International Journal of Humanities and Social Science Invention (IJHSSI)
ISSN (Online): 2319 – 7722, ISSN (Print): 2319 – 7714
www.ijhssi.org ||Volume 8 Issue 5 || May 2019 || PP. 103-105

Track Annealing Revisited: A New Approach of Study of Progression of Track Anneling in Solid State Nuclear Track Detectors

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Abstract:
Impact of temperature on track registration in Solid State Nuclear Track Detectors has remained a key area of research and interest since the advent of insulting solids as charged particle detectors. Phenomenon of track annealing has throughout occupied a centre stage in all SSNTD research. In the present work, an approach has been developed to express track diameter after post irradiation annealing in terms of pre-annealed track diameter which also makes possible to identify and use an exclusive parameter that can most accurately describe annealing induced repair of damage quantitatively, also it evolves a new approach to study the progress/kinetics of annealing phenomenon.

Keywords: *Track Annealing, Track Etch Rate (V_T), Bulk Etch Rate (V_B), Etch Rate Ratio (V), Track Diameter (D).*

I. Introduction:

Solid State Nuclear Track Detectors have been found to be immensely useful owing to important applications in various areas viz. Radiation Dosimetry, Fission Track Dating, Uranium Exploration, Radon Monitoring, Heavy Ion Reactions, Space Science, Life Sciences, Material Sciences, Cosmic Ray Physics etc. [1], [2], [3], [4].

A sound understanding of the phenomenon of track annealing has been considered to be a very crucial SSNTD aspect not only from the point of view of pure interest in this process but also for the vital information it could provide regarding a more plausible track formation mechanism. It can be imagined that the phenomena of track formation and track repair studied in an integrated framework could lead to better understanding of individual processes. Track repair on account of annealing is gradual and it passes through various partial stages with different extents of the annealing effect to finally culminate in complete erasure of etchable tracks. [5], [6], [7], [8], [9].

From the beginning of the annealing process till the complete erasure of tracks, an accurate knowledge of (a) the extent to which annealing has taken place upto various partial states (b) extent of annealing between two partial stages (c) pace of the annealing induced track repair process, would be of tremendous benefit in acquiring a sound understanding of the track annealing phenomenon in its correct perspective. This may be referred to as track annealing kinetics. It is because of the scope of obtaining this vital information which could supposedly lead to a better insight into the phenomenon of track formation that interest in elaborate and comprehensive study of the annealing effect has always remained rejuvenated. Progress of annealing can be generally studied by observing change in track length (L), track density (ρ) or track diameter (D) which are manifestations of change in Track Etch Rate V_T (or Etch Rate Ratio V) on account of annealing.

Present Work:

In the present work, a new approach has been developed to follow the progress of annealing by isolating the annealing effect for such tracks as do not become completely unetchable upto various partial annealing states. This approach to study the progress of annealing is in a way based on track diameter but it is not the usual track diameter approach where variation of track diameter with respect to annealing time/temperature is explicitly employed as the basic parameter for this purpose. A different recourse has been followed.

Track Etch Rate (V_T) and bulk Etch Rate (V_B) differ as a result of increase in energy content along the track arising from damage due to energy loss or incident charged particles.

$$V_T = V_B + f \tag{1}$$

Where '*f*' relates to the extent of damage, it is an increasing function of dE/dx.

$$V = \frac{V_T}{V_B} = 1 + \frac{f}{V_B} \tag{2}$$

Track diameter can be expressed as

$$D = 2V_B t \sqrt{\frac{(V-1)}{(V+1)}} \tag{3}$$

Where ‘t’ is the etching time.

Let V_B, V_T, V and D represent the relevant quantities for an unannealed sample. When the detector is subjected to annealing, increase in bulk etch rate depends upon the extent of disturbance in thermal equilibrium and the relaxation processes taking place thereafter. In some detectors, significant increase in V_B is observed depending upon annealing temperature and time and, of course, the storage time. CR-39 belongs to this category. In others, e.g. glasses, there is negligible effect of annealing on bulk etch rate, if any.

In general, we can write the bulk etch rate of an annealed sample as

$$V_{B1} = V_B + \Delta V_B \tag{4}$$

and $\Delta V_B = 0$ i.e. $V_{Bl} = V_B$ for detectors which do not exhibit any measurable change in V_B after annealing.

Track etch rate in a post irradiation annealed sample can be written as

$$V_{T1} = V_{B1} + f_1 \tag{5}$$

$f_l < f$ due to track repair on account of the annealing effect. Eq. (5) can be written as

$$V_{T1} = V_B + \Delta V_B + f - \Delta f \tag{6}$$

Where $\Delta f = f - f_l$, while comparing the annealed and the unannealed states, refers to decrease in the term that relates only to the extent of damage.If x and y are respectively the percentage increase in bulk etch rate and percentage decrease in the f term for a detector subjected to annealing, etch rate ratio after annealing can be expressed as

$$V_1 = \frac{V_{T1}}{V_{B1}} = \frac{\left(V_B + \frac{xV_B}{100} + f - \frac{yf}{100}\right)}{\left(V_B + \frac{x\,V_B}{100}\right)} \tag{7}$$

Track diameter after annealing is given by

$$D_1 = 2\,V_{B1} t \sqrt{\frac{(V_1 - 1)}{(V_1 + 1)}} \tag{8}$$

It is possible to express D_l explicitly in terms of D. This factorisation can be facilitated as follows:

Subtracting V_l [Eq. (7)] from V [Eq. (2)]

$$V - V_1 = \frac{(x+y)(V-1)}{(100+x)} \tag{9}$$

In general, x, y > 0, because of annealing, however, x = 0 for glasses etc. Further, V > 1 for etchable damage, therefore, $V - V_l > 0$

$$V_1 = \frac{V\,(100-y) + x + y}{(100+x)} \tag{10}$$

Using Eq. (4) and Eq. (10), Eq. (8) becomes

$$D_1 = 2\left(V_B + \frac{xV_B}{100}\right) t \sqrt{\frac{(V-1)(100-y)}{V\,(100-y) + 2\,x + y + 100}}$$

$$D_1 = 2V_B t \left(1 + \frac{x}{100}\right) \sqrt{\frac{(V-1)}{(V+1)}} \sqrt{\frac{(V+1)(100-y)}{V\,(100-y) + 2x + y + 100}}$$

$$D_1 = D\left(1 + \frac{x}{100}\right) \sqrt{\frac{(V+1)\,(100-y)}{V\,(100-y) + 2x + y + 100}} \tag{11}$$

Eq. (11) expresses track diameter after annealing in terms of the unannealed track diameter, etch rate ratio of the unannealed sample, percentage increase in the bulk etch rate and percentage decrease in the damage-related ‘f’ term. Eq. (11) is consistent with the boundary conditions of the annealing problem which are:

(a) for no annealing, D_l must be equal to D and

(b) for complete annealing i.e., after complete erasure of tracks, D_l must be zero.

From Eq. (11), in case of no annealing, x = 0, y = 0 and $D_l = D$ and for complete annealing effect, y = 100 and $D_l = 0$.

For materials which do not exhibit any measurable change in bulk etch rate on annealing, x = 0 and hence Eq. (11) becomes

$$D_1 = D\sqrt{\frac{(V+1)(100-y)}{V(100-y)+y+100}} \tag{12}$$

Referring to eq. (1), as mentioned earlier also, V_T relates to damage through *'f'* which has been defined as an increasing function of the magnitude of damage. Further, apart from the extent of damage and the factors governing it, the term *'f'* does not depend upon any other parameter. As a consequence of track repair by annealing, *'f'* decreases. The absolute magnitude of the extent of annealing can be purely and solely interpreted in terms of the change in the value of *'f'*, i.e., in terms of *'y'* which is the percentage change in *'f'*.

All other parameters in terms of which quantitative effect of annealing is usually described V_T, V, D, track density, track length, 'y' is the most relevant parameter since it leads us to complete isolation and identification of the annealing effect. In the absence of any annealing effect, the damage remains fully intact, hence *'f'* remains unchanged and $y = 0$. For complete erasure of tracks, there would not be any residual damage and hence $f = 0$ so that $y = 100\ \%$. When annealing has proceeded half way, the residual damage is half of original and hence $y = 50\%$. Experimental annealing studies need to be extensively undertaken and by the use of Eq (11) developed above, y can be determined at various stages of annealing which can most faithfully and accurately throw light on the progress of annealing quantitatively.

II. Conclusion:

Using the approach developed above, it is possible to express track diameter in an annealed sample in terms of the track diameter in the unannealed state. This expression explicitly contains a parameter 'y' which is the percentage charge in f on account of annealing, f term depends only on the extent of damage, therefore y purely depends on repair of damage on account of annealing and no dependence on any other condition. All other parameters involve dependence on bulk property of the detector. Hence 'y' can be interpreted as the most accurate and exclusive parameter to describe repair of damage as a result of track annealing.

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