HIROSAKI UNIVERSITY

Radiation Emergency Medicine 2015 Vol.4, No.2 25–28

REM
Radiation Emergency Medicine

Note

Transmission of Light through Recoiled Proton Tracks in Polycarbonate

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Received 30 September 2014; revised 16 December 2014; accepted 29 May 2015

Effect of light transmission through particle tracks due to scattering may be useful for softening the light to prevent glare in room lighting and in photography. This research aimed to investigate the effect of track density and track size of recoiled proton tracks registered in polycarbonate (PC) sheet on transmission of light. Locally-available PC plastic sheets for sunshade were irradiated with neutrons to produce latent recoiled proton tracks from (n, p) reaction. The latent tracks were then etched in a PEW solution which composed of 15% KOH, 40% ethanol and 45% water. The recoiled proton tracks were observed under an optical microscope and characterized by using the ImageJ program to obtain the average track density and size. Light and infrared transmission were finally tested using an energy transmission meter-SD 2400. In this study, four proton track-etch PC plastic sheets were prepared at 3 and 7 day irradiation times and different etching times from 15 to 60 minutes. The results showed that the prepared track-etch PC sheets could reduce intensity of visible light and infrared by approximately 4.7-15% and 1-12% in comparison with the untreated polycarbonate, respectively. The degree of reduction increased with increasing of track density. It could be concluded that the recoiled proton track-etched in PC sheets with different track densities lead to variation of transmission of visible light and IR by scattering with proton tracks.

Key words: Proton track, track-etch, polycarbonate, light transmission, light scattering

1. Introduction

The passage of nuclear particles through organic polymers breaks the long molecular chains by ionization and excitation. Broken chains ends and free radicals are produced in this region. The damaged region, called *latent track* (LT), extends to few tens of nm around the particle trajectory. These latent tracks can be made visible upon etching in a base solution and can be seen at low magnification under an optical microscope. Fleischer *et al.*[1] mentioned that cellulose nitrate, cellulose acetate and UV-sensitized Lexan are sensitive to protons of energy up to ~100 keV. Cellulose nitrate, cellulose acetate and Lexan have been widely used to detect protons and alpha particles. Lexan polycarbonate (PC) contains 45% of hydrogen atoms. Thus, irradiation PC with neutrons can produce recoiled proton tracks from interaction of neutrons with hydrogen atoms through (n, p) reaction. This method is most practical to produce uniformly distributed proton tracks in PC.

A commercial polycarbonate manufactured in Thailand is used in this study as nuclear track detector replacing the well-known detector materials Makrofol and CR-39. PC plastic, known by the trademarked names Lexan, Makrolon and Makroclear and others, are a particular group of thermoplastic polymers. The main polycarbonate material is produced by the reaction of bisphenol A and

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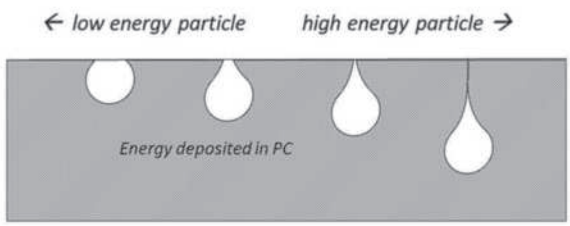

Fig. 1. Illustration of energy deposition in PC by low and high energy charged particles incident on its surface.

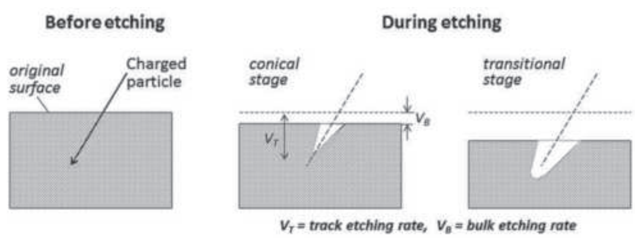

Fig. 2. Illustration of track enlargement during etching to make latent track visible.

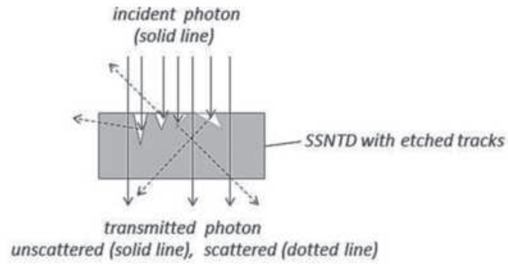

Fig. 3. Illustration of light photon scattering by etched tracks on PC.

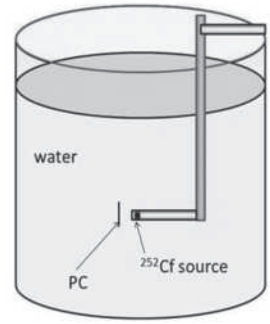

Fig. 4. The neutron irradiation facility using ^{252}Cf source.

Phosgene ($COCl_2$). It is a versatile, tough plastic used for a variety of applications. There are many researchers who used PEW solution as the etchant for nuclear track on PC[2-4] such as PEW solution composed of 15% KOH, 40% ethanol and 45% H_2O.

Track density is a function of neutron intensity and neutron irradiation time while track size is a function of neutron energy and etching condition including kind of chemical etchant, etching temperature and etching time. Figure 1 illustrates the energy deposition in PC by charged particles having different kinetic energies incident on the surface. The incident angles can also vary from 0 to 90 degrees which make track shapes and sizes different. For recoiled proton tracks from (n, p) reaction with hydrogen atoms in PC, the reaction can randomly take place throughout the PC sheet. Recoiled proton tracks, therefore, will be distributed uniformly in the PC. Etching is a chemical reaction which is faster at higher temperature. Thus, etching at lower temperature requires longer etching time. The etching temperature also affects track shape because ratio of the etching rate along the particle trajectory (V_T) to the bulk etching rate (V_B) decreases with increasing of the etching temperature. In conclusion, at low temperature longer etching time is needed and the tracks are longer but narrower. Inversely, at high temperature shorter etching time is needed and the tracks are shorter with larger in diameters. Prolong etching time affects track shape reaching to transitional stage or spherical phase as illustrated in Figure 2.

Transmission of light depends on light scattering by nuclear tracks[5] as illustrated in Figure 3. In this preliminary study, the transmission of visible light and infrared (IR) through the variation of track densities and sizes of recoiled proton track-etched PC were investigated using a device called "Spectrum Detective" Energy Transmission Meter model SD2400.

2. Experimental

2.1. Preparation of track etched PC chips having different track densities and sizes

Etching temperature and etching time affect the size, shape and number of tracks on PC as mentioned earlier. Recoiled proton tracks on PC having different track densities and sizes were prepared by irradiating with neutrons from a californium-252 (^{252}Cf) radioisotope source. Locally available PC plastic having thickness of 1.5 mm was cut into small chips about 2 cm × 3 cm then placed near the ^{252}Cf radioisotope source submerged in the middle of a 100 cm diameter and 120 cm height water tank as shown in Figure 4. From measurement and calculation, the neutron flux at 1 cm was found to be approximately 5.6×10^6 cm^{-2} s^{-1}. The first two of PC chips were irradiated with neutrons for 3 days and the other two chips were irradiated for 7 days. All the four chips were etched in a PEW solution at 70℃ but using different etching times of 15, 35, 40 and 60 minutes as shown in Table 1. After etching, the PC chips were observed under an optical microscope with a magnification of × 100. Then

Table 1. Neutron irradiation times and etching times at 70°C of the prepared PC chips

PC Chip	Irradiation time	Etching time
No. 1	3 days	15 min.
No. 2	3 days	35 min.
No. 3	7 days	40 min.
No. 4	7 days	60 min.

Table 2. Track sizes and densities in the prepared PC under various conditions

Chip no.	Track density (tracks cm^{-2})	Track diameter (μm)			
		Mean	SD	Min.	Max.
1	3.74×10^5	6.76	2.21	2.31	12.77
2	5.83×10^5	6.35	2.46	2.19	16.61
3	5.39×10^5	7.81	1.64	1.03	13.31
4	1.11×10^6	7.53	1.65	3.10	15.97

Table 3. Percentages of visible light and IR transmission through the prepared PC chips

Condition	Transmission (%)		Difference (compared to the untreated PC)	
	Visible light	Infrared	Visible light	Infrared
Untreated	85	91	0	0
Chip no. 1	79	86	7.06	5.49
Chip no. 2	77	84	9.41	7.69
Chip no. 3	81	90	4.71	1.10
Chip no. 4	72	80	15.29	12.09

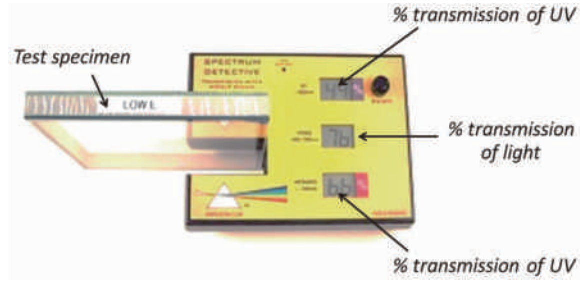

Fig. 5. "Spectrum Detective" Energy Transmission Meter model SD2400.

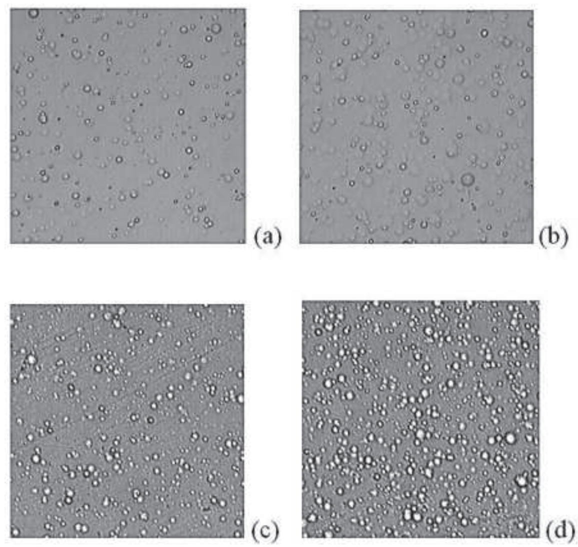

Fig. 6. Captured track images from optical microscope (× 100) (a) chip no. 1, (b) chip no. 2, (c) chip no. 3 and (d) chip no. 4.

the images were captured by using the Motic MC1000 software. The captured images were finally analyzed for track densities and sizes by using the ImageJ software. The results are shown in Table 2.

2.2. Effect of track density and size on transmission of light through the recoiled proton track-etched PC

The transmission of visible light and infrared (IR) through the track etched PC chips were measured by using the "Spectrum Detective" Energy Transmission Meter model SD2400 as shown in Figure 5. The device could be used to measure transmission of UV (365 nm), light and infrared (950 nm) simultaneously. In addition, light scattering was also tested by using red laser beam from a laser pointer pointing at the track etched PC to observe light diffision in comparison with the untreated PC having no recoiled proton trasks.

3. Results and Discussion

3.1. Track densities and sizes on the prepared PC chips

Recoiled proton track images in the four prepared PC chips are shown in figure 6. The track densities in the four chips were found to be 3.74×10^5, 5.83×10^5, 5.39×10^5 and 1.11×10^6 tracks cm^{-2} while the arithmatic means and the standard deviations of track sizes were found to be 6.60 ± 2.21, 6.35 ± 2.46, 7.81 ± 1.64 and 7.53 ± 1.65 mm, respectively.

3.2. Effect of track density and size on transmission of light through the recoiled proton track etched PC

According to Table 3, the percentages of transmission for visible light through the prepared track etched PC chips measured by using the Energy Transmission Meter model SD2400 were found to be 79, 77, 81 and 72%, respectively. For IR, they were found to be 86, 84, 90 and 80%, respectively. For the untreated PC chip (without recoiled proton tracks), the percentages of transmission for visible light and IR were found to be 85 and 91%, respectively. It could be noted that the transmission of visible light decreased with increasing of track density not track size. This was probably due to the fact that track sizes in the four chips of this experiment were within the same range from 1 to 16.6 mm. Obviously, the chip no. 4 which had the maximum track density of 1.11×10^6 tracks cm^{-2} could decrease transmission of light from 85 to 72% and of IR from 91 to 80% compared to the

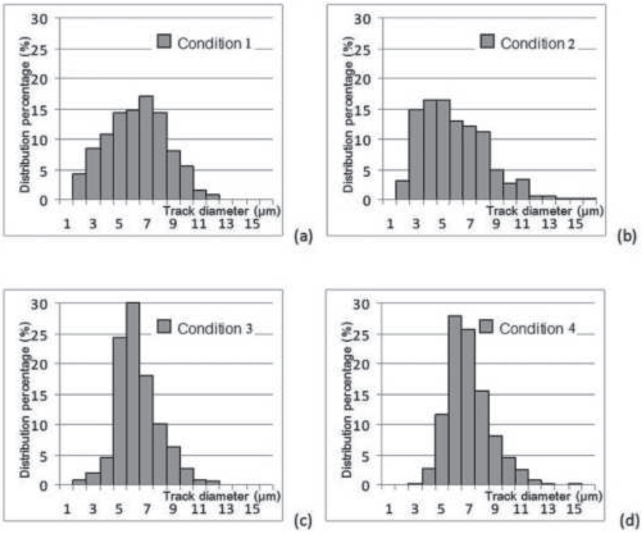

Fig. 7. Distribution of track diameters in (a) chip no. 1, (b) chip no. 2, (c) chip no. 3 and (d) chip no. 4.

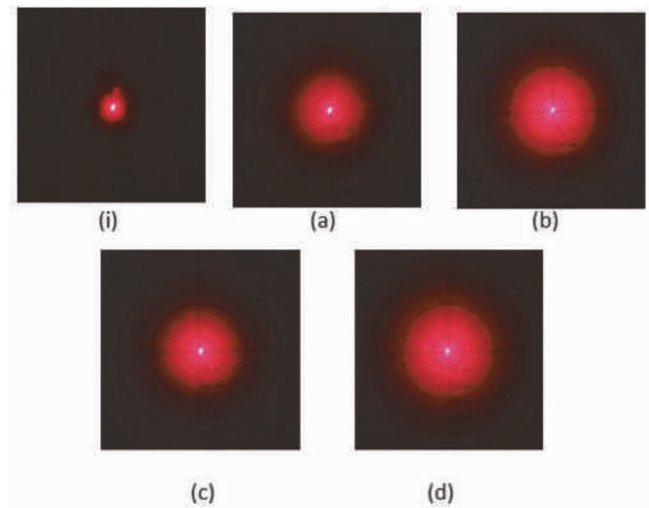

Fig. 8. Projection of red laser beam on the screen after passing through the untreated and the prepared track-etched PC chips.
(i) untreated, (a) chip no. 1, (b) chip no. 2, (c) chip no. 3, and (d) chip no. 4.

untreated PC, respectively.

Diffusion of red laser beam by the recoiled proton tracks in the four chips was compared by comparison of the diameters of the beams projected on a screen as shown in Figure 8. It was clearly observed that all of the track etched PC chips could cause diffusion of the laser beam compared to the untreated PC and the degree of diffusion increased with increasing of track density. In comparison to a frosted glass, diffusion of laser beam through the chip no.4 was nearly the same. Importantly, we could still see through the track etched PC chips but could not see through the frosted glass.

4. Conclusions

In this preliminary study, it could be concluded that the track-etched PCs could be used to reduce light intensity and the degree of reduction was dependent on the track density. Unfortunately, effect of track size on reduction of light intensity could not be observed in this study due to small difference of track sizes of the prepared track etched PCs. Further study is still needed to obtain the effect from track size. The advantage of track etched PC is that we can still see through it and it also can reduce light intensity. Diffusion of light through PC may help in softening of light to prevent glare such as in room lighting and photography. Preparation of thin recoiled proton track etched PC sheets to be used as window film for softening of light is under investigation.

Acknowledgements

The authors would like to express their deepest thanks to Dr. Chutima Kranrod, Mr. Surakit Khaopaew and Mr. Chalermpong Polee for their advices and support in theoretical and experimental aspects regarding track-etch technique.

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