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A computer program TRACK_P for studying proton tracks in PADC detectors

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Abstract

A computer program for studying proton tracks in solid state nuclear track detectors was developed and described in this paper. The program was written in Fortran 90, with an additional tool for visualizing the track appearance as seen under the optical microscope in the transmission mode, which was written in the Python programming language. Measurable track parameters were determined and displayed in the application window and written in a data file. Three-dimensional representation of tracks was enabled. Examples of calculated tracks were also given in the present paper.

Keywords: Solid state nuclear track detectors; CR-39; Proton tracks

Metadata

Current code version	1.0
Permanent link to code/repository used of this code version	https://github.com/ElsevierSoftwareX/SOFTX-D-15-00053
Legal Code License	GPL
Code versioning system used	None
Software code languages, tools, and services used	Fortran90, python
Compilation requirements, operating environments & dependencies	Any Fortran compiler
If available Link to developer documentation/manual	https://github.com/ElsevierSoftwareX/SOFTX-D-15-00053
Support email for questions	nikezic@kg.ac.rs (D. Nikezic) or peter.yu@cityu.edu.hk (K.N. Yu)

Software metadata

Current software version	1.0
Permanent link to executables of this version	https://github.com/ElsevierSoftwareX/SOFTX-D-15-00053
Legal Software License	GPL
Computing platforms/Operating Systems	Microsoft Windows
Installation requirements & dependencies	
If available, link to user manual — if formally published include a reference to the publication in the reference list	https://github.com/ElsevierSoftwareX/SOFTX-D-15-00053
Support email for questions	nikezic@kg.ac.rs (D. Nikezic) or peter.yu@cityu.edu.hk (K.N. Yu)

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1. Motivation and significance

In many applications, solid state nuclear track detectors (SSNTDs) are used as detectors of protons, which included neutron detection and dosimetry [1], cosmic-ray physics [2], and various medical applications like hadron therapy [3]. Several types of SSNTDs are in use for proton detection, among which the most popular one is the polyallyldiglycol carbonate (PADC) films (commercially available under the trade name CR-39). However, up to now, there is still no software for simulating the development of proton tracks in PADC films, or for calculating the corresponding track parameters. The motivation for development of the current software is to provide a tool which can handle these tasks, and also to enable rendering of optical appearance of the tracks.

The software described here can be used in all research fields where protons are involved and where the protons should be characterized through their etched tracks developed in the PADC detector. These fields include neutron physics and dosimetry, cosmic ray studies, and radiation protection in radiation therapy. For example, it is a challenging task to determine the proton energies in these applications, which can be revealed by comparing the measured parameters of the real tracks with the corresponding results generated by this software. The methodology is particularly useful when long-term determination of the proton energies is required, which preclude active measurements using traditional electronic devices.

2. Problems and background

This work is related to the applications of SSNTDs. When heavy charged particles, like protons, alpha particles or heavier charged particles, pass through some dielectric materials, the particles will cause densely damaged regions along the incident particle trajectory in the materials, which are referred to as latent tracks. The nature of latent tracks varies with different dielectric materials. For example, the latent tracks can consist of spatially correlated replacement of some atoms in glasses or broken long molecules in polymers. Latent tracks are typically cylinders with diameters of about 10–20 nm around the incident particle trajectories and could be seen under electronic microscopes. The damaged regions or the latent tracks are chemically more active than the surrounding non-damaged area, and as such can be enlarged through chemical or electrochemical etching. Aqueous solutions of aggressive chemicals like NaOH or KOH are usually employed for the etching process. Upon etching, the latent tracks will be enlarged and form tracks which become visible as etch pits under the common optical microscope. SSNTDs have been commonly employed for registering the tracks caused by various types of heavily charged particles. From the track density, expressed in the number of tracks per unit area and per unit time of irradiation, revealed on an SSNTD, the particle fluence incident on the SSNTD can be determined. However, in more sophisticated applications where information beyond the particle fluence, e.g., the energies of the incident particles, is needed, the track density alone is not sufficient. The nature of SSNTDs, the process and conditions for etching, and applications in various fields of science and technology have been reviewed in books and review papers [4–7].

One of the challenging tasks in radiation protection nowadays is to accurately evaluate equivalent doses from neutrons, which depend on the neutron energies. A promising method to determine the energies of neutrons is the neutron spectrometry with PADC films [8], which relies on information such as the energies and the incident angles of recoiled protons generated from the interaction of the incident neutrons and the PADC films. Such information can be inferred from the track parameters and optical characteristics of the tracks formed by the recoiled protons on the PADC films, and can be used to reconstruct the proton-energy spectra, which is related to the original incident neutron-energy spectra. In the following, the scientific principles underlying the development for a computer program for such a purpose as well as the methodology involved will be described.

Optical microscopy is the basic tool for studying or counting the tracks in SSNTDs [4,5]. Other methods included automatic or semi-automatic counting and image analysis [8]. Optical microscopes can work in two modes, namely, the transmission and reflection modes. In most applications, the transmission mode is applied. In this mode, total internal reflection of light on the boundary surface of the etched tracks plays a dominant role in image formation. The track parameters (lengths of the major and minor axes, the depths of the track, and the shape) and appearance under the optical microscope depends on many parameters, which can be divided in three groups:

1. those related to the *detector processing* (the etching conditions, the removed layer of the SSNTDs during etching, the readout procedure and the visibility criteria);
2. *irradiation conditions* (incident angle of particles with respect to the detector surface, the particle mass and energy); and
3. *characteristics of particle interactions* with the detector (stopping power or linear energy transfer [LET]), which are also related to the particle and detector characteristics.

Previous computer programs TRACK_TEST [9] and TRACK_VISION [10] were developed for studying of alpha-particle tracks in PADC films. Those programs were developed in the Fortran 90 programming language. However, interactions of protons with PADC is different from those of alpha particles because the mass of a proton is one-fourth while the charge is half when compared to the alpha particles. These differences resulted in smaller LET values and much longer ranges of protons compared to alpha particles. As a result, protons cause smaller damages in the detector material along the particle trajectories in the SSNTDs, and thus smaller track etch rate V_t along proton tracks. Since the critical detection angle θ (with respect to the detector surface) is given as $\sin\theta = V_b/V_t$ [6], a smaller value of V_t means a smaller efficiency for the PADC film to record protons than to record alpha particles. Here, V_b is the bulk etch rate, and both V_b and V_t are usually expressed with the unit μm/h.

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