Radiation Measurements 58 (2013) 94–100

Contents lists available at ScienceDirect

Radiation Measurements

journal homepage: www.elsevier.com/locate/radmeas

New approach of modeling charged particles track development in CR-39 detectors

A.A. Azooz [a,*], D. Hermsdorf [b], M.A. Al-Jubbori [c]

[a] Department of Physics, College of Science, Mosul University, Mosul, Iraq
[b] Dresden University of Technology, Dresden, Germany
[c] Department of Physics, College of Education, Mosul University, Mosul, Iraq

HIGHLIGHTS

- New modeling of ions track length evolution measured by different authors.
- Ions considered are p, d, α, Li, B, C, N, O.
- Equations obtained to describe $L(t)$ and etch rate for all ions at wide energy range.
- Equations obtained do not involve any free fitting parameters.
- Ions range values obtained compare well with results of SRIM software.

ARTICLE INFO

Article history:
Received 13 June 2013
Received in revised form
14 August 2013
Accepted 26 August 2013

Keywords:
CR-39
SSNTD
Charged ions range

ABSTRACT

In this work, previous modeling of protons and alpha particles track length development in CR-39 solid state nuclear track detectors SSNTD is modified and further extended. The extension involved the accommodation of heavier ions into the model. These ions include deuteron, lithium, boron, carbon, nitrogen and oxygen ions. The new modeling does not contain any case sensitive free fitting parameters. Model calculation results are found to be in good agreement with both experimental data and SRIM software range energy dependence predictions. The access to a single unified and differentiable track length development equation results in the ability to obtain direct results for track etching rates.

1. Introduction

Experimental studies of charged particles track length in CR-39 detectors have received increased attention in recent years (Hermsdorf and Hunger, 2009; Zaki et al., 2005; Saad et al., 2012). This type of studies has become possible through the use of atomic force microscopy (AFM) (Vazquez-Lopez et al., 2007; Fragoso et al., 2007; Johnson et al., 2009), *confocal microscopy* (Fromm et al., 2000; Vaginay et al., 2001; Félix-Bautista et al., 2013) and lateral irradiation techniques to obtain the longitudinal track profile (Nikezic and Yu, 2003, 2004). In view of the absence of a complete analytical theory which can fully describe track formation and development against etching time under different etching conditions, empirical parameterization has become the second best alternative used to describe experimental results. The availability of track length and track profile data has served well in developing empirical models for this purpose.

One such modeling has been presented in Azooz et al. (2012a). In this model, a tangent hyperbolic type function is used to describe the track length–etching time dependence. The model involved four free fitting parameters to describe alpha particles tracks. The model was extended to cover protons tracks (Azooz et al., 2012b). The model produces reasonable description of experimental data for particle energies up to 5 MeV. However, one limitation with this model is that its performance at higher energy values is not equally adequate. The main reason for this is attributed to the fact that the energy dependence of the first free fitting parameter in the model has been assumed to be linear. This parameter is directly related to the track length saturation value. A more recent compilation of experimental results indicates that although the linear energy dependence is approximately valid at energies below 5 MeV, marginal deviations from linearity start to take place at higher energy values.

In this work, more suitable power law energy dependence is assumed. Furthermore, the model is further developed to describe

* Corresponding author.
E-mail address: aasimazooz1@yahoo.com (A.A. Azooz).

1350-4487/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.radmeas.2013.08.012

tracks of heavier ions in CR-39 detectors. Such modeling can be regarded as a step forward in the direction of attempting to use CR-39 detectors for both particles identification and charged particles energy spectroscopy.

2. The data

An attempt has been made to compile as much as possible published experimental data related to track length against etching time of different charged particles in CR-39 SSNTD. Data related to protons (Dörschel et al., 1999), deuterons (Hermsdorf, 2012), alpha particles (El Ghazaly, 2012), lithium, boron and carbon (Dörschel et al., 2002), nitrogen and oxygen (Dörschel et al., 2003) ions has been spotted. It is worth mentioning that the majority of these experimental data were the results of works by the late professor Dörschel group. As far as alpha particles data are concerned, and in spite of the fact that such data were presented in Dörschel et al. (1999), these data were used in Azooz et al. (2012a). Thus and in order to achieve more diversity generality, it is decided to use data from El Ghazaly (2012), in this work. Furthermore, and as far as protons and alpha particles are concerned, all data related to particle energy values used in previous modeling have not been used in this work. Different energy values are selected instead. The energy values for each particle type used in this work are: 1.87, 2.25 MeV for protons, 1.60 MeV for deuterons, 2.50, 3.00, 3.50, 4.00, 4.50, 5.00, 5.50 MeV for alpha particles, 2.87, 4.82, 6.75, 7.99, 9.02, 10.96, 11.66 MeV for lithium, 13.30, 17.50, 19.50, 21.50 MeV for boron, 14.80, 19.20, 22.50 MeV for carbon, 15.96, 20.48, 22.08 MeV for nitrogen, and 17.26, 22.23, 26.41 MeV for oxygen.

Due to the fact that almost all published data are in the form of graphical presentations, a method of numerical data extraction has to be employed. A special image processing matlab based computer code is written for this purpose. The software operation is based on calibration of image pixel digital image point of any selected location on a graphic presentation to real x–y coordinate values. In this data extraction process, data points indicated by the original authors with specific point markers representing experimental measurement are only selected. Points on spline lines are not selected. The accuracy of this technique is only governed by the size of the point marker in the original graphic presentation. This is due to the fact that any point marker will usually extend over several digital image pixels. All efforts have been made to ensure that data points selected fall at the center of actual experimental data point's markers.

3. Previous modeling

In the pervious modeling (Azooz et al., 2012a), the relation of alpha particles track length $L(t)$ to etching time t was suggested to have the form given by:

$$L(t) = A_1 \left[\tanh\left\{ \exp\left(\frac{t - A_2}{A_3} \right) \right\} \right]^{\frac{1}{A_1 A_2 A_3}} \quad (1)$$

A_1, A_2, and A_3 are free fitting parameters. The energy dependence of these three parameters was estimated as

$$A_1 = a_1 E - 1.5 \quad (2)$$

$$A_2 = a_2 \exp\left(\frac{E^{0.5}}{a_3} \right) E^{1.5} \quad (3)$$

$$A_3 = a_4 E^{-0.7} \quad (4)$$

The new parameters a_1, a_2, a_3, and a_4 are energy scaled parameters for each particle type and have almost no energy dependence. This modeling works well in estimating track length, etching rates and profiles for protons and alpha particles in the energy range up to 5 MeV. Some deviations from this model have been observed at higher energies.

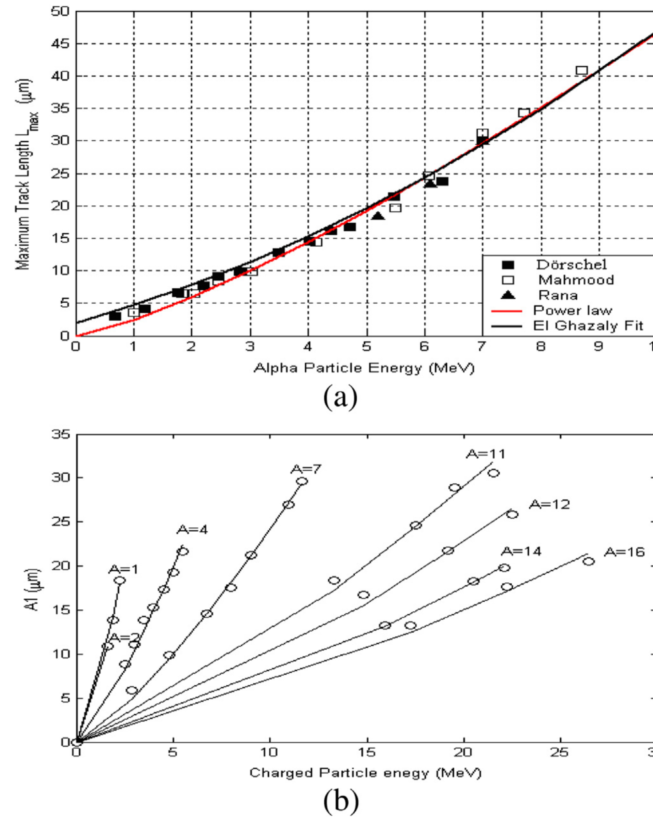

Fig. 1. (a) Energy dependence of compiled experimental data for track saturation length A_1 for alpha particles fitted to power law (red) and second degree polynomial (black). (b) Track saturation length A_1 (circles) with fits to power law (line). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

4. New modeling

The above mentioned deviations above 5 MeV dictate the necessity for further improvement on the model. It is thought that this limitation is due to the linear energy dependence of the first parameter A_1 assumed. This parameter is a direct measure of the track saturation length when the detector is over etched. A data compilation of track length saturation values for alpha particles tracks against energy is plotted in Fig. 1(a). It is clear from these data, that in spite of the fact that the linear energy dependence can provide reasonable description below 5 MeV, the situation changes at higher energies. El-Ghazaly, has fitted these data to a second degree polynomial with three fitting parameters. However, it is more useful to try to reduce the number of fitting parameters to the minimum possible. For such reason, a power law dependence of the form given in equation (5) will be more convenient with almost the same result

$$L_{max} = a_1 E^{a_2} \quad (5)$$

Results of fitting all available data for alpha particles shows that the data can be reasonably described by equation (5) with $a_1 \approx 2.45$ microns/MeV$^{1.2}$, $a_2 = 1.2$. This type of fitting equation does not only reduce the number of fitting parameters to two instead of three, but also satisfies the physical constrain $L_{max}(E = 0) = 0$. The fitted