View metadata, citation and similar papers at core.ac.uk
brought to you by CORE
provided by Universiti Teknologi Malaysia Institutional Repository

SILVER NANOPARTICLE ENHANCED THE OPTICAL PROPERTIES OF THE RARE EARTH DOPED MEGNESIUM ZINC SULFOPHOSPHATE GLASS

FAHIMEH AHMADI

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Doctor of Philosophy (Physics)

Faculty of Science
Universiti Teknologi Malaysia

AUGUST 2017

I dedicated this thesis to my beloved father and mother for their support and encouragement.

ACKNOWLEDGEMENTS

I would like to express my gratitude to my supervisor, Prof. Dr. Rosli Bin Hussin for his guidance, advice, constructive feedback, and critical review of this thesis. His support, time and help are the motivations for me to strive harder in my academic journey. I also would like to thank my co-supervisor Dr. Sib Krishna Ghoshal for his critical feedbacks on my research. I wish to thank Universiti Teknologi Malaysia for giving me the opportunity to do my research in a supportive academic environment.

My parents receive my deepest gratitude and love for their patience, pray, and the many years of support during my studies that provided the foundation for this work. I also would like to thank my brother for his love and support throughout the years. Special thanks to my husband for his understanding and love throughout the years. His support and encouragement was in the end what made this research possible.

ABSTRACT

Magnesium-zinc-sulfophosphate (P_2O_5-MgO-$ZnSO_4$) glasses being a prospective host for lasing active media require precise composition optimization and systematic characterization. A series of glass samples in the composition of (60.0-x)P_2O_5-20.0MgO-20.0$ZnSO_4$-xRE_2O_3 ($0.0 \leq x \leq 2.0$ mol% and rare earth (RE) = Sm, Dy, and Er), (59.5-y)P_2O_5-20.0MgO-20.0$ZnSO_4$-0.5RE_2O_3-yAgCl ($0.0 \leq y \leq 0.5$ mol% and RE = Sm and Dy) and (59.5-z)P_2O_5-20.0MgO-20.0$ZnSO_4$-0.5Er_2O_3-zAgCl ($0.0 \leq z \leq 1.5$ mol%) were synthesized using melt-quenching technique. The samples were thoroughly characterized using X-ray diffraction (XRD), transmission electron microscopy (TEM), Fourier transform infrared (FTIR), ultraviolet-visible (UV-Vis) absorption, photoluminescence (PL) and Raman spectroscopy. XRD verified the samples amorphous nature and TEM images manifested the nucleation of homogeneously distributed spherical silver (Ag) nanoparticles in the glass matrix. FTIR spectra revealed the bonding vibrations for P-O bonds, P-O-P linkages, and PO_2 units. There is no evidence in Raman spectra of RE (RE= Sm, Dy and Er) doped P_2O_5-MgO-$ZnSO_4$ glasses to confirm the incorporation of the sulfate ions to the network formation. The absorption spectrum of RE (RE = Sm, Dy and Er) doped P_2O_5-MgO-$ZnSO_4$ glasses with and without incorporation of Ag nanoparticles is originated from electronic transitions from the ground level to various excited levels belonging to the $4f^9$ electronic configuration of the RE ions. Absorption and emission spectra are used to evaluate the Judd-Ofelt (JO) intensity parameters and radiative transition probabilities, branching ratios and stimulated emission cross-sections of the three RE ion (RE = Sm, Dy, and Er) doped glass systems. The room temperature PL spectra of samarium-doped glass revealed four emission peaks centered at around 562, 599, 644, and 702 nm, which are assigned to the transitions from $^4G_{5/2}$ to $^6H_{5/2}$, $^6H_{7/2}$, $^6H_{9/2}$ and $^6H_{11/2}$, respectively. The PL spectra of dysprosium-doped glass displayed two prominent peaks at around 480 nm and 574 nm corresponding to the $^4F_{9/2} \rightarrow {}^6H_{15/2}$ and $^4F_{9/2} \rightarrow {}^6H_{13/2}$ transitions, respectively and two weak peaks. Conversely, erbium-doped glass system exhibited two strong emission peaks centered at around 541 nm and 654 nm attributed to the $^4S_{3/2} \rightarrow {}^4I_{15/2}$ and $^4F_{9/2} \rightarrow {}^4I_{15/2}$ transitions, respectively. All glass series containing Ag nanoparticles showed considerable emission intensity enhancement, which is attributed to the nanoparticle surface plasmon resonance mediated intensified local field effect in the proximity of RE ions. Overall properties of each glass series are demonstrated to be modified due to the embedment of Ag nanoparticles. Among all the glass series produced, the stimulated emission cross-section for $^4S_{3/2} \rightarrow {}^4I_{15/2}$ transition in erbium-doped glass system is discerned to be the highest.

ABSTRAK

Kaca magnesium-zink-sulfofosfat (P_2O_5-MgO-$ZnSO_4$) sebagai satu hos prospektif bagi media aktif las memerlukan pengoptimuman komposisi yang persis dan pencirian yang sistematik. Satu siri kaca dengan komposisi (60.0-x)P_2O_5-20.0MgO-20.0$ZnSO_4$-xRE_2O_3 ($0.0 \leq x \leq 2.0$ mol% dan nadir bumi (RE) = Sm, Dy, dan Er), (59.5-y)P_2O_5-20.0MgO-20.0$ZnSO_4$-0.5RE_2O_3-yAgCl ($0.0 \leq y \leq 0.5$ mol%) dan (59.5-z)P_2O_5-20.0MgO-20.0$ZnSO_4$-0.5Er_2O_3-zAgCl ($0.0 \leq z \leq 1.5$ mol%) telah disintesis menggunakan teknik lebur-lindap kejut. Sampel telah dicirikan secara terperinci dengan menggunakan pembelauan sinar-x (XRD), mikroskopi elektron penghantaran (TEM), spektroskopi infra merah jelmaan Fourier (FTIR), spektroskopi serapan ultraungu-nampak (UV-Vis), spektroskopi kefotopendarcahayaan (PL) dan spektroskopi Raman. XRD telah menentusahkan sifat amorfus sampel dan imej TEM telah menunjukkan penukleusan zarah nano perak (Ag) berbentuk sfera yang teragih secara homogen dalam matriks kaca. Spektrum FTIR memperlihatkan getaran ikatan bagi ikatan P-O, rantaian P-O-P, dan unit PO_2. Tidak ada sebarang petunjuk pada spektrum Raman kaca P_2O_5-MgO-$ZnSO_4$ berdop RE (RE = Sm, Dy dan Er) yang mengesahkan penggabungan ion sulfat dalam pembentukan rangkaian. Spektrum penyerapan kaca P_2O_5-MgO-$ZnSO_4$ berdop RE (RE = Sm, Dy dan Er) dengan dan tanpa penggabungan zarah nano Ag berasal daripada peralihan elektronik dari aras asas ke pelbagai aras teruja ion RE yang berkonfigurasi elektronik $4f^9$. Spektrum serapan dan pancaran telah digunakan untuk menilai parameter keamatan Judd-Ofelt (JO) dan kebarangkalian peralihan pancaran, nisbah pencabang dan keratan rentas pancaran teransang bagi tiga sistem kaca berdop ion RE (RE = Sm, Dy, dan Er) tersebut. Spektrum PL kaca berdop Samarium pada suhu bilik memperlihatkan empat puncak pancaran berpusat sekitar 562, 599, 644, dan 702 nm, yang terumpu kepada peralihan masing-masing dari $^4G_{5/2}$ ke $^6H_{5/2}$, $^6H_{7/2}$, $^6H_{9/2}$ dan $^6H_{11/2}$. Spektrum PL bagi kaca berdop dysprosium mempamerkan dua puncak yang ketara berpusat sekitar 480 nm dan 574 nm yang masing-masing berpadanan dengan peralihan $^4F_{9/2} \rightarrow {}^6H_{15/2}$ dan $^4F_{9/2} \rightarrow {}^6H_{13/2}$ dan dua puncak yang rendah. Sebaliknya, sistem kaca berdop erbium telah mempamerkan dua puncak pancaran yang tinggi berpusat pada 541 nm dan 654 nm yang terumpu masing-masing kepada peralihan $^4S_{3/2} \rightarrow {}^4I_{15/2}$ dan $^4F_{9/2} \rightarrow {}^4I_{15/2}$. Kesemua siri kaca yang mengandungi zarah nano Ag menunjukkan peningkatan keamatan pancaran yang agak banyak, yang terumpu kepada peningkatan kesan medan setempat berperantaraan resonans plasmon permukaan zarah nano di kehampiran ion RE. Sifat keseluruhan setiap siri kaca menunjukkan perubahan yang disebabkan oleh pembenaman zarah nano Ag. Antara semua siri kaca yang terhasil, keratan rentas pancaran teransang untuk peralihan $^4S_{3/2} \rightarrow {}^4I_{15/2}$ bagi sistem kaca berdop erbium adalah dianggap sebagai yang tertinggi.

TABLE OF CONTENTS

CHAPTER	TITLE		PAGE
	DECLARATION		ii
	DEDICATION		iii
	ACKNOWLEDGEMENTS		iv
	ABSTRACT		v
	ABSTRAK		vi
	TABLE OF CONTENTS		vii
	LIST OF TABLES		xii
	LIST OF FIGURES		xviii
	LIST OF ABBREVIATIONS		xxv
	LIST OF SYMBOLS		xxvi
	LIST OF APPENDICES		xxviii
1	**INTRODUCTION**		**1**
	1.1	Background of the Study	1
	1.2	Problem Statement	6
	1.3	Research Objectives	7
	1.4	Significance of Research	7
	1.5	Scope of the Study	8
	1.6	Outline of Thesis	8
2	**LITERATURE REVIEW**		**10**
	2.1	Introduction	10
	2.2	Basic Glass Structure	12
	2.3	The Structure of Phosphate Glass	14
	2.4	Zinc Phosphate Glass	17

	2.5	Magnesium Phosphate Glass	18
	2.6	Sulfophosphate Glass	19
	2.7	Rare Earth Ions	24
		2.7.1 Samarium Ion	25
		2.7.2 Dysprosium Ion	26
		2.7.3 Erbium Ion	27
	2.8	Different Transition Inside RE^{3+} Doped Glass	27
	2.9	Judd-Ofelt (JO) Theory	29
		2.9.1 Radiative Properties	33
	2.10	Optic and Plasmonic	34
		2.10.1 Maxwell's Equation and Optics of Metals	36
		2.10.2 Plasmonics	44
	2.11	Some Important Parameters	45
		2.11.1 Bonding Parameters	46
		2.11.2 Hypersensitive Transitions	47
		2.11.3 Direct and Indirect Band Gap Energy	47
		2.11.4 Determination of Urbach Energy	48
3	**RESEARCH METHODOLOGY**		**50**
	3.1	Introduction	50
	3.2	Sample Preparation	50
	3.3	X-ray Diffractometer (XRD)	52
	3.4	Density Measurement	53
	3.5	Infrared (IR) Spectrometer	54
	3.6	Raman Spectrometer	55
	3.7	UV-Vis-NIR Spectrometer	55
	3.8	Photoluminescence (PL) Spectrometer	56
	3.9	Transmission Electron Microscope (TEM)	57
4	**SPECTRAL FEATURES OF RE^{3+} (RE = Sm, Dy AND Er) DOPED MAGNESIUM-ZINC-SULFOPHOSPHATE GLASS: JUDD-OFELT ANALYSIS**		**59**

4.1 Introduction 59

4.2 Glass Compositions 59

4.3 X-ray Diffraction (XRD) Analysis 60

4.4 Infrared (IR) Spectra Analysis 61

4.5 Raman Spectra Analysis 65

4.6 Density and Molar Volume 70

4.7 Absorption Spectra Analysis 73

4.7.1 Sm^{3+}-Doped Magnesium-Zinc-Sulfophosphate Glass 73

4.7.2 Dy^{3+}-Doped Magnesium-Zinc-Sulfophosphate Glass 76

4.7.3 Er^{3+}-Doped Magnesium-Zinc-Sulfophosphate Glass 79

4.8 Optical Band Gap Energy 81

4.9 Refractive Index and Molar Polarizability 88

4.10 Emission Spectra Analysis 92

4.10.1 Sm^{3+}-Doped Magnesium-Zinc-Sulfophosphate Glass 92

4.10.2 Dy^{3+}-Doped Magnesium-Zinc-Sulfophosphate Glass 97

4.10.3 Er^{3+}-Doped Magnesium-Zinc-Sulfophosphate Glass 102

4.11 Judd-Ofelt Analysis 104

4.11.1 Sm^{3+}-Doped Magnesium-Zinc-Sulfophosphate Glass 104

4.11.2 Dy^{3+}-Doped Magnesium-Zinc-Sulfophosphate Glass 108

4.11.3 Er^{3+}-Doped Magnesium-Zinc-Sulfophosphate Glass 112

4.12 Radiative Properties 115

4.12.1 Sm^{3+}-Doped Magnesium-Zinc-Sulfophosphate Glass 115

4.12.2 Dy^{3+}-Doped Magnesium-Zinc-Sulfophosphate Glass 122

4.12.3 Er^{3+}-Doped Magnesium-Zinc-Sulfophosphate Glass 126

5 SPECTROCOPIC PROPERTIES OF RE^{3+} (RE = Sm, Dy AND Er) DOPED MAGNESIUM-ZINC-SULFOPHOSPHATE GLASS CONTAINING Ag NANOPARTICLES 133

5.1 Introduction 133

5.2 X-ray Diffraction (XRD) Analysis 134

5.3 Infrared (IR) Spectra Analysis 135

5.4 Density and Molar Volume 138

5.5 Absorption Spectra 141

5.5.1 Sm^{3+}-Doped Magnesium-Zinc-Sulfophosphate Glass Containing Ag Nanoparticles 141

5.5.2 Dy^{3+}-Doped Magnesium-Zinc-Sulfophosphate Glass Containing Ag Nanoparticles 145

5.5.3 Er^{3+}-Doped Magnesium-Zinc-Sulfophosphate Glass Containing Ag Nanoparticles 148

5.6 Optical Band Gap Energy 150

5.7 Morphology Analysis 154

5.8 Emission Spectra Analysis 156

5.8.1 Sm^{3+}-Doped Magnesium-Zinc-Sulfophosphate Glass Containing Ag Nanoparticles 156

5.8.2 Dy^{3+}-Doped Magnesium-Zinc-Sulfophosphate Glass Containing Ag Nanoparticles 159

5.8.3 Er^{3+}-Doped Magnesium-Zinc-Sulfophosphate Glass Containing Ag Nanoparticles 161

5.9 Judd-Ofelt Analysis 164

5.9.1 Sm^{3+}-Doped Magnesium-Zinc-Sulfophosphate Glass Containing Ag Nanoparticles 164
5.9.2 Dy^{3+}-Doped Magnesium-Zinc-Sulfophosphate Glass Containing Ag Nanoparticles 167
5.9.3 Er^{3+}-Doped Magnesium-Zinc-Sulfophosphate Glass Containing Ag Nanoparticles 169
5.10 Radiative Properties 173
5.10.1 Sm^{3+}-Doped Magnesium-Zinc-Sulfophosphate Glass Containing Ag Nanoparticles 173
5.10.2 Dy^{3+}-Doped Magnesium-Zinc-Sulfophosphate Glass Containing Ag Nanoparticles 176
5.10.3 Er^{3+}-Doped Magnesium-Zinc-Sulfophosphate Glass Containing Ag Nanoparticles 179

6 CONCLUSION AND RECOMMENDATIONS 184
6.1 Introduction 184
6.2 Conclusion 184
6.3 Recommendation for Future Works 186

REFERENCES 187
Appendix A 209

LIST OF TABLES

TABLE NO.	TITLE	PAGE
2.1	The absorption matrix elements of aqueous Sm^{3+} ion	31
2.2	The absorption matrix elements of aqueous Dy^{3+} ion	31
2.3	The absorption matrix elements of aqueous Er^{3+} ion	32
3.1	Glass composition for $(60.0-x)P_2O_5$-20.0MgO-$20.0ZnSO_4$-xRE_2O_3, where $0.0 \leq x \leq 2.0$ mol% and RE = Sm, Dy and Er	51
3.2	Glass composition for $(59.5-y)P_2O_5$-20.0MgO-$20.0ZnSO_4$-$0.5RE_2O_3$-yAgCl, RE = Sm and Dy where $0.0 \leq y \leq 0.5$ mol% and $(59.5-z)P_2O_5$-20.0MgO-$20.0ZnSO_4$-$0.5Er_2O_3$-zAgCl, where $0.0 \leq z \leq 1.5$ mol% glasses	52
4.1	IR absorption band position and assignment of the $(60.0-x)P_2O_5$-20.0MgO-$20.0ZnSO_4$-xRE_2O_3 ($0.0 \leq x \leq 2.0$ mol% and RE = Sm, Dy and Er) glass samples	64
4.2	Assignment of experimentally observed Raman-active vibrations in $59.0P_2O_5$-20.0MgO-$20.0ZnSO_4$-$1.0RE_2O_3$ (RE = Sm, Dy and Er) glasses	68
4.3	Some physical properties of $(60.0-x)P_2O_5$-20.0MgO-$20.0ZnSO_4$-xRE_2O_3 ($0.0 \leq x \leq 2.0$ mol% and RE = Sm, Dy and Er) glass samples	71
4.4	Comparison of the calculated band positions (cm^{-1}) and bonding parameters (β and δ) of $(60.0-x)P_2O_5$-20.0MgO-$20.0ZnSO_4$-xSm_2O_3 ($0.5 \leq x \leq 2.0$ mol%) glass system with reported values	76

4.5	Observed band positions (cm^{-1}) and bonding parameters (β and δ) of the (60.0-x)P_2O_5-20.0MgO-20.0$ZnSO_4$-xDy_2O_3 (0.5 ≤ x ≤ 2.0 mol%) glasses	79
4.6	Comparison of the calculated band positions (cm^{-1}) and bonding parameters (β and δ) of (60.0-x)P_2O_5-20.0MgO-20.0$ZnSO_4$-xEr_2O_3 (0.5 ≤ x ≤ 2.0 mol%) glasses glass system with reported values	80
4.7	Optical energy band gap and Urbach energy of the (60.0-x)P_2O_5-20.0MgO-20.0$ZnSO_4$-xRE_2O_3 (0.0 ≤ x ≤ 2.0 mol% and RE = Sm, Dy and Er) and reported glass system	85
4.8	Refractive index of the (60.0-x)P_2O_5-20.0MgO-20.0$ZnSO_4$-xRE_2O_3 (0.0 ≤ x ≤ 2.0 mol% and RE = Sm, Dy and Er) and reported glass system	91
4.9	Some physical properties of (60.0-x)P_2O_5-20.0MgO-20.0$ZnSO_4$-xRE_2O_3 (0.0 ≤ x ≤ 2.0 mol% and RE = Sm, Dy and Er) glass samples	92
4.10	PL peak positions (in nm) and their assignments for (60.0-x)P_2O_5-20.0MgO-20.0$ZnSO_4$-xSm_2O_3 (0.5 ≤ x ≤ 2.0 mol%) glass system	94
4.11	Band position (nm) and their assignment of (60.0-x)P_2O_5-20.0MgO-20.0$ZnSO_4$-xDy_2O_3 (0.5 ≤ x ≤ 2.0 mol%) glasses	99
4.12	The yellow-to-blue luminescence intensity ratios (Y/B) ratios for (60.0-x)P_2O_5-20.0MgO-20.0$ZnSO_4$-xDy_2O_3 (0.5 ≤ x ≤ 2.0 mol%) glass along with reported Dy^{3+}: glasses	100
4.13	Emission peak positions (nm) and their assignment of (60.0-x)P_2O_5-20.0MgO-20.0$ZnSO_4$-xEr_2O_3 (0.5 ≤ x ≤ 2.0 mol%) glasses	103
4.14	Experimental and calculated oscillator strengths ($\times 10^{-6}$) of (60.0-x)P_2O_5-20.0MgO-20.0$ZnSO_4$-xSm_2O_3 (0.5 ≤ x ≤ 2.0 mol%) glass system	105

4.15	Comparison of JO parameters ($\times 10^{-20}$ cm^2) and quality factors (Ω_4/Ω_6) of (60.0-x)P_2O_5-20.0MgO-20.0$ZnSO_4$-xSm_2O_3 (0.5 ≤ x ≤ 2.0 mol%) glass system with others	106
4.16	Experimental and calculated oscillator strengths ($\times 10^{-6}$) of (60.0-x)P_2O_5-20.0MgO-20.0$ZnSO_4$-xDy_2O_3 (0.5 ≤ x ≤ 2.0 mol%) glasses	109
4.17	The JO ($\times 10^{-20}$ cm^2) parameters, trends of Ω_i parameters and spectroscopic quality factor (Ω_4/Ω_6) of the (60.0-x)P_2O_5-20.0MgO-20.0$ZnSO_4$-xDy_2O_3 (0.5 ≤ x ≤ 2.0 mol%) glasses	111
4.18	Experimental and calculated oscillator strengths ($\times 10^{-6}$) of (60.0-x)P_2O_5-20.0MgO-20.0$ZnSO_4$-xEr_2O_3 (0.5 ≤ x ≤ 2.0 mol%) glass system	113
4.19	Comparison of JO parameters ($\times 10^{-20}$ cm^2) of (60.0-x)P_2O_5-20.0MgO-20.0$ZnSO_4$-xEr_2O_3 (0.5 ≤ x ≤ 2.0 mol%) glass system with others	114
4.20	The values of energy difference (cm^{-1}), A_{ed} (s^{-1}), A_{md} (s^{-1}), A (s^{-1}), β_R (%), and τ_R (ms) for various transitions originating from $^4G_{5/2}$ level of 59.5P_2O_5-20.0MgO-20.0$ZnSO_4$-0.5Sm_2O_3 glass	117
4.21	The values of energy difference (cm^{-1}), A_{ed} (s^{-1}), A_{md} (s^{-1}), A (s^{-1}), β_R (%), and τ_R (ms) for various transitions originating from $^4G_{5/2}$ level of 59.0P_2O_5-20.0MgO-20.0$ZnSO_4$-1.0Sm_2O_3 glass	118
4.22	The values of energy difference (cm^{-1}), A_{ed} (s^{-1}), A_{md} (s^{-1}), A (s^{-1}), β_R (%), and τ_R (ms) for various transitions originating from $^4G_{5/2}$ level of 58.5P_2O_5-20.0MgO-20.0$ZnSO_4$-1.5Sm_2O_3 glass	119
4.23	The values of energy difference (cm^{-1}), A_{ed} (s^{-1}), A_{md} (s^{-1}), A (s^{-1}), β_R (%), and τ_R (ms) for various transitions originating from $^4G_{5/2}$ level of 58.0P_2O_5-20.0MgO-20.0$ZnSO_4$-2.0Sm_2O_3 glass	120

4.24	The values of λ_p (nm), $\Delta\lambda_{eff}$ (nm), A (s^{-1}), σ_p^E ($\times 10^{-22}$ cm^2) as well as experimental and calculated β_R (%) for (60.0-x)P_2O_5-20.0MgO-20.0$ZnSO_4$-xSm_2O_3 ($0.5 \leq x \leq$ 2.0 mol%) glass system and the reported Sm^{3+}-doped glasses	121
4.25	Values of λ_p (nm), $\Delta\lambda_{eff}$ (nm), A (s^{-1}), σ_p^E ($\times 10^{-22}$ cm^2) as well as experimental and calculated β_R (%) for 59.5P_2O_5-20.0MgO-20.0$ZnSO_4$-0.5Sm_2O_3 glass system and the reported Sm^{3+} doped glasses	122
4.26	The values of A (s^{-1}), and β_R (%) of (60.0-x)P_2O_5-20.0MgO-20.0$ZnSO_4$-xDy_2O_3 ($0.5 \leq x \leq 2.0$ mol%) glass	123
4.27	The values of λ_p (nm), $\Delta\lambda_{eff}$ (nm), A (s^{-1}), σ_p^E ($\times 10^{-22}$ cm^2) and experimental, calculated β_R (%) and τ_R (ms) for the $^4F_{9/2}$ transition level of (60.0-x)P_2O_5-20.0MgO-20.0$ZnSO_4$-xDy_2O_3 ($0.5 \leq x \leq 2.0$ mol%) glasses and the reported Dy^{3+} glasses	124
4.28	The values of λ_p (nm), $\Delta\lambda_{eff}$ (nm) and σ_p^E ($\times 10^{-22}$ cm^2) for the $^4F_{9/2} \rightarrow {}^6H_{15/2}$ and $^4F_{9/2} \rightarrow {}^6H_{13/2}$ transitions of Dy^{3+} ions in different glasses	126
4.29	The values of energy difference (ΔE), A_{ed} (s^{-1}) and A_{md} (s^{-1}), β and τ_R (ms) for (60.0-x)P_2O_5-20.0MgO-20.0$ZnSO_4$-xEr_2O_3 ($0.5 \leq x \leq 2.0$ mol%) glass system	128
4.30	The values of λ_p (nm), $\Delta\lambda_{eff}$ (nm), A (s^{-1}), σ_p^E ($\times 10^{-22}$ cm^2) as well as experimental and calculated β_R (%) for (60.0-x)P_2O_5-20.0MgO-20.0$ZnSO_4$-xEr_2O_3 ($0.5 \leq x \leq 2.0$ mol%) glass system	131
4.31	Values of λ_p (nm), $\Delta\lambda_{eff}$ (nm), A (s^{-1}), σ_p^E ($\times 10^{-22}$ cm^2), calculated and experimental β_R (%) for the $^4S_{3/2}$ level under 476 nm excitation of the prepared glass system	132
5.1	The values of M_{av} (g mol^{-1}), ρ (g cm^{-3}) and V_M (cm^3 mol^{-1}) for studied glasses	139

5.2	Observed band positions (cm^{-1}) and bonding parameters (β and δ) of the (59.5-y)P_2O_5-20.0MgO-20.0$ZnSO_4$-0.5Sm_2O_3-yAgCl (0.0 ≤ y ≤ 0.5 mol%) glasses	144
5.3	Observed band positions (cm^{-1}) and bonding parameters (β and δ) of the (59.5-y)P_2O_5-20.0MgO-20.0$ZnSO_4$-0.5Dy_2O_3-yAgCl (0.0 ≤ y ≤ 0.5 mol%) glasses	147
5.4	Comparison of the calculated band positions (cm^{-1}) and bonding parameters (β and δ) of (59.5-z)P_2O_5-20.0MgO-20.0$ZnSO_4$-0.5Er_2O_3-zAgCl (0.0 ≤ z ≤ 1.5 mol%) glass system with reported values	150
5.5	The values of E_{opt}^{dir} (eV), E_{opt}^{indir}(eV), n and ΔE (eV) for studied glasses	151
5.6	Experimental and calculated oscillator strengths ($\times 10^{-6}$) of (59.5-y)P_2O_5-20.0MgO-20.0$ZnSO_4$-0.5Sm_2O_3-yAgCl (0.0 ≤ y ≤ 0.5 mol%) glass system	165
5.7	Comparison of JO parameters ($\times 10^{-20}$ cm^2) and quality factors (Ω_4/Ω_6) of the (59.5-y)P_2O_5-20.0MgO-20.0$ZnSO_4$-0.5Sm_2O_3-yAgCl (0.0 ≤ y ≤ 0.5 mol%) glass system with other findings	166
5.8	Experimental and calculated oscillator strengths ($\times 10^{-6}$) of (59.5-y)P_2O_5-20.0MgO-20.0$ZnSO_4$-0.5Dy_2O_3-yAgCl (0.0 ≤ y ≤ 0.5 mol%) glasses	167
5.9	The Judd-Ofelt ($\times 10^{-20}$ cm^2) parameters, trends of Ω_i parameters and spectroscopic quality factor (Ω_4/Ω_6) of (59.5-y)P_2O_5-20.0MgO-20.0$ZnSO_4$-0.5Dy_2O_3-yAgCl (0.0 ≤ y ≤ 0.5 mol%) and the results of other works	168
5.10	Experimental and calculated oscillator strengths ($\times 10^{-6}$) of (59.5-z)P_2O_5-20.0MgO-20.0$ZnSO_4$-0.5Er_2O_3-zAgCl (0.0 ≤ z ≤ 1.5 mol%) glass system	170
5.11	Comparison between JO parameters ($\times 10^{-20}$ cm^2) of the (59.5-z)P_2O_5-20.0MgO-20.0$ZnSO_4$-0.5Er_2O_3-zAgCl (0.0 ≤ z ≤ 1.5 mol%) glass and other reports	171

5.12	Comparison between JO parameters ($\times 10^{-20}$ cm^2) of the (59.5-y)P_2O_5-20.0MgO-20.0$ZnSO_4$-0.5RE_2O_3-yAgCl (0.0 ≤ y ≤ 0.5 mol% and RE = Sm and Dy) (59.5-z)P_2O_5-20.0MgO-20.0$ZnSO_4$-0.5Er_2O_3-zAgCl (0.0 ≤ z ≤ 1.5 mol%) glass	173
5.13	The values of A (s^{-1}), and β_R (%) of (59.5-y)P_2O_5-20.0MgO-20.0$ZnSO_4$-0.5Sm_2O_3-yAgCl (0.0 ≤ y ≤ 0.5 mol%) glass	174
5.14	The values of λ_p (nm), $\Delta\lambda_{eff}$ (nm), A (s^{-1}), σ_p^E ($\times 10^{-22}$ cm^2), τ_R (ms) as well as experimental and calculated β_R (%), for (59.5-y)P_2O_5-20.0MgO-20.0$ZnSO_4$-0.5Sm_2O_3-yAgCl (0.0 ≤ y ≤ 0.5 mol%) glass system and the reported Sm^{3+} glasses	175
5.15	The values of A (s^{-1}) and β_R (%) of (59.5-y)P_2O_5-20.0MgO-20.0$ZnSO_4$-0.5Dy_2O_3-yAgCl (0.0 ≤ y ≤ 0.5 mol%) glass	177
5.16	The values of λ_p(nm), $\Delta\lambda_{eff}$(nm), A (s^{-1}), σ_p^E($\times 10^{-22}$ cm^2), experimental, calculated β_R (%) and τ_R (ms) for the $^4F_{9/2}$ transition level of the (59.5-y)P_2O_5-20.0MgO-20.0$ZnSO_4$-0.5Dy_2O_3-yAgCl (0.0 ≤ y ≤ 0.5 mol%) glasses and the reported Dy^{3+} glasses	178
5.17	The values of A_{ed} (s^{-1}), A_{md} (s^{-1}), β_R (%) and τ_R(ms) of (59.5-z)P_2O_5-20.0MgO-20.0$ZnSO_4$-0.5Er_2O_3-zAgCl (0.0 ≤ z ≤1.5 mol%) glass system	180
5.18	The values of λ_p (nm), $\Delta\lambda_{eff}$ (nm), A (s^{-1}), σ_p^E ($\times 10^{-22}$ cm^2) as well as experimental and calculated β_R (%) for (59.5-z)P_2O_5-20.0MgO-20.0$ZnSO_4$-0.5Er_2O_3-zAgCl (0.0 ≤ z ≤ 1.5 mol%) glass system	183

LIST OF FIGURES

FIGURE NO.	TITLE	PAGE
2.1	Schematic illustration of the change in volume with temperature as a liquid is cooled, showing the difference in behaviour between glass and crystalline solids	13
2.2	Phosphate tetrahedral sites that can exist in phosphate glasses	15
2.3	Different structural positions in sulfate-polyphosphate chains	21
2.4	FTIR spectra of glasses: (1) Crystalline sodium sulphate Na_2SO_4; (2) Vitreous $NaPO_3$; and (3) $20Na_2SO_4 \cdot 80NaPO_3$ (mol %) (Sokolov *et al.*, 2011)	22
2.5	Deconvoluted Raman spectrum of a (Na, Zn) pyrophosphate glass Labels indicated positions of individual Gaussian peaks (Da *et al.*, 2011)	23
2.6	Raman spectra of (Na, Zn) sulfophosphate glasses for increasing SO_4^{2-} content. Spectra of crystalline samples are shown for comparison (Da *et al.*, 2011)	23
3.1	The X-ray Diffractometer	٥٣
3.2	Perkin-Elmer Spectrum GX FTIR spectroscopy	٥٤
3.3	The confocal Jobin Yvon (Model HR800 UV) spectrometer	55
3.4	UV-Vis-NIR scanning spectrometer	٥٦
3.٥	Fluorescence spectrometer (FP-8500, JASCO)	٥٧
3.٦	The Transmission Electron Microscope (TEM 2100, JEOL)	58

4.1	XRD pattern of $59.5P_2O_5$-20.0MgO-20.0$ZnSO_4$-0.5Sm_2O_3 glass	٦٠
4.2	XRD pattern of $59.5P_2O_5$-20.0MgO-20.0$ZnSO_4$-0.5Dy_2O_3 glass	٦0
4.3	XRD pattern of $59.5P_2O_5$-20.0MgO-20.0$ZnSO_4$-0.5Er_2O_3 glass	٦1
4.4	IR spectra of (60.0-x)P_2O_5-20.0MgO-20.0$ZnSO_4$-xSm_2O_3 ($0.0 \leq x \leq 2.0$ mol%) glasses	٦2
4.5	IR spectra of (60.0-x)P_2O_5-20.0MgO-20.0$ZnSO_4$-xDy_2O_3 ($0.0 \leq x \leq 2.0$ mol%) glasses	٦3
4.6	IR spectra of (60.0-x)P_2O_5-20.0MgO-20.0$ZnSO_4$-xEr_2O_3 ($0.0 \leq x \leq 2.0$ mol%) glasses	٦3
4.7	Raman spectra analysis of $59.0P_2O_5$-20.0MgO-20.0$ZnSO_4$-1.0Sm_2O_3 glass	٦٦
4.8	Raman spectra analysis of $59.0P_2O_5$-20.0MgO-20.0$ZnSO_4$-1.0Dy_2O_3glass	67
4.9	Raman spectra analysis of $59.0P_2O_5$-20.0MgO-20.0$ZnSO_4$-1.0Er_2O_3 glass	67
4.10	Variation of density and molar volume of (60.0-x)P_2O_5-20.0MgO-20.0$ZnSO_4$-xSm_2O_3 ($0.0 \leq x \leq 2.0$ mol%) as a function of Sm^{3+} ion concentration	72
4.11	Variation of density and molar volume of (60.0-x)P_2O_5-20.0MgO-20.0$ZnSO_4$-xDy_2O_3 ($0.0 \leq x \leq 2.0$ mol%) as a function of Dy^{3+} ion concentration	72
4.12	Variation of density and molar volume of (60.0-x)P_2O_5-20.0MgO-20.0$ZnSO_4$-xEr_2O_3 ($0.0 \leq x \leq 2.0$ mol%) as a function of Er^{3+} ion concentration	73
4.13	Absorption spectra of $59.5P_2O_5$-20.0MgO-20.0$ZnSO_4$-0.5Sm_2O_3 glass sample in the region of (a) UV-Vis and (b) NIR	75
4.14	Absorption spectrum of $59.5P_2O_5$-20.0MgO-20.0$ZnSO_4$-0.5Dy_2O_3 glass in (a) UV-Vis and (b) NIR region	78

4.15	UV-Vis-NIR spectra of $59.0P_2O_5$-20.0MgO-$20.0ZnSO_4$-$1.0Er_2O_3$ glass	80
4.16	Typical Tauc's plot for (a) direct and (b) indirect band gap energy of $59.5P_2O_5$-20.0MgO-$20.0ZnSO_4$-$0.5Sm_2O_3$ glass	82
4.17	Typical Tauc's plot for (a) direct and (b) indirect band gap energy of $59.5P_2O_5$-20.0MgO-$20.0ZnSO_4$-$0.5Dy_2O_3$ glass	83
4.18	Typical Tauc's plot for (a) direct and (b) indirect band gap energy of $59.0P_2O_5$-20.0MgO-$20.0ZnSO_4$-$1.0Er_2O_3$ glass	84
4.19	Optical band gap energy of $(60.0-x)P_2O_5$-20.0MgO-$20.0ZnSO_4$-xSm_2O_3 ($0.0 \leq x \leq 2.0$ mol%) glass samples	86
4.20	Optical band gap energy of $(60.0-x)P_2O_5$-20.0MgO-$20.0ZnSO_4$-xDy_2O_3 ($0.0 \leq x \leq 2.0$ mol%) glass samples	87
4.21	Optical band gap energy of $(60.0-x)P_2O_5$-20.0MgO-$20.0ZnSO_4$-xEr_2O_3 ($0.0 \leq x \leq 2.0$ mol%) glass samples	87
4.22	Variation of refractive index and molar polarizability of $(60.0-x)P_2O_5$-20.0MgO-$20.0ZnSO_4$-xSm_2O_3 ($0.0 \leq x \leq 2.0$ mol%) glass	89
4.23	Variation of refractive index and molar polarizability of $(60.0-x)P_2O_5$-20.0MgO-$20.0ZnSO_4$-xDy_2O_3 ($0.0 \leq x \leq 2.0$ mol%) glass sample	89
4.24	Variation of refractive index and molar polarizability of $(60.0-x)P_2O_5$-20.0MgO-$20.0ZnSO_4$-xEr_2O_3 ($0.0 \leq x \leq 2.0$ mol%) glass sample	90
4.25	Excitation spectrum of $59.5P_2O_5$-20.0MgO-$20.0ZnSO_4$-$0.5Sm_2O_3$ glass (λ_{emi} = 600 nm)	93
4.26	Luminescence spectra of $(60.0-x)P_2O_5$-20.0MgO-$20.0ZnSO_4$-xSm_2O_3 ($0.5 \leq x \leq 2.0$ mol%) glass samples	94

4.27	Sm_2O_3 concentration dependent variation of PL peak intensity for (60.0-x)P_2O_5-20.0MgO-20.0$ZnSO_4$-xSm_2O_3 (0.0 ≤ x ≤ 2.0 mol%) glasses	95
4.28	Partial energy level diagram of 58.5P_2O_5-20.0MgO-20.0$ZnSO_4$-1.5Sm_2O_3 glass (a) enhancement and (b) quenching	97
4.29	Excitation spectrum of 58.5P_2O_5-20.0MgO-20.0$ZnSO_4$-1.5Dy_2O_3 glasses (Emission wavelength = 574nm)	98
4.30	Luminescence spectra of (60.0-x)P_2O_5-20.0MgO-20.0$ZnSO_4$-xDy_2O_3 (0.5 ≤ x ≤ 2.0 mol%) glasses. The inset shows the luminescence spectra in the region of 620 ≤ λ ≤ 800 nm	99
4.31	Peak intensity of (60.0-x)P_2O_5-20.0MgO-20.0$ZnSO_4$-xDy_2O_3 (0.0 ≤ x ≤ 2.0 mol%) glasses as a function of concentration of Dy_2O_3	100
4.32	Partial energy level diagram of 58.5P_2O_5-20.0MgO-20.0$ZnSO_4$-1.5Dy_2O_3 glass	102
4.33	Luminescence spectra of (60.0-x)P_2O_5-20.0MgO-20.0$ZnSO_4$-xEr_2O_3 (0.5 ≤ x ≤ 2.0 mol%) glasses	103
4.34	Partial energy level diagram of 58.5P_2O_5-20.0MgO-20.0$ZnSO_4$-1.5Er_2O_3 glass	104
4.35	Sm_2O_3 ions concentration dependent variation of JO intensity parameters and quality factor	107
4.36	Dy_2O_3 ions concentration dependent variation of JO intensity parameters and quality factor	112
4.37	Er_2O_3 ions concentration dependent variation of JO intensity parameters and quality factor	115
5.1	XRD pattern of 59.0P_2O_5-20.0MgO-20.0$ZnSO_4$-0.5Sm_2O_3-0.5AgCl glass	134
5.2	XRD pattern of 59.0P_2O_5-20.0MgO-20.0$ZnSO_4$-0.5Dy_2O_3-0.5AgCl glass	135
5.3	XRD pattern of 59.0P_2O_5-20.0MgO-20.0$ZnSO_4$-0.5Er_2O_3-0.5AgCl glass	135

5.4	IR spectra of (59.5-y)P_2O_5-20.0MgO-20.0$ZnSO_4$-0.5Sm_2O_3-yAgCl (0.0 ≤ y ≤ 0.5 mol%) glass system	137
5.5	IR spectra of (59.5-y)P_2O_5-20.0MgO-20.0$ZnSO_4$-0.5Dy_2O_3-yAgCl (0.0 ≤ y ≤ 0.5 mol%) glass system	137
5.6	IR spectra of (59.5-z)P_2O_5-20.0MgO-20.0$ZnSO_4$-0.5Er_2O_3-zAgCl (0.0 ≤ z ≤ 1.5 mol%) glass system	138
5.7	Variation of density and molar volume of (59.5-y)P_2O_5-20.0MgO-20.0$ZnSO_4$-0.5Sm_2O_3-yAgCl (0.0 ≤ y ≤ 0.5 mol%) glass sample as a function of Ag nanoparticles concentration	140
5.8	Variation of density and molar volume of (59.5-y)P_2O_5-20.0MgO-20.0$ZnSO_4$-0.5Dy_2O_3-yAgCl (0.0 ≤ y ≤ 0.5 mol%) glass sample as a function of Ag nanoparticles concentration	140
5.9	Variation of density and molar volume of (59.5-z)P_2O_5-20.0MgO-20.0$ZnSO_4$-0.5Er_2O_3-zAgCl (0.0 ≤ z ≤ 1.5 mol%) glass sample as a function of Ag nanoparticles concentration	141
5.10	Absorption spectra of (59.5-y)P_2O_5-20.0MgO-20.0$ZnSO_4$-0.5Sm_2O_3-yAgCl (0.0 ≤ y ≤ 0.5 mol%) glass sample in the region of (a) UV-Vis and (b) NIR region	143
5.11	SPR band positions of Ag nanoparticles of (59.5-y)P_2O_5-20.0MgO-20.0$ZnSO_4$-0.5Sm_2O_3-yAgCl (0.0 ≤ y ≤ 0.5 mol%) glass sample	144
5.12	Absorption spectra of (59.5-y)P_2O_5-20.0MgO-20.0$ZnSO_4$-0.5Dy_2O_3-yAgCl (0.0 ≤ y ≤ 0.5 mol%) glass sample in the region of (a) UV-Vis (b) NIR	146
5.13	SPR band position of Ag nanoparticles of (59.5-y)P_2O_5-20.0MgO-20.0$ZnSO_4$-0.5Dy_2O_3-yAgCl (0.0 ≤ y ≤ 0.5 mol%) glass sample	147
5.14	Absorption spectra of (59.5-z)P_2O_5-20.0MgO-20.0$ZnSO_4$-0.5Er_2O_3-zAgCl (0.0 ≤ z ≤ 1.5 mol%)	149

5.15	SPR band position of Ag nanoparticles of (59.5-z)P_2O_5-20.0MgO-20.0$ZnSO_4$-0.5Er_2O_3-zAgCl ($0.0 \leq z \leq 1.5$ mol%)	149
5.16	Variation of (a) optical band gap energy and (b) Urbach energy of (59.5-y)P_2O_5-20.0MgO-20.0$ZnSO_4$-0.5Sm_2O_3-yAgCl ($0.0 \leq y \leq 0.5$ mol%) glass as a function of Ag nanoparticles concentration	152
5.17	Variation of (a) optical band gap energy and (b) Urbach energy of (59.5-y)P_2O_5-20.0MgO-20.0$ZnSO_4$-0.5Dy_2O_3-yAgCl ($0.0 \leq y \leq 0.5$ mol%) glass as a function of Ag nanoparticles concentration	153
5.18	Variation of (a) optical band gap energy and (b) Urbach energy of (59.5-z)P_2O_5-20.0MgO-20.0$ZnSO_4$-0.5Er_2O_3-zAgCl ($0.0 \leq z \leq 1.5$ mol%) glass as a function of Ag nanoparticles concentration	154
5.19	TEM images of sample (a) confirming the existence of spherical nanoparticles and (b) Histogram of the distribution of nanoparticles in 59.0P_2O_5-20.0MgO-20.0$ZnSO_4$-0.5Sm_2O_3-0.5AgCl glass sample	155
5.20	TEM images of sample (a) confirming the existence of spherical nanoparticles and (b) Histogram of the distribution of nanoparticles in 59.0P_2O_5-20.0MgO-20.0$ZnSO_4$-0.5Dy_2O_3-0.5AgCl glass sample	155
5.21	TEM images of sample (a) confirming the existence of spherical nanoparticles and (b) Histogram of the distribution of nanoparticles in 59.0P_2O_5-20.0MgO-20.0$ZnSO_4$-0.5Er_2O_3-0.5AgCl glass sample	156
5.22	Luminescence spectra of (59.5-y)P_2O_5-20.0MgO-20.0$ZnSO_4$-0.5Sm_2O_3-yAgCl ($0.0 \leq y \leq 0.5$ mol%) glasses. Inset shows the luminescence spectra in the region of the $670 \leq \lambda \leq 750$ nm	157
5.23	Relative intensity of emissions after (I) and before (I_0) presenting NP of (59.5-y)P_2O_5-20.0MgO-20.0$ZnSO_4$-	

	$0.5Sm_2O_3$-yAgCl ($0.0 \leq y \leq 0.5$ mol%) as a function of Ag nanoparticles concentration	158
5.24	Schematic energy level diagram of $59.3P_2O_5$-20.0MgO-20.0$ZnSO_4$-$0.5Sm_2O_3$-0.2AgCl glass	158
5.25	Luminescence spectra of the (59.5-y)P_2O_5-20.0MgO-20.0$ZnSO_4$-$0.5Dy_2O_3$-yAgCl ($0.0 \leq y \leq 0.5$ mol%) glasses. Inset shows the luminescence spectra in the region of the $630 \leq \lambda \leq 790$ nm	159
5.26	Relative intensity of emissions after (I) and before (I_0) presenting NP of (59.5-y)P_2O_5-20.0MgO-20.0$ZnSO_4$-$0.5Dy_2O_3$-yAgCl ($0.0 \leq y \leq 0.5$ mol%) as a function of Ag nanoparticles concentration	160
5.27	Schematic energy level diagram of $59.3P_2O_5$-20.0MgO-20.0$ZnSO_4$-$0.5Dy_2O_3$-0.2AgCl glass	161
5.28	Luminescence spectra ($\lambda_{exc} = 476$ nm) of Schematic energy level diagram of (59.5-z)P_2O_5-20.0MgO-20.0$ZnSO_4$-$0.5Er_2O_3$-zAgCl ($0.0 \leq z \leq 1.5$ mol%) glasses	162
5.29	Relative intensity of emissions after (I) and before (I_0) presenting NP of (59.5-z)P_2O_5-20.0MgO-20.0$ZnSO_4$-$0.5Er_2O_3$-zAgCl ($0.0 \leq z \leq 1.5$ mol%) as a function of Ag nanoparticles concentration	163
5.30	Schematic energy level diagram of $59.0P_2O_5$-20.0MgO-20.0$ZnSO_4$-$0.5Er_2O_3$-0.5AgCl glass	164
5.31	Ag nanoparticles concentration dependent variation of JO parameters	166
5.32	Ag nanoparticles concentration dependent variation of JO parameters	169
5.33	Ag nanoparticles concentration dependent variation of JO parameters	172

LIST OF ABBREVIATIONS

BO	Bridging Oxygen
CB	Conduction Band
CR	Cross Relaxation
CW	Continuous Wave
DTP	Dithiophosphate
ET	Energy Transfer
EDFA	Erbium Doped Fiber Amplifiers
ESR	Electron-Spin Resonance
FTIR	Fourier Transform Infrared
GSA	Ground State Absorption
IR	Infrared
JO	Judd-Ofelt
LSPR	Localized Surface Plasmon Resonance
LFE	Local Field Effect
NBO	Non-Bridging Oxygen
NIR	Near Infrared
NMR	Nuclear Magnetic Resonance
NR	Non-Radiative
PL	Photoluminescence
RD	Radiative Decay
RE	Rare Earth
SPR	Surface Plasmon Resonance
TEM	Transmission Electron Microscope
UV	Ultraviolet
VB	Valence Band
VIS	Visible
XRD	X-Ray Diffraction

LIST OF SYMBOLS

ρ_{ext}	External Charge
2θ	Angle of Diffraction
A	Radiative Probability
A_{ed}	Electric-Dipole Transition Probability
A_{md}	Magnetic-Dipole Transition Probability
B	Magnetic Induction
C	Speed of Light
d	Dielectric Displacement
e	Charge of Electron
E	Electric Field
E_{opt}^{dir}	Direct Optical Band Gap
E_{opt}^{indir}	Indirect Optical Band Gap
F	Field Strength
ΔE	Urbach Energy
f_{cal}	Experimental Oscillator Strength
f_{exp}	Experimental Oscillator Strength
H	Magnetic Field
I	Intensity
J_{ext}	Current Densities
K	Wave vector
m	Mass of Electron
M_{av}	Average Molecular Weight
n	Refractive index
N	Concentration
N_A	Avogadro's number
r_p	Polaron Radius
r_i	Inter Nuclear Distance

R_m	Molar Refraction
S_{ed}, S_{md}	Electric and Magnetic Dipole Line Strengths
T	Temperature
T_c	Crystallization Temperature
T_g	Glass Transition Temperature
T_m	Melting Temperature
t	Time
$\left\|U^{(i)}\right\|^2$	Reduced Matrix Elements
V_M	Molar Volume
W	Weight
α	Absorption Co-efficient
α_m	Molar Polarizability
β	Branching Ratio
ε	Dielectric Function
ε_0	Permittivity of Volume
h	Plank's Constant
ρ	Density of Glass
σ_{emi}	Emission Cross-Section
$\eta(v)$	Molar Absorptivity
Ω_i	Judd-Ofelt Intensity Parameters
δ_{rms}	Root Mean Square Deviation between Experimental and Calculated Oscillator Strengths
λ	Wavelength
τ	Lifetime
v	Wavenumber
$\|(S,L)J>$	Electronic State of an Element Defined by its Spin, Orbital and Total Momentums
σ_P^E	Stimulated Emission Cross-Section
$\Delta\lambda_{eff}$	Effective Band Width

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A	List of Publications	209

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

The history of glass may extend back in time to the formation of the earth as mentioned by Porai-Koshits (1990) and Vogel (1994). About thousands of years ago, the first glass prepared by man in furnaces was applied in the ancient art of pottery (Shelby, 2005). The nature of the glass during those old days remained mysterious and unexplored until later. Although some systematic studies on glass composition and their properties along with growth of new glasses occurred, glass preparation with sufficient homogeneity was impossible until 1800 when a new fabrication method was developed by Guinad and Fraunhofer. The glass is capable to be modified both chemical and physical properties of the material by changing the compositions. Compositional modifications which are accompanied by distinct alterations in atomic-level glass structure lead to variations in glass properties. The ability to monitor these atomic-level structure changes as a function of composition may eventually lead to a better understanding of structure/property relationships in glasses.

Besides, due to primitive utility of oxide glasses as decorative pottery to the biocompatible and laser communication technology, they have been and will be used as potential materials in many aspects of ordinary life (Concas *et al.*, 1998; Farok *et al.*, 1994; Wang *et al.*, 1993; Weber, 1990). The most important oxide glasses are silicate glasses (SiO_2), borate glasses (B_2O_3), germinate glasses (GeO_2) and phosphate glasses (P_2O_5). Silicate glasses are of interest with regard to their commercial application structural properties and optical application. Borate glasses are of interest

due to their structures. Rare earth (RE) doped borate glasses have a very high refractive index. Germanium glasses have the important property of transmission of longer wavelength infrared than the silicate glasses but they are limited due to the high cost. Among the three known oxides of phosphates P_2O_3, P_2O_4 and P_2O_5; only P_2O_5 forms glasses. The structure of binary phosphate glasses is based on tetrahedral units. Phosphate glasses can be made with a range of structures from a cross-linked network of Q^3 tetrahedra (vitreous P_2O_5) to polymer-like metaphosphate chains of Q^3 tetrahedra to invert glasses based on small pyro-Q^1 and orthophosphate (Q^0) anions, depending on the [O]/[P] ratio as set by glass composition (Brow, 2000).

The properties of phosphate glasses such as relatively high thermal expansion coefficients, low optical dispersions and low glass transition temperatures compared with their silicate or borate glasses, make them technologically important material in spite of their hygroscopic and poor chemical durability properties (Brow, 2000; Moustafa and El-Egili, 1998). However, most of the existing binary and ternary glass systems contain toxic elements, chemically unstable, highly reactive with water, display powerful devitrification tendency together with complex preparation conditions. During past two decades, continuous efforts have been made to overcome these limitations, where sulfophosphate glasses played a vital role (Da *et al.*, 2011; Da *et al.*, 2010).

Sulphate containing alkali/alkaline phosphate glasses are suitable for electrolytic applications due to their unique electrical properties (Scholz, 2011). The SO_4^{2-} ions largely dissolve in the phosphate glass matrix. There is a weak interaction between SO_4^{2-} ions and metaphosphate ions, resulting in a small dynamic concentration of dithiophosphate (DTP) units. Interaction between these two ions provides suitable environment for incorporation of RE ions to offer high luminescence efficiencies with minimal non-radiative (NR) losses in these glasses. Moreover, the interaction between sulphate and phosphate ions can be modified by the presence of different modifier oxides. Both disruption of the glass network and formation of non-bridging oxygens (NBO) groups are due to the incorporation of alkali-earth oxides in the glass structure (Vogel, 1994). Regard to these facts, structural modifications occur by incorporation of magnesium oxide (MgO) (as modifier) to the zinc sulfophosphate

glasses. REs doped magnesium-zinc-sulfophosphate glasses are technologically prospective due to their several unique attributes. The RE doped glasses have gained some attention due to high dielectric constants, a wide band infrared transmittance and large third order non-linear optical susceptibility (Auzel *et al.*, 2001; Chillcce *et al.*, 2006; Inoue *et al.*, 2002b; Jha *et al.*, 2000; Kumar *et al.*, 2003; Mori *et al.*, 1997; Prakash *et al.*, 2001; Souza *et al.*, 2002; Tanabe *et al.*, 2002).

Amongst various RE ions, samarium (Sm^{3+}) reveals most remarkable luminescence properties (Brahmachary *et al.*, 2015; Carnall *et al.*, 1968; Lin *et al.*, 2007; Venkatramu *et al.*, 2007). Sm^{3+} ion is well-suited to explore the energy transfer processes because of its lowest emitting level $^4G_{5/2}$ possesses relatively higher quantum efficiency and shows different quenching channels. Sm^{3+} ions are added to glass to create prominent orange-red color or unique optical properties to make lasers for special applications (Elisa *et al.*, 2013; Lim *et al.*, 2013; Thomas *et al.*, 2013). In its usual oxidized form, it is added to ceramics and glasses to increase the absorption of infrared light. Sm^{3+} ions are also combined with many other substances under relatively mild conditions. Looking at these wealthy prospects, sulfophosphate system with Sm^{3+} are prepared in order to achieve lasing glass material. In addition, Sm^{3+} ions are exploited for high-density optical storage, under sea communication and color displays.

Another lanthanide ion chosen for the present study is dysprosium (Dy^{3+}) ion. Since the $^6F_{11/2}$ ($^6H_{9/2}$) $\rightarrow$ $^6H_{15/2}$ transition of Dy^{3+} around 1.3 μm is found to be useful for the optical amplification and its visible upconversion emission can be used as a solid state laser, this RE ion received much practical attention (Heo and Shin, 1996; Kityk *et al.*, 2002; Yang *et al.*, 2005). Dy^{3+} gives very strong emission in yellow region, which is expected to give lasing from $^4F_{9/2} \rightarrow {}^6H_{7/2}$, $^4F_{9/2} \rightarrow {}^6H_{9/2}$, $^4F_{9/2} \rightarrow {}^6H_{11/2}$, $^4F_{9/2} \rightarrow {}^6H_{13/2}$ and $^4F_{9/2} \rightarrow {}^6H_{15/2}$ consider as emission transitions for Dy^{3+} ions in the visible and near infrared (NIR) regions. Among these emission transitions, $^4F_{9/2} \rightarrow {}^6H_{13/2}$ (electric dipole) in yellow and $^4F_{9/2} \rightarrow {}^6H_{15/2}$ (magnetic dipole) in blue regions are the main transitions (Babu and Jayasankar, 2000).

Erbium (Er^{3+}) as a RE ion has played an important role in the development of broadband erbium-doped fiber amplifiers (EDFA) (Auzel *et al.*, 2001; Jha *et al.*, 2000; Kumar *et al.*, 2003; Prakash *et al.*, 2001; Tanabe *et al.*, 2002). Optical properties of Er^{3+} ion in various glasses make it as a promising materials for the optical application for instance, it can be used as a solid-state laser due to its 1.54 μm emission and it can be used as a solid-state laser because of its visible upconversion emission.

RE doped glasses are applicable in various practical application such as optical amplifiers, optical recording, infrared sensors, laser active media and infrared-to-visible converters (Xiao and Yang, 2007). Earlier, the good characteristics of RE doped glasses such as nonlinear optical performance and optical bi-stability have been reported. Besides, high RE ions solubility, good thermal and mechanical stability, low cutoff phonon energy, higher refractive indices than the silicates and fluoride glasses, large amplification bandwidth and enhanced luminescence are the remarkable characteristics of RE doped glasses (Liu *et al.*, 2007; Sahar *et al.*, 2008). As the results of these notable advantages, they become promising candidates for photonic applications such as window materials and optical memory (Xiao and Yang, 2007). In order to make devices with optimized photonic properties, usually, the RE ion concentration needs to be kept low to minimize luminescence quenching (Jlassi *et al.*, 2010; Shen *et al.*, 2007). Since the absorption cross-section of majority of RE ions in such glasses are very small, some modifications are needed to improve it for applications (Lin *et al.*, 2004). One way is to exploit energy transfer from a RE with a large absorption cross-section to the RE with small absorption cross-section (Lin *et al.*, 2003b; Lin *et al.*, 2004; Madden and Vu, 2009; Mirgorodsky *et al.*, 2006; Rai and Rai, 2007). RE ion environment by embedding metallic nanoparticles can be modified to compensate the harmful effect of quenching (Amjad *et al.*, 2013; Eroni *et al.*, 2009; Kassab *et al.*, 2008; Kassab *et al.*, 2009; Li *et al.*, 2004; Lin *et al.*, 2008; Rai and Rai, 2007; Singh *et al.*, 2010; Ueda *et al.*, 2009).

Glasses embedded with metallic nanoparticles have received much attention because of their notable optical properties that could lead to the development of new solid-state short-wavelength lasers, biological labelling and efficient solar cells (Švrček *et al.*, 2004). The luminescence intensity RE doped glasses can be enhanced

by embedding the semiconducting and metallic nanoparticles. The excitation or luminescence wavelength is near to the surface plasmon resonance (SPR) wavelength for metallic nanoparticles and must be greater than optical band gap energy for semiconducting nanoparticles. The preparation and characterization of RE doped glasses embedded with metallic nanoparticles have been studied by many researchers in the past few years (Almeida *et al*., 2008; Carmo *et al.*, 2009; Jime´nez *et al.*, 2010). Several attempts have been made to indicate that luminescence efficiency of the glass matrix containing RE ions can be enhanced by the presence of nanoparticles inside it (Carmo *et al.*, 2009; de Almeida *et al.*, 2008; Manoj Kumar *et al.*, 2003; Mattarelli *et al.*, 2007). In all these studies, the large local field on the RE ions present within the vicinity of metallic nanoparticles and the energy transfer from metallic nanoparticles to the RE ions are responsible for luminescence enhancement. In the previous reported studies, various nanoparticles such as Au, Ag, AgCl, CuCl, CdSe, CdTe have been introduced into glasses to improve the optical nonlinearity to a big extent (Amjad *et al.*, 2013; Kassab *et al.*, 2009; Lin *et al.*, 2003b; Lin *et al.*, 2008; Mirgorodsky *et al.*, 2006).

Size-controlled optical properties of silver (Ag) nanoparticles are promising material for technological applications such as diffraction elements, optical filters, nanoplasmonic devices, bi-sensors, and nonlinear media (Nikonorov *et al*., 2010). Ag nanoparticles can be made in various media such as water solutions, polymers, glasses, and crystalline media. In addition, the inorganic glasses are the unique matrix for Ag nanoparticles formation. Ag nanoparticles size within the wide range can be controlled by means of altering the temperature and duration of thermal processing in the inorganic glasses due to the wide temperature range of glass viscosity growth in these glasses (Nikonorov *et al*., 2010). In regard to this fact, controlling and exploring all the stages of Ag nanoparticles formation including the starting stage is possible in this kind of matrix (Nikonorov *et al*., 2010).

Few studies have been made on metallic nanoparticles embedded RE doped phosphate glasses. Silicate or tellurite are the usual host matrix that phenomenon of enhanced luminescence have been investigated. Phosphate glasses are widely applicable in photonic applications as a consequence of their mechanical properties

and ability to accept higher concentration of RE ions, however, they have not received much attention in the field of plasmonics or nanophotonics. Specifically, there is no report on metallic nanoparticles embedded inside the magnesium-zinc-sulfophosphate glass matrix with RE ions. Regards to this matter, deeper study of the effect of nanoparticles on luminescence enhancement and energy transfer processes in the magnesium-zinc-sulfophosphate glass matrix is necessary.

1.2 Problem Statement

Since phosphate glasses also have a very high solubility for RE ions, many researchers have been reported the properties of phosphate glasses doped with RE ions. For example, the photoluminescence properties of the Dy^{3+}-doped and Dy^{3+}-Tm^{3+} co-doped phosphate glasses have been studied by absorption, excitation and emission spectra (Liang *et al.*, 2008). The observation of white light is allowed when the glasses are excited by the ultraviolet light because a combination of blue and yellow emissions has emerged in the glasses. Spectral properties of Nd^{3+} and Dy^{3+} ions in different phosphate glasses have been studied by Seshadri *et al.* (2010) and several spectroscopic parameters such as Judd-Ofelt intensity parameters, radiative transition probabilities and radiative lifetimes of certain excited states of these RE ions in these glass matrices have been reported. Other researchers (Kesavulu and Jayasankar, 2012; Lim *et al.*, 2013; Rao *et al.*, 2011; Reddy *et al.*, 2011; Sreedhar *et al.*, 2013) investigated the effects of RE ions on luminescence properties of the glasses. Although a large number of studies has been done on luminescence and structural properties of RE doped phosphate glasses, the luminescence and structural features of RE^{3+} (RE = Sm, Dy and Er) doped magnesium-zinc-sulfophosphate glasses are rarely investigated.

Moreover, emission characteristics of RE ions are enhanced by the presence of the metal. The preparation and characterization of RE doped glasses embedded with metallic nanoparticles have been studied by many researchers in the past few years (Carmo *et al.*, 2009; de Almeida *et al.*, 2008). For instance, Naranjo *et al*. (2005) reported down conversion luminescence enhancement for Pr^{3+}-doped lead-germanate

glass containing silver nanoparticles. But, the influence of embedded silver nanoparticles on optical and structural features of RE^{3+} (RE = Sm, Dy and Er) doped magnesium-zinc-sulfophosphate glasses has not been studied yet.

1.3 Research Objectives

In line with the aim of the research, the followings are the research objectives:

i. To determine the structural and physical features of RE^{3+} (RE = Sm, Dy and Er) doped magnesium-zinc-sulfophosphate glass with and without incorporation of Ag nanoparticles
ii. To determine the influence of RE^{3+} (RE = Sm, Dy and Er) concentration on the optical properties of magnesium-zinc-sulfophosphate glass with and without Ag inclusion
iii. To analyse the Judd-Ofelt analysis for magnesium-zinc-sulfophosphate in the presence of various concentration of RE^{3+} (RE = Sm, Dy and Er) and Ag nanoparticles

1.4 Significance of Research

The importance of the study is to obtain high efficiency of luminescence in glasses. The significant of research are as follows:

i. To demonstrate the influence of the RE^{3+} (RE = Sm, Dy and Er) on the structural and optical properties of magnesium-zinc-sulfophosphate glasses. Therefore, the outcomes of the study contribute better understanding towards the behaviour of the RE^{3+} (RE = Sm, Dy and Er) on the luminescence enhancement since these glasses are applicable in many optical devices due to their potential applications.

ii. To study the effects of the Ag nanoparticles on the optical properties of RE^{3+} (RE = Sm, Dy and Er) doped magnesium-zinc-sulfophosphate glasses. Consequently, it provides promising materials with enhanced optical properties for photonic devices, such as, sensors, solid state lasers, and optical switches.

1.5 Scope of the Study

In this study, RE^{3+} (RE = Sm, Dy and Er) doped and undoped magnesium-zinc-sulfophosphate glass as well as RE doped magnesium-zinc-sulfophosphate glass containing Ag nanoparticles were prepared. Investigation of structural and optical properties were the main purposes of the study. The structural properties can be determined by X-Ray diffraction (XRD) spectroscopy, Fourier Transformed Infrared (FTIR), and Raman spectroscopy. Ultraviolet-Visible-Near Infrared (UV-Vis-NIR) and photoluminescence (PL) spectroscopy were operated to describe the optical properties. In order to observe the small structure of nanoparticles embedded in samples, the Transmission Electron Microscope (TEM) was utilized.

1.6 Outline of Thesis

This thesis is composed of six chapters and three appendices. The summaries of the chapters are as follows:

Chapter 1 presents the background of the study, statement of the problems, research objectives, scope of the study and brief review on characterization tools.

Chapter 2 explains briefly about Judd-Ofelt theory. Furthermore, literature are invoked to describe the sulfophosphate glass.

Chapter 3 explains the experimental procedure to synthesize the studied sample glass. In addition, instruments and their fundamental concepts which have been operated to characterize the sample glass are also introduced.

Chapter 4 describes the effect of RE^{3+} (RE = Sm, Dy and Er) ions on structural and optical properties of magnesium-zinc-sulfophosphate glass.

Chapter 5 presents general descriptions of the influence of the nanoparticles on structural and optical properties of RE^{3+} (RE = Sm, Dy and Er) doped magnesium-zinc-sulfophosphate glass. In this chapter, new RE^{3+} (RE = Sm, Dy and Er) doped glasses containing metallic Ag nanoparticles were prepared using melt quenching technique. They were characterized to investigate the structural and optical properties.

Chapter 6 gives the conclusion of the research and some recommendations for future works.

REFERENCES

Agnesi, A., Dallocchio, P., Pirzio, F., and Reali, G. (2009). Compact sub-100-fs Nd: silicate laser. *Optics Communications*, 282(10), 2070-2073.

Al-Ani, S., and Higazy, A. A. (1991). Study of optical absorption edges in MgO-P_2O_5 glasses. *Journal of materials science*, 26(13), 3670-3674.

Ali, A. (2009). Optical properties of Sm^{3+}-doped CaF_2 bismuth borate glasses. *Journal of Luminescence*, 129(11), 1314-1319.

Ardelean, I., Rusu, D., Andronache, C., and Ciobotă, V. (2007). Raman study of $xMeO\cdot(100-x)[P_2O_5\cdot Li_2O](MeO \Rightarrow FeO_3$ or $V_2O_5)$ glass systems. *Materials Letters*, 61(14), 3301-3304.

Arkhipov, V., Ivanova, L., Mamoshin, V., Buler, P., Lushchai, O., and Galnykina, L. (1986). A spectroscopic study of structural features in alkali-bearing sulfate-phosphate glasses. *Journal of Applied Spectroscopy*, 45(3), 976-978.

Amjad, R. J., Sahar, M., Ghoshal, S., Dousti, M., Riaz, S., Samavati, A. R, Jamaludin, M.A. and Naseem, S. (2013). Plasmon-Enhanced Upconversion Fluorescence in Er^{3+}: Ag Phosphate Glass: the Effect of Heat Treatment. *Chinese Physics Letters*, 30(2), 027301.

Annapoorani, K., Murthy, N. S., Ravindran, T., and Marimuthu, K. (2016). Influence of Er^{3+} ion concentration on spectroscopic properties and luminescence behavior in Er^{3+} doped strontium telluroborate glasses. *Journal of Luminescence*, 171, 19-26.

Auzel, F., Bonfigli, F., Gagliari, S., and Baldacchini, G. (2001). The interplay of self-trapping and self-quenching for resonant transitions in solids; role of a cavity. *Journal of luminescence*, 94, 293-297.

Babu, A. M., Jamalaiah, B., Kumar, J. S., Sasikala, T., and Moorthy, L. R. (2011). Spectroscopic and photoluminescence properties of Dy^{3+}-doped lead tungsten

tellurite glasses for laser materials. *Journal of Alloys and Compounds*, 509(2), 457-462.

Babu, P., and Jayasankar, C. (2000). Spectroscopic properties of Dy^{3+} ions in lithium borate and lithium fluoroborate glasses. *Optical materials*, 15(1), 65-79.

Babu, P., Seo, H. J., Kesavulu, C., Jang, K. H., and Jayasankar, C. (2009a). Thermal and optical properties of Er^{3+}-doped oxyfluorotellurite glasses. *Journal of Luminescence*, 129(5), 444-448.

Babu, S. S., Babu, P., Jayasankar, C., Tröster, T., Sievers, W., and Wortmann, G. (2009b). Optical properties of Dy^{3+}-doped phosphate and fluorophosphate glasses. *Optical Materials*, 31(4), 624-631.

Babu, Y. C. R., Naik, P. S. R., Kumar, K. V., Prasad, S., and Kumar, A. S. (2012). Spectral studies of Erbium doped heavy metal borophosphate glass systems. *Physica B: Condensed Matter*, 407(4), 705-711.

Bach, H., and Krause, D. (2013). *Analysis of the composition and structure of glass and glass ceramics*: Springer Science & Business Media.

Barnes, W. L., Dereux, A., and Ebbesen, T. W. (2003). Surface plasmon subwavelength optics. *Nature*, 424(6950), 824-830.

Basavapoornima, C., and Jayasankar, C. (2014). Spectroscopic and photoluminescence properties of Sm^{3+} ions in Pb-K-Al-Na phosphate glasses for efficient visible lasers. *Journal of Luminescence*, 153, 233-241.

Basavapoornima, C., Jayasankar, C., and Chandrachoodan, P. (2009). Luminescence and laser transition studies of Dy^{3+}: K-Mg-Al fluorophosphate glasses. *Physica B: Condensed Matter*, 404(2), 235-242.

Bingham, P., Hand, R., Hannant, O., Forder, S., and Kilcoyne, S. H. (2009). Effects of modifier additions on the thermal properties, chemical durability, oxidation state and structure of iron phosphate glasses. *Journal of Non-Crystalline Solids*, 355(28), 1526-1538.

Boehm, L., Reisfeld, R., and Spector, N. (1979). Optical transitions of Sm^{3+} in oxide glasses. *Journal of Solid State Chemistry*, 28(1), 75-78.

Borrelli, N., and McSwain, B. (1963). col.«The infra-red spectra of vitreous boron oxide and sodium borate glasses». *Physics and Chemistry of Glasses*, 4(1), 11-21.

Bouzidi, C., Elhouichet, H., and Moadhen, A. (2011). Yb^{3+} effect on the spectroscopic properties of Er-Yb codoped SnO_2 thin films. *Journal of Luminescence*, 131(12), 2630-2635.

Brahmachary, K., Rajesh, D., and Ratnakaram, Y. (2015). Radiative properties and luminescence spectra of Sm^{3+} ion in zinc–aluminum–sodium-phosphate (ZANP) glasses. *Journal of Luminescence*, 161, 202-208.

Brow, R. K. (2000). Review: the structure of simple phosphate glasses. *Journal of Non-Crystalline Solids*, 263, 1-28.

Brow, R. K., Tallant, D. R., Hudgens, J. J., Martin, S. W., and Irwin, A. D. (1994). The short-range structure of sodium ultraphosphate glasses. *Journal of Non-Crystalline Solids*, 177, 221-228.

Brow, R. K., Tallant, D. R., Myers, S. T., and Phifer, C. C. (1995). The short-range structure of zinc polyphosphate glass. *Journal of Non-Crystalline Solids*, 191(1), 45-55.

Burling, L. D. (2006). *Novel phosphate glasses for bone regeneration applications.* University of Nottingham.

Carmo, A., Bell, M., Anjos, V., De Almeida, R., Da Silva, D. M., and Kassab, L. (2009). Thermo-optical properties of tellurite glasses doped with Eu^{3+} and Au nanoparticles. *Journal of Physics D: Applied Physics*, 42(15), 155404.

Carnall, W., Fields, P., and Rajnak, K. (1968). Electronic energy levels in the trivalent lanthanide aquo ions. I. Pr^{3+}, Nd^{3+}, Pm^{3+}, Sm^{3+}, Dy^{3+}, Ho^{3}+, Er^{3+}, and Tm^{3+}. *The Journal of Chemical Physics*, 49(10), 4424-4442.

Carnall, W. T., Fields, P., and Wybourne, B. (1965). Spectral intensities of the trivalent lanthanides and actinides in solution. I. Pr^{3+}, Nd^{3+}, Er^{3+}, Tm^{3+}, and Yb^{3+}. *The Journal of Chemical Physics*, 42(11), 3797-3806.

Chen, H., Leblanc, M., and Schinn, G. (2003). Gain enhanced L-band optical fiber amplifiers and tunable fiber lasers with erbium-doped fibers. *Optics Communications*, 216(1), 119-125.

Chicklis, E., Naiman, C., Folweiler, R., Gabbe, D., Jenssen, H., and Linz, A. (1971). High-Efficiency Room-Temperature 2.06-μm Laser Using Sensitized Ho^{3+}: YLF. *Applied Physics Letters*, 19(4), 119-121.

Chillcce, E., Rodriguez, E., Neves, A., Moreira, W., César, C., and Barbosa, L. (2006). Er^{3+}-Tm^{3+} co-doped tellurite fibers for broadband optical fiber amplifier around 1550 nm band. *Optical Fiber Technology*, 12(2), 185-195.

Concas, G., Congiu, F., Spano, G., Speghini, A., and Gatterer, K. (1998). Mössbauer investigation of rare earth sites in europium containing glasses. *Journal of Non-Crystalline Solids,* 232, 341-345.

Da, N., Grassmé, O., Nielsen, K. H., Peters, G., and Wondraczek, L. (2011). Formation and structure of ionic (Na, Zn) sulfophosphate glasses. *Journal of Non-Crystalline Solids,* 357(10), 2202-2206.

Da, N., Krolikowski, S., Nielsen, K. H., Kaschta, J., and Wondraczek, L. (2010). Viscosity and softening behavior of alkali zinc sulfophosphate glasses. *Journal of the American Ceramic Society,* 93(8), 2171-2174.

Dai, S., Yu, C., Zhou, G., Zhang, J., Wang, G., and Hu, L. (2006). Concentration quenching in erbium-doped tellurite glasses. *Journal of Luminescence,* 117(1), 39-45.

Damak, K., Rüssel, C., and Maâlej, R. (2014). White light generation from Dy^{3+} doped tellurite glass. *Journal of Quantitative Spectroscopy and Radiative Transfer,* 134, 55-63.

da Silva, D. M., Kassab, L. R. P., Lüthi, S. R., de Araújo, C. B., Gomes, A. S., and Bell, M. J. V. (2007). Frequency upconversion in Er^{3+} doped PbO-GeO_2 glasses containing metallic nanoparticles. *Applied Physics Letters,* 90(8), 081913.

Davis, E., and Mott, N. (1970). Conduction in non-crystalline systems V. Conductivity, optical absorption and photoconductivity in amorphous semiconductors. *Philosophical Magazine,* 22(179), 0903-0922.

de Almeida, R., da Silva, D. M., Kassab, L. R., and de Araujo, C. B. (2008). Eu^{3+} luminescence in tellurite glasses with gold nanostructures. *Optics Communications,* 281(1), 108-112.

Desirena, H., De la Rosa, E., Diaz-Torres, L., and Kumar, G. (2006). Concentration effect of Er^{3+} ion on the spectroscopic properties of Er^{3+} and Yb^{3+}/Er^{3+} co-doped phosphate glasses. *Optical Materials,* 28(5), 560-568.

Desirena, H., De la Rosa, E., Shulzgen, A., Shabet, S., and Peyghambarian, N. (2008). Er^{3+} and Yb^{3+} concentration effect in the spectroscopic properties and energy transfer in Yb^{3+}/Er^{3+} codoped tellurite glasses. *Journal of Physics D: Applied Physics,* 41(9), 095102.

Dimitrov, V., and Sakka, S. (1996). Electronic oxide polarizability and optical basicity of simple oxides. I. *Journal of Applied Physics,* 79(3), 1736-1740.

Dousti, M. R., Ghoshal, S., Amjad, R. J., Sahar, M., Nawaz, F., and Arifin, R. (2013). Structural and optical study of samarium doped lead zinc phosphate glasses. *Optics Communications,* 300, 204-209

ElBatal, F. H., Ouis, M. A., Morsi, R. M., and Marzouk, S. Y. (2010). Interaction of gamma rays with some sodium phosphate glasses containing cobalt. *Journal of Non-Crystalline Solids,* 356(1), 46-55

Elisa, M., Sava, B., Vasiliu, I., Monteiro, R., Veiga, J., Ghervase, L., et al. (2013). Optical and structural characterization of samarium and europium-doped phosphate glasses. *Journal of Non-Crystalline Solids,* 369, 55-60.

El-Mallawany, R. (1999). Tellurite glasses: Part 2. Anelastic, phase separation, Debye temperature and thermal properties. *Materials Chemistry and Physics,* 60(2), 103-131.

Eroni, F., dos Santos, P., Fávero, F., Gomes, A., Xing, J., Chen, Q., et al. (2009). Evaluation of the third-order nonlinear optical properties of tellurite glasses by thermally managed eclipse Z-scan. *Journal of Applied Physics,* 105(2).

Farok, H., Senin, H., Saunders, G., Poon, W., and Vass, H. (1994). Optical and ultrasonic properties of europium phosphate glasses. *Journal of Materials Science,* 29(11), 2847-2859.

Fayon, F., Massiot, D., Suzuya, K., and Price, D. L. (2001). ^{31}P NMR study of magnesium phosphate glasses. *Journal of Non-Crystalline Solids,* 283(1), 88-94.

Ganguli, M., Bhat, M. H., and Rao, K. J. (1999). Lithium ion transport in Li_2SO_4-Li_2O-P_2O_5 glasses. *Solid State Ionics,* 122(1–4), 23-33.

Gervais, F., Blin, A., Massiot, D., Coutures, J., Chopinet, M., and Naudin, F. (1987). Infrared reflectivity spectroscopy of silicate glasses. *Journal of Non-Crystalline Solids,* 89(3), 384-401.

Görller-Walrand, C., and Binnemans, K. (1998). Spectral intensities of ff transitions. *Handbook on the Physics and Chemistry of Rare Earths,* 25, 101-264.

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

Hapanowicz, R., and Condrate Sr, R. (1996). Raman spectral investigation of sulfate inclusions in sodium calcium silicate glasses. *Journal of Solid State Chemistry,* 123(1), 183-185.

Hauret, G., Vaills, Y., Luspin, Y., Gervais, F., and Coté, B. (1994). Similarities in the behaviour of magnesium and calcium in silicate glasses. *Journal of Non-Crystalline Solids,* 170(2), 175-181.

Heo, J., and Shin, Y. B. (1996). Absorption and mid-infrared emission spectroscopy of Dy^{3+} in Ge-As (or Ga)-S glasses. *Journal of Non-Crystalline Solids,* 196, 162-167.

Hoppe, U. (1996). A structural model for phosphate glasses. *Journal of Non-Crystalline Solids,* 195(1), 138-147

Hoppe, U., Walter, G., Kranold, R., Stachel, D., and Barz, A. (1995). The dependence of structural peculiarities in binary phosphate glasses on their network modifier content. *Journal of Non-Crystalline Solids,* 192, 28-31.

Im, S. H., Na, Y. H., Kim, N. J., Kim, D. H., Hwang, C. W., and Ryu, B. K. (2010). Structure and properties of zinc bismuth phosphate glass. *Thin Solid Films,* 518(24), e46-e49.

Inoue, H., Soga, K., and Makishima, A. (2002). Simulation of the optical properties of Er: ZBLAN glass. *Journal of Non-Crystalline Solids,* 298(2), 270-286.

Inoue, S., Nukui, A., Yamamoto, K., Yano, T., Shibata, S., and Yamane, M. (2002). Refractive index patterning of tellurite glass surfaces by ultra short pulse laser spot heating. *Journal of Materials Science,* 37(16), 3459-3465.

Jackson John, D. (1999). Classical electrodynamics: John Wiley & Sons, Inc., New York, NY.

Jacobs, R. R., and Weber, M. J. (1976). Dependence of the $^4F_{3/2} \rightarrow {}^4I_{11/2}$ induced-emission cross section for Nd^{3+} on glass composition. *Quantum Electronics, IEEE Journal of,* 12(2), 102-111.

Jamalaiah, B., Kumar, J. S., Babu, A. M., Suhasini, T., and Moorthy, L. R. (2009). Photoluminescence properties of Sm^{3+} in LBTAF glasses. *Journal of Luminescence,* 129(4), 363-369.

Jamalaiah, B., Moorthy, L. R., and Seo, H. J. (2012). Effect of lead oxide on optical properties of Dy^{3+} ions in $PbO\text{-}H_3BO_3\text{-}TiO_2\text{-}AlF_3$ glasses. *Journal of Non-Crystalline Solids,* 358(2), 204-209.

Jayasankar, C., and Rukmini, E. (1997). Spectroscopic investigations of Dy^{3+} ions in borosulphate glasses. *Physica B: Condensed Matter,* 240(3), 273-288.

Jayasimhadri, M., Jang, K., Lee, H. S., Chen, B., Yi, S.-S., and Jeong, J.-H. (2009). White light generation from Dy^{3+}-doped $ZnO-B_2O_3-P_2O_5$ glasses. *Journal of Applied Physics,* 106(1), 013105.

Jayasimhadri, M., Moorthy, L., Kojima, K., Yamamoto, K., Wada, N., and Wada, N. (2005). Er^{3+}-doped tellurofluorophosphate glasses for lasers and optical amplifiers. *Journal of Physics: Condensed Matter*, 17(48), 7705.

Jayasimhadri, M., Moorthy, L., Kojima, K., Yamamoto, K., Wada, N., and Wada, N. (2006a). Optical properties of Dy^{3+} ions in alkali tellurofluorophosphate glasses for laser materials. *Journal of Physics D: Applied Physics,* 39(4), 635.

Jayasimhadri, M., Moorthy, L., Saleem, S., and Ravikumar, R. (2006b). Spectroscopic characteristics of Sm^{3+}-doped alkali fluorophosphate glasses. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*, 64(4), 939-944.

Jha, A., Shen, S., and Naftaly, M. (2000). Structural origin of spectral broadening of 1.5-μm emission in Er^{3+}-doped tellurite glasses. *Physical Review B*, 62(10), 6215.

Jiang, S., Myers, M., and Peyghambarian, N. (1998). Er^{3+} doped phosphate glasses and lasers. *Journal of Non-Crystalline Solids,* 239(1), 143-148.

Jime´nez, J.A. Lysenko, S. Liu, H. Fachini, E., and Cabrera, C.R. (2010). X-ray photoelectron spectroscopy of silver nanoparticles in phosphate glass. *Journal of Luminesence*, 130, 163.

Jlassi, I., Elhouichet, H., Ferid, M., Chtourou, R., and Oueslati, M. (2010). Study of photoluminescence quenching in Er^{3+}-doped tellurite glasses. *Optical Materials,* 32(7), 743-747.

Jørgensen, C. K., and Judd, B. (1964). Hypersensitive pseudoquadrupole transitions in lanthanides. *Molecular Physics,* 8(3), 281-290.

Jørgensen, C. K., and Reisfeld, R. (1983). Judd-Ofelt parameters and chemical bonding. *Journal of the Less Common Metals, 93*(1), 107-112.

Judd, B. (1962). Optical absorption intensities of rare-earth ions. *Physical Review,* 127(3), 750

Kalele, S. A., Tiwari, N. R., Gosavi, S. W., and Kulkarni, S. K. (2007). Plasmon-assisted photonics at the nanoscale. *Journal of Nanophotonics,* 1(1), 012501-012501-012520.

Karakassides, M., Saranti, A., and Koutselas, I. (2004). Preparation and structural study of binary phosphate glasses with high calcium and/or magnesium content. *Journal of Non-Crystalline Solids*, 347(1), 69-79

Karmakar, B., Som, T., Singh, S. P., and Nath, M. (2010). Nanometal-glass hybrid nanocomposites: synthesis, properties and applications. *Transactions of the Indian Ceramic Society*, 69(3), 171-186.

Karthikeyan, B., and Mohan, S. (2003). Structural, optical and glass transition studies on Nd^{3+}-doped lead bismuth borate glasses. *Physica B: Condensed Matter*, 334(3), 298-302.

Kassab, L. R., de Almeida, R., da Silva, D. M., and de Araojo, C. B. (2008). Luminescence of Tb(3+) doped TeO(2)-ZnO-Na(2) O-PbO glasses containing silver nanoparticles. *Journal of Applied Physics*, 3.

Kassab, L. R., de Almeida, R., da Silva, D. M., de Assumpção, T. A., and de Araújo, C. B. (2009). Enhanced luminescence of Tb^{3+}/Eu^{3+} doped tellurium oxide glass containing silver nanostructures. *Journal of Applied Physics*, 3.

Kesavulu, C., and Jayasankar, C. (2011). White light emission in Dy^{3+}-doped lead fluorophosphate glasses. *Materials Chemistry and Physics*, 130(3), 1078-1085.

Kesavulu, C., and Jayasankar, C. (2012). Spectroscopic properties of Sm^{3+} ions in lead fluorophosphate glasses. *Journal of Luminescence*, 132(10), 2802-2809.

Kesavulu, C., Sreedhar, V., Jayasankar, C., Jang, K., Shin, D.-S., and Yi, S. S. (2014). Structural, thermal and spectroscopic properties of highly Er^{3+}-doped novel oxyfluoride glasses for photonic application. *Materials Research Bulletin*, 51, 336-344.

Khafagy, A., El-Adawy, A., Higazy, A., El-Rabaie, S., and Eid, A. (2008). Studies of some mechanical and optical properties of:(70-x) TeO_2+15B_2O_3+15P_2O_5+xLi_2O glasses. *Journal of Non-Crystalline Solids*, 354(27), 3152-3158.

Khor, S., Talib, Z., and Yunus, W. M. (2012). Optical properties of ternary zinc magnesium phosphate glasses. *Ceramics International*, 38(2), 935-940.

Kim, C.-W., and Day, D. E. (2003). Immobilization of Hanford LAW in iron phosphate glasses. *Journal of Non-Crystalline Solids*, 331(1), 20-31.

Kim, C.-W., Ray, C., Zhu, D., Day, D. E., Gombert, D., Aloy, A., et al. (2003). Chemically durable iron phosphate glasses for vitrifying sodium bearing waste

(SBW) using conventional and cold crucible induction melting (CCIM) techniques. *Journal of Nuclear Materials*, 322(2), 152-164.

Kindrat, I., Padlyak, B., and Drzewiecki, A. (2015). Luminescence properties of the Sm-doped borate glasses. *Journal of Luminescence*, 166, 264-275.

Kiran, N., and Kumar, A. S. (2013). White light emission from Dy^{3+} doped sodium–lead borophosphate glasses under UV light excitation. *Journal of Molecular Structure*, 1054, 6-11.

Kityk, I., Wasylak, J., Kucharski, J., and Dorosz, D. (2002). $PbO–Bi_2O_3–Ga_2O_3–BaO–Dy^{3+}$ glasses for IR luminescence. *Journal of Non-Crystalline Solids*, 297(2), 285-289.

Klimesz, B., Dominiak-Dzik, G., Solarz, P., Żelechower, M., and Ryba-Romanowski, W. (2005). Optical study of $GeO_2–PbO–PbF_2$ oxyfluoride glass singly doped with Pr^{3+}, Nd^{3+}, Sm^{3+} and Eu^{3+}. *Journal of Alloys and Compounds*, 403(1), 76-85.

Kreidl, N. J., and Uhlmann, D. R. (1983). *Glass: Science and Technology. Glass Forming Systems*: Academic Press.

Krupke, W. F. (1966). Optical Absorption and Fluorescence Intensities in Several Rare-Earth-Doped Y_2O_3 and LaF_3 Single Crystals. *Physical Review*, 145(1), 325.

Kumar, A. R., Rao, C. S., Krishna, G. M., Kumar, V. R., and Veeraiah, N. (2012). Structural features of MoO_3 doped sodium sulpho borophosphate glasses by means of spectroscopic and dielectric dispersion studies. *Journal of Molecular Structure*, 1016, 39-46.

Kumar, C. S. (2009). Metallic nanomaterials (Vol. 1): John Wiley & Sons.

Kumar, K. U., Rao, C. S., Jayasankar, C., Babu, S. S., Lucio, J., and Gamez, M. A. M. (2011). Optical properties of Dy^{3+}-doped P_2O_5-K2O−MgO/MgF_2−Al_2O_3 glasses. *Physics Procedia*, 13, 70-73.

Kumar, V., George, A., Knight, J., and Russell, P. (2003). Tellurite photonic crystal fiber. *Optics Express*, 11(20), 2641-2645.

Lai, Y., Liang, X., Yang, S., Wang, J., Cao, L., and Dai, B. (2011). Raman and FTIR spectra of iron phosphate glasses containing cerium. *Journal of Molecular Structure*, 992(1), 84-88.

Lakshmikantha, R., Rajaramakrishna, R., Anavekar, R.V., and Ayachit, N.H. (2012). Characterization and structural studies of lithium doped lead zinc phosphate glass system. *Materials Chemistry and Physics*, 133(1), 249-252.

Lakshminarayana, G., and Qiu, J. (2009). Photoluminescence of Pr^{3+}, Sm^{3+} and Dy^{3+}: SiO_2–Al_2O_3–LiF–GdF_3 glass ceramics and Sm^{3+}, Dy^{3+}: GeO_2–B_2O_3–ZnO–LaF_3 glasses. *Physica B: Condensed Matter,* 404(8), 1169-1180.

Lakshminarayana, G., Yang, R., Mao, M., and Qiu, J. (2009a). Spectral analysis of RE^{3+}(RE= Sm, Dy, and Tm): P_2O_5–Al_2O_3–Na_2O glasses. *Optical Materials,* 31(10), 1506-1512.

Langar, A., Bouzidi, C., Elhouichet, H., and Férid, M. (2014). Er–Yb codoped phosphate glasses with improved gain characteristics for an efficient 1.55 μm broadband optical amplifiers. *Journal of Luminescence*, 148, 249-255.

Le, F., Brandl, D. W., Urzhumov, Y. A., Wang, H., Kundu, J., Halas, N. J., et al. (2008). Metallic nanoparticle arrays: a common substrate for both surface-enhanced Raman scattering and surface-enhanced infrared absorption. *American Chemical Society nano*, 2(4), 707-718.

Li, J., Sun, Z., Zhu, X., Zeng, H., Xu, Z., Wang, Z., et al. (2004). Optical bistability for ZnO–Nb_2O_5–TeO_2 glasses. *Optical Materials,* 25(4), 401-405.

Lim, K.-S., Vijaya, N., Kesavulu, C., and Jayasankar, C. (2013). Structural and luminescence properties of Sm^{3+} ions in zinc fluorophosphate glasses. *Optical Materials*, 35(8), 1557-1563.

Lin, J., Huang, W., Li, B., Jin, C., Liu, C., Lei, S., et al. (2008). Preparation of AgCl Nano-Crystal Embedded Tellurite Nonlinear Optical Glasses under Electric Field Accompanied Heat Treatment. *Journal of Materials Science & Technology*, 24(6), 863.

Lin, J., Huang, W., Sun, Z., Ray, C. S., and Day, D. E. (2004). Structure and non-linear optical performance of TeO_2–Nb_2O_5–ZnO glasses. *Journal of Non-Crystalline Solids*, 336(3), 189-194.

Lin, H., Jiang, S., Wu, J., Song, F., Peyghambarian, N., and Pun, E. (2003). Er^{3+} doped Na_2O–Nb_2O_5–TeO_2 glasses for optical waveguide laser and amplifier. *Journal of Physics D: Applied Physics,* 36(7), 812.

Lin, H., Meredith, G., Jiang, S., Peng, X., Luo, T., Peyghambarian, N., et al. (2003). Optical transitions and visible upconversion in Er^{3}+ doped niobic tellurite glass. *Journal of Applied Physics*, 93(1), 186-191.

Lin, H., Wang, X., Li, C., Li, X., Tanabe, S., and Yu, J. (2007). Spectral power distribution and quantum yields of Sm^{3+}-doped heavy metal tellurite glass under the pumping of blue lighting emitting diode. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy,* 67(5), 1417-1420.

Lin, H., Yang, D., Liu, G., Ma, T., Zhai, B., An, Q., et al. (2005). Optical absorption and photoluminescence in Sm^{3+}-and Eu^{3+}-doped rare-earth borate glasses. *Journal of Luminescence,* 113(1), 121-128.

Linganna, K., Rao, C. S., and Jayasankar, C. (2013). Optical properties and generation of white light in Dy^{3+}-doped lead phosphate glasses. *Journal of Quantitative Spectroscopy and Radiative Transfer,* 118, 40-48

Liu, Y., Chen, Y., Lin, Y., Tan, Q., Luo, Z., and Huang, Y. (2007). Energy transfer in Yb^{3+}-Er^{3+}-codoped bismuth borate glasses. *Journal of the Optical Society of America B,* 24(5), 1046-1052.

Losso, P., Schnabel, B., Jäger, C., Sternberg, U., Stachel, D., and Smith, D. (1992). ^{31}P NMR investigations of binary alkaline earth phosphate glasses of ultra phosphate composition. *Journal of Non-Crystalline Solids,* 143, 265-273.

Machewirth, D., Wei, K., Krasteva, V., Datta, R., Snitzer, E., and Sigel, G. (1997). Optical characterization of Pr^{3+} and Dy^{3+} doped chalcogenide glasses. *Journal of Non-Crystalline Solids,* 213, 295-303.

Madden, S., and Vu, K. (2009). Very low loss reactively ion etched Tellurium Dioxide planar rib waveguides for linear and non-linear optics. *Optics Express,* 17(20), 17645-17651.

Mahato, K., Rai, D., and Rai, S. (1998). Optical studies of Sm^{3+} doped oxyfluoroborate glass. *Solid State Communications,* 108(9), 671-676.

Maheshvaran, K., and Marimuthu, K. (2012). Concentration dependent Eu^{3+} doped boro-tellurite glasses-Structural and optical investigations. *Journal of Luminescence,* 132(9), 2259-2267.

Mahraz, Z. A. S., Sahar, M., Ghoshal, S., and Dousti, M. R. (2013a). Concentration dependent luminescence quenching of Er^{3+}-doped zinc boro-tellurite glass. *Journal of Luminescence,* 144, 139-145.

Maier, S. A. (2007). *Plasmonics: fundamentals and applications*: Springer Science & Business Media.

Malta, O., and dos Santos, M. C. (1990). Theoretical analysis of the fluorescence yield of rare earth ions in glasses containing small metallic particles. *Chemical Physics Letters,* 174(1), 13-18.

Malta, O., Santa-Cruz, P., De Sa, G., and Auzel, F. (1985). Fluorescence enhancement induced by the presence of small silver particles in Eu^{3+} doped materials. *Journal of Luminescence,* 33(3), 261-272.

Mamoshin, V. (1996). Theoretical estimation of the possibility of glass formation in sulfate, phosphate, and sulfate-phosphate systems. *Glass and Ceramics,* 53(4), 104-106.

Mamoshin, V., Arkhipov, V., Buler, P., and Ivanova, L. (1987). Investigation of glasses in the Na_2SO_4-$ZnSO_4$-$NaPO_3$ system. *Fizika i Khimiya Stekla,* 13(4), 510-517.

Manoj Kumar, G., Narayana Rao, D., and Agarwal, G. (2003). Measurement of local field effects of the host on the lifetimes of embedded emitters. *Physical Review Letters,* 91(20), 203903.

Marion, J., and Weber, M. (1991). Phosphate laser glasses. *European Journal of Solid State and Inorganic Chemistry,* 28(1), 271-287.

Massera, J., Bourhis, K., Petit, L., Couzi, M., Hupa, L., Hupa, M., et al. (2013). Effect of the glass composition on the chemical durability of zinc-phosphate-based glasses in aqueous solutions. *Journal of Physics and Chemistry of Solids,* 74(1), 121-127.

Mattarelli, M., Montagna, M., Vishnubhatla, K., Chiasera, A., Ferrari, M., and Righini, G. (2007). Mechanisms of Ag to Er energy transfer in silicate glasses: A photoluminescence study. *Physical Review B,* 75(12), 125102.

May, P., Metcalf, D., Richardson, F., Carter, R., Miller, C., and Palmer, R. (1992). Measurement and analysis of excited-state decay kinetics and chiroptical activity in the $^6H_J \leftarrow {}^4G_{5/2}$ transitions of Sm^{3+} in trigonal $Na_3[Sm(C_4H_4O_5)^3]\cdot 2NaClO_4\ 6H_2O$. *Journal of Luminescence,* 51(5), 249-268.

Mazurak, Z., Bodył, S., Lisiecki, R., Gabryś-Pisarska, J., and Czaja, M. (2010). Optical properties of Pr^{3+}, Sm^{3+} and Er^{3+} doped P_2O_5–CaO–SrO–BaO phosphate glass. *Optical Materials,* 32(4), 547-553.

Mertens, H., Koenderink, A., and Polman, A. (2007). Plasmon-enhanced luminescence near noble-metal nanospheres: Comparison of exact theory and an improved Gersten and Nitzan model. *Physical Review B,* 76(11), 115123.

Merzbacher, C. I., and White, W. B. (1991). The structure of alkaline earth aluminosilicate glasses as determined by vibrational spectroscopy. *Journal of Non-Crystalline Solids,* 130(1), 18-34.

Meyer, K. (1997). Characterization of the structure of binary zinc ultraphosphate glasses by infrared and Raman spectroscopy. *Journal of Non-Crystalline Solids,* 209(3), 227-239.

Meyer, K., Barz, A., and Stachel, D. (1999). A study of the structure of binary magnesium ultraphosphate glasses by vibrational spectroscopy. *Ceramics,* 43(4), 169-174.

Mirgorodsky, A., Soulis, M., Thomas, P., Merle-Méjean, T., and Smirnov, M. (2006). Ab initio study of the nonlinear optical susceptibility of TeO_2-based glasses. *Physical Review B,* 73(13), 134206.

Mmamoshin, V. (1996). Fabrication of low-melting glasses in the $ZnSO_4$-KPO_3-$NaPO_3$ and Li_2SO_4-Na_2SO_4-K_2SO_4-$NaPO_3$ Systems. *Glass and Ceramics,* 53(6), 166-168.

Montagne, L., Palavit, G., and Delaval, R. (1998). Effect of ZnO on the properties of (100-x)($NaPO_3$)-xZnO glasses. *Journal of Non-Crystalline Solids,* 223(1), 43-47.

Mori, A., Ohishi, Y., and Sudo, S. (1997). Erbium-doped tellurite glass fibre laser and amplifier. *Electronics Letters,* 33(10), 863-864.

Moustafa, Y., and El-Egili, K. (1998). Infrared spectra of sodium phosphate glasses. *Journal of Non-Crystalline Solids,* 240(1), 144-153.

Murthy, D., Jamalaiah, B., Babu, A. M., Sasikala, T., and Moorthy, L. R. (2010). The luminescence properties of Dy^{3+}-doped alkaline earth titanium phosphate glasses. *Optical Materials,* 32(9), 1112-1116

Nachimuthu, P., Jagannathan, R., Kumar, V. N., and Rao, D. N. (1997). Absorption and emission spectral studies of Sm^{3+} and Dy^{3+} ions in PbO-PbF_2 glasses. *Journal of Non-Crystalline Solids,* 217(2), 215-223.

Nandi, P., and Jose, G. (2006a). Erbium doped phospho-tellurite glasses for 1.5 μm optical amplifiers. *Optics Communications,* 265(2), 588-593.

Nandi, P., and Jose, G. (2006b). Spectroscopic properties of Er^{3+} doped phospho-tellurite glasses. *Physica B: Condensed Matter*, 381(1), 66-72.

Naranjo, L. P., de Araújo, C. B., Malta, O. L., Cruz, P. A. S., & Kassab, L. R. (2005). Enhancement of Pr^{3+} luminescence in $PbO–GeO_2$ glasses containing silver nanoparticles. *Applied Physics Letters*, 87(24), 241914.

Nelson, C., Furukawa, T., and White, W. B. (1983). Transition metal ions in glasses: Network modifiers or quasi-molecular complexes? *Materials Research Bulletin*, 18(8), 959-966

Nepomiluev, A., Pletnev, R., Lapina, O., Kozlova, S., and Bamburov, V. (2002). Structure of Glasses in the $Na_2SO_4–P_2O_5–H_2O$ System. *Glass Physics and Chemistry*, 28(1), 1-4.

Nikonorov, N., Sidorov, A., and Tsekhomskii, V. (2010). *Silver nanoparticles in oxide glasses: technologies and properties*: INTECH Open Access Publisher.

Ofelt, G. (1962). Intensities of crystal spectra of rare-earth ions. *The Journal of Chemical Physics*, 37(3), 511-520.

Oh, K., Kilian, A., and Morse, T. (1999). Analysis of spectroscopic properties of erbium doped $Ta_2O_5–Al_2O_3–SiO_2$ optical fiber. *Journal of Non-Crystalline Solids*, 259(1), 10-15.

Osorio, S. P., Rivera, V. A. G., Nunes, L. A. O., Marega Jr, E., Manzani, D., and Messaddeq, Y. (2012). Plasmonic coupling in Er^{3+}: Au tellurite glass. *Plasmonics*, 7(1), 53-58.

Ozbay, E. (2006). Plasmonics: merging photonics and electronics at nanoscale dimensions. *Science*, 311(5758), 189-193.

Pal, I., Agarwal, A., Sanghi, S., and Aggarwal, M. (2012). Structure and optical absorption of Sm^{3+} and Nd^{3+} ions in cadmium bismuth borate glasses with large radiative transition probabilities. *Optical Materials*, 34(7), 1171-1180.

Porai-Koshits, E. A (1990) In: Glass science and technology, Edited by Uhlmann and Kreidl, 1-25.

Pascuta, P., Borodi, G., Popa, A., Dan, V., and Culea, E. (2010). Influence of iron ions on the structural and magnetic properties of some zinc-phosphate glasses. *Materials Chemistry and Physics*, 123(2), 767-771.

Patil, S. D., Jali, V., and Anavekar, R. (2009). Elastic properties of Na_2O-ZnO-ZnF_2-B_2O_3 oxyfluoride glasses. *Bulletin of Materials Science*, 32(6), 597-601.

Pisarski, W. A., Żur, L., and Pisarska, J. (2011). Optical transitions of Eu^{3+} and Dy^{3+} ions in lead phosphate glasses. *Optics Letters*, 36(6), 990-992.

Pisarski, W., Pisarska, J., Mączka, M., and Ryba-Romanowski, W. (2006). Europium-doped lead fluoroborate glasses: Structural, thermal and optical investigations. *Journal of Molecular Structure*, 792, 207-211.

Pradeesh, K., Oton, C., Agotiya, V., Raghavendra, M., and Prakash, G. V. (2008). Optical properties of Er^{3+} doped alkali chlorophosphate glasses for optical amplifiers. *Optical Materials*, 31(2), 155-160.

Prakash, G. V., Rao, D. N., and Bhatnagar, A. (2001). Linear optical properties of niobium-based tellurite glasses. *Solid State Communications*, *119*(1), 39-44.

Praveena, R., Venkatramu, V., Babu, P., and Jayasankar, C. (2008). Fluorescence spectroscopy of Sm^{3+} ions in P_2O_5–PbO–Nb_2O_5 glasses. *Physica B: Condensed Matter*, 403(19), 3527-3534

Praveena, R., Vijaya, R., and Jayasankar, C. (2008b). Photoluminescence and energy transfer studies of Dy^{3+}-doped fluorophosphate glasses. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*, 70(3), 577-586.

Qian, B., Liang, X., Yang, S., He, S., and Gao, L. (2012). Effects of lanthanum addition on the structure and properties of iron phosphate glasses. *Journal of Molecular Structure*, 1027, 31-35.

Rai, V. K., and Rai, S. (2007). A comparative study of FIR and FL based temperature sensing schemes: an example of Pr^{3+}. *Applied Physics B*, 87(2), 323-325.

Rajendran, V., Palanivelu, N., Chaudhuri, B., and Goswami, K. (2003). Characterisation of semiconducting V_2O_5–Bi_2O_3–TeO_2 glasses through ultrasonic measurements. *Journal of Non-Crystalline Solids*, *320*(1), 195-209.

Rao, C. S., and Jayasankar, C. (2013). Spectroscopic and radiative properties of Sm^{3+}-doped K–Mg–Al phosphate glasses. *Optics Communications*, 286, 204-210.

Rao, K. V., Ratnakaram, Y., Seshadri, M., and Rao, J. (2010). Optical and luminescence studies of Pr^{3+} and Er^{3+} doped different phosphate glasses. *Physica B: Condensed Matter*, 405(9), 2297-2304.

Rao, P. R., Pavić, L., Moguš-Milanković, A., Kumar, V. R., Kityk, I., and Veeraiah, N. (2012). Electrical and spectroscopic properties of Fe_2O_3 doped Na_2SO_4–BaO–P_2O_5 glass system. *Journal of Non-Crystalline Solids*, 358(23), 3255-3267.

Rasool, S. N., Moorthy, L. R., and Jayasankar, C. (2013). Spectroscopic Investigation of Sm^{3+} doped phosphate based glasses for reddish-orange emission. *Optics Communications*, 311, 156-162.

Ravi, O., Reddy, C. M., Manoj, L., and Raju, B. D. P. (2012). Structural and optical studies of Sm^{3+} ions doped niobium borotellurite glasses. *Journal of Molecular Structure*, 1029, 53-59.

Ravi, O., Reddy, C. M., Reddy, B. S., and Raju, B. D. P. (2014). Judd–Ofelt analysis and spectral properties of Dy^{3+} ions doped niobium containing tellurium calcium zinc borate glasses. *Optics Communications*, 312, 263-268.

Ravikumar, R., Yamauchi, J., Chandrasekhar, A., Reddy, Y., and Rao, P. S. (2005). Identification of chromium and nickel sites in zinc phosphate glasses. *Journal of Molecular Structure*, 740(1), 169-173.

Rayappan, I. A., Selvaraju, K., and Marimuthu, K. (2011). Structural and luminescence investigations on Sm^{3+} doped sodium fluoroborate glasses containing alkali/alkaline earth metal oxides. *Physica B: Condensed Matter*, 406(3), 548-555.

Reddy, A. A., Sekhar, M. C., Pradeesh, K., Babu, S. S., and Prakash, G. V. (2011). Optical properties of Dy^{3+}-doped sodium–aluminum–phosphate glasses. *Journal of Materials Science*, 46(7), 2018-2023.

Reis, S., Faria, D., Martinelli, J., Pontuschka, W., Day, D., and Partiti, C. (2002). Structural features of lead iron phosphate glasses. *Journal of Non-Crystalline Solids*, 304(1), 188-194

Reisfeld, R. (1975). Radiative and non-radiative transitions of rare-earth ions in glasses. In *Rare Earths* (pp. 123-175): Springer.

Reisfeld, R., Hormadaly, J., and Muranevich, A. (1976). Intensity parameters, radiative transitions and non-radiative relaxations of Ho^{3+} in various tellurite glasses. *Chemical Physics Letters*, 38(1), 188-191.

Rodriguez, V., Martin, I., Alcala, R., and Cases, R. (1992). Optical properties and cross relaxation among Sm^{3+} ions in fluorzincate glasses. *Journal of Luminescence*, 54(4), 231-236.

Rudramadevi, B., and Buddhudu, S. (2008). Spectral and thermal analysis of Sm^{3+} and Dy^{3+}: B_2O_3-BaO-LiF/AlF_3 glasses. *Indian Pure Applied Physics*, 46, 825-832.

Sahar, M., Mohammad Yusoff, N., Ghosal, S., Rohani, M., Hamzah, K., and Arifin, R. (2012). *Luminescence Properties of Magnesium Phosphate Glass Doped Samarium.* Paper presented at the Advanced Materials Research, 111-115.

Sahar, M. R., Sulhadi, K., and Rohani, M. (2008). The preparation and structural studies in the (80−x) TeO_2–20ZnO–(x)Er_2O_3 glass system. *Journal of Non-Crystalline Solids,* 354(12), 1179-1181.

Scholz, F. (2011). From the Leiden jar to the discovery of the glass electrode by Max Cremer. *Journal of Solid State Electrochemistry,* 15(1), 5-14.

Saleem, S., Jamalaiah, B., Jayasimhadri, M., Rao, A. S., Jang, K., and Moorthy, L. R. (2011). Luminescent studies of Dy^{3+} ion in alkali lead tellurofluoroborate glasses. *Journal of Quantitative Spectroscopy and Radiative Transfer,* 112(1), 78-84.

Šantić, A., Moguš-Milanković, A., Furić, K., Bermanec, V., Kim, C., and Day, D. E. (2007). Structural properties of Cr_2O_3–Fe_2O_3–P_2O_5 glasses, Part I. *Journal of Non-Crystalline Solids,* 353(11), 1070-1077.

Sastry, S. S., and Rao, B. R. V. (2014). Spectroscopic studies of copper doped alkaline earth lead zinc phosphate glasses. *Physica B: Condensed Matter,* 434, 159-164.

Sdiri, N., Elhouichet, H., Barthou, C., and Ferid, M. (2012). Spectroscopic properties of Er^{3+} and Yb^{3+} doped phosphate–borate glasses. *Journal of Molecular Structure,* 1010, 85-90.

Selvaraju, K., and Marimuthu, K. (2013). Structural and spectroscopic studies on concentration dependent Sm^{3+} doped boro-tellurite glasses. *Journal of Alloys and Compounds,* 553, 273-281.

Selvi, S., Marimuthu, K., and Muralidharan, G. (2015). Structural and luminescence behavior of Sm^{3+} ions doped lead boro-telluro-phosphate glasses. *Journal of Luminescence,* 159, 207-218.

Seshadri, M., Radha, M., Rajesh, D., Barbosa, L., Cordeiro, C., and Ratnakaram, Y. (2015). Effect of ZnO on spectroscopic properties of Sm^{3+} doped zinc phosphate glasses. *Physica B: Condensed Matter,* 459, 79-87.

Seshadri, M., Rao, K. V., Rao, J., and Ratnakaram, Y. (2009). Spectroscopic and laser properties of Sm^{3+} doped different phosphate glasses. *Journal of Alloys and Compounds,* 476(1), 263-270.

Seshadri, M., Rao, K. V., Rao, J. L., Rao, K. K., and Ratnakaram, Y. (2010). Spectroscopic investigations and luminescence spectra of Nd^{3+} and Dy^{3+} doped different phosphate glasses. *Journal of Luminescence,* 130(4), 536-543.

Sharma, Y., Surana, S., Singh, R., and Dubedi, R. (2007). Spectral studies of erbium doped soda lime silicate glasses in visible and near infrared regions. *Optical Materials*, 29(6), 598-604.

Shelby, J. E. (2005). *Introduction to glass science and technology*: Royal Society of Chemistry.

Shelby, J. E., and Ruller, J. (1987). Properties and structure of lithium germanate glasses. *Physics and Chemistry of Glasses,* 28(6), 262-268.

Shen, X., Nie, Q., Xu, T., Dai, S., Li, G., and Wang, X. (2007). Effect of Ce^{3+} on the spectroscopic properties in Er^{3+} doped TeO_2–GeO_2–Nb_2O_5–Li_2O glasses. *Journal of Luminescence,* 126(2), 273-277.

Sidek, H., Rosmawati, S., Talib, Z., Halimah, M., and Daud, W. (2009). Synthesis and optical properties of ZnO-TeO_2 glass system. *American Journal of Applied Sciences,* 6(8), 1489.

Singh, S., Giri, N., Rai, D., and Rai, S. (2010). Enhanced upconversion emission in Er^{3+}-doped tellurite glass containing silver nanoparticles. *Solid State Sciences,* 12(8), 1480-1483.

Sinha, S. P. (2013). *Complexes of the rare earths*: Elsevier.

Sirotkin, S., Meszaros, R., and Wondraczek, L. (2012). Chemical stability of ZnO–Na_2O–SO_3–P_2O_5 glasses. *International Journal of Applied Glass Science,* 3(1), 44-52.

Snoeks, E., Van den Hoven, G., Polman, A., Hendriksen, B., Diemeer, M., and Priolo, F. (1995). Cooperative upconversion in erbium-implanted soda-lime silicate glass optical waveguides. *Journal of the Optical Society of America B,* 12(8), 1468-1474.

Sokolov, I., Murin, I., Kriyt, V., and Pronkin, A. (2011). Structure and electrical conductivity of glasses in the Na_2O-Na_2SO_4-P_2O_5 system. *Glass Physics and Chemistry*, 37(4), 351-361.

Sokolov, I., Valova, N., Tarlakov, Y. P., and Pronkin, A. (2003). Electrical Properties and the Structure of Glasses in the Li_2SO_4–$LiPO_3$ System. *Glass Physics and Chemistry*, 29(6), 548-554.

Som, T., and Karmakar, B. (2009). Nanosilver enhanced upconversion fluorescence of erbium ions in Er^{3+}: Ag-antimony glass nanocomposites. *Journal of Applied Physics,* 105(1), 013102.

Som, T., and Karmakar, B. (2011). Nephelauxetic effect of low phonon antimony oxide glass in absorption and photoluminescence of rare-earth ions. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy,* 79(5), 1766-1782.

Souza Filho, A., Mendes Filho, J., Melo, F., Custodio, M., Lebullenger, R., and Hernandes, A. (2000). Optical properties of Sm^{3+} doped lead fluoroborate glasses. *Journal of Physics and Chemistry of Solids,* 61(9), 1535-1542.

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

Sreedhar, V., Ramachari, D., and Jayasankar, C. (2013). Optical properties of zincfluorophosphate glasses doped with Dy^{3+} ions. *Physica B: Condensed Matter,* 408, 158-163.

Subbalakshmi, P., and Veeraiah, N. (2003). Optical absorption and fluorescence properties of Er^{3+} ion in MO–WO_3–P_2O_5 glasses. *Journal of Physics and Chemistry of Solids,* 64(7), 1027-1035.

Sudhakar, K., Reddy, M. S., Rao, L. S., and Veeraiah, N. (2008). Influence of modifier oxide on spectroscopic and thermoluminescence characteristics of Sm^{3+} ion in antimony borate glass system. *Journal of Luminescence,* 128(11), 1791-1798.

Surendra Babu, S., Babu, P., Jayasankar, C., Tröster, T., Sievers, W., and Wortmann, G. (2009). Optical properties of Dy^{3+}-doped phosphate and fluorophosphate glasses. *Optical Materials,* 31(4), 624-631.

Švrček, V., Slaoui, A., and Muller, J.-C. (2004). Silicon nanocrystals as light converter for solar cells. *Thin Solid Films,* 451, 384-388.

Talib, Z. A., Daud, W., Tarmizi, E., Sidek, H., and Yunus, W. (2008). Optical absorption spectrum of Cu_2O–CaO–P_2O_5 glasses. *Journal of Physics and Chemistry of Solids,* 69(8), 1969-1973.

Tanabe, S. (2002). Rare-earth-doped glasses for fiber amplifiers in broadband telecommunication. *Comptes Rendus Chimie,* 5(12), 815-824.

Tanabe, S., Hayashi, H., Hanada, T., and Onodera, N. (2002). Fluorescence properties of Er^{3+} ions in glass ceramics containing LaF_3 nanocrystals. *Optical Materials,* 19(3), 343-349.

Tanabe, S., Ohyagi, T., Soga, N., and Hanada, T. (1992). Compositional dependence of Judd-Ofelt parameters of Er^{3+} ions in alkali-metal borate glasses. *Physical Review B,* 46(6), 3305.

Tanabe, S., Sugimoto, N., Ito, S., and Hanada, T. (2000). Broad-band 1.5 μm emission of Er^{3+} ions in bismuth-based oxide glasses for potential WDM amplifier. *Journal of Luminescence,* 87, 670-672.

Tao, A. R., Habas, S., and Yang, P. (2008). Shape control of colloidal metal nanocrystals. *Small,* 4(3), 310-325.

Thomas, S., George, R., Nayab Rasool, S., Rathaiah, M., Venkatramu, V., Joseph, C., Unnikrishnan, N.V. (2013). Optical properties of Sm^{3+} ions in zinc potassium fluorophosphate glasses. *Optical Materials,* 36(2), 242-250.

Thyagarajan, K., and Kaur, J. (2000). A novel design of an intrinsically gain flattened erbium doped fiber. *Optics Communications,* 183(5), 407-413.

Tischendorf, B., Otaigbe, J., Wiench, J., Pruski, M., and Sales, B. (2001). A study of short and intermediate range order in zinc phosphate glasses. *Journal of Non-Crystalline Solids,* 282(2), 147-158.

Tsai, P., and Greenblatt, M. (1988). Lithium ion conducting glasses in the system LiCl-Li_2O-P_2O_5-SiO_2. *Journal of Non-Crystalline Solids,* 103(1), 101-107

Ueda, J., Tanabe, S., and Ishida, A. (2009). Surface plasmon excited infrared-to-visible upconversion in Er^{3+}-doped transparent glass ceramics. *Journal of Non-Crystalline Solids*, 355(37), 1912-1915.

Urbach, F. (1953). The long-wavelength edge of photographic sensitivity and of the electronic absorption of solids. *Physical Review,* 92(5), 1324.

Van Wazer, J.R. (1985). *Phosphorus and its Compounds*. New York: Wiley Interscience.

Venkatramu, V., Babu, P., Jayasankar, C., Tröster, T., Sievers, W., and Wortmann, G. (2007). Optical spectroscopy of Sm^{3+} ions in phosphate and fluorophosphate glasses. *Optical Materials,* 29(11), 1429-1439.

Vijayakumar, R., Venkataiah, G., and Marimuthu, K. (2015). White light simulation and luminescence studies on Dy^{3+} doped Zinc borophosphate glasses. *Physica B: Condensed Matter,* 457, 287-295.

Vogel, W. (1994). Glass Chemistry, Springer-Verlag: Berlin.

Walter, G., Hoppe, U., Vogel, J., Carl, G., and Hartmann, P. (2004). The structure of zinc polyphosphate glass studied by diffraction methods and ^{31}P NMR. *Journal of Non-Crystalline Solids,* 333(3), 252-262.

Walter, G., Vogel, J., Hoppe, U., and Hartmann, P. (2003). Structural study of magnesium polyphosphate glasses. *Journal of Non-Crystalline Solids,* 320(1), 210-222.

Wang, J., Brocklesby, W., Lincoln, J., Townsend, J., and Payne, D. (1993). Local structures of rare-earth ions in glasses: the 'crystal-chemistry'approach. *Journal of Non-Crystalline Solids,* 163(3), 261-267.

Weber, M. (1990). Science and technology of laser glass. *Journal of Non-Crystalline Solids,* 123(1), 208-222.

Weber, M., Ziegler, D., and Angell, C. A. (1982). Tailoring stimulated emission cross sections of Nd^{3+} laser glass: Observation of large cross sections for BiCl3 glasses. *Journal of Applied Physics,* 53(6), 4344-4350.

Wei, K., Machewirth, D., Wenzel, J., Snitzer, E., and Sigel, G. (1995). Pr^{3+}-doped Ge-Ga-S glasses for 1.3 μm optical fiber amplifiers. *Journal of Non-Crystalline Solids,* 182(3), 257-261.

Wiench, J. W., Tischendorf, B., Otaigbe, J. U., and Pruski, M. (2002). Structure of Zinc polyphosphate glasses studied by two-dimensional solid and liquid state NMR. *Journal of Molecular Structure*, 602, 145-157.

Xiao, K., and Yang, Z. (2007). Thermal stability and optical transitions of Er^{3+}/Yb^{3+}-codoped barium gallogermanate glass. *Optical Materials,* 29(11), 1475-1480.

Yang, G., Zhang, Q., Li, T., Shi, D., and Jiang, Z. (2008). Laser-diode-excited intense luminescence and green-upconversion in erbium-doped bismuth–germanate–lead glasses. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy,* 69(1), 41-48.

Yang, J., Dai, S., Dai, N., Wen, L., Hu, L., and Jiang, Z. (2004). Investigation on nonradiative decay of $^4I_{13/2} \rightarrow {}^4I_{15/2}$ transition of Er^{3+}-doped oxide glasses. *Journal of Luminescence,* 106(1), 9-14.

Yang, Z., Chen, W., and Luo, L. (2005). Dy^{3+}-doped Ge–Ga–Sb–Se glasses for 1.3 μm optical fiber amplifiers. *Journal of Non-Crystalline Solids,* 351(30), 2513-2518.

Yao, Z., Ding, Y., Nanba, T., and Miura, Y. (1999). Compositional dependences of Judd–Ofelt parameters of Er^{3+} in borosilicate glasses. *Physics and Chemistry of Glasses*, 40(4), 179-183.

Zayats, A. V. (1999). Electromagnetic field enhancement in the context of apertureless near-field microscopy. *Optics communications,* 161(1), 156-162.

Zhang, L., Peng, M., Dong, G., and Qiu, J. (2012). Spectroscopic properties of Sm^{3+}-doped phosphate glasses. *Journal of Materials Research, 27*(16), 2111-2115.

Zheng, H., Gao, D., Fu, Z., Wang, E., Lei, Y., Tuan, Y., Cui, M. (2011). Fluorescence enhancement of Ln^{3+} doped nanoparticles. *Journal of Luminescence,* 131(3), 423-428.

Zou, X., and Izumitani, T. (1993). Spectroscopic properties and mechanisms of excited state absorption and energy transfer upconversion for Er^{3+}-doped glasses. *Journal of Non-Crystalline Solids,* 162(1), 68-80.