Infrared absorption spectra analysis of TeO$_2$-ZnO-Bi$_2$O$_3$-TiO$_2$ doped B$_2$O$_3$ glasses

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Abstract. Boro-tellurite glasses with composition 60TeO$_2$- (30-x)ZnO- 5Bi$_2$O$_3$- 5TiO$_2$- xB$_2$O$_3$ (where x = 0, 2.5, and 5 mol%) have been successfully fabricated by melt quenching technique. FTIR characterization was carried out in range 400-4000 cm$^{-1}$ using a KBr pellet method to study the glass chemical bond. The results show that several absorption peaks were recorded in range 400-4000 cm$^{-1}$. However, most of the absorption peaks were detected in the region 400-1600 cm$^{-1}$. It can be divided into 5 groups from 400-450 cm$^{-1}$, 620-650 cm$^{-1}$, 900-940 cm$^{-1}$, and 1100-1300 cm$^{-1}$. The main absorption peak of TZBT glass located at 620-650 cm$^{-1}$, which is the fingerprint of TeO$_2$ glass from Te-O vibration of TeO$_4$ units. The addition of B$_2$O$_3$ components constructed a new absorption at 930 cm$^{-1}$ and 1100-1300 cm$^{-1}$. The absorption at 930 cm$^{-1}$ belongs to B-O vibrations of BO$_4$ units. While the absorption at 1100-1300 cm$^{-1}$ relates to B-O vibrations of BO$_3$ units. For further investigation, the deconvolution process was performed to discover the effect of the addition of B$_2$O$_3$ in the main absorption spectra. It was confirmed that six bands detected in the main absorption peak. The effect of B$_2$O$_3$ reduces the absorption band and shift the wavenumbers in TZBT glass.

1. Introduction
In the last decade, the development of tellurite glass as one of Heavy Metal Oxides (HWO) glass drawn much attention because of its bright future application for IR technologies, lasing material, fiber optics, nonlinear optics, optoelectronic devices, and recently as Gamma radiation shielding [1-5]. Besides its application researcher also interest in the physical and structural study of tellurite glass due to its excellent thermal stability, posses low melting point, good chemical and thermal durability, high refractive index, high density, low phonon energy, and wide transmittance range in the infrared region [6-13]. However, tellurite has difficulty to manage itself for forming glass in normal condition [14]. To solve this problem, the addition of certain oxides compounds reported can improve its glass-forming range [15-16].

ZnO compound is well known as one of the best modifiers for the tellurite glass system. It can reduce the melting point of tellurite glass and increase its glass-forming region. In other cases, ZnO also provides good improvement for optical and spectral properties in vice versa [17-18]. The addition of heavy metal oxides components likely TiO$_2$ and Bi$_2$O$_3$ can increase the hardness, thermal strength, density of glass, and respectively decrease the bandgap energy of glass [19-21]. In a current study, addition tellurite with another glass-forming compound, such B$_2$O$_3$ becomes highlight because of its technological applications, especially in the optical device and shielding radiation [22-23].

The combination of tellurite and Borate glass promises good physical, structural, and optical properties. In order to understand the structural change due to compositional change the present
paper discuss the spectral analysis on the TeO$_2$-ZnO-Bi$_2$O$_3$-TiO$_2$ (TZBT) glass with variations amount of B$_2$O$_3$ in the infrared range.

2. Experiment

Three glass samples were made using a melt quenching method. The composition of glass is 60TeO$_2$-(30-x) ZnO-5Bi$_2$O$_3$-5TiO$_2$-xB$_2$O$_3$ with x varied by 0, 2.5, and 5 mol%. An appropriate mass of each chemical material was weighed using an electrical balance to obtain a 10 grams glass raw batch. The mixture milled for 30 minutes using agate mortar and pestle to obtain a homogeneous batch before transferred into a platinum crucible.

The platinum crucible put into an electric furnace at a temperature of 900°C for 45 minutes. A stainless steel mold was prepared and heated into an oven at heating temperature 250°C. The free bubble melt rapidly poured into a preheated mold and then annealed at a temperature of 285°C for 3 hours to remove thermal and mechanical stress. The fabricated glasses were polished and cut into 1.5x1.5 cm dimension for characterization purposes.

The characterization carried out by Shimadzu 1100 IR Spectroscopy using the KBr pellet method. About 5 mg of the glass crushed to powder and mixed with 200 mg KBr. The mixture then pressed with a hydraulic vacuum pump into a pellet. The pellet then used to obtain infrared absorption of all glass samples in the mid-infrared wavelength region which ranging from 400-4000 cm$^{-1}$.

3. Result

![FTIR Spectrum of TZBTB glasses at range: (a) 400-4000 cm$^{-1}$ and (b) 400-1600 cm$^{-1}$](image)

The FTIR spectrum of the three glass samples has successfully recorded. Figure 1 (a). shows several absorption peaks formed in the range of 400-4000 cm$^{-1}$. This result generally confirms the difference in the infrared absorption spectrum between undoped and doped B$_2$O$_3$ glasses samples. There are two types of absorption peaks in the spectrum, strong and weak absorption peaks. The absorption peaks mostly detected in the range of 400-1600 cm$^{-1}$, which revealed in Figure 1 (b). Another absorption peaks also detected in the range of 3200-3400 cm$^{-1}$. According to several reports, that peak formed due to the vibration of the O-H hydroxyl group [24-26]. In other side the absorption peaks in region 400-1600 cm$^{-1}$ can be divided into 5 groups from 400-450 cm$^{-1}$, 620-650 cm$^{-1}$, 900-940 cm$^{-1}$, and 1100-1300 cm$^{-1}$. These peaks location varies depending on the B$_2$O$_3$ addition to the sample.
In this study, a deconvolution process was carried out on the three samples to confirm the exact location of the peaks, and information about bond types that make the peaks. Deconvolution took place in the range of 400-900 cm\(^{-1}\), where a lot of absorption peaks formed in this area. The deconvolution results for the following samples shown in Figure 2.

According to the deconvolution result, there are six bands exist in TZBT basic glass. These bands have an exact location at 427, 458, 496, 562, 652, and 770 cm\(^{-1}\), which illustrated in Figure 2(a). However, when B\(_2\)O\(_3\) inserted into the glass network by 2.5 and 5 mol\%, it can be confirmed a change in the constructed bands. Figure 2 (b) show TZBTB 2.5 glass bands, the bands located at 438, 471, 494, 551, 626, and 761 cm\(^{-1}\). While Figure 2 (c) show TZBTB 5 glass bands, the bands located at 427, 457, 498, 535, 648, and 760 cm\(^{-1}\). The resume of all glass samples band and its assignment tabulated in Table 1.

Figure 2 shows the deconvolution results of all three glass samples. All samples display six absorption bands in a similar place. However, there changes in both strong and weak bonding bands, as B\(_2\)O\(_3\) material presented in the glass composition. The exchange between ZnO and B\(_2\)O\(_3\) causes in a shift wavenumbers and changes the area under the absorption band. The addition of 2.5 and 5 mol\% B\(_2\)O\(_3\) alters the bond structure of the glass.

The first absorption band is in the area of 427-438 cm\(^{-1}\). This band identified as vibrations in the Zn-O bond on the ZnO\(_4\) unit or Te-O-Te [27-28]. Wavenumber shift occurs due to a reduction in Zn-O bonds in the glass. The second band detected in the area of 457-471 cm\(^{-1}\). This area is a Bi-O-Bi vibration in the BiO\(_6\) units [29]. The third band at 494-498 cm\(^{-1}\) is a vibration by the Te-O-Te bond on the TeO\(_4\) units [30]. In this area, wavenumber relatively the same. Meanwhile, the fourth band is at 535-562 cm\(^{-1}\). According to several studies, this area illustrates the vibrations of Te-O-Te in TeO\(_4\) units [31].

The fifth band formed in the fingerprint area of the TeO\(_2\) glass. Pure TeO\(_2\) glass has an absorption of around 640 cm\(^{-1}\). In this case, the absorption band values appear in the range of 628-652 cm\(^{-1}\), which represents the stretching of the Te-O vibrations of the TeO\(_4\) units [33,34]. Finally, the sixth band formed in the area of 760-770 cm\(^{-1}\). This band created by symmetrical and asymmetrical vibrations from the Te-O bonds of TeO\(_3\) and TeO\(_{3+1}\) units [35]. The shifted wavenumber due to the presence of B-O vibrations from the BO\(_3\) unit on this area.

The addition of B\(_2\)O\(_3\) constructs a new absorption peak. In the TZBTB 5 glass, the weak absorption band spotted in the area of 930 cm\(^{-1}\), which belongs to the B-O bond from the BO\(_3\) units [36]. Furthermore, in TZBTB 2.5 and TZBTB 5 glasses, the new peak also appeared in the 1100-1300 cm\(^{-1}\) region. This absorption peak caused by B-O vibrations of BO\(_3\) units [37]. This research discovers that

### Table 1. Absorption peak position of TZBT doped B\(_2\)O\(_3\) glasses

| Code       | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  |
|------------|----|----|----|----|----|----|----|----|
| TZBT       | 427| 458| 496| 562| 652| 770| -  | -  |
| TZBTB 2.5  | 438| 471| 494| 551| 626| 761| -  | -  |
| TZBTB 5    | 427| 457| 498| 535| 648| 760| 930| 1300|
| Assignment | Zn-O vibrations in ZnO\(_4\) units or Bi-O-Bi vibrations in BiO\(_6\) units or Te-O-Te vibration | Te-O-Te vibration of TeO\(_4\) | Te-O stretching vibration of TeO\(_4\) units | Te-O symmetrics and Te-O asymmetric vibration of TeO\(_{3+1}\) units | B-O stretching vibrations of BO\(_4\) units | B-O stretching vibrations of BO\(_3\) units |
| Reference(s)| [27-28] | [29] | [30-32] | [33-35] | [35] | [36-38] | [39-40] |
the addition of B$_2$O$_3$ can extend the infrared absorption range of TZBT glass. It makes this glass potentially developed into radiation shielding applications.

![Figure 2. Deconvoluted infrared spectra of: (a) TZBT (b) TZBTB 2.5 (c) TZBTB 5 Glass](image)

4. Conclusion

Infrared absorption spectra of boro-tellurite glasses with compositions of 60TeO$_2$-(30-x)ZnO-5Bi$_2$O$_3$-5TiO$_2$-xB$_2$O$_3$ (the value of x varies by 0.2.5, and 5 mol%) have been successfully studied. In order to discover the effect of B$_2$O$_3$ on the infrared absorption. The result shows that 4 mains absorption occur at area 400-450 cm$^{-1}$, 620-650 cm$^{-1}$, 900-940 cm$^{-1}$, and 1100-1300 cm$^{-1}$. The strongest and widest absorption located in the area of 600-900 cm$^{-1}$. For further investigation, a deconvolution process of 400-900 cm$^{-1}$ carried out. It found that there 6 absorption bands formed. As the B$_2$O$_3$ increases, it found that the wavenumber shifted and the area under the bands reduced. Besides, two new peaks formed in the 930 cm$^{-1}$ and 1100-1300 cm$^{-1}$ regions due to the addition of B$_2$O$_3$.

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