Performance of Convenient Film Scanner System for Automatic Counting of Track Etched Pits on PADC Detectors

Daisuke Maki¹,²*, Fuminobu Sato¹, Isao Murata¹, Yushi Kato¹, Takayoshi Yamamoto² and Toshiyuki Iida¹

¹Division of Electrical, Electronic and Information Engineering, Graduate School of Engineering, Osaka University, 2-1 Yamadaoka, Suita, Osaka 565-0871, Japan
²Oarai Research Center, Chiyoda Technol Corporation, 3681 Narita-cho, Oarai-machi, Higashiibaraki-gun, Ibaraki 311-1313, Japan

Received Jun. 1, 2010; accepted Jul. 20, 2010

A commercially available film scanner and image processing software “ImageJ” were satisfactorily used for automatic counting of track etched pits on a PADC detector irradiated with α-rays. The performance of the α-ray counting system with the film scanner was examined by the use of a goniometric α-ray irradiation equipment. Under the etching condition of the soakage in 6.25M NaOH solution at 70°C for 20 hours, the α-ray detection efficiency of the film scanner system was about 0.6 time as small as that of the general system with an optical microscope. It was confirmed that PADC detectors together with the film scanner system could be conveniently used for radon monitoring in atmosphere.

Key words: PADC detector, track etched pit, film scanner observation system, ImageJ, automatic counting, radon monitoring

1. Introduction

Radon monitoring in living space has gradually become important around the world. One of radon detectors is polyallyl diglycol carbonate (PADC or CR-39) for counting α-rays from radon and its daughters. PADC detectors have been often used for monitoring of radon concentration in atmosphere since the early years of the 1970’s. The radon monitoring with PADC detectors is simple, inexpensive and effective in checking radon concentration in atmosphere at many positions. The number of tracks due to α-rays from radon and its daughters is integrated on a PADC detector over a long time interval. The counting of α-rays, actually of track etched pits on a PADC detector, is desired to be done automatically because the counting up to large number is necessary for sufficient statistics and such work is considerably troublesome. Thus, several automatic counting systems¹–⁴ based on optical microscopy have been developed for the analysis of track etched pits on PADC detectors with high resolution, though the cost of such systems is generally expensive.

A group of Health Protection Agency in UK has successfully used a commercial film scanner as an automated track counting system for PADC radon detectors.⁵,⁶ An image observed with a normal film scanner has lower resolution as compared with one observed with an optical microscope. It is, therefore, difficult to analyze the shape of track etched pits with high resolving power. However, the commercial film scanner is expected to be a simple and convenient tool for PADC radon detection system of which use is not limited to laboratories with a modern facility. Thus, the characteristic of the automated track counting with the film scanner is significant for the measurement of etched pits of α-rays. The comparison of image resolution between a film scanner and an optical microscope is very important, though there is not enough technical information on the automated track counting with a film scanner. The purpose of this paper is to examine the performance of a commercially available film scanner system for automatic counting of track etched pits on a PADC detector. Several PADC detector samples were irradiated with α-rays from an ²⁴¹Am source, and track...
etched pits on them were observed with the film scanner system. In a preliminary experiment, the film scanner system automatically counted the number of α-ray tracks on PADC detectors set in a basement.

2. Performance test

2.1 Alpha-ray irradiation

In order to examine the performance of the film scanner system counting track etched pits, several pieces of PADC detectors (Baryotrack, Fukubi Chemical Industry) were irradiated with $^{241}$Am α-rays at different incident angles. The track detection sensitivity depends on an angle of α-rays incident upon the PADC detector.\(^{(7)}\)

Figure 1 shows a schematic drawing of the experimental arrangement for the α-ray irradiation on a PADC detector sample in a vacuum chamber. The α-ray irradiation system was composed of the $^{241}$Am α-ray source, a collimator, a goniometric sample stage, a mechanical shutter, a vacuum chamber and a rotary pump. The PADC detector sample was set on the goniometric sample stage. The size of the sample pieces was $10 \times 10 \times 0.9 \text{ mm}^3$. The vacuum level in the chamber was kept around 10 Pa. The radioactivity of the α-ray source was $5.5 \times 10^3 \text{ Bq}$. The α-ray beam with a divergence angle of 5 degrees was obtained by means of a stainless steel tube (collimator) set in front of the α-ray source. The inside diameter and the length of the collimator were 4 and 50 mm, respectively. The exposure of the PADC detector samples to $^{241}$Am α-rays was controlled by means of the mechanical shutter. The incident angle $\theta$ of $^{241}$Am α-rays upon the PADC detector sample was changed by means of the goniometric sample stage from 0 to 70 degrees.

2.2 Observation of track etched pits

The α-ray-irradiated PADC detector samples were chemically etched in 6.25M NaOH solution at 70°C\(^{(8)}\) for 20 hours. Under this etching condition, the bulk etch velocity of the PADC detector was estimated to be about 1.5 μm/h from the thickness measurement by a digital micrometer (MD-C25MJ, Mitutoyo). The track etched pits on the PADC detector sample were observed with both a commercially available film scanner (CanoScan 8800F, Canon) and an optical microscope (OPTIPHOT-2, Nikon) every 4 hours.

A digital image, which was composed of 1959 pixels $\times$ 1959 pixels, was acquired with the film scanner for a few minutes. The film scanner had an optical resolution of 189 pixels/mm. The digital data on images of the track etched pits were recorded as 16-bit grayscale Bit MaP (BMP) images.

The analysis of the digital image data on the track etched pits was performed by the use of image processing software “ImageJ”. This software was developed at National Institute of Health (NIH) in USA and it can be downloaded at its website\(^{(9)}\) through the Internet. The α-ray tracks were counted on the basis of the judgment on their circular shapes after binarization process on the digital image data.

3. Results and discussion

$^{241}$Am α-rays almost perpendicularly entered a flawless face of a PADC detector sample through the collimator ($\theta = 0$ degree). The surface of the α-ray-irradiated PADC sample was observed with the optical microscope and the film scanner after the etching processes for 3, 6, 12, 20 hours. The observed images of track etched pits on the sample and their size (diameter) were compared between the microscope and film scanner systems.

Table 1 summarizes a series of observed images of track etched pits and their size on the PADC sample irradiated with $^{241}$Am α-rays. The images with the microscope had clear outlines of the etched pits on the basis of sufficient contrast, while on the other hand those with the film scanner gave rough outlines of the etched pits because of the low resolving power and poor contrast. Moreover, it should be noted that in the film scanner system light from an illuminator is refracted at an etched pit and it acts as like a concave lens\(^{(10)}\), in other words an etched pit itself magnifies its size. In geometrical optics, the PADC sample was uniformly exposed to light from the illuminator of the film scanner. Most part of light penetrated through the PADC sample without refraction and absorption, and a part of light was evidently refracted at an etched pit wall\(^{(11)}\), which caused contrast...
image of an etched pit on the light image sensor of the film scanner. This effect was found out also from the present experiment, i.e. from the comparison of the size of the observed images of the etched pits shown in Table 1. The size of every image of the etched pits observed with the film scanner is clearly larger than that with the microscope. Thus it is important to consider the light refraction at the etched pit in the film scanner system.

Contrast adjustment on digital image data was performed for the optimum computer display of the track etched pits. In the film scanner system, no image of track etched pits was observed for etching time shorter than 3 hours. Moreover, in the count of track etched pits of up to 4 pixels, i.e. about 20 µm in diameter, miscounting was frequently caused due to micron-sized dusts and/or scratches on the PADC detector. It was confirmed from these discussions that chemical etching time of about 20 hours was suitable for the observation of track etched pits due to α-rays in the present system. In addition, it was confirmed that the present system with the film scanner could count track etched pits on both sides of a PADC detector at the same scanning through the suitable contrast adjustment.

Table 2 shows a series of observed images of track etched pits on a PADC sample irradiated with 241Am α-rays. The chemical etching time was 20 hours. As shown in Table 2, the film scanner system detected track etched pits on the PADC sample for the region of smaller incident angle of α-rays than the microscope system. Under the normal etching condition of the soakage in 6.25M NaOH solution at 70°C for 20 hours, the critical angle $\theta_c$, that is the maximum incident angle of α-rays at which their etched pits are detectable, was 70 degrees ($= \theta_c^{\text{m}}$) for the microscope system. This value agrees with that reported by Dörschel, B. et al.\textsuperscript{12).} While on the other hand the critical angle $\theta_c^{\text{fs}}$ for the film scanner system was about 55 degrees. The critical angle naturally affects the sensitivity of counting α-rays with a PADC detector.

In order to examine the measurable dose range of the film scanner system, several PADC detector samples were irradiated with 241Am α-rays of different fluences. The irradiated PADC detector samples were chemically etched in 6.25M NaOH solution at 70°C for 20 hours. After etching, the surface of each sample was observed with the film scanner and the optical microscope, and the number of the track etched pits on each sample was counted with both systems.

Figure 2 shows the relation between the track etched pit density measured with the microscope system and that measured with the film scanner system. As shown in Fig. 2, the track density measured with the film scanner was directly proportional to that measured with the microscope in the density region below 2000 tracks/cm². The ratio $\eta$ of α-ray sensitivity of the microscope system to that of the film scanner system is approximately given by

\[
\eta = \frac{\text{Density measured with the film scanner}}{\text{Density measured with the microscope}}
\]
Performance of Convenient Film Scanner System for Automatic Counting of Track Etched Pits on PADC Detectors

\[ \eta = \frac{(1 - \cos \theta_c^{fs})}{(1 - \cos \theta_c^{m})}. \]  

(1)

Substituting the relations \( \theta_c^{m} = 70 \) degrees and \( \theta_c^{fs} = 55 \) degrees into Eq. (1), we obtain the relation \( \eta = 0.65 \). This value roughly agrees with the constant of the proportional relation shown in Fig. 2. In the density region higher than about 3000 tracks/cm\(^2\), the digression from the proportional response was caused by the overlap of track etched pits in a scanning image of the film scanner system. The reason was because a set of two adjacent track etched pits was considered to be one track etched pit in the software.

4. Radon monitoring in basement

In order to ascertain the usefulness of the film scanner system for PADC detectors for the measurement of radon concen-
tration in air, fifteen PADC detectors of $10 \times 10 \times 0.9 \text{ mm}^3$ were hung with strings randomly at three sample points from the ceiling in a basement at the accelerator facility “OKTAVIAN” of Osaka University. The basement is surrounded with concrete walls and has no ventilation system. After the hanging of 19 days, the PADC detectors were chemically etched in 6.25M NaOH solution at 70°C for 20 hours. The PADC plates detected $\alpha$-rays from radon and its daughters, and the number of track etched pits on each detector was automatically counted with the film scanner system. Variation of radon concentration in air was also measured with a portable radon monitor (Radim 3A, Radon Analytics).

Table 3 summarizes measured results on the average density of track etched pits on the PADC detectors hung in the basement. The indication of the portable radon monitor was 120~190 Bq/m$^3$ in the basement. The radon sensitivity of the present system with the film scanner for a long exposure time was about 0.14 [(tracks $\cdot$ cm$^{-2}$) / (Bq $\cdot$ m$^{-3}$ $\cdot$ day)], which was given by the track density divided by the radon concentration and measurement time. It should be noted that this value roughly corresponded to the radon sensitivity (with the microscope) multiplied by the ratio $\eta$. It was confirmed that the present system could be satisfactorily used for the radon monitoring at many positions.

5. Conclusions

The inexpensive film scanner and the image processing software “ImageJ” were satisfactorily used for the automatic and speedy counting of track etched pits on many PADC detectors irradiated with $\alpha$-rays. The performance of the $\alpha$-ray counting system with the film scanner was examined by the use of the goniometric $^{241}$Am $\alpha$-ray irradiation equipment. It was found that the film scanner system had good linearity in the density region below 2000 tracks/cm$^2$ under the etching condition of the soakage in 6.25M NaOH solution at 70°C for 20 hours. However, the $\alpha$-ray detection efficiency of the film scanner system was about 0.6 time as small as that of the general system with an optical microscope. It was found that the decline in the $\alpha$-ray detection efficiency was due to the decrease of the critical angle in the observation of track etched pits. It was confirmed that PADC detectors together with the film scanner system could be conveniently used for radon monitoring in atmosphere.

Acknowledgements

The authors sincerely thank Jun Datemichi and Hisashi Sugimoto of Osaka University for their valuable suggestions in setting PADC detectors in the basement. This work was supported in part by Grants-in-Aid for Scientific Research from the Ministry of Education, Culture, Sports, Science and Technology, Japan.

References

1) Boukhair, A., Haessler, A., Adloff, J., C., Nourreddine, A.: New code for digital imaging system for track measurements, Nucl. Instr. Meth. B 160, 550–555 (2000).
2) Dolleiser, M., Hashemi-Nezhad, S., R.: A fully automated optical microscope for analysis of particle tracks in solids, Nucl. Instr. Meth. B 198, 98–107 (2002).
3) Yasuda, N., Namiki, K., Honmac, Y., Umeshima, Y., Marumo, Y., Ishii, H., Benton, E., R.: Development of a high speed imaging microscope and new software for nuclear track detector analysis, Radiat. Meas. 40, 311–315 (2005).
4) Tawara, H., Eda, K., Takahashi, K., Doke, T., Hasebe, N., Kodaira, S., Ota, S., Kurano, M., Yasuda, N.: Development of an automated multi sample scanning system for nuclear track etched detectors, Nucl. Instr. Meth. A 593, 475–480 (2008).
5) Steele, J., D., Bhakta, J., R., Tanner, R., J., Bartkett, D., T.: Development of a reader for track etch detectors based on a commercially available slide scanner, Radiat. Meas. 31, 179–184 (1999).
6) Ibrahim, Z., F., Miles, J., C., H.: Performance review of a slide scanner based automated counting system for PADC radon detectors, Radiat. Meas. 43, S395–S400 (2008).
7) Calamosca, M., Penzo, S., Gualdrini, G.: Experimental determination of CR-39 counting efficiency to particles to design the holder of a new radon gas dosimeter, Radiat. Meas. 36, 217–219 (2003).

| Distance from floor (cm) | Track density (tracks/cm$^2$) | Radon monitor (Bq/m$^3$) |
|-------------------------|-------------------------------|--------------------------|
| 50                      | 500 ± 30                      | 190                      |
| 150                     | 440 ± 30                      | 160                      |
| 250                     | 330 ± 20                      | 120                      |
8) Randhawa, G. S., Kumar, S., Virk, H.S.: Response of different plastic track detectors to $\alpha$-particles, Radiat. Meas. 27(3), 523–527 (1997).

9) ImageJ.: Available at http://rsb.info.nih.gov/ij/

10) Groetz, J. E., Lacourt, A., Chambaudet, A.: Coherent light scattering by nuclear etched tracks in the PADC (a form of CR-39), Nucl. Instr. Meth. B 142, 503–514 (1998).

11) Nikezic, D. and Yu, K. N.: Analyses of light scattered from etched alpha-particle tracks in PADC, Radiat. Meas. 43, 1417–1422 (2008).

12) Dörschel, B., Bretschneider, R., Hermsdorf, D., Kadner, K., Kühne, H.: Measurement of the track etch rates along proton and alpha-particle trajectories in CR-39 and calculation of the detection efficiency, Radiat. Meas. 31, 103–108 (1999).

13) Šutej, T., Križman, M.: Response of a new charcoal-etched track radon dosimeter, Nucl. Tracks Radiat. Meas. 21, 441–443 (1993).

14) Nelson, R. A.: Measurement uncertainties of long-term 222Rn averages at environmental levels using $\alpha$ track detectors, Health Phys. 53, 447–453 (1987).