Finding Bulk etch rate \( V_B \) using the maximum value of the \( L_{\text{max}} \) effect using practical diameters calculated from the falling alpha particles on the CR-39 nuclear track detector.

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Abstract

A lot of research was focused on studying the engineering shape of the impact and its development and finding its parameters. It was based on pictures of the side effects of the effects formed in the detector as a result of the detector's etching. Obtaining pictures of the side effects of the effects to measure their lengths is a difficult process compared to its diameters. There are many methods used to find Bulk etch rate \( V_B \) including gravimetric method or thickness difference; but we will use in this research an alternative method to find \( V_B \) which is the maximum value method for saturation of the effect length "\( L_{\text{max}}\)-method". Using the source Am241 (1\( \mu \text{Ci} \)) emitting alpha particles in irradiation of the PDAC CR-39 irradiation With MeV energies (2.3, 3.3, 4.3), the detectors etching by NaOH aqueous solution at different concentrations (N: 6, 7, 8) at a temperature of 70\( \pm \)1 \( ^\circ \text{C} \), we suggested in our research a D-Le calibration method that is based on direct experimental measurement of the diameters of the projected effects in Detector instead of lengths. An empirical relationship was used to find \( V_B \), which depends on the maximum values of saturation of effects lengths and their saturation times. The results we obtained for \( V_B \) values at the concentrations used were (1.199, 1.490, 2.184) \( \mu \text{m h}^{-1} \) in order and they correspond well to the values resulting from different methods, it is observed The Bulk etch rate increases with the concentration of the abrasive solution, and the maximum values of saturation of the effect length are directly proportional to the energy of the bombing particles and the time of saturation of the impact lengths.

Keywords: CR-39 detector; solid nuclear track detectors; Bulk etch rate; maximum values of saturation of \( L_{\text{max}} \) effect; alpha particles.
1. Introduction

Solid State Nuclear Detectors (SSNTDs) have been usefully used in many fields such as science and technology as they possess a good property which is their ability to store the effect of ions in the form of damage or impair to their internal structure, this damage or impair can be shown either in a direct or indirect way. The electron microscope is used to show this effect in a direct way. As for the indirect method, the ordinary optical microscope is used after the treatment of the exposed reagent with an abrasive chemical solution and suitable skimming conditions such as the temperature of the abrasive solution or its concentration to show this damage and enlarge it to watch it. Called latent tracks [1,2]. Polly Allyl Diglychol Carbonate (PADC) is one of the most widely used reagents especially in scientific and industrial fields and is commercially known as CR-39. It is characterized by the high sensitivity of heavy particles and protons [3,5]. One of the most important basic parameters required for the use of solid-state nuclear impact detectors is the overall bulk rate ($V_B$) (bulk etch rate)). The overall skimming rate is an amount of still surface of the detector in the unaffected areas during the chemical reaction process between A. Abrasive and reagent material, which leads to erosion of the target material in all directions which reduces its thickness with the progress of the etch process [4], the value of $V_B$ should be known, for example, to determine the charge of falling ions or to identify some important parameters What is required in some practical applications of nuclear impact detectors, such as Track Etch Rate,$V_T$ or impact detection efficiency, among others. The effect formed on the detector is closely related to its shape and development by two main parameters: the Bulk etch rate $V_B$ and the track etch rate $V_T$. The track etch rate is along the damaged path in the detector. These two parameters are related to the relationship Etch rate ratio ($V = V_T / V_B$) which is called Ratio of skimming, and for this reason it is important to familiarize yourself with some of the methods used in calculating the general skimming rate [6].

There are several methods or patterns that are used to calculate the bulk etch rate in the solid-state nuclear tracks, including the corrosive thickness method (Removal thickness) of the nuclear trace detector $\Delta x$ during the process of skimming the detector’s surface during a selected time period for the skimming process $\Delta t$ through the equation:

$$V_B = \frac{\Delta x}{2\Delta t} \quad \text{............... (1)}$$

$\Delta x$ : change in thickness during etching time.

$\Delta t$ : the change in etching times.

Parameter 2 indicates that the amount of material removed or corroded is carried out by both ends of the detector during the etching process.

Despite the widespread prevalence of this method in the process of calculating the bulk etch rate, it may sometimes produce inaccurate results [7]. The reason is that the surface of the detector may become uneven after successive skimming operations, as the surfaces are not equal. It may give incorrect and different results to thickness at different locations from the surface of the reagent used.
Moreover, during periods of short etching, the increase in thinning reagent fish continues before the water absorption stability is reached by it \[8\]. Therefore, as a result of these reasons, equation (1) can be modified by replacing the coefficient \(\Delta x\) with the coefficient \(\frac{\Delta m}{ad}\) to become as follows \[6,9\]:

\[
\Delta \frac{m}{2\Delta t ad} \quad \text{……………(2)}
\]

\(\Delta m\) : removed surface mass.
\(a\) : detection surface area used.
\(d\) : Density of the detector.

This method is called gravitational method, which is based on measuring the mass of the reagent before and after etching \[10, 4\].

As a result of scientific development, another method was used to calculate the bulk etch rate (\(V_B\)), which is the method for measuring the length-diameter of the effect (Le-D). This modern method is not easy, but it gives accurate results compared to previous methods in the process of calculating \(V_B\). This method requires obtaining images of the effects formed in the detector, and requires accurate measurement of both the diameter of the impact (\(D\)) and its length (\(L_e\)) empirically directly and this requires effort and time. Long and the bulk etch rate is calculated by the formula: \[11,12,13\]

\[
V_B = \frac{D^2}{4tL_e} \left[1 + \sqrt{1 + \frac{4L_e^2}{D^2}}\right] \quad \text{……………… (3)}
\]

The method for measuring the length-diameter of the effect (\(L_e - D\) method) used in calculating the bulk etch rate is used during the first stage of impact growth, which is the stage of the regular conical pattern until the impact head reaches the end of the particle range in the detector.

Another way to find the bulk etch rate that we will use in this research is to find the maximum value of the "Lmax-method" as an alternative way to find \(V_B\) by means of an experimental equation (4) that depends on the maximum saturated effects lengths and the saturation times at the saturation point, where it was found The lengths of the effects formed on the detector in this research by calibration between the lengths-diameters (DL), based on direct measurements of the effects of the effects on the detector due to the fall of alpha particles after successive skimming operations \[14\]

\[
L_{max} = R - V_Bt_{sat} \quad \text{………………… (4)}
\]
2. Experimental approach (The method of work)

The PDAC CR-39 impact detector is radiated with a thickness (200 µm) after being cut into pieces with dimensions (1 × 1) cm² vertically with alpha particles from a source $^{241}$Am (1 μCi) at a small stereoscopic angle within a small area with a diameter of approximately (1mm) to ensure that the particles fall vertically over the area determined from the detector using the energies (2.3, 3.3, 4.3) MeV, the energies chosen in this research were obtained which are less than the maximum or main energy emitted from the used radioactive source and are within the limits of 5.485 MeV by changing the distance between the radioactive source and the detector according to the formula:

$$E_\alpha = E_0 \left(1 - \frac{X}{R}\right)^{\frac{3}{2}}$$ \hspace{1cm} (5)

Where R: The range of alpha particles in the air is approximately 4.16 cm.

X : distance detectors from the radioactive source.

E₀ : The maximum alpha (main) energy from the radioactive source $^{241}$Am at the distance X = 0 equals 5.485 MeV.

Eₘ : is alpha particle energy at the chosen distance X from the radioactive source.

After the irradiation process of the detectors is completed, the detectors is etching with chemical NaOH solution for concentrations (6, 7, and 8) at a temperature of 70 ± 1°C for successive etching periods for each case dependent on the energy of the falling particle and the concentration of the abrasive solution. To see the holes of the effects of falling alpha particles on the detector and measure their diameters after performing the etching of the specified energies and the specific concentration of the specified times, we used a digital camera MDCE-5C installed on an optical microscope connected to a PC calculator.

3. Results and discussion

Figure (1) depicts the alpha-effect trace diameters with the specified skimming time for energies (2.3, 3.3, 4.3) MeV on the CR-39 used reagent. These diameters are from direct measurement of the traceability images after the process of performing the NaOH abrasive solution for concentrations (8, 7, and 6) at a temperature of 70 ± 1°C, as it is observed that they change linearly with etching times.
Figure (1) Relationship of alpha particle diameters with etching times for alpha energies used at N = 6,7,8 and 70°C temperature.
Figure (2) shows the change in the lengths of the indirect effects of alpha particles with the etching times of the energies (2.3, 3.3, 4, 3) MeV at the concentrations used, to obtain these indirect lengths from the slots of the diameters of the experimental effects of alpha particles on the detector (from the slot images) Effects. Instead of direct measurements of lengths, use the program (Track Test) [15], the experimental data obtained for the energies used and for all concentrations of skimming under study were used using one of the equations included in the program that relate to the CR-39 detector which is the GREEN equation Others (1982) with their default parameters provided in the program To get the diameters and the effects of alpha particles of energy used within the etching conditions specified, by drawing curves "diameter-length" (D-L) effect for use calibration curves to find the lengths of the corresponding effects of the diameters measured depending on the specific cases. It is noted from the figure that the length of the impact (the impact shape) passes through two stages of growth, in the first part where the ratio of the rate of skimming is greater than one (V> 1) where the length of the effect increases linearly from the progress of the period of the skimming process, as the length of the impact reaches its maximum value At Lmax, which is the starting point of saturation and longevity of the trace length, this condition occurs when the etching starts to reach the intact region (the end of the range of the blasting particle inside the detector), the effect of the effect at this stage of etching is conical in shape with a sharp and tapered end that is at the end of the trace, This stage is the stage of the conical shape of the impact [16]. As for the second part of the stage of growth of the length of the impact, which It is called the over-etched phase, and it is called another spherical shape, where the ratio of the rate of etching is close to one (V ~ 1). This stage does not last for long, as its value soon becomes one where The length of the effect continues to be saturated and proven until the time average of the effect is equal to zero [L'(t) = 0] with the continuation of the etching process and the impact head begins to shift to the rounded and then to the spherical shape, this stage represents the confirmation of the length of the impact and the arrival of etching to Sound areas below the end of the conical impact [16].
Figure (2) Lengths of quasi-experimental effects with etching periods obtained from the D-L titration curve at concentrations N = 6,7,8 at 70°C temperature of alpha particles with energies (2.3,3.3,4,3) MeV on CR-39.

Table (1) Maximum values of effects length and saturation times for different alpha energies in CR-39, at 70°C and N = 6, 7, 8

| N  | Etching Normality,N | E (MeV) | R (µm) | L_{max} (µm) | saturation time of track length, t_{sat} (µm) | R-L_{max} (µm) |
|----|---------------------|--------|--------|-------------|------------------------------------------|---------------|
| 8  |                     | 4.3    | 23.04  | 16.694      | 3                        | 6.346         |
| 7  |                     | 3.3    | 15.9   | 12.22       | 1.7                      | 3.68          |
| 6  |                     | 2.3    | 10.02  | 8.059       | 0.9                      | 1.961         |
From Figure (2), the maximum values of the longest effects $L_{\text{max}}$ at the saturation point as well as the saturation periods $t_{\text{sat}}$ can be obtained according to each energy of the alpha particles and each concentration of the abrasive solution under study as shown in table(1), where we will use these data later to find the bulk etch rate $\text{And}$. As we mentioned previously, the length of the $L_{\text{max}}$ effect is the maximum that the effect can reach at the point of stability (saturation) when the process of scraping reaches the head of the conical effect, which represents the end of the extent of the falling particle (etching in the intact area), while $t_{\text{sat}}$ represents the time at which the length of the effect $L_{\text{max}}$ reaches its maximum value, which represents the saturation point.

Figure (3) shows the relationship between the energy of the falling alpha particle with the maximum value of the length of the impact of this energy for all energies and for all concentrations, as it is noted, as in many studies specialized in this field, that the maximum value of the effect length $L_{\text{max}}$ increases linearly with energy and that it depends only on the energy of the particles Fallen.

Figure (4) shows the relationship between the time of saturation $t_{\text{sat}}$ and the energy of the alpha particles. It is noted that the time of saturation increases with the increase of the energy of the falling particles and that the time of stability or saturation not only depends on the energy of the falling particles but also depends on the skimming conditions of the type of abrasive solution and its concentration and degree, Its temperature. These factors have a significant impact on the rate of impact skimming and on the bulk etch rate. The increase in the concentration of abrasive solution or its temperature does not affect the saturation of the effect length (maximum length) of the falling alpha energy, but it speeds up the time to reach the maximum value of the effect length. In other words, it reduces from the time of arrival to $L_{\text{max}}$, the degree of increase is free. The time or concentration of the abrasive solution leads to the removal of more quantities of intact areas and thus leads to an increase in $V_{\text{B}}$ and also leads to the removal of more quantities of the detection substance towards the
path of the falling particle and thus an increase in $V_t$, which in turn leads to an increase in the diameter and length of the effect [10,18,12].

Figure 4: Changing the time saturation of the impact length and holding it at its saturation point with the alpha massive energy in the CR-39 detector under the conditions of etching used.

With reference to the data in Table (1), the general rate of abrasion of the reagent used can be found in a method-Lmax method, where the difference relationship $R-L_{max}$ ($\mu$m) is drawn as a function of the saturation time (hr) $t_{sat}$ as shown in Figure (5). The slope of the line The straight line based on relationship (4) represents the general abrasion rate, $R$ in relationship (4) represents the extent of the alpha particles in the CR-39, and its value depends on the energy of the falling alpha particles and its value can be found from the SRIM- (Stopping Power and Range of Ions in the Matter program) ) [20] by energy used.

With reference to the data in Table (1), the bulk etch rate of the detector used can be found in a method-Lmax method, where the difference relationship $R-L_{max}$ ($\mu$m) is drawn as a function of the saturation time (hr) $t_{sat}$ as shown in Figure (5). The slope of the line The straight line based on relationship (4) represents the bulk etch rate, $R$ in relationship (4) represents the extent of the alpha particles in the CR-39, and its value depends on the energy of the falling alpha particles and its value can be found from the SRIM- (Stopping Power and Range of Ions in the Matter program) ) [20] by energy used.
Figure (5) shows the difference between R-Lmax as a function of the slope of the saturation time length of the t_{sat} effect according to the alpha particle energy in the CR-39 reagent under the etching conditions used. T straight lines is the bulk etch rate.

The results obtained for the bulk etch rate were compared by method-L max method which was (1.199, 1.490, 2.184) µm h^{-1} for concentrations (6, 7, 8), respectively, with other research results for the bulk etch rate, as they appeared identical and close to the results that Both researchers obtained [18] [21] using other methods, which were within the limits of (1.268, 1.421) µm h^{-1} respectively, under close etching conditions, and it also appeared close to another study by researchers [22, 23, 24] where (1.23, 1.45, 1.317) µm h^{-1} were arranged in convergent etching conditions which are also NaOH (6.25N, 70°C) conditions, knowing that these conditions represent the optimum etching conditions for the CR-39 reagent used in most research were also observed to converge with the results obtained by [25] under etching conditions NaOH (6.25N, 70°C) using the removed fish method of 1.274µm h^{-1}.

4. Conclusions

The alternative method "diameter-length" (D-L) is characterized by the effect of finding the lengths of the effects indirectly through direct measurement of the diameters of the effects of falling particles on the detector after performing the etching process without resorting to photographing the side effects of the effects, with its high accuracy in studying the evolution of the effects of As its track shape growth, its profiles and other parameters are compared to other methods. The Lmax-method used in our research is characterized by its ease and ability to find implicitly the bulk etch rate by determining the maximum value of the length of the effect (Saturation value) in addition to the saturation time that is j. It does not have the length of the effect to the stability in addition to the range of alpha R particles, and this method can be used to find V_{B} through empirical data for the length of the effect after photographing its longitudinal sections. This method can reduce the researcher's time in finding the bulk etch rate instead of using other methods that take time The longest.
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