An improvement to nuclear track counting systems using laser light scattering

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In this work we present a device to measure the angular distribution of the diffuse optical transmittance produced by etched nuclear tracks in a polyallyl diglycol carbonate (PADC) detector. The device makes use of a stepper motor to move an array of four photodetectors around the sample in 1.8-degree steps. The effect of additional scatterers is reflected in the width at half height of the angular distribution curves. The width at half height was found to be a linear function of the nuclear track density in the range from zero to 2.8×10^5 cm^{-2}. An Am-Be neutron source was used.

Keywords: Transmittance; angular distribution; PADC (CR-39); nuclear tracks.

En este trabajo reportamos un dispositivo para medir la distribución angular de la transmisión óptica difusa producida por trazas nucleares reveladas en el detector policarbonato alil diglicol. El dispositivo emplea un motor de pasos para mover un arreglo de cuatro fotodetectores alrededor de la muestra en pasos de 1.8 grados. El efecto de agregar trazas nucleares se refleja en el ancho a la mitad del pico de la distribución angular. Se observó que esta cantidad es una función lineal con la densidad superficial de trazas, en el rango desde cero hasta 2.8×10^5 cm^{-2}, usando una fuente de Am-Be.

Descriptores: Transmitancia; distribución angular; PADC; CR-39; trazas nucleares.

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1. Introduction

The fast reading of CR-39 detectors is an important application of high-throughput data analysis technology. Commercially available systems usually make use of optical microscopy instrumentation, with automated mechanisms and software to acquire images and morphologically characterize the samples [1,2] On the other hand, the optical characterization of etched nuclear tracks has been extensively considered since the early days of nuclear track methodology [3]. In this work we describe a device to determine the angular distribution of the optical transmittance produced by etched nuclear tracks and show how the angular distribution curves may be used to measure nuclear track density

2. Experimental procedure

Sample preparation

PADC (CR-39) Landauer polycarbonate in the form of 1.8×0.9 cm^2 chips was used as the neutron detector material. Each polycarbonate chip comes supplied with an attached 125 μm protective foil to reduce background exposure and damage due to handling. The protective foils were peeled from the detectors, and the detectors chemically pre-etched in a 6.25 M KOH solution at $70\pm1^\circ$C for 2 hours in order to eliminate surface impurities, scratches and irregularities. After pre-etching the detectors were washed in distilled water and air-dried.

Irradiation

Irradiations were performed in the facilities of Oak Ridge National Laboratory's Dosimetry Applications Research (DOSAR) group. The CR-39 chips were placed on the face of a $40\times40\times15$ cm^3 phantom of polymethyl methacrylate (PMMA) and overlaid with a 3 mm thick PMMA sheet serving as a charged particle generator. The front face of the PMMA phantom was located 50 cm from a ^{241}Am-Be neutron source with a total neutron emission rate of 9.86×10^7 s^{-1} (4π). Neutron exposure times were 24, 48 and 72 hours, and the incidence was normal.

Chemical etching

After exposure to the neutron field the detectors were developed using a one-step chemical etch in a 6.25 M KOH solution at $60\pm1^\circ$C for 18 hours and subsequently washed in clean running water for 15 minutes and sandwiched between layers of desiccant paper for drying.

Measurement device

A photograph of the experimental setup is shown in Fig. 1. The sample holder consists of a disk with slots to hold eight CR-39 detectors. A light beam from a He-Ne laser of 10 mW nominal power, perpendicular to the rear surface of the detector, enters and then passes through the detector. The illuminated area is circular and has a diameter of 1.5 mm. The illuminated region was chosen so as to minimize the effects of singular scatterers such as impurities or scratches in the

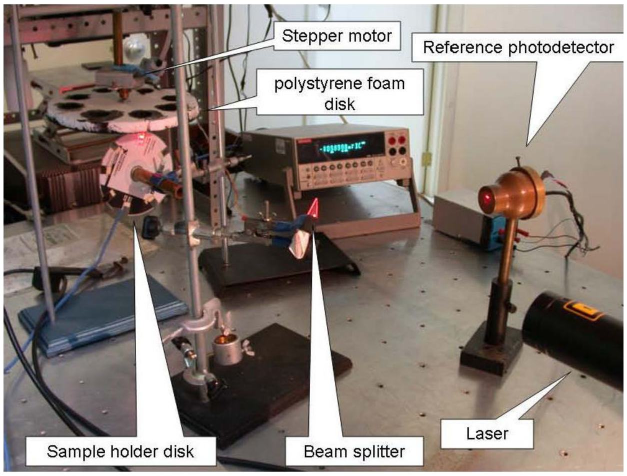

FIGURE 1. Photograph of the experimental setup.

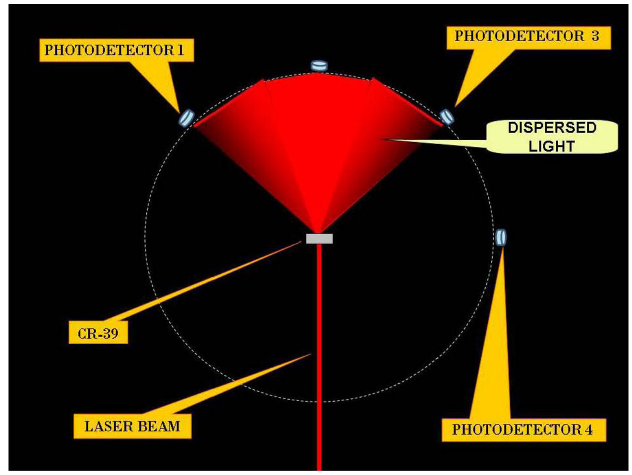

FIGURE 2. Schematic overhead view of the experimental setup.

material. Part of the transmitted light is scattered by the tracks etched on the rear surface of the detector. The scattering coherent cone depends on the size, shape, and density of the scatterers.

To measure the intensity of the scattered transmitted light, four PIN silicon photodetectors each with a sensitive area of 1 mm^2, were attached to the edge of a 30 cm diameter polystyrene foam disk at intervals of 45° The incident light was monitored by using a beam splitter consisting of a piece of microscope glass to reflect 8% of the laser beam to a reference photodetector. The position of the sample coincided with the axis of the polystyrene disk.

The angular distribution of the transmitted scattered light was obtained by coupling the axis of the polystyrene foam disk to a stepper motor shaft. A four-coil stepper motor from an old floppy driver was chosen due to the simplicity of the buffer circuit, which feeds each coil sequentially using the data bus of the DB25 parallel port of a PC. The stepper motor advanced in steps of 1.8 degrees. This automated system allows rapid determination of the angular distribution curves.

The transmittance T of the scattered transmitted light as a function of θ, the angle between the line normal to the far side of the sample and the direction of the scattered light, is given by

$$T(\theta) = \frac{I(\theta)}{I_0 r^2}, \tag{1}$$

where $I(\theta)$ is the light intensity measured by the set of photodetectors, I_o is the intensity of the incident light as measured by the reference photodetector and the factor r^{-2} accounts for the decrease of scattered light intensity with distance. In order to avoid undesirable diffused light, a black iris was placed in the trajectory of the incident beam, and the surface of the polystyrene foam disk was sprayed with black paint.

Figure 2 shows a schematic overhead view of the experimental setup centered on the sample. The photodetectors were initially positioned at 45, 0, -45 and -90 degrees A Keithley multimeter provided with a multiplexer card and a 232 serial communication port as a DCE, connected to the serial port of the PC, which operated as a DTE, permitted the reading of the photodetectors in the appropriate order at each step of the stepper motor A 180-degree scan around the sample required the stepper motor to make only 25 steps (Twenty-five steps of 1.8 degrees add up to an advance of the disk of 45 degrees.) The plane of the set of photodetectors was situated 5 mm above the main transmitted laser beam in order to avoid overloading the photodetectors. The use of a small beam blocker was not convenient as the shadow would have produced a spurious signal

There was a lapse of one second between two consecutive steps of the stepper motor, during which the voltmeter with the multiplexing card performed the reading of the photodetectors. Thus the time required to obtain one angular distribution curve was 25 seconds. In principle the scattered light exhibits axial symmetry, implying a suitable range of the angle θ from 0 to 90 degrees, however we scanned from -90 to 90 degrees to experimentally verify the symmetry in this dimension.

3. Results

Figure 3 shows typical 100× optical microscopy images of the detector surface for different exposure times. The small tracks correspond to (n, p) conversion and the larger ones to (n,α) conversion. The circular shape of the nuclear track apertures reflects the normal incidence of the particles. Track production efficiency was found to be 3.2×10^{-4}. Track density saturation is observed in the lower right image of Fig. 3.

Figure 4 shows the angular distribution $I(\theta)/I_o$ of the transmitted scattered light as measured by the device described above. All of the data sets clearly exhibit Lorenztian behavior. Lorenztian curves were fitted to the data sets to distinguish the track distributions from noise and fluctuations, and to determine the widths at half height. The correlation coefficients were all greater than 0.98. Note that the blank sample shows a background signal due to surface imperfections.

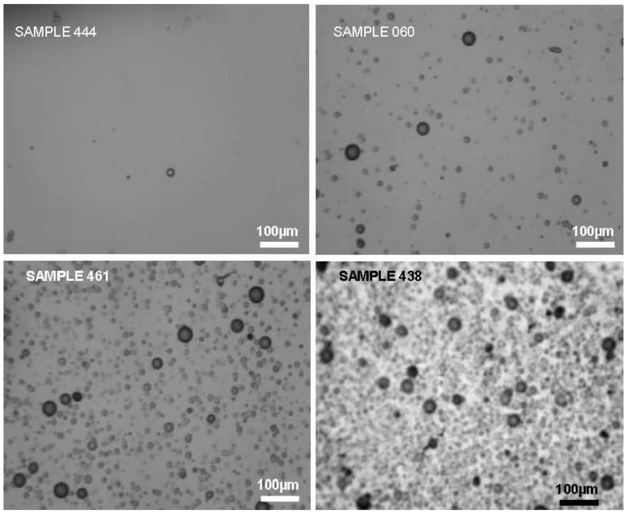

FIGURE 3. Typical optical microscopy images of the samples studied.

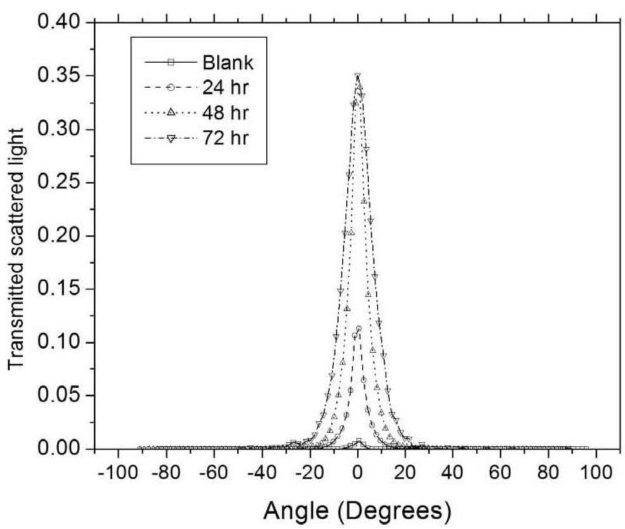

FIGURE 4. Angular distribution of the transmitted scattered light produced by etched nuclear tracks.

The effect of additional scatterers is reflected in the width at half height (WHH) of the curves. Figure 5 shows the relation between the WHH and surface track density. The relation is highly linear, with a correlation coefficient greater than 0.99. The WHH in degrees is described by the equation

$$W(\sigma) = 2.73 \times 10^{-5}\sigma + 3.8 \tag{2}$$

where σ is the surface track density in cm^{-2}

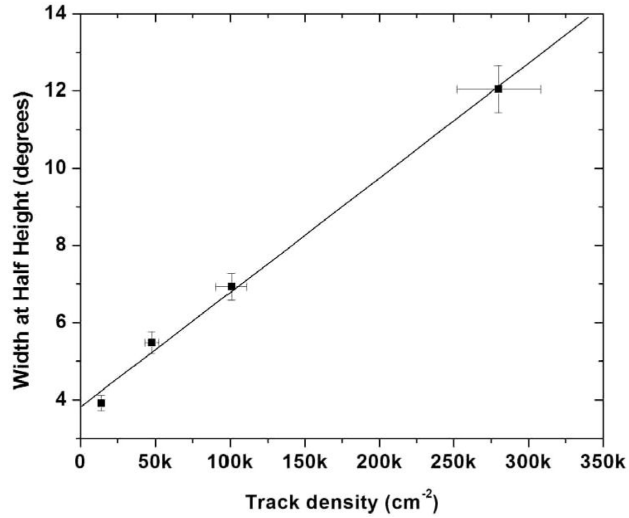

FIGURE 5. Width at half height as a function of track density.

4. Conclusions

- The relation between the WHH and the etched nuclear track density produced by a ^{241}Am-Be neutron source was demonstrated to be highly linear, with a correlation coefficient greater than 0.99.
- The method described for reading the CR-39 detectors is fully automated and takes only 25 seconds to obtain the angular distribution curve for a given region of the detector.
- This diffuse optical transmittance methodology provides a new alternative in the field of nuclear track measurements.

Acknowledgments

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