A NOVEL DETECTION TECHNIQUE FOR NUCLEAR RADIATIONS: SOLID STATE NUCLEAR TRACK DETECTOR, CR-39: A REVIEW

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Abstract – *In the present paper solid state nuclear track detector viz.CR-39 plastic track detector has been particularly discussed. The radioactive elements convert to stable elements by emitting some radiations. The tracks on the CR-39 by the cosmic rays with the help of different etching methods have been studied. The physical and chemical characteristics of CR-39 by using different experimental methods have been taken into consideration. Electrochemical etching and Chemical etching are done for the enlargement of latent tracks occurred on the etch pits by the nuclear reactions. Several methods have been discovered for the count of etch pits. Different conditions are used for the counting and etching purpose.*

Key Words: Etching, CR-39, Cosmic, Solid state nuclear track detector, etch pits, electrochemical etching, latent tracks.

1. INTRODUCTION

During the last past years, the technique called 'Solid State Nuclear Track Detector' has grown so much. According to a study there is hardly any branch of science and technology where this technique do not have its applications. The detection of charged particles by track detectors is based on the principle that when heavily ionized charged particles passes through most dielectric solids then the excitation and ionization of atoms produces intense damage trails on the atomic scale (̃30-100Å) with the trajectory [1].

The "Solid State Nuclear Track Detection" (SSNTD) field was originated in 1958 when first observations were given by D.A. Young at AERE Harwell (England) [2], where he originated that LiF crystals were in contact with the uranium foil irradiating thermal neutrons, which revealed many etches. In 1959 Silk and Barnes also reported the observations of these etch pits in mica at AERE (Harwell), which appeared to be very small tracks like hair using electron microscope. During 1960's the credit for the development of new particle detector goes to R.L Fleischer, P.B Price and R.M. Walker who started working in 1961 where silk and Barnes left it (A.M. Bhagwat) [2]. S.A. Durrani et al. previously studied that the etchable tracks are only produced by the heavy ionizing particles such as alpha particles in plastic and fission fragments in crystals and they are only produced in electrical insulators and poor semiconductors [3]. They are stable even when they are treated to light or to high dose of X-rays, ß particles, ultraviolet radiations, etc.

Solid State Nuclear Track Detectors are formed by cooling of insulating solidified matter such as meteorites since the cooling down of minerals (i.e feldspars, quartz, micas, etc.) and glassy matter. SSNTDs were rediscovered about three decades ago. Three American scientists; Fleischer, Price and Walker begin the work on this field. Initially, natural substances like minerals are used as solid state detectors. With passing time they developed many man-made substances to be used as track detectors. They have not only evolved the technique but had also applied in many branches of science. In the last two decades this technique has developed a lot and its applications are extremely useful all over the world. This technique is not only simple, robust, inexpensive, electricity consuming but also it has many different unique applications which makes it an important tool in the scientific fields all over the world [2].

The properties of these detectors such as durability, simplicity and the specific response nature led to the application of these detectors in various fields. Solid state nuclear track detectors are insulators (natural and manmade). There are distinct types of detectors like inorganic crystals, plastics and glasses. At the point when a heavy ionizing charged particle goes through insulating solids, they leave a tight trail of harm of about 50 Å in diameter across along its way and this is called latent track as it is not visible to our naked eyes. The Latent track can be visible by using an electron microscope on treating with some specific chemical reagents. [4]

CR-39 Nuclear Track Detectors have been aligned for identification of alpha-particles and protons in a high neutron transition condition. These detectors can be utilized to distinguish harm brought about by ionizing radiation on the plastic by a procedure of chemical etching. Charged particles abandon a trademark way of substance bonds broken by approaching ionized radiation. The CR-39 plastic detector has a place with natural indicators; it is a sort of multi-carbon detectors. The business name of this polymer is CR-39 and the most regularly utilized name is Solid State Nuclear Track Detector. It comprises of polymeric material and is set up from polymerization and from its high sensitivity in recognizing charged particles. The principle purpose behind the high sensitivity of the detector is the availability of carbon bonds in the CR-39 polymer where it is frail and breaks effectively when presented to radiation [3, 12]. It likewise has a low detection threshold [18]. Because of the highlights of this locator, it has been utilized in numerous applications; it is utilized to thoron concentrations and gauge radon in structure materials, indoor structure, water, soil, nourishment and agrarian materials.

2. REVIEW OF LITERATURE

Takao Tsuruta et al. in 1992 [5] found that Solid State Nuclear Track Detectors have the characteristics that the latent tracks do not fade and they are not sensitive to UV-rays, X-rays, ß-rays and γ- rays. The property of CR-39 plastic track detector of being highly sensitive to fast neutrons and the low threshold energy of it for the formation of tracks makes it the mostly used and an important detector material. At 60^0C the aqueous solutions of 6_N KOH and at 70^0C 6_N NaOH are used for the purpose of chemical etching. An automatic scanning method which involves microdensitometer is used for the counting of electrochemically etched samples and other etched samples are counted with an optical microscope and bacterial colony counter system which is commercially available. In this experiment the composition of CR-39 which was used was, allyl diglycol carbonate $C_{12}H_{18}O_7$ (97%) and diisopropyl peroxy dicarbonate $C_8H_{14}O_6$ (3%).The plates of CR-39 are of 1.6mm in diameter. The polyethylene sheets with diameter of 0.1 mm were used to sandwich the CR-39 plate. The polyethylene sheets increases the sensitivity of the detector. The etch-pit size distribution is measured by the measurement of the diameter of the etch-pit microphotographs. An image analyzer is used for counting the etch-pits and for measuring the distribution in size of the etch-pit.

Reynaldo Pugliesi et al. in 1998 [6] discussed the characteristics of CR-39 detector in neutron radiography technique. The main objective of their work was to find the characteristics of the SSNTD CR-39, using a natural boron converter screen. Using the NR technique (The Newton-Raphson technique is a standout among the most broadly utilized strategies for root finding. It is very well effectively summed up to the issue of discovering arrangements of an non linear equation, which is alluded to as Newton's strategy). They irradiated a sample by a uniform neutron beam which when made to fall upon the screen, convert the transmitted thermal neutrons to ionizing radiation which was able to introduce damages into the SSNTD. An increment in the contrast of image with the etching time up to t_e =25 min and a decrement for t_e>25 min was recorded. They likewise confirmed that the behavior in the natural unsharpness was subjectively in great concurrence with the one predicted by the hypothesis of the formation of image in solid state nuclear track detector.

Roussetski A.S et al. in 2000 calculated CR-39 plastic track detector register the products of dd-fusion reaction and dT reactions [7]. For finding different particles of dd and dT-reaction the procedures have been suggested and as per these procedures the levels of dd and dT-reactions which are possible in different experiments have been find out. CR-39 detector is a suitable kind of detection in dd-fusion reaction

$d + d \rightarrow n$ (2.45 Mev) + He- 3 (0.82 Mev) (~50%) (i)
$d + d \rightarrow p$ (3.02Mev) + T (1.02Mev) (~50%) (ii)
But dT reaction:
$d + T \rightarrow n$ (14.01MeV) + He-4 (3.5MeV) (iii)

The recent work shows the response of CR-39 detector by the use of different types of particles from reactions (i) to (iii) in different experimental conditions. It has been found that CR-39 detect all particles from reactions (i) to (iii) and can be successfully used in cold fusion in long-duration experiments.

K.C.C. Tse et al. in 2007 shows that in mechanism of etching of CR-39 in NaOH/H_2O and NaOH/ethanol the bulk etch rate of CR-39 in NaOH or ethanol was much quicker than those in the aqueous solution of NaOH and on the CR-39 detector's surface. A layer of precipitate accumulates while etching in NaOH/ethanol, which is not present while etching in NaOH/H_2O [8]. This shows that etching mechanism of CR-39 is same in both the etchants. The studies have been made on the etch products of CR-39 to yield information on the etching mechanisms of CR-39 in NaOH/H_2O and NaOH/ethanol. The dimensions of CR-39 detector were 3 x 3x 0.1 cm^3 and were etched in 6.25 M NaOH/H_2O at 70^0C and 0.5 M NaOH/ethanol at 55^0C, for 6 h. The temperature was consistent with an accuracy to almost $\pm 1^0$C. In this research, the results of mass spectrometry have depicted that in the etchants of NaOH/H_2O and NaOH/ethanol, same etched products are available after the etching of CR-39. The analysis of the Fourier transform infrared (FTIR) spectroscopy of the solute that is made from the etchants display the formation of carbonate and allyl alcohol while etching of CR-39 in both the etchants of NaOH/H_2O and NaOH/ethanol. The solute is formed from the etchants and the after the etching of CR-39 X-ray diffractometer (XRD) analyses review the formation of sodium carbonate (Na_2CO_3) and sodium bicarbonate (NaHCO3) in the etchant of NaOH/H_2O and mineral Natrite Na_2CO_3 and Thermonatrite Na_2CO_3. H_2O is formed in the etchant of NaOH/ethanol and it is also formed in the layer of precipitate which occurs on the surface of the CR-39 detector while etching of CR-39 in NaOH/ethanol.

Vijay kumar et al. in 2009 [9] an important plastic CR-39 films which is an amorphous polymer has been taken. The main objective of this investigation is to study the before and after neutron irradiation effects on the UV-visible spectra of CR-39 detector. By taking an idea of the direct and indirect optical band gaps, it has been have tried to figure out the relationship between radiation doses against the band gap and an investigation on the Urbach's energy and the number of carbon atoms present in a cluster by using Tauc's expression. A commercially purchased CR-39 sheets were used in the study and thickness of the sheets were nearly 500μm, density 1.3 g/cm^3 and size 2cm×2cm.The CR-39 polymeric samples were irradiated by pristine and neutron was based on spectral studies in the ultraviolet and visible range which has been performed to study the variations of the optical band gaps. At room temperature, UV-visible spectrophotometer in the wavelength range of 200-700 nm is used to record the optical absorption spectra of neutron and pristine. For the influence of high irradiation the region of optical absorption extends to higher wavelength. It proves that in the most sensitive SSNTDs, the damage effects in neutron radiation are complex and non-linear. It is concluded from this experiment that in neutron and pristine irradiated CR-39 polymers the values of the indirect band gap are relatively less than the values of the direct band gap and the band gap (E_g) decreases with the increasing neutron fluency, due to the formation of defects and cluster in the material and the degradation of CR-39. For both the cases, the cluster size increases with the increase in the fluence.

N. Sinenian et al. in 2011 [10] In this the study has been done on the response of CR-39 to protons of 1-9 MeV, which include the piece-to-piece variations of the response and the effects that it carries due to different etch times and the temperature of the etchant. Studies have shown that the shape of the diameter of proton track vs. curve of energy response differ from one to next piece. The observations were made on a relationship between etch time and diameter of the track, which allows the staged-etch processing of CR-39. Over a time of 5-years and from the experiments it was determined that the diameter of the track of alpha particle with 5.5 MeV decreases as it is a function of age of the plastic but not the age of the track. These characteristics of the response of CR-39 to protons are very important for calibrating the existing diagnostics and for the enhancement of new capabilities of diagnostics for the facilities OMEGA and NIF laser.

Cuihong Liu etal. 2015-2016 [11], In this paper, radon focuses in China JinPing underground Laboratory were estimated utilizing the solid state nuclear track detector. Three areas in the experimental lobby were furnished with a well-working system of ventilation with normal yearly radon convergences of (55±7) $Bq.m^{-3}$, (58±10) $Bq.m^{-3}$ and (53±9) $Bq.m^{-3}$ individually, all lower than the deliberate outcomes amid the dispatching time of ventilation equipment. Without radon reduction system in the storage tunnel, the radon fixations rose to (345±15) $Bq.m^{-3}$, mirroring the first normal yearly radon focus levels in the underground lab and the spatial varieties for radon fixations at four areas were likewise exhibited. At each area, radon fixations at various inspecting focuses shifted with the ventilation conditions. The examining focuses with lower radon fixations were situated in very much ventilated zones, and those with higher radon fixations were in the profound inside of the live with poor ventilation conditions. Comparing other universal underground research facilities, the normal radon focus in CJPL-I was at a middle level. This radon radiation condition can fulfill the need for low background and uncommon occasion physical trials. For additionally decrease radon radiation gas engaged with low experiment tests, more radon decrease strategies will be embraced later on, for example, and the arranged low-radon air framework.

Rupali Pal et al. in 2016 [12] had used Zr with CR-39 which showed an enhanced track density on the CR-39 track detector. By using both theoretical and experimental studies this paper depicted the enhancement of the response of neutron by using Zr on CR-39. At 13.0 MeV for reaction (n, 2n), Zirconium has a higher cross-section. Simulation studies were used for the observation in the rise in number of neutrons in 14 MeV monoenergetic neutrons with 0.1 mm of Zr and with 1mm of Zr. By the observation it was found that both neutrons and protons number are increased with the thickness of Zr. According to the Monte Carlo code FLUKA 2011.2c.3 version, the enhancement factor (i.e. increase in proton number) for 14 MeV monoenergetic beams is 1.05 with 1.18 with 1mm thick Zr and 0.1 mm Zr. It is concluded from this paper that this is revealed by simulation studies and experimental measurements there is an enhancement in the number of protons with zirconium degrader over CR-39. The (n, 2n) reactions can degrade the high energy neutrons to produce CR-39 tracks.

Nada Tawfiq et al. in 2017 [13] study the registration properties of alpha particle tracks, Helium-Neon (He-Ne) laser effects on CR-39 track detector. CR-39 locators were presented to various powers (1, 5 and 10 mW) of He-Ne laser beam at various time occasions (5, 10 and 15 min) and after that illuminated to alpha-particles from 226 Ra source (laser+α). 6.25_N NaOH at 60°C is used to determine Track), density (ρ), track densities (D). It's discovered increment in the estimations of (D, ρ, v_B, v_T)and critical angle $\boldsymbol{\theta}_c$ with increment in the introduction times of laser at every power case, and reduction in the estimations of etching efficiency, etching sensitivity and etch rate ratio (η, S and V) with increment in the exposure time of laser at 1 mw power, while expanding inside increment of uncovered occasions of laser at (5 and 10 mW). The ideal scratching time of CR-39 detectors was 4 hours with NaOH etchant solation and 6.25 at temperature 60^0C. The ideal scratching time of CR-39 detectors presented to (α+laser) was 4 hours for solution of etchant NaOH and 6N ordinariness at 60°C. The increment in the presentation times of laser at various powers lead to expanding in the track thickness and track breadth and the best case its seen at (15 min) uncovered of (10 mW) (He-Ne) laser beam since they recorded most extreme qualities as compared to different cases.

Ahmed Abed Ibrahim et al. 2018 [14] in this study the various factors of etching on the attributes of CR-39, nuclear track detector and the impact of two sorts of etching solutions have been contemplated. The primary kind of arrangement was set up from dissolving NaOH in (Ethanol+water) by various normalities under various temperatures and contrasted and the second sort of the arrangement arranged from dissolving NaOH in water (NaOH/water) by various normalities under various temperatures. With alpha particles all the detectors were irradiated with 4.7MeV produced from ^{241}Am source in amid 20 Seconds. The outcomes demonstrated that the utilization of the solution of NaOH/Ethanol+water lessens the time of appearance the particle tracks due the increment in the bulk etch rate v_B and track etch rate v_T and altogether de-sharpens the plastic. Activation energy of the bulk etch rate E_B and Track etch rate E_T was additionally determined for the two solutions, They were 0.78eV, 0.71eV individually for NaOH/Ethanol+water and 0.74eV, 0.64eV separately for NaOH/water.

3. CONCLUSION

In this paper the study is based on the CR-39 plastic track detector, which is a solid state nuclear track detector (SSNTD). CR-39 detectors do not fade away easily and physical parameters of this detector are determined by etch-pit microphotographs. The main aim of above discussed work was to find the important characteristics of the CR-39 detector. The studies have been made on the etch products of CR-39 to yield information on the etching mechanisms of CR-39 in NaOH/H_2O and NaOH/ethanol. It is concluded from this experiment that in neutron and pristine irradiated CR-39 polymers the values of the indirect band gap are relatively lower than the values of the direct band gap and the band gap (Eg) decreases with the increasing neutron fluency. Study has been done on the response of CR-39 to protons of 1-9 MeV. To additionally decrease radon radiation gas engaged with low experiment tests, more radon decrease strategies will be embraced later on, for example, the arranged low-radon air framework. This is revealed by simulation studies and experimental measurements there is an enhancement in the number of protons with zirconium degrader over CR-39. CR-39 plastic track detector including tracks of charged particles in SSNTDs, a larger part of the studies is identified with the splitting procedure and the nearness of these tracks has mostly been utilized to get definite proof for the event of splitting time, with a very small amount of effort to exactly distinguish the particles that caused them.

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