Review Article

SOLID STATE NUCLEAR TRACK DETECTION (SSNTD): A USEFUL SCIENTIFIC TOOL FOR BASIC AND APPLIED RESEARCH

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SUMMARY: 'SSNTD' stands for Solid State Nuclear Track Detection, one of the most fascinating nuclear particle detection techniques, developed to date. It has been found to be equally useful in basic and applied research work, particularly for scientists, engineers, and technologists in the developing countries. This paper, very briefly, summarizes the useful contribution this technique has made in the past and is making at present. The state of the art of applications of Solid State Nuclear Track Detectors in fields like nuclear physics, geochronology, cosmology, biology, bird altimetry, seismology, elemental analysis, material science, lithography, etc. has been given. Some of the future applications have also been pointed out.

Key Words: Radiation detection, nuclear physics, geochronology, cosmology, seismology.

SOLID STATE NUCLEAR TRACE DETECTORS: INTRODUCTORY REMARKS

Solid State Nuclear Track Detectors were formed with the cooling down of the insulating solid matter in the space around us (1). They have always been in existence on our earth, moon and other solidified matter (such as meteorites) since their cooling down in the form of minerals (i.e. feldspars, quartz, micas, etc.) and glassy matter. However, they were "rediscovered" only about three decades ago (2-5).

Three American scientists, namely: Fleischer, Price and Walker, pioneered most of the early work in this field (6-12). In the beginning, mostly natural substances such as minerals were used as solid state nuclear track detectors. However, with the passage of time many man made materials were successfully developed for their use as track detectors. Fleischer and his colleagues, not only developed the technique, but also applied it in almost every branch of science (1,6-15). The last two decades or so, saw the development and successful applications of this extremely useful scientific tool all over the world (1,16). With the passage of time the technique of SSNTD (inspite of its simplicity) became a powerful scientific tool. Not only this technique system is simple, inexpensive, employs very little electronics, is portable but also it has found some unique applications in almost all scientific fields.

PRINCIPLE AND SALIENT FEATURES OF THE TECHNIQUE

A massive charged particle passing through an electrical insulator, produces a narrow region of radiation damaged material, known as a 'latent damage trail' or simply as a 'track'. The process of track formation seems to be as follows: a positively charged particle knocks out the orbital electrons of the atoms lying along its trajectory. Soon afterwards, a cylindrical regain full of positive ions is produced (1). The positive ions so formed thereupon repel one another violently, thus producing a more or less cylindrical-strained-region. Such regions because of their higher dif-

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fraction contrast and enhanced chemical reactivity can be seen at a very high magnification of a transmission electron microscope (1-3).

Since the latent damage trails are very thin (thickness a few hundred Angstroms) and an optical microscope cannot be used for their analyses, the use of an 'etching process' is made to ‘enlarge', 'develop' and 'fix' them (Figures 1 to 3).

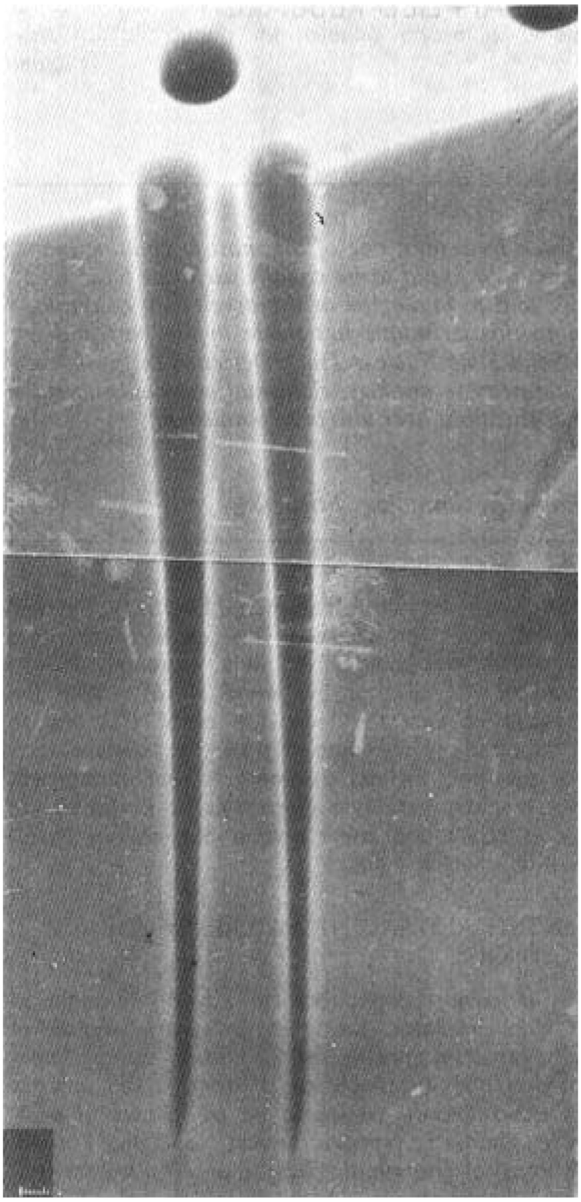

Figure 1: A photomicrograph showing profiles of two long etched tracks along with two etch pits due to energetic uranium ions in a CR-39 (a polycarbonate) plastic track detector. The etched channels are conical in shape and the etch pit openings are uniform in the amorphous matrix of the detector.

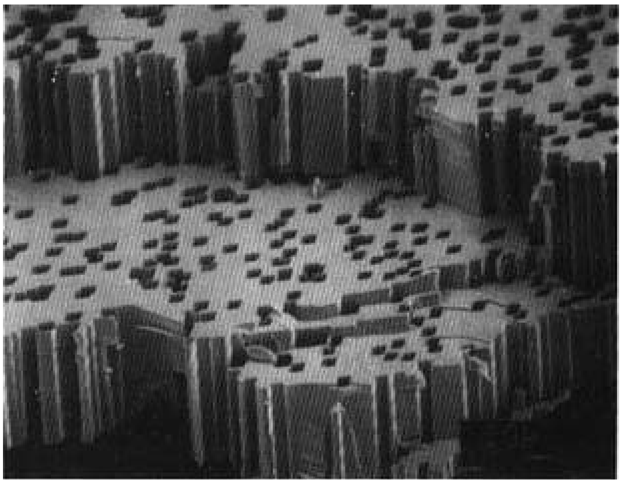

Figure 2: Etched channel profiles and etch pit openings of the etched tracks due to 2380 MeV ^{84}Kr-ions in the crystalline matrix of a Muscovite mica track detector. The profiles are cylindrical with diamond shaped etch pit openings in the crystalline matrix of mica track detector.

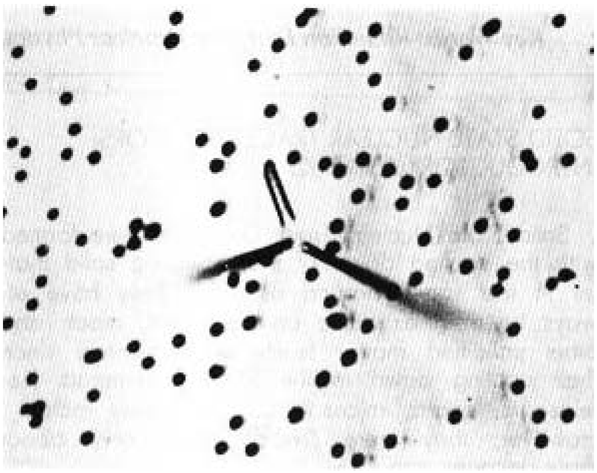

Figure 3: A photomicrograph showing the top view of the etch pits due to energetic ^{136}Xe-ions in a plastic track detector. A three prong event resulted in the interaction of ^{136}Xe-ions with a gold target is also present in the photograph.

Utimately, a modified, enlarged version of the original damaged trail is produced, which can be seen easily under an ordinary optical microscope. Experience shows that the shape of an etched track depends on (a) nature of the track forming medium, (b) the charge, mass, and velocity of the incoming particle, (c) the environmental conditions existing at the time of irradiation, (d) the pre-etching treatments and (e) the nature, concentration, and temperature of the etchant.

In the past, choosing the best etchant has been largely a matter of trial and error. Neverthless, in the light of the experience of nearly thirty years, some guidelines have been developed (1). Fission fragments of normal energy, produce long and almost cylindrical etch pits with slightly tapered ends in Lexan, Makrofol polycarbonates (etched in NaOH), mica (etched in HF acid), etc. In soda lime glass (etched using HF acid), charged particles produce conical etch-pits, which appear circular or oval (depending upon the angle of incidence on the detector surface) when viewed from above. Materials such as feldspars require strong alkalis at high temperatures; and zircon is best treated with phosphoric acid heated more than 500°C.

Experience shows that different materials have different sensitivities to nuclear particles. For example, organic polymers are found to be the most sensitive track detectors, some of which produce etchable latent damage trails even for low energy protons, deuterons, alpha particles, etc. Experiments carried out with heavy ion irradiations and cosmic rays have shown that each track detecting material has "a well defined threshold damage density", below which no tracks are produced. This characteristic threshold" has contributed significantly to the establishment of this technique of SSNTD as an important tool in many notable applications in physical sciences (1,7,13-15).

When one compares the properties of SSNTDs with the conventional detectors, it can be seen that the SSNTDs have many advantages over other detectors in gineral, and over nuclear emulsions in particular. The fact that fission fragments can be recorded and distinguished in a mixed field of unwanted light charged particles, neutrons and gamma rays, has made these detectors extremely useful in experiments where fission reaction rate is very low and a very high detection efficiency is required (1,16,21-24).

SOME IMPORTANT APPLICATIONS OF THE TECHNIQUE

APPLICATIONS IN NUCLEAR PHYSICS

As already mentioned, the SSNTDs can perform background free detection of fission fragments in the presence of high doses of light charged particles, gamma rays and neutrons. They are ideal for the study of rare type of heavy charged reaction products emitted in nuclear reactions. They have been advantageously employed in the measurement of spontaneous fission decay constant of a number of heavy nuclides, and other parameters of great importance in nuclear science (1,16,21-24). One of the important research problems tackled by nuclear physicists these days using SSNTD deal with heavy ion-heavy nucleus interactions (1,25-36).

It is of basic interest to study the behaviour of a heavy nucleus under extreme conditions of temperature, density, angular momentum, etc. Nuclear physics using heavy projectile-heavy target systems is concerned with entirely new phenomena (29-31). Here the reaction patterns are governed by (a) large mass-and charge-transfers between the colliding nuclei and (b) dissipative features (31). Some of these experiments have shown that when the target and the projectile overlap, the frictional forces slow down the radial and the angular motions of both the nuclei and with increasing overlap a large fractionn of the kinetic energy is transferred into intrinsic excitation energy. The parameters and the assumptions in the theoretical models proposed to date are suited only to a phenomenological approach. A lot more experimental results are needed to establish the proposed theoretical models. Since the reaction pattern of multibody processes is extremely complex, a knowledge of the kinematical correlations between the correlated reaction products is of utmost importance. It has been observed that the use of the presently available sophisticated on-line electronic counter systems is rather limited, because of their restrictions to deal with only about three outgoing coincident particles. Of we use a suitable SSNTD, all the reaction products of interest can be registered. Also, besides the problem of high multiplicity, the events of interest have to be discriminated against a high background of light charged particles. Track detectors have been found to be extremely suitable for such a purpose because their use makes selective registration possible. Light charged particles accompanying the heavy ion reactions can be either eliminated altogether or studied alongwith heavy reaction products, by selection of appropriate track detector (1,34,37,38).

It may be pointed out at this juncture that the most attractive characteristics of the technique of SSNTD as far as research workers from developing countries are concerned are its (a) simplicity, (b) obvious and inituitive demonstration of reaction pattern, and (c) ability to provide direct evidence for certain phenomena. Of course, the samples have to be irradiated in special laboratories. On the other hand, the evaluation of the data can be easily carried out off-line. The technique involves simple instrumentation (such as a microscope, etching baths, etc.) and careful, reliable, interested and dedicated scientists, having experience in analytical techniques. As far as the published literature shows, no competing technique is available, at the time of writing, which gives results of high multiplicity events, say 4,5 or 6 reaction products of occasionally good accuracy with inexpensive and simple instrumentation. Scientists at the Pakistan Institute of Nuclear Science and Technology (PINSTECH) and elsewhere have studied elastic and inelastic interactions using these detectors. Many rare type of four and five pronged events have been observed (29-38). Analysis of these events has shown that they were produced as a result of the "double-sequential fission" and "triplesequential-fission" processes. PINSTECH scientists have studied the behaviour of 960 MeV/nucleon ^{238}U ions while passing through a stack of CR-39 detectors. It was observed that the uranium ions not only underwent binary fission, but also broke into protons, alpha particles, and heavier ions while moving through the stack. These results are unique due to the fact that the break up takes place only when the 960 MeV/nucleon-^{238}U ions are slowed down to about 200 MeV/nucleon energy and such events are not observed when these ions having a starting energy of 460 MeV/nucleon are slowed down to about 200 MeV/nucleon in CR-39. The results suggest that the starting energy is of great importance in such break ups. We feel that our observation may be having an important connection to "anomalon" research. Further work in this regard is being pursued at our laboratory.

The published literature shows a number of unique application of SSNTD in Nuclear Physics (1,7,13-24, 39-48).

APPLICATIONS OF SSNTD IN GEOCHRONOLOGY

It has been found that all materials contain some traces of natural uranium. Since their solidification, some of the uranium atoms have been decaying through spontaneous fission process. The fission fragments so produced, created latent damage trails in these materials. Generally speaking, the density of such naturally produced latent damage trails is proportional to the product of uranium contents and the age of the material. The age of solidification of the sample can thus be determined if the uranium contents are known. This is known as the technique of 'Fission Track Dating' (1). It has been established over the years and is now considered to be a standard method for the dating of geological (1, 49, 51), archaeological, and cosmological samples (51) and in studies like "Ocean Bottom Spread" (52) and the Continental Drift (53). The method has also been used to find not only the contents but also the distribution of elements like Pu, U, Th, B, Pb, Bi etc. in a wide variety of materials (1,13,54,55).

Alpha sensitive plastic track detectors has been successfully used for uranium/thorium prospection and personnel monitoring (1,56,58). Recent work carried out by us in Pakistan and by others elsewhere has given a strong indication that radon/thoron sensitive detectors can be used in the prediction of earthquakes (1, 59). The principle seems to be simple: Radon gas which is trapped within the ground, is released through small fractures resulting from many changes taking place in the earth's crust in that region prior to the major physical jolt of an earthquake. Under favourable conditions a careful measurements of radon intensity (at a fixed point) as a function of time should correlate these changes with seismic activity in the area. The signals can be used for earthquake prediction. Many interesting applications of the technique of Fission Track Dating have been made in Geochronology (1,49,50,60).

COSMOLOGICAL APPLICATIONS

Track detectors have been successfully employed in measuring the cosmic ray fluxes at high altitudes and track studies of Apollo-and Lunasamples yielded important information concerning their past radiation and thermal histories and the dynamic processes on the moon (1,54,61). Track analyses alongwith the microcrater studies yielded interesting information concerning the composition and fluxes of micrometeoroids in space in the past (62). In this respect, track detectors can be termed as the 'oldest nuclear particle detector' ever existed. Allah (The Almighty) kept them in space and on the planets for us to analyze later on in order to reveal their past histories. Track analysis of the meteoritic objects made possible the measurement of the duration of various types of space exposures and provided information about the following processes: a) the erosion and accretion rates on the lunar surface, b) the original size of meteorites prior to their loss of mass caused by ablation while entering the earth's atmosphere, c) the time of fall of tektites on the earth, and d) the fluxes of cosmic ray particles existing during different periods in the past (1). Macdougal and co-workers (63) deduced very interesting results from track studies of various meteorites. They observed that the outer surfaces of the individual grains of certain meteorites received different exposures to cosmic rays. They inferred that the grains enjoyed independent existence before joining together to form meteoritic bodies. Detailed analysis yielded information about the dates of their independent existence, and their later thermal and radiation histories. Such conclusions would not be possible with any other technique.

It is interesting to note that as recent as 1966, the known cosmic ray spectrum extended upto only iron. This 'Iron Curtain' was lifted up by Fleischer and co-workers in 1967 during their track studies of meteorites (12). Their work helped in finding the presence of many trans-iron nuclei in the past and the present day cosmic rays.

ELEMENTAL ANALYSIS

The technique of Solid State Nuclear Track Detection (SSNTD) has been used for the measurement of concentration and distribution of a number of elements (uranium, plutonium, thorium, polonium, bismuth, lead, boron, lithium, etc.) in a variety of materials (1,54,55). The only requirement is that some highly (or moderately) ionizing reaction products should emanate from the samples under study. The incident particles upon hitting the sample (placed next to an alpha sensitive plastic track detector), form reaction products which produce latent trails in the track detector. The detector is subsequently etched and canned.The spatial resolution of this method is limited primarily by the range of the reaction products in the track detector. The resuolution will amount to about 10 μm, for example, in the case of uranium in silicate minerals. If an isotope of the element of interest is radioactive and emits alpha particles, it may be possible to carry out elemental mapping without any irradiation.

APPLICATIONS IN SEISMOLOGY

It has been found that interesting changes take place in natural environments and in the behaviour of living beings before the physical jolt due to an earthquake (1,59). Some successful forecasting of earthquakes has been reported in the scanty literature available on this subject. Enough attention has not been paid to this extremely important problem. Recently some efforts were made to replace the magic art of earthquake forecasting to scientific prediction. In the past a number of attempts were made to study the causes of earthquakes and to develop some sort of method for their prediction. These early efforts could not produce any satisfactory method for earthquake prediction. Recently, idea of movement of fluids and gases within the earth's crust prior to a physical jolt was advanced (1, 59). Fleischer *et al.* (1,59) carried out systematic work on the movement of gases within the earth's crust and they determined the factors that control the character, magnitude, timing, etc. of an earthquake.

Laboratory and field work so far carried out at the SSTND-, laboratory (PINSTECH, Islamabad, Pakistan) for obtaining advance earthquake warning signals has indicated the existence of a relationship between the earthquake processes and emission of radon and thoron gases. The results obtained have revealed that shock waves greatly affect the emanation of these gases from the earth's crust. The increase (or decrease) in the intensity of these gases can be related to the magnitude of the chock waves. On the basis of the studies carried out at a few monitoring stations, some useful data have been collected. However, further work in the field and in the laboratory is needed for establishing this technique. The method will enable us to delineate earthquake prone areas and hopefully to receive advance warning signals.

At PINSTECH, we have initiated a long term project of getting earthquake warning signals from radon/thoron measurements. It has been planned to study the effect of shock waves on radon/thoron emanation rates of different matrices. Experiments will be conducted to study the radon / thoron diffusion coefficients of different materials and the time sequence of intensity build up with shock waves. It has also been planned to carry out long term and short term radon measurements as a function of time at different fixed locations and then to correlate them with the seismic activity in the area.

APPLICATION IN MATERIAL SCIENCE

Experience shows that when the dimensions of artificial structures approach or become smaller than certain characteristic distances (e.g., grain size, domain size, etc.) wavelength, mean free path, coherence length, molecular size it becomes possible to access phenomena or manipulate materials in new and different ways (64) thus suggesting an entirely new application of nuclear tracks in solids. Such an application is possible because of the ability of nuclear tracks to influence the global properties of the material through structural changes in a region. One of the most important examples of such an application is in the fining of magneto-optic iron garnets. Here the latent tracks as well as etched tracks can be applied for the purpose of changing magnetic properties. Epitaxially grown single-crystal ferrimagnetic garnet films were originally conceived of for use in bubble memories, which vitally depend on a high magnetic domain-wall mobility. For this purpose, garnet films were developed for low intrinsic coercivity and, in orter to achieve this, low dislocation density. Thus their magnetic properties are highly susceptible to nuclear track damage.

One of the main applications of this material in the production of stable and fast switchable displays and printers (65). Such properties are mainly due to locally fixed magnetic domains in a thin ferrimagnetic garnet film supported by a magnetically inactive garnet substrate (66). The conventional technique for magnetic isolation of neighboring storage sites is based on lithography, which resolves the exitaxial film into a regular array of discreate islands, corresponding to elementary information cells, separated by groowes etched down to the substrate. This way, the cross-talk between neighboring domains of different magnetic orientation is eliminated (66). However, because of the restricted aspect ratio (depth to width) of the etched grooves, this lithigraphic approach (a) the storage density is limited and (b) the deposition of auxiliary layers on top of the island array are hampered by the steep slopes of the groves. This may result in an eventual prevention of coherent deposits. This problem can be partially overcome with the help of nuclear tracks (67). Nuclear tracks are found to increase the coercivity of the garnet by several orders of magnitude. Using nuclear tracks continuos planar surface (which is better for depositing auxiliary layer than a grooved surface) is obtained. Simultaneously, the Faraday contrast is enhanced because of the possibility of increasing the film thickness without increasing the depth of the grooves. Both etched tracks or latent damage trails nuclear tracks can be used to stabilize the inscribed domain pattern, giving one-to-one correspondence between the magnetic domains and the recorded data (66). Using this technique the magnetic anisotropy can also be influenced, which can act as an additional parameter to modify the storage properties according to the specific requirements (66). Nuclear tracks studies in a magnetic iron garnet can also help in understanding the structure of latent tracks in crystals (68) and for the determination of nuclear track radii from the dose dependence of the saturation magnetization and the Faraday rotation (69).

BIOLOGICAL APPLICATIONS OF SSNTD

The use of producing "through holes" by etching latent damage trails has also helped in making "filters" (1,8,56). The size, shape, number, and the position of these holes can be controlled through experimental conditions (1,56). Such filters have been used in filtering cancer cells from human blood (1,8) and for cleaning air form dust particles (1,56,70). Some successful applications of SSNTDs have also been made in the radiobiology of plutonium (12,56). One may feel the importance of these studies due to extensive involvement of scientists in plutonium production, and the latent danger of its increased intake by the working personnel. SSNTDs have also been employed for mapping the locations of plutonium concentrates in living matter. The method is fairly simple: The detector is placed in contact with the tissue under study and a direct autoradiograph of natural alpha decay is obtained. Alternatively, a more rapid mapping is obtained by irradiating the detector tissue assembly by thermal neutrons in a reactor. An image resolution of about ten microns or better can be achieved by using Solid State Nuclear Track Detectors.

The study of individual living cells is gaining importance in medical diagnostic. Conventional flow cytometry uses capillaries with inner diameters between 10 and 100 μm. One of the most ingenous and economical uses of etched tracks employs one single etched track to count, size, and measure the electrokinetic mobility of submicron size particles (66). Red blood cells are doughnut shaped and have (a) diameter of about 7.5μm and (b) thickness between 1 and 2 μm. Healthy red blood cells are extremely flexible and easily squeeze through the considerably finer capillaries of the human body, diameters 3-5 μm. In recent years, many disease of the heart and circulatory system have been traced, to an insufficient deformability of the red blood cells. Even the influence of drugs can drastically change the characteristics of red blood cells. Experience shows that the passage times of these cells through single pores can yield important information about the rigidity of these cells. It has been found that stiffer a cell is, the longer it takes to pass "through" the pores of a nuclear track microfilter. The single pore memberance is the central unit of a measuring cell, which is divided into upper and lower compartments (66). The measuring pore has a precisely known diameter of about 5 μm. Only one humar red blood cell at a time, can "squeeze" itself through this artificial capillary (66). It is important to keep the pressure difference between the upper and lower compartments of the measuring cell is kept constant. Other experimental conditions correspond to those in a normal human body. A number of red blood cells are measured in succession to obtain the passage time spectrum, representing the different degrees of deformability. Important conclusions on the health of the blood can be drawn from these studies. The effects of a drug, as studied in pharmacology, can be assessed on the level of the individual cells before starting any experiments with patients (66).

LITHOGRAPHY USING HEAVY ION

Photolithography, took its present-day scientific status from a rather obscure art initiated around the middle of the 19th Century. This technique has been dramatically refined with the use of uv light, x-rays, and electron beam exposure. In general, in the past this technique involves irradiation with visible and uv light. It is one of the main tools used to create fine structures on solid surfaces. During the recent years, the packing density of integrated circuits has been doubled, and the price per active element has been decreased. For some years, microprocessors have been performing tasks of ever increasing complexity. More recently, high patterns for microelectronics applications have been developed. The capabilities of the conventional techniques have now been fully realized. Presently, the applicability of heavy ion beams in microstructure technology has been explored. In contrast to conventional techniques, heavy ion lithography offers a way to generate very fine and, at the same time, very deep structures (66). Heavy ion lithography involves the use of a mask, which is imposed onto a track sensitive substrate. The high beam collimation attainable with this technique is an essential condition for such a scheme and allows one, at the same time, to locate the object and track recording material even at a relatively large distance from each other. The resulting relief elevation is directly related to the projected areal density of the mask (66). This feature thus adds a third dimension to the conventional planar lithography in which relief elevation depends very sensitively on the time of development. It is defined directly by the thickness of the deposited layer. The depth could not be correlated directly with the irradiation itself and is defined by the depth of the sensitive layer on top of the substrate. The well defined depth observed in ion lithography, is inherent in the well defined ion range. This in contrast in the exponentially decaying radiation damage, produced by photons and electrons. Another important advantage of ion lithography over x ray lithography is the ease with which ion beams can be created, accelerated, and deflected. Owing to the very high damage density of heavy ions, the technique is not restricted to photosensitive materials. Most of the insulating materials are sensitive to heavy ions.

The amorphizing action of heavy ions gives rise to drastic changes in the bulk etch rate of a material. For example, silicon single crystals can be selectively etched just at the onset of amorphization using dislocation sensitive etchants. In this way, grating patterns with submicron periods can be engraved on Si substrates with an accuracy of 0.01 μm (66).

In addition to its use as a microlithographic structuring tool, heavy ion lithography has a considerable potential as a tool for observing the inner details of microscopic objects. This is possible without dissecting the object. Already a single ion is capable of measuring density variations of the order of a few percent, making it possible to observe with very little associated radiation damage per picture element (66). Heavy ion radiography which involves relativistic energies, is an extension of heavy ion lithography. For specific ion energies of the order of a hundred MeV per nucleon, where ion ranges are of the order of 10 cm, medical diagnostics and cancer treatment become possible. Heavy ion radiography uses a thick stack of plastic sheets for recording the projected areal density of a macroscopic object. Different plastic sheets are etched separately after the irradiation. Only the track "end points" are revealed by etching due to the low energy loss of relativistic ions. Computer tomograms with high density contrast can be obtained, by using multiple irradiation's under different angles (66).

BIRD ALTIMETRY USING SSNTD

An interesting application of the technique of Solid State Nuclear Track Detection in bird altimetry was made by Kristiansson and co-corkers. They built a simple, light weight and integrating type barometer and employed it for the measurement of the distribution of flight altitudes of birds (71). In this simple and inexpensive barometric system, while on ground had an alpha source fixed in such a way that its alpha source fixed in such a way that its alpha particles could reach only the nearest position of the sensitive detector. At higher altitudes, the ranges of alpha particles increased due to the lower atmospheric density and so did the track formation along the detector length. Systematic studies of the distribution of the distances of tracks along the detector length, yielded useful information about the distribution of the times spent by the birds at different altitudes. These experiments provided the favourite altitudes of a variety of birds both in dry and wet weathers. Such an application indicates the extreme of flexibility of this highly fascinating technique. Inspite of its simplicity, it can help in tackling fairly complicated problems.

FUTURE OF THE TECHNIQUE OF SOLID STATE NUCLEAR TRACK DETECTION

The foregoing brief account of the technique of SSNTD shows that it has found applications in such diverse fields as 'Heavy Ion Physics' to 'Bird Altimery'. Some of the applications such as the study of radiation and thermal histories of cosmological and geological samples are rather unique, and apparently are unmatched by other existing techniques.

It has been clearly shown that applications in basic sciences are linked with the exploitation of the uniquely important fine integrating properties of these detectors. The technique has a great future in the measurements which deal with low reaction cross-sections and low emission rates. Although a lot of progress has been made in such measurements in the past, and nano-born cross-sections have been very successfully measured, further refinements in the properties of these detectors and improvement in the energy resolution may lead to measurement of even smaller reaction cross-sections in the pecobarn range. The technique also has a great potential in the study of nuclear interactions resulting in high multiplicity events, containing a large spectrum of particles with wide energies and produced in widely different angular intervals.

There is no doubt that the technique has an upper hand over all other existing methods in situations where one has to deal with a variety of reaction products in the presence of a high background of unwanted radiations. Provided improvements can be made in the timing characteristics, these detectors, can be advantageously employed in space physics studies. Not only the size and weight of the experimental set up will be reduced but will also provide unique results concerning the spatial distribution of the parameters of interest. The use of this technique in the study of super heavy elements (from the ancient sources and samples) and of the magnetic monopolies is one of its potential future applications. Study of in-flight break up of nuclear systems having exceptionally high nuclear densities and nuclear temperatures is another future direction of its applications in basic physics.

One must admit that the future applications of SSNTD in the applied sciences seem to be equally fascinating. These range from earthquake warning signals to the study of correlation of the health of a person to the properties of blood cells. In nuclear industry, particularly the studies of the spent fuel elements and the behaviour of fuel under different environmental conditions, are the areas where the SSNTD-systems seem to have a very bright future. Although some more work is needed in studying the migration of radon gas in different geological matrices, the technique has already shown a great future in the localization of deeply burred low enrichment uranium deposites. A combination of its use in uranium exploration and the fission track dating of geological samples taken from the same area will throw useful light on the geological and geophysical problems of the area.

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