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Geometrical parameters of tracks registered by collimated alpha particles on CR-39 detector

Pranav M. Joshirao [a], Jae Won Shin [b], Do Yoon Kim [a], Seung-Woo Hong [b,*], Rajesh V. Kolekar [c], Vijay Kumar Manchanda [a,*]

[a] Department of Energy Science, Sungkyunkwan University, Republic of Korea
[b] Department of Physics, Sungkyunkwan University, Republic of Korea
[c] Radiation Safety Systems Division, BARC, Mumbai, India

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ABSTRACT

The latent tracks formed on CR-39 solid state track detector on exposure of alpha radiations emanating from a collimated ^{241}Am source were developed by a chemical etching method. Alpha track images were captured by an optical microscope and were processed by using Image Pro-Plus (6.0) software. GEANT4 simulations were carried out to obtain the angular and energy distribution profiles of the alpha particles. Apart from fluence, geometric parameters like aspect ratio (the ratio of the major to minor axis) and the depth profiles of etched tracks were measured experimentally and correlated with simulated angular and energy profile of incident radiations. Reasonable agreement was observed in the fluence and depth profile information obtained from experiments and simulations.

1. Introduction

Solid state nuclear track detectors (SSNTDs) are ultrasensitive to charged particle radiations. CR-39 (polyallyl diglycol carbonate) has been used for a variety of applications including radon monitoring in the environment, uranium prospecting, personnel dosimetry in nuclear facilities and basic nuclear science studies. Latent tracks formed on exposure to radiations are developed by using chemicals and can be inspected with an optical microscope. Chemicals chosen are such that they cause etching of latent tracks at a rate much larger than the rate of etching of bulk material. The identification of the tracks is based on their discrimination from background (caused by stray radiations or manufacturing defects). The geometry of the tracks depends on the energy and angle of incidence of the charged particles on the detector. 2D images of the tracks are either circular (for normal incidence) or elliptical (for acute/obtuse angle incidence). The track diameter values also find their applications in energy spectrometry [1]. An attempt has been made to determine the uranium and thorium contents present in different materials using SSNTDs, LR-115 and CR-39 [2]. It was based on the evaluated critical angles of CR-39 for the varying residual energies of alpha particles (emitted by uranium and thorium series radionuclides) incident on detectors and observed track densities. A model has been proposed to evaluate the critical registration angle of alpha particles in CR-39 [3]. It implies that for each incident energy there is a particular angle below which alpha particles can no longer induce an observable etched track. It is thus necessary to know the variation of the critical angle with incident energy of alpha particle for given etching conditions in order to determine the detection efficiency of a radon detector. The bulk etch rates and track etch rates can be determined from the diameter/major axis of tracks and etching period.

Various computer programs have also been developed to determine the geometrical parameters of tracks [4–8]. The end user has to provide certain values like the energy of incident radiation, the geometry of experimental set up etc. to arrive at the values of track geometrical parameters. The TRACK_TEST program developed by Nikezic and Yu [7] for the determination of alpha track parameters follows four steps as listed below.

(1) Calculation of alpha particle ranges (using the program on SRIM, Stopping and Range of Ions in Matter) [9].
(2) Determination of particle trajectory across the depth of the detector film.

* Corresponding authors.
E-mail addresses: swhong@skku.ac.kr (S.W. Hong), vkm25749@gmail.com (V.K. Manchanda).

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(3) Splitting the distance into intervals, and
(4) Calculation of track co-ordinates (geometrical track parameters).

The three dimensional image of track is formed after processing of the obtained set of points using methods of translation and rotation described by Nikezic and Yu [5,6,10]. The cross section of this three dimensional figure is then used for calculating the track parameters like major and minor axes and track opening contours.

The angular response of CR-39 for alpha particles with different energies and its effect on the geometrical track parameters has been studied [11–13]. The dependence of registration efficiency on alpha particle energy and incident angle has been reported [14]. However, the dependence of the aspect ratio values (ratio of major axis to minor axis) on the angle of incident radiation has not been studied. An attempt has been made in the present work to correlate the geometric parameters of the tracks with the incident angle of alphas as obtained by GEANT4 (v10.0) [15,16] simulations. Experimentally observed geometrical parameters like aspect ratios and depths of the tracks were found to be in good agreement with the simulation results from GEANT4.

2. Experimental

Schematic of the experimental setup is given in Fig. 1. The alpha source was a planar, discoid electroplated ^{241}Am (main alpha energy of ~5.49 MeV) having the activity of 3.585 kBq (4π geometry), procured from Eckert & Ziegler-Isotope Products, USA. The active area of the source was covered with an aluminum collimator of 0.6 cm thickness with a circular slit of 0.3 or 0.5 cm diameter at the centre (for reducing the divergence of the alpha particles).

Two different sizes of CR-39 were used for two different collimators. When the size of the aperture was 0.3 cm, the dimensions of CR-39 film were 1.0 cm × 0.5 cm (see Fig. 1). On the other hand, CR-39 of 2.0 cm × 0.5 cm size was used for the aperture of 0.5 cm. For the case of film dimension 1.0 cm × 0.5 cm, the breadth was divided into 10 equal parts of 0.1 cm width (9 such parts are shown on the right hand side of Fig. 1, thus each sub-region corresponds to 0.1 cm × 0.5 cm dimensions). The sub regions are denoted by E′, D′, C′, B′, A, B, C, D, and E. The sub regions B′, A, and B are aligned with the 0.3 cm aperture of the collimator, as shown by the dotted lines in Fig. 1. The second set of samples was exposed by using the collimator with a circular aperture of 0.5 cm at its centre. This caused the exposure of sub regions with alphas at wider angles of incidence. The sub regions of 2.0 cm × 0.5 cm detector are denoted by I′, H′, G′, F′, E′, D′, C′, B′, A, B, C, D, E, F, G, H, and I, as shown in Fig. 1. The sub regions C′, B′, A, B, and C are aligned with the 0.5 cm aperture of the collimator, as shown by the dotted lines in Fig. 1. Different sub regions are irradiated by alphas incident on them with different ranges of angles.

In our previous work [17], alpha track densities were measured for varying distances between CR-39 and ^{241}Am source, and were compared with those obtained from GEANT4 Monte Carlo simulations. It was found that there was good agreement between our measurements and simulations. In the present work, the alpha fluence (the number of alphas per unit detector surface area) at a fixed distance of 1.5 cm from the collimated ^{241}Am source was computed by using GEANT4 simulation and the fluence in different sub regions was correlated with the incident angles of alphas on the detector surface.

Track development was done by etching the latent tracks with 6 M NaOH at 60 °C for 4 h. Alpha track images were taken by an optical microscope (Olympus BX51M – N35MF) at 50× magnification using Tomoroscope eye 3.5 software with least count of 0.01 μm. Images were recorded in the JPEG format by a digital camera attached to the microscope. A minimum of 50–100 frames were selected from the centre of a sub region of the exposed detector and the images were processed by the software, Image Pro-Plus (6.0). Track images were counted using tiling method. All the frames stored were used for computing the aspect ratios of these alpha tracks. The data obtained is then exported to an excel sheet where it is further processed to determine number of tracks corresponding to specified aspect ratio range. Track depth measurements were carried out using Zeiss microscope "Axio Imager M2 m" with motorized stage extending 100 × 80 mm with resolution of 0.05 μm. It implies that the stage can go up to 100 mm along X axis and 80 mm along Y axis. The Z axis motorized with resolution of 0.25 μm, is used to acquire images with 5 mega pixel CCD camera at different Z-positions and to combine these into a single image representing the in-focus points. A corresponding depth-map is produced and the surface profile can be displayed along a line. The depth-map is exported to a 3D visualization program in order to examine the surface appearance in more detail. The Z axis being motorized, the depth profile was measured by focusing the track at the surface and then moving down the sensor tip to get depth profile. Fig. 2 shows the typical depth profiles of aligned sub regions.

3. Results and discussion

GEANT4 simulations were carried out to arrive at the number of alphas impinging on each sub region (A, B, C,...) along with their energies and incident angles. The number of alphas registered on each sub region at each incident angle is divided by the total number of alphas scored in each sub region to get the percentage fluence, which is plotted in Figs. 3a and 3b, for 0.3 and 0.5 cm apertures respectively. They show the angular distributions of alpha particles on different sub regions of the detector. It is seen that the angle of incidence shifts towards lower angle (θ) and has a narrower width of distribution as we move away from the central sub region (A).

Figs. 4a and 4b show the simulated energy distribution of alphas incident on different sub regions for 0.3 and 0.5 cm

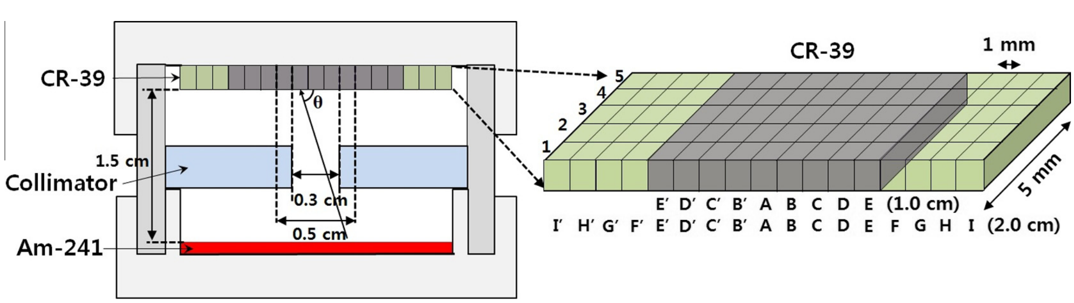

Fig. 1. Schematic of experimental set up with a collimator aperture of 0.3 or 0.5 cm.