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Semi Empirical Equation for the Calculation of the Track Diameter of Alpha Particles in CR-39 as a Function of Etching Temperature

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ABSTRACT

In this paper a new semi empirical equation describing the track diameters of α particles in CR-39 is presented. The equation involves three free fitting parameters. It is shown that this equation can reproduce tracks diameter formed on the CR-39 by alpha particles at 3.1MeV, different etching times and temperature (70, 75, 80, 85) ^{o}C . Parameters values obtained from the experimental data were used to predict etched track diameters at different temperatures (T=70-85)^{o}C and etching times (t=0-6)h. The suggested empirical equation is self consistent as far as reproducing all features of track diameter development as a function of etching time and temperature.

Keywords: SSNTD, CR-39, Alpha Particle Track Diameters.

إيجاد معادلة شبه تجريبية لحساب أقطار آثار جسيمات الفا في كاشف الأثر النووي CR-39 كدالة لدرجة حرارة القاشط

الملخص

في هذا البحث تم اقتراح معادلة شبه تجريبية جديدة تصف قطر الأثر لجسيمات الفا مع تطور عملية قشط كاشف الأثر النووي CR-39، تتضمن المعادلة ثلاث معلمات حرة. هذه المعادلة بإمكانها ان تحسب أقطار الجسيمات المتكونة في CR-39 المشعع بطاقة 3.1MeV والمقشوط بأزمان مختلفة ولدرجات حرارة (70, 75, 80, 85) ^{o}C. قيم المعلمات يمكن الحصول عليها من النتائج العملية ومن ثم استخدام هذه القيم لاستنتاج أقطار أثار جسيمات الفا عند أزمان قشط (t=0-6)h ودرجات حرارة (T=70-85)^{o}C. ان المعادلة التجريبية المقترحة تصلح لوصف تطور قطر الأثر كدالة لمتغيرين هما زمن قشط الكاشف ودرجة حرارة المحلول القاشط (تحت نفس الظروف).

الكلمات الدالة: كاشف الأثر النووي CR-39، أقطار أثار جسيمات الفا.

INTRODUCTION

The etching of solids is a highly complex phenomenon including dynamical and chemical processes involving both the chemical activity (interaction of ions and molecules in solution with each other) (Dörschel *et al*., 2003; Gaillard *et al*., 2005 a, b) and the diffusion of the solution through the surface into bulk material. Therefore the solid state nuclear track detectors SSNTDs have become essential tools in many applications of the nuclear track methodology (NTM) (Azooz *et al*., 2012 a, b). The possibility of performing alpha particle energy analysis has been of interest to many research groups (Espinosa and Silva, 2001), (Ditlov, 2005). Making use of the relationship between the geometrical size of the formed track and the energy deposited in polycarbonates, alpha-emitting radioisotopes may be identified (Fleischer *et al*., 1975). Charge, energy and direction of the incident particle can be investigated by measuring the track profile after etching the latent tracks at properly chosen as the concentration C of the etching solution and its temperature *T* (Hermsdorf *et al*., 2007; Hermsdorf, 2012) . These parameters strongly influence the etching processes for removing non-irradiated material and the revealing of the tracks.

EXPERIMENTAL PROCEDURE

In order to obtain track diameter at different temperature of etching solution and etching times, a 1 × 1 cm^2, 200 μm thick CR-39 detectors (made by Page Moldings Pershore UK) were exposed to alpha radiation from an ^{241}Am for about ten minuets. Distance between the source and detector (2.4 cm) corresponding to the measured alpha particle energy of 3.1 MeV was selected because this energy causes a maximum damage in the detector (El Ghazaly, 2012; Hamzeh *et al*., 2012). The exposure system involves a narrow collimation in order to obtain almost perpendicular incidence angle. After an initial etching in 6.25 N NaOH solution, at (70 , 75, 80, 85)±1^{o}C, by a water bath for various periods. The etching solution was changed by a new one every three hours and in a glass cup with a tight lid to prevent change in concentration due to vaporization of water and absorption of moisture the tracks having. These tracks are etched for 15-30 minuets and a high resolution digital camera (type, MDCE-5A) with (10×25) magnification were connected to a microscope (Series Biological XSZ-H) to measure the track's diameter. The etching process at different etching time, and a digital picture is taken each time. A set of digital pictures of the diameter of each developed track was thus obtained and their track diameters were measured.

RESULTS AND DISCUSSION

The aim of this work is to obtain a semi empirical equation that can describe the track diameter as a function of etching time and the temperature of the solution, then the measured data were fitted to equation (1). (Fig.1) shows that the track diameter increases with etching time. Any empirical parameterization of such behavior must be able to reproduce the following effects:

1. The time development of the track diameter.

2. The temperature of solution dependences on the charged particle and etching conditions.

3. It is favorable that these conditions should be met by a single continuous function.

One good candidate for a mathematical form that has the inherited ability to satisfy the conditions above is an exponential function. However, the track diameter development with time is always slower at the beginning of the etching process.

$$D(t) = A_1(1 - \exp(-A_2 t)) \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots(1)$$

A_1 and A_2 are free fitting parameters depending on the temperature of the solution. The data at different temperatures are fitted independently to equation (1). The fits were performed using the matlab curve fitting facility which gives a minimum 95% confidence level by default. Convergent fits were obtained. It was found that equation (1) reproduces the experimental data very well.

(Fig. 2) shows that track diameter increasing with temperature of solution at the same etching time.

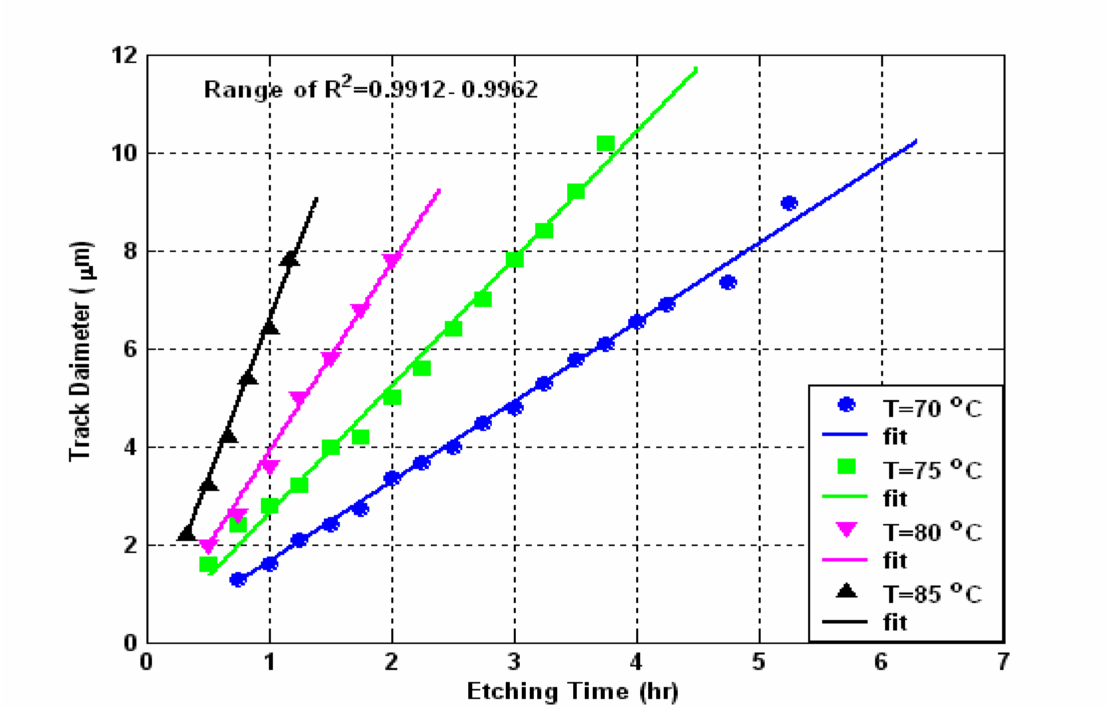


Fig. 1: Track diameter versus etching time data compared to fits to equation (1).

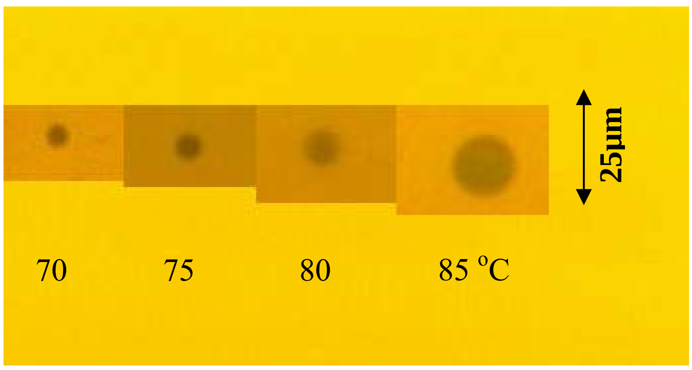
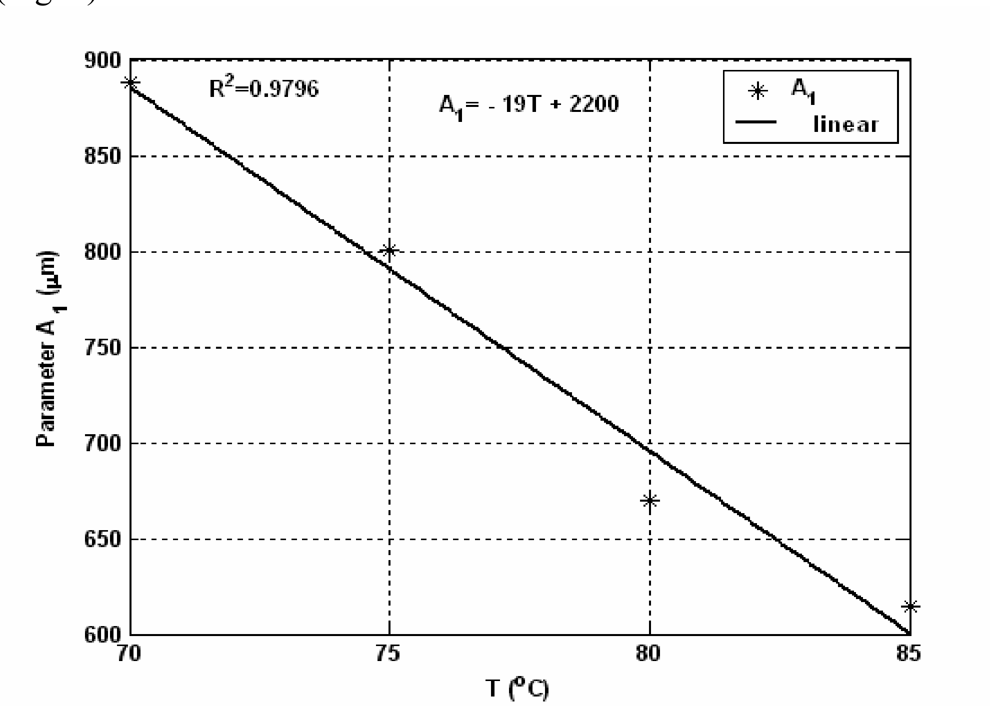
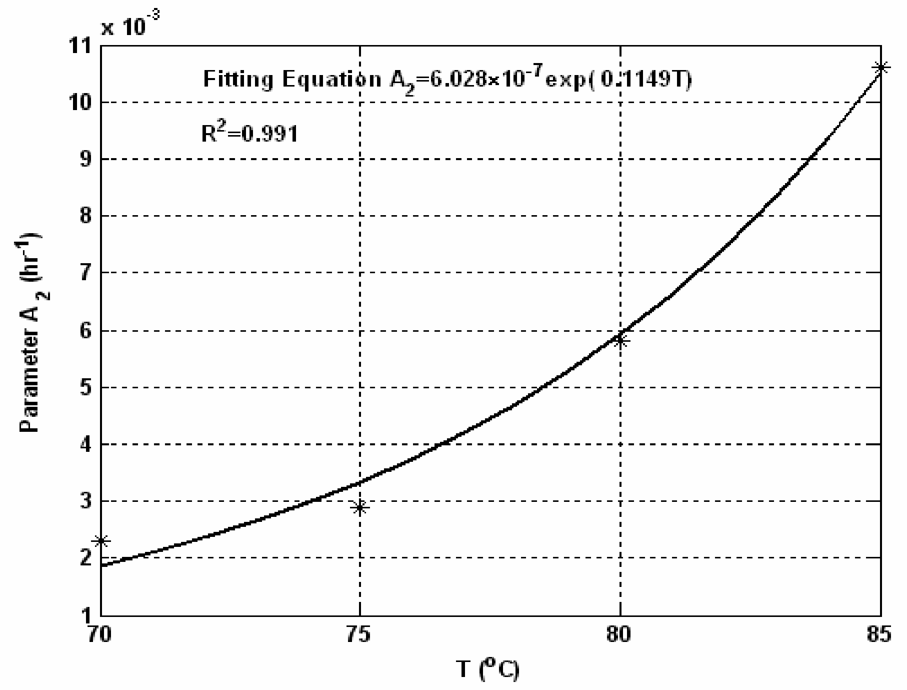


Fig. 2: Photograph of track diameter at 1 hr for E=3.1MeV for different temperature.

In order to write equation (1) in a more useful form, the temperature dependence of each of the free fitting parameters has to be established in to which values of each of the two fitting parameters are plotted against the corresponding temperature values. These plots are shown in (Fig. 3).



(a)



(b)

Fig. 3: Temperature dependence of the two free fitting parameters (a) A_1, (b) A_2

It is clear from (Fig. 3) that the fitting parameter A_1 is almost linearly dependent on temperature. The linear fit to the data is over 95% confidence level straight line with intercept +2200.

$$A_1 = -a_1 T + 2200 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

The behavior of the second parameter A_2 is not linear with temperature. This parameter can be easily fitted exponential. The temperature dependence of this parameter is thus represented as

$$A_2 = a_2 \exp(a_3 T) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

The new parameters a_1, a_2 and a_3 are supposed to be scaled parameters which should have the same values for all temperatures. Equation (1) can now be rewritten as

$$D(t,T) = (-a_1 T + 2200)(1 - \exp(-(a_2 \exp(a_3 T))t)) \ldots\ldots\ldots(4)$$

where a_1=19, a_2=6.028×10^{-7} and a_3=0.1149

Equation (4) is a semi empirical equation which is supposed to describe the track diameter dependence upon both temperature and etching time. However, if this equation is to be an acceptable one, the values of the parameters a_1, a_2 and a_3 must be the same for all temperatures within the present temperature range. Equation 4 was in a reasonable agreement with the measured track diameter as shown in (Fig. 4). Track's diameter growth rate $V_D = \dfrac{dD}{dt}$ as a function of temperature which can be obtained from equation 4 was shown in (Fig. 5).

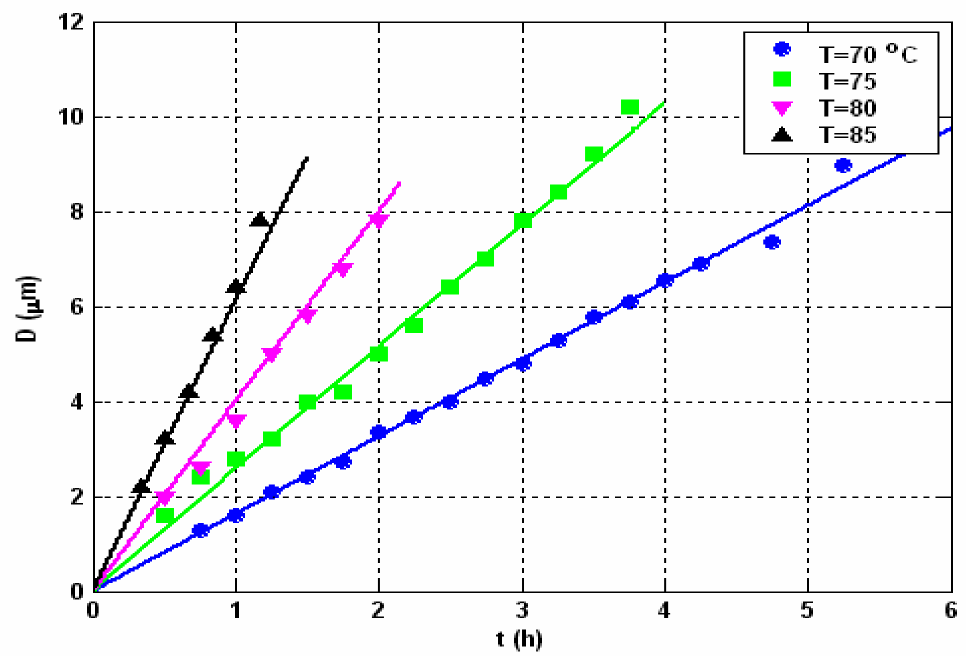


Fig. 4: Calculated track diameter at different etching time compared with measured values.

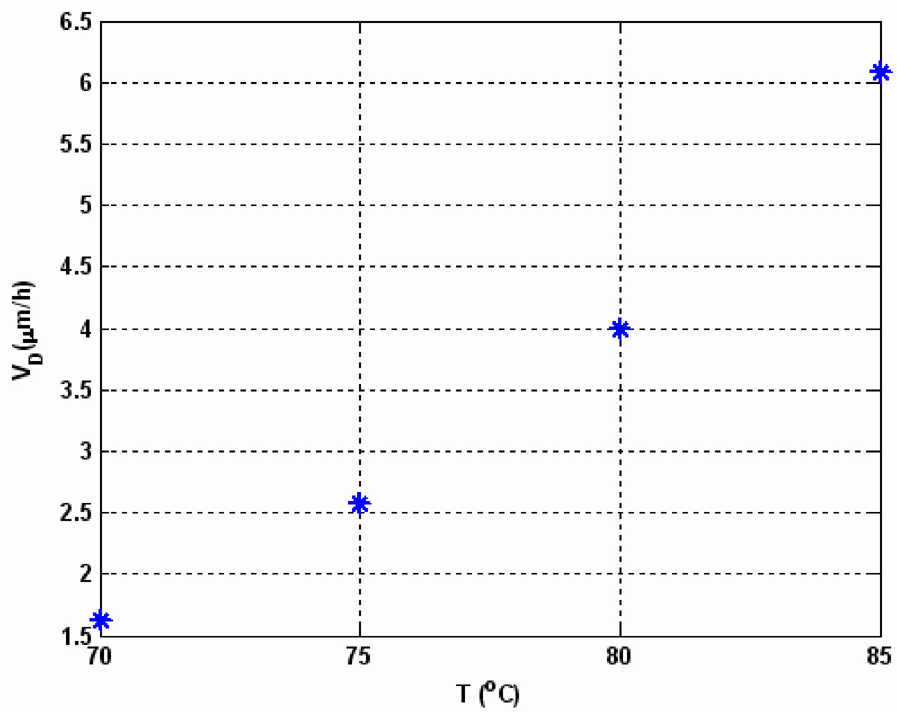


Fig. 5: Track's diameter growth rate as a function of temperature

CONCLUSION

A fitting equation to describe the behavior of the track diameter produced by alpha particle bombardment on CR-39 was obtained from the measurement of the track diameter at temperature range from 70 to 85 °C at a different etching time between 0 to 6 hours. It was found that equation (4) describes the measured values fairly well.

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