Optical Characterisation of Gamma Irradiated Microscope Glass Slide

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Abstract
The study herein provides analysis of radiation-induced structural interaction changes and the associated luminescence that originates from the energy absorption in the microscope glass slide samples exposed to ^{60}Co gamma-ray source. Raman, Fourier Transform Infrared (FTIR) and Photoluminescence (PL) spectroscopies have been undertaken to characterise the alterations in order-disorder defect generation at these relatively low doses from 0 to 10 Gy of ^{60}Co gamma irradiation. Present work can facilitate optimal implementation of microscope glass slide for a range of radiation measurement applications by understanding the radiation effect, medical and sterilisation work included.

Keywords: Borosilicate; Microscope glass slide; Gamma radiation; Fourier transform infrared spectroscopy; Raman spectroscopy; Photoluminescence;

1.0 Introduction
Glass is formed when liquid is cooled below its melting temperature, causing “freezing” state rather than crystallisation. This process slowing down the atom transitions to the more stable state due to low final temperature, thus creates an amorphous glass of the same chemical composition that only has short range order. Zachariasen has reported that the structure of these amorphous materials are not entirely random and have similar structural elements as their crystalline counterparts, but lack a large periodic and symmetrical network (Zachariasen, 1932), results from variations in bond angles and torsion angles, also to distortions in the silica tetrahedron (Wright et al., 1980; Salmon, 2002).
Borosilicate glass can be formed via combination of B_2O_3 with SiO_2. The atomic structures of these glasses have a systematic variation in boron coordination and the distributing of non-bridging oxygen (NBO) between B and Si as the alkali/alkaline earth oxide. The basic structural unit of B_2O_3 glass consists mainly of three corner-shared BO_3 triangles, forming a B_3O_6 boroxol ring that connected to one another by a small non-ring population of BO_3 triangles, indicating the presence of substantial intermediate-range order in B_2O_3 glass (Youngman & Zwanziger, 1994; Takada et al., 2003; Greaves & Sen, 2007). The structure of borosilicate glasses by using several optical techniques has been extensively investigated due to its wide variety

technological applications more recently in dosimetry (Abdul Sani et al., 2020; Abdul Sani et al., 2021; Ahmad Nazeri et al., 2021; Almugren et al., 2021; Alqahtani et al., 2020a; Alqahtani et al., 2020b), also including optical lenses, nuclear waste materials, shielding and electronic industry.

The disrupted repeat structure of amorphous silica also includes strain and intrinsic point defects that underpin the route to energy absorption, subsequent radiative transitions from the stored energy manifest the luminescence stimulated via various modes of excitation, and irradiation included. Energy absorption occurs during the promotion of electrons and holes to the trapping centres that are formed by the impurities and defects in non- and sparsely conducting transparent media, providing the basis of luminescence and hence dosimetric capability. It has long been known that strain as well as extrinsic dopants and irradiation can modify the optical properties of such amorphous material, with vacancies and interstitial atoms created within the medium as a result of the various interactions. Despite the enormous amount of work accumulated over the few last years, a thorough understanding of the structural modifications due to gamma irradiation of glasses and their relationship with the dosimetry is still far from being achieved.

With these opening statements, present work concerns the structural properties of low dose irradiated microscope glass slide material, utilizing the commonly available in materials research labs. In as far as physical measurements are concerned, use is made herein of low linear energy transfer (LET) penetrating gamma-rays. The latter is limited in present study to the emission of light from photon-irradiated microscope glass slide media, defects in the medium absorbing and storing energy. To seek support of this, borosilicate glass with defect states can both show associated optical properties, probed for instance using Raman, FTIR and photoluminescence spectroscopy. These underpin the performance properties of such silica media when applied as radiation dosimeters, particularly in regard to thermoluminescence (TL) based detectors. As such, fundamental understanding of the radiation effect can facilitate optimal implementation of borosilicate glass in many applications, such as highly sensitive medical (e.g., radiotherapy or radiodiagnostic) dosimetry as well as lightweight and strong materials for space applications, in satellites, aircraft and spacecraft exposed to cosmic radiation.

2.0 Methodology

The effect of ionizing radiation is examined in respect of commercially available microscope glass slide (Sail, China) (a borosilicate medium) with thickness varying between 1.0 to 1.2 mm. Samples of this was prepared by cutting into lengths of approximately (0.5 x 0.5 x 0.1) ± 0.1 cm, use being made of a diamond cutter. Prior to irradiation, annealing at 400 °C has been performed on the microscope glass slide for a period of 1 hour to remove any previously stored triboluminescence and irradiation history, also to stabilize the trap structure. The samples were subsequently irradiated with ^{60}Co gamma rays (mean energy 1.25 MeV) using an irradiator available at the Department of Physics, University of Malaya, with dose delivery ranging from 0 to 10 Gy. The irradiations were performed 24 hours before the spectroscopic characterisation.

The optical properties of material gives information on vibrational states, impurities, the existence and nature of defects. Herein, the Raman, Fourier Transform Infrared (FTIR) and Photoluminescence spectroscopies were used to determine the defects of crystalline lattice on vibrational modes, the absorption energy bang-gap and lattice structure of microscope glass slide samples, respectively. Raman and photoluminescence (PL) spectra were obtained using a RENISHAW InVia Raman Spectroscope available at Department of Physics, University of Malaya based on an Argon Ion laser source operating at 514 nm. The Raman system provides resolution of 0.5 cm^{-1}, use being made of a Qontor confocal Raman Microscope with confocal depth profiling at step sizes down to 0.1 µm at room temperature. Raman spectra were taken for inverse wavelengths of 400 cm^{-1} to 1200 cm^{-1}. Photoluminescence (PL) measurement was followed through; a detector built-in into the Renishaw Raman spectroscopy and with the same operating laser, PL spectra were obtained from 400 cm^{-1} to 1500 cm^{-1}. Fourier-transform infrared spectroscopy (FTIR) measurements was carried out at the Department of Chemistry, University kof Malaya, using Perkin Elmer (FTIR-Spectrum 400) in the range between 400-4000 cm^{-1} to identify the functionalization of silica structures present in microscope glass slide.

3.0 Results and Analysis

3.1 Raman spectroscopy analysis of microscope glass slide

Raman spectroscopy has been one of the established technique in studying radiation damage on matter due to its high sensibility to the presence of structural defects and relatively non-destructive. Figure 1 shows the room-temperature Raman spectra of microscope glass slide irradiated to ^{60}Co gamma-rays source for doses 0 to 8 Gy. The Raman peaks herein were fitted using OriginPro 2018 software to represent the vibrational bands in the glass media. The prominent peaks of microscope glass slide are observed at 595-, 796- and 1091 cm^{-1} Raman bands for 0 and 2 Gy dose (Figure 1(a)), meanwhile the 609-, 693- and 810 cm^{-1} Raman peaks appeared at 4, 6 and 8 Gy doses (Figure 1(b)). For the investigated microscope glass slide, it has been found that the 595 cm^{-1} of Raman band is the characteristic of ring breathing modes where further deconvolution of spectra lead to demonstrate the metaborate rings and of other borate- and borosilicate-ring unit groups. The Raman peak below the 550 cm^{-1} band is due to couple vibrations of the same type by changing the Si-O-Si angle which resulted in the asymmetric band. The 609 cm^{-1} and 693 cm^{-1} Raman bands correspond to the breathing mode of borosilicate rings, showing its characteristics in the regime between 550 to 850 cm^{-1} (Meera et al, 1990, 1993). The significant Raman band at 796 cm^{-1} is observed to possess a behavior of four-coordinated boron in diborate and boroxol rings (Meera et al, 1990; Konijnendijk & Stevels, 1975, 1976; Maniu et al, 1995, 1997; Iliescu et al, 1993), attributing to bending vibration of B-O-B bond. The frequency region of 810 cm^{-1} Raman band complies the stretching and deformation modes of Si-O-Si bond. The intense band around 1091 cm^{-1} is assigned to the $Si-O^-$ stretching in a structural unit with one non-bridging oxygen atoms per silicon. The mentioned band is considered to represent a vibrational frequency assignable to a Si-O bridging oxygen stretching mode (Mysen & Frantz, 1994) or alternatively to a vibration in structural units associated with the metal cation (Fukumi et al, 1990; Neuville, 2006; Neuville et al, 2008).

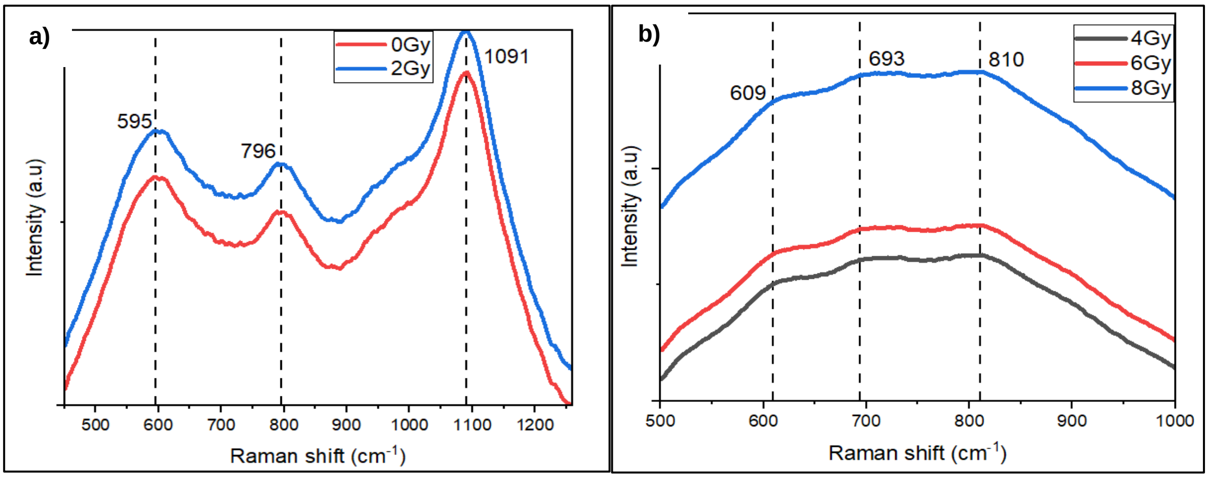

Figure 1 Room-temperature Raman spectra of microscope glass slide samples exposed to ^{60}Co gamma-rays for doses: (a) 0 and 2 Gy, and (b) 4, 6 and 8 Gy doses.

3.2 Fourier Transfer Infrared (FTIR) analysis of microscope glass slide

The information on infrared spectrum of adsorption that correspond to the frequency of vibration between the bonds of atoms in the material can be obtained by the fourier transfer infrared spectroscopy (FTIR) technique. The FTIR peak intensity is a direct indication of the nature of the materials present. The quantitative information about the change in structure of microscope glass slide due to irradiation, and the difference between irradiated and unirradiated spectra is shown in Figure 2 within the wavenumber range 500 to 4000 cm^{-1}. For qualitative analysis, the spectra is divided into three regions, including 500-1500 cm^{-1}, 1500-2000 cm^{-1} and 2000-2500 cm^{-1}. As seen in Figure 2, the FTIR spectra of Si–O stretching region of microscope glass slide is observed at 1060 cm^{-1} band; whereas the boron structure is appeared at around 1000 cm^{-1} due to stretching vibrations of BO_4 tetrahedron (Mcmillan et al., 1998). The FTIR band of the microscope glass slide from 800 to 1270 cm^{-1} centred around 1000 cm^{-1} is the combination of stretching vibration of Si-O-Si and B-O-B network of tetrahedral structural units, consisting of borate and silicate groups (Elbatal et al., 2016; Damrawi et al., 2016; Du & Stebbins, 2003; Nesbitt et al., 1998). A small peak appeared at around 700 cm^{-1} is correspond to bending vibrations of bridging oxygen between trigonal boron atoms (Stoch & Sroda, 1999). The position of the FTIR band at around 800 and 1000 cm^{-1} remain unchanged upon exposure to gamma radiation, conforming the main structure of microscope glass slide which consist of tetrahedral units of borate and silicate groups. This phenomenon influenced the degree of connectivity of the glass forming network and plays a significant role in radiation hardness. The latter proves the suitability of microscope glass slide to be used in dosimetry sterilisation application as demonstrated by the study of Abdul Sani et al., 2020 in thermoluminescence. The most striking feature due to gamma irradiation is the rapid decrease at about 800 cm^{-1} band and the concurrent increase around 1000 cm^{-1}. The observed band at 1500–1700 cm^{-1} can be attributed to molecular water vibration (Elbatal et al., 2016).

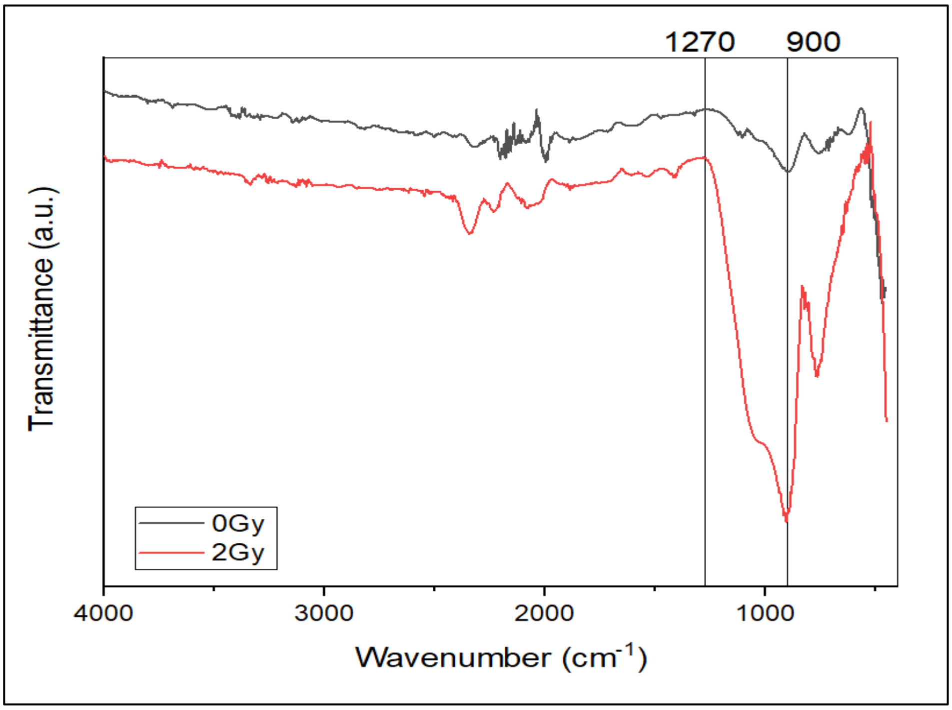

Figure 2 FTIR spectra for microscope glass slide. Comparison has been made between the unirradiated (at 0 Gy) and irradiated at 2 Gy dose of gamma-ray.

3.3 Photoluminescence (PL) spectroscopy analysis of microscope glass slide

Photoluminescence (PL) is a widely used technique for characterisation of the optical properties prior to yield valuable information of intrinsic and extrinsic transitions. In PL, the light directed onto a material is absorbed and subsequently re-emit photons where photoexcitation occurs. The distribution of energies involved in the photoabsorption and photoemission processes can be analysed in PL spectroscopy. Present work utilises PL spectroscopy to quantify the physical luminescence of microscope glass slide irradiated to gamma, which depends strongly on active centres, surrounding host composition and structural interactions. Figure 3 demonstrates the PL spectra with two prominent broad peaks centred at 595 nm and 1078 nm for dose range from 0 Gy to 10 Gy. The first peak, accordingly of shorter wavelength represent the absorption peak and the emission peak is correspond to the second peak, of longer wavelength within the range 400-1400 nm. The PL intensity of microscope glass slide has found to be increased linearly with respect to absorbed dose in line with results obtained in thermoluminescence (TL) study investigated by Abdul Sani et al., 2020; 2021, Ahmad Nazeri et al., 2021 and Alqahtahni et al., 2020a; 2020b. Based on the emission peak, the average bandgap, Eg values for microscope glass slide sample was evaluated using $Eg = hc/\lambda$, where h is the Planck constant, c the speed of light and λ the corresponding wavelength based on PL spectra. Sample average energy band gap value is observed to be 1.15 eV post-irradiation.

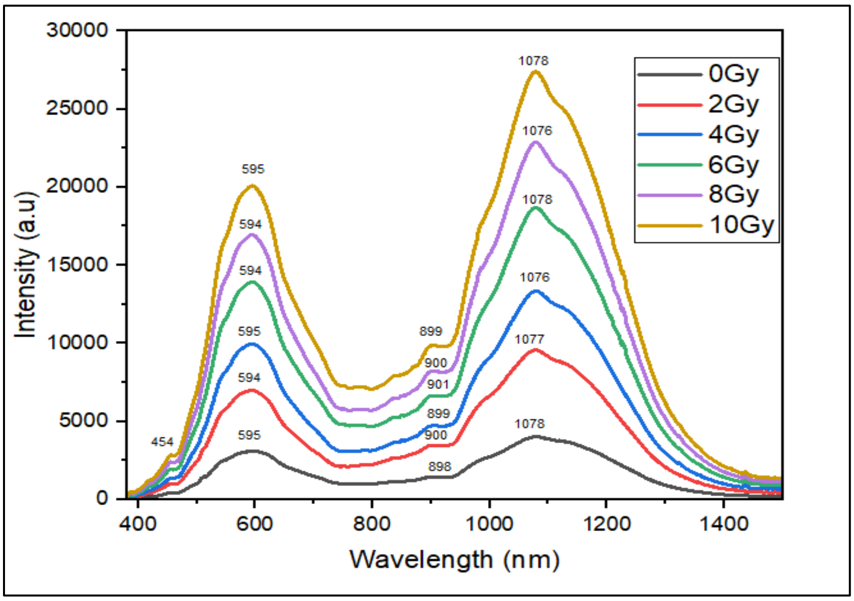

Figure 3 PL spectra of 0.1 mm microscope glass slides subjected to ^{60}Co gamma-rays irradiation.

Conclusion

We have investigated the optical properties of commercial microscope glass slides exposed to ^{60}Co gamma-rays through use of Raman, FTIR and photoluminescence (PL) spectroscopic techniques. These techniques are capable in identifying and establishing some understanding of the structural defects in the glassy media that influence the origin of luminescence of the material of interest. The results obtained from the various characterization techniques have been found to be mutually supportive, their response to gamma radiation exposures being readily understood at the microscopic level. Significant structural and chemical modifications by breaking bonds between BO_3 trigonal, SiO_2 and BO_4 tetragonal units have been found at such gamma irradiation, manifesting in changes in the shape, intensity and position of Raman, FTIR and PL spectra.

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