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Empirical parameterization of CR-39 longitudinal track depth

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ABSTRACT

In this work, new empirical equation describing the charged particles radiation track development against etching time and track longitudinal depth are presented. The equation involves four free fitting parameters. It is shown that this equation can reproduce tracks depth formed on the CR-39 by alpha particles at different energies and etching times. Parameters values obtained from experimental data can be used to predict etched track lengths at different energies and etching times. The empirical equation suggested is self consistent as far as reproducing all features of track depth development as a function of etching time and energy are concerned.

1. Introduction

Solid state nuclear track detectors SSNTD have become essential tools in many applications related to charged particles radiation studies. Tracks number density counting in such detectors has proved to be a powerful tool for relatively accurately estimating concentrations of various alpha particles emitters. Such detectors have become approved standard tools for radon concentration measurements in a wide range of environments (USEPA, 2009). These detectors have found applications in many other studies connected to charged particles detection and intensity measurements in radiation therapy (Kohno et al., 2005). The basic principle involved in the operation of these detectors is related to the development of the damaged path produced by charged particles when passing through the detector. Alkaline solution etching technique is widely used in developing tracks of damaged regions. Even so, there is no complete theory so far which completely describes the physics of track formation. In spite of the fact that such theory is not so essential as far as SSNTD practical uses are concerned, the problem is still an open one. Thus, the problem of the track development geometry has been the subject of many studies in recent years. Emphases have been paid on two aspects of three dimensional track developments upon etching. The first is an experimental one. This involves the use of atomic force microscopes (Yu et al., 2004; Fragoso et al., 2007; Vazquez et al., 2007) and confocal microscopy techniques (Fromm et al., 2000, 2003, 2004; Vaginay et al., 2001) to obtain a direct view of the track three dimensional profiles. The second type of studies is mainly concerned with geometrical equations related to track shapes upon different etching times (Barillon et al., 1997; Nikezic et al., 2003, 2008; Nikezic and Yu., 2003). Both normal and oblique incidences have been treated. An end user computer program that can calculate track profiles under different conditions has been presented by Nikezic and Yu (2006). A reviews article by Nikezic and Yu (2004) contains discussion of many aspects of SSNTD and their applications in the radon and other research fields. In this reference, several geometrical models for the track growth are described and compared. However, the authors point out that there is not a single complete theory that satisfactorily explains track formation and development. It may be thus useful from instrumentation point of view, to try to utilize the potentials of empirical modeling to describe the track profile as a function of charged particle energy and etching time. It is the purpose here to present such empirical modeling. This is made possible through the use of matlab image processing technique to convert two dimensional visual pictures of the track profile into a set of numerical *x*-*y* coordinates. The original visual picture can be obtained using any one of the currently used techniques described in several references mentioned above.

2. Experimental

In order to obtain track longitudinal profiles at different alpha particle energies and etching times, 1 × 1 cm 250 μm thick CR-39 detectors made by Page Moldings (Pershore) UK were exposed to alpha radiation from an ^{241}Am for about ten minuets .Distances between the source and detector corresponding to tentative alpha particle energies of 1, 2, 3, 4 and 5 MeV were selected. However, and

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due the suspected inaccuracies in the energy selection system, these values were adjusted using the SRIM software (Ziegler et al., 2003) depending on measured range values in the detector. The calibrated energy values from range measurements turned out to be 1.43, 2.26, 3, 4.15, and 5.34 MeV The exposure system involves narrow collimation in order to obtain almost perpendicular incidence angle. The detectors are sharply broken at the small 1 mm^2 exposed area to expose the maximum number of tracks longitudinally. After initial etching in 6.25 N NaOH solution, at $70 \mp 1^{\circ}$C, the tracks having the highest length are selected. These correspond to alpha particles having lowest deviations from perpendicular incidence and the tracks are formed well within the detector matrix. These represent the majority of tracks observed. These tracks are etched for fifteen minuets and then digitally photographed under a 25 times magnification calibrated optical "Microscope Series Biological XSZ-H" attached to a high resolution digital camera. The etching process is repeated over several 15 min periods, and a digital picture is taken each time. A set of digital pictures of the longitudinal development of each particular track is thus obtained. The track boundaries in each picture are converted to digital, micron units' x-y data using a special matlab image processing program (Azooz, 2011). Several hundred numerical data points are obtained from each picture. Fig. 1 shows some typical digital image with its corresponding retrieved numerical data plot.

The track depths of several tracks are measured. These measurements are carried out automatically by the software. The software defines the track length as the difference between the maximum and minimum values of the track vertical profile as deduced from the image processing described above. However, visual traveling microscope measurements were also carried out and compared with computer data. No major discrepancies were observed and the computer data were taken as the bases for the following analysis. Furthermore, results of repeated track depth measurements showed a standard deviation from the mean values by about 6%.

2.1. Empirical parameterization

The aim of this work is to suggest and test an empirical equation that can describe the track depth as a function of alpha particle energy and etching time. For this purpose, the procedure of fitting carefully obtained experimental data to suitable suggested empirical formulas is followed.

As far as track depth development against etching time is concerned, one may remember that it is well known fact that track depth tend to follow a nonlinear increase with etching time up to a certain etching time value. This value depends on the energy of the charged particle. As this etching time is reached, the track depth saturates at an almost constant value. At the latter stage, the track is said to be over etched and the track etch rate V_T becomes equal to the bulk etch rate V_B.

Any empirical parameterization of such behavior must be able to reproduce the following effects:

1. The nonlinear increase in track depth as a function of etching time
2. The saturation of the track depth at high enough etching times
3. The energy dependences of all above for a particular charged particle type and etching conditions.
4. It is favorable that all above conditions should be met by a single continuous function rather than resorting to more than one mathematical form to describe different parts of the same curve.
5. The track etch rate V_T should reflect the main features of the Bragg peak.

In order to perform any empirical modeling of track depth development, one can follow one of two procedures. The first is to model the track etch rate V_T and perform integration over etching time. The second is to model the measured track depth itself and perform differentiation to obtain the track etch rate function. The first type of modeling proved to be a nontrivial type of task. This is due to the fact that although some suitable mathematical forms of $V_T(t)$ obeying any particular type of constrains can be written, mathematical integration can not usually be performed to obtain track depth $L(t)$ as a function of time. It is thus not unusual to use manual analysis of data. One of the most common type of constrains imposed on V_T are the energy independence of both height and position of the point at which V_T reaches its maximum value.

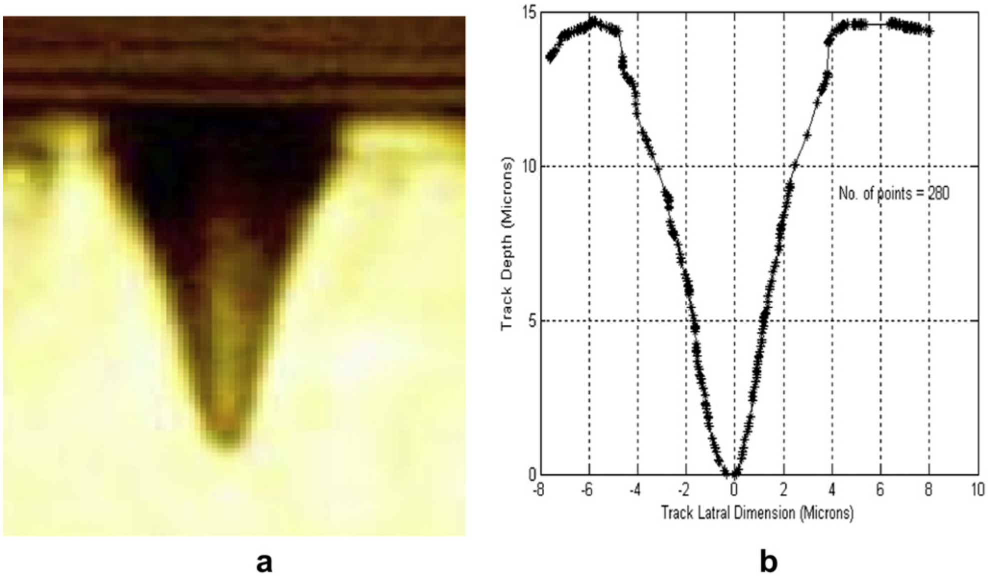

Fig. 1. Image processing of typical track longitudinal profile to obtain numerical data (a) original digital picture for $E = 4.15$ MeV, etching time = 5.75 h (b) plot of retrieved numerical data 280 data points in all.