1st International Workshop on Space Radiation Research and
11th Annual NASA Space Radiation Health Investigators' Workshop
Arona (Italy), May 27-31, 2000

3-D Confocal Microscopy of Etched Nuclear Tracks in CR-39

M. Fromm[1], F. Vaginay[1], D. Pusset[1], G. Meesen[2], A. Chambaudet[1], A. Poffijn[2]

1. *Laboratoire de Microanalyses Nucléaires, La Bouloie, 16 route de Gray, F-25030 Besançon Cedex (France).*
2. *Department of Subatomic and Radiation Physics, University Gent, Proeftuinstraat 86, B-9000 Gent (Belgium).*

Abstract

Solid State Nuclear Track Detectors (SSNTD's) are used in a wide range of applications such as Geological Dating, Environmental Sciences (radon), life Sciences (Radiobiology, Dosimetry...), as well as Nuclear and Astro-Physics. In order to be observable under a microscope, the nanometric latent damaged trails due to the slowing down of charged particles into the SSNTD have to be specifically etched. In our laboratory, we are studying this chemical action and propose models that enable simulations to be performed. In the literature, the basic model uses two distinct etch-rates that are considered constant, V_B; the Bulk and V_T the Track etch-rate. A little bit more sophisticated and realistic, a model with a variable track etch-rate was established, taking into account the variation of energy deposition along the particle's trajectory.

Up to now, the known methods used for determining the response function of CR-39 are very time consuming and strenuous. The method we present here is based on the use of the confocal microscope, which provides three-dimensional track images. The obtained set of 3-D co-ordinates can be treated mathematically, giving, in the framework of the two etch-velocity model, the response function. With this new approach, tracks are analysed one by one; response functions are obtained for each track and can be compared to fundamental characteristics of the charged Particle-Matter interactions. Moreover, the method we propose is applied semi-automatically and could easily be automated in the near future.

KEYWORDS: CR-39 SSNTD, light ions, confocal microscope, radial dose.

1. Concepts for track etching in isotropic detecting material

1.1. *Etching Process*

The slowing down of charged particles in SSNTD's generates latent tracks that can specifically be etched under given conditions [1]. After such a chemical treatment, the etched tracks can be analysed, under a microscope. In this study the SSNTD's are 1 mm thick sheets of allyl diglycol polycarbonate commercialised by Fukuvi Chemical Ltd., Japan, under the Name of BARYOTRAK Our approach aims at relating measurable geometric etched track parameters to the fundamental characteristics of the Particle-Matter interaction such as Total or Restricted Energy Losses (LET or REL) or Radial Dose from the Track Structure Theory. For a fixed target material such variations of energy deposition depends upon both the particle's relative velocity β and it's effective electrical charge Z^*.

Turning now to the chemical etching (Fig. 1), the detector is processed at 70.0 ± 0.1°C in 7.25 Molar sodium hydroxyde aqueous solution. We assume that two distinct but simultaneous etch velocities V_B and V_T are sufficient to accurately describe the chemical etching phase. V_B is the bulk etch velocity of the undamaged material, it is considered constant and has been measured equal to 1.79 $\mu m.h^{-1}$ under our etching conditions. The specific track-etch velocity V_T depends on the amount of etchable damage surrounding the particle's trajectory. In this work, we used a new approach for measuring the V_T. As mentioned by Fleischer et al, [1], Somogyi and Szalay [2], Fujii and Nishimura [3], we find that the application of the mathematical conditions of the envelope provides:

$$\sin\theta(x,t) = \frac{V_B}{V_T(x,t)} \qquad (1)$$

1.2. *Response Function*

Relation (1) shows that the envelope of an etched track can be seen as the analogue of the production of Mach's waves by a mobile moving with a variable speed V_T in a medium where sound propagates with a constant speed V_B. Application of analytical

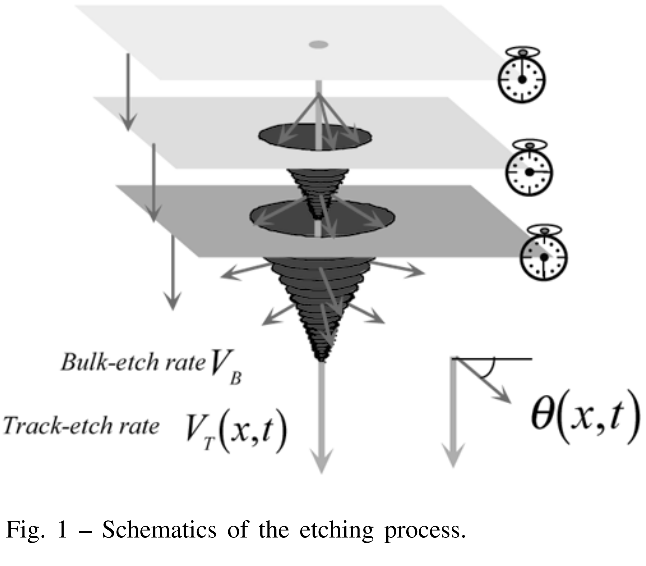

Fig. 1 – Schematics of the etching process.

geometry provides an additional and very useful expression:

$$V^{-1} = \frac{V_B}{V_T(x,t)} = \frac{\left|\frac{\Delta y}{\Delta x}\right|}{\sqrt{1+\left(\frac{\Delta y}{\Delta x}\right)^2}} \qquad (2)$$

Where $\Delta y/\Delta x$ is the slope of the envelope at each point. Insofar as we are able to determine this slope we obtain the detector's response function V^{-1}. Recently, a computer based method was developed [4] using fluorescent dyeing and a confocal microscope, that enables 3-D etched tracks to be observed and measured. Rule (2) can then easily be applied to the numerical file of a track's sagittal section. This computation provides the response function of the detector to a given particle.

2. Experiment and results with Li ions

In order to test this new approach, we first used lithium ions with an energy 10.77 A MeV (Rossendorf Tandem Accelerator, Germany). Tracks were etched in Baryotrak detectors for 5.5 hours under the above mentioned conditions. On Figure 2, we present a raw confocal image of such an etched track and the result of a Gaussian smoothing that enables a binarisation to be performed. A tailor-made software is used for computing the response function (2) of a single track. It should be noticed that the track presented in Figure 2 corresponds to the case of over-etching, so the etching process has been applied to the full range of the particle (i.e. the etched track bottom is rounded).

The obtained response as well as the total LET (SRIM2000) [5], REL [6] and cumulative Radial Delta Ray Dose [7] have been plotted as a function of the particle's range (Fig. 3). The best fit is obtained with the Radial Dose, D(0 < r < 10 nm) where both maximum value and slopes are in rather good agreement with the CR-39's response.

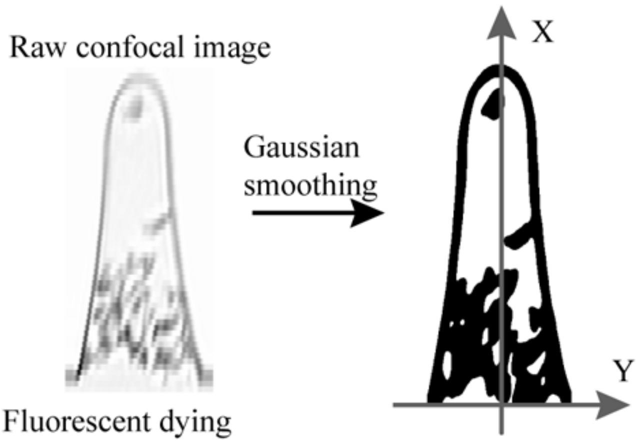

Fig. 2 – Raw and Gaussian smoothed sagittal section of a 10.77 A MeV Li track etched for 5.5 hours in CR-39.

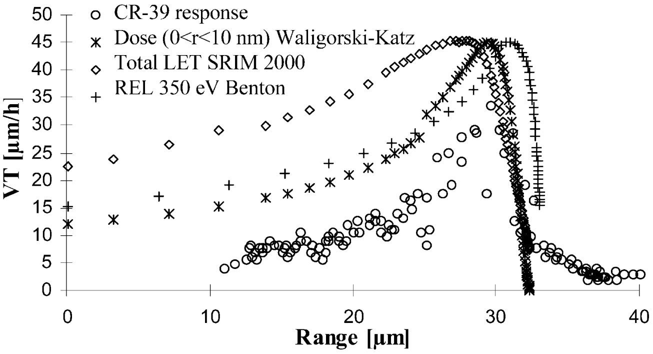

Fig. 3 – Detector's Track-etch velocity for Li ions, Total LET (SRIM2000) [5], REL_{350} [6], cumulative Radial Dose up to 10 nm [7] as a function of the particle's range.

This example demonstrates the potential of the method for light ions with non relativistic kinetic energies at normal incidence.

3. Discussion and Conclusion.

Our preliminary results indicate that the response extracted from one Li track exhibits a (quasi-)linear behaviour when plotted as a function of Radial Dose.

This is illustrated on Figure 4.

Such a new result is very interesting for track physics as well as for applications in the various fields where SSNTD's find applications. In particular, for a given detector, Radial Dose is governed by the ratio Z^{*2} / β^2. This means that spectra of Z^{*2} / β^2 could be measured in appropriate radiation fields (fields where the fluence is such that it avoids etched track overlapping).

Experiments are currently in progress in order to test the proposed method for other light ions (H, He, Be, B, C, N ...) at perpendicular but also variable particle incidences. An oblique incidence does not cause problems for the measurements and already has been modelised in terms of etching [8, 9]. Moreover, as the proposed method is computer

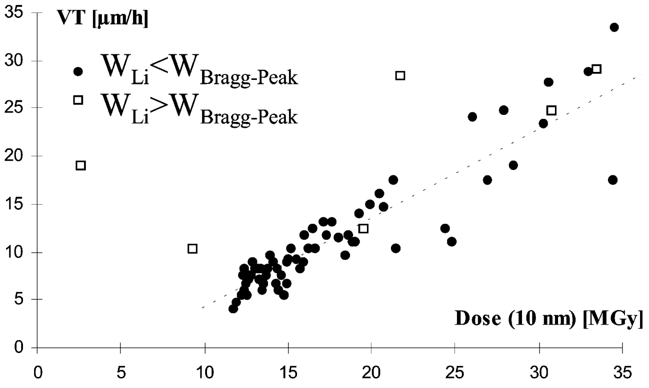

Fig. 4 – VT as a function of Radial Dose (up to 10 nm from the particle's trajectory).

based, measurements of the incidence angles can be provided too. This also should be of high interest for experiments where an information on the (an)isotropy of a beam, or a flux of charged particles, is needed.

The next steps of this research will concern heavier particles (Si, Fe...) with higher energies.

Acknowledgments

The authors would like to warmly thank Dr. Tomoya Yamauchi (KUMM, Japan) for providing the detectors as well as Dr. Dietrich Hermsdorf (TUD, Germany) for performing the Li irradiations.

REFERENCES

[1] Fleischer RL, Price PB, Walker RM. Nuclear Tracks in Solids - Principles and Applications. University of California Press 1975.

[2] Somogyi G and Szalay SA. Track Diameter Kinetics in Dielectric Track Detectors. Nucl Instr and Meth: 1973 109; 211-232.

[3] Fujii M and Nishimura J. Generalized etch-pit equations and their applications to analyses of tracks in CR-39 with depth-dependent etching properties. Nucl Tracks Radiat Meas: 1986: 11; 25-33.

[4] Jakes J, Gais P, Voigt J. Electrochemically etched tracks by means of Confocal Microscopy. Radiat Meas 1997: 28(1-6); 853-856.

[5] Biersack JP and Ziegler JF. Calculation Code TRIM 91. New York. Pergamon Press 1991.

[6] Benton EV and Nix WD. The Restricted Energy Loss criterion for registration of charged particles in plastics. Nucl Instrum Methods 1969: 67; 343-352.

[7] Waligorski MPR, Hamm RN and Katz R. Radial distribution of Dose around the path of a heavy ion in liquid water. Nucl Tracks Radiat Meas 1986: 11(6); 309-319.

[8] Fromm M, Meyer P and Chambaudet A. Ion Track etching in isotropic polymers: etched track shape and detection efficiency. NIM B 1996: XXX; 337-343.

[9] Meyer P, Jouffroy M, Membrey F, Fromm M and Chambaudet A. Parameters influencing the existence and the observability of etched tracks: application to alpha particle detection in CR-39. Radiation Protection Dosimetry 1997: 74; 75-83.