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EXAMINATION OF NUCLEAR TRACKS IN MICA AND LR-115 TYPE II SSNTDs WITH NEUTRONS, GAMMA AND ALPHA RADIATION

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Abstract

Solid state detectors (SSNTDs) are the most effective devices currently utilized in ionizing radiation detection due to their ease of usage. The relationship between SSNTDs (mica and LR-115) and various radiations (neutrons, gamma, and alpha) were examined in this work. Mica and LR-115 type II detectors were irradiated by neutrons from the Am(Be) source with a flux of 10^4 neutrons $cm^{-2}s^{-1}$, alpha from the Po-210 source with activity of 0.1 µCi, and gamma from the Co-60 and Cs-137 sources. For preliminary studies, the neutrons and gamma irradiation times for mica and for LR-115 were 7 days. After irradiation, the detectors were etched with 48 % HF solution and 6 M NaOH solution, respectively, by using two etching methods: conventional chemical etching (CE) and ultrasonic-induced chemical etching (UCE). To study the relation between radiation exposure time and nature of detectors, the detectors were exposed to neutrons for 7, 14, 21, and 28 days and alpha radiation for 30, 45, 60, and 75 min. The doses of gamma rays for mica and for LR-115 were 100 Gy, 200 Gy, 300 Gy, and 400 Gy, respectively. After irradiation, the tracks formed were etched with 48 % HF solution (for mica) and 6 M NaOH solution (for LR-115) for 30 s using an ultrasonic cleaner. The etched tracks in irradiated mica and LR-115 detectors were observed by using optical microscopes and FT IR methods. The LR-115 detector is the most effective at detecting alpha radiation, while the mica detector is better at detecting neutrons and gamma radiation. Because a higher track density forms, the LR-115 detector is better suited for alpha detection than mica. The potential of SSNTDs (mica and LR-115) to serve as reliable dosimeters has been demonstrated.

Keywords: SSNTDs, Mica, LR-115, neutrons, gamma and alpha radiations

Introduction

Innovative materials called solid state nuclear track detectors (SSNTDs) are utilized mainly in nuclear and radiation safety applications to detect ionizing radiation (Durrani and Bull, 1987). These detectors capture the tracks made by charged particles as they go through a medium by taking advantage of special characteristics of some solid materials (Shi-Lun *et al*., 2020). The interaction of ionizing radiation with a solid medium, usually made of polymers or crystalline solids, is the fundamental idea underlying SSNTDs. Ionization occurs along the path of a charged particle, like an alpha or beta particle, as it passes through the detector. The material develops latent tracks as a result of the localized damage caused by this ionization (Fleischer *et al*., 1975). The detector undergoes a chemical etching procedure to reveal these tracks. The damaged areas are removed selectively by the etching, leaving behind pits or tracks that are visible under a microscope. Quantitative analysis is possible since the density and distribution of these tracks are proportional to the radiation exposure level (Nikezic and Yu, 2009). There are mainly two types of SSNTDs: inorganic detectors such as crystals, glass, mica, etc. and organic detectors, mainly polymers.

Mica is found in sedimentary, metamorphic, and igneous environments and is extensively spread. Mica is mechanically stable in micrometer-thin sheets that are comparatively transparent

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to radiation and stable when exposed to electricity, light, moisture, and extremely high or low temperatures. Muscovite mica has been utilized as windows in high-temperature furnaces and ovens due to its excellent heat tolerance and ability to split into thin, clear sheets. It was once used to create circuit boards and is an insulator (Gauidotti, 1984). For high voltage, muscovite mica is a very stable and good insulator material. It can withstand vibration, high temperatures, and mechanical and thermal shock. Additionally, muscovite mica is utilized for radiation insulation, X-ray equipment, and radiation pyrometers (Win Ko *et al*., 2019).

Thin films of a unique cellulose nitrate, coated on a polyester foundation that is 100 μm thick and dyed a deep red, compose the LR-115 type II detectors. These films are sensitive only on one side. The sensitive layer of "LR-115 type II" films has a thickness of 12 μm. At the end of the washing step, the base must be still wet in order to remove the red-sensitive layer of the Type II stripping film (strippable) (Benton and Henke, 1972).

In the present work, the preliminary determination of nuclear tracks in mica and LR-115 was studied using neutrons isotopic sources and gamma isotopic sources. After irradiating, the detectors were etched using two different etching methods, and the resulting track density values were compared. From this preliminary study, the best etching method was chosen for further studies. The relation between exposure time and nature of detectors was also studied by varying the different exposure times and radiation doses. Track visualization was examined by an optical microscope, and characterization was done by FT IR spectroscopy.

Materials and Methods

Materials

Muscovite mica ($KAl_3Si_3O_{10}(OH)_2$) was collected from the Department of Geology, University of Yangon, and LR-115 type II SSNTDs ($C_6H_8O_9N_2$) are available commercially. The standard isotopic sources Am(Be), Co-60, and Cs-137 are from the Nuclear Lab, Department of Chemistry, University of Yangon. A Co-60 gamma chamber is installed at the Department of Atomic Energy (DAE), Ministry of Science and Technology. The isotopic source Po-210 is located at the Nuclear Physics Lab, Department of Physics, University of Yangon. All other chemicals utilized were of an analytical reagent grade. The suggested standard procedures and methodologies, utilizing both conventional and modern methods, were provided throughout each study.

Interaction with thermal neutrons

The 1×1 cm^2 size mica and LR-115 type II SSNTDs were irradiated with thermal neutrons from an Am(Be) isotopic source with a flux of 10^4 ncm^{-2} s^{-1} at 3 cm distance from the source for 7, 14, 21, and 28 days at the Nuclear Laboratory, Department of Chemistry, University of Yangon.

Interaction with Co-60 and Cs-137 sources

The prepared SSNTDs were irradiated with gamma rays from Co-60 (4092 kBq) and Cs-137 (4109 kBq) sources for 7 days at the Nuclear Laboratory, Department of Chemistry, University of Yangon.

Irradiation with Co-60 gamma chamber

Similarly, 1×1 cm^2 size mica and LR-115 type II SSNTDs were irradiated with 100 Gy, 200 Gy, 300 Gy, and 400 Gy gamma radiation of Co-60 with the dose rate of 420 Gy/h at the Department of Atomic Energy (DAE), Ministry of Science and Technology.

Interaction with alpha radiations

The prepared 1×1 cm^2 size SSNTDs were irradiated with alpha radiation from the Po-210 isotopic source with 0.1 µCi for 30 min, 45 min, 60 min, and 75 min at Nuclear Physics Lab, Department of Physics, University of Yangon.

Etching methods

Two etching methods—conventional chemical etching (CE) and ultrasonic-induced chemical etching (UCE)—were used to compare the track density of SSNTDs in the preliminary investigation. In conventional chemical etching, a mica detector was etched with a 48 % HF solution for 1 h at room temperature, and an LR-115 type II detector was etched with a 6 M NaOH solution for 1 h at 50 °C using a water bath. In ultrasonic-induced chemical etching, the same procedure was used as the conventional method but used an ultrasonic cleaner instead of operating at room temperature and using a water bath. The etching time is much reduced for ultrasonic-induced chemical etching. It is only 30 s.

Track investigation and characterization

After etching, the latent etched tracks on the SSNTDs were enlarged and investigated using an optical microscope (OLYMPUS BX51) at the Microscopy Lab, Universities' Research Centre. The images 40× (400) were recorded in the JPEG format. It was also concerned with examining the composition of SSNTDs before and after irradiation by using other auxiliary methods such as FT IR (Perkin Elmer Spectrum Two) at the Department of Chemistry, University of Yangon.

Results and Discussion

Preliminary investigation with standard isotopic sources

In the preliminary investigation, the detection of neutrons from Am(Be) source and gamma rays from Co-60 and Cs-137 sources with mica and LR-115 was studied. According to the photomicrographs as shown in Figures 1 (a and b) and 3 (a and b), the used isotopic sources are active as both detectors gave latent tracks under an optical microscope after etching with two etching methods (Skvarc, 1999).

According to Table 1, the net track density on mica detector etched at room temperature gave a lower in net track density value in comparison with using an ultrasonic cleaner. Similar to mica, LR-115 detector etched with an ultrasonic cleaner provided higher net track density than etched with a water bath (Layth, 2016). The results are shown in Table 2. It can also be clearly seen on Figures 2 and 4 that the ultrasonic-induced chemical etching provides higher track density than conventional chemical etching method.

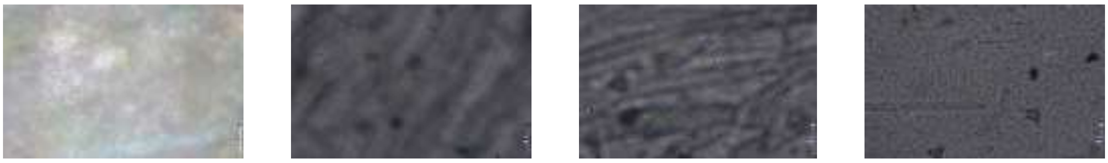


Figure 1 (a) Photomicrographs of mica detector before and after irradiation (etched with 48 % HF solution at room temperature)

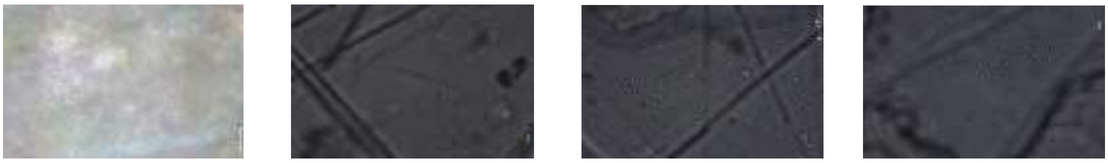


Figure 1 (b) Photomicrographs of mica detector before and after irradiation (etched with 48 % HF solution using ultrasonic cleaner)

Table 1. Net Tracks Density on Mica Irradiated with Different Radiation Sources

Sources	Net Tracks Density (tracks/cm^2)	
	Etched at Room Temperature	Etched with Ultrasonic Cleaner
Am(Be)	0.4729 $\times 10^4$	0.5966 $\times 10^4$
Co-60	1.0040 $\times 10^4$	1.1132 $\times 10^4$
Cs-137	0.8803 $\times 10^4$	1.0477 $\times 10^4$

Microscopic view area = 19.635$\times 10^{-4}$cm^2 ($\times$400 magnification)

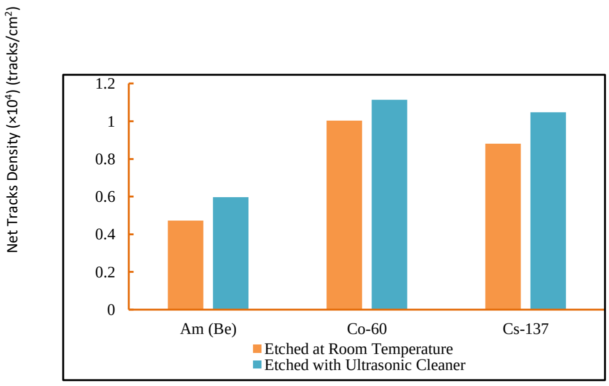
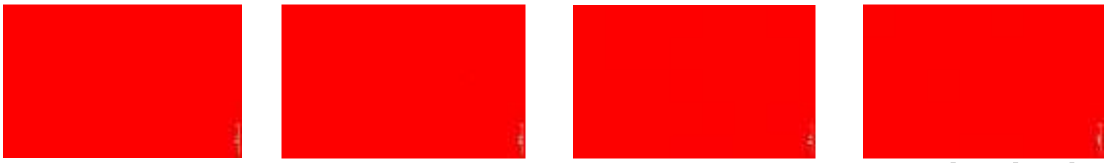


Figure 2. A bar graph of net track density on mica irradiated with different radiation sources

Figure 3 (a) Photomicrographs of LR-115 detector before and after irradiation (etched with 6 M NaOH solution using water bath)



Non-irradiated Irradiated with Am(Be) Irradiated with Co-60 Irradiated with Cs-137

Figure 3 (b) Photomicrographs of LR-115 detector before and after irradiation (etched with 6 M NaOH solution using ultrasonic cleaner)

Table 2 Net Tracks Density on LR-115 Irradiated with Different Radiation Sources

Sources	Net Tracks Density (tracks/cm^2)	
	Etched with Water Bath	Etched with Ultrasonic Cleaner
Am(Be)	0.0873×10^4	0.1964×10^4
Co-60	0.8367×10^4	0.9095×10^4
Cs-137	0.6912×10^4	0.8003×10^4

Microscopic view area = 19.635×10^{-4} cm^2 (×400 magnification)

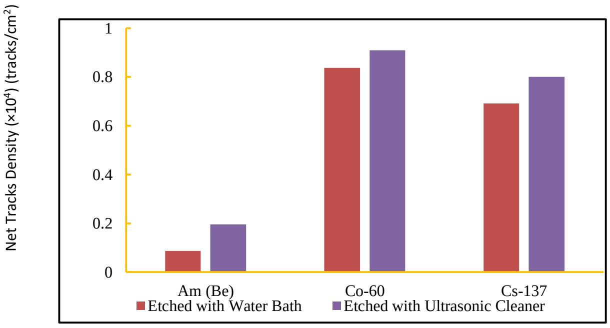
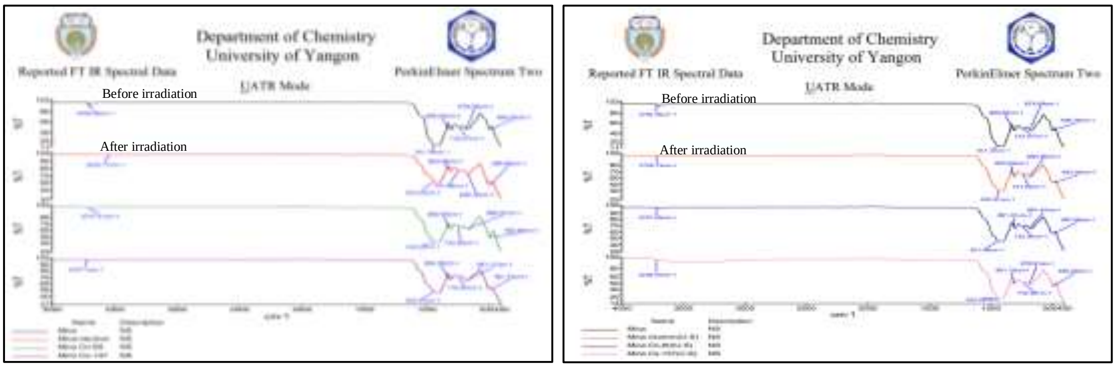


Figure 4 A bar graph of net track density on LR-115 irradiated with different radiation sources

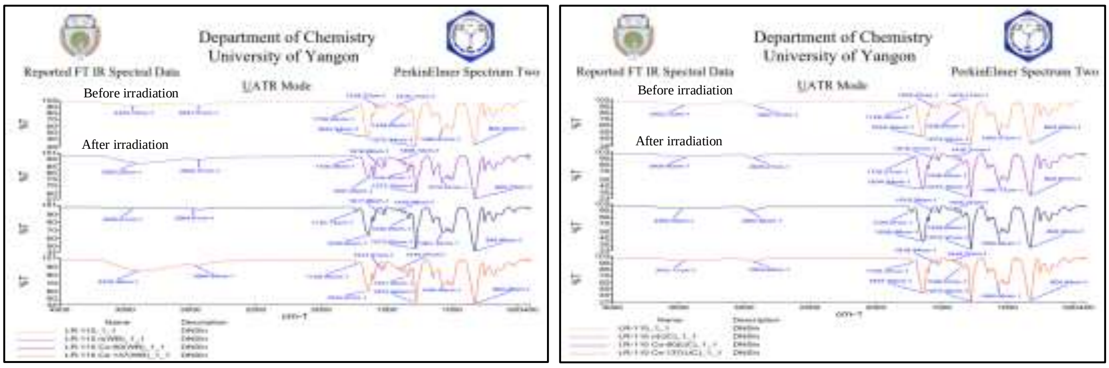
Characterization by FT IR

After irradiation, it is necessary to confirm that the chemical composition of detectors may be changed or not due to radiation. Therefore, FT IR technique was used to confirm. The FT IR spectra (Figures 5 and 6) show that there is a slight shift in wavenumber and % T in detectors but no significance change in the main functional group of the detectors (Win Ko *et al.*, 2019).



(a) At room temperature (b) Using ultrasonic cleaner

Figure 5 FT IR spectra of mica detector before and after irradiated with Am(Be), Co-60 and Cs-137 sources (etched with 48 % HF solution (a) at room temperature and (b) using ultrasonic cleaner)



(a) Using water bath (b) Using ultrasonic cleaner

Figure 6 FT IR spectra of LR-115 detector before and after irradiated with Am(Be), Co-60 and Cs-137 sources (etched with 6M NaOH solution (a) using water bath and (b) using ultrasonic cleaner)

Relation between exposure time and nature of detectors

Interaction with thermal neutrons

The study on the interaction of thermal neutrons with mica and LR-115 detectors (Figures 7 and 8) showed a positive correlation between radiation exposure time and the track density in both mica and LR-115 detectors. From the characterization of nuclear tracks by neutrons irradiation, it was found to give the formation of lines and the whole tracks on mica and LR-115. These formations of tracks agreed well with the literature (Acharya, 2011). As shown in Figure 9, mica can detect thermal neutrons for short exposure times; in contrast, LR-115 can detect them for longer exposure times. Moreover, Mica showed more latent tracks than the LR-115 detector. Therefore, Mica has a good neutrons-detecting nature, whereas LR-115 showed poor sensitivity to neutrons. The data on net track density are shown in Table 3. The highest value of net track density on both detectors was found to appear in highest irradiation time (28 days).

Non-irradiated 7 days 14 days 21 days 28 days

Figure 7 Photomicrographs of un-irradiated mica and mica irradiated with thermal neutrons (7, 14, 21, 28 days)

Non-irradiated 7 days 14 days 21 days 28 days

Figure 8 Photomicrographs of un-irradiated LR-115 and LR-115 irradiated with thermal neutrons (7, 14, 21, 28 days)

Table 3 Net Tracks Density on Neutrons- Irradiated Mica and LR-115 with Different Radiation Time

Irradiation Time (days)	Net Tracks Density (tracks/cm^2)	
	Mica	LR-115
7	0.5966×10^4	0.1964×10^4
14	0.6912×10^4	0.2692×10^4
21	0.8003×10^4	0.3492×10^4
28	0.8949×10^4	0.4147×10^4

Microscopic view area = 19.635×10^{-4}cm^2 (×400 magnification)

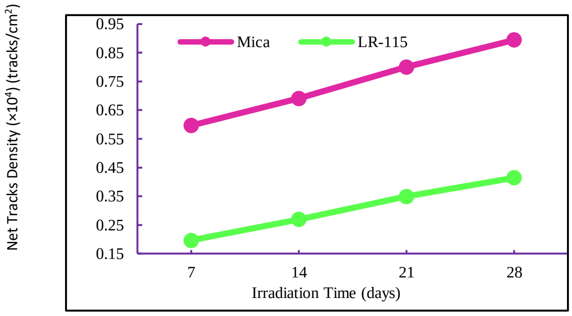


Figure 9 A line graph of net track density on neutrons-irradiated mica and LR-115 with different radiation time

Irradiation with Co-60 gamma chamber

From the characterization of nuclear tracks by different doses of gamma radiation (100 Gy, 200 Gy, 300 Gy, and 400 Gy) on mica and LR-115, it was found to give the formation of line and large hole tracks on mica, whereas less etched tracks with black spots appeared on the LR-115 detector. These formations of tracks agreed well with the literature (Boyett et al., 1970). It can be seen in Figures 10 and 11. Moreover, with the higher radiation doses, the higher track density on both mica and LR-115 was observed. According to Figure 12, mica has a good gamma-detecting nature, whereas LR-115 showed less sensitivity to gamma detection than mica. The calculated data of net track density are shown in Table 4. The track density in both detectors was getting greater along with the increasing doses of radiation.

Non-irradiated 100 Gy 200 Gy 300 Gy 400 Gy

Figure 10 Photomicrographs of un-irradiated mica and mica irradiated with gamma rays (100, 200, 300, 400 Gy)

Non-irradiated 100 Gy 200 Gy 300 Gy 400 Gy

Figure 11 Photomicrographs of un-irradiated LR-115 and LR-115 irradiated with gamma rays (100, 200, 300, 400 Gy)

Table 4 Net Tracks Density on γ- Irradiated Mica and LR-115 with Different Radiation Doses

Irradiation Doses (Gy)	Net Tracks Density (tracks/cm^2)	
	Mica	LR-115
100	8.2506×10^4	7.4357×10^4
200	9.4219×10^4	8.7598×10^4
300	9.7275×10^4	9.5238×10^4
400	10.084×10^4	9.7785×10^4

Microscopic view area = 19.635×10^{-4} cm^2 (×400 magnification)

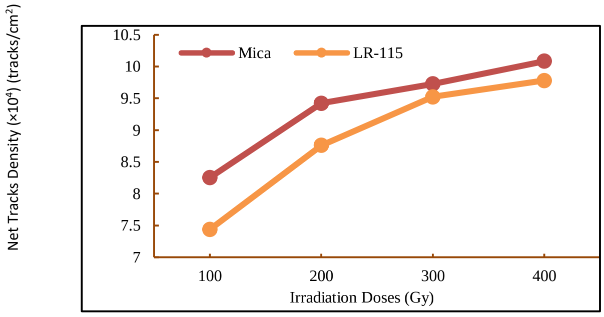


Figure 12. A line graph of net track density on γ-irradiated mica and LR-115 with different radiation doses

Interaction with alpha radiations

From this study, it can be confirmed that LR-115 can detect, especially for alpha. Across the tested alpha irradiation times (30, 45, 60, 75 min), track density in both mica and LR-115 showed a consistent increase with longer exposure. The characterization of nuclear tracks by alpha irradiation found the formation of holes and clear bright spots on mica and LR-115 (Boyett *et al*., 1970). It can be seen in Figures 13 and 14, LR-115 can detect alpha particles for short exposure times; in contrast, mica can only detect for longer exposure times. Moreover, LR-115 showed more and larger latent tracks than the mica detector. Therefore, LR-115 has better sensitivity for alpha detection, whereas mica showed poor sensitivity for alpha, as shown in Figure 15. These formations of tracks agreed well with the literature (Durrani, 1997). The data on net track density are shown in Table 5. The highest exposure time (75 min) provides the greatest value of track density on both mica and LR-115 detectors.

Non-irradiated 30 min 45 min 60 min 75 min

Figure 13 Photomicrographs of un-irradiated mica and mica irradiated with alpha particles (30, 45, 60, 75 min)

Non-irradiated 30 min 45 min 60 min 75 min

Figure 14 Photomicrographs of un-irradiated LR-115 and LR-115 irradiated with alpha particles (30, 45, 60, 75 min)

Table 5 Net Tracks Density on α- Irradiated Mica and LR-115 with Different Radiation Time

Irradiation Time (min)	Net Tracks Density (tracks/cm^2)	
	Mica	LR-115
30	1.4260×10^4	2.8011×10^4
45	2.2409×10^4	3.5651×10^4
60	3.3613×10^4	4.9910×10^4
75	3.8706×10^4	5.6022×10^4

Microscopic view area = 19.635×10^{-4} cm^2 (×400 magnification)

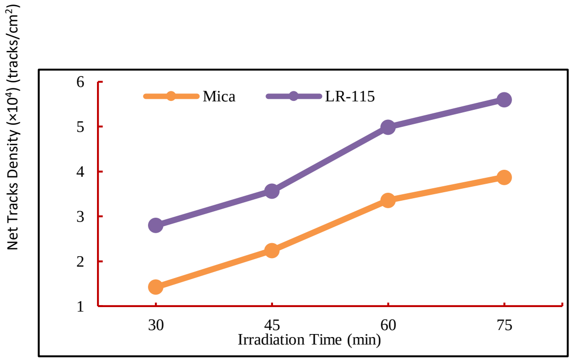
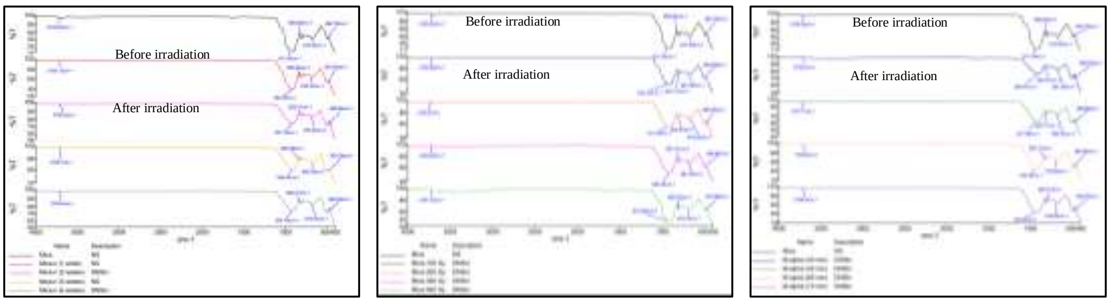


Figure 15 A line graph of net track density on α-irradiated mica and LR-115 with different radiation time

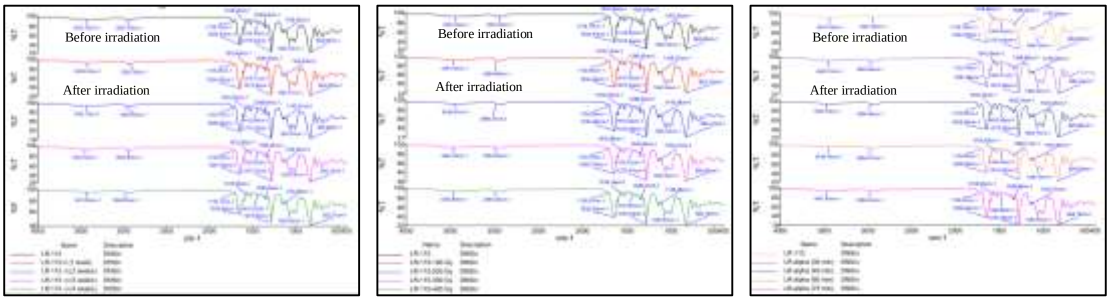
Characterization of irradiated SSNTDs by FT IR

The changes in composition of non-irradiated and irradiated mica and LR-115 SSNTDs were studied by FT IR. In this work, the effect of three different radiations (neutrons, gamma, and alpha) with different exposure times and doses on the sensitivity of mica and LR-115 detectors was studied by using the FT IR spectrometer. FT IR spectra are presented in Figures 16 and 17, respectively. FT IR spectroscopy is an important technique to understand the changes in molecular bands after irradiation. The changes have been estimated from the relative increase or decrease in the intensity of the typical bands associated with the functional group present in the detectors (Win Ko *et al.*, 2019). It was found that the wavenumber of functional groups in all irradiated detectors is slightly shifted by both three radiations, but there is no change in their functional groups. The observed potentiality of SSNTDs (mica and LR-115) suggested that they can be used as dosimeters.



(a) Neutrons irradiation (b) Gamma irradiation (c) Alpha irradiation

Figure 16 FT IR spectra of mica detector before and after irradiation (a) neutrons (b) gamma and (c) alpha radiations



(a) Neutrons irradiation (b) Gamma irradiation (c) Alpha irradiation

Figure 17 FT IR spectra of LR-115 detector before and after irradiation (a) neutrons (b) gamma and (c) alpha radiations

Conclusion

The present work deals with the study of the solid state nuclear track detectors (mica and LR-115) irradiated with neutrons, alpha and gamma radiation. The first part of this work is the preliminary investigation of nuclear tracks in mica and LR-115 detectors with neutrons and gamma standard isotopic sources. From the preliminary studies, the isotopic sources used are confirmed to be still active. From the comparison of the values of track density by using conventional chemical etching (CE) and ultrasonic-induced chemical etching methods (UCE), the UCE provides larger tracks with better discrimination from the background pits and improved selectivity of tracks. Moreover, using the UCE method enabled etching in a short period of time because the etching time lasted only 30 s. According to the second part, the relation between exposure time and the nature of detectors, different nuclear tracks were found by different kinds of radiation (neutrons, alpha, and gamma). Mica detectors are good for neutrons and gamma detection, but have a poor detection limit for alpha radiation. In contrast, the LR-115 detector has poor sensitivity to neutrons. It also has lower detection for gamma rays than mica. LR-115 performance as a detector is better for alpha than mica, as it is more sensitive to the alpha particles. Hence, the shape and density of nuclear tracks can be applied for searching for radioactive materials in the environment. From FT IR spectra of neutrons, gamma and alpha irradiated (mica and LR-115) detectors, it was found that the wavenumber of functional groups in all irradiated detectors of different irradiation times is slightly shifted. Thus, there is no change in their functional groups. The observations suggested that the potential of SSNTDs (mica and LR-115) can be used to produce dosimeters with them. The LR-115 detector is more suitable for alpha detection than mica due to the formation of higher track density. Mica can be used for the detection of neutrons and gamma rays, and due to lower cost and greater availability, a mica detector can also be utilised for the detection of alpha. It has been proven that both mica and LR-115 SSNTDs can be employed in the detection of neutrons, gamma, and alpha radiations.

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