PHYSICAL, STRUCTURAL AND OPTICAL PROPERTIES OF ERBIUM DOPED TELLURITE GLASS WITH COPPER OXIDE NANOPARTICLES EMBEDMENT

NUR E’ZZATI NABILAH SYAQILAH BINTI ABDUL HAMID

UNIVERSITI TEKNOLOGI MALAYSIA

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Specially dedicated to

My beloved father and mother

Abdul Hamid Bin Bagong

Norwati Binti Husin

My dearest siblings

Along, Nazrah, Jeha

My dedicated lectures,

My supportive friends,

Maisalmah, Zulaiha, Fiona, Alina, Syifa, SOTO members

My labmates,

And all my friends.

Thank you so much….

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ABSTRACT

Two series of glass with composition of (70–x)TeO_2 – 10ZnO – 10MgO – 10 Na_2O – (x)Er_2O_3 where $0.0 \leq x \leq 2.0$ mol% and (69–y)TeO_2 – 10ZnO – 10MgO – 10Na_2O – 1Er_2O_3 – (y)CuO where $0.05 \leq y \leq 1.50$ mol% are prepared using melt quenching technique. The physical properties are measured in terms of glass density, ionic packing density and molar volume while the glass hardness is determined by using Vickers Microhardness. The amorphous nature of the glass is determined by X-ray Diffractometer (XRD). The occurrence of copper oxide nanoparticles (CuO NPs) is verified by using High-Resolution Transmission Electron Microscopy (HRTEM). The structural and optical properties are characterized by using Fourier Transform Infrared (FTIR), UV-Visible-NIR spectrophotometer and Photoluminescence (PL) spectrometer, respectively. The glass density, molar volume, ionic packing density and hardness are found in the range of (4.799 – 4.951) g cm^{-3}, (26.575 – 27.202) cm^3 mol^{-1}, (0.457 – 0.467) and (235 – 349), respectively. It is found that all glasses are amorphous in nature while the presence of CuO NPs with lattice spacing 0.23 nm at (111) plane is verified by HRTEM analysis. FTIR spectrum exhibited three major bands which are attributed to Te – O – Te, TeO_4 and TeO_3 in the range of 400 – 4000 cm^{-1}. Meanwhile, UV-Visible-NIR spectra reveal nine absorption peaks centered at about 407, 449, 488, 522, 545, 652, 799, 976 and 1530 nm originating from $^4I_{15/2}$ to $^2H_{9/2}$, $^4F_{5/2}$, $^4F_{7/2}$, $^2H_{11/2}$, $^4S_{3/2}$, $^4F_{9/2}$, $^4I_{9/2}$, $^4I_{11/2}$ and $^4I_{13/2}$ transitions respectively. Down-conversion emission spectra under 380 nm excitations shows four peaks centered at about 408, 530, 550, and 660 nm allocated to $^4F_{3/2} \rightarrow {}^4I_{15/2}$, $^2H_{11/2} \rightarrow {}^4I_{15/2}$, $^4S_{3/2} \rightarrow {}^4I_{15/2}$ and $^4F_{9/2} \rightarrow {}^4I_{15/2}$ transition. Meanwhile, up-conversion emission spectra under 980 nm excitations shows peaks three centered at about 530, 550, and 660 nm allocated to $^2H_{11/2} \rightarrow {}^4I_{15/2}$, $^4S_{3/2} \rightarrow {}^4I_{15/2}$ and $^4F_{9/2} \rightarrow {}^4I_{15/2}$ transition.

ABSTRAK

Dua siri kaca dengan komposisi (70–x) TeO_2 – 10 ZnO – 10 MgO – 10 Na_2O – (x)Er_2O_3 dengan $0.0 \leq x \leq 2.0$ mol% dan (69–y)TeO_2 – 10ZnO – 10MgO – 10Na_2O – 1Er_2O_3 – (y)CuO dengan $0.05 \leq y \leq 1.50$ mol% disediakan menggunakan teknik pelindap-kejutan leburan. Ciri-ciri fizikal diukur dari segi ketumpatan kaca, isipadu molar dan ketumpatan kepadatan ionik sementara itu kekerasan kaca ditentukan dengan menggunakan kekerasan mikro Vikers. Sifat semulajadi amofus kaca ditentukan menggunakan pembelauan sinar-X (XRD). Kewujudan nanopartikel kuprum oksida (CuO NPs) disahkan dengan menggunakan transmisi electron mikroskopi yang beresolusi tinggi (HRTEM). Sifat-sifat struktur dan optikal dicirikan dengan menggunakan spektroskopi Transformasi Fourier infra merah (FTIR), spektofotometer UV-Visible-NIR dan spectrometer fotoluminesen (PL). Ketumpatan kaca, isipadu molar, ketumpatan padatan ionic dan kekerasan masing-masing didapati dalam julat (4.799 – 4.951) g cm^{-3}, (26.575 – 27.202) cm^3 mol^{-1}, (0.457 – 0.467) dan (235 – 349). Didapati semua kaca adalah adalah bersifat amofus sementara kewujudan CuO NPs dengan jarak kekisi 0.23 nm pada satah (111) disahkan dengan menggunakan analisis HRTEM. Spektrum FTIR memaparkan tiga jalur utama iaitu Te – O – Te, TeO_4 dan TeO_3 dalam julat 400 – 4000 cm^{-1}. Sementara itu, spektrum UV-Visible-NIR mendedahkan sembilan puncak serapan berpusat di sekitar 407, 449, 488, 522, 545, 652, 799, 976 and 1530 nm yang masing-masing berasal dari transisi $^4I_{15/2}$ kepada $^2H_{9/2}$, $^4F_{5/2}$, $^4F_{7/2}$, $^2H_{11/2}$, $^4S_{3/2}$, $^4F_{9/2}$, $^4I_{9/2}$, $^4I_{11/2}$ dan $^4I_{13/2}$. Spektra pancaran penukaran turun pada pengujaan 380 nm menunjukkan empat puncak berpusat di sekitar 408, 530, 550, and 660 nm dengan masing-masing berasal dari transisi $^4F_{3/2} \rightarrow {}^4I_{15/2}$, $^2H_{11/2} \rightarrow {}^4I_{15/2}$, $^4S_{3/2} \rightarrow {}^4I_{15/2}$ dan $^4F_{9/2} \rightarrow {}^4I_{15/2}$. Sementara itu, spektra pancaran penukaran naik pada pengujaan 980 nm menunjukkan tiga puncak berpusat di sekitar 530, 550, and 660 nm dengan masing-masing berasal dari transisi $^2H_{11/2} \rightarrow {}^4I_{15/2}$, $^4S_{3/2} \rightarrow {}^4I_{15/2}$ dan $^4F_{9/2} \rightarrow {}^4I_{15/2}$.

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LIST OF ABBREVATIONS

BO	-	Bridging oxygen
CB	-	Conduction band
CCD	-	Charge-couple device
CuO NPs	-	Copper oxide nanoparticles
DC	-	Down-conversion
Er_2O_3	-	Erbium oxide
eV	-	Electron Volt
FFT	-	Fast Fourier Transform
FTIR	-	Fourier Transform Infrared
g	-	gram
HRTEM	-	High-Resolution Transmission Electron Microscopy
KBr	-	Potassium Bromide
LSPR	-	Localized surface plasmon resonance
MgO	-	Magnesium Oxide
NR	-	Non-radiative
Na_2O	-	Sodium Oxide
NBO	-	Non-bridging Oxygen
NIR	-	Near Infrared
nm	-	Nanometer
PL	-	Photoluminescence
RE	-	Rare earth
TeO_2	-	Tellurium Dioxide
tbp	-	Trigonal bipyramids

tp	-	Trigonal pyramid
UV	-	Ultraviolet
UC	-	Up-conversion
Vis	-	Visible
VB	-	Valence band
XRD	-	X-ray Diffraction
Xe	-	Xenon
ZnO	-	Zinc oxide

LIST OF SYMBOLS

θ	-	Bragg angle
Å	-	Angstrom
A	-	Absorbance
α_e	-	Electronic polarizability
α	-	Absorption coefficient
β	-	Nephelauxetic ratio
$\bar{\beta}$	-	Nephelauxetic effect
c	-	Speed of light
d	-	Indention diagonal length / interatomic spacing
E	-	Energy
E_g	-	Optical band gap energy
E_u	-	Urbach energy
F	-	Test load
h	-	Planck constant
H	-	Hardness
H_V	-	Vickers hardness
I	-	Intensity of light transmitted from sample
I_o	-	Intensity of light entering the sample
M	-	Molecular weight
n	-	Refractive index
N_A	-	Avogadro's number
ρ_l	-	Density in immersion fluid
ρ	-	Density
ρ_a	-	Density of air

r_M	-	Ionic radius of metal
r_o	-	Ionic radius of oxygen
T_g	-	Glass Transition temperature
T_m	-	Glass Melting temperature
T_c	-	Glass Crystallization temperature
T	-	Transmittance
$\bar{v}$	-	Wavenumber
v	-	Frequency
V_M	-	Molar volume
V_i	-	Ionic packing density
v_a	-	Wavenumber in aquo ion system
v_c	-	Wavenumber in host matrix
W_a	-	Weight of sample in air
W_l	-	Weight of sample in immersion liquid
x_i	-	Molar Fraction
δ	-	Bonding parameter
λ	-	Wavelength

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CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Nowadays, glass plays important role in our daily life. It has attracted strong attention in both technologically and scientifically. The evolution of glass expended and the advent of technology provide new opportunities for glass applications such as in electronics and optical fibres for telecommunications industry. Glasses can be defined as an amorphous solid completely lacking in long range, periodic atomic structure and more important exhibits a region of glass transformation behaviour [1]. It is hard, brittle and usually transparent. It also can be obtained by quenching of melts or rapid cooling [2]. Lately, an extensive research has been done to obtain the best compositions for host, glass modifier and rare earth (RE) to improve the properties of the glass. The use of tellurite glass as a host material is demanded for the past few years due to its various and unique properties compare to other oxide glasses. It has high refractive index, good transmission in infrared region, low melting temperature (~800 °C) and low phonon energy that make tellurite glass suitable to be used in laser applications [3]. Moreover, tellurite glass has Te-O bond that can break easily and suitable as a host to be doped with heavy metal or RE ions [4].

However, under normal quenching conditions, pure tellurium dioxide (TeO_2) cannot easily form glasses by itself [5]. By introducing other oxide name as glass modifiers such as alkaline oxide, alkaline earth oxide or transitions metal oxides, high transparent of tellurite glass can be obtained. Among alkali oxides, sodium oxide (Na_2O) is classified as the best modifier due to the most glass forming ability [6]. Meanwhile, addition of zinc oxide (ZnO) as a modifier improved the opacity, chemical durability and melting properties of glass that is necessary for optical properties in making glass filter [7] and increase the glass transition temperature (T_g) of the glass [8]. Furthermore, addition of another modifier which is magnesium oxide (MgO) disturb the glass network and promotes the formation of large number of non-bridging oxygen (NBO) groups [9].

Tellurite glass doped with RE elements has great interest on their properties that leads toward worldwide applications [10]. Er^{3+} is one of the most important RE materials used in the research. Introduction of erbium oxide (Er_2O_3) help to improve the optical properties of tellurite glasses. By using high concentrations of RE ions luminescence enhancement can be obtained [11]. Tellurite glass doped with erbium oxide are extensively used in optical and photonic applications such as in making waveguide amplifiers and optical fibre [12]. In addition, Yousef *et al.* reported Er^{3+} doped tellurite glasses which are very useful for nonlinear optical device and up-conversion lasers [4]. Thus, Er^{3+} ions doped tellurite glass will present good performance in optical applications. On the other hand, some of the researcher reported that high concentrations of RE ions can cause luminescence quenching. So, the content of RE ions must be low in order to enhance the optical characteristic of the glass. For this reason, low concentration of RE ions doped to the glass consist of nanoparticles (NPs) are of considerable interest [13].

Addition of NPs into the glass network leads to the strong structural changes of the glass as a result of changing the environment felt by RE ions. Thus, introduction of NPs help to modify the spectral behaviour and improved the luminescence efficiency of the glasses. NPs play a role as a transmitter, meanwhile excited Er^{3+} ions become emitters due to the energy transfer between NPs and Er^{3+}

ions [14]. Transition metal ions are the simplest and perfect dopants for glass since they are identified by the presence of partly filled d shells and are strongly related with the magnetic, electrical and optical features of glasses [15]. Recently, transition metal oxide such as copper oxide (CuO) are of considerable interest due to its behaviour that present two different valence states in the glass system which are Cu^{1+} monovalent and Cu^{2+} divalent where Cu^{2+} ions present as the stable element [16]. Interestingly, luminescence quenching of Cu^{2+} ions with various RE-doped glasses have attracted attention. Addition of CuO NPs into the glass network make the glass electrically good semiconductor and super-paramagnetic [15]. CuO NPs have good thermal stability and low bulk resistivity despite of its cost effective material compare to silver and gold [17]. CuO NPs doped glasses have received significant attention in the field of materials science in their potential for various optical device applications such as lighting systems, optical fibres and photonic waveguides [18].

1.2 Problem Statement

It is well reported that RE ions doped glasses have many applications and become interest based on active glass material especially in optical devices in laser applications, waveguide amplifier and fibre for optical transmission [5]. In the last decade, luminescence properties of RE doped tellurite glass have been investigated. Increase the concentrations of Er^{3+} ions causing quenching effect through energy transfer between Er^{3+} ions. Despite much effort, optimization the luminescence enhancement of Er^{3+} ions remains challenges and need further improvement. Therefore, it is important to know the best composition of the glass. Thus, the luminescence properties of the glass can be enhanced [13].

Glasses containing RE ions and metallic NPs attracted much attention due to its enhancement in optical properties [19]. Many studies had been done involving transition metal ions with various glasses. CuO NPs is one of the transition metal that is practically importance due to its unique properties [17]. Yet, most of the study focuses of doping gold and silver NPs to the host glass but embedment of CuO NPs doped glass are far from being understood and require further attention.

In addition, interactions of CuO NPs with the atoms inside the glass matrix embedded into Er^{3+} doped tellurite glass are at present lacking in the literature and not much explored. The detailed studies on the effect of CuO NPs on the absorption and luminescence emission are important to be determined and should be done for further investigation. Therefore, due to the lack of reports in this study, it is very important to study the effect of CuO NPs doped with RE especially Er^{3+} doped tellurite glass in the physical, structural and optical properties to give better information with beneficial features.

1.3 Objective of the Study

The objectives of this study are:

i. To prepare two series of RE doped tellurite glass of composition (70–x–y)TeO_2 – 10ZnO – 10MgO – 10Na_2O – (x)Er_2O_3 – (y)CuO with and without CuO NPs by melt quenching technique.

ii. To verify the presence of CuO NPs nucleated inside the glass.

iii. To determine the influence of different concentration of Er^{3+} ions and CuO NPs on the physical, structural and optical properties into tellurite glass.

1.4 Scope of the Study

In order to achieve the objectives, this study has been divided into several scopes as follows:

i. Preparations of two glass series via melt quenching technique.
   (a) Glass with different concentration of RE with molar composition (70-x)TeO_2 – 10ZnO –10MgO – 10Na_2O – (x)Er_2O_3 where ($0.0 \leq x \leq 2.0$ mol%).
   (b) Glass with different concentrations of CuO NPs with molar composition (69-y)TeO_2 – 10ZnO – 10MgO –10Na_2O – 1Er_2O_3 – (y)CuO where ($0.05 \leq y \leq 1.5$ mol%).

ii. Determination of the amorphous nature of glass using X-ray Diffraction (XRD).

iii. Determination of physical and mechanical properties of both glass series.

iv. Confirmation of the existence CuO NPs using HRTEM.

v. Determination of the types of bonding vibration in glass with and without CuO NPs using Fourier Transform Infrared spectroscopy (FTIR).

vi. Determination of the influence of different concentration of Er^{3+} ions and CuO NPs on the absorption spectra using UV-Vis-NIR spectroscopy and emission spectra using Photoluminescence spectroscopy (PL).

1.5 Significance of the Study

Studies on the glass material become important due to the large potential in diverse applications such as in optics and laser system. In this study, the role of Er^{3+} doped tellurite glass embedded with CuO NPs will be explained by controlling and optimizing the content of RE and NPs. Understanding the physical, structural and optical properties of this glass is important to determine the optimum composition of CuO NPs. This is due to the CuO NPs present their unique properties with extremely small dimensions and magnetic behaviour. Therefore, this research is done to give better understanding and to enhance the efficiency of tellurite glass for development wide range applications especially in nano-glass technology.

REFERENCES

1. James, E. S. (2005). *Introduction to Glass Science and Technology*, The Royal Society of Chemistry.
2. Aldabert, F. (1993). *Amorphous Inorganic Materials and Glasses.* VCH Verlagsgesellschaft mbH.
3. Yusoff, N. M. and Sahar, M. R. (2015). The Incorporation of Silver Nanoparticles in Samarium doped Magnesium Tellurite Glass: Effect on the Characteristic of Bonding and Local Structure. *Phys. B Condens. Matter*. 470–471: 6–14.
4. Yousef, E. S., Elokr, M. M., Aboudeif, Y. M. (2016). Optical, Elastic Properties and DTA of TNZP Host Tellurite Glasses doped with Er^{3+} ions. *J. Mol. Struc.* 1108: 257–262.
5. Jlassi, I., Elhouichet, H., Hraiech, S., Ferid. M. (2012). Effect of Heat Treatment on the Structural and Optical Properties of Tellurite Glasses doped Erbium. *J. Lumin.* 32: 832–840.
6. Mawlud, S. Q., Ameen, M. M., Sahar, M. R., Mahraz, Z. A. S., Ahmed, K. F. (2017). Spectroscopic properties of Sm^{3+} doped Sodium–Tellurite Glasses: Judd-Ofelt Analysis. *Opt. Mater. (Amst).* 69: 318–327.
7. Rayan, D. A., Elbashar, Y. H., Rashad, M. M., El-Korashy, A. (2013). Optical Spectroscopic Analysis of Cupric Oxide doped Barium Phosphate Glass for Bandpass Absorption Filter. *J. Non. Cryst. Solid.* 382: 52–56.
8. Linda, D., Duclère, J. R., Hayakawa, T., Dutreilh-Colas, M. (2013). Optical Properties of Tellurite Glasses Elaborated within the TeO_2 – Tl_2O– Ag_2O and TeO_2 – ZnO – Ag_2O Ternary Systems. *J. Alloys Compd.* 561, 151–160.
9. Ahmadi, F., Hussin, R., Ghoshal, S. K. (2016). Judd-Ofelt Intensity Parameters of Samarium-doped Magnesium Zinc Sulfophosphate Glass. *J. Non. Cryst. Solids*. 448: 43–51.
10. Sazali, E. S., Sahar, M. R., Ghoshal, S. K., Arifin, R. (2014). Optical Properties of Gold Nanoparticle Embedded Er^{3+} doped Lead-Tellurite Glasses. *J. Alloys Comp.* 607: 85–90.
11. Azlan, M. N., Halimah, M. K., Sidek, H. A. A. (2017). Linear and Nonlinear Optical Properties of Erbium doped Zinc Borotellurite Glass System. *J. Lumin.* 181: 400–406.

12. Savikin, A. P., Grishin, I. A., Sharkov, V. V., Budruev, A. V. (2013). Luminescence of Erbium Ions in Tellurite Glasses. *J. Solid State Chem.* 207: 80–86.

13. Singh, S. K., Giri, N. K., Rai, D. K., Rai, S. B. (2010). Enhanced Upconversion Emission in Er^{3+}-doped Tellurite Glass Containing Silver Nanoparticles. *Solid State Sci.* 12: 1480–1483.

14. Awang, A., Ghoshal, S. K., Sahar, M. R., Arifin, R., Nawaz, F. (2014). Non-spherical Gold Nanoparticles Mediated Surface Plasmon Resonance in Er^{3+} doped Zinc-Sodium Tellurite Glasses: Role of heat treatment. *J. Lumin.* 149: 138–143.

15. Hasim, N. B. (2017). Effects of Embedded Silver Nanoparticles on Physicals and Optical Properties of Erbium and Neodymium Codoped Lithium Niobate Tellurite Glass. Universiti Teknologi Malaysia.

16. Bhogi, A., Vijaya Kumar, R., Kistaiah, P. (2015). Effect of Alkaline Earths on Spectroscopic and Structural Properties of Cu^{2+} ions–doped lithium borate glasses. *J. Non. Cryst. Solids.* 426: 47–54.

17. Barna, S. F., Ramanathan, A., Jacobs, K. E., Mensing, G. (2017). Solid State Electrochemical Direct Writing of Copper Nanostructures on an Ion Conductive Phosphate Glass Using Atomic Force Microscopy. *Procedia Manuf.* 10: 641–651.

18. Jiménez, J. A. (2015). Samarium (III) as luminescent Probe for Copper(II). *J. Lumin.* 161: 352–357.

19. Sastry, S. S. and Venkateswara, B. R. (2014). Spectroscopic Studies of Copper doped Alkaline Earth Lead Zinc Phosphate Glasses. *Phys. B Phys. Condens. Matter*. 434: 159–164.

20. Hajer, S. S., Halimah, M. K., Azmi, Z., Azlan, M. N. (2014). Optical properties of Zinc-Borutellurite doped Samarium. 11: 553–566.

21. Vogel, W. (1994). *Glass Chemistry*. Springer-Verlag, Germany.

22. Aldabert F. (1993). *Amorphous Inorganic Materials and Glasses*. VCH Verlagsgesellschaft mbH.

23. Popov, A. Disodered Semiconductor: Physics and Applications. USA: Pan Standford Pte. Ltd. 2011.

24. Sestak, J., Mares, J. J., Hubik, P. (2011). *Glassy, Amorphous and Nano-Crystalline Materials*. Springer.

25. Hussain, N. S. and Santos, J.D.D.S. (2008). *Physics and Chemistry of Rare-Earth Ions Doped Glasses*. Trans Tech Publications Ltd.

26. Yamane, M. and Asahara, Y. (1996). Glasses for Photonic.

27. Vijaya, N. and Jayasankar, C. K. (2013). Structural and Spectroscopic Properties of Eu^{3+}-doped Zinc Fluorophosphate Glasses. *J. Mol. Struct.* 1036: 42–50.

28. Paul, A. (1982). *Chemistry of Glasses*. Chapman and Hall Ltd.

29. Smith, W.F. and Hashemi, J. (2011). *Foundations of Materials Science and Engineering*. McGraw-Hill Companies.

30. Bagnall, K. W. (1966). *The Chemistry of Selenium, Tellurium and Polonium*. Elsivier Publishing Company.

31. El-mallawany, R. A. H. (2002). T*ellurite Glasses Handbook Phsical Properties and Data*. CRC PRESS.

32. Petragnani, N. and Stefani, H. A. (2007). *Tellurium in Organic Synthesis*. Academic Press.

33. Bilir, G., Ozen, G., Tatar, D., Ovecoglu, M. L. (2011). Judd–Ofelt Analysis and Near Infrared Emission Properties of the Er^{3+} Ions in Tellurite Glasses Containing WO_3 and CdO. *Opt. Commun.* 284: 863–868.

34. di Prátula, P.E., Terny, S., Sola, M. E., Frechero, M. A. (2017). Ionic Conductivity Enhancement Achieved by the Incorporation of ZnO in a Lithium Tellurite Glass. *J. Non. Cryst. Solids.* 461: 18–23.

35. Wu, L., Huang, B., Yang, F., Qi, Y. (2015). Heat-treating Temperature Dependent 1.53 μm Fluorescence Enhancement in Er^{3+}/Yb^{3+} codoped Tellurite Glasses Containing Silver NPs. *Mater. Lett.* 152: 220–223.

36. Selvaraju, K. and Marimuthu, K. (2012). Structural and Spectroscopic Studies on Concentration Dependent Er^{3+} doped Boro-Tellurite Glasses. *J. Lumin.* 132: 1171–1178.

37. Schlager, N., Weisblatt, J., Newton, D. E. (2006). *Chemical Compounds*. Thomson Gale.

38. Schlager, N., Weisblatt, J., Newton, D.E. (2006). *Chemical Compounds*. Farmington Hills,

39. Grelowska, I., Reben, M., Burtan, B., Sitarz, M. (2016). Structural and Optical Study of Tellurite Barium Glasses. *J. Mol. Struct.* 1126: 219–225.

40. Yoshida, S., Matsuoka, J., Soga, N. (2001). Crack Growth Behavior of Zinc tellurite Glass With or Without Sodium Oxide. *J. Non. Cryst. Solids.* 279: 44–50.

41. Kaur, A., Khanna, A., Pesquera, C., Gonzalez, F., Sathe, V. (2010). Preparation and characterization of Lead and Zinc Tellurite Glasses. *J. Non. Cryst. Solids*. 356: 864–872.

42. Kaur, A., Khanna, A., Aleksandrov, L. I. (2017). Structural, Thermal, Optical and Photo-luminescent Properties of Barium Tellurite Glasses doped with Rare-Earth Ions. *J. Non. Cryst. Solids.* 476: 67–74.

43. Sabadel, J. C., Armand, P., CachauHerreillat, D., Baldeck, P. (1997). Structural and Nonlinear Optical Characterizations of Tellurium Oxide-Based Glasses: TeO_2-BaO-TiO_2. *J. Solid State Chem.* 132: 411–419.

44. Awang, A., Ghoshal, S. K., Sahar, M. R., Arifin, R. (2015). Gold Nanoparticles Assisted Sructural and Spectroscopic Modification in Er^{3+}-doped Zinc Sodium Tellurite Glass. *Opt. Mater. (Amst).* 42: 495–505.

45. Dousti, M.R., Ghoshal, S. K., Amjad, R. J., Sahar, M. R. (2013). Structural and Optical Study of Samarium doped Lead Zinc Phosphate Glasses. *Opt. Commun.* 300: 204–209.

46. Amjad, R. J., Dousti, M. R., Sahar, M. R., (2015). Spectroscopic Investigation and Judd-Ofelt Analysis of Silver Nanoparticles Embedded Er^{3+}-doped Tellurite Glass. *Curr. Appl. Phys.* 15: 1–7.

47. Nandi, P. and Jose, G. (2006). Spectroscopic Properties of Er^{3+} doped Phospho-Tellurite Glasses. *Phys. B Condens. Matter*. 381: 66–72.

48. Qi, Y., Zhou, Y., Wu, L. and Yang, F. Annealing Time Dependent 1.53 µm Fluorescence Enhancement in Er^{3+}-doped Tellurite Glasses Containing Silver NPs. *Mater. Lett.* 2014. 125: 56–58.

49. Reza Dousti, M. and Amjad, R. J. (2017). Effect of Silver Nanoparticles on the Upconversion and Near-Infrared Emissions of Er^{3+}: Yb^{3+} co-doped Zinc Tellurite Glasses. *Meas. J. Int. Meas. Confed.* 105: 114–119.

50. Gomes, J. F., Lima, A. M. O., Sandrini, M., Medina, A. N. (2017). Optical and Spectroscopic study of Erbium doped Calcium Borotellurite Glasses. *Opt. Mater. (Amst).* 66, 211–219.

51. Sajna, M. S., Thomas, S., Jayakrishnan, C., Joseph, C. (2016). NIR Emission Studies and Dielectric Properties of Er^{3+}-doped Multicomponent Tellurite Glasses. *Spectrochim. Acta - Part A Mol. Biomol. Spectrosc.* 161: 130–137.

52. Said Mahraz, Z. A., Sahar, M. R., Ghoshal, S. K. (2014). Band gap and Polarizability of Boro-Tellurite Glass : Influence of Erbium Ions. *J. Mol. Struct.* 1072: 238–241.

53. A, S.D., Yu, C., Zhou, G., Zhang, J. (2006). Concentration Quenching in Erbium-doped Tellurite Glasses. 117: 39–45.

54. Obayes, H.K., Wagiran, H., Saeed, M. A. (2016). A New Strontium/ Copper Co-doped Lithium Borate Glass Composition with Improved Dosimetric Features. *J. Lumin.* 176: 202–211.

55. Assadi, A. A., Damak, K., Lachheb, R., Herrmann, A. (2015). Spectroscopic and Luminescence Characteristics of Erbium doped TNZL Glass for Lasing Materials. *J. Alloys Compd.* 620: 129–136.

56. Sazali, E. S., Rohani, M. S., Sahar, M. R., Arifin, R. (2014). Erbium Concentration Dependent Absorbance in Tellurite Glass. *AIP Conf. Proc.* 1617: 134–136.

57. Chescoe, D. and Goodhew, P. J. (1990). *The Operation of Transmission and Scanning Electron Micrscope*. Oxford Science Publications.

58. Reza Dousti, M., Sahar, M. R., Ghoshal, S. K., Amjad, R. J., Arifin, R. (2013). Plasmonic Enhanced Luminescence in Er^{3+}: Ag co-doped Tellurite Glass. *J. Mol. Struct.* 1033: 79–83.

59. Reza Dousti, M. and Hosseinian, S. R. (2014). Enhanced Upconversion Emission of Dy^{3+}-doped Tellurite Glass by Heat-Treated Silver Nanoparticles. *J. Lumin.* 154: 218–223.

60. Moustafa, S. Y., Sahar, M. R., Ghoshal, S. K. (2017). Spectroscopic Attributes of Er^{3+} Ions in Antimony Phosphate Glass Incorporated with Ag Nanoparticles: Judd-Ofelt Analysis. *J. Alloys Compd.* 712: 781–794.

61. Malta, O. L., Santa-Cruz, P. A., De Sa, G. F., Auzel, F. (1985). Fluorescence Enhancement Induced by the Presence of Small Silver Particles in Eu^{3+} doped Materials. *J. Lumin.* 33: 261–272.

62. Upender, G., Devi, C. S., Kamalaker, V., Mouli, V. C. (2011). The Structural and Spectroscopic Investigations of Ternary Tellurite Glasses, doped with Copper. *J. Alloys Compd.* 509: 5887–5892.

63. Pavani, P. G., Prasad, M. and Mouli, V. C. DSC , ESR and Optical Absorption Studies of Cu^{2+} Ion doped in Boro Cadmium Tellurite Glasses. *J. Alloys Compd.* 2012. 527: 5–9.

64. Said Mahraz, Z. A., Sahar, M. R., Ghoshal, S. K. (2015). Enhanced Luminescence from Silver Nanoparticles Integrated Er^{3+}-doped Boro-Tellurite Glasses: Impact of Annealing Temperature. *J. Alloys Compd.* 649: 1102–1109.

65. Zamyatin, O. A., Plotnichenko, V. G., Churbanov, M. F., Zamyatina, E. V. Karzanov, V. V. (2017). Optical Properties of Zinc Tellurite Glasses doped with Cu^{2+} Ions. *J. Non. Cryst. Solids.* 0–1.

66. Earnshaw, A. and Harrington, J. (1973). *The Chemistry of the Transition Elements*. Oxford University Press.

67. Ding, C., Wu, S., Hu, X., Li, G., Xu, Y. (2016). An Investigation of the Local Distortions and the EPR Parameters for Cu^{2+} in 40 MgO–(10–x)PbF_2–50SiO_2–xCuO glasses. *J. Alloys Compd.* 664: 250–255.

68. Schlager, N., Weisblatt, J., Newton, D. E. (2006). *Chemical Compounds*. Thomson Gale.

69. Zhang, H. M. and Wan, X. (2013). Theoretical Studies of Spin Hamiltonian Parameters for the Tetragonally Elongated Cu^{2+}Centers in $ARbB_4O_7$ (A = Li, Na, K) Glasses. *J. Non. Cryst. Solids.* 361: 43–46.

70. Oruc, C. and Altındal, A. (2017). Structural and Dielectric Properties of CuO Nanoparticles. *Ceram. Int.* 43: 10708–10714.

71. Malakhovskii, A. V., Edelman, I. S., Radzyner, Y., Yeshurun, Y. (2003). Magnetic and Magneto-Optical Properties of Oxide Glasses Containing Pr^{3+}, Dy^{3+} and Nd^{3+} ions. *J. Magn. Magn. Mater.* 263: 161–172.

72. Soltani, I., Hraiech, S., Horchani-Naifer, K., Elhouichet, H. (2016). Growth of Silver Nanoparticles Stimulate Spectroscopic Properties of Er^{3+} doped Phosphate Glasses: Heat treatment effect. *J. Alloys Compd.* 686: 556–563.

73. Hassan, M. A.and Hogarth, C. A. (1988). A study of the Structural, Electrical and Optical properties of Copper Tellurium Oxide Glasses. *J. Mater. Sci.* 23: 2500–2504.

74. Awang, A., Ghoshal, S. K., Sahar, M. R., Reza Dousti, M. (2013). Enhanced Spectroscopic Properties and Judd-Ofelt Parameters of Er-doped tellurite Glass: Effect of Gold Nanoparticles. *Curr. Appl. Phys.* 13: 1813–1818.

75. Perkampus, H. H. (1992). *UV-Vis Spectroscopy and its Applications*. Springer-Verlag.

76. Zamyatin, O. A., Churbanov, M. F., Medvedeva, J. A., Gavrin, S. A. (2018). Glass-forming Region and Optical Properties of the TeO_2 – ZnO – NiO System. *J. Non. Cryst. Solids.* 479: 29–41.

77. Eric Le Bourhis. (2008). *Glass*. WILEY-VCH Verlag GmbH & Co.

78. Suryanarayana, C. and Norton, M. G. (1998). *X-ray Diffraction: A Practical Approach*. Springer Science.

79. Chatwal, G. and Anand, S. (1985). *Spectroscopy (Atomic and Molecular)*. Himalaya Publishing House.

80. Fultz, B. and Hove, J. M. (2008). *Transmission Electron Microscopy and Diffractometry of Materials*. Springer-Verlag Berlin Heidelberg.

81. Banhart, F. (2008). *In-situ Electron Microscope at High Resolution*. World Scientific Pblishing Co. Pte. Ltd.

82. Shan, X., Tang, G., Chen, X., Peng, S. (2016). Silver Nanoparticles Enhanced NearIinfrared Luminescence of Er^{3+}/ Yb^{3+} co-doped Multicomponent Phosphate Glasses. *J. Rare Earths*. 34: 868–875.

83. Teng, Y., Qian, B., Jiang, N., Liu, Y. (2010). Light and Heat Driven Precipitation of Copper Nanoparticles Inside Cu^{2+}–doped Borate Glasses. *Chem. Phys. Lett.* 485: 91–94.

84. Dewan, S. K. (2010). *Organic Spectroscopy*. CBS Publishers.

85. Maraner, P. (2014). The Effect of Rotations on Michelson Interferometers. *Ann. Phys. (N. Y).* 350: 95–104.

86. Reza Dousti, M., Ghassemi, P., Sahar, M. R., Mahraz, Z. A. (2014). Chemical Durability and Thermal Stability of Er^{3+}–doped Zinc Tellurite Glass Containing Silver Nanoparticles. *Chalcogenide Lett.* 11: 111–119.

87. Gaafar, M. S. and Marzouk, S. Y. (2017). Judd–Ofelt Analysis of Spectroscopic Properties of Er^{3+} doped TeO_2 – BaO – ZnO Glasses. *J. Alloys Compd.* 723: 1070–1078.

88. Said Mahraz, Z. A, Sahar, M. R., Ghoshal, S. K. (2017). Reduction of Non-Radiative Decay Rates in Boro-Tellurite Glass via Silver Nanoparticles Assisted Surface Plasmon Impingement: Judd Ofelt analysis. *J. Lumin.* 190: 335–343.

89. Nawaz, F., Sahar, M. R., Ghoshal, S. K., Awang, A., Amjad, R. J. (2014). Judd-Ofelt analysis of spectroscopic properties of Sm^{3+} doped Sodium Tellurite Glasses co-doped with Yb^{3+}. *J. Lumin.* 147: 90–96.

90. Barron, A. R. (2011). *Photoluminescence Spectroscopy and its Applications*. 1–11.

91. Straughan, B. P. and Walker, S. (1976). *Spectroscopy*. Chapman and Hall Ltd.

92. Quantum, B. (2007). An Introduction to Fluorescence Spectroscopy. *Chem 312.*

93. Yusof, N. N., Ghoshal, S. K., Ari, R., Awang, A. (2018). Self-cleaning and Spectral Attributes of Erbium doped Sodium–Zinc–Tellurite Glass: Role of Titania Nanoparticles. 481: 225–238.

94. El-Mallawany, R., Abdalla, M. D., Ahmed, I. A. (2008). New tellurite glass: Optical properties. *Mater. Chem. Phys.* 109: 291–296.

95. Widanarto, W., Sahar, M. R., Ghoshal, S. K., Arifin, R. (2013). Effect of Natural Fe_3O_4 Nanoparticles on Structural and Optical Properties of Er^{3+} doped Tellurite Glass. *J. Magn. Magn. Mater*. 326: 123–128.

96. Berwal, N., Dhankhar, S., Sharma, P. and Kundu, R. S. (2017). Physical, Structural and Optical Characterization of Silicate Modified Bismuth–Borate–Tellurite Glasses. *J. Mol. Struct.* 1127: 636–644.

97. Boetti, N. G., Lousteau, J., Chiasera, A., Ferrari, M. (2012). Thermal stability and Spectroscopic Properties of Erbium–doped Niobic–Tungsten Tellurite Glasses for Laser and Amplifier Devices. *J. Lumin.* 132: 1265–1269.

98. Wang, F., Tian, Y., Cai, M., Jing, X. (2015). Glass Forming Ability and Enhanced 2.7 m Emission of Erbium Ions in TeO_2 doped Fluoroaluminate Glass. *Opt. Mater. (Amst).* 48: 133–138.

99. Nurbaisyatul, E. S., Azman, K., Azhan, H., Razali, W. A. W., Noranizah, A. (2014). The Structural Properties of Trivalent Rare Earth Ions (Er^{3+}) Doped. *Jurnal Teknologi Full paper*. 2: 97–100.

100. Mhareb, M. H. A., Hashim, S., Ghoshal, S. K., Alajerami, Y. S. M. (2016). Effect of Dy_2O_3 Impurities on the Physical, Optical and Thermoluminescence Properties of Lithium Borate Glass. *J. Lumin.* 177: 366–372.

101. Tanko, Y. A., Ghoshal, S. K., Sahar, M. R. (2016). Ligand field and Judd-Ofelt intensity parameters of samarium doped tellurite glass. *J. Mol. Struct.* 1117: 64–68.

102. Gayathri, P. P., Sadhana, K., Chandra, M. V. (2011). Optical, Physical and Structural Studies of Boro-Zinc Tellurite Glasses. *Phys. B Condens. Matter*. 406: 1242–1247.

103. Yusoff, N. M. and Sahar, M. R. (2015). Effect of Silver Nanoparticles Incorporated with Samarium–doped Magnesium Tellurite Glasses. *Phys. B Condens. Matter.* 456: 191–196.

104. Sazali, E. S., Sahar, M. R., Ghoshal, S. K., Arifin, R. (2015). Efficient Optical Enhancement of Er^{3+} doped Lead–Tellurite Glass Embedded with Gold Nanoparticles: Role of Heat-Treatment. *J. Non. Cryst. Solids.* 410: 174–179.

105. Reza Dousti, M., Sahar, M. R., Ghoshal, S. K., Amjad, R. J., Samavati, A. R. (2013). Effect of AgCl on Spectroscopic Properties of Erbium doped Zinc Tellurite Glass. *J. Mol. Struct.* 1035: 6–12.

106. Nurhafizah, H., Rohani, M. S., Ghoshal, S. K. (2016). Er^{3+}: Nd^{3+} Concentration Dependent Spectral Features of Lithium–Niobate–Tellurite Amorphous Media. *J. Non. Cryst. Solids.* 443: 23–32.

107. Ahmmad, S. kareem, Samee, M. A., Edukondalu, A., Rahman, S. (2012). Physical and Optical Properties of Zinc Arsenic Tellurite Glasses. *Results Phys.* 2: 175–181.

108. Mahraz, Z A. S., Sahar, M. R., Ghoshal, S. K. (2018). Near-infrared Up-conversion Emission from Erbium Ions doped Amorphous Tellurite Media: Judd-Ofelt Evaluation. Elsevier B.V.

109. Suresh, S., Pavani, P. G., Mouli, V. C. (2012). ESR , Optical bsorption , IR and Raman studies of x TeO_2 + (70–x) B_2O_3 + $5TiO_2$ + $24R_2O$: 1CuO (x = 10 , 35 and 60 mol %; R = Li , Na and K) Quaternary Glass System. *Mater. Res. Bull.* 47: 724–731.

110. Khafagy, A. H., El-Adawy, A. A., Higazy, A. A., El-Rabaie, S., Eid, A. S. (2008). Studies of Some Mechanical and Optical properties of: (70–x)TeO_2+15B2O3+ $15P_2O_5$+ xLi_2O Glasses. *J. Non. Cryst. Solids.* 354: 3152–3158.

111. Richardson, H. W. (1997). *Handbook of Copper Compounds and Applications*. Marcel Dekker Inc.

112. Upender, G., Prasad, M., Mouli, V. C. (2011). Vibrational, EPR and Optical Spectroscopy of the Cu^{2+} doped Glasses with (90–x)TeO_2–$10GeO_2$-xWO_3 (7.5 $\leq x \leq$ 30) Composition. *J. Non. Cryst. Solids.* 357: 903–909.

113. Widanarto, W., Sahar, M. R., Ghoshal, S. K., Arifin, R. (2013). Natural Fe_3O_4 Nanoparticles Embedded Zinc-Tellurite Glasses: Polarizability and Optical Properties. *Mater. Chem. Phys.* 138: 174–178.

114. El-Mallawany, R., Patra, A., Friend, C. S., Kapoor, R., Prasad, P. N. (2004). Study of Luminescence Properties of Er^{3+}–Ions in New Tellurite Glasses. *Opt. Mater. (Amst).* 26: 267–270.

115. Aziz, S. M., Sahar, M. R., Ghoshal, S. K. (2018). Spectral Attributes of Eu^{3+} doped Borotellurite Glasses Containing Mn_3O_4 Nanoparticles. *J. Alloys Compd.* 735: 1119–1130.

116. Yusof, N. N., Ghoshal, S. K., Azlan, M. N. (2017). Optical Properties of Titania Nanoparticles Embedded Er^{3+}–doped Tellurite Glass: Judd-Ofelt analysis. *J. Alloys Compd.* 724: 1083–1092.

117. Ahmadi, F., Hussin, R., Ghoshal, S. K. (2017). Spectral Characteristics of Er^{3+} doped Magnesium Zinc Sulfophosphate Glasses. *J. Alloys Compd.* 711: 94–102.

118. Halimah, M. K., Azlan, M. N., Shafinas, S. Z. (2015). Optical Properties of Erbium Doped Borotellurite Glass System. *Adv. Mater. Res.* 1112: 7–10.

119. Reddy, S. L., Endo, T., Reddy, G. S. (2012). Electronic (Absorption) Spectra of 3d Transition Metal Complexes. 3–48.