Structural and Radiation Shielding Properties of Dy\textsuperscript{3+} doped Phosphate Glasses

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Abstract. X - Rays has become integral and indispensable part of health care diagnosis and intervention. Which involve the risks of occupational overexposure of radiation to the patients and health care personnel. The Radiation exposure depends on “Time-Distance-Shielding”. Reduction of the exposure time, increasing the distance from source proper shielding are important for protection. We need a high quality or suitable shielding material for reduction of unnecessary radiation. Although the material commonly used for radiation shielding is lead, but the environmental toxicity of lead (Pb) is a global threat that has led to the need to develop lead-free (Pb-free) and non-toxic radiation shielding glasses. In this study, the effect of Dy\textsubscript{2}O\textsubscript{3} on physical and radiation shielding properties of 59P\textsubscript{2}O\textsubscript{5}: 10Al\textsubscript{2}O\textsubscript{3}: 20 Na\textsubscript{2}O: 10 Gd\textsubscript{2}O\textsubscript{3}: 1Dy\textsubscript{2}O\textsubscript{3} glasses have been investigated were fabricated by melt-quenching technique. The X-rays shielding properties such as the mass attenuation coefficients (\(\mu_m\)) and half value layer (HVL) of glass sample. It may also be mentioned that glass has the double function of being a radiation shielding material because of the properties of glass being transparent to visible light, absorption X-rays. Thus, the developed glasses shielding had good shielding properties, and highly practical potentials in the environmental friendly radiation shielding materials without an additional of lead.

1. Introduction
Radiation energy such as X-ray and Gamma ray are energetics ionizing radiation that can damage living cell and human organs as its transfers its energy and slow down energy to living cell. Different radiation
shielding materials have been produced to reduce radiation dose for radiologic technology or radiation operator at radiology department [1-3]. The radiation shielding materials are important concerns that new potential for researchers to finding appropriate radiation shielding materials to attenuation radiation for operator in radiologic department. Radiation shielding materials for radiation attenuation should have high density, good radiation attenuation, high stability and low toxicity in manufacture process [4-7].

Several years ago, Lead (Pb) was the primary selection used for added or doped to radiation shielding. Lead is physical, optical and radiation shielding properties make is excellent radiation attenuation [8]. Recently, concern has been growing that the use of lead poses a safety and health hazards. Lead introduces an insidious hazard to the workers and patients that affecting biochemical systems of the human body and high toxicity in manufacture. Nowadays, recent studies focus on finding a low toxic and low-cost radiation shielding materials [4-7].

Glass doped chemical composition materials are suitably alternatives to lead due to their physical and optical properties that can be easily modified by composition and preparation technique low cost and can be recyclable [9-10]. In present work reports on the physical, optical and X-ray radiation shielding properties of Dy$^{3+}$ based glasses in formula of (60-x) P$_2$O$_5$: 10Al$_2$O$_3$: 20 Na$_2$O: 10 Gd$_2$O$_3$: xDy$_2$O$_3$ where x = 0.05, 0.10, 0.50, 1.00 and 3.00 %mol. This glass formula has never been studied in X-ray shielding and this present work is the first time for understanding the effects of Dy$^{3+}$ doped glass system composition, developed for using to glass radiation shielding which Pb-free glasses radiation shielding.

2. Materials and Methods

2.1 Physical properties

The weight of the prepared glass samples were measured in air and in xylene by using a 4-digit sensitive microbalance (A&D, HR-200). By applying Archimedes’ Methods, the density, $\rho$, was determined from the following in equation [11] Where $W_a$ is the weight in air, $W_b$ is the weight in xylene and $\rho_b$ is the density of xylene ($\rho_b = 0.863$ g/cm$^3$).

$$\frac{W_a - W_b}{W_a - \rho_b W_b} x \rho_b$$  \hspace{1cm} (1)

2.2 Optical absorption properties

The optical absorption spectra of the glass samples of equal thickness were recorded at room temperature using a spectrophotometer (Variance, Cary 50) in the UV-VIS-NIR region at 300-1100 nm.

2.3 Measurement of X-ray shielding properties

The X-ray shielding efficiency was assessed using different categories of partial interaction parameters such as mass attenuation coefficient ($\mu_m$) and half value layer (HVL). The X-ray shielding characterization was measured with a high frequency digital radiography Shimadzu model RAD Speed Pro X-ray machine operated at 50-120 kVp and 20 mAs. The spectra were measurement and recorded by using Cd-Te X-ray Spectrometer. The optimum experimental distance set up between X-ray generators to glass samples and from glass samples to Cd-Te X-ray Spectrometer being at 50 cm separation distance. The X-ray shielding experiment set up is shown in Figure 1.
2.4 Mass attenuation coefficient ($\mu_m$)
The mass attenuation coefficient ($\mu_m$) of glass samples are calculated by following equation [9]

$$\mu_m = \frac{ln\left(\frac{I}{I_0}\right)}{\rho} \tag{2}$$

Where $I_0$ is incident intensity, $I$ is intensity attenuation beam, $\rho$ is the density of glass samples (g/cm$^3$)

2.5 Half Value Layer (HVL)
Half Value Layer (HVL) are defined in terms of the attenuation of parallel X-ray beam is needed to reduce the X-ray intensity/ incident radiation by factor of 2. The HVL defined by following equation [9].

$$HVL = \frac{\ell n}{\mu} \tag{3}$$

Where $\mu$ is linear attenuation coefficient

3. Results and Discussions
3.1 Physical Properties
The density of glass samples increased with increasing the concentration of Dy$_2$O$_3$. This is due to higher molecular weight of Dy$_2$O$_3$ compared to that of P$_2$O$_5$. The results of densities are shown in Figure 2.
3.2. Optical Properties
The optical spectra of glass samples containing 3% of Dy\(^{3+}\) are shown in comparison with commercial windows and commercial Pb-glass (X-ray Window), are shown in Figure 3. The results shown that similar optical spectra of each glass samples in visible region.

![Figure 2. The density of Dy\(^{3+}\) doped glass samples](image1)

![Figure 3. The Optical spectra of Dy\(^{3+}\) doped glass samples](image2)
3.3. **X-ray Shielding Properties**
The X-ray shielding efficiencies of newly developed lead-free Dy$^{3+}$ ions doped in glass samples are discussed using the mass attenuation coefficients ($\mu_m$), half value layer (HVL). These shielding properties are discussed in this results.

3.4. **Mass attenuation coefficient ($\mu_m$)**

![Figure 4](image_url)

**Figure 4** Mass attenuation coefficient of glass samples

The plot between mass attenuation coefficient and X-ray energies of lead-free Dy$^{3+}$ ions doped in glass samples are shown in Figure 4. It has been found that the mass attenuation coefficient were increased with the decreasing of X-ray energies and increased when the lead-free Dy$^{3+}$ ions doped in glass samples. This indicated that more photons energies are being attenuated at lower photon energies while the probability of photon attenuation is reduced with the increasing of photon energies.

3.5. **Half value layer (HVL)**
The HVL values of Dy$^{3+}$ doped glass samples tend to decrease with decrease in kVp technique and increase with Dy$^{3+}$ concentration increase. The HVL of glass with different Dy$^{3+}$ concentration at 120 kVp 20 mAs compared with commercial Pb shielding windows (Lead glass), Concrete, Red Brick and commercial glass, the results are shown in Figure 5.

![Figure 5](image_url)

**Figure 5.** Half Value Layer
Acknowledgement
Authors would like to thank the Department of Radiologic Technology, Faculty of Associated Medical Sciences, and Chiang Mai University for the research scholarship to perform this study. J. Kaewkhao would like to thank CEGM, Rajabhat Naknow Phathom University for providing research instruments.

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