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Track etch velocity and chemical damages induced by ions in a cellulose nitrate detector

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Abstract

We sum up here the results obtained on a cellulose nitrate detector (LR 115). LR 115 was irradiated with ions from proton and oxygen ions in the energy range 1–10 MeV/amu. Each irradiated sample consisted of a stack of several detectors (about 20–30) each 12 μm thick. So chemical damages were studied according to the energy lost in each detector. Broken bonds were identified and quantified using infrared spectroscopy. In the same time we develop the same approach as proposed by Katz R. for the nuclear emulsion response. This approach is based on the hit theory, where the hits are produced by the secondary electrons removed by the incoming ion. Using this approach, neglecting any differences in the initial electron energy spectra and in the temporal aspect of energy deposition, it is surprising to simulate, with the very same parameters, the chemical cross sections from protons and oxygen ions.

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1. Latent track and track etch velocity

This study attempts to find answers based on physical and chemical criteria that are the best suited for describing the formation of tracks induced by ions in plastic detectors. Only the area where the energy loss is mainly governed by excitation and ionisation processes is studied. Before going further on those considerations, we begin this paper reminding the principle of the track detectors insisting particularly on the track etch velocity. Indeed this velocity gives information on the latent track and has been attempted to be explained for many years by the notions of linear energy transfer (LET) or the restricted energy loss (REL), or the dose deposited in a given volume. To be observable a latent track must be enlarged using an appropriate chemical etchant. During etching two velocities act simultaneously. The bulk etch velocity (V_B) occurs in the undamaged area while the track etch velocity (V_T) occurs in the latent track. The track-etch velocity carries crucial information on the latent track. Several methods are described in literature to determine V_T as a function of the residual range of the ion in the detector (Fromm et al., 1993; Doerschel et al., 1997; Yamauchi et al., 2001; Barillon et al., 1997). Fig. 1 shows V_T of α-particles in LR 115. In Fig. 1, the track-etch velocity looks more like the LET, since the maximum of the track-etch velocity is close to the LET maximum. Nevertheless, if we observe carefully Fig.1, the attempt to model V_T with LET in LR 115 fails (Barillon et al., 1997). Doerschel et al. (1997) showed, even for CR-39, that LET does not enable a precise description of V_T and that the REL, with an energy cut for electrons at 350 eV, is a better parameter. They

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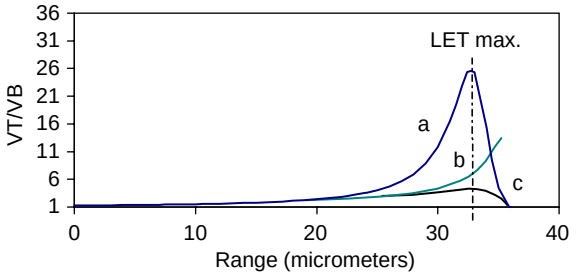

Fig. 1. Comparison of estimates of the ratio of the track etch rate (V_T) to bulk etch rate (V_B) of an α-particle in LR 115 based on (a) a parameter fit to data (Barillon et al., 1997), (b) the average dose from δ rays within 4 nm of the ion's path, and (c) the LET. The location of maximum LET is indicated.

observed that protons and α-particles of same REL have the same track-etch velocity. This last observation must be confirmed for heavier ions. The dose is the other concept found in literature for describing V_T. One can cite the work of Miterev (1995). He developed calculation for radial distribution of absorbed energy including energy losses of both projectile ions and secondary electrons. He observed that the average dose deposited at 4 nm describes the V_T function for protons in CR-39. In fact the two concepts of the REL with an energy cut at 350 eV and the dose deposited in a cylinder of 4 nm radius are similar. Indeed, electrons of 350 eV deposit almost all their energy over a range of 4 nm. Finally, the dose deposited by α-particles in a cylinder of 4 nm radius in LR 115 given by Miterev (1995) as well as the dose reported in Fig. 1 calculated considering only secondary electrons (Katz et al., 1996) does not enable to describe the important variation of the track-etch velocity at the end of the alpha particle range. Our assumption is that the fact that V_T can be described in CR-39 by the REL or the dose, is just coincidence. The REL (or the dose, or the LET) for a given ion is almost the same both in CR-39 and LR 115, and neither the REL nor the dose can explain the V_T function in LR 115. To understand such different behaviours we must study the radiation chemistry of the detectors. Surprisingly, beside the extensive work on etching velocity, there is little data in literature on chemical damages induced by ions in CR-39 and LR 115. In the following part we present some results on chemical damages in LR 115 and their simulation.

2. Material

LR 115 is a trade mark by Kodak. The detector is 12 μm thick. Cellulose nitrate (CN) constitutes 90% in weight, the other 10% are additives. The degree of nitration of the CN used is around 2.3 (Fig. 2).

3. Irradiations

Irradiations in the energy range 1–10 MeV/amu were respectively performed on a 3.4 MeV tandem accelerator for protons at Kobe, and at a tandem—Van de Graff accelerator (Vivitron) at Strasbourg for oxygen ions. Each irradiated sample consists of a stack of several detectors (about 20–30 according to the ion energy) each 12 μm thick. So chemical damages are studied according to the energy lost in each detector. Energy is estimated using the TRIM code (Biersack et al., 1985). The fluences are ranging from 10^{11} to 10^{13} ions cm^{-2} depending on the ion and its energy.

4. Chemical damages in LR 115

The chemical damages were mainly analysed using a Fourrier tansform infra-red spectrometer. The analyses of the vibration bands show the decrease of the glycosidic bond (C_1–O–$C_{4'}$) which links two pyranose rings (see Fig. 2), the loss of the nitrate functions, and a dehydrogenation (Barillon et al., 2002). The same damages were observed in cellulose nitrate irradiated by X-rays (Fowler et al., 1984). The loss of the nitrate functions is the origin of the production of NO, NO_2 gases. Those oxidative gases are able to react with radicals produced by the incoming particle to give nitroxyde-like radicals, which are very stable in time as observed after electrons irradiations (Chipara et al., 1994). We have observed those radicals in LR 115 irradiated with carbon ions of 130 MeV using electron spin resonance spectroscopy. We must remember that the radiation chemistry of any material is rather complex. For LR 115 one can imagine a zone of lower density with H_2, NO, NO_2 degassing,

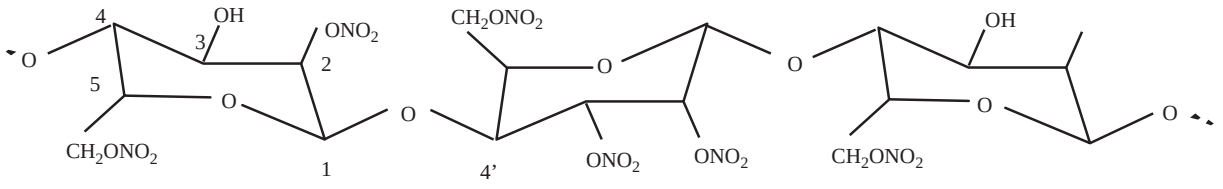

Fig. 2. Cellulose nitrate structure.