Solid State Phenomena
ISSN: 1662-9779, Vol. 317, pp 95-99
doi:10.4028/www.scientific.net/SSP.317.95

Submitted: 2020-01-06
Revised: 2020-07-30
Accepted: 2020-07-30
Online: 2021-05-10

The Optical Performance of Holmium Oxide Doped Tellurite Glass for Potential Optical Fiber

MUHAMMAD NOORAZLAN Abd Azis[1,2,a*], HALIMAH Mohamed Kamari[3,b], SURIANI Abu Bakar[1,2,c], AZLINA Yahya[1,2,d] and UMAR Saad Aliyu[4,e]

[1]Physics Department, Universiti Pendidikan Sultan Idris, 43400, Tanjung Malim, Perak, Malaysia

[2]Nanotechnology Research Center, Faculty of Science and Mathematics, Universiti Pendidikan Sultan Idris, 35900 Tanjung Malim, Perak, Malaysia

[3]Physics Department, Universiti Putra Malaysia, 35900, Serdang, Selangor, Malaysia

[4]Department of Physics, Faculty of Science, Federal University Lafia, Nigeria

[a]azlanmn@fsmt.upsi.edu.my, [b]halimahmk@upm.edu.my, [c]suriani@fsmt.upsi.edu.my, [d]azlinayahya15@gmail.com, [e]usaltilde@yahoo.com

Keywords: Tellurite glass, holmium oxide, optical fiber materials List the keywords covered in your paper.

Abstract. Borotellurite glass had been widely applied in the field of optical communications and devices. In this work, holmium oxides doped borotellurite glass had been successfully fabricated via conventional melt-quenched technique. The structural properties of holmium doped tellurite glass were found using x-ray diffraction (XRD) method. The nonexistence of sharp peaks in XRD pattern shows that the inclusion of holmium tellurite glass leads to the formation long range of disorderness. The optical properties of the glass system such as refractive index and optical band gap energy are investigated using UV-Vis spectrophotometer. The value of refractive index is found in nonlinear trend along with holmium oxides concentration. It is found that the refractive index is more than 2 at 0.01, 0.03 and 0.04 of holmium concentrations. The optical band gap energy was found in similar trend with refractive index which is in nonlinear pattern.

Introduction

The extensive research on optical glass materials had been done to produce the high optical ability in glass materials for optoelectronics applications. Among the heavy metal oxides, tellurite oxide shows outstanding optical properties such as high refractive index, high dielectric constants, a wide band infrared transmittance and large third order non-linear optical susceptibility [1]. It is known that tellurite glass has high potential to be used in core clad fiber optics [1]. However, the current materials for fiber optics are made from silicate oxide which has numerous weaknesses for fiber optics [2]. Hence, it is highly important to introduce tellurite oxide as the novel materials for fiber optics.

The single component of tellurite glass has low stability and prone to fractures. The multi-component glass system is the best solution to increase the glass forming stability and to enhance the structural properties. Boron and zinc oxides had been chosen in this research due to several reasons as follows [2]:

a. Boron oxide: Excellent materials to increase the hardness properties and phonon energy (from 770 to 1335 cm^{-1})
b. Zinc oxide: Outstanding materials to reduce the melting temperature and may act as former glass

The introduction of rare earth oxides as dopants in glass materials had been widely investigated. Rare earth oxides are known to have sharp spectral properties which is beneficial to be used in wide optoelectronics applications. Erbium oxide are the well-known dopant which had been used in many glass materials. However, there are few more rare-earth oxides which have high potential to be used in optical glass materials. Holmium oxide is one of the rare-earth oxides which have high potential to improve the optical performance of tellurite glass.

In this work, holmium oxide had been chosen due to high compatibility with tellurite glass. Holmium oxide has high potential to be used as fiber amplifiers in long-range optical fiber communications. The study of erbium and neodymium oxides in tellurite glass had been done by El-Mallawany *et al*. which found that the holmium oxide has the highest refractive index of known glass [3]. However, the study of holmium oxide doped tellurite glass is still few in number.

The focus of this research is to develop holmium oxide doped tellurite glass as fiber optics. This work consists of the characterization of holmium doped tellurite glass, optical absorption and optical band gap.

Experimental

The conventional melt-quenched technique had been used to fabricate the glass system. The chemical composition of the holmium oxide doped zinc borotellurite glass system is as follows:

$\{[(TeO_2)_{0.70}(B_2O_3)_{0.30}]_{0.7}(ZnO)_{0.3}\}_{1-y}(Ho_3O_2)_y$ glass, y=0.005, 0.01, 0.02, 0.03, 0.04, 0.05 mol%

The raw materials of the glass system are as follows; Alfa Aesar- high purity reagent grade of holmium (III) oxide (Ho_2O_3), Alfa Aesar- high purity reagent grade tellurium (IV) oxide (TeO_2), Alfa Aesar- high purity reagent grade zinc oxide (ZnO), Alfa Aesar- high purity reagent grade boron oxide (B_2O_3).

The raw materials which consist of Ho_3O_2, TeO_2, ZnO and B_2O_3 were mixed together in a platinum crucible. The mixtures were placed in electrical furnace at 400 ºC for 30 minutes and transferred to the second furnace at 900 °C for 2 hours. The liquid-form glass (molten) was quenched in cylindrical stainless-steel mould. The glass sample was cooled down to room temperature. The refractive index and optical absorption were measured by using UV-1650PC UV-Vis Spectrophotometer (Shimadzu).

Results and Discussion

X-Ray Diffraction(XRD). The x-ray diffraction technique is used to confirm the amorphous structural arrangement in the glass system. The difference between amorphous and crystalline structure in XRD pattern is determined by the peaks. The obtained result of XRD pattern as shown in Fig. 1 confirm that the crystalline structure is absent in all glass samples. The broad hump of the XRD pattern indicates the amorphous structural arrangement in the glass system. It can be seen from Fig. 1 that the broad peak at around $2\Theta = 28^0$ is found in all glass samples. The increasing intensity of the broad hump is due to the effect of holmium oxide which tend to form crystalline structure with an increase of the dopants.

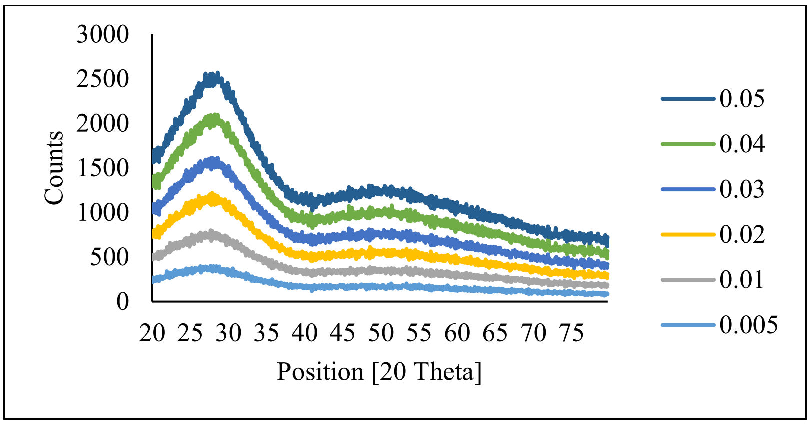

Fig. 1: X-ray diffraction pattern of the glasses

Optical Absorption, Optical Band Gap and Refractive Index. The optical absorption study in glass materials is crucial to relate with the theory of electronic structure of amorphous materials. Rare earth oxides is known to have sharp spectral lines which contributes to the peaks in optical absorption. The sharp spectral lines are due to the 4f-4f orbital which are benifical for luminescence parameter [4]. Fig. 2 shows the optical absorption of the glass system. It can be seen from the figure that the absorption transitions arise from the ground state to several exicited states. These transitions are important to determine the judd-ofelt parameters and to be used as excited value in photoluminescence [5]. It is revealed that the absorption edge shifts to longer wavelength with an increase of holmium oxide. This pattern indicates the conversion from less covalent to more ionic character in the glass system. The optical band gap energy is obtained by extrapolating the absorption coefficient curve as shown in Fig. 3. Mott and Davis proposed the relationship between absorption coefficient and photon energy which is important to investigate the optical band gap energy [6]. The photon energy can be calculated by the following relation:

$$\alpha(\omega) = \frac{B(\hbar\omega - Eopt)^n}{\hbar\omega} \quad (1)$$

where B is an energy-independent constant known as band tailing parameter, E_{opt} is the optical band gap energy, and n is a constant index that shows different values, 1/2, 2, 3/2, and 3 depending on the type of optical transitions. The obtained optical band gap is shown in Fig. 4. It is noted from the figure that the trend of optical band gap is nonlinear. However, the average optical band gap shows that the glass materials are semiconductor. The lowest optical band gap is found at 0.03 concentration. This result indicates that the glass materials is more conductor at 0.03 concentration. It is known that zinc oxide may act as glass former at certain amount of rare-earth oxide, hence the reduction of optical band gap may due to the effect of zinc oxide in the glass system [7]. The optical band gap is high at 0.02 concentration which may due to the high number of bridging oxygen in the glass system. The high number of optical band gap correspond to the widen of forbidden gap in the electronic transitions.

The refractive index is determined by using optical band gap energy from the relation proposed by Dimitrov and Sakka [8]:

$$\frac{n^2-1}{n^2+1} = 1 - \sqrt{\frac{E_{opt}}{20}} \quad (2)$$

where n represents the refractive index and E_{opt} denotes as the indirect band gap values. The trend of refractive index is plotted in Fig. 5. It can be seen from the figure that the refractive index is in nonlinear pattern which reflect to the value of optical band gap. However, it is revealed that the refractive index is at the highest value, which is more than 1 at 0.01, 0.03 and 0.05 concentrations. The increasing number of refractive indices is due to the high coordination number of holmium ions [9, 10, 11]. Moreover, the increasing number of polarizabilities of the glass system contributes to the high number of refractive indices [12].

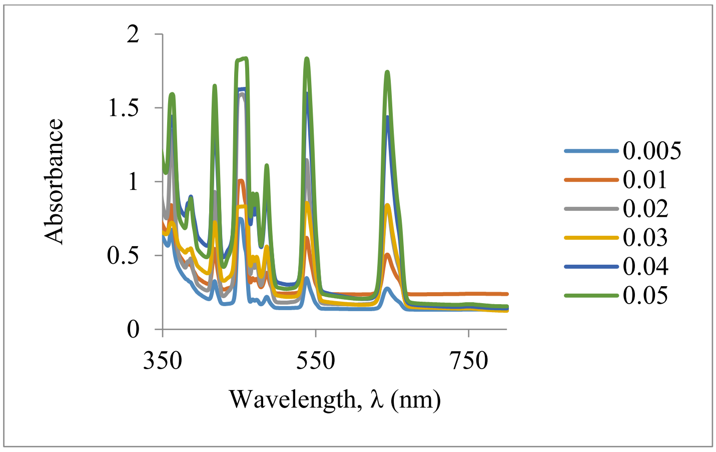

Fig. 2: Optical absorption spectra of the glass system

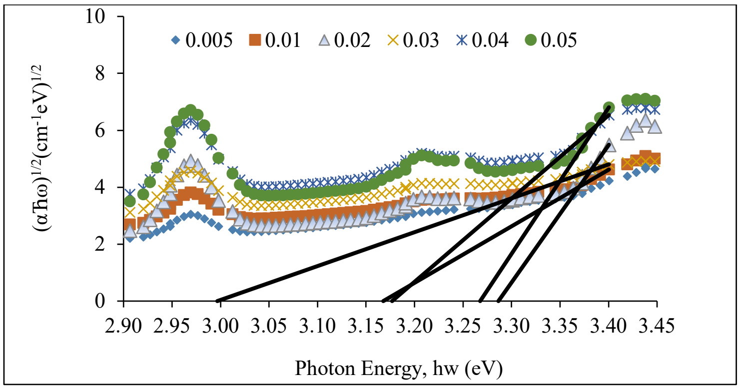

Fig. 3: Extrapolation of absorption coefficient of the glass system

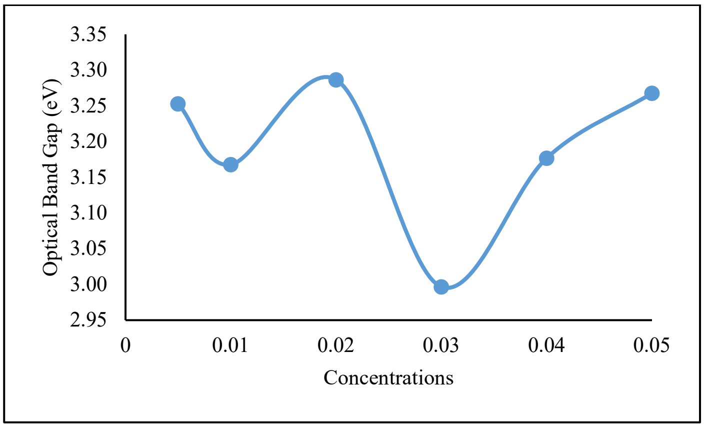

Fig. 4: Optical band gap energy of the glass system

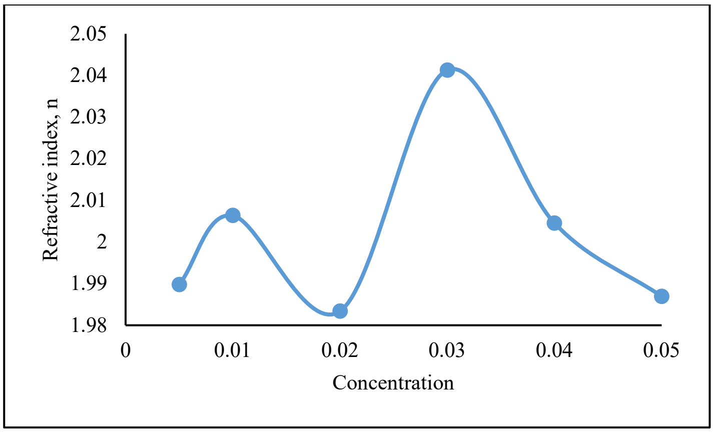

Fig. 5: Refractive index of the glass system

Conclusions

The amorphous structural arrangement of the holmium doped tellurite glass samples was confirmed by the XRD analysis. The optical absorption pattern shows several sharp peaks indicating the excitation from the ground state to several excited states. The optical band gap was found in nonlinear trend along with holmium concentrations. The average optical band gap proposed that the glass system is in semiconductor. The refractive index of the glass samples was found in nonlinear trend with increasing concentration of holmium. The refractive index is more than two at 0.01, 0.03 and 0.04 concentrations. The high value of refractive index is due to the high coordination number and polarizability of holmium oxide. Hence, these results suggest that the glass system has high potential to be used in optical fiber.

Acknowledgements

This paper is based on the research project entitled Enhanced optical efficiency of novel Graphene coated Neodymium Tellurite laser glass for advanced fiber laser and optical sensor. The authors would like to extend their gratitude to the Ministry of Education of Malaysia for the Fundamental Research Grants Scheme (code: FRGS/1/2018/STG07/UPSI/02/1) that helped fund the research.

References

[1] M.N. Azlan, M.K. Halimah, A.B. Suriani, Y. Azlina, R. El-Mallawany, Electronic polarizability and third-order nonlinearity of Nd^{3+} doped borotellurite glass for potential optical fiber, Materials Chemistry and Physics 236 (2019) 121812.

[2] H.A.A. Sidek, S. Rosmawati, Z.A. Talib, M.K. Halimah, W.M.Daud, Synthesis and Optical Properties of ZnO-TeO2 Glass System, Journal of Applied Science 6(8) (2009) 1489-1494.

[3] R. El-Mallawany, M. Dirar Abdalla, I. Abbas Ahmed, New tellurite glass:Optical properties, Materials Chemistry and Physics 2-3 (2008) 291–296.

[4] Y. Azlina, M.N. Azlan, M.K. Halimah, S.A. Umar, R. El-Mallawany, G. Najmi, Optical performance of neodymium nanoparticles doped tellurite glasses, Physica B: Condensed Matter 577 (2020) 411784.

[5] A.M. Noorazlan, H.M. Kamari, S.S. Zulkefly, D.W. Mohamad, Effect of Erbium Nanoparticles on Optical Properties of Zinc Borotellurite Glass System, Journal of nanomaterials 2013 (2013).

[6] N.F. Mott, E.A. Davis, Electronic Process in Non-Crystalline Materials, Clarendon Press, Oxford, 1979.

[7] A.S. Asyikin, M.K. Halimah, A.A. Latif, M.F. Faznny, S.N. Nazrin, Physical, structural and optical properties of bio-silica borotellurite glass system doped with samarium oxide nanoparticles, Journal of Non-Crystalline Solids 529 (2020) 119777.

[8] V. Dimitrov, S. Sakka, Linear and nonlinear optical properties of simple oxides II, Journal of Applied Physics 79 (1996) 1741-1745.

[9] H.A.A. Sidek, S.H. Elazoumi, R. El-Mallawany, M.H.M. Zaid, K.A. Matori, M.K. Halimah, Effect of lead and zinc oxides on the thermal properties of tellurite glass systems, Journal of Non-Crystalline Solids 523 (2019) 119640.

[10] M.K. Halimah, C. Eevon, Comprehensive study on the effect of Gd_2O_3 NPs on elastic properties of zinc borotellurite glass system using non-destructive ultrasonic technique, Journal of Non-Crystalline Solids 511 (2019) 10-18.

[11] A.M. Hamza, M.K. Halimah, F.D. Muhammad, K.T. Chan, A. Usman, M.F. Faznny, I. Zaitizila, R.A. Tafida, Structural, optical and thermal properties of Er^{3+}-Ag codoped bio-silicate borotellurite glass, Results in Physics 14 (2019) 102457.

[12] M.N. Azlan, M.K. Halimah, Role of Nd^{3+} nanoparticles on enhanced optical efficiency in borotellurite glass for optical fiber, Results in Physics 11 (2018) 58-64.