INVESTIGATION ON THE GOLD NANOPARTICLES CONCENTRATION EFFECTS TO THE OPTICAL AND STRUCTURAL PROPERTIES OF NANOSTRUCTURE GLASS

REUBEN HO CHEE WUI

FACULTY OF SCIENCE AND NATURAL RESOURCES
UNIVERSITI MALAYSIA SABAH
2019

INVESTIGATION ON THE GOLD NANOPARTICLES CONCENTRATION EFFECTS TO THE OPTICAL AND STRUCTURAL PROPERTIES OF NANOSTRUCTURE GLASS

REUBEN HO CHEE WUI

THESIS SUBMITTED IN FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE

FACULTY OF SCIENCE AND NATURAL RESOURCES
UNIVERSITI MALAYSIA SABAH
2019

UNIVERSITI MALAYSIA SABAH

BORANG PENGESAHAN TESIS

JUDUL : ____
____
____

IJAZAH : ____
____

SAYA : ___________________________________ **SESI PENGAJIAN** : ______________________________
(HURUF BESAR)

Mengaku membenarkan tesis *(LPSM/Sarjana/Doktor Falsafah) ini disimpan di Perpustakaan Universiti Malaysia Sabah dengan syarat-syarat kegunaan seperti berikut:-

1. Tesis adalah hak milik Universiti Malaysia Sabah.
2. Perpustakaan Universiti Malaysia Sabah dibenarkan membuat salinan untuk tujuan pengajian sahaja.
3. Perpustakaan dibenarkan membuat salinan tesis ini sebagai bahan pertukaran antara institusi pengajian tinggi.
4. Sila tandakan (/)

☐ SULIT (Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysia seperti yang termaktub di AKTA RAHSIA RASMI 1972)

☐ TERHAD (Mengandungi maklumat TERHAD yang telah ditentukan oleh organisasi/badan di mana penyelidikan dijalankan)

☐ TIDAK TERHAD

Disahkan oleh:

_____________________ _________________________
(TANDATANGAN PENULIS) (TANDATANGAN PUSTAKAWAN)

Alamat Tetap: ________________
____
____
____

____
(NAMA PENYELIA)

TARIKH: _______________ TARIKH: ___________________

Catatan:
*Potong yang tidak berkenaan.
*Jika tesis ini SULIT dan TERHAD, sila lampirkan surat daripada pihak berkuasa/organisasi berkenaan dengan menyatakan sekali sebab dan tempoh tesis ini perlu dikelaskan sebagai SULIT dan TERHAD.
*Tesis dimaksudkan sebagai tesis bagi Ijazah Doktor Falsafah dan Sarjana Secara Penyelidikan atau disertai bagi pengajian secara kerja kursus dan Laporan Projek Sarjana Muda (LPSM).

DECLARATION

I hereby declare that the work in this thesis is my own except for quotation, equations, summaries and references which have been acknowledged.

9 July 2019

Reuben Ho Chee Wui

MS1421113T

CERTIFICATION

NAME : **REUBEN HO CHEE WUI**

MATRIC NO. : **MS1421113T**

TITLE : **INVESTIGATION ON THE GOLD NANOPARTICLES CONCENTRATION EFFECTS TO THE OPTICAL AND STRUCTURAL PROPERTIES OF NANOSTRUCTURE GLASS**

DEGREE : **MASTER OF SCIENCE (PHYSICS WITH ELECTRONICS)**

VIVA DATE : **9 APRIL 2019**

CERTIFIED BY:

1. CHAIRPERSON OF RESEARCH COMMITTEE Signature

Assoc. Prof. Dr. Jedol Dayou

10.7.2019

Prof. Madya Dr. Jedol Dayou
Program Fizik Dengan Elektronik
Fakulti Sains dan Sumber Alam
UNIVERSITI MALAYSIA SABAH

2. MEMBER OF RESEARCH COMMITTEE 1

Dr. Asmahani Awang

3. MEMBER OF RESEARCH COMMITTEE 2

Dr. Alvie Lo Sin Voi

ACKNOWLEDGEMENT

A special gratitude to my chairperson (Assoc. Prof. Dr. Jedol Dayou) and members (Dr. Asmahani Awang and Dr. Alvie Lo Sin Voi) of the research committee who helped and guided me during the period of this research. Their guidance, idea and constructive comments helped me to coordinate my research and finally complete my thesis.

Last but not least, I would like to thank my fellow lab mates (e-vibs, Makmal Bahan Kimia Semula Jadi and Makmal Bahan Sains) for ideas and encouragement during the period of my research.

Reuben Ho Chee Wui

9 July 2019

ABSTRACT

Achieving enhancement of photoluminescence and Raman spectra of glasses containing rare-earth ions and metallic nanoparticles are prerequisite. Many studies only reported the effect of concentration of the nanoparticles on structural and optical properties of the glasses instead of the variation in size and shape of nanoparticles. Thus, the current study aims to investigate effect of concentration of the gold (Au) nanoparticles on structural and optical properties of the glasses. Further, their geometric effect on photoluminescence and Raman enhancement with varying concentration of the gold nanoparticles for optimizing photoluminescence and Raman enhancement are addressed. A series of glass with composition of $70TeO_2$-$20ZnO$-$10Na_2O$-$0.5Er_2O_3$-(x)Au where x=0.0, 0.1, 0.2, 0.3 and 0.4 mol% were examined with X-ray diffraction (XRD), ultraviolet-visible (UV-Vis) spectroscopy, transmission electron microscopy (TEM), scanning electron microscopy (SEM), energy dispersive X-ray spectroscopy (EDX), photoluminescence spectroscopy, Fourier Transform Infrared (FTIR) spectroscopy and Raman spectroscopy. Modification in UV-Vis spectra was observed due to non-bridging oxygen created by gold nanoparticles with increasing concentration of gold nanoparticles. TEM images verified the presence of non-spherical gold nanoparticles. Photoluminescence spectra revealed luminescence enhancement caused by the effect of surface plasmon resonance (SPR) and energy transfer from the gold nanoparticles to erbium ions as concentration of the gold nanoparticles was increased up to 0.3 mol%. However, when the concentration of the gold nanoparticles exceeded 0.3 mol%, luminescence quenching occurs due to energy transfer from erbium ions to gold nanoparticles. Amplification of Raman spectra was attributed to the effect of SPR. The concentrations of the gold nanoparticles for maximizing photoluminescence and Raman spectra were found to be 0.3 and 0.4 mol%, respectively. Non-spherical shaped nanoparticles were found to optimize photoluminescence and Raman enhancement. The results demonstrated the effect of varying concentration of nanoparticles on the properties of the glasses due to the geometric effect of the nanoparticles especially on the enhancement of photoluminescence and Raman spectra.

ABSTRAK

KAJIAN KESAN KEPEKATAN ZARAH NANO EMAS TERHADAP SIFAT OPTIK DAN STRUKTUR BAGI KACA BERSTRUKTUR NANO

Peningkatan spektra fotoluminesen dan Raman bagi kaca yang mengandungi ion-ion bumi nadir dan zarah nano logam adalah sangat penting. Kebanyakan kajian hanya melaporkan pengaruh kepekatan zarah nano terhadap sifat-sifat struktur dan optik kaca tersebut tetapi tidak melaporkan kepelbagaian pada saiz dan bentuk zarah nano. Maka, kajian ini bertujuan untuk mengkaji kesan kepekatan zarah nano emas pada sifat struktur dan optik kaca. Tambahan pula, kesan geometri pada peningkatan fotoluminesen dan Raman dengan kepelbagaian zarah nano emas untuk mendapatkan peningkatan fotoluminesen dan Raman yang optimum dibincangkan. Satu siri kaca yang mempunyai komposisi $70TeO_2$*-20ZnO-10*Na_2O*-0.5*Er_2O_3*-(x)Au di mana x=0.0, 0.1, 0.2, 0.3 dan 0.4 mol% telah dikaji menggunakan teknik pembelauan sinar-X (XRD), spektroskopi ultraungu-cahaya nampak (UV-Vis), mikroskopi pancaran elektron (TEM), mikroskopi pengimbasan elektron (SEM), spektroskopi serakan tenaga sinar-X (EDX), spektroskopi fotoluminesen, spektroskopi Inframerah Pengubah Fourier (FTIR) dan spektroskopi Raman. Perubahan pada spektrum UV-Vis disebabkan oleh ikatan oksigen tidak bersambung yang dihasilkan oleh zarah nano emas apabila kepekatan zarah nano emas ditingkatkan. Imej TEM membuktikan kehadiran zarah nano emas yang mempunyai bentuk bukan sfera. Spektrum fotoluminesen menunjukkan peningkatan daripada kesan resonan plasmon permukaan (SPR) dan pemindahan tenaga daripada zarah nano emas kepada ion-ion erbium apabila kepekatan zarah nano emas ditingkatkan sehingga 0.3 mol%. Bagaimanapun, apabila kepekatan zarah nano emas melebihi 0.3 mol%, penurunan pada keamatan fotoluminesen berlaku disebabkan pemindahan tenaga daripada ion-ion erbium kepada zarah nano emas. Peningkatan spektrum Raman disebabkan oleh kesan SPR. Didapati kepekatan zarah nano emas untuk mengoptimumkan peningkatan fotoluminesen dan Raman ialah 0.3 dan 0.4 mol%. Zarah nano berbentuk bukan sfera mengoptimumkan peningkatan fotoluminesen dan Raman. Keputusan tersebut menunjukkan kesan kepekatan zarah nano terhadap sifat-sifat kaca disebabkan kesan geometri terutamanya pada peningkatan spektra fotoluminesen dan Raman.*

TABLE OF CONTENTS

Page

TITLE i

DECLARATION ii

CERTIFICATION iii

ACKNOWLEDGEMENT iv

ABSTRACT v

ABSTRAK vi

TABLE OF CONTENTS vii

LIST OF TABLES x

LIST OF FIGURES xi

LIST OF ABBREVIATIONS AND SYMBOLS xvii

LIST OF APPENDICES xxi

CHAPTER 1 : INTRODUCTION

1.1 Overview of the Study 1

1.2 Research Problem 3

1.3 Research Objectives 4

1.4 Scope of Study 4

1.5 Research Limitation 5

CHAPTER 2 : LITERATURE REVIEW

2.1 Introduction 6

2.2 Glass 7

2.2.1 Definition of Glass and Amorphous Solids 7

2.2.2 Structural Properties of Glass 8

2.2.3 Tellurite Glass 10

2.3 Glass Modifiers 12

2.4 Rare Earth Ions 14

2.5 Metallic Nanoparticles and Advantages of Glasses as Encapsulating Hosts 16

2.6 Aspect Ratio 20

2.7 Surface Plasmon and Surface Plasmon Resonance (SPR) 20

2.8 Band Gaps 23

2.9 Urbach Energy 25

2.10 Physical Principles of Experimental Techniques 26

2.10.1 X-ray Diffraction (XRD) 26

2.10.2 UV-Vis Spectroscopy 28

2.10.3 Photoluminescence Spectroscopy 29

2.10.4 Fourier Transform Infrared Spectroscopy (FTIR) 31

2.10.5 Raman Spectroscopy 33

2.10.6 Transmission Electron Microscopy (TEM) 35

2.10.7 Scanning Electron Microscopy (SEM) 36

2.10.8 Energy Dispersive X-ray Spectroscopy (EDX) 37

CHAPTER 3 : METHODOLOGY

3.1 Introduction 39

3.2 Sample Preparation 41

3.3 Sample Cutting Process 42

3.4 Sample Polishing Process 43

3.5 Sample Cleaning Process 45

3.6 Sample Characterization 45

3.6.1 X-Ray Diffraction (XRD) 45

3.6.2 UV-Vis Spectroscopy 47
3.6.3 Photoluminescence Spectroscopy 51
3.6.4 Fourier Transform Infrared Spectroscopy (FTIR) 56
3.6.5 Raman Spectroscopy 59
3.6.6 Transmission Electron Microscopy (TEM) 62
3.6.7 Scanning Electron Microscopy (SEM) 64
3.6.8 Energy Dispersive X-Ray Spectroscopy (EDX) 67

CHAPTER 4 : RESULTS AND DISCUSSIONS

4.1 Introduction 70
4.2 Structural Characterization 70
4.3 UV-Vis Spectroscopy 73
4.4 Transmission Electron Microscopy (TEM) 80
4.5 Scanning Electron Microscopy (SEM) 86
4.6 Energy Dispersive X-ray Spectroscopy (EDX) 87
4.7 Photoluminescence Spectroscopy 90
4.8 Fourier Transform Infrared Spectroscopy (FTIR) 100
4.9 Raman Spectroscopy 103
4.10 Summarization 107

CHAPTER 5 : CONCLUSION

5.1 Conclusion 110
5.2 Future Outlook 112

REFERENCES 113

APPENDICES 134

LIST OF TABLES

		Page
Table 2.1:	Values of n, and the types of optical transition that can occur in the material.	25
Table 3.1:	Glass samples and their corresponding compositions and glass codes.	41
Table 4.1:	Information about XRD peak and type of NPs in both samples.	72
Table 4.2:	Positions of UV-Vis absorption peaks and their corresponding transitions of Er^{3+} ions from ground state to excited states.	74
Table 4.3:	Direct optical band gap (E_{dir}, eV), indirect optical band gap (E_{indir}, eV) and Urbach energy (E_U, eV) of glass samples with different concentration of the Au NPs.	75
Table 4.4:	Variation of range of longitudinal axis, range of transverse axis, and mean aspect ratio of the Au NPs with increasing concentration of the Au NPs.	83
Table 4.5:	Effect of increasing the concentration of the Au NPs on estimated size and standard deviation of the Au NPs.	86
Table 4.6:	Excitation peaks and their corresponding transitions of Er^{3+} ion from ground state to excited energy levels.	90
Table 4.7:	Emission peaks and their corresponding peak labels, peak positions, transitions of Er^{3+} ion from an excited state to the ground state, and corresponding references.	91
Table 4.8:	Photoluminescence enhancement factor and concentration of Au NPs.	95
Table 4.9:	IR peaks and their corresponding IR peak assignment	102
Table 4.10:	Raman bands and their corresponding Raman band assignments.	105
Table 4.11:	Change of FWHM of Raman spectrum with increasing Au concentration.	106

LIST OF FIGURES

		Page
Figure 2.1:	(a) Orderly arrangement of a crystalline solid (crystalline silica); (b) random arrangement of particles in an amorphous solid (silica glass).	7
Figure 2.2:	Intensity distribution of X-ray diffraction pattern of: cristobalite (crystalline form of silicon dioxide) (top); and silica glass (amorphous form of silicon dioxide).	8
Figure 2.3:	Volume against temperature (in Kelvin) showing liquid, crystalline and glass states of a glass.	9
Figure 2.4:	Schematic diagram of TeO_2 unit in the structure of α-TeO_2.	10
Figure 2.5:	TeO_4 tbp, TeO_{3+1} and TeO_3 tp units of tellurite glass.	11
Figure 2.6:	A flow chart illustrating preparation of glasses by melt-quenching technique.	18
Figure 2.7:	Schematic diagram of Ostwald ripening process.	19
Figure 2.8:	Simplified classical pictures of interaction between incident electromagnetic field and surface plasmons of gold NPs.	21
Figure 2.9:	Schematic diagram of interaction between metallic NPs through field of different polarizations for (a) the first five metallic NPs interacting with each other is for transverse modes (b) the last five metallic NPs interacting with each other is for longitudinal modes.	23
Figure 2.10:	An illustration of (a) a direct transition and (b) an indirect transition.	24
Figure 2.11:	X-ray diffraction.	27
Figure 2.12:	Absorption spectrum and energy level of Er^{3+} ion in glass.	29
Figure 2.13:	(a) Excitation spectra; (b) emission spectra of Er^{3+} ions in Ge-Ga-S glass without silver NPs (shown by a black line and the label (a)) and the same type of glass with silver NPs	30

(shown by a blue line and the label (b)) as examples.

Figure 2.14: Partial energy level diagram of Er^{3+} ion in tungstate-tellurite glasses as an example. 31

Figure 2.15: An evanescent wave and how attenuated total reflection (ATR) occurs. 32

Figure 2.16: A schematic diagram of Rayleigh and Raman scattering of electromagnetic wave from matter where ω_1 is angular frequency of the incident electromagnetic wave while ω_M is shift of frequency after Raman scattering. 34

Figure 2.17: Rayleigh and Raman spectra of carbon tetrachloride (liquid). 34

Figure 2.18: Characteristic X-rays are emitted upon bombardment of an incident electron beam with an electron in an electron shell and subsequent ejection of the electron from electron shell. 38

Figure 3.1: A flow chart summarizing the methodology of the current study. 40

Figure 3.2: Glass samples and their corresponding labels based on their glass composition. 42

Figure 3.3: Glass cutter. 43

Figure 3.4: (a) Lam Plan 410 polishing pad; (b) Hyprez OS Type IV lubricant; (c) Hyprez Five Star 1 μm (blue), 3 μm (green) and 6 μm (yellow) diamond polishing paste. Blue, green and yellow diamond polishing paste are at bottom right, upper left and bottom left of Figure 3.3 (c) respectively. 44

Figure 3.5: A schematic diagram of X-ray diffractometer. 46

Figure 3.6: Philips X'Pert Pro X-ray diffractometer. 47

Figure 3.7: A schematic diagram of operation of UV-Vis spectrophotometer shows (a) a single-beam UV-Vis spectrophotometer; (b) a double-beam UV-Vis spectrophotometer. 48

Figure 3.8: (a) Sample holders for each sample; (b) preparation of a sample holder with a label (S1 for an instance) to hold its 50

corresponding glass sample (TZNE0.5 for an example) before characterization of the glass sample by using the UV-Vis spectroscopy.

Figure 3.9: (a) Agilent Technologies Cary 60 UV-Vis spectrophotometer; (b) internal structure of Agilent Technologies Cary 60 UV-Vis spectrophotometer. The hole to the sample detector is shown by a yellow oval mark. 50

Figure 3.10: Demonstration of putting a sample holder sandwiching a glass sample before the use the UV-Vis spectrophotometer. The exposed part of the glass sample that is covering the hole to a sample detector is shown by a yellow oval mark while the holt where an incident light beam is indicated by a blue oval mark. 51

Figure 3.11: A schematic diagram of photoluminescence spectroscopy. 52

Figure 3.12: (a) Agilent Technologies Cary Eclipse fluorescence spectrophotometer; (b) internal structure of Cary Eclipse fluorescence spectrophotometer. 54

Figure 3.13: (a) Illustration of inserting a glass sample labelled with S1 for TZNE0.5 into a sample holder as an example; (b) insertion of the sample holder containing the glass sample into a left hole of a cuvette holder inside the sample compartment before the use of the photoluminescence spectrophotometer. 55

Figure 3.14: A schematic diagram of Michelson interferometer that is part of FTIR. 56

Figure 3.15: Operation of ATR-FTIR. It shows an ATR crystal, and pressure being applied to a solid sample with a clamp for good sample/hot spot contact. 57

Figure 3.16: (a) Perkin Elmer Spectrum 100 FTIR spectrometer; (b) an ATR accessory (shown by a yellow oval mark); (c) structure of the ATR accessory and analysis of powdered glass sample (shown by another yellow oval mark) on an ATR diamond inside the ATR accessory. 58

Figure 3.17: Operation of ASEQ Raman spectrometer. 59

Figure 3.18: ASEQ Raman spectrometer. 61

Figure 3.19: (a) View of a sample chamber of ASEQ Raman spectrometer when the cover of the sample chamber was turned up; (b) a glass sample labelled with S1 for TZNE0.5 that was inserted into a sample holder before its characterization with Raman spectroscopy. 61

Figure 3.20: A schematic diagram of the structure of a transmission electron microscope. 62

Figure 3.21: (a) TEM with a model called Fei Tecnai Spirit at IPB of UMS; (b) ultrasonic bath used for sample preparation for TEM for current study; (c) 300-mesh copper grid with carbon film. 64

Figure 3.22: A schematic diagram of a scanning electron microscope. 65

Figure 3.23: FEI Quanta FEG 650 scanning electron microscope (SEM). 66

Figure 3.24: Quorum Q150T at USM for coating a glass sample with carbon via vacuum-evaporation method. 66

Figure 3.25: A schematic diagram of an EDX detector and its detection process. 68

Figure 3.26: Oxford instrument X-Max 50 mm^2 silicon drift detector (SDD) attached to FEI Quanta FEG 650 scanning electron microscope (SEM) at Makmal Pencirian Bahan Bumi (MPBB) of Universiti Sains Malaysia (USM). This figure is an example of Oxford instrument X-Max SDD which comes with 3 different areas (30, 50 or 80 mm^2) as taken from brochures about X-Max SDD. 69

Figure 4.1: X-ray diffraction pattern of glass samples. 71

Figure 4.2: A diagram showing estimation of FWHM of an XRD peak due to Au NPs in TZNE0.5-Au 0.4 as an example. 73

Figure 4.3: UV-Vis absorption spectra of glass samples. 74

Figure 4.4: (a) Tauc plot for determining direct optical band gap of glass samples; (b) illustration to calculating direct optical band gap of TZNE0.5 sample as an example after drawing a straight line from the linear part the graph of the sample. 76

Figure 4.5: (a) Tauc plot for determining indirect optical band gap of glass samples; (b) illustration to calculating indirect optical band gap of TZNE0.5 sample as an example after drawing a straight line from the linear part the graph of the sample. 76

Figure 4.6: A graph of direct optical band gap versus concentration of Au NPs. 77

Figure 4.7: A graph of indirect optical band gap versus concentration of Au NPs. 78

Figure 4.8: (a) A graph of ln α versus photon energy; (b) illustration of calculating Urbach energy of TZNE0.5 sample as an example after drawing a straight line from the linear part the graph of the sample. 79

Figure 4.9: A graph of Urbach energy versus concentration of Au NPs. 79

Figure 4.10: TEM image of Au NPs in (a) TZNE0.5-Au 0.2; (b) TZNE0.5-Au 0.3; (c) TZNE0.5-Au 0.4. 81

Figure 4.11: Distribution of aspect ratio fitted with lognormal distribution functions of Au NPs in (a) TZNE0.5-Au 0.2 (containing 90 NPs); (b) TZNE0.5-Au 0.3 (containing 37 NPs); (c) TZNE0.5-Au 0.4 (containing 60 NPs). The frequency of a histogram of each sample represents the number of Au NPs counted in TEM image of that sample. 82

Figure 4.12: Size distribution fitted with lognormal distribution functions of Au NPs in (a) TZNE0.5-Au 0.2 (containing 90 NPs); (b) TZNE0.5-Au 0.3 (containing 37 NPs); (c) TZNE0.5-Au 0.4 (containing 60 NPs). The frequency of a histogram of each sample represents the number of Au NPs counted in TEM image of that sample. 85

Figure 4.13: SEM image of TZNE0.5-Au 0.4 glass sample. 87

Figure 4.14: EDX spectrum of TZNE0.5-Au 0.4 glass sample. 89

Figure 4.15: Excitation spectra of TZNE0.5 glass sample with emission wavelength set to be 550 nm. 90

Figure 4.16: Emission spectrum of glass samples in wavelength of: (a) 300-520 nm, and (b) 530-640 nm respectively under 91

excitation wavelength of 522 nm.

Figure 4.17: (a) – (c) Graphs of photoluminescence enhancement factor versus concentration of the Au NPs. 96

Figure 4.18: Energy level diagram showing transitions of Er^{3+} ion between energy levels, interaction between Er^{3+} ion and gold NPs (Au NPs). GSA: ground state absorption; ESA: excited state absorption; LFE: local field enhancement; ET: energy transfer between Au NPs and Er^{3+} ion; ETU: energy transfer upconversion; NR: non-radiative decay; R: radiative decay. 99

Figure 4.19: ATR-FTIR spectra of glass samples. 101

Figure 4.20: Raman spectra of glass samples. It also shows FWHM of TZNE0.5 as an example to indicate width of its Raman spectrum. 104

Figure 4.21: Raman spectrum of TZNE0.5-Au 0.4 showing Raman bands after performing deconvolution with Gaussian peaks. 105

Figure 4.22: A graph of FWHM of Raman spectrum of the glass sample against concentration of the Au NPs. 107

LIST OF ABBREVIATIONS AND SYMBOLS

TeO_2	-	Tellurium dioxide
Na_2O	-	Sodium oxide
ZnO	-	Zinc oxide
Er_2O_3	-	Erbium (III) oxide
Au	-	Gold element
Te	-	Tellurium element
Zn	-	Zinc element
Na	-	Sodium element
Er	-	Erbium
O	-	Oxygen element
C	-	Carbon element
SPR	-	Surface plasmon resonance
XRD	-	X-ray diffraction
n	-	Order of diffraction based on Bragg's law of XRD
d	-	Spacing between two successive lattice planes of a crystal based on Bragg's law of XRD
θ	-	Angle of incidence of X-ray based on Bragg's law of XRD
λ	-	Wavelength of an electromagnetic wave (for the case of spectroscopy) or an electron (for the case of de Broglie equation for operation of TEM) or a characteristic X-ray emitted by an atom (for the case of analysis of EDX)
2θ	-	Angle between an X-ray source and an X-ray detector
β	-	Full-width at half-maximum (FWHM) of XRD peak due to

		crystallite based on Debye-Scherrer equation
Å	-	Angstrom
Cu	-	Copper
Kα	-	K alpha of X-ray emitted by copper atoms in copper anode in XRD of current study
Kα_1	-	K alpha 1 (One of K alpha X-ray doublets emitted by copper atoms in copper anode in XRD of current study)
Kα_2	-	K alpha 2 (One of K alpha X-ray doublets emitted by copper atoms in copper anode in XRD of current study)
nm	-	Nanometer
UV-Vis	-	Ultraviolet-visible obtained from ultraviolet-visible spectroscopy
A	-	Absorbance of a glass sample
T	-	Transmittance of a glass sample given by $T = I/I_0$
a.u.	-	Arbitrary unit (a unit used by absorbance for UV-Vis spectra, intensity of excitation and emission spectra of photoluminescence spectroscopy, and intensity of Raman spectra)
α	-	Absorption coefficient
d	-	Thickness of a glass sample
I_0	-	Intensity of incident light on a glass sample
I	-	Intensity of transmitted light through a glass sample
dI	-	The differential of intensity of light to represent the change of intensity of light as the light passes through the glass sample
dx	-	The differential of distance travelled by light inside the glass sample to represent the amount of distance travelled by the light inside the glass sample

h	-	Planck's constant equal to 6.626×10^{-34} J s where J s is pronounced as Joule second
ΔL	-	Change in orbital angular momentum L during a transition between two energy levels
ΔS	-	Change in spin angular momentum S during a transition between two energy levels
ΔJ	-	Change in total angular momentum J during a transition between two energy levels where $J = L + S$
eV	-	Electron volt (a unit used to quantify optical band gaps of glass samples and Urbach energy for UV-Vis spectral analysis)
$\hbar$	-	Planck's constant h divided by 2π
c	-	Speed of light in vacuum equal to 3.0×10^{8} m/s
ω	-	Angular frequency of light, $\omega = 2\pi f$ with f representing frequency of light
E_{opt}	-	Optical band gap
n	-	Exponent of a factor $(\hbar\omega - E_{opt})$ that depends on type of optical transition based on Davis-Mott theory
E_{dir}	-	Direct optical band gap
E_{indir}	-	Indirect optical band gap
E_U	-	Urbach energy
B	-	Energy-independent constant in mathematical expression of Davis-Mott theory
cm^{-1}	-	Per unit centimeter (a unit of energy for energy level diagram in section of photoluminescence spectroscopy; a unit of wavenumber for FTIR, and a unit of Raman shift for Raman spectroscopy)
ATR	-	Attenuated total reflection

FTIR	-	Fourier Transform Infrared spectroscopy
n_i	-	Refractive index of a first medium that an infrared light is incident on based on principle of ATR-FTIR
n_r	-	Refractive index of a second medium that an infrared light passes through based on principle of ATR-FTIR
θ_i	-	Angle of incidence of an infrared light based on principle of ATR-FTIR
θ_r	-	Angle of refraction of an infrared light based on principle of ATR-FTIR
TEM	-	Transmission electron microscopy
p	-	Momentum of an electron based on de Broglie's equation in physical principle of TEM
U	-	Electrostatic potential difference (or accelerating voltage) to accelerate electrons emitted by electron guns of TEM
μ	-	Location parameter of a lognormal distribution function
σ	-	Shape parameter of a lognormal distribution function
SEM	-	Scanning electron microscopy
EDX	-	Energy dispersive X-ray spectroscopy; an abbreviation with the same meaning as that of EDS
E_i	-	Energy of an initial state of an electron of a given atom based on physical principle of EDX
E_f	-	Energy of a final state that has lower energy than that of an initial state of an electron of a given atoms based on physical principle of EDX
E_0	-	Beam energy of an incident electron beam in SEM and EDX
keV	-	Kilo electron volt (used in EDX spectrum in the current study)

LIST OF APPENDICES

		Page
Appendix A:	Analysis of XRD peak due to Au NPs shown by (a) XRD pattern of TZNE0.5-Au 0.2 glass sample with an oval-shaped mark showing presence of the Au NPs due to diffraction of X-ray by them; (b) a diagram about estimating FWHM of an XRD peak due to the Au NPs in that glass sample; (c) a magnified view of two points for estimating the FWHM of the XRD peak.	134
Appendix B:	Estimation of size of the Au NPs in TZNE0.5-Au 0.2 glass sample in Appendix A based on Table 1 (a), (b) and (c). Table 1 (a) shows parameters of an XRD peak for estimating the FWHM of the XRD peak and the size of the Au NPs in TZNE0.5-Au 0.2 glass sample. Table 1 (b) indicates FWHM and position of the XRD peak and their respective uncertainties for TZNE0.5-Au 0.2 glass sample where average and standard deviation are calculated with Microsoft Excel. Table 1 (c) depicts calculation of estimated size of the Au NPs and its uncertainty for TZNE0.5-Au 0.2 glass sample by using Debye-Scherrer equation given by equation (1), and equation (2) respectively.	135
Appendix C:	Analysis of XRD peak due to Au NPs shown by (a) XRD pattern of TZNE0.5-Au 0.4 glass sample with an oval-shaped mark showing presence of the Au NPs due to diffraction of X-ray by them; (b) a diagram about estimating FWHM of an XRD peak due to the Au NPs in that glass sample; (c) a magnified view of two points for estimating the FWHM of the XRD peak.	137
Appendix D:	Estimation of size of the Au NPs in TZNE0.5-Au 0.4 glass sample in Appendix C based on Table 2 (a), (b) and (c). Table 2 (a) shows parameters of an XRD peak for estimating the FWHM of the XRD peak and the size of the Au NPs in TZNE0.5-Au 0.4 glass sample.	138

Table 2 (b) indicates FWHM and position of the XRD peak and their respective uncertainties for TZNE0.5-Au 0.4 glass sample where average and standard deviation are calculated with Microsoft Excel.

Table 2 (c) depicts calculation of estimated size of the Au NPs and its uncertainty for TZNE0.5-Au 0.4 glass sample by using Debye-Scherrer equation given by equation (1), and equation (2) respectively.

Appendix E: Result of nonlinear curve fit applied to a graph of direct optical band against concentration of the gold nanoparticles (Au NPs). Table 3 depicts equation of fitting function to fit the experimental data in Figure 4.6 and its parameters where y represents direct optical band gap E_{dir} while x represents concentration of the Au NPs in the unit of mol%. 140

Appendix F: Result of nonlinear curve fit applied to a graph of indirect optical band against concentration of the gold nanoparticles (Au NPs). Table 4 depicts equation of fitting function to fit the experimental data in Figure 4.7 and its parameters where y represents direct optical band gap E_{indir} while x represents concentration of the Au NPs in the unit of mol%. 142

Appendix G: Result of nonlinear curve fit applied to a graph of Urbach energy against concentration of the gold nanoparticles (Au NPs). Table 5 depicts equation of fitting function to fit the experimental data in Figure 4.9 and its parameters where y represents Urbach energy E_U while x represents concentration of the Au NPs in the unit of mol%. 144

Appendix H: Results of testing for normality using level of significance equal to 0.05 for aspect ratio distribution of Au NPs in: (a) TZNE0.5-Au 0.2; (b) TZNE0.5-Au 0.3; (c) TZNE0.5-Au 0.4. 146

Appendix I: Probability plot for aspect ratio distribution of Au NPs in: (a) TZNE0.5-Au 0.2; (b) TZNE0.5-Au 0.3; (c) TZNE0.5-Au 0.4 where the red solid lines (reference lines) in these figures are the normal distribution functions for each sample. 147

Appendix J: Probability plot for aspect ratio distribution of Au NPs in: (a) TZNE0.5-Au 0.2; (b) TZNE0.5-Au 0.3; (c) TZNE0.5-Au 0.4 where the red solid lines (reference lines) are lognormal 148