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Comparative analysis of CR-39 sensitivity for different sets of measurable track parameters

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HIGHLIGHTS

- Experimental comparison of different methods for PNTD CR-39 sensitivity (response) evaluation is carried out.
- An appropriate technique for the secondary fragment measurement is proposed.
- The verification of the proposed method is performed.

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ABSTRACT

In the present paper the sensitivity V of plastic nuclear track detectors CR-39 to the space radiation, accelerated heavy ions in wide LET range and α-particles is studied. Different approaches for V evaluation are considered and compared. Main attention is given to the method that is appropriate for the measurement of short range heavy secondaries of space radiation. Finally, the experimental verification of the designed V function is carried out via simulation of the secondaries with low energy α-particles in the vicinity of the Bragg peak.

1. Introduction

Plastic nuclear track detector (PNTD) CR-39 is extensively applied in space radiation experiments. Nuclear track technique allows measuring the flux and the linear energy transfer (LET) distribution of high-LET charged particles. Absorbed dose and dose equivalent are derived from spectrum data with the use of appropriate calculation procedure. LET spectrum in this investigation is the result of large number ($>10^3$) of individual tracks observation, and measurement of track geometrical parameters. Data processing enables to estimate the sensitivity V of the detector to each scanned track. According to the common definition, the sensitivity is $V = V_t/V_B$, where V_t and V_B are the track and the bulk etch rates correspondingly. The sensitivity depends on the particle energy loss rate in matter. This relation makes it possible to convert V into LET with the help of a calibration function V = f (LET). It is generally accepted in calibration measurements to assign LET-value to biological tissue (or to water as a tissue-equivalent) in order to consider final LET distribution in biological tissue (Szabó and Pálfalvi, 2012). In addition, universal LET (H_2O) unit is convenient for experimental data comparison from different PNTDs.

Some well-known models are used for description of a track growing during etching (Nikezic and Yu, 2004). All these models consider the geometrical track parameters in dependence on relative etch ratio. Conversely, in practice the set of measured track parameters is used to obtain the sensitivity V value in assumption of the selected model validity. Unfortunately, there is no single generally accepted numerical approach of track formation suitable for the whole variety of space radiation tracks. That is why the relative etch ratio can be dependant on a particular method that has been used, track scanning technique and data processing

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algorithm applied in the experiment. Moreover, in the case of complicated track events (such as nuclear fragmentation) the conventional model can be completely inappropriate.

The approach, commonly used for relative etch ratio estimation, also known as “classical” method (Durrani and Bull, 1987), requires the simplest set of measurable parameters: major D and minor d track pit axes diameters for oblique incidence of the particle. In this case sensitivity V is calculated via the following expression:

$$V_{DdH} = \sqrt{1 + \frac{4 \cdot \left(\frac{D}{2 \cdot H}\right)^2}{\left(1 - \left(\frac{d}{2 \cdot H}\right)^2\right)^2}} \tag{1}$$

where H is the etched off layer thickness, which is assumed to be invariable for given etching conditions. The subscript “DdH” indicates the set of parameters to be measured. Scanning of 2-D track opening image is sufficient for the measurement of the required values. Automated scanning procedure and image analysis software can be easily applied for rapid evaluation of relevant track parameters. The calibration function $V_{DdH} = f(LET)$ in 10–500 keV/μm (H_2O) range for different etching conditions is described in detail in paper (Szabó and Pálfalvi, 2012).

It is established that “classical” approach yields reliable results for the long range primary particles at the beginning of track development (Hermsdorf, 2009b). In addition to the primary component, space radiation contains a significant fraction of secondaries originated in nuclear fragmentations of charged particles or neutrons with environment, including detector substance or biological tissue. There are some indications in literature that the contribution of secondaries to LET − spectrum can be considerable or even exceeds the contribution at LET>100 keV/μm (H_2O) (Benton et al., 2002; Kushin, 2010). Nuclear interactions yield short range charged fragments with high energy loss rate variable along the trajectory. Several particles can be produced at one apex in detector with residual ranges less than detector thickness (Fig. 1). Unless the particle trajectory intersects the initial detector surface, the origin of track etching is indefinite. In other words, fragment track etching time and consequently the third parameter H in expression (1) are unknown. Apparently, the “classical” approach is unsuitable for such complicated event analysis.

The aim of this work is comparison of different CR-39 sensitivity measurement techniques, and to find out approach which is appropriate for the study of nuclear fragmentation events.

2. Experimental design

2.1. Basic consideration

In Fig. 2 a track evolution in the first and second phases of etching process is shown for oblique particle incidence to the detector surface. The particle incidence from outside is considered.

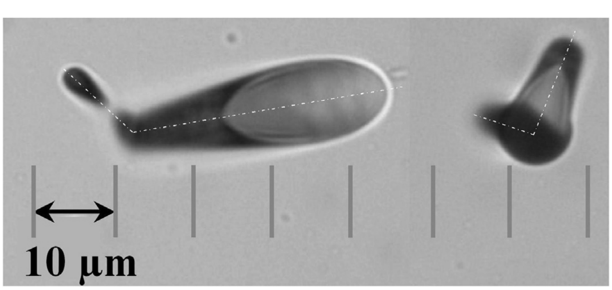

Fig. 1. Typical image of fragmentation events inside CR-39 detector after the exposition onboard the “FOTON-M” No. 4 spacecraft (additional information is in the text below).

Generally a track pit shape is semi-conical in the initial phase when the etch length of the track does not exceed the particle range in detector $L < L_r$. For $V = const$ (relative etch ratio is invariable along the particle trajectory), track shape is fully conical with cone angle δ given by the following equation: $\sin \delta = V^{-1}$.

The second stage begins when the etching front reaches the end point of particle trajectory (in this case $L = L_r$). After that moment the etching proceeds in all directions perpendicular to the track surface with bulk etch rate V_B. Sharp apex of track cone in this phase is transformed into a sphere of radius r (Fig. 2).

Tracks in the first and second phases of formation correspond in the best way to the tracks of secondaries. One feature should be noted that damage trail of fragment can be completely contained in the bulk of detector.

Several models for track growing are available in literature (Nikezic and Yu, 2004; Shomogy and Szalay, 1973). Present investigation uses the basic concept published in Henke and Benton, (1971) that describes track scanning and geometrical track data processing applicable to a variety of situations. It was established that the minimal number of measured track parameters (those required for a complete geometrical description of track growing)

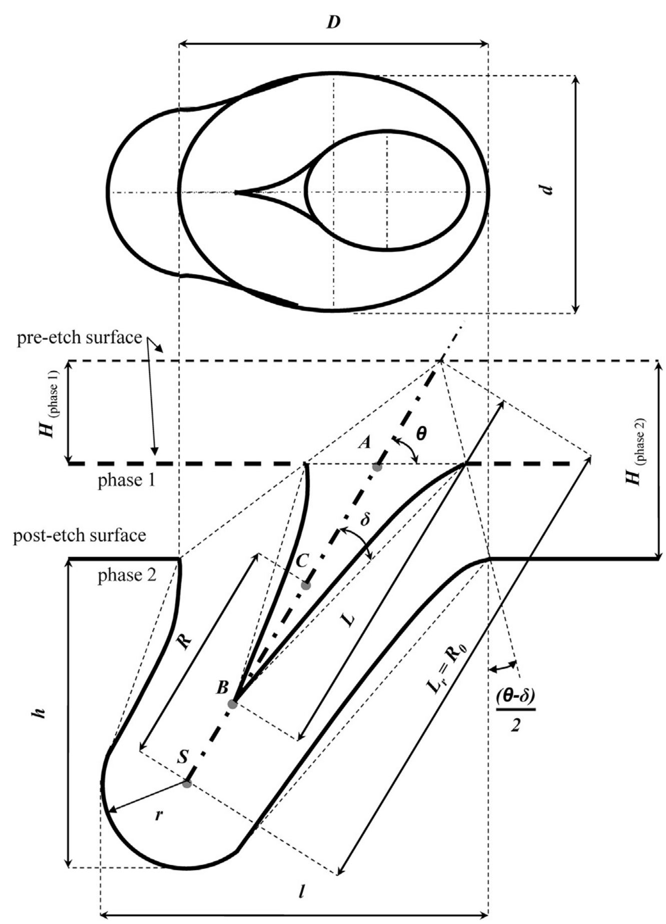

Fig. 2. Geometrical representation of the track development and measurable track parameters: d − the minor track opening ellipse diameter; D − the major track opening ellipse diameter; H − etched off layer thicknesses; h − the track tip depth; l − the track projected length; r − the bottom sphere radius; θ − the particle incident angle; δ − the track cone angle; L − the track etched length; L_r − the particle range in detector; AB −visible track length (the additional comments on the segment CS and the particle's residual range R are in the text below).