THE OPTICAL PROPERTIES OF ERBIUM DOPED ZIRCONIUM OXYFLUORIDE TELLURITE GLASS EMBEDDED WITH SILVER NANOPARTICLES

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This thesis is specially dedicated to:

My beloved parent,

Md Zain Banain, Surati A. Ghani

My supportive sister,

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My dedicated lecturer,

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and all my friend.

...thanks...

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ABSTRACT

Achieving enhanced optical properties of rare earth doped glass by the introduction of metal nanoparticle remains a challenging task. In addition, upconversion emission and infrared emission of erbium doped glass are ever-demanding for a large variety of optical applications. Therefore, in this study four series of erbium doped zirconium oxyfluoride tellurite glasses embedded with silver nanoparticles (Ag NPs) with composition of $(90\text{-}x)TeO_2 – 10MgO – (x)ZrF_4$ $(0 \leq x \leq 6$ mol%), $(84\text{-}y)$ TeO_2 - 10MgO - $6ZrF_4$ - $(y)Er_2O_3$ $(0 \leq y \leq 2$ mol%), $(88.5\text{-}z)$ TeO_2 - 10MgO - $(z)ZrF_4$ - $1.5Er_2O_3$ $(0 \leq z \leq 4$ mol%) and $(82.5\text{-}w)$ TeO_2 - 10MgO - $6ZrF_4$ - $1.5Er_2O_3$ - (w)AgCl $(0 \leq w \leq 1.0$ mol%) were prepared using melt quenching technique and investigated through optical characteristics. It is found that, the presence of a broad hump in X-ray diffraction (XRD) pattern confirms the amorphous nature of glass. HTEM images verify the existence of silver nanoparticles with two interplanar spacings about 0.20 nm and 0.23 nm corresponding to d_{111} and d_{200} spacing, respectively. The glass density and molar volume are found to be in the range of 4.11-5.09 g/cm^3 and 29.1 to 36.9 cm^3 mol^{-1}, respectively. It is also found that as the amount of zirconium fluoride is increased, the glass stability increases. The UV-Vis-NIR spectra reveal seven absorption bands centered at 486, 524, 544, 655, 803, 980 and 1526 which are assigned to the transition from ground state $^4I_{15/2}$ to the various excited levels $^4F_{7/2}$, $^2H_{11/2}$, $^4S_{3/2}$, $^4F_{9/2}$, $^4I_{9/2}$, $^4I_{11/2}$, and $^4I_{13/2}$ respectively. Two surface plasmon resonances (SPR) are observed at 530 nm and 570 nm. The optical band gap energy, Urbach energy and refractive index have also been determined, and they were in the range of 2.23 – 3.05 eV, 0.09 – 0.50 eV and 2.384 - 2.650, respectively. The Judd-Ofelt intensity parameter, spontaneous emission probabilities, radiative lifetime and branching ratios of all transitions were calculated based on Judd-Ofelt theory. The upconversion (λ_e = 980 nm) emission and infrared (λ_e = 633 nm) emission peaks of Er^{3+} ion exhibit at 525 nm (strong green), 555 nm (moderate green), 657 nm (strong red) and 1530 nm (near-infrared), respectively. The zirconium oxyfluoride tellurite glass sample contains 1.5 mol% Er_2O_3 and 1.0 mol% of AgCl shows the highest enhancement in the emission peak of 1530nm ($^4I_{13/2} \rightarrow$ $^4I_{15/2}$). The enhancement is attributed to the energy transfer from Ag nanoparticle to Er^{3+} ions. The result of the present work revealed that the investigated glass can be a potential material for photonic devices and solid state lasers.

ABSTRAK

Penghasilan sifat optik yang lebih baik bagi kaca berdopkan nadir bumi dengan menambah zarah nano logam merupakan tugas yang sentiasa mencabar. Di samping itu, pancaran penukaran ke atas dan pancaran inframerah bagi kaca berdopkan erbium sentiasa diperlukan bagi pelbagai jenis aplikasi optik. Oleh itu, dalam kajian ini empat siri kaca tellurite zirkonium oksifluorida berdopkan erbium oksida yang tertanam zarah nano perak (Ag NPs) dengan komposisi (90-x) TeO_2 - 10MgO - (x)ZrF ($0 \leq x \leq 6$ mol%), (84-y) TeO_2 - 10MgO - 6ZrF_4 - (y)Er_2O_3 ($0 \leq y \leq 2$ mol%), (88.5-z) TeO_2 - 10MgO - (z)ZrF_4 - 1.5Er_2O_3 ($0 \leq z \leq 4$ mol%) dan (82.5-w) TeO_2 - 10MgO - 6ZrF_4 - 1.5Er_2O_3 - (w)AgCl ($0 \leq w \leq 1.0$ mol%) telah disediakan menggunakan teknik pelindapan leburan dan dikaji menerusi ciri optik. Kewujudan puncak yang lebar pada corak pembelauan sinar-X (XRD) membuktikan sifat amorfus kaca. Imej HTEM pula membuktikan kewujudan zarah nano perak dengan jarak dua satah 0.20 nm dan 0.23 nm yang masing-masingnya mewakili jarak d_{111} dan d_{200}. Ketumpatan kaca dan isipadu molar didapati masing-masing berada di dalam julat 4.11 - 5.09 g / cm^3 dan 29.1 - 36.9 cm^3 mol^{-1}. Turut ditemui bahawa apabila jumlah zirkonium fluorida meningkat, kestabilan kaca turut meningkat. Spektrum UV-Vis-NIR menunjukkan tujuh jalur serapan yang berpusat di 486, 524, 544, 655, 803, 980 dan 1526 nm yang mewakili transisi daripada keadaan asas $^4I_{15/2}$ kepada pelbagai keadaan teruja $^4F_{7/2}$, $^2H_{11/2}$, $^4S_{3/2}$, $^4F_{9/2}$, $^4I_{9/2}$, $^4I_{11/2}$ dan $^4I_{13}$. Dua puncak resonans plasmon permukaan (SPR) diperlihatkan pada 530 nm dan 570 nm. Jurang tenaga optik, tenaga Urbach dan indeks biasan juga telah ditentukan, dan masing-masing berada dalam lingkungan 2.23 – 3.05 eV, 0.09 – 0.50 eV dan 2.384 - 2.650. Pembolehubah keamatan Judd-Ofelt, kebarangkalian pancaran spontan, jangka hayat radiatif dan nisbah cabangan bagi semua transisi telah dikira berdasarkan teori Judd-Ofelt. Pancaran penukaran ke atas (λ_e = 980 nm) dan pancaran inframerah (λ_e = 633 nm) mempamerkan puncak bagi ion Er^{3+} masing-masing pada 525 nm (hijau kuat), 555 nm (hijau sederhana), 657 nm (merah kuat) dan 1530 nm (inframerah). Sampel kaca tellurite zirkonium oksifluorida yang mengandungi 1.5 mol% Er_2O_3 dan 1.0 mol% AgCl menunjukkan peningkatan pada puncak pancaran yang jelas pada 1530 nm ($^4I_{13/2} \rightarrow {}^4I_{15/2}$). Penambahan ini disebabkan oleh pemindahan tenaga daripada zarah nano Ag kepada ion Er^{3+} . Hasil daripada kerja ini, membuktikan bahawa kaca yang diselidiki merupakan bahan berpotensi untuk peranti fotonik dan laser keadaan pepejal.

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LIST OF SYMBOLS

λ	-	Wavelength
θ	-	Diffraction angle
$\rho 1$	-	Liquid density
ρ	-	Sample density
W_a	-	Weight of sample glass
W_1	-	Weight of sample in liquid
V_m	-	Molar volume
M	-	Molar weight
α	-	Absorption coefficient
d,L	-	Thickness of sample
A	-	Intensity absorption
$\hbar\omega$	-	Photon energy
ω	-	Frequency dependent
m	-	Index value (m = 1/2, 3/2, 2 or 3)
B	-	Constant
n	-	Refractive index

D	-	Crystalline size
T_g	-	Glass transition temperature
T_x	-	Onset crystalline transition temperature
T_c	-	Crystalline transition temperature
T_m	-	Melting temperature
ΔT	-	Thermal stability
ΔE	-	Urbach energy
E_{opt}	-	Optical band gap energy
E'_{opt}	-	Optical band gap energy between tail
h	-	Planck's constant
c	-	Velocity of light in vacuum
m	-	Rest mass of electron
v	-	Mean energy of transition in cm^{-1}
J	-	Total angular momentum quantum number
S	-	Spin angular momentum quantum number
L	-	Orbital angular momentum quantum number
f_{cal}	-	Calculated oscillator strength
f_{exp}	-	Experimental oscillator strength
Ω_λ	-	Judd Ofelt parameter
e	-	Electron charge
I	-	Intensity

I_o	-	Intensity of first sample
I_i	-	Integrated intensity
K	-	Wave number
τ_r	-	Radiative lifetime
S_{ed}	-	Electric dipole line strength
A_{ed}	-	Electric dipole transition
A_{md}	-	Magnetic dipole transition
β	-	Branching ratio
Q	-	Quality factor
σ_{em}	-	Stimulated emission cross section
λ_{peak}	-	peak emission
$\Delta\lambda_{eff}$	-	Effective bandwidth
A_{tot}	-	total spontaneous transition probability
C_2^i	-	Reduced matrix element

LIST OF ABBREVIATIONS

NBO	**-**	Non Bridging Oxygen
BO	**-**	Bridging Oxygen
XRD	**-**	X -ray Diffraction
UV	**-**	Ultra Violet
Vis	**-**	Visible
IR	**-**	Infrared
NIR	**-**	Near Infrared
TEM	**-**	Transmission Electron Microscopy
HRTEM	**-**	High Resolution Transmission Electron Microscopy
RE	**-**	Rare Earth
M	**-**	Modifier
CR	**-**	Cross Relaxation
GSA	**-**	Ground State Absorption
ESA	**-**	Excited State Absorption
ET	**-**	Energy Transfer

NPs	**-**	Nanoparticles
EDFA	**-**	Erbium Doped Fiber Amplifier
SPR	**-**	Surface Plasmon Resonance
NDT	**-**	Non Destructive Test
FWHM	**-**	Full Width at Half Maximum
DTA	**-**	Differential Thermal Analysis
UC	**-**	Upconversion
DC	**-**	Downconversion
HSTs	**-**	Hypersensitive Transitions
PL	**-**	Photoluminesence
SERs	**-**	Surface Enhanced Raman spectroscopy
NMR	**-**	Nuclear Magnetic Resonance
FTIR	**-**	Fourier Transform Infrared

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CHAPTER 1

INTRODUCTION

1.1 Research Background

Over the last few eras, tellurite has been the high interest subject due to its capability as host for the development of application such as optical amplifier and solid state laser. Tellurite glass has some remarkable characteristic over other host material such as broad transparency window in visible and near IR (0.35-6 μm), high lanthanide ion solubility, high linear and non-linear refractive index (≥2), low melting point (~800^{o}C), low phonon energy (~750 cm^{-1}), high dielectric constant (~20) and very good stability [1].

Recently, ZrF_4 based fluoride glass also has attracts many researchers' attentions due to its great properties of high solubility for rare earth ions, low linear refractive index and has long florescence lifetime of the excited electronic state [2]. Compared with tellurite, fluoride glass has lower phonon energy around 500 cm^{-1} because it has high ionic bond character [3]. But, fluoride glass shows poor water resistance, mechanical durability and thermal stability. In order to overcome this problem, oxyfluoride tellurite glass is produced by the combination of fluoride with oxide glass because oxide glass has better water resistance, mechanical durability and thermal stability. Cheng, *et. al* [4]., reported that, oxyfluoride-tellurite glass exhibit unique properties such as high lanthanide solubility, wide transmission window and low phonon energy particularly suitable used as host material of rare-earth for waveguide amplifier and laser.

Additionally, the incorporation of easily polarized heavy metal oxides with tellurite glass will enhance polarizability of Te^{4+} ions in glass network [5]. According to previous work, the addition of MgO in the glass structure will enhance the chemical durability of the glass [6]. Moreover, the addition of modifiers will modify and increase non-bridging oxygen, at the same time open up the glass structure. Therefore, the substitution of MgO in the glass network would produce the stable tellurite glass [7]. In order to achieve stable tellurite glass with high chemical durability, MgO will be added as one of the component in this study glass system.

In current investigation, Er^{3+} doped tellurite glass or fluoride glass has been studied by many researchers due to its great optical properties. Among the rare earth ions, Er^{3+} ion gets more attention due to its energy level structure that has been useded in variety of glasses for application in solid-state lasers and optical amplifiers. It was reported that Er^{3+} doped oxyfluoride-tellurite glasses containing high concentration of ZnF_2 presented low density, long $^4I_{13/2}$ level lifetime, low OH^- ions concentration and wider transparency window. In comparison, the oxide tellurite glasses exhibits emission cross section spectra of $^4I_{13/2}$-$^4I_{15/2}$ transition were quenched with a higher concentration of ZnF_2 [8]. In this study, it is expected that the presence of ZrF_4 in Er^{3+} doped oxyfluoride-tellurite glass will give better properties than other glasses due to the low phonon energy of ZrF_4 [8].

A lot of modification and work have been done in order to increase the luminescence in RE doped glass. Presently, the embedment of metallic nanoparticles (NPs) into glass matrices is the best approach to enhance the luminescence. The rare earth (Er^{3+} ion) is certified as dopant, while metallic nanoparticles (Au or Ag NPs) are react as stimulating agent to enhance the optical properties (absorption and emission) [9]. The presence of metallic nanoparticles inside the glass host will change the glass matrix environment and can be optimize the spectroscopic properties of Er^{3+} ions including the change of chemical bonding in glass network and optical properties [10]. The luminescence intensity of RE strongly depends on the local electric field between the RE and NPs and subsequent energy transfer (ET) mechanism [9].

In order to understand the optical properties of the Er^{3+} doped oxyfluoride-tellurite glass embedded with Ag NPs, the glass will be characterized using X-Ray Diffractometer, High Resolution Transmission Electron Microscopyr, UV-Vis-NIR spectrometer and Photoluminescence spectrometer. The optical energy band gap, refractive index, fluorescence branching ratios, thermal parameter, Judd-ofelt intensity parameter, spontaneous radiative transition probabilities and lifetimes were calculated to further evaluated the luminescence characteristic of the Er^{3+} doped zirconium oxyfluoride-tellurite glass embedded with Ag NPs.

1.2 Problem statement

Recently, the upconversion and downconversion of infrared light to visible light by various rare earth doped glass ions have widely been studies due to the capability in the field of photonics [11]. Generally, glass host with low phonon energy could be ideal for doping Er^{3+} ion due to the reducing of multiphonon de-excitation and enhancement on the quantum efficiency of luminescent transition [12]. Therefore, much effort has been spent on fluoride glass owing to their lower phonon energy [11]. However, fluoride glass frequently exhibit very poor on it’s chemical stability and mechanical durability [11]. On the other hand, oxide glass have better chemical stability and mechanical durability but unfortunately their higher phonon energy will limit their applications. Therefore in this study, the combination of fluoride glass with oxide glass will be developed to overcome this problem, it is called oxyfluoride glass. In this study, the concentration of MgO is fixed at 10 mol% , which is similar concentration as other previous study [13–16].

From previous literature, it was reported that the Er^{3+}doped zinc oxyfluoride tellurite glass exhibits quenching emission cross section spectra at 1.5μm with the increasing of ZnF_2 concentration [8]. However, in this study it is expected that Er^{3+}doped zirconium oxyfluoride tellurite glass embedded with Ag NPs will get the enhancement of emission cross section spectra with the higher concentration of ZrF_4. It is known that, the introduction of metallic NPs and RE ions in glass host exhibit higher potential on the enhancement of glass luminescence [17]. Additionally, since there are only few studies on these glasses and it is lack of information on the influence of Ag NPs and Er^{3+} ion on the oxyflouride tellurite glass as shown in Table 1.1. Therefore, it is the aim of this research to provide more information on the physical and optical analysis of erbium doped zirconium oxyfluoride tellurite glass embedded with Ag NPs

1.3 Objective

The objectives of this study are:

i. To prepare the oxyfluoride tellurite glass samples with different concentration of ZrF_4, Er^{3+} ion and AgCl by melt quenching technique.
ii. To determine the amorphous nature of the glass and verify the presence of Ag NPs.
iii. To determine the influence of ZrF_4, Er^{3+} ion and Ag NPs concentration on the optical properties of oxyfluoride tellurite glass.

Table 1.1: The previous study on Oxyfluoride tellurite glass.

Year.	Sample glass	Charecterization														
		Thermal properties				Absorption properties				Luminescene properties		Judd-Ofelt analysis ($^4S_{3/2}$-$^4I_{15/2}$)				Structural properties
		Spectra	T_g (^oC)	T_c (^oC)	ΔT (^oC)	Spectra	E_{opt} (eV)	ΔE (eV)	n	Up	Down	Ω_2	β	A	T (ms)	Raman
2003	TeO_2 –ZnO -ZnF_2 -Er_2O_3 - Na_2CO_3 -[18]		-	-	-	2 peak			-	-	2 peak (infrared)	-	-	-	-	3 band
2005	TeO_2-WO_3-ZnF_2[19]		339	493	154	-	2.69	0.12	-	-	-	-			-	-
2011	TeO_2–GeO_2–PbF_2–BaF_2–Er_2O_3 [11]		503	646	143	8 peak	-	-	-	6 peak (red, green)	-	-	-	-	-	3 peak
2011	TeO_2- ZnF-ZnO-Er_2O_3[8]		302	488	126	11 peak	-	-	2.07	5 peak (red, green)	2 Peak (infrared)	4.40	-	-	8.80	6 peak
2013	TeO_2-ZnO-ZnF_2-Er_2O_3[81]	-	-	-	-	10 peak	-	-	2.002	3 peak (red, green)	2 peak (infrared0	4.71	67.3	3430.3	0.29	-
2017	TeO_2-P_2O_5-ZnO-PbF_2-MgO-Er_2O_3[20]	-	-	-	-	10 peak	-	-	2.91	10 peak	-	4.51	-	-	0.41	-

1.4 Scope of Study

Preparation of oxyfluoride tellurite glass by melt-quenching technique in four glass series of composition,

- Series 1: (90-x)TeO_2-10MgO-(x) ZrF_4,where $0 \leq x \leq 6$ in mol%.
- Series 2: (84-y)TeO_2-10MgO-6 ZrF_4-(y)Er_2O_3,where $0 \leq y \leq 2$ in mol%
- Series 3: (88.5-z)TeO_2-10MgO-(z)ZrF_4-1.5Er_2O_3,where $0 \leq z \leq 6$ in mol%
- Series 4: (82.5-w)TeO_2-10MgO-6ZrF_4-1.5Er_2O_3-(w)AgCl, where $0 \leq w \leq 0.8$ in mol%.

The amorphous characteristic is confirmed using X-ray Diffraction spectroscopy (XRD) and the presence of Ag NPs in glass system is observed by High Resolution Transmission Electron Microscopy (HRTEM).

The optical properties of glass was determined by UV-Vis NIR and Photoluminescence spectroscopy in term of absorption coefficient, optical energy band gap, Urbach energy band gap, refractive index, Judd Ofelt intensity parameter, lifetime decay, Quality factor and stimulated emission cross section area.

1.5 Significance of study

Presently, the development of upconversion solid state laser has drawn many attentions in optical material sciences. The low phonon energy and large refractive index of oxyfluoride tellurite glass is the key to improving the fluorescence emission compare to other oxides and fluorides host. Low phonon energy of glass will reduced

REFERENCES

1. Krishnaiah, K. V., Marques-hueso, J., Suresh, K., Venkataiah, G., Richards, B. S., & Jayasankar, C. K. (2016). Spectroscopy and near infrared upconversion of Er^{3+} -doped TZNT glasses. *Journal of Luminescence*, *169*, 270–276.
2. Wang, X., Hu, L., Xu, W., Wang, S., Zhang, L., Yu, C., & Chen, D. (2015). Spectroscopic properties of Ho^{3+} and Al^{3+} co-doped silica glass for 2-μm laser materials. *Journal of Luminescence, 166*, 276–281.
3. Stevenson, Adam J., Gredin, P., & Mortier, M. (2011). *Fluoride materials for optical applications : Single crystals, ceramics, glasses, and glass – ceramics, 132*, 1165–1173.
4. Cheng, C., Yu, Y., Zhang, F., Zhang, H., & Qiu, J. (2014). Femtosecond laser induced microstructure and luminescence changes in oxyfluoride tellurite glasses. *Journal of Non-Crystalline Solids*, *406*, 1–4.
5. Salem, S. M. (2010). Role of molybdenum ions on physical, optical, electrical and vibrational studies in Er^{3+} co-doped TeO 2 – ZrO 2 – PbCl 2 glasses. *Journal of Alloys and Compounds*, *503*, 242–247.
6. Smith, C. E., Brow, R. K. (2014). The properties and structure of zinc magnesium phosphate glasses. *Journal of Non-Crystalline Solids*, *390*, 51–58.
7. Terny, S., Rubia, M. A. De, Alonso, R. E., Frutos, J. De, & Frechero, M. A. (2015). Structure and electrical behavior relationship of a magnesium tellurite glass using Raman and impedance spectroscopy. *Journal of Non-Crystalline Solids*, *411*, 13–18.
8. Chillcce, E. F., Mazali, I. O., Alves, O. L., & Barbosa, L. C. (2011). Optical and physical properties of Er^{3+} -doped oxyfluoride tellurite glasses. *Optical*

Materials, *33*(3), 389–396.

9. Sazali, E. S., Sahar, M. R., Ghoshal, S. K., Arifin, R., Rohani, M. S., & Amjad, R. J. (2015). Efficient optical enhancement of Er^{3+} doped lead-tellurite glass embedded with gold nanoparticles: Role of heat-treatment. *Journal of Non-Crystalline Solids*, *410*, 174–179.
10. Dousti, M. R., Sahar, M. R., Amjad, R. J., Ghoshal, S. K., & Awang, A. (2013). Surface enhanced Raman scattering and up-conversion emission by silver nanoparticles in erbium-zinc-tellurite glass. *Journal of Luminescence*, *143*, 368–373.
11. Zhang, Y., Lu, C., Feng, Y., Sun, L., Ni, Y., & Xu, Z. (2011). Effects of GeO_2 on the thermal stability and optical properties of Er^{3+} / Yb^{3+} -codoped oxyfluoride tellurite glasses. *Materials Chemistry and Physics*, 126(3), 786–790.
12. Feng, L., Wu, Y. (2016). Spectrochimica Acta Part A : Molecular and Biomolecular Spectroscopy Optical properties of Er^{3+} -doped oxyfluoride glasses. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*, 155, 125–129.
13. Yamusa, Y. A., Hussin, R., Shamsuri, W. N. W., & Tanko, Y. A. (2018). Optik Impact of Eu^{3+} on the luminescent , physical and optical properties of $BaSO_4$ – B_2O_3 – P_2O_5 glasses. *Optik - International Journal for Light and Electron Optics*, *164*, 324–334.
14. Lakshminarayana, G., Kaky, K. M., Baki, S. O., Lira, A., Nayar, P., Kityk, I. V, & Mahdi, M. A. (2017). Physical , structural , thermal , and optical spectroscopy studies of TeO_2 - B_2O_3 - MoO_3 - ZnO - R_2O(R¼ Li , Na , and K)/ MO (M¼ Mg , Ca , and Pb) glasses, *690*.
15. Balakrishna, A., Rajesh, D., & Ratnakaram, Y. C. (2013). Structural and optical properties of Nd^{3+} in lithium fluoro-borate glass with relevant modifier oxides. *Optical Materials*, *35*(12), 2670–2676.
16. Yusoff, N. M., & Sahar, M. R. (2015). The incorporation of silver nanoparticles in samarium doped magne- sium tellurite glass : Effect on the characteristic of bonding and local structure Ag NPs S4 Intensity (a . u .). *Physica B: Physics of Condensed Matter*, *470–471*, 6–14.
17. Yusoff, N. M., & Sahar, M. R. (2015). Stimulated luminescence behavior by embedding activated silver nanoparticles in tellurite glass. *Chalcogenide*

Letters, *12*(6), 313–323.

18. Nazabal, V., Todoroki, S., Nukui, A., Matsumoto, T., Suehara, S., Hondo, T., & Cardinal, T. (2003). Oxyfluoride tellurite glasses doped by erbium: Thermal analysis, structural organization and spectral properties. *Journal of Non-Crystalline Solids*, *325*(1–3), 85–102.
19. Yousef, E. S. S. (2005). Characterization of oxyfluoride tellurite glasses through thermal, optical andultrasonic measurements. *Journal of Physics D Applied Physics*, *38*, 3970–3975.
20. Burtan-Gwizdała, B., Reben, M., Cisowski, J., Grelowska, I., Yousef, E. S., Algarni, H., & Nosidlak, N. (2017). Spectroscopic properties of Er^{3+}-doped fluorotellurite glasses containing various modifiers. *Optical Materials, 73,* 509–516.
21. Alfred, R. C. J. C. (1982). W.H. Zachariasen - The Melody Linger. *Journal of Non-Crystalline Solids,* 49 (1982) *49*, 1–17.
22. Elliott, S. R. (1990). *Physics of amorphous materials*. Harlow, Essex, England : Longman Scientific & Technical .
23. Doremus, R. H. (1994). *Glass Science* (2nd ed.). John Wiley & Sons Inc., New York.
24. Gupta, P. K. (1996). *Non-crystalline solids : glasses and amorphous solids, 195*, 158–164.
25. Shimakawa, J. & Shimakawa, K. (2003). *Advance in Amorphous Semiconductors.* 11 New Fetter Lane, Landon: Taylor & Francis.
26. Mott, N. F. and, & Davis, E. A. (1979). *Electronic processes in non-crystalline materials.* Oxford : Clarendon ; New York : Oxford University
27. Sajna, M. S., Thomas, S., Mary, K. A. A., Joseph, C., Biju, P. R., & Unnikrishnan, N. V. (2015). Spectroscopic properties of Er^{3+} ions in multicomponent tellurite glasses. *Journal of Luminescence*, *159*, 55–65.
28. Neov, S., Kozhukharov, V., Gerasimova, I., Krezhov, K., & Sidzhimov, B. (2001). A model for structural recombination 26. El-Mallawany, R. A. H. (2016). *Tellurite Glasses Handbook: Physical Properties and Data* (2nd ed.). CRC Press.
29. El-Mallawany, R. A. H. (2016). *Tellurite Glasses Handbook: Physical Properties and Data* (2nd ed.). CRC Press.
30. Venkataiah, G., & Jayasankar, C. K. (2015). Dy^{3+} -doped tellurite based

tungsten-zirconium glasses : Spectroscopic study. *Journal of Molecular Structure*, *1084*, 182–189. 28. Of, L. (1992). NON-CRYSTALLINE SOLIDS Raman spectra of MO1 / z-TeO 2 (M = Li , Na , K , Rb , Cs and T1), *144*, 128–144.

31. Manning, S., Ebendorff-Heidepriem, H., & Monro, T. M. (2012). Ternary tellurite glasses for the fabrication of nonlinear optical fibres. *Optical Materials Express*, *2*(2), 140.
32. Sekiya, T., Mochida, N., Soejima, A. (1995). Raman spectra of binary tellurite glasses containing tri- or tetra-valent cations. *Journal of Non-Crystalline Solids*, *191*(1–2), 115–123.
33. Yousef, E. S., El-adawy, A., Koshkhany, N. El, & Shaaban, E. R. (2006). Optical and acoustic properties of TeO_2 / WO_3 glasses with small amount of additive ZrO_2. *Journal of Physics and Chemistry of Solids 67*, 1649–1655.
34. Noguera, O., Thomas, P., Masson, O., & Champarnaud-Mesjard J. C. (2003). *Refinement of the crystal structure of zirconium tritellurate (IV)*. Z. Kristallogr. NCS : Oldenbourg Wissenschaftsverlag, München, 293 *218*, 293–294.
35. Shinozaki, K., Pisarski, W., Affatigato, M., Honma, T., & Komatsu, T. (2015). Glass structure and NIR emission of Er^{3+} at 1.5l m in oxyfluoride. *Optical Materials*, *50*, 238–243.
36. Gao, G., Wang, G., Yu, C., Zhang, J., & Hu, L. (2009). Investigation of 2.0mm emission in Tm^{3+} and Ho^{3+} co-doped oxyfluoride tellurite glass. *Journal of Luminescence*, *129,* 1042–1047. 35. Kenyon, A. J. (2002). *Recent developments in rare-earth doped materials for optoelectronics* (Vol. 26).
37. Kenyon, A. J. (2002). *Recent developments in rare-earth doped materials for optoelectronics* (Vol. 26).
38. Polman, A. (2001). Erbium as a probe of everything. *Physica B,* 300, 78–90.
39. Ter-Mikirtychev, V. V. (2016). *Fundamentals of Fiber Lasers and Fiber Amplifiers* . Cham, Switzerland: Springer International Publishing AG.
40. Miniscalco, W. J. (1993). Optical and Electronic Properties of Rare Earth Ion in Glass. *Rare Earth Doped Fiber Laser and Amplifiers*. Madison Avenue, Nee York: Marcel Dekker, Inc. 19–134, 270

41. Lu Sun, L. L. and.Cheng, P. (2016). Enhanced Molecular Spectroscopy via Localized Surface Plasmon Resonance. *Applications of Molecular Spectroscopy to Current Research in the Chemical and Biological Sciences*. *Cc By 3.0 license :* InTech.

42. Willets, K. A., Van Duyne, R. P. (2007). Localized Surface Plasmon Resonance Spectroscopy and Sensing. *Annual Review of Physical Chemistry*, *58*(1), 267–297.

43. Amjad, R. J., Dousti, M. R., Sahar, M. R. (2015). Spectroscopic investigation and Judd e Ofelt analysis of silver nanoparticles embedded Er^{3+} -doped tellurite glass. *Current Applied Physics*, *15*(1), 1–7.

44. 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. *Journal of Alloys and Compounds*, *649*, 1102–1109.

45. Noguez, C. (2007). Surface Plasmons on Metal Nanoparticles: The Influence of Shape and Physical Environment. *J. Phys. Chem. C*, *111*, 3806–3819.44.

46. V.A.G. Rivera1, F. A. and E. M. J. . (2012). Localized Surface Plasmon Resonances. In K. young Kim (Ed.), *Plasmonis-Principles and applications*, 558.

47. Duque, J. S., Blandón, J. S., & Riascos, H. (2017). Localized Plasmon resonance in metal nanoparticles using Mie theory. *Journal of Physics: Conference Series*, *850*(1).

48. Qi, J., Xu, T., Wu, Y., Shen, X., Dai, S., & Xu, Y. (2013). Ag nanoparticles enhanced near-IR emission from Er^{3+} ions doped glasses. *Optical Materials*, *35*(12), 2502–2506.

49. Petryayeva, E., Krull, U. J. (2011). Localized surface plasmon resonance: Nanostructures, bioassays and biosensing-A review. *Analytica Chimica Acta*, *706*(1), 8–24.

50. 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 Sciences*, *12*(8), 1480–1483.

51. Dousti, M. R., Amjad, R. J., & Mahraz, Z. A. S. (2015). Enhanced green and red upconversion emissions in Er^{3+}-doped boro-tellurite glass containing gold nanoparticles. *Journal of Molecular Structure*, *1079*, 347–352.

52. Amjad, R. J., Dousti, M. R., Sahar, M. R., Shaukat, S. F., Ghoshal, S. K., Sazali, E. S., & Nawaz, F. (2014). Silver nanoparticles enhanced luminescence of Eu^{3+}-doped tellurite glass. *Journal of Luminescence*, *154*, 316–321.

53. Culea, E., Vida-simiti, I., Borodi, G., Nicolae, E., Stefan, R., & Pascuta, P. (2014). Effects of Er^{3+} :Ag codoping on structural and spectroscopic properties of lead tellurite glass ceramics. *Ceramics International*, *40*(7), 11001–11007.

54. Cheng, P., Zhou, Y., Zhou, M., Su, X., Zhou, Z., & Yang, G. (2017). Enhanced broadband near-infrared luminescence from Pr^{3+} -doped tellurite glass with silver nanoparticles. *Optical Materials*, *73*, 102–110.

55. Kittel, C. (2005). Introduction to Solid State Physics.United Stated of America : John Wiley & Sons, Inc.

56. Jena, P. (2007). S Synthesis and characterization of glass-ceramic $Bi_{2-x}Ga_xSr_2Ca_2Cu_3O_{10+y}$ superconductors *Superconductor Science and Technology*, *34*(2), 192–193.

57. Sazali, E. S., Sahar, M. R., Ghoshal, S. K., Arifin, R., Rohani, M. S., & Awang, A. (2014). Optical properties of gold nanoparticle embedded Er^{3+} doped lead-tellurite glasses. *Journal of Alloys and Compounds*, *607*, 85–90.

58. Rao, G. V., & Shashikala, H. D. (2014). Optical , dielectric and mechanical properties of silver nanoparticle embedded calcium phosphate glass. *Journal of Non-Crystalline Solids*, *402*, 204–209.

59. Yusoff, N. M., & Sahar, M. R. (2015). Effect of silver nanoparticles incorporated with samarium-doped magnesium tellurite glasses. *Physica B: Physics of Condensed Matter*, *456*, 191–196.

60. Kuznetsov, A. S., Cuong, N. T., Tikhomirov, V. K., Jivanescu, M., Stesmans, A., Chibotaru, L. F., & Moshchalkov, V. V. (2012). Effect of heat-treatment on luminescence and structure of Ag nanoclusters doped oxyfluoride glasses and implication for fiber drawing. *Optical Materials*, *34*(4), 616–621.

61. Rao, G. V., & Shashikala, H. D. (2015). Effect of heat treatment on optical , dielectric and mechanical properties of silver nanoparticle embedded CaO - CaF_2 - P_2O_5 glass. *Journal of Alloys and Compounds*, *622*, 108–114.

62. Jlassi, I., Elhouichet, H., & Ferid, M. (2011). Thermal and optical properties of tellurite glasses doped erbium. *Journal of Materials Science*, *46*(3), 806–812.

63. 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. *Journal of Molecular Structure*, *1035*, 6–12.

64. Yang, F., Huang, B., Wu, L., Peng, S., Qi, Y., & Zhou, Y. (2015). Enhanced 1.53 m m fluorescence and energy transfer mechanism in tellurite glasses doped with Er^{3+}/ Ce^{3+} / Yb^{3+}. *Journal of Quantitative Spectroscopy and Radiative Transfer*, *161*, 1–10.

65. Huang, F., Liu, X., Hu, L., & Chen, D. (2015). Spectroscopic properties and energy transfer parameters of Er^{3+}- doped fluorozirconate and oxyfluoroaluminate glasses. *Scientific Reports*, *4*(1), 5053.

66. Owen, T. (2000). *Fundamental of UV-visible spectroscopy*. *Germany: Agilent Technologies.*

67. Bach, H. (1995). *The Properties of Optical Glass.* Verlag: Springer.

68. Yusoff, N. M., Sahar, M. R., & Ghoshal, S. K. (2015). Sm^{3+} : Ag NPs assisted modification in absorption features of magnesium tellurite glass. *Journal of Molecular Structure*, *1079*, 167–172.

69. Awang, A., Ghoshal, S. K., Sahar, M. R., Reza Dousti, M., Amjad, R. J., & Nawaz, F. (2013). Enhanced spectroscopic properties and Judd-Ofelt parameters of Er-doped tellurite glass: Effect of gold nanoparticles. *Current Applied Physics*, *13*(8), 1813–1818.

70. Urbach, F. (1953). The Long-Wavelength Edge of Photographic Sensitivity and of the Electronic Absorption of Solids. *Physical Review*, *92*(5), 1324–1324.

71. Halimah, M. K., Daud, W. M., Sidek, H. A. A., Zaidan, A. W., & Zainal, A. S. (2010). Optical properties of ternary tellurite glasses. *Materials Science-Poland*, *28*(1), 173–180.

72. Bilir, G., Kaya, A., Cinkaya, H., & Eryürek, G. (2016). Spectroscopic investigation of zinc tellurite glasses doped with Yb^{3+} and Er^{3+} ions. *Spectrochimica Acta - Part A: Molecular and Biomolecular Spectroscopy*, *165*, 183–190.

73. Moss, T. S. (1985). Relations between the Refractive Index and Energy Gap of Semiconductors. *physica status solidi*, *131*(2), Pages 415–427.

74. Santos, N. S. H. & Silva, J. D. D. (2008). *Physics and Chemistry of Rare-Earth Ions Doped Glasses (Materials Science Foundations)*. United Stated: Trans Tech Pubn.

75. Soltani, I., Hraiech, S., Horchani-naifer, K., Elhouichet, H., Férid, M. (2015). Effect of silver nanoparticles on spectroscopic properties of Er^{3+} doped phosphate glass. *Optical Materials, 46*, 454–460.

76. Judd, B. R. (1962). Optical Absorption Intensities of Rare-Earth Ions. *Physical Review Journal Archive*, *127*(3), 750.

77. Ofelt, G. S. (1962). Intensities of Crystal Spectra of Rare-Earth Ions. *The Journal of Chemical Physics*, *37*(3), 511–520.

78. Hehlen, M. P., Cockroft, N. J., Gosnell, T. R., & Bruce, A. J. (1997). Spectroscopic properties of Er 3 ⍈ and Yb 3 ⍈doped soda-lime silicate and aluminosilicate glasses, *56*(15), 9302–9318.

79. Murata,T., Takebe, H. & Department, K. M. (1998). Compositional Dependence of Infrared-to-Visible Upconversion in Yb^{3+} and Er^{3+} -Codoped Germanate, Gallate, and Tellurite Glasses. *Journal of the American Ceramic Society*, *51*, 249–251..

80. Miguel, A., Morea, R., Gonzalo, J., Arriandiaga, M. A., Fernandez, J., & Balda, R. (2013). Near-infrared emission and upconversion in Er^{3+}-doped TeO_2-ZnO-ZnF_2 glasses. *Journal of Luminescence, 140*, 38–44.

81. Desurvire, E. (2002). *Erbium doped fiber amplifier (Principle and application).* Deparment of Electrical Engineering, Columbia University: John Wiley & Son Inc.

82. Frackowiak, D. A. N. U. T. A. (1988). The Jablonski diagram. *Journal of Photochemistry and Photobiology, B: Biology*, *2*, 399–408.

83. Loiko, P. A., Rachkovskaya, G. E., Zakharevich, G. B., Kornienko, A. A., Dunina, E. B., Yasukevich, A. S., & Yumashev, K. V. (2014). Cooperative up-conversion in Eu^{3+},Yb^{3}+-doped SiO_2–PbO–PbF_2–CdF_2 oxyfluoride glass. *Journal of Non-Crystalline Solids*,*393*, 39–44.

84. Nagao, (2018). *X-ray Diffraction* . UTM Summer school. Leading With Innovation.

85. Abudayyeh, H. (2012). . *Synthesis and Analysis of ZnO Nanowire*

86. Patro, S. K., & Babu, P. R. (2018). *Drug- Excipient Compatability Studies using Thermal methods.* 1–25.

87. Hajer, S. S., Halimah, M. K., Zakaria, A., & Azlan, M. N. (2016). Effect of Samarium Nanoparticles on Optical Properties of Zinc Borotellurite Glass System. *Materials Science Forum*, *846*, 63–68.

88. Ma, Y., Wang, X., Zhang, L., Huang, F., & Hu, L. (2015). Increased radiative lifetime of Tm^{3+} :$^3F_4 \rightarrow ^3H_6$ transition in oxyf uoride tellurite glasses. *Materials Research Bulletin*, *64*, 262–266.

89. Elbashar, Y. H., Ali, M. I., Elshaikh, H. A., & El-Din Mostafa, A. G. (2016). Influence of CuO and Al_2O_3 addition on the optical properties of sodium zinc phosphate glass absorption filters. *Optik*, *127*(18), 7041–7053.

90. Patil, S. D., & Jali, V. M. (2013). Optical properties of Neodymium doped Borotellurite glasses. *International Journal of Science Research*, *1*(4), 317–320.

91. Zaid, M. H. M., Matori, K. A., Aziz, S. H. A., Kamari, H. M., Wahab, Z. A., Effendy, N., & Alibe, I. M. (2016). Comprehensive study on compositional dependence of optical band gap in zinc soda lime silica glass system for optoelectronic applications. *Journal of Non-Crystalline Solids*, *449*, 107–112.

92. Halimah, M. K., Azlan, M. N., & Shafinas, S. Z. (2015). Optical Properties of Erbium Doped Borotellurite Glass System. *Advanced Materials Research*, *1112*, 7–10.

93. Sidek, H. A. A., Rosmawati, S., Halimah, M. K., Matori, K. A., & Talib, Z. A. (2012). Effect of AlF_3 on the density and elastic properties of zinc tellurite glass systems. *Materials*, *5*(8), 1361–1372.

94. Upender, G., Vardhani, C. P., Kamalaker, V., &Chandra Mouli, V. (2010). Infrared Spectroscopic Characterization of Tellurite Glasses Containing Heavy Metal Oxides. *Scholarly Research Exchange Physics*, 1–6.

95. Awang, A., Ghoshal, S. K., Sahar, M. R., Arifin, R. (2015). Gold nanoparticles assisted structural and spectroscopic modification in Er^{3+} -doped zinc sodium tellurite glass. *Optical Materials*, *42*, 495–505.

96. Tokonami, S., Yamamoto, Y., Shiigi, H., & Nagaoka, T. (2012). Synthesis and bioanalytical applications of specific-shaped metallic nanostructures: A review. *Analytica Chimica Acta*, *716*, 76–91.

97. Jauhariyah, M. N. R., & Cari, Marzuki, A. (2016). Optical Properties of Erbium Doped Tellurite Glasses. *Materials Science Forum*, *864*, 37–41.

98. Yousef, E. S. S. (2005). Characterization of oxyfluoride tellurite glasses through thermal, optical andultrasonic measurements. *Journal of Physics D Applied Physics*, *38*, 3970–3975.

99. Sidek, H. A. A., Rosmawati, S., Talib, Z. A., Halimah, M. K., & Daud, W. M.

(2009). Synthesis and optical properties of ZnO-TeO_2 glass system. *American Journal of Applied Sciences*, *6*(8), 1489.

100. Ismail, S. F., Sahar, M. R., & Ghoshal, S. K. (2016). Physical and absorption properties of titanium nanoparticles incorporated into zinc magnesium phosphate glass. *Materials Characterization*, *111*, 177–182.

101. Jlassi, I., Elhouichet, H., & Ferid, M. (2016). Influence of MgO on structure and optical properties of alumino-lithium-phosphate glasses. *Physica E: Low-Dimensional Systems and Nanostructures*, *81*, 219–225.

102. Macdonald, E. K., & Shaver, M. P. (2015). Intrinsic high refractive index polymers. *Polymer International*, *64*(1), 6–14.

103. Seshadri, M., Barbosa, L. C., Cordeiro, C. M. B., Radha, M., Sigoli, F. A., & Ratnakaram, Y. C. (2015). Study of optical absorption , visible emission and NIR – vis luminescence urite glasses. *Journal of Luminescence*, *166*, 8–16.

104. Wang, F., Tian, Y., Jing, X., Cai, M., & Zhang, J. (2015). emission properties of fluoroaluminate – tellurite glass. *Journal of Quantitative Spectroscopy and Radiative Transfer*, *165*, 93–101.

105. Jlassi, I., Elhouichet, H., Hraiech, S., & Ferid, M. (2012). Effect of heat treatment on the structural and optical properties of tellurite glasses doped erbium. *Journal of Luminescence*, *132*(3), 832–840.

106. Srinivasa, C., Kityk, I. V, Srikumar, T., Raju, G. N., Kumar, V. R., Gandhi, Y., & Veeraiah, N. (2011). Spectroscopy features of Pr^{3+} and Er^{3+} ions in Li_2O – ZrO_2 – SiO_2 glass matrices mixed with some sesquioxides. *Journal of Alloys and Compounds*, *509*, 9230–9239.

107. Krishnaiah, K. V., Kumar, K. U., & Jayasankar, C. K. (2013). Spectroscopic properties of;-doped oxyfluoride glasses for white light emitting diodes. *Materials Express*, *3*(1), 61–70.

108. Fares, H., Stambouli, W., Elhouichet, H., Gelloz, B., & Férid, M. (2016). Nano-silver enhanced luminescence of Er^{3+} ions embedded in tellurite glass, vitro-ceramic and ceramic: impact of heat treatment. *RSC Adv.*, *6*(37), 31136–31145.

109. Souza, N. M., Ramos, A. Y., & Barbosa, L. C. (2002). Er^{3+} environment in TeO_2-ZnO-Na_2O glasses. *Journal of Non-Crystalline Solids*, *304*(1–3), 195–199.

110. Jaba, N., Ben Mansour, H., Kanoun, A., Brenier, A., & Champagnon, B.

(2009). Spectral broadening and luminescence quenching of 1.53µm emission in Er^{3+}-doped zinc tellurite glass. *Journal of Luminescence*, *129*(3), 270–276.

111. Hraiech, S., Bouzidi, C., & Férid, M. (2017). Luminescence properties of Er^{3}+ -doped phosphate glasses. *Physica B: Condensed Matter*, *522*(April), 15–21.

112. Saisudha, M. B., Ramakrishna, J. (2002). Optical absorption of Nd^{3+} , Sm^{3+} and Dy^{3+} in bismuth borate glasses with large radiative transition probabilities. *Optical Materials*, *18*, 403–417

113. Kim, H., Zhou, D., Wang, R., Jiao, Q., Yang, Z., & Song, Z. (2015). Effects of gold nanoparticles on the enhancement of upconversion and near- infrared emission in Er^{3+} / Yb^{3+} co-doped transparent glass – ceramics containing BaF_2 nanocrystals. *Ceramics International*, *41*(2), 2648–2653.

114. Azlan, M. N., Halimah, M. K., & Sidek, H. A. A. (2017). Linear and nonlinear optical properties of erbium doped zinc borotellurite glass system. *Journal of Luminescence*, *181*(October), 400–406.

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