THE HARDNESS AND THERMAL EXPANSION OF ERBIUM DOPED TELLURITE GLASS

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In the name of Allah, Most Gracious Most Merciful

All praise and thanks are due to Allah Almighty and

peace and blessing be upon His Messenger

To my *Ayah, Umie, siblings and friends* for their prayers,

encouragement, sacrifice and especially for their love.

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ABSTRACT

A series of glass based on (80-*x*) TeO_2- 20 ZnO–*x* Er_2O_3 where $0<x\leq 2.5$ mol % was prepared using melt quenching technique. The amorphosity of the glass was determined by X-ray diffraction (XRD) and the physical properties such as density and hardness was determined by means of Archimedes and Vickers Hardness method respectively. The thermal expansion was measured using dilatometric method. The fine glass rods were prepared using rotary ultrasonic machine (RUM) with diamond rods tools of 4 mm in diameter. Meanwhile, the surface roughness of the rods was measured using profilometry technique. The result of XRD patterns confirmed that the glass was in amorphous phase. It was found that, the density of the glass increased with increasing Er_2O_3 content. The range of density was found to be between 5.541g/cm^3 and 5.663g/ cm^3. It was also found that as the amount of Er_2O_3 content increased, the hardness of glass decreased from 3.21 GPa to 2.277 GPa. Meanwhile, the thermal expansion coefficient of the glass was found to decrease from 15.8 X 10^{-06} °C^{-1} to 13.3 X10^{-06} °C^{-1}. It was found that the composition of 78.5 TeO_2 – 20 ZnO – 1.5 Er_2O_3 exhibited the smallest thermal expansion coefficient and thus suitable for the fabrication of the glass rod. The surface roughness of the glass rods in the range of 2.15 μm to 1.18 μm was found to be dependent on the composition of the glass. In this work, the feed rate of 0.5, 1.0, 1.5 and 2.0 mm/min with spindle speed at 3000 rpm was the most suitable parameter to produce the desired glass rod.

ABSTRAK

Sampel kaca menggunakan siri sistem (80-*x*) TeO_2- 20 ZnO –*x* Er_2O_3 dimana $0 < x \leq 2.5$ mol % telah disediakan menggunakan teknik pelindapan leburan. Fasa amorfoskaca dikenalpasti melalui teknik pembelauan Sinar-X (XRD) dan sifat-sifat fizikal seperti ketumpatan dan kekerasan masing-masing telah diukur menggunakan kaedah *Archimedes* dan *Vickers Hardness*. Pengembangan terma kaca pula diukur melalui kaedah dilatometer. Mesin *rotary ultrasonic* (RUM) dengan mata berlian berdiameter 4 mm telah digunakan untuk menyediakan rod kaca. Sementara itu, kekasaran permukaan kaca ditentukan melalui teknik profilometri. Hasil yang diperolehi daripada XRD telah mengesahkan sampel kaca adalah amorfos. Didapati bahawa ketumpatan kaca meningkat dengan bertambahnya kandungan Er_2O_3. Julat Ketumpatan kaca yang diperolehi berada diantara 5.541 g/cm^3 dan 5.663 g/cm^3. Selain itu, dengan peningkatan kandungan Er_2O_3, kekerasan kaca berkurang dari 3.215 GPa sehingga 2.277 GPa. Manakala, pekali pengembangan terma kaca didapati menurun dari 15.8 x 10^{-06} C^{-1} sehingga 13.3 x 10^{-06} °C^{-1}. Didapati, komposisi kaca 78.5 TeO_2 – 20 ZnO – 1.5 Er_2O_3 mempunyai pekali pengembangan terma yang paling rendah dan sesuai untuk dijadikan rod kaca. Kekasaran permukaan di sepanjang rod kaca berada pada julat 2.15 μm hingga 1.18 μm dan sangat bergantung kepada komposisi kaca tersebut. Dalam kajian ini, kadar suapan 0.5, 1.0, 1.5 and 2.0 mm/min dengan kelajuan pengumpar 3000 rpm merupakan parameter yang paling sesuai untuk menyediakan rod kaca.

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LIST OF SYMBOLS

λ	Wavelength
E_v	Interatomic Potential
r	Interatomic Distance
T_g	Transformation Temperature
T_u	Upper Annealing Limit
M_g	Point of Incipient Deformation
T_d	Dilatometric Softening Point
A, B, n, m	Integer Number
ρ	Density
m_u	Weight of Sample In Air
m_t	Weight In Immersion Fluid
ρ_0	The Density of The Immersion Fluid
Hv	Vickers Hardness
L	Applied Load
Ѳ	Angle.
D	The Mean Diagonal
l	Length
l_o	Initial Length
T_o	Initial Temperature
α	The Linear Thermal Expansion Coefficient
ε	Relative Elongation
Δ	Changes
T	Temperature

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CHAPTER 1

INTRODUCTION

1.1 General Introduction

Laser an acronym for light amplification by stimulated emission of radiation, is certainly one of the greatest innovation of twentieth century. Its persisted growth and development has been an exciting division in the history of science, technology and engineering. Laser is distinguished from other electromagnetic radiation mainly in terms of its coherence, spectral purity and ability to propagate in a straight line.

Erbium is a well known element used in laser applications especially in an eye-safe rare-earth solid state laser. A significant characteristic of erbium doped host glass is the Er^{3+} concentration which is located in the eye-safe spectral region due to wavelength around 1.5μm (Jiang *et al.*,1998; Ding *et al.*, 2000; Nandi *et al.*, 2006). The absorption in the region of greater than 1.4μm laser wavelength spectrum by liquid water in the eye provides enhanced eye-safety. Mierczyk *et al.* (2000) also collected that the wavelength of around 1.55 μm is in the eye-safe regime where significantly higher pulse energies can be used without damaging human eyes. Laser action in erbium has been demonstrated in a variety of material such as garnets, fluorides, and glasses. Erbium laser performance is not very impressive in terms of efficiency or energy output. However, erbium has attracted attention because of two particular wavelength of interest. A crystal, such as YAG with highly doped erbium produces an output at around 2.9 µm (Yaqin *et al.,* 2000) and erbium doped phosphate glass generates an output at 1.54µm (Li *et al.,* 2009). Both of these wavelengths are absorbed by water, which leads to interesting medical applications. The wavelength 1.54 µm arises from a transition between the $^4I_{13/2}$ state and the $^4I_{15/2}$ ground state of Er^{3+} (Snoeks *et al.,* 1995). In fact, owing to the laser properties, thermal conductivity of glass is considerably lower than that of most crystal hosts, the emission lines of the ions in glasses are inherently broader than in crystals. A broader line increases the laser threshold value of amplification. Nevertheless, this broadening has an advantage. It offers the possibility of obtaining and amplifying medium for the same linear amplification coefficient. Thus, glass and crystalline lasers complement each other. For continuous or very high repetition rate of operation, crystalline materials provide higher gain and greater thermal conductivity. Glasses are more suitable for high-energy pulsed operation because of their large size, flexibility in their physical parameters and the broadened fluorescent line (Jaba *et al.,* 2009; Koechner *et al.,* 2003; Edward *et al.,* 1974).

Not withstanding the above, erbium doped with tellurite as a host also has extensively being studied in recent years owing to the excellent properties exhibit in tellurite glass. Tellurite glass has been demonstrated to have excellent rare-earth (RE) ion solubility and high quality specialty glass requirement for potential insulating in solid state laser material. The emission spectrum from erbium in tellurite glasses is almost as broad as the corresponding spectrum in silica (Marjanovic *et al.,* 2003). Meanwhile, tellurite as a host material posses to have various excellent properties such as the lowest phonon energy among oxide glasses, high dielectric constant, strength and corrosion resistance over other host such as fluoride glass. Whereas, rare-earth elements in tellurite glass generally have lower non-radiative decay rates, larger values of the radiative cross section (or transition strength), shorter fluorescent lifetimes and a red shift of the radiative transition (Wang *et al.,* 1994; Rolli *et al.,* 2002; El Mallawany, 2002). Furthermore, tellurium oxide is covalently bonded, stable and has a highly deformed octahedral in its structure because of the valence characteristics of Te results in two sets of Te-O distance. Since, each oxygen atom must be shared with three tellurium atoms, symmetry requirements force a distortion of octahedral to accommodate them into a regularly repeating lattice, thus there are six different Te-O distances, four Te-Te distances and twelve O-O distances. It is possible that this distortion produces a structure energetically similar to the vitreous state in which there is only short range order (El Mallawany, 2002).

This research concentrates on the system of $(80\text{-}x)TeO_2 - 20ZnO - xEr_2O_3$ with $0 \leq x \leq 2.5$ mol % glasses because of its wide and stable glass formation range (Sulhadi, 2007). The glass system is prepared through conventional melt quenching technique. This research contributes to fabricate rod glass with desired diameter and length when operating with end pumping laser cavity system.

1.2 Problem Statement

The study of erbium-doped tellurite glass which emphasized on the optical, physical, chemical durability and mechanical properties has previously been done by many researchers (Sulhadi, 2007; Jaba *et al.*, 2000). However for some reasons, the property that effected on the fabrication process especially in machining the laser material has not very well mention in literature. So it is the aim of this project to study an appropriate required physical and some thermal parameters to fabricate the glass rod (active medium) during machining procedure. The optimization of these physical and thermal parameters is very important to get the accuracy in rod design especially their geometrical parameters. From this point of view, this research is engaged towards the performance improvement of the fabrication in machining the optical glasses and to characterize the sufficient minimum surface roughness that can be considered as confidential to many manufactures. Thus, research should be accelerated to find the hardness and thermal properties especially to measure the strengthening of the samples in order to get the most sufficient condition when operate during machining process.

1.3 Research Objective

The objectives of this project are as follow:

i) To prepare Er^{3+} doped Tellurite glass of the (80-*x*) TeO_2- 20 ZnO –*x* Er_2O_3 system with ($x \leq 2.5$mol %)

ii) To determine the amorphousity of these glass.

iii) To study the density, hardness and thermal expansion of the glasses.

iv) To estimate the process parameter (spindle speed and feed rate) to fabricate the fine glass rods.

v) To determine the optimum surface roughness along the glass rods

1.4 Scope of Study

In this study, the glass based on (80-*x*) TeO_2- 20 ZnO –*x* Er_2O_3 system ($x \leq$ 2.5 mol %) is prepared using melt quenching method. The system is choose due to the wide and stable glass formation range, and have high quality specialty in structural and optical properties as reported by Sulhadi (2007). The sample is characterized in term of their amorphosity, density, hardness, and thermal expansion. X-ray diffraction method is used to reveal the amorphousity of the glasses. Density measurement is performed by Archimedes method in toluene. The hardness of the glass is measured using Vickers Hardness. The dilatometry method is used to estimate the thermal expansion of the glass system. The rod of erbium doped tellurite glass is fabricated using Rotary Ultrasonic machining (RUM) with appropriate machining parameters such as spindle speed and feed rate. In addition, Mitutoyo Formtracer CS-5000 is also used to determine the surface roughness of the glass rod after machining procedure.

REFERENCES

Ahmad N. E. B. (2010). *Structural and Luminescence Properties of Magnesium Aluminate Borate Glass Doped With Eu and Dy Ions*. Master of Science (Physics). Universiti Teknologi Malaysia

Annapurna, K. Das, M. Kundu, P. Dwivedi, R.N. Buddhudu, S. (2005). Spectral Properties of Eu^{3+}: $ZnO–B_2O_3–SiO_2$ Glasses. *J. of Molecular Structure.* 741: 53–60

Annapurna, K. Dwivedi, R.N. Buddhudu, S. (1999). Temperature Dependent Luminescence in ($Eu^{3+,}$ Dy^{3+}) Doped Tellurite Glass. *J. of Materials Letters* 40:259–262

Babu, P. Seo, H. J. Kesavulu, C.R. Jang, K. H. Jayasankar, C.K. (2009). Thermal and Optical Properties of Er^{3+}-Doped Oxyfluorotellurite Glasses. *J. of Luminescence*. 129:444–448.

Babu, S. S. Rajeswari, R. Jang, Jin, K.C.E. Jang, K. H. Seo, H. J. Jayasankar, C.K. (2010). Spectroscopic Investigations of 1.06 mm Emissionin Nd^{3+-} Doped Alkali Niobium Zinc Tellurite Glasses. *J. of Luminescence*. 130 : 1021–1025

Baizura, N. Yahya A.K. (2011). Effects of Nb_2O_5 Replacement by Er_2O_3 on Elastic and Structural Properties of $75TeO_2–(10−x)Nb_2O_5–15ZnO–(x)Er_2O_3$ Glass. *J. of Non-Crystalline Solids* 357 : 2810–2815

Barrett, D. S., Dhesi, S. S. (2001). *The Structure of Rare-Erath Metal Surfaces (Chap 1)*. London : Imperial College Press.

Belwalkar, A. Xiao, H. J. Misiolek, W. Z. Toulouse. (2010). Extruded Tellurite Glass Optical Fiber Preforms. *J. of Materials Processing Technology*. 210 : 2016-2022.

Bengisu, M. (2001), *Engineering Ceramics.* Berlin Heidelberg: Springer–Verlag.

Brown, J. G. (1966). *X-rays and Their Applications* (Chap 8).New York: Plenum Press.

Chappard, D. Degasne, I. Hure, G. Legrand, E. Audran, M. Basle, M.F. (2003). Image Analysis Measurements of Roughness By Texture and Fractal Analysis Correlate With Contact Profilometry. *J. of Biomaterials* 24 : 1399–1407

Chen, D.D. Qian, Q. Peng, M.Y. Xu, S.H. Yang, Z.M Zhang, Q.Y. Jiang, Z.H. (2010). Effect of Ce^{3+}, Dy^{3+}, and Tb^{3+} Additions on The Spectroscopic Properties of Er^{3+}/Yb^{3+} Codoped Tellurite Glasses. *Physica B* 405 : 4453–4456

Chen, L. He, D. Luan, F. Hu, L. Chen, W. (2009). An Efficient Erbium Doped Phosphate Laser Glass for High Average Power Pumping. *J. of Alloys and Compounds*. 412:261-263.

Cheng, Y. Xiao, H. Guo, W. (2008).Influences of La^{3+} and Er^{3+} On Structure and Properties Of Bi_2O_3–B_2O_3 Glass. *J. of Ceramics International* 34 : 1335–1339.

Clark, A. Pérez, R. Rivera, Rincón, E.J.Ma. (1994). Host-impurity Radiative Energy Transfer in CdO—$Si0_2$:Nd^{3+} Glasses. *J. of Luminescence* 60&61:201—203

Cobbett J. A. Cha. S. S., (1997). Effects of High-Level Energy Pumping on Radiative Thermal Loading of Phosphate Laser Glass. *Elsevier Science Ltd*. (24):1059-1067.

Cognolato, L., Gnazzo, (1993).Active Glass Materials and Optical Fibres For Telecommunication Laser Sources and Amplifiers. *J. of Optical Materials.* 2:1-9.

Cullity, B. D. (1967). *Elements of X-ray Diffraction*. US: Addison-Wesley Pub. Com. Inc.

Daud, R. (2002). *Development of An Optical Approach for The Measurement of Surface Roughness and Brightness in Machining*, (Master of Mechanical Engineering (Advanced Manufacturing Technology)). Universiti Teknologi Malaysia (UTM).

Deriano S. Jarry A. Rouxel T. Sangleboeuf J. C. Hampshire S. (2004). The Indentation Fracture Toughness (Kc) and Its Parameters: The Case of Silica-rich Glasses. *J. of Non-crystalline Solids* 344:44-50

Ding, Y. Jiang, S. Hwang, B. Luo, T. Peyghambarian, Himei, Y. Ito, T. Miura, Y. (2000). Spectral Properties of Erbium Doped Lead Halotellurite Glasses for 1.5 µm Broadband Amplification. *J. of Optical Materials*, (15) 123-130.

Dyson, N. A. (1990). *X-rays in Atomic and Nuclear Physics (2^{nd} Ed).* New York. Cambridge University Press.

Edward, J. G. Sandoe, J. N. (1974). A theoretical Study of The Nd: Yb: Er Glass Laser, *J. Phys. D, 7:1078.*

El Mallawany, R. A. H. *Tellurite Glasses Handbook*, (2002), Menofia, Egypt, CRC Press LLC.

ElBatal, F.H. Marzouk, S.Y. Ezz-Eldi, F.M. (2010). Gamma-Ray Interactions With WO_3-Doped Sodium Phosphate Glasses. *J. of Non-Crystalline Solids* 356:2750–2759

El-Deen, L.M. S. Al Salhi, M.S. Elkholy, M. M. (2008). IR and UV Spectral Studies For Rare-earths-Doped Tellurite Glasses. *J. of Alloys and Compounds* 465 : 333–339

Elisa, M. Vasiliu, C. Grigorescu, C. E.A. Grigoras, B. Niciu, H. Niciu, D. Meghea, A. Iftimie, N. (2006). Optical and Structural Investigation on Rare-Earth-Doped Aluminophosphate Glasses. *J. of Optical Materials* 28 : 621–625

El-Kheshen, A.A. Khaliafa, F.A. Saad, E.A. Elwan, R.L. (2008). Effect of Al_2O_3 Addition on Bioactivity, Thermal and Mechanical Properties of Some Bioactive Glasses. *J. of Ceramics International* 34 : 1667–1673

Elkholy, M.M. (2002). Thermoluminescence For Rare-Earths Doped Tellurite Glasses. *J. of Materials Chemistry and Physics*. 77:321–330

El-Mallawany, R. (1999), Tellurite Glasses Part 2: Anelastic, Phase Separation, Debye Temperature and Thermal Properties, *J. of Material Chemistry and Physics*. 60:103-131.

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

Elshwain, A. A. (2007). *A Study of Lapping Parameters to Reduce Polishing Time Of Optical Glass.* Master of Engineering (Mechanical). Universiti Teknologi Malaysia

Gong, H. Fang, F. Z. Hu., X. T. (2010). Kinematic View of Tool Life in Rotary Ultrasonic Side Milling of Hard and Brittle Materials, *J. of Machine Tools & Manufacture 50:303-307.*

Hager, I.Z. El-Mallawany, R. Bulou, A. (2011). Luminescence Spectra and Optical Properties of TeO_2–WO_3–Li_2O Glasses Doped With Nd, Sm and Er Rare-earth Ions. *Physica B.* 406:972–980

Halim D. N. B. A. (2011). The Structural and Luminescence Properties of Magnesium Strontium Metaphosphate. Master of Science (Physics). Universiti Teknologi Malaysia.

He B. B. (2009). Two-Dimensional X-Ray Diffraction. New Jersey: John Wiley & Sons. Inc.

Holloway, D. G. (1973). *The Physical Properties of Glass.* Mott, N. Noakes, G. R. (Ed) (Chap 2). London;Wykeham Pub LTD.

Hu, P. Zhang, J.M. Pei, Z.J. Treadwell, C. (2002). Modeling of Material Removal Rate in Rotary Ultrasonic Machining: Designed Experiments, *Journal of Materials Processing Technology* 129:339-344

Hussain, N. S. Santos, J. D. (2008), *Physic & Chemistry of Rare-earth Ions Doped Glasses*, Stafa-Zuerich : Trans Tech Publications Inc.

Ishikawa, K. Suwabe, H. Nishide, T. Uneda, M. (1998). A Study on Combined Vibration Drilling by Ultrasonic and Low Frequency Vibrations for Hard and Brittle Materials., *J Japan Soc. Prec. Eng., 22:196-205.*

Jaba, N. Kanoun, A. Mejri, H. Alaya, S. and Maaref, H. (2000). Inrared to Visible Up-Conversion Study for Erbium- Doped Zinc Tellurite Glasses. *J. Phys Condens. Matter 12:4523-4534.*

Jaba, N. Mansour, H B., Kanoun, A., Brenier, A., Champagnon, B., (2009), Spectral Brodening and Luminescence Quenching of 1.53 μm Emission in Er^{3+} Doped Zinc Tellurite Glass. *J. Luminescence 129:270-276.*

Jia, W. Liu, H. Felofilov, S. P. Meltzer, R. Jiao, J. (2000). Spectroscopic Study of Eu^{3+} -Doped and Eu^{3+}, Y^{3+} -Codoped SiO_2 Sol–gel Glasses. *J. of Alloys and Compounds* 311:11–15

Jiang, S., Myers, J., Rhonehouse, D., Myers, M., Belford, R., Hamlin, S., (1990), Laser and Thermal Performance of A New Erbium Doped Phosphate Glass, Hilton Head Island. Kigre Inc.

Jiang, S. Myers, M. Peyghambarian, N. (1998). Er^{3+} Doped Phosphate Glasses and Lasers. *J. Non-Crystalline Solids 239:143-148.*

Jones, G. O. (1971). *Glass*. Parke, S. (Ed). Gateshead; Northumberland Press Ltd.

Kanagaraj, S. Pattanayak S. (2003). Measurement of The Thermal Expansion of Metal and FRPs. *Cryogenics* 43:399–424

Kashif, I. El-ghany, A. A. El-Maboud, A. A, Elsherbiny, M.A. Sanad, A.M. (2010) IR, Density and DTA Studies The Effect of Replacing Pb_3O_4 by Cuo In Pseudo-Binary $Li_2B_4O_7$–Pb_3O_4 Glass System. *J. of Alloys and Compounds* 503: 384–388

Kaur, A. Khanna, A. Pesquera, C. Gonzalez, F. Sathe, V. (2009). Preparation and Characterization of Lead and Zinc Tellurite Glasses. *J. of Non-Crystalline Solids*. 356 : 864–872

Koechner, W. Bass, M. *Solid-state Laser: A Graduate Text*, (2003), Springer New York, Inc.

Kuisma, R. (2006). Physical Characterization of Plastic Surface and Cleanability Research. Department of Agrotechnology. University of Helsinki

Kumar, M. P. Sankarappa, T. (2009). DC Conductivity of Rare-earth Ions Doped Vanado-Tellurite Glasses. J. of Non-Crystalline Solids 355:295–300.

Li, Z.C. Jiao Y. Deines T.W. Pei Z.J. Treadwell, C. (2005). Rotary Ultrasonic Machining of Ceramic Matrix Composites:Feasibility Study and Designed Experiments. *J. of Machine Tools & Manufacture* 45:1402–1411

Lin, A. Zhang, A. Bushong, E. J. Toulouse, J. (2009). Solid-core Tellurite Glass Fibre for Infrared and Non-Linear Application. J. *of Optical Express* 17:19:16716-16721.

Lin, H. Liu, K. Pun, E.Y. B. Ma, T. C. Peng, X. An, Q. D. Yu, J. Y. Jiang, S. B. (2004). Infrared and Visible Fluorescence in Er^{3+} -doped Gallium Tellurite Glasses, *J. of Chemical Physics Letters*. 398:146-150.

Lofaj, F. Satet, R. Hoffmann, M.J. Lopez A.R. A.(2004). Thermal Expansion And Glass Transition Temperature of The Rare-Earth Doped Oxynitride Glasses. *J. of The European Ceramic Society*. 24:3377–3385

Lou, M. S. Chen, J. C. Li, C. M. (1999) Surface Roughness Prediction Technique for CNC End-Milling, *J. of industrial Technology*. 15:1.

Loughlin., C. *Sensor for Industrial Inspector,* (1993), Ikley, West Yorkshire, U.K: Kluwer Academic Publisher.

Lu, C., Study on Prediction of Surface Quality in Machining Process, (2008), *J. of Materials Processing Technology* 205:439-450

Marjanovic, S. Toulouse, J. Jain, H. Sandmann, C. Dierolf, V. Korton. A. R. Kopylor, N. Ahrens, R. G. (2003). Characterization of New Erbium Doped Tellurite Glasses and Fibers. *J. of Non-Crystalline Solids*. 322:311-318.

Mierczyk, Z. Kwasny, M. Kopczynski, K. Gietka, A. Lukasiemcz, T. Frukacz, Z. Kisielewski, J. Stepien, R. Jedrzejewski, K. (2000). Er^{3+} and Yb^{3+} Doped Active Media for ‘eye safe’ Laser System, *J. of Alloys and Compounds* 300-301:398-406.

Mohamed N. B. Yahya A. K. Deni M. S. M. Mohamed S. N. Halimah M. K. Sidek H. A. A. (2010) Effects of Concurrent TeO_2 Reduction and ZnO Addition on Elastic and Structural Properties of (90-x)TeO_2-10Nb_2O_5-(x)ZnO Glass. *J. of Non-crystalline Solids* 356:1626-1630.

Moustafa, Y.M. El-Egili, K. Doweidar , H. Abbas, I. (2004). Structure and Electrical Conduction of Fe_2O_3–P_2O_5 Glasses. *Physica B* 353:82–91

Nandi, P. Jose, G. (2006). Erbium Doped Phosphor Tellurite Glasses for 1.5 µm Optical Amplifiers. *J. of Optics Communicatios* (265) 588-593.

Nazabal, V. Todoroki, S. Nukui, A. Matsumoto T. Suehara, S Hondo, T. Araki, T. Inoue, S. Rivero, C. Cardinal, T. (2003). Oxyfluoride Tellurite Glasses Doped by Erbium Thermal Analysis, Structural Organization and Spectral Properties. *J. of Non-Crystalline Solids* 325:85–102

Nga, P.T. Barthou, C. Benalloul, P. Thang, P.N. Chung, L.N Hoi, P.V. Luat, L.V Cuong,P.T. (2006). Effects of Yttrium Codoping on Fluorescence Lifetimes of Er^{3+} Ions In SiO_2–Al_2O_3 Sol–Gel. *J. of Non-Crystalline Solids* 352 : 2385–2389

Noor, H. (2009). *Thermal Conductivity of TeO_2 – ZnO – Er_2O_3 Glass System*, Degree of Scince (Material Physics). Universiti Teknologi Malaysia (UTM).

Noriah Bidin, (2002), *Teknologi Laser*, Johor Bharu: Penerbit UTM.

Pavani P. G. Suresh S. Mouli V. (2011) Studies on Boro Cadmium Tellurite Glasses. *J. of Optical Materials* 34:215-220.

Pei, Z.J. Ferreira, P.M.(1998). Modeling of Ductile-Mode Material Removal In Rotary Ultrasonic Machining. *International Journal of Machine Tools & Manufacture* (38) 1399–1418.

Pei, Z.J., Prabhakar, D., Ferreira, P.M.,(1994). Rotary Ultrasonic Drilling and Milling of Ceramics, Indianapolis, *The Design For Manufacturability and Manufacture of Ceramic Components Symposium*.

Poon, C. Y. Bhushan, B. (1995). Comparison of Surface Roughness Measurements by Stylus Profiler, AFM and Non-Contact Optical Profiler. *Wear* 190 : 76-88

Praveena, R. Vijaya, R. Jayasankar, C.K. (2008). Photoluminescence and Energy Transfer Study of Dy^{3+}-Doped Fluorophosphate Glasses. *Spectrochimica Acta* Part A 70:577–586

Pye, L. D. Steven, H. J. Lacourse, W. C. (1972). *Introduction to Glass Science (Chap1)*. Pye, L. D.(Ed). New York: Plenum Press.

Rawson, H. (1980). *Properties and Application of Glass*. Amsterdam: North Holland INC.

Reddy, P. V. Kanth, C. L. Kumar, V. P. Veeraiah, N. Kistaiah, P. (2005). Optical And Thermoluminescence Properties of R_2O–RF–B_2O_3 Glass Systems Doped with MnO. *J. of Non-Crystalline Solids* 351 : 3752–3759

Rolli, R., Montagna, M., Chaussedent, S., Monteil, A., Tikhomirov, V. K., Ferrari, M., (2003). Erbium-doped Tellurite Glasses with High Quantum Efficiency and Broadband Stimulated Emission Cross Section at 1.5 µm. *J. of Optical Materials*. 21 : 743-748.

Rosmawati S. Sidek H. A. A. Zainal A. T and Zobir H. M. (2007) Preparation and Physical Studies on Binary Zinc Tellurite Glass System. *J. of St Sci and Technol. Letter* 14(2):95-99.

Sahar M. R. (1998). *Sains Kaca*. Johor Bharu: Penerbit Universiti Teknologi Malaysia.

Sahar M. R. Hamzah K. Rohani M. S. Samah K. A. Razi M. M. (2011). The Microstructure and Physical Properties of Incinerated Paper-Cullet-Clay Ceramics. *Physics Procedia* 22:119-124.

Sene, F.F. Martinelli, J.R. Gomes L. (2004). Optical and Structural Characterization of Rare-earth Doped Niobium Phosphate Glasses. *J. of Non-Crystalline Solids* 348:63–71

Shelby, J. E. (2005). *Introduction to Glass Science and Technology* (2nd ed) (Chap 1). New York: Plenum Press.

Shen, S. Jha, A. Zhang, E. Wilson, S. J. (2002). Compositional Effects and Spectroscopy of Rare-earth (Er^{3+}, Tm^{3+}, And Nd^{3+}) In Tellurite Glasses. *C. R. Chimie* 5:921–938

Shih., P. Y., (2004), Thermal, Chemical and Structural Characteristics Of Erbium-Doped Sodium Phosphate Glasses., *J of Materials Chemistry and Physics.* 84:151- 156.

Sidebottom, D.L. Hruschka, M.A. Potter, B.G. Brow, R.K. (1997). Structure and Optical Properties of Rare-earth-Doped Zinc Oxyhalide Tellurite Glasses. *J. of Non-Crystalline Solids*. 222:282-289

Sidek H. A. A. Rosmawati S. Talib Z. A. Halimah M. K. and Daud W. M. (2009). Synthesis and Optical Properties of $ZnO-TeO_2$ Glass System American. *J. of Applied Sciences* 6(8):1489-1494.

Singh, R. Khamba, J.S. (2006). Ultrasonic Machining of Titanium and Its Alloys: A Review. *J. of Materials Processing Technology*. 173:125–135.

Snoeks, E. Kik, P. G. Polman, A. (1995). Concentration Quenching In Erbium Implanted Alkali Silicate Glasses. *J. Optical Materials* 5:159-167.

Srilatha, K. Rao, K. S. Gandhi, Y. Ravikumar, V. Veeraiah, N. (2010). Fe Concentration Dependent Transport Properties of $LiI–AgI–B_2O_3$ Glass System. *J. of Alloys and Compounds*. 507:391–398

Stoneman,:R., C., *Eyesafe Rare-Earth Solid State Laser, in Solid state laser and Application* (edited by Alphan Sennaroglu) (2007). London, New York: CRC Press Taylor & Francis Group, LLC.

Sulhadi, (2007). *Structural and Optical Properties Studies of Erbium Doped Tellurite Glass,* PHD Thesis: Universiti Teknologi Malaysia, (UTM).

Wang, J. S. Vogel, E. M. Snitzer. E. (1994). Tellurite Glass: A New Candidate for Fiber Devices. *J. of Optical Materials*. 3:187-203.

Wang, Q. Cong, W. Pei, Z.J. Gao, H. Kang, R. (2009). Rotary Ultrasonic Machining of Potassium Dihydrogen Phosphate (KDP) Crystal: An Experimental Investigation on Surface Roughness. *J. of Manufacturing Processes*. 11 : 66-73

Weber, R. Neuenschwander, B. Weber, H.P. (1999). Thermal Effects in Solid-State Laser Materials. *J. of Optical Materials* 11 : 245-254.

Wirkus, C. D. Berard, M. F. (1982). Abradability and Hardness in Rare-earth Oxide Stabilized Hafnia. *J. of Materials Science* 17:109—114

Xianfeng, M. Qitu, Z. Chunhua, L. Zhongzi, X. (2006). Preparation and Thermal Stability of Phosphate System Protection Glasses Doped with Rare-earths. *J. of Rare-earths*, 24:211

Xunsi, W. Qiuhua, N. Tiefeng, X. Xiang, S. Na, G. (2008). Tm^{3+}-Doped Tellurite Glass With Yb^{3+} Energy Sensitized for Broadband Amplifier at 1400–1700 nm Bands. *J. of Rare-earths.* 26,6:907

Ya, G., Qin, H. W., Yang, S. C., Xu, Y. W., (2002), Analysis of The Rotary Ultrasonic Machining Mechanism, *J. of Materials Processing Technology.* 129 : 182-185.

Yi, W. Langsheng, L. Huiqun, L. Ruiqin, D. (2006). Anneal and Concentration Effect on PL Properties of Sol-Gel Derived Eu^{3+} Doped SiOz Glass. J. *of Rare-earths* 24:199.

Yong, K. C. (2009). *Ultrasonic Machining, Lapping and Polishing of Neodymium Doped Yttrium Aluminum Garnet Laser Crystal Rod*. Master of Engineering (Mechanical). Universiti Teknologi Malaysia

Yu, Y. Wu, Z. Zhang, S. (2000). Concentration Effects of Er^{3+} Ion In YAG: Er Laser Crystal. *J. of Alloys and Compounds*. 412:261-263.

Yukimitu, K., Oliveira, R.C., Araujo, E.B., Moraes, J.C.S., Avanci, L.H., (2005). DSC Studies on Crystallization Mechanisms of Tellurite Glasses. *J. of Thermochimica Acta*. 426 : 157–161

Yusof N. H. B. M. (2011). Optical Properties of Magnesium Phosphate Glass Doped Samarium. Master of Science (Physics). Umiversiti Teknologi Malaysia.

Zeng, W.M. Li, Z.C. Pei, Z.J. Treadwell, C. (2005). Experimental observation of tool wear in rotary ultrasonic machining of advanced ceramics. *International J. of Machine Tools & Manufacture*. 45 : 1468–1473

Zhang, J. Dai, S. Wang, G. Zhang, L. Sun, H. Hu, L. (2005). Investigation on Uponversion Luminescence in Er^{3+}/Yb^{3+} Codoped Tellurite Glasses and Fibers. *Physics Letters A* 345 : 409-414.

Zhao, X. Wang, X. Lin, H. Wang, Z. (2007). Correlation Among Electronic Polarizability Optical Basicity and Interaction Parameter of Bi_2O_3–B_2O_3 Glasses. *Physica B*. 390 : 293–300.

Zhaobing, W. Qingli., Z. Dunlu, S. Shaotang., Yin., (2007), Study on Thermal Expansion of $Nd^{3+:}Gd_3Ga_5O_{12}$ Laser Crystal., *J of Rare-earths, 25:244.*

APPENDIX A

Batch Calculation

The calculation start with determine the weight fraction of each component required to produce the desired molar composition. These begin by multiplying the mole fraction and molecular weight for each component. Then, total up all these contribution to determine the molecular weight of the glass, and divide each individual contribution by the molecular weight of the glass to determine the weight fraction of each component. Lastly, multiply the weight fraction of each component by the amount of glass to be produced ((80-*x*) TeO_2-20 ZnO-*x* Er_2O_3 system). Fortunately, all the batch calculations follow the same procedure.

1. (80-*x*) TeO_2-20ZnO-*x* Er_2O_3 system.

Glass composition: (80-0) TeO_2-20ZnO-(0) Er_2O_3

Molecular weight of component (in $gmol^{-1}$):

TeO_2 = 159.60 ZnO = 81.37 Er_2O_3 = 382.52

Molecular weight of glass: (0.80x159.60) + (0.20x81.37) + (0x382.52) = 143.95

TeO_2 = (0.80x159.60)/ 143.95 = 0.8734

ZnO = (0.20x81.37)/ 143.95 = 0.1131

Er_2O_3 = (0x382.52)/ 143.95 = 0.0000

For 100gm of glass,

TeO_2 = 0.8734x100 = 87.34g, ZnO = 0.1131x100 = 11.31g, Er_2O_3 = 0.0000x100 = 00.00g