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Tellurite Glasses containing Bi_2O_3 for Radiation Shielding

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Abstract: Glass is an essential component of numerous products that being used in everyday life. Some of them, most often unnoticedly, have been used to protect from the UV light. However, protection from other radiation is still a major issue. Tellurite based glass composed of $70TeO_2$-xBi_2O_3-(30-x)PbO where x = 0; 2.5; 5; 7.5; 10; 12.5 and 15 mol% has successfully been made and their absorption characteristic and gamma absorption energy have been determined. It is found that both UV edge absorptions are red shifted and gamma absorption increases as Bi_2O_3 content is systematically increased. These results indicate that some wavelengths have been filtered and these glasses may have some potential usage as a radiation shielding glass.

Glass is an amorphous solid completely lacking in long range periodic atomic structure exhibiting a region of glass transformation behavior. Rapid cooling of liquid can freeze the atoms so that solidification occur before the atoms have had time to rearrange themselves. Obsidian is a volcanic glass, created from molten lava. When molten lava containing large amounts of silica sand, cools quickly after reaching the Earth’s surface, obsidian is formed. Meanwhile, fulgurites are formed when lightning strikes the ground, fusing and vitrifying mineral grains. Material properties (size, color, texture) of fulgurites vary widely, depending on the size of the lightning bolt and composition and moisture content of the surface struck by lightning. Tellurite glass is a good host since it exhibits low internal phonon losses and is very stable.

Absorption edge shifts is due to electronic transition of a valence electron of a network anion to conduction band. This edge is shifted once band gap energy is being changed. Heat that may appear is due to light absorption by molecular gasses composing the air, that is absorption of IR light with molecules having vibrational energy level coincides with the incoming IR light.

Thus, the key technology that can be applied for the production of UV radiation shielding glass is by controlling the band gap energy that suit the refractive index. Since refractive index and density have similar effect to compositional change, any compositional change that increase the density will reduce the band gap energy. If rare earth ion is added into composition, electronic transition can occur from a valence electron to an energy level below conduction band. The absorption to an energy level above conduction band is blocked by strong absorption of the UV-edge. As an example, the absorption peak belongs to Nd^{3+} ion corresponding to energy state of $^4D_{1/2}$+$^2I_{1/2}$+$^4D_{5/2}$+$^4D_{3/2}$ which is clearly seen in [1,2], due to UV absorption edge blocking, cannot be seen in [3]. In addition, adding rare earth ions or transition metal ion into the glass, will enable them to block certain wavelength and create a new color resulted from unblocked colors.

Fig. 1 shows the UV-VIS absorption spectra of tellurite glasses with molar compositions: $70TeO_2$-xBi_2O_3-(30-x)PbO where x = 0; 2.5; 5; 7.5; 10; 12.5 and 15 mol%. Bi_2O_3 ions are added to substitute PbO. From Fig. 1(a), it can be seen that, absorption intensities are generally reduced as Bi_2O_3 concentration is increased. Bi_2O_3 are heavier and more ionically polarizable than PbO. Adding Bi_2O_3 into the glass to substitute PbO increases refractive index and therefore reduces bandgap energy [4]. Possessing such low band gap energy, these glasses are capable of filtering UV light but blocking any absorption peak of rare earth ions possibly doped into the glasses.

The infrared (IR) absorption of glass is generated by the vibration of chemical bonds in the glass network. There are two competing factors that determine the IR absorption edge: bond strength and reduce mass. For a diatomic molecule, the frequency of the vibrational absorption will shift towards the infrared if the bond strength is weak and/or if the reduction masses of the atoms are large. Considering that the glass matrix is composed of a combined of diatomic molecule which is regarded as oscillator harmonics, adding any molecules making either decreasing reduce mass or increasing bond strength will red-shift the IR edge absorption. Adding Bi_2O_3 increases mass reduction resulting in decreasing fundamental frequency (increasing wavelength).

From Fig. 1(b), absorption peak around 15000 nm is generally red-shifted as Bi_2O_3 concentration increases. Absorption peak for 0% Bi_2O_3 is at 14873 nm. It goes to 15175 nm for 2.5 and 5 % of Bi_2O_3. For 7.5 and 10 mol% of Bi_2O_3 the peak goes up to 15553 nm and 15591 nm, respectively. The peak goes down to 15515 nm for 12.50% Bi_2O_3. A similar result has also been obtained elsewhere [5].

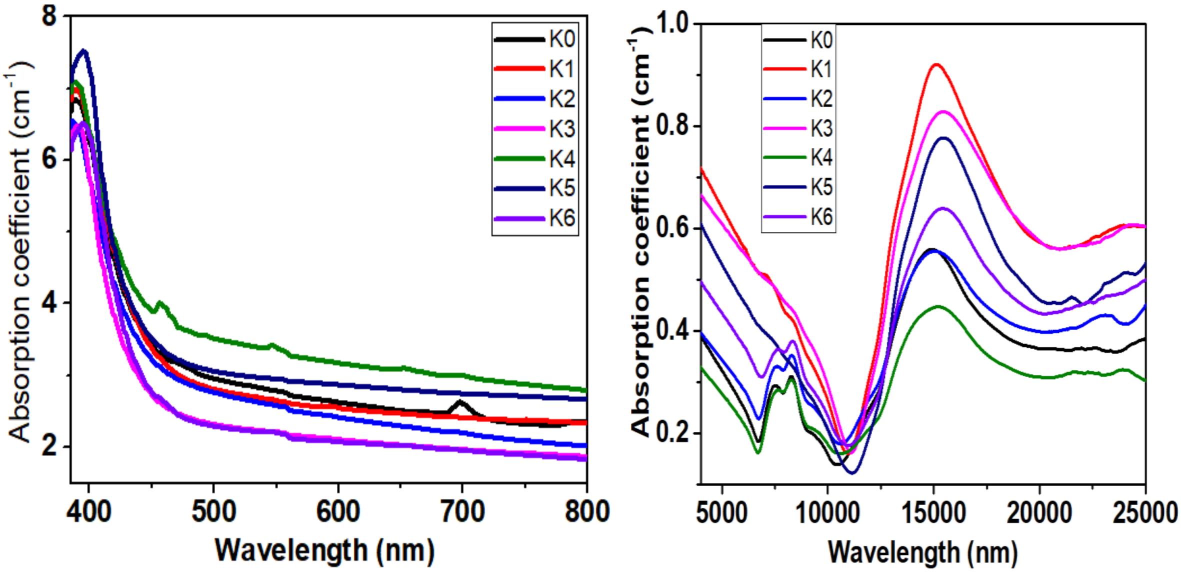

Figure 1: Absorption spectra of TeO_2-Bi_2O_3-PbO glass system with addition of Bi_2O_3 addition to substitute PbO (a) UV-VIS spectra, (b) FTIR

Lead ions (Pb^{2+}) and bismuth ions (Bi^{3+}) ions are very good gamma radiation absorber due to their high atomic number. Doping either of these ions into the glasses may have some potential as a radiation shielding glass especially radiation protection from X-Rays (radiology) and gamma-rays (nuclear). Fig. 2 shows gamma ray absorption energy as function of the Bi_2O_3 content, for both phonon energies corresponding to gamma radiation source of Ba-133 and Cs-137. From this figure, it can be seen that gamma absorption percentage increase as Bi_2O_3 concentration is increased or in other word increasing percentage of PbO. This result shows that Bi_2O_3 provide better shielding to gamma ray than PbO. A similar result has also been obtained elsewhere [6]. From both results, it can be said that tellurite based glass containing Bi_2O_3 can be used as both UV-filtering and a radiation shielding.

Conclusion: Tellurite glasses containing Bi_2O_3 has successfully been prepared and their characteristic has been analyzed. Upon Bi_2O_3 addition, it is found that the glass exhibits an increase of gamma energy absorption and shift the UV-edge absorption toward longer wavelength. This glass may be potentially used for both UV filtering and gamma radiation shielding.

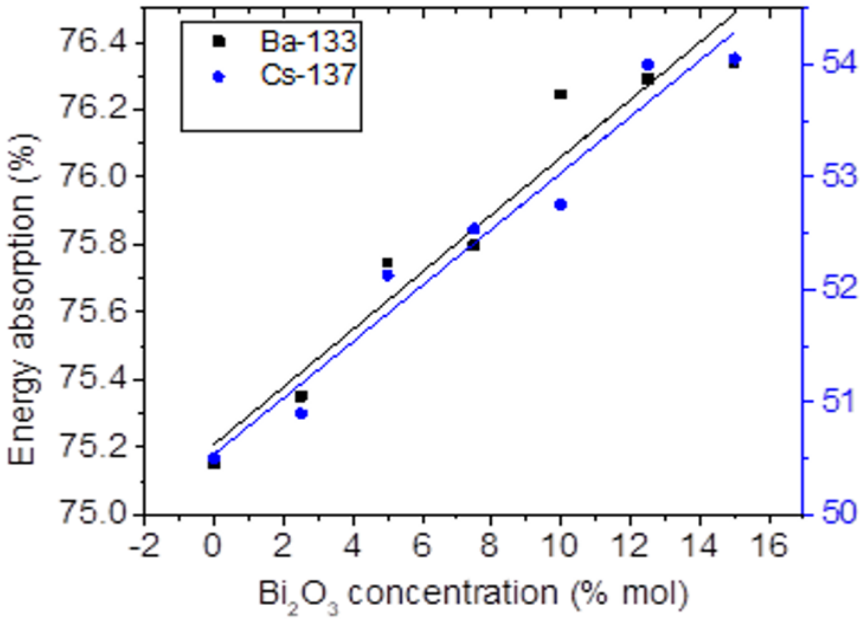

Figure 2: Gamma absorption energy against Bi_2O_3 content (mol%) for glass composition $20B_2O_3$-$60TeO_2$-(20-x) Bi_2O_3-xPbO where x=1, 2, 3, 4, 5, 6, 7, 8, 9 and 10 mol%.

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