

Optical appearance of alpha-particle tracks in CR-39 SSNTDs

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Abstract

The optical appearance of etched alpha-particle tracks in CR-39 SSNTDs under the transmission mode of the optical microscope were studied. The mean grey levels revealed using a digital camera installed on the microscope, together with the major and minor axes were systematically determined for tracks from alpha particles with different incident energies and angles. The grey level properties for the same track could vary to large extents, which could be corrected using optimum operation conditions of the camera. Differentiation among recorded tracks was then automated using a computer program, for which the grey levels, major and minor axes values were used as inputs and from which the angle and energy of the incident alpha particles were given as the outputs. The accuracy of the determined alpha-particle energy is 0.5 MeV. © 2008 Elsevier Ltd. All rights reserved.

Keywords: CR-39 detector; Alpha particles; Tracks; Ray tracing; Grey level

1. Introduction

Solid-state nuclear track detectors (SSNTDs) have found wide applications (Nikezic and Yu, 2004) such as for radon and progeny measurements. However, automation in differentiating among recorded tracks due to alpha particles with different incident energies is rarely investigated. Optical properties such as grey level properties, major and minor axes are useful in automatic track measurements.

Formation of track images in SSNTDs actually depends on light scattering and reflection (Nikezic et al., 2005), so optical properties are potential quantitative variables to distinguish among various types of tracks. In the present work, the first objective is to obtain consistent grey level properties for the same track under different exposures of the camera installed on the microscope, which is used for track observation. The second objective is to identify useful variables for quantitative comparisons with the experimental data. The third objective is to make use of those variables to develop a computer program

for automation in differentiating among recorded tracks due to alpha particles with different incident angles and energies.

2. Methodology

2.1. Sample preparation

CR-39 SSNTDs were employed in this study and they were purchased from Page Mouldings (Pershore) Limited (Worcestershire, England). The CR-39 detectors had a thickness of 1000 μm , and were cut into pieces with an area of $1 \times 1 \text{ cm}^2$ before use. Separate CR-39 detectors were systematically irradiated for 15 min with alpha particles with energies from 1.5 to 4.5 MeV in steps of 0.5 MeV and with angles from 40° to 80° in steps of 10° . The alpha source employed was a planar ^{241}Am source (activity = 0.1 μCi and main alpha energy = 5.49 MeV under vacuum). Normal air was used as the energy absorber to control the alpha energies incident on the detector. Incidence of alpha particles was restricted to the chosen incident angle (with reference to the detector surface) with the help of a collimator.

After irradiation, the detectors were etched in a 6 N aqueous solution of NaOH (etchant) for 6 h at 70°C . The temperature was kept constant by a water bath with an accuracy of $\pm 1^\circ\text{C}$. The detectors were then taken out from the etchant and rinsed

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with distilled water immediately in order to stop the reaction between the detectors and the etchant. The detectors were dried completely and then used for analysis.

2.2. Analytical methods

2.2.1. Optical microscope

An optical microscope operated in the transmission mode was used for observation of tracks. The light coming from the bottom of microscope to the detector was set to the brightest and all lenses were cleaned using alcohol before capturing of images. The images were recorded in the JPEG format by a digital camera (Olympus DP 11) installed on the microscope.

One-touch white balance (WB) setting with a high picture quality (HQ) and sensitivity (ISO) value of 200 was used. The WB setting enabled the camera to record pictures by eliminating the effects of the surrounding light. However, the auto-WB setting was unable to display the track image clearly for too much brightness (overexposure) or too much darkness (underexposure). Under these conditions, the auto-setting cannot offer the optimum brightness for the track image. The one-touch WB setting allowed the camera to store the illumination light conditions in memory, so that the optimum brightness condition could be stored and used for recording of tracks.

Inconsistency of grey level properties of the same track under different exposures was studied, and tackling of this problem through locking the auto-exposure time for each image recording was explored. The optimum mode for observation of tracks was then identified as shown in Section 3.1.

2.2.2. Grey level determination

The software used to determine the grey level properties of the track images is Adobe® Photoshop® (Adobe® Photoshop® CS and ImageReady CS ver. 8) software. The user of the software could define the track boundary to obtain the grey level distribution, including the mean, standard deviation, minimum, maximum and median of the grey levels.

2.2.3. Measurement of major and minor axes

The lengths of major and minor axes were determined by the free software ImageJ (Image processing and Analysis in Java version 1.29x, available on the webpage: <http://rsb.info.nih.gov/ij/>). Calibration was carried out before measurements. An image of a calibration ruler (0.01 mm per division) was captured under the microscope and used for scale setting.

2.3. Computer programs

An in-house computer program was developed and used to distinguish among different types of tracks from their grey level numbers, major and minor axes. The information was input into the program which would then output the incident angle and energy as the results.

The computer program TRACK_TEST (Nikezic and Yu, 2006) (available at <http://www.cityu.edu.hk/ap/nru/test.htm>)

was also used to obtain the lengths of major and minor axes for comparison with the experimental values. The program was developed by Nikezic and Yu (2003a) and was based on equations derived for three-dimensional consideration of track development (Nikezic and Yu, 2003b). The incident alpha-particle energy (in MeV), bulk etch rate (in $\mu\text{m}/\text{h}$), etching time (in h) and the incident angle (in degree) were input to the program. The outputs from the program are the track depth, major and minor axes. Furthermore, the program also shows the track profile and the shape of the track opening.

The light intensity here was presented by the “intensity number” (Nikezic et al., 2005; Yu et al., 2007) with 256 intervals. Intensity number 0 represents completely dark (no transmission through the detector) while 255 represents completely bright (total transmission).

3. Results

3.1. Consistent grey level measurements

As mentioned above, the problem of inconsistent grey level properties for alpha tracks with same track under different exposures should be solved in order to use the grey level properties in quantitative comparisons. The exposure of the digital camera installed on the microscope was the main concern of this problem, and finding the optimum operation conditions of the camera formed our first task.

Table 1 shows the measurements of grey level properties of the same track at five different positions inside the camera field of view (fov). The order of recording the same track at different positions is as follows: (1) Centre of the camera fov, (2) top right-hand side (T-RHS) of the fov, (3) right-hand side at the bottom (B-RHS), (4) left-hand side at the bottom (B-LHS) and (5) top-left hand side (T-LHS). The column (A) in Table 1, which corresponds to the case without locking of exposure time, shows that the variation of grey level properties was large due to exposures at different positions of the camera fov. This was in fact expected due to different brightness conditions at different positions of the same detector.

We tried to solve this by locking the auto-exposure time, i.e., keeping the same exposure time for recording each track image. The results for locking of exposure time (1/13) are shown in column (B) of Table 1, which shows a reduction in the

Table 1

The grey level properties of the same alpha track with 2 MeV incident energy and 50° incident angle at five different positions in the camera field of view: (A) without locking of exposure time; (B) with locking of exposure time

Position	Mean		Median	
	(A)	(B)	(A)	(B)
Centre	113.1	100.5	110	98
T-RHS	93.7	93.6	90	90
B-RHS	97.3	96.5	94	93
B-LHS	97.4	98.7	93	95
T-LHS	99.5	99.2	95	96

Table 2
Mean grey level numbers for tracks from alpha particles with different incident energies for incident angles from 40° to 80°

Incident alpha energy (MeV)	40°	50°	60°	70°	80°
1.5	119 ± 3	114 ± 1	111 ± 3	111 ± 2	108 ± 1
2.0	116 ± 3	114 ± 2	108 ± 3	100 ± 3	114 ± 1
2.5	117 ± 3	105 ± 1	97 ± 2	91 ± 2	102 ± 1
3.0	115 ± 2	97 ± 1	96 ± 0	87 ± 2	94 ± 1
3.5	115 ± 6	105 ± 1	90 ± 1	81 ± 5	92 ± 1
4.0	117 ± 2	105 ± 1	104 ± 2	77 ± 2	85 ± 1
4.5	117 ± 2	114 ± 1	104 ± 2	77 ± 1	86 ± 0

variation of grey level properties. However, the grey level values at the centre position of the camera fov were higher in all cases. Therefore, recording of tracks at the centre position was avoided.

The optimum conditions found for observation of tracks was in REC AUTO mode with a zero exposure, and one-touch WB setting with HQ and an ISO value of 200. These conditions were used for all subsequent experiments in the present work.

3.2. Grey level measurements for tracks with different incident angles and energies

A total of five sets of experiments (with incident angles 40° to 80° in steps in 10°) were performed to determine the relationship between grey level properties and the incident energies. Separate CR-39 detectors were irradiated with alpha particles with energies from 1.5 to 4.5 MeV in steps of 0.5 MeV for each set of the incident angle. Table 2 shows the average values of mean grey level numbers for tracks from alpha particles with different incident energies for incident angles from 40° to 80°.

3.3. Developing a computer program for automatic differentiation

3.3.1. Using grey level properties

The mean grey level values were studied quantitatively for comparisons. They were chosen because of their consistency for the same group of tracks (same incident angle and incident energy), and their similar trends (as shown in Table 2) for different incident angles. The mean light intensity numbers are divided into eight groups according to the experimental results as shown in Table 3. Table 3 shows the corresponding incident angles and energies of alpha particles for each group of intensity number. It was found that each group contained more than one set of incident angles and energies, thus automatic differentiation could not be achieved by using the mean values only. Other optical properties such as the major and minor axes of the tracks should be employed to assist the comparisons.

3.3.2. Using lengths of major and minor axes

The ratio between the major and minor axes was also studied as a potential quantitative variable to assist comparisons. These ratios agreed well with the ratios given by the TRACK_TEST

Table 3
Eight groups of mean light intensity numbers and the corresponding incident angle and energy of the alpha particles

Group	Range of light intensity number	Corresponding incident angle (degree)	Corresponding incident energy (MeV)
1	74.00–79.99	70	4.0 and 4.5
2	80.00–89.99	60 70 80	3.5 3.0 and 3.5 4.0 and 4.5
3	90.00–92.99	70 80	2.5 3.5
4	93.00–98.99	50 60 80	3.0 2.5 and 3.0 3.0
5	99.00–102.99	70 80	2.0 2.5
6	103.00–106.99	50 60	2.5, 3.5 and 4.0 4.0 and 4.5
7	107.00–111.99	60 70 80	1.5 and 2.0 1.5 1.5
8	112.00–123.00	40 50 80	1.5–4.5 1.5, 2.0 and 4.5 2.0

program. Each group of the mean light intensity number of mean values (Table 3) could be further divided into smaller groups according to the ratios of major and minor axes from experiments. Each set of incident angle and energy had a corresponding range of ratios. A computer program was then developed and experimental data were tested using this program. Table 4 shows the results of predicted incident angles and energies of alpha particles from the self-developed computer program by inputting the experimental values of mean grey level number, major and minor axes. The table also shows the results for the predicted angles and energies, which agreed well with the experimental values. All alpha energies could be determined with an accuracy of ±0.5 MeV.

4. Conclusions

- (1) The optical appearance of etched alpha-particle tracks in CR-39 SSNTDs under the transmission mode of the optical microscope were studied. The mean grey levels, major and minor axes were experimentally determined for tracks from alpha particles with incident angles ranging from 40° to 80° and incident energies from 1.5 to 4.5 MeV.
- (2) Images of the tracks were captured using a digital camera installed on the microscope. The grey level properties for the same track could vary to large extents, which could be corrected using optimum operation conditions found for the camera: REC AUTO mode with a zero exposure, and one-touch WB setting with HQ and an ISO value of 200. These conditions were used for all subsequent experiments in the

Table 4
The predicted incident angles and energies of alpha particles by using the self-developed program

Incident angle (degree)	Incident energy (MeV)	Mean light intensity number	Major axis (μm)	Minor axis (μm)	Predicted angle (degree)	Predicted energy (MeV)
40	1.5	122	10.3	8.8	40	1.5
	2.0	113	11.0	9.3	40	1.5
	2.5	114	13.4	7.9	40	2.5
	3.0	114	13.9	6.5	40	3.0
	3.5	118	13.0	6.1	40	3.5
	4.0	117	10.6	5.9	40	4.0
	4.5	113	10.3	5.3	40	4.5
50	1.5	114	11.2	10.6	50	1.5
	2.0	113	12.2	10.6	50	2.0
	2.5	105	14.2	10.1	50	2.5
	3.0	96	13.0	8.9	50	3.0
	3.5	104	11.5	7.9	50	4.0
	4.0	104	11.1	7.6	50	4.0
	4.5	114	10.3	6.8	50	4.5
60	1.5	108	11.0	10.7	60	1.5
	2.0	108	12.0	11.0	60	2.0
	2.5	99	12.0	10.2	60	2.5
	3.0	96	11.3	9.4	60	2.5
	3.5	90	10.3	8.6	60	3.5
	4.0	103	10.2	8.3	60	4.5
	4.5	104	9.8	7.9	60	4.5
70	1.5	109	11.5	11.4	70	1.5
	2.0	101	12.4	11.4	70	2.0
	2.5	93	11.6	11.2	70	2.5
	3.0	86	11.5	10.2	70	3.0
	3.5	83	10.5	9.5	70	4.0
	4.0	76	9.8	9.0	70	4.0
	4.5	76	9.9	8.8	70	4.5
80	1.5	107	11.7	11.6	80	1.5
	2.0	114	11.6	11.3	80	2.0
	2.5	101	10.6	10.4	80	2.5
	3.0	93	10.2	9.9	80	3.0
	3.5	91	10.0	9.5	80	3.5
	4.0	86	9.4	8.9	80	4.5
	4.5	86	8.7	8.3	80	4.5

present work. The grey level values at the centre position of the camera field of view were higher in all cases so recording of tracks at the centre position was avoided.

- (3) Automatic differentiation among recorded tracks was then made possible using a computer program, for which the mean grey levels, major and minor axes values were used as inputs and from which the angle and energy of the incident alpha particles were given as the outputs. The accuracy of the determined alpha-particle energy is 0.5 MeV.

Acknowledgement

The present research is supported by the CERG grant CityU 102803 from the Research Grant Council of Hong Kong (City University of Hong Kong reference no. 9040882).

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