Sakarya University Journal of Science, 22 (6), 1518-1523, 2018.

SAKARYA UNIVERSITY
JOURNAL OF SCIENCE

e-ISSN: 2147-835X
http://www.saujs.sakarya.edu.tr

Received
21-07-2017
Accepted
28-11-2017

Doi
10.16984/saufenbilder.330029

Optical properties of the electron and gamma-ray irradiated soda-lime glass samples

Gulten Onay[1], Ramazan Sahin[*1]

ABSTRACT

Optical transmission and absorption spectra of Soda-lime glass samples were studied after irradiation by 8 MeV electron and γ-ray beams. We used modified clinical LINAC for production of electron beam whereas ^{60}Co was used as a γ-ray source. Optical properties of glass samples were analyzed for different doses and radiation types. Irradiation induced color centers in the glass samples were observed in both cases. Moreover, time-dependent optical properties were also acquired after irradiation source was turned off and we observed that these colour centers disappear slowly even at room temperature. Optical transmission spectra of 8 MeV electron and γ-ray beam irradiated samples show spectacular absorption band in the visible region. On the other hand, these absorption bands nearly recover themselves when the irradiated samples are baked for a short time above 100 ◦C.

Keywords: irradiation**,** soda-lime glass, gamma, electron beam, LINAC and ^{60}Co

1. INTRODUCTION

Interaction of high energy photons and accelerated charged particles with target materials has gathered an increasingly attention. γ-ray, photo-neutron (photo-n^0) and high energy electron beams (e^--beam) are widely used types of radiation. These ionizing beams can excite the electrons in target materials leaving the hole centers [1]. Transition of electrons between the states causes irradiation induced color centers in glassy materials [2]-[6]. Therefore, their contents define the interaction mechanism [7]-[14]. The response of glass samples to different radiation sources make them a better candidate for radiation protection [15]-[17] and sensing [18] applications. Moreover, glasses are used as substrates for thin film deposition. Therefore, when these thin films are exposed to radiation, the glass substrates are also affected by the radiation [19]. The effects of different kind of radiations on glass materials require more attention during and after irradiation with no dependence on field of use. Even though the majority of previous works focus the effects of radiation on the target glass samples, time-dependent analysis about irradiation induced colour centers are missing. So, in this work, we systematically applied different types of radiations to widely used soda-lime glass samples and characterized them at certain time intervals even after the radiation source was turned off. Moreover, bleaching of the irradiated glass samples is applied to quicken the recovery process.

2. EXPERIMENTS

In our experiments, soda-lime glass samples were employed from Sisecam Co., Turkey. The size of the samples were 1x1 *inch* and of 1 mm thickness. Before irradiation process, all glass samples were cleaned with acetone, isopropanol and pure water respectively by using an ultrasonic cleaner. After cleaning, glass samples were handled with dust-

[*] Corresponding Author
[1] Akdeniz University, Faculty of Science, Department of Physics, ramazansahin@akdeniz.edu.tr

free gloves throughout the experiments. One sample was used for each measurement and radiation type. We used ^{60}Co radioisotope as a natural source of γ-rays in the first part of our experiments. As a comparison a modified clinical LINAC (cLINAC) for research activities from Elekta was used as a source of e^-- beam. In cLINAC, a 50 keV potential difference was applied to an electron gun. Then, emitted electrons were accelerated by ~3 GHz radio- frequency and were collimated by magnets and electrostatic components. γ-rays obtained from ^{60}Co with average energy of 1.25 MeV and 8 MeV energy of e^- -beam obtained from cLINAC were directly sent to the glass samples. The beam on the sample side is very stable and homogenous. The details about the cLINAC can be found at [20]. For each type of radiation, consequent γ-ray and e^--beams were almost uniform on the sample. The dose rates are kept constant at 200 Gy/min and 7.5 Gy/min for γ-ray and e^- beams, respectively.

For each radiation type, we applied the following procedures. The glass samples were positioned perpendicular to incoming direction of the radiation beam. All experiments were conducted on at room temperature and in ambient conditions. First, the glass samples were irradiated by radiation source. Then, we measure transmission spectra of irradiated samples in the spectral range of 300-1000 nm by using a fiber coupled spectrometer (CCS200- Thorlabs).

Both total irradiation dose and its time-dependent behavior after the radiation source was turned off were observed through optical transmission measurement. From these results, we also calculated the change in absorption coefficient of the irradiated glass samples. In order to compare observed irradiation induced changes in optical properties, we used Abbe refractometer to measure refractive index of the glass samples before and after the irradiation at a certain irradiation dose.

We also baked the irradiated glass samples between 100-150 °C to see whether there was a recovery of irradiation induced effects in optical properties of glass samples. Therefore, we measured transmission spectra of irradiated samples after they were baked at 100 °C, 125 °C, 150 °C for an hour. Since we are interested in physical properties of irradiation induced effects on the chemical composition of target materials.

3. RESULTS AND DISCUSSION

We started irradiation experiments with ^{60}Co γ-ray source and the glass samples were irradiated for 30 min. then, by using cLINAC 8 MeV energy of e^- beam was used to irradiate the other glass samples for 30 min. Regardless of radiation type, all irradiated samples became brown. In order to observe the effect of the total dose in optical properties of glass samples, we gradually increased the radiation exposure time with 30 min intervals up to 120 min for each radiation type and different glass samples. Fig. 1 shows measured transmission spectra from irradiated samples at different doses. As it can be seen from the Fig. 1 that besides the overall decrease in transmission spectra in all wavelengths, there is a dramatic degradation in the visible region centered at a wavelength of 430 nm for both types of radiation. Moreover, these induced effects are very depend on the applied irradiation dose.

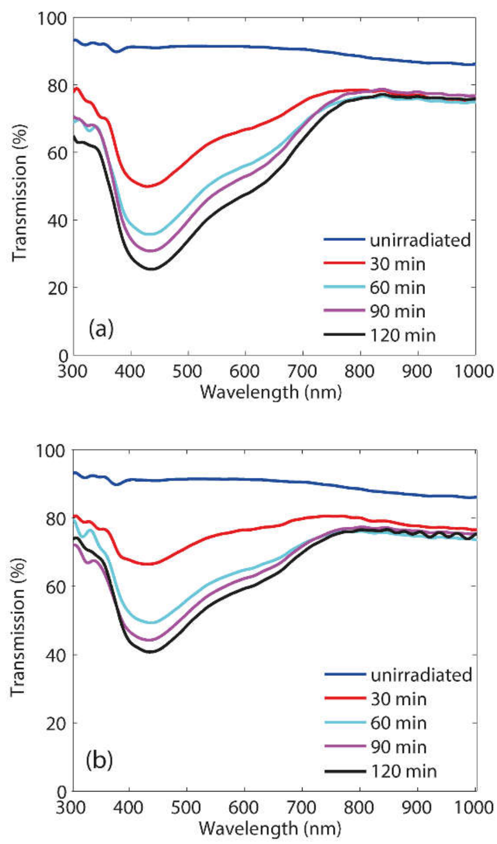


Figure 1 Optical transmission spectra of (a) e^- and (b) γ- ray beams irradiated samples with respect to total dose

We compared the obtained transmission spectra from irradiated samples to see the effect of the radiation type more clearly.

Fig. 2 shows measured transmission spectra of unirradiated and 2 hours irradiated glass samples with γ-ray and e⁻beams.

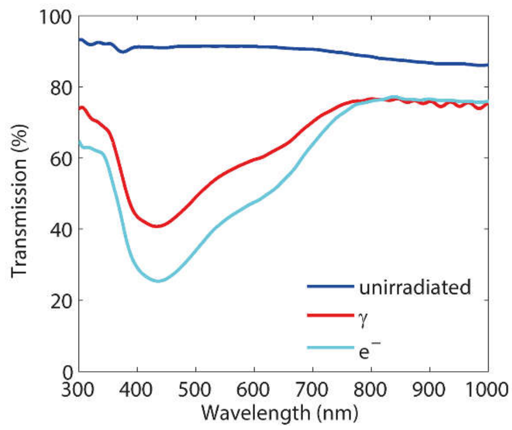


Figure 2 Optical transmission spectra of 2 hours irradiated glass samples with different radiation sources

Results show that absorption band in the VIS is very sensitive to irradiation type and applied dose. The change of refrective index of irradiated samples was also measured in order to relate relative decrease in transmission spectra with reflective index. The variation of the refractive index of the samples was measured at 589.3 nm wavelength (average of sodium D lines) via widely used Abbe refractometer by using proper index matching liquid. The refractive index value of the glass samples was measured as 1.5132±0.0005 prior to irradiation. The variation of the refractive index of the samples were measured as 0.0020 for 2-hour e^-beam irradiated samples.

The absorption coefficient (μ) of glass was defined as follows. T_0 and T_1 are transmission values before and after irradiation in which ω is the thickness of the sample in Eq. 1.

$$\mu = \frac{1}{\omega} In\left(\frac{T_0}{T_1}\right) \quad (1)$$

We calculated the absorption spectra for all irradiated samples. μ is found to increase in our spectral range due to the irradiation. In order to quantify the wavelength dependence, Fig. 3 shows calculated values of μ at three different wavelengths and for different radiation types. Our results showed that the absorption was totally depend on the irradiation dose for both γ-ray and e^--beams irradiation.

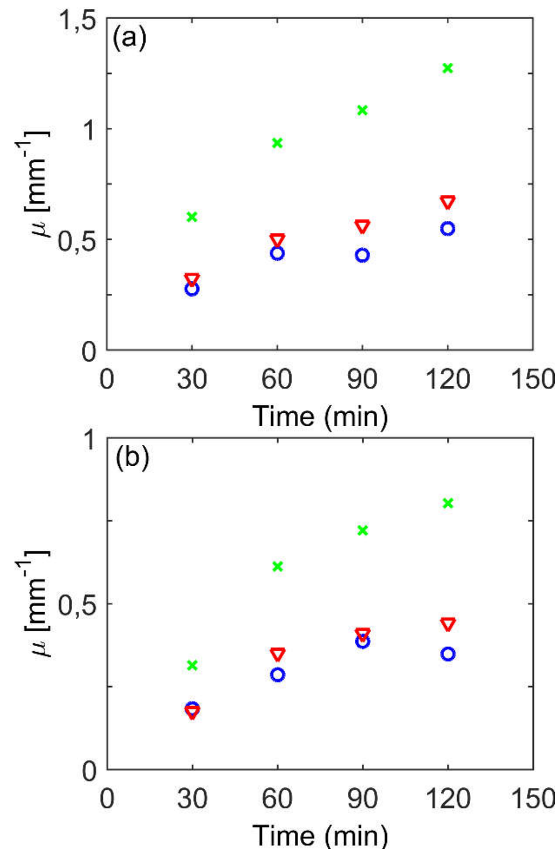
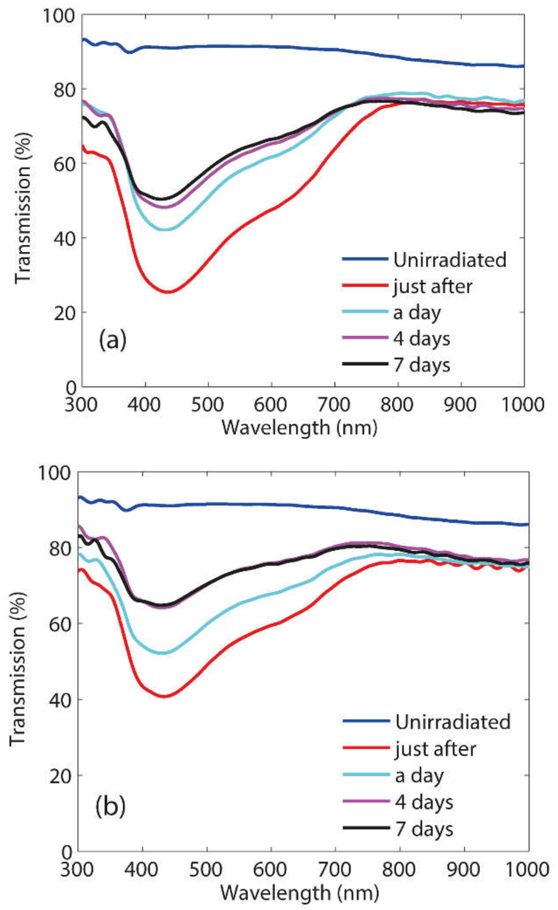


Figure 3 Calculated absorption values for (a) γ-ray and (b) e^- beams irradiation at three wavelengths.

This dependence was very large around 430 nm. Since the irradiation induced refractive index change [21], [22] effects the reflectivity of the glass samples, one should take into acoount the reflectivity change while calculating the absorption coefficient. However, it was found in [5], this was only effective in the range of 220-275 nm. Our results are in the spectral range of 300-1000 nm. Therefore, we disregard its effect on calculation of μ. We also measured % 0.2 change in the refractive index at 590 nm which is in agreement with [5].

We also analyzed the time dependence of induced effects on the glass samples. Throughout the experiments, irradiated samples were kept under daylight at room temperature. Transmission spectra of irradiated samples were 30 min, a day, 4 days and 7 days after the radiation sources were turned off. Fig. 4 shows obtained results from 2-hours irradiated samples. Since the irradiated samples were kept in ambient conditions, a very small increase in transmission spectra in VIS was acquired for both e^- and γ-ray beams irradiation cases even at room temperature.



Şekil 4 Time-dependent optical transmission measurements on 2 hours (a) e⁻ and (b) γ-ray beams irradiated glass samples

However, this recovery nearly stops and transmission spectra preserves itself after 4 days. On the other hand, transmission spectra obtained from irradiated samples kept in dark at room temperature did not show prominent increase even after a week. In order to quicken the recovery process we baked the irradiated samples for an hour at 100 °C, 125 °C and 150 °C. Obtained results are presented in Fig. 5.

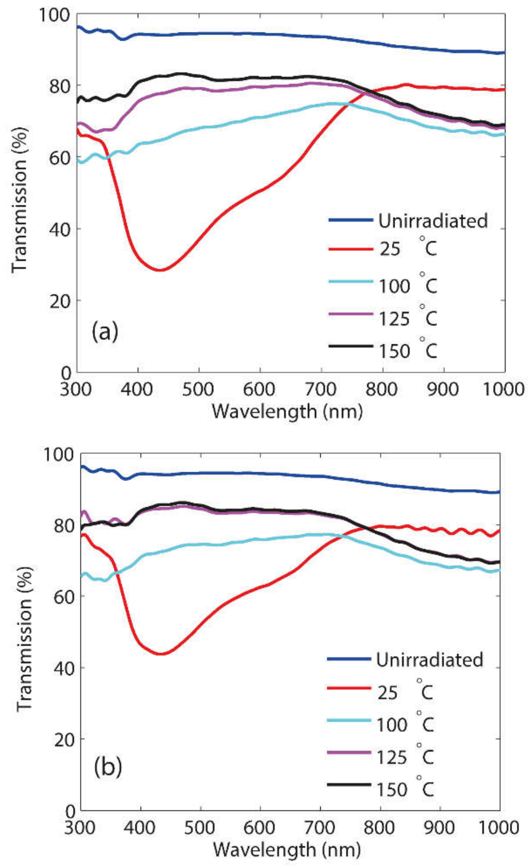


Figure 5 Effects of bleaching on the optical transmission spectra of 2 hours (a) e^- and (b) γ-ray beams irradiated glass samples.

After bleaching, the induced absorption dip around 430 nm was disappeared although the overall increase in absorption was observed. Moreover, the temperatures in our experiments are well below the glass melting point, bleaching allows the rearrangement of electrons in the states. This behavior was also observed by [5] in transmission spectra of γ-ray irradiated borosilicate glass samples.

4. CONCLUSION

Our results showed that regardless of types of irradiation same types of colour centers were produced in soda-lime glass samples. Strong absorption band around 430 nm was obtained with respect to total applied dose. Absorption coefficient of glass samples with respect to total dose and types of irradiation was calculated. These calculations clearly show that one should take into account the optical properties of glass samples exposed to irradiation. We have also conducted on time-dependent experiments immediately after the radiation source was turned off. We also found that irradiation induced effects change in time even at room temperature under daylight. The transmission of irradiated glass samples approximate to that of unirradiated glass samples after a week. In order to quiken this recovery, we baked the irradiated samples at different temperatures for an hour. We found that this process is much efficient at higher temperatures.

ACKNOWLEDGMENTS

The authors thank NUBA (Akdeniz University Nuclear Research and Application Center) for irradiation facility. We also would like to thank Dr. Timur Sahin for useful discussions.

REFERENCES

[1] A. Bishay, “Radiation induced color centers in multicomponent glasses,” *Journal of Non-Crystalline Solids* vol.3 no.1, pp. 54-114, 1970.

[2] S. M. J. Akhtar, M. Ashraf, S. H. Khan, “A study of neutron and gamma radiation effects on transmission of various types of glasses, optical coatings, cemented optics and fiber,” *Optical Materials*, vol. 29, pp. 1595-1603, 2007.

[3] F. H. ElBatal, M. A. Marzouk, A. M. Abdelghany, “Uv-visible and infrared absorption spectra of gamma irradiated V_2O_5-doped in sodium phosphate, lead phosphate, zinc phosphate glasses: A comparative study,” *Journal of Non-Crystalline Solids*, vol. 357, no. 3, pp. 1027-1036, 2011.

[4] A. Morono, P. Martin, A. Gusarov, E. R. Hodgson, “Radiation induced absorption and luminescence of selected alternative radiation resistant glasses,” *Journal of Nuclear Materials*, vol. 386-388, pp. 1030-1033, 2009.

[5] J. Du, J. Wu, L. Song, L. Zhao, “Reflectivity and absorption coefficient of a borosilicate glass during Co-60-gamma irradiation calculated from data measured by an integrating sphere,” *Radiation Effects and Defects in Solids*, vol. 167, no. 1, pp. 37-48, 2012.

[6] J. Du, J. Wu, L. Zhao, L. Song, “Color centers of a borosilicate glass induced by 10 MeV proton, 1.85 MeV electron and ^{60}Co-γ ray,” *Radiation Physics and Chemistry*, vol. 86, pp. 59–63, 2013.

[7] A. M. Abdelghany, H. A. ElBatal, F. M. EzzElDin, “Influence of CuO content on the structure of lithium fluoroborate glasses: Spectral and gamma irradiation studies,” *Spectrochimica Acta Part A-Molecular and Biomolecular Spectroscopy*, vol. 149, pp. 788–792, 2015.

[8] F. H. ElBatal, M. A. Ouis, A. M. Abdelghany, N. A. Ghoneim, “Structural and Optical Correlation of Gamma-Irradiated 3d Transition Metals-Doped Lithium Disilicate Glasses,” *Silicon*, vol. 7, no. 4, pp. 409– 417, 2015.

[9] N. Baydogan, A. B. Tugrul, “Borosilicate glass for gamma irradiation fields,” *Solid State Sciences*, vol. 14, no. 11-12, pp.1692–1697, 2012.

[10] C. Bootjomchai, “Comparative studies between theoretical and experimental of elastic properties and irradiation effects of soda lime glasses doped with neodymium oxide,” *Radiation Physics and Chemistry*, vol. 110, pp. 96–104, 2015.

[11] S. Baccaro, A. Cemmi, I. Di Sarcina, F. Menchini, “Gamma Rays Effects on the Optical Properties of Cerium-Doped Glasses,” *International Journal of Applied Glass Science*, vol. 6, no. 3, pp. 295–301, 2015.

[12] R. Kaur, S. Singh, O. P. Pandey, “Influence of CdO and gamma irradiation on the infrared absorption spectra of borosilicate glass,” *Journal of Molecular Structure*, vol. 1049, pp. 409–413, 2013.

[13] T. V. Bocharova, D. S. Sysoev, V. A. Aseev, N. O. Tagil’tseva, “Radiation-induced color centers in phosphogermanate glass-like materials,” *Glass Physics and Chemistry*, vol. 41, no. 4, pp. 378–384, 2015.

[14] M. A. Marzouk, Y. M. Hamdy, H. A. ElBatal, F. M. E. ElDin, “Photoluminescence and spectroscopic dependence of fluorophosphate glasses on samarium ions concentration and the induced defects by gamma irradiation”, *Journal of Luminescence*, vol. 166, pp. 295–303, 2015.

[15] P. Yasaka, N. Pattanaboonmee, H. J. Kim, P. Limkitjaroenporn, J. Kaewkhao, "Gamma radiation shielding and optical properties measurements of zinc bismuth borate glasses," *Annals Of Nuclear Energy*, vol. 68, pp. 4-9, 2014.

[16] C. Bootjomchai, J. Laopaiboon, C. Yenchai, R. Laopaiboon, "Gamma-ray shielding and structural properties of barium-bismuth-borosilicate glasses," *Radiation Physics and Chemistry*, vol. 81, no. 7, pp.785-790, 2012.

[17] A. Saeed, R. M. El Shazly, Y. H. Elbashar, A. M. Abou El-azm, M. M. El-Okr, M. N. H. Comsan, A. M. Osman, A. M. Abdal-monem, A. R. El-Sersy, "Gamma ray attenuation in a developed borate glassy system," *Radiation Physics and Chemistry*, vol. 102, pp. 167-170, 2014.

[18] P. Dandamudi, M. N. Kozicki, H. J. Barnaby, Y. Gonzalez-Velo, M. Mitkova, K. E. Holbert, M. Ailavajhala, W. Yu, "Sensors based on radiation-induced diffusion of silver in germanium selenide glasses," *IEEE Transactions on Nuclear Science*, vol. 60, no. 6, pp. 4257-4264, 2013.

[19] I. Kabacelik, H. Kutaruk, S. Yaltkaya, R. Sahin, "Gamma irradiation induced effects on the TCO thin films," *Radiation Physics and Chemistry*, vol. 134, pp. 89-92, 2017.

[20] I. Boztosun, H. Dapo, M. Karakoç, S.F. Özmen, Y. Çeçen, A. Çoban, T. Caner, E. Bayram, T.R. Saito, T. Akdoğan, V. Bozkurt, Y. Küçük, D. Kaya, M. N. Harakeh, "Photonuclear reactions with zinc: A case for clinical linacs," *The European Physical Journal Plus*, vol. 130, no. 9, pp. 185, 2015.

[21] F. M. Ezz-Eldin, I. Kashif, H. A. El-Batal, "Some physical properties of gamma irradiated alkali-silicate glasses," *Radiation Physics and Chemistry*, vol. 44, no. (1-2), pp. 39-43, 1994.

[22] A. Gusarov, D. Doyle, A. Hermanne, F. Berghmans, M. Fruit, G. Ulbrich, M. Blondel, "Refractive-index changes caused by proton radiation in silicate optical glasses," *Applied Optics*, vol. 41, no. 4, pp. 678–684, 2002.