PHYSICAL, STRUCTURAL AND ELASTIC PROPERTIES OF SILICATE LITHIUM NIOBATE VANADIUM TELLURITE GLASS SYSTEM

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ABSTRACT

This thesis reports a concise study of physical, structural and elastic properties of tellurite based glasses in search of strong materials for improving their potentials as commercial glasses in wide range of applications. A series of glass samples with the composition (65.0-x)TeO_2–14.9Li_2O–15.0Nb_2O_5–5.0SiO_2–(x)V_2O_5 with $0 \leq x \leq 6.0$ mol% was prepared via melt quenching technique. These samples were characterized by X-ray diffraction (XRD), energy dispersive X-ray (EDX) spectroscopy, atomic force microscopy (AFM), differential thermal analysis (DTA), Fourier transform infrared (FTIR) spectroscopy, Raman spectroscopy, Vicker's hardness and ultrasonic measurement. XRD pattern verified the true amorphous nature of the prepared glass and the EDX spectra detected the presence of right elements in the glass composition. The AFM analysis manifested the surface roughness of the glass sample which increased with the increase of V_2O_5 content, indicating its three-dimensional growth. The synthesized transparent samples revealed good thermal stability over a wide glass formation region. FTIR and Raman spectra showed the incorporation of vanadium slightly modified the glass structure due to the introduction of a small amount of vanadium content in the glass system. The Vicker's hardness values and ultrasonic elastic properties were found to increase with the increase of vanadium content and this showed the glass structure was more rigid and contained the fewest non-bridging oxygen. The sound attenuation coefficients and internal friction of the glass system were found to decrease along with the increase of vanadium concentration due to the absorption and scattering phenomena. The inclusion of V_2O_5 in the tellurite based glass system was verified to improve its physical, structural and elastic properties and it promises a wider application in industries.

ABSTRAK

Tesis ini melaporkan satu kajian padat tentang sifat fizikal, struktur dan elastik kaca berasaskan tellurit dalam mencari bahan yang kukuh bagi penambahbaikan potensi kaca sebagai kaca komersial dalam pelbagai aplikasi. Satu siri sampel kaca dengan komposisi $(65.0\text{-}x)TeO_2–14.9Li_2O–15.0Nb_2O_5–5.0SiO_2–(x)V_2O_5$ dengan $0 \leq x \leq 6.0$ mol% telah disediakan dengan menggunakan teknik lindapan leburan. Sampel ini dicirikan dengan menggunakan pembelauan sinar-X (XRD), spektroskopi serakan tenaga sinar-X (EDX), mikroskopi daya atom (AFM), analisis perbezaan terma (DTA), spektroskopi inframerah jelmaan Fourier (FTIR), spektroskopi Raman, kekerasan Vicker's dan pengukuran ultrasonik. Corak XRD mengesahkan sifat amorfus sebenar kaca yang disediakan dan spektrum EDX mengesan kehadiran unsur sebenar dalam komposisi kaca. Analisis AFM menyatakan kekasaran permukaan sampel kaca didapati meningkat dengan peningkatan kandungan V_2O_5, menunjukkan pertumbuhan tiga-dimensi bagi kaca tersebut. Sampel yang terhasil bersifat lutsinar dan mempamerkan kestabilan terma yang baik dengan julat pembentukan kaca yang lebar. Spektrum FTIR dan Raman menunjukkan kemasukan V_2O_5 mengubah sedikit struktur kaca disebabkan pengenalan kandungan vanadium yang kecil dalam sistem kaca. Nilai kekerasan Vicker's dan sifat elastik ultrasonik didapati meningkat dengan peningkatan kandungan vanadium dan ini menunjukkan struktur kaca adalah lebih tegar dan mengandungi jambatan oksigen tidak bersambung yang paling sedikit. Pekali pengecilan bunyi dan geseran dalaman bagi sistem kaca didapati berkurang bersama-sama dengan peningkatan kepekatan vanadium disebabkan oleh fenomena penyerapan dan serakan. Kemasukan V_2O_5 dalam sistem kaca berasaskan tellurit telah berjaya memperbaiki sifat fizikal, struktur dan elastik kaca tersebut dan ia menjanjikan aplikasi yang lebih luas dalam industri.

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LIST OF ABBREVIATIONS

AFM	-	Atomic Force Microscopy
BO	-	Bridging Oxygen
C	-	Carbon
DTA	-	Differential Thermal Analysis
E	-	Young's Modulus
EDX	-	Energy Dispersive X-ray
FTIR	-	Fourier Transform Infra Red
G	-	Shear Modulus
IR	-	Infrared
K	-	Bulk Modulus
L	-	Longitudinal Modulus
Li	-	Lithium
Nb	-	Niobium
NBO	-	Non Bridging Oxygen
O	-	Oxygen
Si	-	Silicon
Te	-	Tellurite
V	-	Vanadium
XRD	-	X-Ray Diffraction

LIST OF SYMBOLS

Z	-	Acoustic impedance
θ	-	Angle
F	-	Applied load
m_o	-	Atomic weights in kg of anion
m_r	-	Atomic weights in kg of cation
α	-	Attenuation coefficient
$\overline{n_c}$	-	Average cross-link density
N_A	-	Avogadro number
B	-	Brittleness
c	-	Crack length generated off the corners of the indentation
n_c	-	Cross-link density per cation
θ_D	-	Debye temperature
ρ	-	Density
ρ_{liquid}	-	Density of the liquid
C_{ij}	-	Elastic constant
e	-	Electron charge
m	-	Electron mass
f	-	Force constant
d	-	Fractal bond connectivity
K_{IC}	-	Fracture toughness
T_c	-	Glass crystallization temperature
T_m	-	Glass melting temperature
ΔT	-	Glass thermal stability
T_g	-	Glass transition temperature
a	-	Half length of diagonal of the indent
H_R	-	Hruby's parameter

n	-	Integer
Q^{-1}	-	Internal friction
V_t	-	Ionic packing density
d_i	-	Length of the diagonal of the indentation
H	-	Microhardness
V_m	-	Molar volume
x_i	-	Mole fraction
M_w	-	Molecular weight
P	-	Number of atoms in chemical formula
N_c	-	Number of cations per glass formula
V_i	-	Packing density parameter
σ	-	Poisson's ratio
μ	-	Reduced mass
RMS	-	Root-Mean-Square
T_S	-	Softening temperature
T_I	-	Temperature interval
t	-	Thickness of the sample
H_V	-	Vickers hardness
λ	-	Wavelength
v	-	Wave number
W_{water}	-	Weight in distilled water
W_{air}	-	Weight of sample in air

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CHAPTER 1

INTRODUCTION

1.1 Background Study

Glass is a non-crystalline solid material which is typically brittle and often optically translucent with irregular atomic structure. Glass is also known as an amorphous solid and has no long range order in periodic arrangements as a crystalline solid (Shelby, 2005). Nowadays, glass is widely used for many applications because it is relatively reasonable in price, easy to produce and it can be made up over a wide range of compositions (Raewat & Cherdsak, 2015). Glasses is a material with unique properties such as high hardness, transparency at room temperature along with sufficient strength, excellent corrosion resistance, physical isotropy and the absence of grain boundaries (Halimah *et.al.,* 2010). Due to possible utilization in various technological and engineering fields, the study of glass characterization is of great significance. Interest in glasses has escalated in many years because of diverse applications in electronic, nuclear, solar energy and acousto-optic devices (Kannappan *et.al.,* 2009). Glass is one of the most versatile substances on earth where it is used in many applications and a wide variety of forms, from plain clear glass to tempered glass, tinted glass and many more. The technological relevance of glasses has led to an increased effort to resolve their structures where this information permits a deeper insight into their physical, morphology, thermal, structural, mechanical and ultrasonic properties relationship that can be exploited for materials like tellurite based glasses.

Among the variety of glass former, tellurite glasses have shown interesting both physical and optical properties where it possesses several advantages over conventional silicate, phosphate and borate glasses (Baki *et.al.,* 2014; Sib *et.al.,* 2015). Tellurite glasses have an interesting glass forming ability, good semiconducting properties, electrical conductivity, non-hygroscopic properties, great stability and low melting point (Lezal *et.al.,* 2002; Jiang *et.al.,* 2004; Zheng *et.al.,* 2013). Moreover, besides having a unique structure, tellurite glasses also have good mechanical strength and chemical durability (Lin *et.al.,* 2004), high values of linear and non-linear refractive indices (Yousef *et.al*., 2007; Lakshminarayana *et.al.,* 2009) and good optical transmission in a wide range of infrared (IR) (Sidkey *et.al.,* 1997; Mohamad *et.al.,* 2006). Transitional position of Te between metals and non-metals in the periodic table has long held special significance which attracts researchers to explore more about this type of glasses (Raouf, 2002). It has been known that pure tellurium dioxide is only a conditional glass former where it required fast quenching techniques to form glass. The conventional methods were unable to form a glass straightforwardly without adding other elements (transition metal oxides, alkaline or alkaline earth) or glass modifiers to the pure tellurium dioxide (Lambson *et.al.,* 1984; Sharaf *et.al.,* 2008).

Most of the most commercially made glasses today are based on silica (SiO_2) (Kiranpreet, 2011). Silicate glasses are thermally stable, high chemical resistance to corrosion, good fluorescence properties and optically transparent at excitation and lasing wavelength (Wang *et.al.,* 1994). The high viscosity of this type of glasses allows the glass to be formed, cooled and annealed without crystallization. Silicate glasses are useful in optics as beam splitters or lenses, optoelectronics, optical telecommunications, laser and amplification applications (Desirena *et.al.,* 2009). This type of glasses is also commonly used for bottle containers and windows in industries (Neelam *et.al.,* 2016). Studies on tellurite glasses with silicate has been done by previous researchers (Neelam *et.al.*, 2016; Shams & Mostafa, 2017).

Alkaline tellurite glasses have strikingly high non-linear optical susceptibility, excellent chemical durability and provide transparency and homogeneity (McLaughlin *et.al.,* 2001; Khattak & Salim, 2002). Lithium niobate is one of the most versatile material owing to its superior physical, optical and electronic properties, being simultaneously non-linear optic, acousto and electro-optic, ferroelectric, piezoelectric and photorefractive (Rachel *et.al.,* 2009; Dehong *et.al.,* 2016). Tellurite glass doped with alkaline lithium niobate shows high thermal stability against crystallization (Hyun *et.al.,* 1995). Previous studies on tellurite glasses doped with lithium niobate have been reported (McLaughlin *et.al.,* 2001; Rajeswari *et.al.,* 2010; Nurhafizah, 2014).

Semiconducting transition metal oxides glasses have gained importance due to their possible applications in various technological fields (Pant *et.al.,* 2009; Sung *et.al.,* 2009). Among various transition metal ions, the vanadium ions are considered as effective and useful dopant ions owing to the fact that they exist not only in different valence states but also different co-ordinations [VO_4 and VO_5] simultaneously in the glass networks. In addition, glasses containing vanadium oxide (V_2O_5) are also being extensively used in memory and switching devices (Takahashi *et.al.,* 1998; Garbaczyk *et.al.,* 2003). TeO_2–V_2O_5 glass is a new class of vitreous materials. Pure, single crystal vanadium oxide can act as a network former and also network modifier in the presence of tellurium dioxide since it produces structural modification in the tellurite network (Rajinder *et.al.,* 2018). These glasses have relatively high electrical conductivity as compared with vanadium phosphate glasses or other glass containing metal oxides with the same amount of charge carriers (Nadia *et.al.,* 2009). Particularly, a broad variety of different structural units exists in the TeO_2–V_2O_5 glass network (Baia *et.al.,* 2004). Tellurite glasses doped with heavy metal oxides were found to show remarkable physical properties (Mohamed *et.al.,* 2010). Previous studies on binary and ternary tellurite glasses modified by the conditional glass former vanadium oxide have been reported (Baia *et.al.,* 2004; Abd El-Moneim, 2011; Thirumaran & Earnest, 2014; Raewat & Cherdsak, 2015; Majid, 2016). Tellurite glass systems containing transition metal oxides are a type of non-crystalline solids with a lot of applications over a wide range of compositions, temperatures and frequencies (El-Mallawany *et.al.,* 1998).

For almost a century, the non-destructive evaluation (NDE) or non-destructive testing (NDT) of materials has been an area of continued growth. NDT of materials is commonly performed to identify, characterize, assess voids, defects and damage in metals, metal alloys, composites and other materials (Berke & Hoppenkamps, 1990). This method is well known for finding defects in a structure or component without interfering with its integrity, causing no damage and undesirable effects on the test material (Worden, 2001; Mehdi *et.al.,* 2014). There is a large number of NDT techniques for identifying local damage and material characterization such as eddy current testing, magnetic particle inspection, radiographic testing, dye penetrant testing and ultrasonic testing where each represents different ways with distinct advantages and disadvantages depending on their actual existing inspection conditions (Schadow *et.al.,* 2017). Among all of them, ultrasonic testing is a well-known technique which has been used regularly due to its flexibility, inspection capability, minimal part preparation, fast inspection speed and relative cost-effectiveness (Karasawa *et.al.,* 2000; Kundu, 2003; Victor & Adrian, 2005; Xuan & Piervincenzo, 2011; Sina, 2011; Lynnworth, 2013; Pavel, 2014; Wissam *et.al.,* 2015).

Ultrasonic NDT has been used in industrial applications for over than 80 years. The laws of physics that govern the propagation of high frequency sound waves through solid materials have been used to detect surface and subsurface discontinuities (Chung, 1984; Bernard, 2006), thickness measurements (Thompson & Chimenti, 1993; Kenneth *et.al.,* 1997) and material characterizations (Farley & Saunders, 1975; Daponte *et.al.,* 1995; Dodd *et.al.,* 2001; Rojek *et.al.,* 2007; Shiuh & Sheng, 2014). For material characterization, ultrasonic testing is a versatile tool for investigating the changes in structure, deformation process, mechanical properties of materials and controlling the material behaviour based on the physical mechanism to predict the future performance of the materials (Dharmendra & Shri, 2010; Diamanti & Soutis, 2010). These possibilities owing to the fact that ultrasonic waves are closely related to the elastic and inelastic properties of the materials. The increased application of this technique is due to the availability of different frequency ranges and many modes of vibration provided by the ultrasonic waves (Rajendran, 2000).

The ultrasonic velocities, elastic properties and attenuation are the important parameters, which are required for the ultrasonic NDT of material characterization. The velocities of ultrasonic waves in glasses as well as the elastic properties are practically very useful for describing the glasses as a function of composition since they give information about the microstructure and all the dynamics of glass (Tariq *et.al.,* 2012; Karabutov & Podymova, 2013). Sound travels through the material at velocity characteristic of that material and the type of wave being propagated. On the basis of mode of propagation, there are four types of ultrasonic velocities which are longitudinal, shear, Rayleigh (surface) and Lamb (plate) wave velocity (Zhongqing *et.al.,* 2006). However, longitudinal and shear wave velocities are more important for the material characterization because they are well related to elastic moduli and density of material (Halimah *et.al.,* 2005; Dharmendra & Shri, 2010). Studying the elastic properties for selection of glasses for application in industries such as electrical, optical, electronic and other fields are immense due to their ability to gives useful information about the glass structural stability, strength, rigidity and they are directly related to the interatomic forces and potentials (El-Mallawany *et.al.,* 1994; El-Mallawany *et.al.,* 2006; Thirumaran & Earnest, 2014).

Several elastic studies have been reported for the binary and ternary tellurite glasses such as TeO_2–ZnO (Lambson *et.al.,* 1984), TeO_2–V_2O_5–Bi_2O_3 (Rajendran *et.al.,* 2003), TeO_2–WO_3–PbO (Hesham *et.al.,* 2007), TeO_2–WO_3 (Begum & Rajendran, 2007), TeO_2–La_2O_3 (El-Mallawany *et.al.,* 2010), TeO_2–Nb_2O_5 (Gaafar *et.al.,* 2011). From these previous studies, it has been observed that all the elastic moduli variations are similar in trend with the velocity variations along with the composition. The increasing trend of the elastic moduli and velocities were attributed to the increased connectivity of the network structure thus, the glass network rigidity (Sidkey *et.al.,* 2008). Attenuation of ultrasonic waves in a material is mainly due to the absorption and scattering phenomena. The absorption converts sound energy into heat via viscosity, relaxation and heat conduction while the scattering converts the energy of the coherent, collimated beam into incoherent and divergent waves (Viktorov, 1967; Kazys *et.al.,* 2008). Previous studies on ultrasonic testing on tellurite based glasses network have been reported (Rajendran *et.al.,* 2003; Sidkey & Gaafar, 2004; El-Mallawany *et.al.,* 2006; Nadia *et.al.,* 2009; Mohamed *et.al.,* 2010).

In this research, the physical, morphology, thermal, structural, and mechanical properties of silicate lithium niobate tellurite glasses with different vanadium oxide concentrations will lead to the discovery of new glass network systems where it can be used for various applications in industries. Addition of transition metal oxides has been suggested to increase the glass network rigidity through the formation of bridging oxygen and permits the possibility for the glasses to exhibit semiconducting behaviour, as reported by previous researchers (Hesham & Samier, 2003; El-Mallawany *et.al.,* 2006; Saddeek *et.al.,* 2015; Majid, 2016; Emara *et.al.,* 2017).

1.2 Problem Statement

Glasses based on tellurium dioxide (TeO_2) and modified by transition metal oxides have promising properties that are of technological interest due to their increasing applications in different fields (Raewat & Cherdsak, 2015). Many different works such as tellurite lead vanadium glasses, tellurite lithium vanadium glasses, tellurite vanadium titanium glasses, tellurite vanadium copper glasses, tellurite vanadium sodium glasses, tellurite vanadium lithium glasses, tellurite vanadium glasses and tellurite vanadium silver glasses (Vinokurov *et.al.,* 2006; Krins *et.al.,* 2006; El-Mallawany *et.al.,* 2006; Nadia *et.al.,* 2009; Umair & Yahya, 2013; Laila *et.al.,* 2014; El-Mallawany *et.al.,* 2014; Souri *et.al.,* 2016) have been carried out in the study of the physical, morphology, thermal and structural properties of different composition of tellurite and vanadium glasses. However, according to the previous study, elastic properties are among the least studied of all the physical properties of glasses where this is a topic that is completely omitted in most standard glass science studies and it has been given only limited attention in the scientific literature (Mauro *et.al.,* 2014). Therefore, in this research, a deeper understanding of the elastic properties of the tellurite based glass systems will be part of the discussion.

The mechanical properties of TeO_2–V_2O_5 glasses depends on the percentage of vanadium oxide concentration. According to previous studies, when the vanadium oxide (V_2O_5) concentration is below 20 mol% in the tellurite glass structure, the three-dimensional tellurite network is partially broken by the formation of TeO_3 trigonal pyramids which in turn reduce the glass elastic properties and rigidity. Meanwhile, it is observed that the glass structure changes from the continuous tellurite network to the continuous vanadate network when the vanadium concentration is above 20 mol% in tellurite based glass system (El-Mallawany *et.al.,* 1998; Nadia *et.al.,* 2009).

The existence of transition metal oxide Nb_2O_5 and V_2O_5 in the same group in the periodic table of elements are expected to exhibit a similar trend in glass mechanical properties. However, the addition of second transition metal oxide in the glass system was suggested to increase the rigidity of the glasses through the formation of bridging oxygen as reported in previous ultrasonic studies (Umair & Yahya, 2013). This is confirmed by the addition of Nb_2O_5 in tellurite vanadium glasses from 5 to 20 mol% which results in an increasing trend of glass elastic properties (Gaafar & Azzam, 2014). Hence, in this study, the concentration of 15 mol% Nb_2O_5 is chosen due to the expected increase in glass mechanical properties.

The addition of alkaline earth modifiers to TeO_2 network causes a change of the Te coordination polyhedron from TeO_4 trigonal bipyramid (tbp) to TeO_3 trigonal pyramid (tp) (Laila *et.al.,* 2014). Based on the previous study, the addition of alkaline Li_2O leads to significant modifications in the tellurite vanadium glass structure (Krins *et.al.,* 2006; Laila *et.al.,* 2014). This is proven by current study on $35V_2O_5$–$(65\text{-}x)TeO_2$–xLi_2O, (x = 10, 20, 30, 40, 50 mol%) where the ternary glass network shows an increase in elastic properties with the increase of Li_2O content. In this research, the concentration of 15 mol% of Li_2O is chosen where it is expected to modify and improve the glass mechanical properties.

Previous works have demonstrated that composition and type of oxide material significantly contribute to stiffness, rigidity and elastic properties of the glasses. As stated by the previous study on (80-x)TeO_2–20WO_3–(x)PbO glass system, as the PbO content increases from 10 - 20 mol% in tellurite glass network, the elastic properties are found to increase. Therefore, in this study, the increasing trend of glass mechanical properties are predicted due to the same group of PbO and SiO_2 in the periodic table of elements. Silicon dioxide was reported to act as either a network former or network modifier when incorporated into tellurite glass systems. In addition, SiO_2 is also known as a good glass former with an excellent rigidity characteristic (Raewat & Cherdsak, 2015). Therefore, the addition of SiO_2 into the glass system is expected to improve the glass elastic properties where in this study, the addition of 5 mol% of SiO_2 are anticipated to increase the glass compactness, stiffness and rigidity.

Various element addition into tellurite glasses which is silica, lithium, niobium and vanadium are expected to modify the properties of tellurite based glasses. This research is focused on the effect of vanadium oxide in tellurite glass system by varying the vanadium concentration from 0 - 6 mol% where it is expected to improve the physical, structural and mechanical properties of glass network. These glasses have potential applications in the fields of electronics, nuclear and solar energy technologies and acoustic-optic devices.

1.3 Objectives

In this research, a stable with wide formation ranges of tellurite glasses are prepared to full fill the objectives which are:

i. To prepare the tellurite based glasses in the form of $(65.0\text{-}x)TeO_2–14.9Li_2O–15.0Nb_2O_5–5.0SiO_2–(x)V_2O_5$ with $0 \leq x \leq 6.0$ mol%, which prepared using conventional melt quenching technique.

ii. To determine the physical, structural and elastic properties of silicate lithium niobate vanadium tellurite glass system.

iii. To determine the effect of vanadium oxide on the physical, structural and elastic properties of the tellurite based glass system.

1.4 Scope of Study

Tellurite based glasses have been attracted as gain media because of their variety of promising properties but unfortunately, there is some difficulty such as low tensile strength of tellurite glasses that have so far been hindering the tellurite glass devices for practical applications. It is stated that the difficulty could be overcome by adding heavy metal oxides to the glass matrix which results in better thermal stability and tensile strength. The existence of a heavy metal element of Nb_2O_5 in tellurite glass is found to exhibit a remarkable physical property which reported to improve the chemical durability of the tellurite glass network. In addition, the superlative performance of $TeO_2–Li_2O–Nb_2O_5$ glass system could enhance the thermal stability to improve the resistance for crystallization. Previous studies proved that the addition of transition metal oxide is capable to modify the basic TeO_4 (tbp) of the tellurite host matrix and facilitate better glass formation. In this study, the glass composition of $(65.0\text{-}x)TeO_2–14.9Li_2O–15.0Nb_2O_5–5.0SiO_2–(x)V_2O_5$ with $0 \leq x \leq 6.0$ mol% are chosen due to the optimal performance of tellurite based glasses with transition metal compositions.

The bonding and structural behaviour of the prepared glass sample is demonstrated using X-Ray Diffraction (XRD), Energy Dispersive X-Ray Spectroscopy (EDX), Fourier Transform Infrared Spectroscopy (FTIR) and Raman Spectroscopy meanwhile, the mechanical properties of the glass network are determined using the Vickers Hardness and ultrasonic measurements of pulse echo technique. In the case of ultrasonic testing, the mechanical properties include the glass velocities (longitudinal and shear), elastic moduli (longitudinal modulus, shear modulus, bulk modulus, Young's modulus), fractal bond connectivity, Poisson's ratio, cross-link density, Debye temperature, softening temperature, microhardness, acoustic impedance, attenuation coefficient and internal friction.

In the current study, special attention is given to transition metal oxides, vanadium oxide which is also known as a network former and also a network modifier. The employment of silicate lithium niobate vanadium tellurite glasses is also known as quinary tellurite glasses. These element combinations were expected to increase the glass stability, compactness, rigidity, thermal stability and elastic properties. Therefore, the effect of vanadium oxide on the physical, structural and elastic properties of prepared tellurite based glass system are investigated in this study.

1.5 Significance of Study

The study on glass materials is important due to the increasing demands from various applications in industries. The measurement of elastic properties of glasses yields valuable information regarding the forces operating between the atoms or ions in a solid. Studies of the glassy materials elastic properties give information about the structure of the amorphous materials since the elastic moduli are directly related to the interatomic forces and potentials. Moreover, the acoustical parameters are very informative about the microstructure and also the behaviour of the glass network former and modifiers.

Nowadays, the acoustic properties of glass are becoming more technologically important as glass becomes a candidate material for use in many automotive and architectural applications and electronic devices. In recent years, the elastic properties of glass network are quite significant because of their applications in certain devices such as delay lines, light modulators and solid-state sensors. The different mechanical properties in every compound such as tensile strength hardness, fracture toughness at different composition, direction, and temperature can be determined by the measurement of ultrasonic velocity which is useful for quality control and assurance in material producing industries.

Despite the recent flow of technology in the glass field, there is still much opportunity for new breakthroughs in the fundamental understanding of chemically strengthened glass and the development of new types of glassy materials with enhanced mechanical properties. To be suitable for a particular application, a glass must meet stringent requirements for all the properties of interest, which include characteristic of the glass properties such as resistance to brittle failure. To achieve the desired requirements, the material optimization involves a careful balancing of the chemical composition of the glasses and therefore, it is highly beneficial to take advantage of fundamental understanding of glass structural property relationships when designing a new glass composition. However, the combination of multiple networks forming oxides with a mixture of network modifiers can be a challenging endeavour for many industrial glass composition networks. The structural role of each network former and modifier depends on both the chemical composition of the glass and its thermal history.

Since the elastic properties describe the mechanical behaviour of the materials, the study of these properties is of fundamental importance in interpreting and understanding the nature of bonding in the solid-state. In addition, the elastic properties are suitable for describing the compactness of the glass structure. In the present work, efforts are made to study the effects of different concentration of vanadium oxide on physical and structural properties of the silicate lithium niobate tellurite glasses with the exposure to morphology, thermal and elastic studies where this can be seen as an alternative to produce glass materials with high modified ultrasonic properties which useful for applications in industries.

1.6 Thesis Outline

This thesis describes the preparation and characterization of silicate lithium niobate tellurite glasses doped with vanadium oxide prepared by melt quenching technique. This thesis has been divided into five main chapters. Chapter 1 is the introduction where the research studies reviewed. In addition, it will also describe the problem statement, objectives, scope of study and significance of the research as well as the thesis outline. Chapter 2 will describe some theories related to glass such as glass formation, general glass structure as well as the structure of tellurite glass. Theory on physical (glass density, molar volume and ionic packing density), morphology (XRD, EDX and AFM), thermal (DTA), structural (FTIR and Raman spectroscopy), mechanical (Vickers Hardness) and ultrasonic elastic properties will be elucidated in details in this chapter. Chapter 3 will focus on glass preparation, research methodology and experimental techniques. In Chapter 4, all the experimental results and discussion will be given in detail. Special attention will be given on the effect of vanadium oxide on physical, thermal, structural and mechanical properties of tellurite glass as well as its ultrasonic elastic properties. Finally, Chapter 5 will present the major conclusions that can be derived from the discussion and the future outlook.

REFERENCES

Abd El-Aal N.S. (2001). Elastic Properties of γ-Radiated Borate Glasses Using Pulse Echo Technique. *Egyptian Journal of Solids 24(2)*: 181-192.

Abd El-Moneim A. (2002). DTA and IR Absorption Spectra of Vanadium Tellurite Glasses. *Materials Chemistry and Physics 73(2-3)*: 318-322.

Abd El-Moneim A. (2011). Tellurite Glasses Containing Silver and Vanadium Oxides: Correlations Between Room Temperature Ultrasonic Attenuation and Structural Properties. *Physics and Chemistry of Glasses: European Journal of Glass Science and Technology Part B 52(5)*: 200-206.

Abd El-Moneim A., Mohammed D.A., El-Namrouty A., Badawi M.H., El-Metwally E.G. (2011). Tellurite Glasses Containing Silver and Vanadium Oxides: Quantitative Analysis of Elastic Moduli. *Physics and Chemistry of Glasses-European Journal of Glass Science and Technology Part B 52(5)*: 193-199.

Abdel-Baki M. & El-Diasty F. (2011). Role of Oxygen on the Optical Properties of Borate Glass Doped with ZnO. *Journal of Solid State Chemistry 184(10)*: 2762-2769.

Abdelsalam Mohammed (2011). *Theoretical Studies of Raman Scattering*. Royal Institute of Technology Stockholm: PhD Thesis.

Abd-Shukor R. (2002). Acoustic Debye Temperature and the Role of Phonons in Cuprates and Related Superconductors. *Superconductor Science and Technology 15*: 435-438.

Agrawal D.H., Pathan A.M., Bhatt P.M., Dave B.V., Bora N.V. (2011). A Portable Experimental Set-up for AFM to Work at Cryogenic Temperature. *National Conference on Recent Trends in Engineering & Technology*: 1-4.

Agus S.B., Rosli H., Md Rahim S. (2002). Study of Fractal Bond Connectivity of Neodymium Phosphate Glasses by Ultrasonic Technique. *Journal of Technology 37*: 11-20.

Ahmed M.E., Mohamed A.F., Khaled A.A., Mohamed M.E. (2016). Ultrasonic Study on Complex Glass System Doped with Erbium Oxide. *Journal of Materials Research 31(4)*: 495-505.

Ahmmad K.S., Samee M.A., Edukondalu A., Rahman S. (2012). Physical and Optical Properties of Zinc Arsenic Tellurite Glasses. *Results in Physics 2*: 175-181.

Ake K. (1999). Materials Science Applications of X-Ray Diffraction. *Encyclopedia of Spectroscopy and Spectrometry*: 1248-1257.

Aksan M.A., Yakinci M.E., Balci Y. (2000). Synthesis and Characterization of Glass-Ceramic $Bi_{2-x}Ga_xSr_2Ca_2Cu_3O_{10+y}$ Superconductors. *Superconductor Science and Technology 13(7)*: 955.

Alazoumi S.H., Sidek H.A.A., Halimah M.K., Matori K.A., Zaid M.H.M., Abdulbaset A.A. (2017). Synthesis and Elastic Properties of Ternary ZnO–PbO–TeO_2 Glasses. *Chalcogenide Letters 14(8)*: 303-320.

Almeida R.M. & Santos L.F. (2015). Raman Spectroscopy of Glasses. In Affatigato, M. (Ed). *Modern Glass Characterization*. (pp. 74-106). New Jersey: John Wiley & Sons, Inc.

Alvar C.E. (2012). *Market Analysis for a Long Range Ultrasonic Inspection Program of the Enterprise Areva*. Ansbach University of Applied Science: Master Thesis.

Amin A.E.M. (2014). Correlation Between Acoustical and Compositional Properties of Binary and Multi-Component Oxide Glasses. *International Journal of Chemistry and Material Science 2(1)*: 10-17.

Amin A.E.M. (2018). Theoretical Analysis for Ultrasonic Properties of Vanadate Glasses Over a Wide Range of Composition. *Journal of Non-Crystalline Solids 498*: 134-144.

Anand P.S., Anita P., Bhatti S.S. (1990). Ultrasonic Absorption and Velocity Measurement in Barium Borate Glasses and Their Elastic Properties. *Indian Journal of Pure and Applied Physics 28(8)*: 483-485.

Anderson A.R. & Rusell G.J. (1996). *Measuring Internal Friction at Sonic and Ultrasonic Frequencies in High Temperature Superconductors*. Conference: 20 Condensed Matter Physics Meeting. 31 December 1996. Australia: ETDE Web.

Anderson O.L. & Bömmel H.E. (1955). Ultrasonic Absorption in Fused Silica at Low Temperatures and High Frequencies. *Journal of the American Ceramic Society 38(4)*: 125-131.

Anderson O.L. & Mason W.P. (1965). *Physical Acoustics Vol 3 (Part B)*. New York and London: Academic Press.

Andrei A.B., Elena G.U., Hassan Y.A. (2015). X-Ray Diffraction: Instrumentation and Applications. *Critical Reviews in Analytical Chemistry 45(4)*: 289-299.

Arun K.K.V., Revathy K.P., Prathibha V., Sunil T., Biju P.R., Unnikrishnan N.V. (2013). Structural and Luminescence Enhancement Properties of Eu^{3+}/Ag Nanocrystallites Doped SiO_2–TiO_2 Matrices. *Journal Of Rare Earths 31(5)*: 441-448.

Ashish C. & Priyanka C. (2014). Powder XRD Technique and Its Applications in Science and Technology. *Journal of Analytical & Bioanalytical Techniques 5*: 1001212.

Ashraf I.M., Farouq M., Ahmad F., El Okr M.M., Abde-Aziz M.M., Yousef E. (2019). Raman Spectra, Physical Parameters and Microhardness of Glasses with Composition: TeO_2–V_2O_5–Li_2O. *Digest Journal of Nanomaterials and Biostructures 14(3)*: 805-815.

Awang A. (2014). *Structural and Optical Properties of Erbium Doped Zinc Sodium Tellurite Glass: Effects of Gold Nanoparticles*. Universiti Teknologi Malaysia: PhD Thesis.

Awang A., Ghoshal S.K., Sahar M.R., Dousti M.R., Amjad R.J., Nawaz F. (2013). Enhanced Spectroscopic Properties and Judd–Ofelt Parameters of Er Doped Tellurite Glass: Effect of Gold Nanoparticles. *Current Applied Physics 13(8)*: 1813-1818.

Azianty S. & Yahya A.K. (2013). Enhancement of Elastic Properties by WO_3 Partial Replacement of TeO_2 in Ternary $(80–x)TeO_2–20PbO–xWO_3$ Glass System. *Journal of Non-Crystalline Solids 378*: 234-240.

Azianty S., Yahya A.K., Halimah M.K. (2012). Effects of Fe_2O_3 Replacement of ZnO on Elastic and Structural Properties of $80TeO_2–(20−x)ZnO–xFe_2O_3$ Tellurite Glass System. *Journal of Non-Crystalline Solids 358(12-13)*: 1562-1568.

Azman K. (2010). *Neodymium/Erbium Codoped Tellurite Glass System*. Universiti Teknologi Malaysia: PhD Thesis

Babita T., Anupam D., Kothiy G.P., Pandey M., Deb S.K. (2007). Preparation and Characterization of Phosphate Glasses Containing Titanium. *Barc Newsletter 285*: 167-173.

Baia L., Bolboaca M., Kiefer W., Yousef E.S., Russel C., Breithbarth F.W., Mayerhofer T.G., Popp J. (2004). Spectroscopic Studies on the Structure of Vanadium Tellurite Glasses. *Physics and Chemistry of Glasses 45(3)*: 178-182.

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. *Journal of Non-Crystalline Solids 357(15)*: 2810-2815.

Baki S.O., Tan L.S., Kan C.S., Kamari H.M., Noor A.S.M., Mahdi M.A. (2014). Spectroscopic Studies of Er^{3+}-Yb^{3+} Codoped Multicomposition Tellurite Oxide Glass. *Sains Malaysiana 43(6)*: 843-850.

Balachandran U.G.E.N. & Eror N.G. (1982). Raman Spectra of Titanium Dioxide. *Journal of Solid State Chemistry 42(3)*: 276-282.

Balthazar J.M., Tusset A.M., Thomas S.S.L., Bueno A.M. (2012). Microcantilever Chaotic Motion Suppression in Tapping Mode Atomic Force Microscope. *Journal of Mechanical Engineering Science 227(8)*: 1730-1741.

Balu L., Amaravel R., Ezhil Pavai R. (2016). Effect of ZnO on Physical, Structural and Mechanical Properties of B_2O_3–Na_2O–ZnO Glasses. *IOSR Journal of Applied Physics (IOSR-JAP) 8(6)*: 140-146.

Bao Y.W., Wang W., Zhou Y.C. (2004). Investigation of the Relationship Between Elastic Modulus and Hardness Based on Depth Sensing Indentation Measurements. *Acta Materialia 52*: 5397-5404.

Barady G.W. (1957). Structure of Tellurium Oxide Glass. *The Journal of Chemical Physics 27(1)*: 300-303.

Bauer G., Güther V., Hess H., Otto A., Roidl O., Roller H., Sattelberger S. (2000). Vanadium and Vanadium Compounds. *Ullmann's Encyclopedia of Industrial Chemistry 38*: 49-69.

Begum A.N. & Rajendran V. (2007). Structure Investigation of TeO_2–BaO Glass Employing Ultrasonic Study. *Materials Letters 61*: 2143-2146.

Berke M. & Hoppenkamps U. (1990). *Nondestructive Material Testing with Ultrasonics*. 3rd ed. Krautkrämer Training System Level 1.

Bernard C., Chaussedent S., Monteil A., Montagna M., Zampedri L., Ferrari M. (2003). Simulation by Molecular Dynamics of Erbium-Activated Silica-Titania Glasses. *Journal of Sol-Gel Science and Technology 26(1-3)*: 925-929.

Bernard M. (2006). Ultrasonic Surface Crack Characterization Using Rayleigh Waves. Swiss Federal Institute of Technology Zurich: PhD Thesis.

Bindal V.N. (2000). Water-Based Couplants for General Purpose Use for Ultrasonic NDT Applications. *Journal of Scientific & Industrial Research 59*: 935-939.

Binnig G., Quate C.F., Gerber C. (1986). Atomic Force Microscope. *Physical Review Letters 56(9)*: 930-934.

Birks A.S., Green R.E., Mclntire P. (1991). *The Nondestructive Testing Handbook: Ultrasonic Testing (Vol. 7*). 2nd ed. American Society for Nondestructive Testing.

Blitz J. & Simpson G. (1995). *Ultrasonic Methods of Non-Destructive Testing (Vol.2)*. Springer Science & Business Media.

Bob Kyeyune (2017). *Atomic Force Microscopy*. Lappeenranta University of Technology, Finland: Master Thesis.

Bochentyn B., Warych A., Szreder N., Mielewczyk-Gryn A., Karczewski J., Przesniak-Welenc M. (2016). Characterization of Structural, Thermal and Mechanical Properties of Bismuth Silicate Glasses. *Journal of Non-Crystalline Solids 439*: 51-56.

Bogue R. & Sladek R.J. (1991). Ultrasonic Attenuation and Internal Friction in (AgI)*x* $(AgPO_3)$1-*x* Superionic Glasses. *Physical Review B 43(5)*: 4408-4414.

Bridge B. & Higazy A.A. (1986). Acoustic and Optical Debye Temperatures of the Vitreous System $CoO–CO_2O_3–P_2O$. *Journal of Materials Science 21*: 2385-2390.

Bridge B., Patel N.D., Waters D.N. (1983). On the Elastic Constants and Structure of The Pure Inorganic Oxide Glasses. *Physica Status Solidi (A) 77(2)*: 655-668.

Brigante M. & Sumbatyan M.A. (2013). Acoustic Methods for the Nondestructive Testing of Concrete: A Review of Foreign Publications in the Experimental Field. *Russian Journal of Nondestructive Testing 49(2)*: 100-111.

Carini G., Cutroni M., Federico M., Galli G., Tripodo G. (1984). Acoustic Properties and Diffusion in Superionic Glasses. *Physical Review B 30(12)*: 7219.

Chander S. & Dhaka M.S. (2015). Optimization of Physical Properties of Vacuum Evaporated CdTe Thin Films with the Application of Thermal Treatment for Solar Cells. *Materials Science in Semiconductor Processing 40*: 708-712.

Chao W.C., Paul W.W., Hwa L.G. (2008). Pressure Dependence of Elastic Properties of Low-Silica Calcium Alumino - Silicate Glasses. *Journal of Non-Crystalline Solids 354*: 1389-1392.

Charles A.H. (2001). *Handbook of Ceramics Glasses and Diamonds*.1st ed. Maryland: McGraw-Hill Professional.

Charles K. (1996). *Introduction to Solid State Physics*.7th ed. Canada: John & Wiley Sons, Inc.

Chee S.L., Khamirul A.M., Sidek H.A.A., Halimah M.K., Ismayadi I., Mohd Hafiz M.Z. (2017). Comprehensive Study on Elastic Moduli Prediction and Correlation of Glass and Glass Ceramic Derived from Waste Rice Husk. *Advances in Materials Science and Engineering*: 1-10.

Cheeke J.D.N. (2012). *Fundamentals and Applications of Ultrasonic Waves*. 2nd ed. Boca Raton, Florida: CRC Press.

Chen D.D., Liu Y.H., Zhang Q.Y., Deng Z.D., Jiang Z.H. (2005). Thermal Stability and Spectroscopic Properties of Er^{3+} -Doped Niobium Tellurite Glasses for Broadband Amplifiers. *Materials Chemistry and Physics 90*: 78-82.

Chen L., Lv P., Duan B.H., Zhang D.F., Wang T.S. (2017). Composition Dependence of Mechanical Property Changes in Electron Irradiated Borosilicate Glasses. *Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atom 405:* 61-66.

Chinna B.J. & Chandra M.V. (2009). Spectroscopic and DC Conductivity Studies of Cu^{2+} Spin Probe in $10Li_2O$-$x$$Nb_2O_5$-(89-$x$)$TeO_2$ Glass System. *Indian Journal of Pure & Applied Physics 47*: 241-247.

Chopra N., Mansingh A., Mathur P. (1992). Electron Paramagnetic Resonance and Microhardness of Binary Vanadium Tellurite Glasses. *Journal of Non-Crystalline Solids 146*: 261-266.

Chowdari B.V.R. & Gopalakrishnan R. (1988). Investigations of AgX: Ag_2O: MoO_3: P_2O_5 Glassy System (X= I, Br, Cl). *Journal of Non-Crystalline Solids 105(3)*: 269-274.

Christoph S., Dusan L., Leonard L. (2012). Differential Scanning Calorimetry and Differential Thermal Analysis. *Characterization of Materials*: 483-495.

Christopher G.D., John R.B., Whitehead J.P. (1992). A Simple Method of Determining Debye Temperatures. *American Journal of Physics 60*: 422-425.

Chung S.M. (1984). *The Interactions of Ultrasonic Rayleigh Waves with Surface Discontinuities in Steel*. Iowa State University: PhD Thesis.

Coates J. (2006). Interpretation of Infrared Spectra: A Practical Approach. *Encyclopedia of Analytical Chemistry: Applications, Theory and Instrumentation*: 1-23.

Daniel J., Nidal H., Richard B.W. (2009). Basic Principles of Atomic Force Microscopy In: *Atomic Force Microscopy in Process Engineering*: Elsevier Ltd. 1-30.

Daponte P., Maceri F., Olivito R.S. (1995). Ultrasonic Signal-Processing Techniques for the Measurement of Damage Growth in Structural Materials. *IEEE Transactions on Instrumentation and Measurement 44(6)*: 1003-1008.

Datta S.K. (1978). Scattering of Elastic Wave In: Nemat N.S. *Mechanics Today* (*Vol 4*). Pergamon Press. 149-208.

David N.A. (1991). *The Nondestructive Testing of Plates Using Ultrasonic Lamb Waves.* University of London: PhD Thesis.

Dehong H., Zi J.C., Yilun S., John H., Yan Z. (2016). Diamond Micro-Milling of Lithium Niobate for Sensing Applications. *Journal of Micromechanics and Microengineering 26(9)*: 1-10.

Denry I.L. & Holloway J.A. (2004). Elastic Constants, Vickers Hardness and Fracture Toughness of Fluorrichterite Based Glass Ceramics. *Dental Materials 20*: 213-219.

Derek A.L. (2002). *The Raman Effect: A Unified Treatment of the Theory of Raman Scattering by Molecules*. England: John Wiley & Sons Ltd.

Desirena H., Schulzgen A., Sabet S., Ramos-Ortiz G., Rosa E.D.L., Peyghambarian N. (2009). Effect of Alkali Metal Oxides R_2O (R=Li, Na, K Rb and Cs) and Network Intermediate MO (M=Zn, Mg, Ba and Pb) in Tellurite Glasses. *Optical Materials 31*: 784-789.

Dharmendra K.P. & Shri P. (2010). Ultrasonics: A Technique of Material Characterization In: Don W.D. *Acoustic Waves*. Croatia: Sciyo Publication. 397-430.

Diamanti K. & Soutis C. (2010). Structural Health Monitoring Techniques for Aircraft Composite Structures. *Progress in Aerospace Sciences 46(8)*: 342-352.

Dodd S.P., Saunders G.A., Cankurtaran M., James B. (2001). Ultrasonic Study of the Elastic and Nonlinear Acoustic Properties of Ceramic Aluminum Nitride. *Journal of Materials Science 36*: 723-729.

Doremus R.H. (1973). *Glass Science*. New York: John Wiley & Sons, Inc..

Dousti M.R., Sahar M.R., Ghoshal S.K., Amjad R.J., Samavati A.R. (2013). Effect of AgCl on Spectroscopic Properties of Erbium Doped Zinc Tellurite Glass. *Journal of Molecular Structure 1035*: 6-12.

Doweidar H. & Saddeek Y.B. (2009). FTIR and Ultrasonic Investigations on Modified Bismuth Borate Glasses. *Journal of Non-Crystalline Solids 355(6)*: 348-354.

Drury J.C. (1984). *Ultrasonic Flaw Detection for Technician*. 4th ed. Rawlings Rd, Llandybïe, Ammanford UK: Salesbury Press.

Duffy J.A. & Ingram M.D. (1975). Optical Basicity-IV: Influence of Electronegativity on the Lewis Basicity and Solvent Properties of Molten Oxyanion Salts and Glasses. *Journal of Inorganic and Nuclear Chemistry37(5)*: 1203-1206.

Dun Yi., Shi X.H., Xu Z.S. (2008). Ultrasonic Nondestructive Evaluation on Bond Quality of SRM Interface Based on Second Harmonic Technique. *Journal of Solid Rocket Technology 31(2)*: 198-200.

Ediguer E.F., Marco A.B.A., Ricardo T.H., Julio C.A., Flavio B. (2006). Acoustic Transmission with Mode Conversion Phenomenon. *ABCM Symposium Series in Mechatronics 2*: 113-120.

Eevon C., Halimah M.K., Azmi Z., Azurahanim C. (2016). Elastic Properties of TeO_2–B_2O_3–ZnO–Gd_2O_3 Glasses Using Non-Destructive Ultrasonic Technique. *Chalcogenide Letters, 13(6)*: 281-289.

El Latif L.A. (2005). Ultrasonic Study on the Role of Na_2O on the Structure of Na_2O–B_2O_3 and Na_2O–B_2O_3–SiO_2 Glasses. *Journal of Pure and Applied Ultrasonics, 27*: 80-91.

Elazoumi S.H., Sidek H.A.A., Rammah Y.S., El-Mallawany R., Halimah M.K, Matori K.A., Zaid M.H.M. (2018). Effect of PbO on Optical Properties of Tellurite Glass. *Results in Physics 8*: 16-25.

El-Damrawi G., Doweidar H., Kamal H. (2014). Characterization of New Categories of Bioactive Based Tellurite and Silicate Glasses. *Silicon 9(4)*: 503-509.

Elgazery M., Ali A.A., El-Mallawany R. (2019). Ultrasonic and Thermal Properties of Bismuth Borotellurite Glasses Doped with $NdCl_3$. *Egyptian Journal of Chemistry 62(4)*: 1055-1064.

El-Malak N.A. (2002). Ultrasonic Studies on Irradiated Sodium Borate Glasses. *Materials Chemistry and Physics73(2-3)*: 156-161.

El-Mallawany R.A., Saunders G.A. (1988). Elastic Properties of Binary, Ternary and Quaternary Rare Earth Tellurite Glasses. *Journal of Materials Science Letters 7*: 870-874.

El-Mallawany R., Sidkey M., Khafagy A., Afifi H. (1994). Elastic Constants of Semiconducting Tellurite Glasses. *Materials Chemistry and Physics 37*: 295-298.

El-Mallawany R., Abousehly A., El-Rahamani A.A., Yousef E. (1998). Radiation Effect on the Ultrasonic Attenuation and Internal Friction of Tellurite Glasses. *Materials Chemistry and Physics 52(2)*: 161-165.

El-Mallawany R., El-Khoshkhany N., Afifi H. (2006). Ultrasonic Studies of $(TeO_2)_{50}$–$(V_2O_5)_{50-x}(TiO_2)_x$ Glasses. *Materials Chemistry and Physics 95*: 321-327.

El-Mallawany R., Abdel-Kader A., El-Hawary M., El-Khoshkhany N. (2010). Volume and Thermal Studies for Tellurite Glasses. *Journal of Materials Science 45(4)*: 871–887.

El-Mallawany R. & Afifi H. (2013). Elastic Moduli and Crosslinking of Some Tellurite Glass Systems. *Materials Chemistry and Physics 143*: 11-14.

El-Mallawany R. (2013). Thermal Properties and Crosslinking of Binary TeO_2–Nb_2O_5 and TeO_2–WO_3 Glasses. *Journal of Non-Crystalline Solids 379*: 177-179.

El-Mallawany R., Elkhoshkhany N., Abbas R., Fraih A.J. (2014). Optical Properties of Quaternary TeO_2–ZnO–Nb_2O_5–Gd_2O_3 Glasses. *Ceramics International 40(9)*: 14477-14481.

El-Mallawany R., Gaafar M.S., Mostafa A.M.A., Marzouk S.Y. (2014). Simulation of Acoustic Properties of Some Tellurite Glasses. *Ceramics International 40*: 7389-7394.

El-Sayed Y., Al-Salami A.E., Mario H. (2012). Optical and Thermal Characteristics of Glasses Based on TeO_2. *Bulletin of Materials Science 35(6)*: 961-967.

El-Sayed Y., Elokr M.M., AbouDeif Y.M. (2016). Optical, Elastic Properties and DTA of TNZP Host Tellurite Glasses Doped with Er^{3+} Ions. *Journal of Molecular Structure 1108*: 257-262.

Emad E.M. & Richard V.N. (2011). *Glasses and Glass Ceramics for Medical Applications*. London: Springer Science & Business Media.

Emara A.M., Mansour S.F., Hassaan M.Y., El Sayed Y. (2017). Evaluation of the Elastic Properties of Monovalent Oxides Using TeO_2-Based Glasses. *Bulletin of Materials Science 40(3)*: 555-560.

Emmanuel P.P. (1999). Nondestructive Testing In: *Physical Acoustics Vol XXIII*. New Holland: Academic Press.

Enrique R.R. (2011). Fracture Toughness Determinations by Means of Indentation Fracture In: John C. *Nanocomposites with Unique Properties and Applications in Medicine and Industry.* United Kingdom: InTech Open.

Epp J. (2016). X-Ray Diffraction (XRD) Techniques for Materials Characterization In: Gerhard H., Iris A., Ralf T., Hans G.H. *Materials Characterization Using Nonderstructive Evaluation (NDE) Methods*. Woodhead Publishing. 81-124.

Eraiah B., Smitha M.G., Anavekar R.V. (2010). Elastic Properties of Lead Phosphate Glasses Doped with Samarium Trioxide. *Journal of Physics and Chemistry of Solids 71(3)*: 153-155.

Ersundu A.E., Celikbilek M., Aydin S. (2011). Characterization of B_2O_3 and/or WO_3 Containing Tellurite Glasses. *Journal of Non-Crystalline Solids 358*: 641-647.

Ezhil P.R. & Shalini P.D.P. (2017). Effect of Na_2O on Structural and Thermal Properties of Cadmium Borate Glasses. *IOSR Journal of Applied Physics (IOSR-JAP) 9(3)*: 67-70.

Ezhil P.R. & Sujeetha S. (2012). Ultrasonic and Structural Properties of SiO_2–PbO–Li_2O Glasses. *International Journal of Recent Scientific Research 3(11)*: 936-939.

Ezz Eldin M. (2003). Copper Redox Behavior, Structure and Properties of Copper Lead Borate Glasses. *Journal of Non-Crystalline Solids 317(3)*: 221-230.

Ezzaty N.A. (2010). *The Structure and Luminescence Properties of Magnesium Aluminate Borate Glass Doped with Eu and Dy ions*. Universiti Teknologi Malaysia: Master Thesis.

Fan J., Haibo C. (2008). *Advances in Heterogeneous Material Mechanics 2008: Proceedings of the Second International Conference on Heterogeneous Materials Mechanics*. Huangshan: DEStech Publications, Inc.

Fares H., Jlassi I., Elhouichet H., Férid M. (2014). Investigations of Thermal, Structural and Optical Properties of Tellurite Glass with WO_3 Adding. *Journal of Non-Crystalline Solids 396*: 1-7.

Farley J.M. & Saunders G.A. (1975). Ultrasonic Wave Velocities and Attenuation in IVb-Vb-VIb Chalcogenide Glasses: 2-300K. *Journal of Non-Crystalline Solids 18*: 417-427.

Felipe T.A., Jefferson L.F., Sidney J.L.R., Alban F., Philippe G., Rogeria R.G. (2013). Broadband NIR Emission in Novel Sol–Gel Er^{3+}- Doped SiO_2–Nb_2O_5 Glass Ceramic Planar Waveguides for Photonic Applications. *Optical Materials 35(3)*: 387-396.

Franz J.G. (2003). Advances in Atomic Force Microscopy. *Reviews of Modern Physics 75(3)*: 949-983.

Gaafar M.S. & Azzam Y.A. (2014). Acoustic Relaxation of Some Lead Niobium Tellurite Glasses. *Bulletin of Materials Science 38(1)*: 119-128.

Gaafar M.S. & Marzouk S.Y. (2007). Mechanical and Structural Studies on Sodium Borosilicate Glasses Doped with Er_2O_3 Using Ultrasonic Velocity and FTIR Spectroscopy. *Physica B: Condensed Matter 388(1-2)*: 294-302.

Gaafar M.S. (2014). Determination of Ultrasonic Velocities Theoretically for Tellurite Glasses Using Makishima and Mackenzie Model. *Journal of Engineering and Applied Sciences 1(2)*: 15-22.

Gaafar M.S., Afifi H.A., Mekawy M.M. (2009). Structural Studies of Some Phospho-Borate Glasses Using Ultrasonic Pulse–Echo Technique, DSC and IR Spectroscopy. *Physica B: Condensed Matter 404(12-13)*: 1668-1673.

Gaafar M.S., Marzouk S.Y., Zayed H.A. (2013). Structural Studies and Mechanical Properties of Some Borate Glasses Doped with Different Alkali and Cobalt Oxides. *Current Applied Physics 13*: 152-158.

Gaafar M.S., Mostafa A.M.A.., Marzouk S.Y. (2011). Structural Investigation and Simulation of Acoustic Properties of Some Tellurite Glasses Using Artificial Intelligence Technique. *Journal of Alloys and Compounds 509*: 3566–3575.

Gabriel W., Lukasz W., Sebastian P. (2007). A Method for Ultrasonic Quality Evaluation of Glass/Polyester Composites. *Archives of Materials Science and Engineering 28(12)*: 729-734.

Garbarczyk J.E., Machowski P., Wasiucionek M., Jakubowski W. (2003). Electrical Properties of AgI–Ag_2O–V_2O_5–P_2O_5 Glasses. *Solid State Ionics 157(1-4)*: 269-273.

Garrell R.L. (1989). Surface-Enhanced Raman Spectroscopy. *Analytical Chemistry, 61(6)*: 401A-411A.

George D.Q. (2006). Fracture Toughness of Ceramics by the Vickers Indentation Crack Length Method: A Critical Review. *Ceramic Engineering and Science Proceedings 27*: 1-18.

Georgiana L.P., Sinue G., John C.M., Lothar W., Yuanzheng Y., Morten M.S. (2015). Hardness of Oxynitride Glasses: Topological Origin. *The Journal of Physical Chemistry B 119*: 4109-4115.

Gerhard M., Michael Weber., Georg R., Dirk G. (2007). *Theory of Elastic Waves*. University of Potsdam., Frankfurt., Hamburg, German. Lecture Notes.

Gholizadeh S. (2016). A Review of Non-Destructive Testing Methods of Composite Materials. *Procedia Structural Integrity 1*: 50-57.

Ghosh A. & Chaudhuri B.K. (1986). DC Conductivity of V_2O_5–Bi_2O_3 Glasses. *Journal of Non-Crystalline Solids 83(1-2)*: 151-161.

Gianvito C., Ana V.G., Marta C.F. (2017). Application of Scanning Electron Microscopy–Energy Dispersive X-Ray Spectroscopy (SEM-EDS) In: *Comprehensive Analytical Chemistry Vol. 75*: Elsevier. 153-168.

Gilbert C.J., Schroeder V., Ritchie R.O. (1999). Mechanisms for Fracture and Fatigue Crack Propagation in a Bulk Metallic Glass. *Metallurgical and Materials Transactions A 30A*: 1739-1753.

Goldstein J.I., Newbury D.E., Echlin P., Joy D.C., Lyman C.E., Lifshin E., Sawyer L., Michael J.R. (2003). Scanning Electron Microscopy and X-Ray Microanalysis. (3rd ed). New York. Kluwer Academic/ Plenum Publishers.

Gowda V.V. (2015). Physical, Thermal, Infrared and Optical Properties of Nd^{3+} Doped Lithium-Lead-Germanate Glasses. *Physica B: Condensed Matter 456*: 298-305.

Grega K., Jozef M., Primoz M. (2010). Differential Thermal Analysis (DTA) and Differential Scanning Calorimetry (DSC) as a Method of Material Investigation. *RMZ-Materials and Geoenvironment 57(1)*: 127-142.

Gu X., Raghavan D., Nguyen T., VanLandingham M.R., Yebassa D. (2001). Characterization of Polyester Degradation Using Tapping Mode Atomic Force Microscopy: Exposure to Alkaline Solution at Room Temperature. *Polymer Degradation And Stability 74(1)*: 139-149.

Guanhua L., Zhentang L., Junjun F., Zuokun S., Zhenjing L. (2017). Experimental Research on the Ultrasonic Attenuation Mechanism of Coal. *Journal of Geophysics and Engineering 14(3)*: 502-512.

Gupta N., Kaur A., Khanna A., Gonzàlez F., Pesquera C., Iordanova R., Chen B. (2017). Structure-Property Correlations in TiO_2–Bi_2O_3–B_2O_3–TeO_2 Glasses. *Journal of Non-Crystalline Solids 470*: 168-177.

Halimah M.K., Daud W.M., Sidek H.A.A. (2010). Effect of AgI Addition on Elastic Properties of Quaternary Tellurite Glass Systems. *Chalcogenide Letters 7(11)*: 613-620.

Halimah M.K., Sidek H.A.A., Daud W.M., Zainul H., Talib Z.A., Zaidan A.W., Mansor H. (2005). Ultrasonic Study and Physical Properties of Borotellurite Glasses. *American Journal of Applied Sciences 2 (11)*: 1541-1546.

Halmshaw R. (1987). *Non-Destructive Testing (Metallurgy and Materials Science)*. London: Edward Arnold.

Hana V. (2011). A Powerful Tool for Material identification: Raman Spectroscopy. *International Journal of Mathematical Models and Methods in Applied Sciences 5(7)*: 1205-1212.

Hansen S.B., Berg R.W., Stenby E.H. (2000). *The Application of Raman Spectroscopy for Analysis of Multi-Component Systems*. Technical University of Denmark: PhD Thesis.

Harry C. (1999). *Hardness Testing Second Edition*. United States of America: ASM International.

Hasim N., Rohani M.S., Sahar M.R., Ghoshal S.K. (2016). Luminescence of Er^{3+}/Nd^{3+} Co-Doped Lithium Niobate Tellurite Glass. *Materials Science Forum 846*: 131-136.

Hesham A. & Samier M. (2003). Ultrasonic Velocity and Elastic Moduli of Heavy Metal Tellurite Glasses. *Materials Chemistry and Physics 80*: 517-523.

Hesham A., Samier M., Nadia A.E.A. (2007). Ultrasonic Characterization of Heavy Metal TeO_2–WO_3–PbO Glasses Below Room Temperature. *Phyisca B 390*: 65-70.

Hideo T. (2016). Introduction to X-Ray Analysis Using Diffraction Method. *Rigaku Journal 32(2)*: 35-43.

Higazy A.A., Bridge B., Hussein A., Ewaida M.A. (1989). Elastic Constants and Structure of the Vitreous System ZnO–P_2O_5. *The Journal of the Acoustical Society of America 86(4)*: 1453-1458.

Hisam R. & Yahya A.K. (2019) Elastic Moduli, Optical and Electrical Properties of Mixed Electronic-Ionic $30Li_2O$–4MoO3–(66-x)TeO_2–xV_2O_5 Tellurite Glass System. *Results in Physics 13*: 102219

Holloway D.G. (1973). *The Physical Properties of Glass*. London and Windchester: Wykeham Pub.

Hoppe U., Yousef E., Russel C., Neuefeind J., Hannon A.C. (2004). Structure of Zinc and Niobium Tellurite Glasses by Neutron and X-Ray Diffraction. *Journal of Physics: Condensed Matter 16*: 1645-1663.

Hueter T.F., Bolt R.H., Yeager E. (1955). Sonics. *Journal of the Electrochemical Society 102(9)*: 235C-235C.

Humphreys C.J. (2013). The Significance of Bragg's Law in Electron Diffraction and Microscopy and Bragg's Second Law. *Acta Crystallographica Section A: Foundations of Crystallography 69(1)*: 45-50.

Hyun G.K., Takayuki K., Ryuji S., Kazumasa M. (1995). Fiber Drawing of $LiNbO_3$ Doped Mixed Alkali Tellurite Glasses. *Journal of the Ceramic Society of Japan 103(10)*: 1073-1076.

Idris K. (2017). Hardness and Structural Properties of Yb^{3+} Doped B_2O_3–ZnO–TiO_2 Glasses. *Key Engineering Materials 744*: 387-392.

Idris K., Zheng J., Wang L., Tan L., Xue Y., Zhang Z., Peng M. (2017). Novel Compositions of Bi_2O_3–ZnO–TeO_2 Glasses: Structure and Hardness Analysis. *Journal of Non-Crystalline Solids 464*: 23-29.

Indrajit S.B., Robi P.S., Srinivasan A. (2003). Microhardness of Ternary Vanadium Pentoxide Glasses. *Materials Letters 57*: 3504-3507.

Innovatest Instrument Manual (2018). *Hardness Testers: Overview of Bench & Floor Type Machines*. Innovatest Europe BV.

Iskandar S.M., Halimah M.K., Daud W.M., Sidek H.A.A., Zaman K. (2012). Thermal Stability and Physical Properties of PbO–B_2O_3–TeO_2 Glass System. *Solid State Science and Technology 20(1-2)*: 48-55.

Ismail I.M. & Aseel K.R. (2015). Mechanical and Physical Properties of Glass Wool-Rigid Polyurethane Foam Composites. *Al-Nahrain University, College of Engineering Journal 18(1)*: 41-49.

Jagannatha T.D. & Harish G. (2015). Mechanical Properties of Carbon/Glass Fiber Reinforced Epoxy Hybrid Polymer Composites. *International Journal of Mechanical Engineering and Robotics Research 4(2)*: 131-137.

Jakevicius L., Butkus J., Vladiauskas A. (2006). Measurement of Thickness Layer and Sound Velocity in Multilayered Structure by the Use of Angular Ultrasonic Transducers. *Journal of Ultragarsas 1(58)*

Jamalaiah B.C. (2018). GeO_2 Activated Tellurite Tungstate Glass: A New Candidate for Solid State Lasers and Fiber Devices. *Journal of Non-Crystalline Solids 502*: 54-61.

Jaroslav F. & Philip B.A. (1999). Theory of Sound Attenuation in Glasses: The Role of Thermal Vibrations. *Physical Review Letters 82(7)*:1478 -1481.

Jesus J.O. & Maria D. (2012). Fourier Transform Infrared Spectroscopy for Molecular Analysis of Microbial Cells In: *Microbial Systems Biology*. Totowa, Nj: Humana Press. 187-211.

Jiang L., Zhenrong S., Xiaorong Z., Heping Z., Zhizhan X., Zugeng W., Jian L., Wenhai H., Robert S.A., Peter A.L. (2004). Optical Bistability for $ZnO–Nb_2O_5–TeO_2$ Glasses. *Optical Materials 25(4)*: 401-405.

Jlassi I., Elhouichet H., Ferid M. (2011). Thermal and Optical Properties of Tellurite Glasses Doped Erbium. *Journal of Materials Science 46(3)*: 806-812.

John K., Jacqueline A.J., Oleg N., Jay D.B. (2006). Structures and Visco-Elastic Properties of Potassium Tellurite: Glass Versus Melt. *Journal of Physics: Condensed Matter 18*: 903-914.

Jones G.O. (1956). *Glass*. New York: Wiley.

Joseph L.R. (2004). *Ultrasonic Waves in Solid Media*. United Kingdom: Cambridge University Press.

Kaky K.M., Lakshminarayana G., Baki S.O., Kityk I.V., Taufiq Yap Y.H., Mahdi M.A. (2017). Structural, Thermal and Optical Absorption Features of Heavy Metal Oxides Doped Tellurite Rich Glasses. *Results in Physics 7*: 166-174.

Kamalaker V., Upender G., Ramesh C., Chandra M.V. (2012). Raman Spectroscopy, Thermal and Optical Properties of $TeO_2–ZnO–Nb_2O_5–Nd_2O_3$ Glasses. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy 89*: 149-154.

Kannappan A.N., Thirumaran S., Palani R. (2009). Elastic and Mechanical Properties of Glass Specimen by Ultrasonic Method. *Journal of Engineering and Applied Sciences 4(1)*: 27-31.

Karabutov A.A. & Podymova N.B. (2013). Nondestructive Porosity Assessment of CFRP Composites with Spectral Analysis of Backscattered Laser-Induced Ultrasonic Pulses. *Journal of Nondestructive Evaluation 32(3)*: 315-324.

Karasawa H., Izumi M., Suzuki T., Nagai S., Tamura M., Fujimori S. (2000). Development of Under-Sodium Three-Dimensional Visual Inspection Technique Using Matrix-Arrayed Ultrasonic Transducer. *Journal of Nuclear Science and Technology 37(9)*: 769-779.

Kasala J., Masiar H., Pernis I. (2010). Investigation of Selected Thermo Physical Properties in the Co-Based Superalloy: Experiment and Application Study. *Archives of Foundry Engineering 10*: 203-206.

Kaur A., Khanna A., González F., Pesquera C., Chen B. (2016). Structural, Optical, Dielectric and Thermal Properties of Molybdenum Tellurite and Borotellurite Glasses. *Journal of Non-Crystalline Solids 444*: 1-10.

Kaur A., Khanna A., Pesquera C., González F., Sathe V. (2010). Preparation and Characterization of Lead and Zinc Tellurite Glasses. *Journal of Non-Crystalline Solids 356(18-19)*: 864-872.

Kawasaki S., Honma T., Benino Y., Fujiwara T., Sato R., Komatsu T. (2003). Writing of Crystal-Dots and Lines by YAG Laser Irradiation and Their Morphologies in Samarium Tellurite Glasses. *Journal of Non-Crystalline Solids 325(1-3)*: 61-69.

Kazys R., Tumsys O., Pagodinas D. (2008). A New Ultrasonic Technique for Detection and Location of Defects in Three-Layer Plastic Pipes with a Reinforced Internal Layer. *Journal of Ultragarsas (Ultrasound) 63(3)*.

Kenneth A.F., Gerry M.E., Karen A.S., Thomas J.N. (1997). Theory and Application of Precision Ultrasonic Thickness Gaging. *Journal of British Institute of Non-Destructive Testing 2(10).*

Khafagy A.H., El-Adawy A.A., Higazy A.A., El-Rabaie S., Eid A.S. (2008). Studies of Some Mechanical and Optical Properties of (70-x)TeO_2+ 15B_2O_3+ 15P_2O_5+ $x$$Li_2O$ Glasses. *Journal of Non-Crystalline Solids 354(27)*: 3152-3158.

Khairani H.J. & Andrew Y. (2017). X-Ray Microanalysis Using Energy Dispersive X-Ray Spectroscopy. *Technical Support Bulletin Faculty of Engineering University of Nottingham 34*.

Khalifa F. (1989). Density and Molar Volume of Some Sodium Silicate Load Borate and Lead Silicate Glasses. *Indian Journal of Pure and Applied Physics 27(6)*: 279-281.

Khan A.A. (1999). *Ultrasonic Testing of Materials at Level 2: Manual for the Syllabi Contained in IAEA-TECDOC-628, Training Guidelines in Non-Destructive Testing Techniques*. Vienna, Austria: Industrial Applications and Chemistry Section, International Atomic Energy Agency.

Khattak G.D. & Salim M.A. (2002). X-Ray Photoelectron Spectroscopic Studies of Zinc–Tellurite Glasses. *Journal of Electron Spectroscopy and Related Phenomena 123(1)*: 47-55.

Kiranpreet K.G. (2011). *Effect of Different Glass Modifiers on Structural, Optical and Mechanical Properties of Borosilicate Glasses*. Thapar University: Master Thesis.

Klaus G. & Carsten K. (2010). Fourier Transform Infrared (FTIR) Spectroscopy In: *Encyclopedia of Life Sciences (ELS)*. John Wiley & Sons, Ltd: Chichester.

Kolsky H. (1963). *Stress Waves in Solids*. United States of America: Dover Publications, Inc.

Komatsu T., Tawarayama H., Mohri H., Matusita K. (1991). Properties and Crystallization Behaviors of TeO_2–$LiNbO_3$ Glasses. *Journal of Non-Crystalline Solids 135(2-3)*: 105-113.

Kosuge T., Benino Y., Dimitrov V., Sato R., Komatsu T. (1998). Thermal Stability and Heat Capacity Changes at the Glass Transition in K_2O–WO_3–TeO_2 Glasses. *Journal of Non-Crystalline Solids 242(2-3)*: 154-164.

Krautkramer F., Krautkramer H. (1977). *Ultrasonic Testing of Materials*. 2^{nd} ed. Berlin: SpringerVerlag.

Krautkrämer J. (1983). *Ultrasonic Testing of Materials*. 3^{rd} ed. New York: Springer Verlag Berlin Heidelberg.

Krins N., Rulmont A., Grandjean J., Gilbert B., Lepot L., Cloots R., Vertruyen B. (2006). Structural and Electrical Properties of Tellurovanadate Glasses Containing Li_2O. *Solid State Ionics 177(35-36)*: 3147-3150.

Kundu T. (2003). *Ultrasonic Nondestructive Evaluation: Engineering and Biological Material Characterization*. Boca Raton: CRC Press.

Laila S., Suraya A.K., Yahya A.K. (2014). Effect of Glass Network Modification on Elastic and Structural Properties of Mixed Electronic-Ionic $35V_2O_5$–$(65\text{-}x)TeO_2$–$(x)Li_2O$ Glass System. *Chalcogenide Letters 11(2)*: 91-104.

Lakshmikantha R., Ayachit N.H., Anavekar R.V. (2014). Optical, Physical and Structural Studies of Vanadium Doped P_2O_5–BaO–Li_2O Glasses. *Journal of Physics and Chemistry of Solids 75*:168-173.

Lakshminarayana G., Hucheng Y., Jianrong Q. (2009). Photoluminescence of Pr^{3+}-, Nd^{3+}- and Ni^{2+}-Doped TeO_2–ZnO–WO_3–TiO_2–Na_2O Glasses. *Journal of Alloys and Compounds 475*: 569–576

Lambson E.F., Saunders G.A., Bridge B., El-Mallawany R.A. (1984). The Elastic Behaviour of TeO_2 Glass Under Uniaxial and Hydrostatic Pressure. *Journal of Non-Crystalline Solids 69*: 117-133.

Lawn B.R. & Marshall D.B. (1979). Hardness, Toughness and Brittleness: An Indentation Analysis. *Journal of the American Ceramic Society 62(7-8)*: 347-350.

Lezal D., Bludska J., Horak J., Sklenar A., Karamazov S., Vleck N. (2002). Raman Spectra of TeO_2–$PbCl_2$ Glasses. *Physics and Chemistry of Glasss 43(6)*: 296-299.

Lima S.M., Andrade L.H.C., Falcão E.A., Steimacher A., Astrath N.G.C., Medina A. N., Araújo E.B. (2009). Inversion in the Temperature Coefficient of the Optical Path Length Close to the Glass Transition Temperature in Tellurite Glasses. *Applied Physics Letters 94(25)*: 251903.

Lin J., Wenhai H., Zhengrong S., Chandra S.R., Delbert E.D. (2004). Structure and Non-Linear Optical Performance of TeO_2–Nb_2O_5–ZnO Glasses. *Journal of Non-Crystalline Solids 336*: 189-194.

Lodha G.S., Yamashita K., Kunieda H., Tawara Y., Yu J., Namba Y., Bennett J.M. (1998). Effect of Surface Roughness and Subsurface Damage on Grazing Incidence X-Ray Scattering and Specular Reflectance. *Applied Optics 37(22)*: 5239-5252.

Lynnworth L.C. (2013). *Ultrasonic Measurements for Process Control: Theory, Techniques, Applications*. 2^{nd} ed. San Diego: Academic Press.

Magalas L.B. (2009). Mechanical Spectroscopy, Internal Friction and Ultrasonic Attenuation: Collection of Works. *Materials Science and Engineering A521*: 405-415.

Maheshvaran K., Arunkumar S., Sudarsan V., Natarajan V., Marimuthu K. (2013). Structural and Luminescence Studies on Er^{3+}/Yb^{3+} Co-Doped Boro-Tellurite Glasses. *Journal of Alloys and Compounds 561*: 142-150.

Majid F. (2016). Structure and Optical Study of Vanadium Tellurite Glasses Containing Potassium Oxide. *Applied Research Journal 2(2)*: 50-53.

Marcos E. (2006). *A Narrowband Ultrasonic Spectroscopy Technique for the Inspection of Layered Structures*. University of Uppsala: Degree Thesis.

Marina B., Jean M.D., Thibault C., Mickael G., Daniel B., Tanguy R., Cindy L.R. (2015). Hardness and Toughness of Sodium Borosilicate Glasses Via Vicker's Indentations. *Journal of Non-Crystalline Solids 417-418*: 66-79.

Marioli D., Narduzzi C., Offelli C., Petri D., Sardini E., Taroni A. (1992). Digital Time of Flight Measurement for Ultrasonic Sensors. *IEEE Transactions on Instrumentation and Measurement 41(1)*: 93-97.

Marzouk S.Y. & Gaafar M.S. (2007). Ultrasonic Study on Some Borosilicate Glasses Doped with Different Transition Metal Oxides. *Solid State Communications 144(10-11)*: 478-483.

Matori K.A, Zaid M.H.M., Quah H.J., Sidek H.A.A., Zaidan A.W., Mohd Sabri M.G. (2015). Studying the Effect of ZnO on Physical and Elastic Properties of $(ZnO)_x(P_2O_5)_{1-x}$ Glasses Using Nondestructive Ultrasonic Method. *Advances in Materials Science and Engineering*: 1-6.

Mauro J.C., Philip C.S., Vaughn D.J., Pambianchi M.S. (2014). Glass Science in the United States: Current Status and Future Directions. *International Journal of Applied Glass Science 5(1)*: 2-15.

McLaughlin J.C., Tagg S.L., Zwanziger J.W. (2001). The Structure of Alkali Tellurite Glasses. *The Journal of Physical Chemistry B 105*: 67-75.

McLaughlin J.C., Tagg S.L., Zwanziger J.W., Haeffner D.R., Shastri S.D. (2000). The Structure of Tellurite Glass: A Combined NMR, Neutron Diffraction and X-Ray Diffraction Study. *Journal of Non-Crystalline Solids 274*: 1-8.

Mehdi J.M., Seyyed Y.M., Amir S.P. (2014). Investigating the Acoustical Properties of Carbon Fiber, Glass Fiber and Hemp Fiber Reinforced Polyester Composites. *Polymer Composites 35(11)*: 1-9.

Michael D.G. (1999). Attenuation of Ultrasonic Rayleigh-Lamb Waves by Small Horizontol Defects in Thin Aluminium Plates. *International Journal of Mechanical Sciences 41*: 581-594.

Mirgorodsky A.P., Merle-Méjean T., Champarnaud J.C., Thomas P., Frit B. (2000). Dynamics and Structure of TeO_2 Polymorphs: Model Treatment of Paratellurite and Tellurite: Raman Scattering Evidence for New γ-and δ-Phases. *Journal of Physics and Chemistry of Solids 61(4)*: 501-509.

Modderman T.M. & Wiebe F.P. (1994). Method of and an Apparatus for Frequency Selective Ultrasonic Inspection of Multi-Layered Structures. *U.S. Patent 5,303,590, Issued April 19, 1994*.

Mohamad M.A., El Sayed Y., El Sayed M. (2006). Dielectric Properties of the Ternary TeO_2/ Nb_2O_5/ ZnO Glasses. *Physica B: Condensed Matter 371(1)*: 74-80.

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. *Journal of Non-Crystalline Solids 356*: 1626-1630.

Mohamed S.N., Yahya A.K. (2018). Effects of V_2O_5 on Elastic, Structural and Optical Properties of Mixed Ionic-Electric 20Na_2O–20CaO–(60-x)B_2O_3–xV_2O5 Glasses. *Ionics (24)*: 2647-2664.

Montani R.A., Lorente A., Vincenzo M.A. (2000). Effect of Ag_2O on the Conductive Behaviour of Silver Vanadium Tellurite Glasses. *Solid State Ionics 130(1-2)*: 91-95.

Mori H., Matsuno H., Sakata H. (2000). Small Polaron Hopping Conduction in V_2O_5–Sb–TeO_2 Glasses. *Journal of Non-Crystalline Solids 276(1-3)*: 78-94.

Mott N.F. (1968). Conduction in Glasses Containing Transition Metal Ions. *Journal of Non-Crystalline Solids 1(1)*: 1-17.

Murugeshan R. & Sivaprasath E.K. (2012). *Properties of Matter and Acoustic*. Revised Ed. New Delhi: S. Chand & Company Ltd.

Mustofa N.A. (2014). *A Study of Guided Ultrasonic Wave Propagation Characteristics in Thin Aluminum Plate for Damage Detection*. University of Toledo: Master Thesis.

Nadia S., Abd El-Aal., Hesham A.A. (2009). Structure and Ultrasonic Properties of Vanadium Tellurite Glasses Containing Copper Oxide. *Archives of Acoustics 34(4)*: 641-654.

Nanekar P.P. & Shah B.K. (2003). Characterization of Material Properties by Ultrasonics. *BARC Newsletter 249*: 25–38.

Narayana R.C., Veeranna G.V.C., Sreekanth C.R.P. (2008). Elastic Properties and Structural Studies on Lead-Boro-Vanadate Glasses. *Journal of Non-Crystalline Solids 354(1)*: 32-40.

Narita K., Benino Y., Fujiwara T., Komatsu T. (2003). Vickers Nanoindentation Hardness and Deformation Energy of Transparent Erbium Tellurite Nanocrystallized Glasses. *Journal of Non-Crystalline Solids 316*: 407-412.

Naruo S. & Masaru T. (1997). Theory of Atomic-Force Microscopy (STM Theory). Science Reports of the Research Institutes, Tohoku University. *Ser. A, Physics, Chemistry and Metallurgy 44(1)*: 1-15.

Neelam B., Sunil D., Preeti S., Kundu R.S., Punia R., Kishore N. (2016). Physical, Structural and Optical Characterization of Silicate Modified Bismuth Borate Tellurite Glasses. *Journal of Molecular Structure*.

Neena J. & Vij D.R. (2007). Fourier Transform Infrared Spectroscopy In: *Handbook of Applied Solid State Spectroscopy*: New York. Springer Science+ Business Media. 411-450.

Newby J.R. (1985). *Metals Handbook, Volume 8: Mechanical Testing*. United States: American Society for Metals.

Nishara B.A. & Rajendran V. (2007). Structure Investigation of TeO_2–BaO Glass Employing Ultrasonic Study. *Materials Letters 61*: 2143-2146.

Noorsyam B.Y. (2008). *Optical and Thermal Properties of Samarium Oxide Doped Tellurite Glasses*. Universiti Teknologi Malaysia: Master Thesis.

Novatski A., Somer A., Goncalve A., Piazzetta R.L.S., Gunha J.V., Andrade A.V.C., Lenzi E.K., Medina A.N., Astrath N.G.C., El-Mallawany R. (2019). Thermal and Optical Properties of Lithium-Zinc-Tellurite Glasses. *Materials Chemistry and Physics 231*: 150-158.

Nurhafizah H. (2014). *Thermal, Structural and Optical Properties of Lithium Niobate Tellurite Glass Doped Erbium and Neodymium*. Universiti Teknologi Malaysia: Master Thesis.

Nurhafizah H. (2017). *Optical and Catalyst Studies of Erbium/ Neodymium Codoped Lithium Niobate Tellurite Glass Embedded With Silver Nanoparticles*. Universiti Teknologi Malaysia: PhD Thesis.

Oldrich N. (1999). *Seismic Surface Waves*. Federal University of Bahia. Lecture Notes.

Pakade S.V. & Yawale S.P. (1996). Ultrasonic Velocity and Elastic Constants Measurement in Some Borate Glasses. *Journal of Pure and Applied Ultrasonics 18*: 74-79.

Palani R. & Selvarasi J. (2017). Elastic and Structural Properties of Potassium and Calcium -Doped Borate Lithium Glasses. *International Journal of Current Research 9*: 71-79.

Palani R. & Srinivasan G. (2013). Microhardness and Electron Paramagnetic Resonance Studies of Manganese Doped Lithium Borate Glasses. *Research Journal of Physics Sciences 1(1)*: 17-20.

Palanivelu N. & Rajendran V. (2006). Dependence of Elastic Properties and Ultrasonic Velocities on the Structure of Vanadate Lead Tellurite Glasses. *Physica Status Solidi 203(10)*: 2347-2355.

Pant M., Kanchan D.K., Gondaliya N. (2009). Transport Properties and Relaxation Studies in BaO Substituted Ag_2O–V_2O_5–TeO_2 Glass System. *Materials Chemistry and Physics 115(1)*: 98-104.

Pantic M., Mitrović S., Babić M., Jevremović D., Kanjevac T., Džunić D., Adamović D. (2015). AFM Surface Roughness and Topography Analysis of Lithium Disilicate Glass Ceramic. *Tribology in Industry 37(4)*: 391-399.

Pao Y.H. (1983). Elastic Waves in Solids. *Journal of Applied Mechanics 50(4b)*: 1152-1164.

Papadakis E.P. (1976). Ultrasonic Velocity and Attenuation: Measurement Methods with Scientific and Industrial Applications In: *Physical Acoustics Vol. 12*: Academic Press. 277-374.

Pascal L. & Guillaume H. (2011). *Bone Quantitative Ultrasound*. Paris: Springer.

Pasquale P., Luigi S., Alessandro V., Antonio A., Massimo G., Esther F., Giancarlo C.R. (2011). Large Raman Gain in a Stable Nanocomposite Based on Niobiosilicate Glass. *The Journal of Physical Chemistry C 115(35)*: 17314-17319.

Paul A., Roychoudhury P., Mukherjee S., Basu C. (2000). Ultrasonic Study of $(CuO)_x(TeO_2)_{1-x}$ Glass System. *Journal of Non-Crystalline Solids 275*: 83-92.

Pavani P.G., Sadhana K., Mouli V.C. (2011). Optical, Physical and Structural Studies of Boro-Zinc Tellurite Glasses. *Physica B: Condensed Matter 406(6-7)*: 1242-1247.

Pavel M. (2014). Simulation as a Support for Ultrasonic Testing. *Journal of Modern Physics 5(13)*: 1167-1172.

Peng X., Yongjiang H., Shu G., Hongbo F., Zhiliang N., Jianfei S., Peter K.L. (2018). Understanding the Structure Poisson's Ratio Relation in Bulk Metallic Glass. *Journal of Materials Science 53*: 7891-7899.

Perkin Elmer (2000). Spectrum GX User's Guide. United Kingdom.

Plotnichenko V.G., Sokolov V.O., Koltashev V.V., Dianov E.M., Grishin I.A., Churbanov M.F. (2005). Raman Band Intensities of Tellurite Glasses. *Optics Letters 30(10)*: 1156-1158.

Preston F.W. (1942). The Mechanical Properties of Glass. *Journal of Applied Physics 13*: 623-634.

Qin Shen., Omar M., Dongri S. (2012). Ultrasonic NDE Techniques for Impact Damage Inspection on CFRP Laminates. *Journal of Materials Science Research 1(1)*: 2-16.

Rachel G., Jae W.C., Chia L.H., Ye P., Arnaud M., Rita S., Laszlo F., Demetri P. (2009). Lithium Niobate Nanowires Synthesis, Optical Properties and Manipulation. *Applied Physics Letters 95*: 1-4.

Rada S., Culea E., Rus V., Pica M., Culea M. (2008). The Local Structure of Gadolinium Vanado-Tellurite Glasses. *Journal of Materials Science 43(10)*: 3713-3716.

Rada S., Dehelean A., Culea E. (2011). FTIR, Raman and UV-Vis Spectroscopic and DFT Investigations of the Structure of Iron–Lead–Tellurate Glasses. *Journal of Molecular Modeling 17(8)*: 2103-2111.

Rada S., Rada M., Chulea E. (2010). Infrared Spectroscopic and DFT Investigations of the Vanadate-Tellurate Glasses Structures. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy 75*: 846-851.

Raewat L. & Cherdsak B. (2015). Characterization of Elastic and Structural Properties of Alkali-Borosilicate Glasses Doped with Vanadium Oxide Using Ultrsonic Technique. *Glass Physics and Chemistry 41(4)*: 352-358.

Rafiq T.J. & Ashton J.N. (1990). Non-Destructive Evaluation of GRP Using Ultrasonic Techniques. *In Proc. of the 9th International Conference on Experimental Mechanics*: 517-526.

Raghavaiah B.V. & Veeraiah N. (2004). The Role of As_2O_3 on the Stability and Some Physical Properties of PbO–Sb_2O_3 Glasses. *Journal of Physics and Chemistry of Solids 65(6)*: 1153-1164.

Rahman K.S., Haque F., Islam M.A., Alam M.M., Alothman Z.A., Amin N. (2013). Effect of Growth Techniques on the Properties of CdTe Thin Films for Photovoltaic Application. *IEEE Student Conference on Research and Developement*: 265-268.

Rajendran V. & El-Batal H.A. (1995). Behaviour of Acoustical Parameters of Mixed Alkali Silicate Glasses. *Indian Journal of Pure And Applied Physic 33*: 29-33.

Rajendran V. (1995). Acoustical Behaviour of Tetraalkylammonium Salts in Dioxane-Water Solvent Mixtures at 303.15K. *Journal of Pure and Applied Ultrasonics 17*: 65-68.

Rajendran V. (2000). Elastic Properties of the Lead Containing Bismuth Tellurite Glasses - An Ultrasonic Study. *15th World Conference on Nondestructive Testing*. 15-21 October. Roma, Italy: NDT.net. 1-7.

Rajendran V., Begum A.N., Azooz M.A., El Batal F.H. (2003). Microstructural Dependence on Relevant Physical Mechanical Properties on SiO_2–Na_2O–CaO–P_2O_5 Biological Glasses. *Biomaterials 23(21)*: 4263-4275.

Rajendran V., Palanivelu N., Modak D.K., Chaudhuri B.K. (2000). Ultrasonic Investigation on Ferroelectric $BaTiO_3$ Doped $80V_2O_5$-20PbO Oxide Glasses. *Physica Status Solidi (A) 180(2)*: 467-477.

Rajeswari R., Surendra B.S., Jayasankar C.K. (2010). Spectroscopic Characterization of Alkali Modified Zinc-Tellurite Glasses Doped with Neodymium. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy 77*: 135-140.

Rajinder K., Ramandeep K., Atul K., Fernando G. (2017). Structural and Thermal Properties of Vanadium Tellurite Glasses. *DAE Solid State Physics Symposium*: 1-4.

Rajinder K., Ramandeep K., Atul K., Fernando G. (2018). Structural and Thermal Properties of Vanadium Tellurite Glasses. *In AIP Conference Proceedings (Vol. 1942, No. 1, p. 070028)*. AIP Publishing.

Rajinder S.K. & Zakiyyu T. (2017). Comparative Study of Attenuation Properties of Some Ternary Borate Glass Systems. *Journal of Experimental & Theoretical Nanotechnology Specialized Researchers 1(3)*: 149-155.

Raouf A.E. (2002). *Tellurite Glasses Handbook: Physical Properties and Data*. 2nd ed. London. New York: CRC Press.

Raouf E.M. (1998). Tellurite Glasses Part 1. Elastic Properties. *Materials Chemistry and Physics 53*: 93-120.

Raouf E.M. (1999). Tellurite Glasses Part 2. Anelastic, Phase Separation, DebyeTemperature and Thermal Properties. *Materials Chemistry and Physics 60(2)*:103-131.

Raouf E.M., Yasser S.R., Amin E.A., Zahra W. (2017). Optical and Thermal Properties of Some Tellurite Glasses. *American Journal of Optics and Photonics 5(2)*: 11-18.

Reddy M.R., Kumar V.R., Veeraiah N., Rao A. (1995). Effect of Chromium Impurity on Dielectric Relaxation Effects of ZnF_2–PbO–TeO_2 Glasses. *Indian Journal of Pure & Applied Physics 33(1)*: 48-51.

Richard E.B. & David G.S. (2005). *The Physics of Sound*. 3rd ed. Upper Saddle River, New Jersey: Pearson Prentice Hall.

Rivera V.A.G. & Manzani D. (2017). *Technological Advances in Tellurite Glasses: Springer Series in Materials Science (Book 254)*: Springer International Publishing.

Riyatun., Lita R., Ahmad M. (2016). Physical and Optical Properties of Lead Doped Tellurite Glasses. *IOP Conference Series: Materials Science and Engineering 107*: 1-5.

Robert Long (2000). *The Improvement of Ultrasonic Apparatus for the Routine Inspection of Concrete.* Imperial College of Science, Technology and Medicine: PhD Thesis

Rodrigues A.C.M., Keding R., Rüssel C. (2000). Mixed Former Effect Between TeO_2 and SiO_2 in the Li_2O–TeO_2–SiO_2 System. *Journal of Non-Crystalline Solids 273(1-3)*: 53-58.

Roger N.S., Adrian C.W., Bilber B., Yanko B.D., Vesselin V.D., Mikhail G.A. (1998). The Structure of Vitreous V_2O_5–TeO_2. *Journal of Non-Crystalline Solids 232-234*: 38-43.

Rohn T., Charles E., Bruce B.C. (1969). *Ultrasonic Methods in Solid State Physics*. 1st ed. Academic Press.

Rojek M., Stabik J., Sokół S. (2007). Fatigue and Ultrasonic Testing of Epoxy-Glass Composites. *Journal of Achievements in Materials and Manufacturing Engineering 20(1-2)*: 183-186.

Rose J.L. & Goldberg B.B. (1979). *Basic Physics in Diagnostic Ultrasound*. New York: John Wiley & Sons.

Rosmawati S., Sidek H.A.A., Zainal A.T., Mohd Zobir H. (2008). Effect of Zinc on the Physical Properties of Tellurite Glass. *Journal of Applied Sciences 8(10)*: 1956-1961.

Rostron P., Gaber S., Gaber D. (2016). Raman Spectroscopy, Review. *International Journal of Engineering and Technical Research 6(1)*: 50-64.

Saddeek Y.B. & El Latif L.A. (2004). Effect of TeO_2 on the Elastic Moduli of Sodium Borate Glasses. *Physica B: Condensed Matter 348(1-4)*: 475-484.

Saddeek Y.B. (2005). Elastic Properties of Gd^{3+}-Doped Tellurovanadate Glasses Using Pulse-Echo Technique. *Materials Chemistry and Physics 91(1)*: 146-153.

Saddeek Y.B., El-Mallawany R., Afifi H. (2015). Mechanical Relaxation of Some Tellurovanadate Glasses. *Journal of Non-Crystalline Solids 417–418*: 28-33.

Sah R. & Dutta S.K. (2011). Kinetic Studies of Iron Ore–Coal Composite Pellet Reduction by TG–DTA. *Transactions of the Indian Institute of Metals 64*: 583–591.

Sahar M.R., Jehbu A.K., Karim M.M. (1997). TeO_2–ZnO–$ZnCl_2$ Glasses for IR Transmission. *Journal of Non-Crystalline Solids 213*: 164-167.

Sahar M.R., Sulhadi K., Rohani M.S. (2007). Spectroscopic Studies of TeO_2-ZnO-Er_2O_3 Glass System. *Journal of Materials Science 42(3)*: 824-827.

Salah H.A., Sidek A.A., El-Mallawany R., Umar S.A., Halimah M.K., Mohd Hafiz M.Z., Khamirul A.M., Abdulbaset U. (2018). Optical Properties of Zinc Lead Tellurite Glasses. *Results in Physics 9*: 1371-1376.

Samee M.A., Awasthi A.M., Shripathi T., Shashidhar B. (2011). Physical and Optical Studies in Mixed Alkali Borate Glasses with Three Types of Alkali Ions. *Journal of Alloys and Compounds 509*: 3183-3189.

Samir Y.M. (2009). Ultrasonic and Infrared Measurements of Copper -Doped Sodium Phosphate Glasses. *Materials Chemistry and Physics 114(1)*: 188-193.

Samit K.N., Arnab M., Biswanath K., Prasenjit M. (2016). *Doped Bioactive Glass Materials in Bone Generation.* United Kingdom: InTech Open.

Sangheeta N. & Ravibaskar R. (2017). Study on Physical and Elastic Properties of Lead Borate Glasses Using Ultrasonic Techniques and Thermal Analysis. *International Journal for Scientific Research & Development 5(10)*: 599-603.

Sara S.J.M. (2015). *Evaluating Ultrasonic Tomography (UT) Methods Used for the Inspection of Offshore Pipelines*. University of Stavanger: Master Thesis.

Saunders G.A., Metcalfe R.D., Cutroni M., Federico M., Piccolo A. (1996). Elastic and Anelastic Properties, Vibrational Anharmonicity and Fractal Bond Connectivity of Superionic Glasses. *The American Physical Society 53(9)*: 5287-5300.

Sayed E.Y., Amin E.A., El-KhoshKhany N. (2006). Effect of Rare Earth (Pr_2O_3, Nd_2O_3, Sm_2O_3, Eu_2O_3, Gd_2O_3 and Er_2O_3) on the Acoustic Properties of Glass Belonging to Bismuth Borate System. *Solid State Communications 139(3)*: 108-113.

Schadow F., Brackrock D., Gaal M., Heckel T. (2017). Ultrasonic Inspection and Data Analysis of Glass and Carbon Fibre Reinforced Plastics. *Procedia Structural Integrity 7*: 299-306.

Schitter G., Menold P., Knapp H.F., Allgower F., Stemmer A. (2001). High Performance Feedback for Fast Scanning Atomic Force Microscopes. *Review of Scientific Instruments 72(8)*: 3320-3327.

Schreiber E., Anderson O.L., Naohiro S. (1973). *Elastic Constants and Their Measurement*. New York: McGraw-Hill.

Scott D.W. (2013). Sample Preparation Considerations for X-Ray EDS Analysis in The Physical Sciences. *Microscopy and Microanalysis 19(S2)*: 2012-2013.

Sehgal J. & Ito S. (1999). Brittleness of Glass. *Journal of Non-Crystalline Solids 253*: 126-132 .

Seifollah N. & Shokrollah H. (2016). Modern Analytical Techniques in Failure Analysis of Aerospace, Chemical and Oil and Gas Industries In: *Handbook of Materials Failure Analysis with Case Studies from the Oil and Gas Industry*: Butterworth-Heinemann. 39-54.

Seizo M., Franz J.G., Ernst M., Roland W. (2015). *Noncontact Atomic Force Microscopy Volume 3*. Switzerland: Springer International Publishing.

Sekiya T., Mochida N., Ohtsuka A., Tonokawa M. (1992). Raman Spectra of $MO_{1/2}TeO_2$ (M = Li, Na, K, Rb, Cs and Tl) Glasses. *Journal of Non-Crystalline Solids 144*: 128-144.

Sene F.F., Martinelli J.R., Gomes L. (2004). Synthesis and Characterization of Niobium Phosphate Glasses Containing Barium and Potassium. *Journal of Non-Crystalline Solids 348*: 30-37.

Senin H.B., Sidek H.A.A., Saunders G.A. (2000). Acoustic Vibrational Properties and Fractal Bond Connectivity of Praseodymium Doped Glasses. *Australian Journal of Physics 53*: 805-820.

Senthil M.G., Takenobu S., Yasutake O. (2006). Raman Characteristics and Nonlinear Optical Properties of Tellurite and Phosphotellurite Glasses Containing Heavy Metal Oxides with Ultrabroad Raman Bands. *Journal of Applied Physics 100*: 1-6.

Serdyuk I.N., Zaccai N.R., Zaccai J. (2007). *Methods in Molecular Biophysics*. United Kingdom: Cambridge University Press.

Seshasayee M. & Muruganandam K. (1998). Molecular Dynamics Study of V_2O_5 Glass. *Solid State Communications 105(4)*: 243-246.

Shaik K.A., Samee M.A., Taqiullah S.M., Rahman S. (2016). FT-IR and Raman Spectroscopic Studies of ZnF_2–ZnO–As_2O_3–TeO_2 Glasses. *Journal of Taibah University for Science 10(3)*: 329-339.

Shams A.M.I. & Mostafa A.M.A. (2017). Effect of Bi_2O_3 in Borate Tellurite Silicate Glass System for Development of Gamma Rays Shielding Materials. *Journal of Alloys and Compounds 695*: 302-310.

Sharaf E.L.M., Al Salhi M.S., Meawad M.E. (2008). IR and UV Spectral Studies for Rare Earths -Doped Tellurite Glasses. *Journal of Alloys and Compounds 465(1-2)*: 333-339.

Sharma B.I., Pattanaik A.K., Srinivasan A. (2002). Nonisothermal Properties of V_2O_5–SnO–TeO_2 Glasses Exhibiting Majority Charge Carrier Reversal. *Physics and Chemistry of Glasses 43(1)*: 12-15.

Sharma G., Rajendran V., Thind K.S., Singh G., Singh A. (2009). Structural Investigation of Bismuth Borate Glasses Under the Influence of γ-irradiation Through Ultrasonic Studies. *Physica B: Condensed Matter 404(20)*: 3371-3378.

Shashidhar B., Syed R., Awasthi A.M., Sathe V. (2008). Role of Bi_2O_3 Content on Physical, Optical and Vibrational Studies in Bi_2O_3–ZnO–B_2O_3 Glasses. *Journal of Alloys and Compounds 460(1-2)*: 699-703.

Shelby J.E. (1997). *Introduction to Glass Science & Technology (Rsc Paperbacks)*. Cambridge: The Royal Society of Chemistry.

Shelby J.E. (2005). *Introduction to Glass Science and Technology*. 2nd ed. United Kingdom: The Royal Society of Chemistry (RSC).

Shen X., Nie Q., Xu T., Dai S., Wang X. (2008). Investigation on Energy Transfer from Er^{3+} to Nd^{3+} in Tellurite Glass. *Journal of Rare Earths 26(6)*: 899-903.

Shigeki K., Adam S.F., Torbjörn B., Sylwia N., Jonas B., Filippo F.C., Lutz H.G., Thomas A.J., Ernst M. (2016). Van Der Waals Interactions and the Limits of Isolated Atom Models at Interfaces. *Nature Communications*: 1-7.

Shigeki S. & Lothar W. (2018). Scratch Hardness of Glass. *Physical Review Materials 2 (092601 R)*: 1-5.

Shindo D. & Oikawa T. (2002). Energy Dispersive X-Ray Spectroscopy. *Analytical Electron Microscopy for Materials Science*. Tokyo: Springer.

Shiuh C.H. & Sheng T.L. (2014). Non-Destructive Evaluation of Depth of Surface Cracks Using Ultrasonic Frequency Analysis. *Sensors 14(9)*: 17146-17158.

Shriver D.F. & Atkins P.W. (2006). *Shriver & Atkins Inorganic Chemistry*. 4th ed. Oxford: Oxford University Press. 189-190.

Sib K.G., Nurul Syuhada M.Z., Ramli A. (2015). Optical and Structural Behavior of Sm^{3+} Doped Tellurite Glass Containing MN NPs. *Solid State Science and Technology 23(1&2)*: 82-89.

Sidek H.A.A., Rosmawati S., Zainal A.T., Halimah M.K., Halim S.A. (2009). Effect of Zinc on the Elastic Behaviour of $(TeO_2)_{90}(AlF_3)_{10-x}(ZnO)_x$ Glass System. *International Journal of Basic & Applied Sciences 9(9)*: 41-44.

Sidek H.A.A., Rosmawati S., Matori K.A., Halimah M.K., Azmi B.Z. (2011). Elastic Constants of $(TeO_2)_{90}(AlF_3)_{10-x}(ZnO)_x$ Zinc Oxyfluorotellurite Glasses. *IOP Conference Series: Materials Science and Engineering 17(1)*.

Sidek H.A.A. (2011). *Wonders of Glass: Synthesis, Elasticity and Application*. Serdang: Universiti Putra Malaysia Press.

Sidek H.A.A., Rosmawati S., Halimah M.K., Khamirul A.M., Zainal A.T. (2012). Effect of AlF_3 on the Density and Elastic Properties of Zinc Tellurite Glass Systems. *Materials 5*: 1361-1372.

Sidek H.A.A., Rosmawati S., Azmi Z., Shaari A.H. (2013). Effect of ZnO on the Thermal Properties of Tellurite Glass. *Advances in Condensed Matter Physics*: 1-6.

Sidkey M.A. & Gaafar M.S. (2004). Ultrasonic Studies on Network Structure of Ternary TeO_2–WO_3–K_2O Glass System. *Physica B 348*: 46-55.

Sidkey M.A., Abd El-Moneim A., Abd El-Latif L. (1999). Ultrasonic Studies on Ternary TeO_2–V_2O_5–Sm_2O_3 Glasses. *Materials Chemistry and Physics 61*:103-109.

Sidkey M.A., Abd El-Moneim A., Gaafar M.S., Abd El-Aal N.S., Abd El-Latif L., Youssof I.M. (2008). Elastic and Structural Properties of Vanadium Lithium Borate Glasses. *Philosophical Magazine 88(11)*: 1705-1722.

Sidkey M.A., El-Mallawany R., Nakhla R.I., Abd El-Moneim A. (1996). Ultrasonic Attenuation at Different Temperatures of TeO_2–V_2O_5 Glasses. *Journal of Pure and Applied Ultrasonics 18*: 91-97.

Sidkey M.A., El-Mallawany R., Nakhla R.I., Abd El-Moneim A. (1997). Ultrasonic Studies of $(TeO_2)_{1-x}$–$(V_2O_5)_x$ Glasses. *Journal of Non-Crystalline Solids 215*:75-82.

Sidkey M.A., El-Mallawany R.A., Abousehly A.A., Saddeek Y.B. (2002). Relaxation of Longitudinal Ultrasonic Waves in Some Tellurite Glasses. *Materials Chemistry and Physics 74*: 222-229.

Sina Z. (2011). *Evaluating Non-Destructive Testing (NDT) Methods Used for the Inspection of Flowlines on Offshore Production Facilities.* University of Stavanger: Master Thesis.

Skoog D.A. & Leary J.J. (1992). *Principles of Instrumental Analysis*. Philadelphia, PA: Saunders College Publishing.

Snehajyoti C., Shrikanth S.G., Tapas K.K. (2010). Atomic Force Microscopy. *Resonance 15(7)*: 622-642.

Sobczyk M. (2013). Temperature Dependent Luminescence and Temperature Stimulated NIR-to-VIS Up-Conversion in Nd^{3+}-Doped La_2O_3–Na_2O–ZnO–TeO_2 Glasses. *Journal of Quantitative Spectroscopy and Radiative Transfer 119:* 128-136.

Sokolov V.O., Plotnichenko V.G., Koltashev V.V. (2009). Structure of Barium Chloride Oxide Tellurite Glasses. *Journal of Non-Crystalline Solids 355(31-33)*: 1574-1584.

Souri D., Honarvar F., Tahan Z.E. (2016). Characterization of Semiconducting Mixed Electronic-Ionic TeO_2–V_2O_5–Ag_2O Glasses by Employing Ultrasonic Measurements and Vicker's Microhardness. *Journal of Alloys and Compounds 699*: 601-610.

Sreenivasulu V., Upender G., Chandra M.V., Prasad M. (2015). Structural, Thermal and Optical Properties of TeO_2–ZnO–CdO–BaO Glasses Doped with VO^{2+}. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy 148*: 215-222.

Sulhadi (2007). *Structural and Optical Properties Studies of Erbium Doped Tellurite Glasses*. Universiti Teknologi Malaysia: PhD Thesis.

Sung W., Won J., Lee J., Kim H. (2009). Properties and Structure of P_2O_5–V_2O_5–ZnO/B_2O_3 Glasses. *Molecular Crystals and Liquid Crystals 499(1)*: 234-556.

Surendra B.S., Kiwan J., Eun J.C., Hoseop L., Jayasankar C.K. (2007). Thermal, Structural and Optical Properties of Eu^{3+}-Doped Zinc-Tellurite Glasses. *Journal of Physics D: Applied Physics 40(18)*: 5767.

Surendra B.S., Rajeswari R., Kiwan J., Cho E.J., Kyoung H.J., Hyo J.S., Jayasankar C.K. (2010). Spectroscopic Investigations of 1.06 μm Emission in Nd^{3+}-Doped Alkali Niobium Zinc Tellurite Glasses. *Journal of Luminescence 130(6)*: 1021-1025.

Suthanthirakumar P., Karthikeyan P., Manimozhi P.K., Marimuthu K. (2015). Structural and Spectroscopic Behavior of Er^{3+}/Yb^{3+} Co-Doped Boro-Tellurite Glasses. *Journal of Non-Crystalline Solids 410*: 26-34.

Suzuki K. (1987). Experimental Characterization of Amorphous Structures in Metals and Ceramics by Pulsed Neutron Scattering. *Journal of Non-Crystalline Solids 95–96 (1)*: 15-29.

Swapna G.U. & Prasad M. (2017). Raman, FTIR, Thermal and Optical Properties of TeO_2–Nb_2O_5–B_2O_3–V_2O_5 Quaternary Glass System. *Journal of Taibah University for Science 11(4)*: 583-592.

Szilard J. (1982). *Ultrasonic Testing Non-Conventional Testing Techniques.* Loughborough, UK: John Wiley & Sons, Ltd.

Takahashi H., Shishitsuka K., Sakuma T., Shimojo Y., Ishii Y. (1998). Characteristic Features of Ionic Conduction in AgI–Ag_2O–V_2O_5 Glasses. *Solid State Ionics 113*: 685-690.

Tariq F., Naz N., Baloch R.A. (2012). Characterization of Material Properties of 2012 Series Al-Alloys by Non Destructive Testing Techniques. *Journal of Nondestructive Evaluation 31(1)*: 17-33.

Thermo Nicolet Instrument Manual (2001). *Introduction to Fourier Transfrom Infrared Spectrometry*. Thermo Nicolet Corporation USA.

Thirumaran S. & Earnest J.J. (2014). Ultrasonic and Spectroscopic Studies on Structural Elucidation of Some Vanadium Glasses. *Research Journal of Physics 8(1)*: 1-16.

Thirumaran S.& Karthikeyan N. (2013). Structural Elucidation of Some Borate Glass Specimen by Employing Ultrasonic and Spectroscopic Studies. *Journal of Ceramics 2013*.

Thompson D.O. & Chimenti D.E. (1993). *Ultrasonic Measurement of Pipe Thickness.* New York: Plenum Press.

Torres F., Benino Y., Komatsu T., Lavelle C. (2001). Mechanical and Elastic Properties of Transparent Nanocrystalline TeO_2 -Based Glass-Ceramics. *Journal of Materials Science 36(20)*: 4961-4967.

Turky G. & Dawy M. (2002). Spectral and Electrical Properties of Ternary (TeO_2–V_2O_5–Sm_2O_3) Glasses. *Materials Chemistry and Physics 77*: 48-59.

Umair M.M. & Yahya A.K. (2013). Elastic and Structural Changes of $x$$Na_2O$–(35-$_x$)$V_2O_5$–65$TeO_2$ Glass System with Increasing Sodium. *Materials Chemistry and Physics 142*: 549-555.

Umar S.A., Halimah M.K., Azlan M.N., Grema L.U., Ibrahim G.G., Ahmad A.F., Hamza A.M., Dihom M.M. (2020). Structural, Elastic and Thermo-Physical Properties of Er_2O_3 Nanoparticles Doped Bio-Silicate Borotellurite Glasses. *SN Applied Sciences 2*: 291.

Varshneya A. (1994). *Fundamentals of Inorganic Glasses*. 1st ed. New York: Academic Press.

Vasantharani P. & Sankeeda I. (2013). Elastic Properties of Copper Containing Bismuth Silicate Glasses - An Ultrasonic Study. *Global Research Analysis 2(8)*: 175-177.

Veiga J.L.B.C., De Carvalho A.A., Da Silva I.C., Rebello J.M.A. (2005). The Use of Artificial Neural Network in the Classification of Pulse-Echo and TOFD UltraSonic Signals. *Journal of the Brazilian Society of Mechanical Sciences and Engineering 27(4)*: 394-398.

Victor G. & Adrian C. (2005). Embedded Non-Destructive Evaluation for Structural Health Monitoring, Damage Detection, and Failure Prevention. S*hock and Vibration Digest 37(2)*: 83-105.

Vijay P.S. (1976). Investigations of Attenuation and Internal Friction of Rocks by Ultrasonics. *International Journal of Rock Mechanics and Mining Sciences & Geomechanics Abstracts 13(3)*: 69-74.

Viktorov I.A. (1967). *Rayleigh and Lamb Waves: Physical Theory and Applications: Translated from Russian*. Plenum Press.

Villegas M.A. & Navarro J.F. (2007). Physical and Structural Properties of Glasses in the TeO_2-TiO_2-Nb_2O_5 System. *Journal of the European Ceramic Society 27(7)*: 2715-2723.

Vinokurov A.A., Dorofeev S.G., Tananaeva O.I., Artamkin A.I., Kuznetsova T.A., Zlomanov V.P. (2006). Synthesis and Properties of Vanadium Doped Lead Tellurite. *Inorganic Materials 42(12)*: 1318-1325.

Voigt T. (2005). *The Application of An Ultrasonic Shear Wave Reflection Method for Nondestructive Testing of Cement-Based Materials at Early Ages*: An Experimental And Numerical Analysis (No.7). German: Bod–Books on Demand.

Wagner H., Büchsenschütz-Göbeler M., Luo Y., Kumar A., Arnold W., Samwer K. (2014). Measurement of Local Internal Friction in Metallic Glasses. *Journal of Applied Physics 115(13)*: 134307.

Wandel M.E., Rottwitt K., Povlsen J.H. (2006). *Attenuation in Silica-Based Optical Fibers*. Technical University of Denmark: PhD Thesis.

Wang H., Cao W., Zhou Q., Shung K.K. (2003). Characterization of Ultra-Thin Quarter-Wavelength Matching Layers of High Frequency Ultrasonic Transducers. *IEEE Ultrasonics Symposium (1)*: 1048-1051.

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

Watanabe T., Muratsubaki K., Benino Y., Saitoh H., Komatsu T. (2001). Hardness and Elastic Properties of Bi_2O_3-Based Glasses. *Journal of Materials Science 36*: 2427-2433.

Whallon J.H., Flegler S.L., Klomparens K.L. (1989). Energy Dispersive X-Ray Microanalysis. *American Institute of Biological Sciences 39(4)*: 256-259.

Worden K. (2001). Rayleigh and Lamb Waves - Basic Principles. *Journal of Strain 37(4)*.

Wrobel G. & Pawlak S. (2007). A Comparison Study of the Pulse-Echo and Through-Transmission Ultrasonics in Glass/Epoxy Composites. *Journal of Achievements in Materials and Manufacturing Engineering 22(2).*

Xuan Z. & Piervincenzo R. (2011). Guided Ultrasonic Waves for the Health Monitoring of Existing Sign Support Structures In: *Health Monitoring of Structural and Biological Systems (Vol. 7984, p. 79840E)*. International Society for Optics and Photonics.

Yamane M. & Mackenzie J.D. (1974). Vicker's Hardness of Glass. *Journal of Non-Crystalline Solids 15(2)*: 153-164.

Yang D. & Ying Y. (2011). Applications of Raman Spectroscopy in Agricultural Products and Food Analysis: A Review. *Applied Spectroscopy Reviews 46*: 539-560.

Yanlu L., Weiliu F., Honggang S., Xiufeng C., Pan L., Xian Z. (2010). Structural, Electronic and Optical Properties of α , β and γ -TeO_2. *Journal of Applied Physics 107*:1-7.

Yousef E., Hotzel M., Russel C. (2007). Effect of ZnO and Bi_2O_3 Addition on Linear and Non-Linear Optical Properties of Tellurite Glasses. *Journal of Non-Crystalline Solids 353*: 333-338.

Yousef E.S. & Al-Qaisi B. (2013). UV Spectroscopy, Refractive Indices and Elastic Properties of the (76 - x)TeO_2.9P_2O_5.15ZnO.$x$$LiNbO_3$ Glass. *Solid State Sciences 19*: 6-11.

Yusoff N.M. & Sahar M.R. (2015). Effect of Silver Nanoparticles Incorporated with Samarium-Doped Magnesium Tellurite Glasses. *Physica B: Condensed Matter 456*: 191-196.

Zaid M.H.M., Matori K.A., Wah L.C., Sidek H.A.A., Halimah M.K., Wahab Z.A., Azmi B.Z. (2011). Elastic Moduli Prediction and Correlation in Soda Lime Silicate Glasses Containing ZnO. *International Journal of Physical Sciences6(6)*: 1404-1410.

Zaidia E.M.M., Ammar A.A., El-Mallwany R.A. (1985). Infra-Red Spectra, Electron Spin Resonance Spectra and Density of $(TeO_2)_{100-x}$-$(WO_3)_x$ and $(TeO_2)_{100-x}$-$(ZnCl_2)_x$ Glasses. *Physica Status Solidi (A) 91(2)*: 637-642.

Zarzycki J. (1991). *Glasses and Amorphous Materials Volume 9*. Weinheim: Wiley VCH.

Zheng S., Zhou Y., Yin D., Xu X., Qi Y., Peng S. (2013). The 1.53 μm Spectroscopic Properties and Thermal Stability in Er^{3+}/Ce^{3+} Codoped TeO_2–WO_3–Na_2O–Nb_2O_5 Glasses. *Journal of Quantitative Spectroscopy and Radiative Transfer 120*: 44-51.

Zhongqing S., Lin Y., Ye L. (2006). Guided Lamb Waves for Identification of Damage in Composite Structures: A Review. *Journal of Sound and Vibration 295*: 753-780.

Zhou Y., Yang Y., Huang F., Ren J., Yuan S., Chen G. (2014). Characterization of New Tellurite Glasses and Crystalline Phases in the TeO_2–PbO–Bi_2O_3–B_2O_3 System. *Journal of Non-Crystalline Solids 386*: 90-94.

Zhu J. & Popovicks J.S. (2008). *Non-Contact NDT of Concrete Structures Using Air Coupled Sensors*. Newmark Structural Engineering Laboratory. University of Illinois at Urbana-Champaign.

LIST OF PUBLICATIONS

Indexed Journal

1. **Nurulwahidah Z.A.S.,** Nurhafizah H., Md Supar Rohani (2019). Effect of Ag NPs: Ultrasonics Attenuation Properties. *Solid State Phenomena* 290: 93-98. (**Indexed by Scopus**)

2. **Nurul Wahida Zainal Abidin Sham**, Md Supar Rohani (2017). Ultrasonic bulk waves measurements for defect detection of composite materials. *Solid State Phenomena* 268: 401–406. (**Indexed by Scopus**)