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On the long standing question of nuclear track etch induction time: Surface-cap model

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Abstract

Using a systematic set of experiments, nuclear track etch induction time measurements in a widely used CR-39 detector were completed for accessible track-forming particles (fission fragments, 5.2 MeV alpha particles and 5.9 MeV antiprotons). Results of the present work are compared with appropriately selected published results. The possibility of the use of etch induction time for charged particle identification is evaluated. Analysis of experimental results along with the use of well-established theoretical concepts yielded a model about delay in the start of chemical etching of nuclear tracks. The suggested model proposes the formation of a surface-cap (top segment) in each nuclear track consisting of chemically modified material with almost same or even higher resistance to chemical etching compared with bulk material of the track detector. Existing track formation models are reviewed very briefly, which provide one of the two bases of the proposed model. The other basis of the model is the general behavior of hot or energised material having a connection with an environment containing a number of species like ordinary air. Another reason for the delay in the start of etching is suggested as the absence of localization of etching atoms/molecules, which is present during etching at depth along the latent track.

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Keywords: Nuclear tracks; Chemical etching; Etch induction time; Surface-cap model; Free energy; Localized etching; Fission fragments; Alpha particles; Antiprotons; CR-39

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1. Introduction

Charged particle identification is very important due to its fundamental role in cosmic-ray and nuclear physics studies. Solid state nuclear track detectors (SSNTDs) offer an easy and inexpensive method to identify charged particles. CR-39 is one of the most sensitive and the most frequently used track detector. It has the ability to identify a wide spectrum of particles including important cosmological relics, e.g. super-massive magnetic monopoles [1]. It has now been established that etching of nuclear tracks does not start immediately after the exposed solid state nuclear track detectors (SSNTDs) are immersed in an etchant and it takes some time before the actual etching process starts [2–6]. Although direct investigations of etch induction time (EIT) are few, a number of studies on track formation and chemical etching [7–17] provide insight for understanding of this subject. There is no unified view about the delay in the start of nuclear track etching.

McKinley [18] suggested that EIT can be explained by assuming a decrease in restricted energy loss (REL) and as a consequence the track etch rate (V_T) at the surface of the detector. If the decrease in V_T is very severe, the bulk etch rate V_B will exceed V_T until the bulk etching reaches the depth where V_T exceeds V_B [3]. A number of other studies shed some light on the issue of etch induction time along with direct discussion about the mechanism of nuclear track etching [19–23] and observation of very small

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tracks using atomic force microscopy [24–26]. The dependence of EIT on properties of the track-forming particles is studied here. A plot, showing the dependence of experimentally measured EIT on Z/β of known track-forming particles (fission fragments, alpha particles and antiprotons), is generated in the form of a calibration curve for CR-39. Using present and published experimental results along with theoretical analysis and comparison, a simple model of nuclear track etch induction time is suggested.

2. Experiments

2.1. Fission fragment, alpha and antiproton exposures

Three CR-39 detectors (Pershore Mouldings Ltd., UK), each of $(2 \times 2)\ \mathrm{cm}^2$ area and thickness 1000 μm, were irradiated with fission fragments of ^{252}Cf in air using a 2π geometry by placing detectors directly on a fission fragment source, as shown in Fig. 1(a). Another set of CR-39 detectors was exposed to alpha particles of energy 5.2 MeV from a ^{239}Pu source in the same geometry. CR-39 plates of area $(5 \times 5)\ \mathrm{cm}^2$ were exposed with a 5.9 MeV antiproton beam in air using the low energy antiproton ring (LEAR) facility at CERN. The secondary LEAR beam line leading to PS194 was used for antiproton exposure. The distance between the Mylar window at the end of target detector was 10 cm. The momentum (convertible to energy) of antiprotons was measured using a secondary electron device, which consists of a thin foil, a secondary electron accelerating system and a photomultiplier. The integrated intensity of antiprotons during exposure was 5.72×10^7 particles/cm^2, which was measured using a scintillating fiber monitor. Further details on the antiproton experiments are given elsewhere [6].

2.2. Etching of exposed CR-39 detectors

CR-39 detectors exposed to fission fragments, alpha particles and antiprotons were etched in 6 N NaOH solution at 70 °C. The variation in the set value of etching temperature was not more than 1°. A standardized etching procedure was adopted. An efficient stirring was maintained in the surrounding water using a motorized vibrator during etching to produce a kind of convection in the etching bath to avoid the buildup of etch products at the surface of the detectors as shown in Fig. 1(b). It was also ensured that the concentration of the etchant remained constant by using fresh etchant after each etching interval (5–25 min). Detectors exposed to fission fragments, alpha particles or antiprotons were mounted on separate holders as the etch time step was not same for different exposures. Detectors were mounted on the holder at the same depth "*d*" in the etchant during etching as shown in Fig. 1(b). The maximum error in etching time was estimated as ±30 s. After etching, the CR-39 detectors were cleaned in running water and finally in ultrasonic bath to remove etchant and etch products from the surface of the detector and etch pits.

2.3. Track parameter measurements

The diameter of circular fission fragment, 5.2 MeV alpha particle and 5.9 MeV antiproton tracks in CR-39 detectors were measured after each etching step in 6 N NaOH solution at 70 °C, but measurement of track diameters was only possible after a certain etching time, which was quite different for the three exposed detector sets. The diameters of antiproton tracks were measured using an optical microscope, Leitz DAILUX 22EB, with a magnification of 400–1000. The diameters of 300 tracks (100 from each of three detectors) in the case of fission fragments and alpha particles and 108 tracks in the case of antiprotons were measured.

3. Results and discussion

3.1. Experimental results and analysis

Fig. 2(a) shows the complete diametric distribution of fission fragment tracks etched in 6 N NaOH solution for 180 min in CR-39 detector whereas Fig. 2(b) shows the diametric distribution of the biggest 20% of the tracks, the

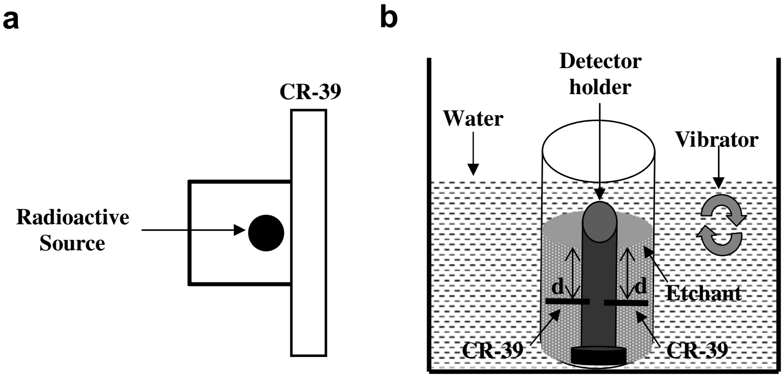

Fig. 1. A schematic diagram showing (a) exposure geometry in the cases of fission fragments and alpha particles and (b) etching process of all CR-39 detectors exposed to fission fragments, alpha particles and antiprotons.