Track forming in organic and inorganic detectors

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Abstract.

Solid-state nuclear track detectors (SSNTDs) have found applications in different branches of science. Many researches have been devoted to understanding the mechanisms of track growth in SSNTDs. The most widely accepted track growth model involves two etch rates, namely, the etched track rate V_t (i.e.along a track in the SSNTD) and the bulk etch rate V_b (i.e. in undamaged areas of the SSNTD). The type of damage produced by irradiation of solids depends not only on the nature of the ionizing radiation but also on the nature of the solid itself. There are considerable differences in the extent and type of damage produced in the two major classes of track-storing solids, viz. inorganic crystals like muscovite mica and glasses, and synthetic organic polymers like CR-39. These differences seem to be reflected in sensitivities for track production of these two classes of material. The aim of this paper is research on this difference.

Keywords: *nuclear track detectors, etched track rate, bulk etch rate, inorganic crystals, CR-39*

Introduction

Operation of the solid-state nuclear track detector is based on the fact that a heavy charged particle will cause extensive ionization of the material when it passes through a medium. For example, an alpha particle with energy of 6 MeV creates about 150,000 of ion pairs in cellulose nitrate. Since the range of a 6 MeV alpha particle in this material is only about 40 mm, that means on average 3700 ion pairs are created per micrometer, or 3–4 ion pairs per nanometer.

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An alpha particle ionizes almost all molecules close to its path. This primary ionizing process triggers a series of new chemical processes that result in the creation of free chemical radicals and other chemical species. Along the path of the alpha particle, a zone enriched with free chemical radicals and other chemical species is then created. This damaged zone is called a latent track. If a piece of material containing latent tracks is exposed to some chemically aggressive solution, chemical reactions would be more intensive along the latent tracks. Aqueous solutions of NaOH or KOH are the most frequently used chemical solutions in this regard. [1]. The overall effect is that the chemical solution etches the surface of the detector material, but with a faster rate in the damaged region. In this way, a ‘‘track’’ of the particle is formed, which may be seen under an optical microscope. This procedure is called ‘‘detector etching’’ or track visualization, and the effect itself is called the ‘‘track effect’’. The track effect exists in many materials. It is particularly pronounced in materials with long molecules, e.g., cellulose nitrates or different polycarbonates, and such materials are the most convenient ones for application and detector manufacturing. The effect is also seen in some amorphous materials like glasses, etc. However, only dielectric materials show the track effect. In conductive materials and in semiconductors, the process of recombination occurs and the latent tracks are not stable. One of the most commonly used nuclear track detectors is the CR-39 detector. Some natural materials that show the track effect, such as apatite, mica, olivine, etc. are used for fission or fossil track studies. The condition for stable latent-track formation is sometimes expressed as a limiting value for the material resistivity. [2]. However, there is not a unique value of resistivity above, which the track effect always appears. In this way, the material resistivity cannot serve as the unique criterion for track formation. Although the track effect is relatively well known, and the technique is rather simple and straightforward, there is not a unique theory that explains track formation. The basic physical processes after the initial charged particle loses its energy are the ionization and excitation of molecules of the material. This first ‘‘physical’’ phase in which the initial particle delivers its energy to the atoms surrounding its path is very short in time; stopping of the particle occurs within a time of the order of picoseconds. The free electrons created in these primary interactions will slow down through a series of ionizations and excitations, and will create more and more free electrons. Some of these may go further away from the initial particle path creating the so-called delta (d) rays. A large number of free electrons and damaged molecules are created close to the particle track. In the second physiochemical phase, new chemical species are created by interactions of the damaged molecules. During etching, the interactions of these new chemical species with the etching solution are stronger than that with the undamaged detector material.

Organic and inorganic detectors

The type of damage produced by irradiation of solids depends not only on the nature of the ionizing radiation but also on the nature of the solid itself. There are considerable differences in the extent and type of damage produced in the two major classes of track-storing solids, viz. inorganic crystals like muscovite mica and glasses, and synthetic organic polymers like CR-39. These differences seem to be reflected in sensitivities for track production of these two classes of material. We discuss plastic first.

Organic polymers

Ionizing radiations directly produce ionized and exited molecules, and electrons. Some excited molecules may de-excite through the emission of radiation or through non-radiative transitions. Excitation energy can also be transferred from one molecule to another. Electrons are trapped at various sites, or can combine with molecules to form negative ions, or recombine with positive ions yielding excited molecules. Ions may participate in charge-transfer reactions. Both ions and excited molecules may acquire considerable vibrational energy and undergo bond rupture to form a complex array of stable molecules, free radicals, ionized molecules, and radical ions. The net effect on the plastic will be production of many broken molecular chains, leading to a reduction in the average molecular weight of the substance. It is shown in fig(1). [3]

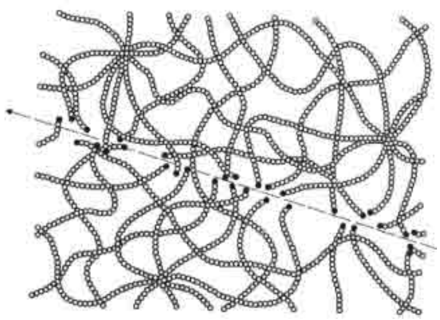

Figure. 1. The breaking of the polimeric bonds by crossing chraged particle. The damaged region, called *latent track* (LT), extends to few tens of nm around the particle trajectory

Inorganic insulating crystals

The effect of radiation upon inorganic detectors will also be to produce ionization and excitation of atoms or molecules. Electrons are raised across the forbidden energy band. Some of these may return to the valence band via luminescence centers with the emission of radiation, while others, after diffusing through the crystal, will either be trapped at the sites of various imperfections or will return, via non-radiative transitions, to positive ions. Low energy heavy ions will produce numerous atomic displacements directly through elastic collisions. Electron irradiation can also cause direct atomic displacements. An electron of kinetic energy E and rest mass m_0 can transfer a maximum energy W_{max} to an atom of mass M given by

$$W_{max} = \frac{2(E + m_0 c^2)E}{Mc^2} \quad \textbf{(1)}$$

Chemical Etching

Chemical etching is the most widely used method of fixing and enlarging the image of the latent damage trail in a solid-state nuclear track detector. First we should discuss about damage irradiation. When ionizing radiation pass through a detector it leaves narrow (30-100 Å) trails of damage. In crystals this consists of atomic displacements, manifesting themselves as interstitials and vacancies, and surrounded by a region of considerable lattice strain. In plastics, the radiation damage produces broken molecular chains, free radicals, etc. certain chemical reagents (etchants) dissolve or degrade these damaged regions at a much higher rate than the undamaged material. The narrow damage trail is thus gouged out by the etchant, forming a hole. This etched track may be enlarged radially until it is visible under an optical microscope.

Some of the etchants for isotropic detectors are: NaOH with concentrations typically within the range 1 to 12 M, the temperature usually employed is in the range 40-70 ^{o}C. In some cases, ethyl alcohol is added to the etchant; this has the effect, generally, of reducing the threshold value of primary ionization at which tracks become etchant although this treatment also renders the plastic more brittle. Alcohole has been found to reduce the sensitivity of CR-39 for track revelation. In the case of Lexan, an increase in the etching sensitivity has also been observed when high concentration of etch products accumulate in the etchant. HF solution is used for muscovite mica and glasses.

Shape of Tracks after Etching under optical microscope

There are two types of detectors in solid track laboratory in nuclear engineering department. One is organic detector and another one is inorganic detector. Organic detector used in laboratory is CR-39 and inorganic detector is muscovite mica that was explained in last sections. Muscovite mica detects fission fragments and heavy ions and CR-39 detects every particle. We use muscovite mica for detecting of fission fragments and CR-39 for detecting of alpha particle in the laboratory. In order to research on shape of track in these detectors, first, mica was put on the uranium foil and was exposed in the reactor. After that, it was etched by HF acid in 50º for 45 minutes. Figure 8 shows rectangular traces on muscovite mica after etching under optical microscope. For CR-39 we put it on Am-241 source, which is an alpha particle emitter. After that, it was etched by NaOH in 70º for 8 hours. Figure 7 illustrates the circular traces after etching under optical microscope. Figures 7 and 8 were pictured with magnification of 10 and 25, respectively, in solid track laboratory.

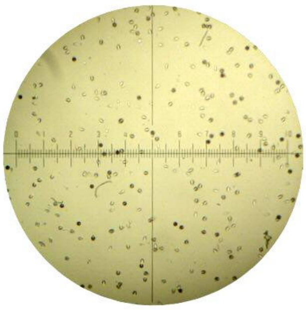

Figure. 2. Shape of track in organic detector

Figure. 3. Shape of track in inorganic detector

Conclusion

As mentioned, etching in organic and inorganic materials is different. Etching in organic detectors is isotropic and it causes that we see circular traces on organic detectors after etching and under optical microscope and Etching in inorganic detectors is anisotropic and we see rectangular traces on these types of detectors after etching and under optical microscope.

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