanoparticles". *The Journal of Physical Chemistry B* (2003) 107.26: 6309-6317.

OluwafemI, S. O.; Revaprasadu, N.; Ramirez, A. J. "A novel one-pot route for the synthesis of water-soluble cadmium selenide nanoparticles". *Journal of Crystal Growth* (2008) 310.13: 3230-3234.

Pankove, Jacques I. Optical processes in semiconductors. Courier Corporation, (2012).

Pankove, JI.Optical properties in semiconductors. Prentice-Hall, Englewood Cliffs, NJ. (1971)

Pathak, C. S. et al., "Optical properties of ZnS nanoparticles prepared by high energy ball milling". *Materials Science in Semiconductor Processing* (2013) 16.2: 525-529.

Peng, Xiaogang, J. Wickham, and A. P. Alivisatos. "Kinetics of II-VI and III-V colloidal semiconductor nanocrystal growth:"focusing" of size distributions." Journal of the American Chemical Society 120, no. 21 (1998): 5343-5344.

Qu, Lianhua; Peng, Z. Adam; Peng, Xiaogang. "Alternative routes toward high quality CdSe nanocrystals". *Nano Letters*. (2001) 1.6: 333-337.

Ren, Xiaoguang. "Hydrothermal synthesis of ZnSe nanoparticle." (2016).

Ribas, I. et al., "Fundamental properties of low-mass stars". Ar Xiv preprint arXiv:0711.4451. (2007).

Roberts, Thomas J. et al., "Energetics of bipedal running. I. Metabolic cost of generating force". *Journal of Experimental Biology* (1998) 201.19: 2745-2751.

Rossetti, R.; Nakahara, S.; Brus, Louis E. "Quantum size effects in the redox potentials, resonance Raman spectra, and electronic spectra of CdS crystallites in aqueous solution". *The Journal of Chemical Physics* (1983) 79.2: 1086-1088.

Ryzhikov, Vladimir D. et al.," Behavior of new ZnSe (Te, O) semiconductor scintillators under high doses of ionizing radiation". *IEEE Transactions on Nuclear Science* (2001) 48.4: 1561-1564.

Saini, Rajiv et al., "Nanotechnology: the future medicine. Journal of cutaneous and aesthetic surgery". (2010) 3.1: 32.

Saion, Elias; Gharibshahi, Elham; Naghavi, Kazem. "Size-controlled and optical properties of monodispersed silver nanoparticles synthesized by the radiolytic reduction method". *International journal of molecular sciences* (2013) 14.4: 7880-7896.

Sattler, Torsten; Leibe, Bastian; Kobbelt, Leif. "Fast image-based localization using direct 2d-to-3d matching". *International Conference on Computer Vision*. IEEE (2011) p. 667-674

Shakir, Mohd et al., "Characterization of ZnSe nanoparticles synthesized by microwave heating process". *Solid State Communications* (2009) 149.45: 2047-2049.

Sharma, Mamta; Tripathi, S. K. "Two photon absorption studies of PVA coated CdSe/ZnSe and CdSe/CdS core/shell nanostructures". *Chemical Physics Letters*. (2015) 634: 266-270.

Singh, S. et al., "Radiolytic synthesis and spectroscopic investigations of Cadmium Selenide quantum dots grown in cationic surfactant based quaternary water-in-oil microemulsions". *Journal of colloid and interface science* (2013) 398: 112-119.

Sobhani, Azam; Salavati-Niasari, "Masoud. CdSe nanoparticles: facile hydrothermal synthesis, characterization and optical properties". *Journal of Materials Science: Materials in Electronics*. (2015) 26.9: 6831-6836.

Sofiienko, Andrii, and Volodimir Degoda. "Research of X-ray induced conductivity of ZnSe sensors for their application in isotopic thickness gauges." arXiv preprint arXiv:1106.2232 (2011).

Srivastava, Punita, and Kedar Singh. "Synthesis of CdSe nanoparticles by solvothermal route: Structural, optical and spectroscopic properties." Adv. Mat. Lett 3, no. 4 (2012): 340.

Sung, Ti-Wen, and Yu-Lung Lo. "Highly sensitive and selective sensor based on silica-coated CdSe/ZnS nanoparticles for Cu 2+ ion detection." Sensors and Actuators B: Chemical 165, no. 1 (2012): 119-125.

Suresh, Sagadevan. "Semiconductor nanomaterials, methods and applications" *A review. Nanoscience and Nanotechnology* (2013) 3.3: 62-74.

Suresh, Subra (ed.). Fundamentals of metal-matrix composites. Elsevier,(2013).

Tan, G. L.; LIU, R. H." Preparation of pure CdSe nanocrystals through mechanical alloying". *Journal of Nanoparticle Research* (2010) 12.2: 605-614.

Torrent, J., and V. Barr´on, V., "Encyclopedia of Surface and Colloid Science" *Inc.: New York, Marcel Dekker*. (2002)

Valentina Zannier, Faustino Martelli, Vincenzo Grillo, et al. Strong blue emission from ZnSe nanowires grown at low temperature. Physica Status Solidi, 2014, 8:182-186.

Wang, Wei-Xiang et al., "Influence of preparation parameters on the particle size of nanosized silicon". *Physica B: Condensed Matter* (1996) 225.1: 137-141.

Whiffen, D. H. (1971). Accurate Molecular Geometry. Chemistry in Britain, 7(2), 57.

Williams, Juandria V. et al.," Hydrothermal synthesis of CdSe nanoparticles". *Industrial and engineering chemistry research* (2007) 46.13: 4358-4362.

Woo, W.-K. et al., "Reversible Charging of CdSe Nanocrystals in a Simple Solid-State Device". *Advanced Materials* (2002) 14.15: 1068-1071.

Xi, L. F.; Lam, Y. M. "Synthesis and characterization of CdSe nanorods using a novel microemulsion method at moderate temperature". *Journal of colloid and interface science* (2007) 316.2: 771-778.

XI, Lifei et al., "Synthesis and characterization of one-dimensional CdSe by a novel reverse micelle assisted hydrothermal method". *Journal of colloid and interface science* (2008) 320.2: 491-500.

Yang, Lin et al., "Preparation and characterization of ZnSe nanocrystals by a microemulsion-mediated method". *Materials Letters* (2012) 72: 113-115.

Yu, Yanghai; Kamat, Prashant V.; Kuno, Masaru. "A CdSe nanowire/quantum dot hybrid architecture for improving solar cell performance". *Advanced Functional Materials* (2010) 20.9: 1464-1472.

Yu, Z., Xu, Z., Wu, X., & Ma, Z. (2014, June). "Electronic structure and optical properties of ZnSe from first-principles calculations". In Fiber-Based Technologies and Applications (pp. JF2A-37). Optical Society of America.

Zeng, Q. Z. et al., "Synthesis, field emission and optical properties of ZnSe nanobelts, nanorods and nanocones by hydrothermal method". *Materials Science in Semiconductor Processing* (2015) 31: 189-194.

Zeng, Qingzi et al., "Synthesis and characterization of ZnSe rose-like nanoflowers and microspheres by the hydrothermal method". *Ceramics International* (2014) 40.2: 2847-2852.

Zeng, Xiping et al., "Structural dependence of silver nanowires on polyvinyl pyrrolidone (PVP) chain length". *Nanotechnology* (2014) 25.49: 495601.

Zhang, Hui, Deren Yang, Dongshen Li, Xiangyang Ma, Shenzhong Li, and Duanlin Que. "Controllable growth of ZnO microcrystals by a capping-molecule-assisted hydrothermal process." Crystal growth & design 5, no. 2 (2005): 547-550.

Zhang, Jie et al.," Microwave-assisted aqueous synthesis of transition metal ions doped ZnSe/ZnS core/shell quantum dots with tunable white-light emission". *Applied Surface Science* (2015) 351: 655-661.

Zhang, Jin Z. "Interfacial charge carrier dynamics of colloidal semiconductor nanoparticles". *The Journal of Physical Chemistry B* (2000) 104.31: 7239-7253.

Zhang, Libing et al., "Luminescent Si nanoparticles in sol-gel matrices stabilized by amino acids". *Chemistry of materials* (1997) 9.11: 2249-2251.

Zhang, Yuan et al., "Brush-like hierarchical ZnO nanostructures: synthesis, photoluminescence and gas sensor properties". *The Journal of Physical Chemistry C* (2009) 113.9: 3430-3435.

Zhao, Lijuan; Hu, Linfeng; Fang, Xiaosheng. "Growth and device application of CdSe nanostructures". *Advanced Functional Materials* (2012) 22.8: 1551-1566.

Zhu, Junjie; Koltypin, Yuri; Gedanken, A. "General sonochemical method for the preparation of nanophasic selenides: synthesis of ZnSe nanoparticles". *Chemistry of Materials*(2000) 12.1: 73-78.

Zhu, Zuo-Ming et al., "Photoluminescence properties of nitrogen-doped ZnSe epilayers.