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Analyses of light scattered from etched alpha-particle tracks in PADC

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Abstract

A computational model for light propagation through an etched alpha-particle track was described. Four different cases for light ray propagation through the etched track were studied in detail. The track profile, optical appearance and distribution of scattered light were given for three typical types of etched tracks. These laid the foundation for future automatic determination of properties of the alpha particles producing the tracks through the scattered light.

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1. Introduction

Solid-state nuclear track detectors (SSNTDs) are commonly used for radon measurements. One of the most widely used SSNTDs is made of polyallyldiglycol carbonate (PADC), which is commercially available as CR-39 detectors. A recent review on SSNTDs can be found in Nikezic and Yu (2004). For radon measurements and many other applications, etched tracks were studied using optical microscopes (see e.g., Yu et al., 2005). However, as expected, the procedures involved were tedious and time consuming. Automatic and semi-automatic systems are desirable, but the optical appearance of tracks or the scattered light intensity was involved.

There were only a few references in the literature on scattering of light from etched tracks in SSNTDs. In most of the cases, scattered light was used to measure track densities from experiments related to neutron dosimetry (Harvey and Weeks, 1987; Popov and Pressyanov, 1997; Meyer et al., 1997; Groetz et al., 1999). Groetz et al. (1998) developed a model for laser light scattering by nuclear tracks in CR-39 detectors. The model was based on wave optics and the so-called "*bi-directional scatter distribution function*" to describe scattered light patterns in two orthogonal planes.

Recently, studies of optical characteristics of etched tracks in PADC films using the *ray tracing method* were performed (Nikezic et al., 2005; Yu et al., 2007). Based on geometrical optics, a computer program called TRACK_VISION 1.0 (Nikezic and Yu, 2008; also available from http://www.cityu.edu.hk/ap/nru/vision.htm) was developed in our laboratory to simulate light propagation through the tracks and to calculate the brightness of all grid elements in the track wall. In the current paper, the model and the corresponding computer program were further developed to facilitate determination of the scattered pattern of light on a single track.

2. Model

As the first step, it is necessary to compute the points that belong to the track wall in three dimensions (3-D). First, the points on the track wall in two dimensions (or referred to as the track profile) were evaluated using our computer code TRACK_VISION 1.0. The 3-D track wall was then generated by rotating the curve representing the track profile around the particle trajectory. This was possible because of the isotropic nature of chemical etching of the track with respect to the particle trajectory. Planes parallel to the detector surface were then constructed to intersect with the 3-D track body. The intersections between these horizontal planes and the 3-D track were in general semi-elliptical curves or some more complicated closed

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curves. The intersections could also be simply regular circles if the incidence of the alpha particle had been normal with respect to the detector surface.

During the computations, the coordinates of points representing these curves were stored in the computer memory. The number of points representing the horizontal curves was kept constant. A mesh of four-angle polygons was formed from these points to represent the track wall. Two vertices of these four-angle polygons belonged to one intersecting plane and the other two vertices to another plane. The procedures of forming polygons were applied for the entire track. In our calculations, all polygons were assumed flat. In fact, this was not true in general, particularly when the size of a polygon was relatively large and there was significant curvature for the corresponding portion of the track. For a proper representation of the track body, the polygons should be very small, so the number of intersecting planes and the number of points per one intersection plane should be sufficiently large. All the polygons were indexed with the corresponding numbers and their coordinates were stored in an array in the computer memory.

For the simulation of light propagation through the track, a line perpendicular to each surface was needed. While it was straightforward to determine the plane from three non-collinear points, we now had four points for each polygon surface, namely, T_1, T_2, T_3 and T_4, which were in general not coplanar. In the present approach, two normal lines were determined, the first one deriving from the points T_1, T_2 and T_3 while the second one from the points T_1, T_2 and T_4. The average normal, $\vec{N}(n_x, n_y, n_z)$, was then chosen to represent the corresponding polygon element.

Simulation of light passage through the track was based on geometrical optics in the present work. In practice, an etched alpha-particle track reached a size as large as 5–20 µm, which was about an order of magnitude larger than the wavelength of visible light (~ 0.5 µm), so that geometrical optics was applicable. Etched tracks smaller than 1 µm are usually not visible under the optical microscope and are irrelevant to practical applications.

The transmission mode of operation was considered for the optical microscope. Here, the light came from the bottom of the detector and entered the track body (assumed to be filled with air) from the detector material which was optically denser than air. The first task here was to determine which polygon was hit by the light ray. The ray was directed vertically upwards, i.e., perpendicular to the detector surface, and was characterized by the coordinates (x_0, y_0). The vector $\vec{p}(p_x, p_y, p_z) = \vec{p}(0, 0, 1)$ described the initial light direction. The coordinates (x_0, y_0) were compared with coordinates of all polygons to determine which polygon was actually hit. The problem was tackled through simple geometrical considerations. If the point was out of the polygon, the sum of angles subtended to all polygon lines should be smaller than 360°. On the contrary, if the point (x_0, y_0) was inside the polygon, the sum of angles should be equal to 360°. The angle α between the incident ray and the normal onto the corresponding polygon was determined through the equation

$$\alpha = \cos^{-1}(\vec{p} \cdot \vec{N}). \tag{1}$$

The next step was the determination of the refraction angle β based on Snell's refraction law as

$$n \sin\alpha = \sin\beta, \tag{2}$$

where n was the refraction index of the detector material (which was taken as 1.5 for PADC). The new direction of the ray was characterized by the vector $\vec{p}_1 = (p_{1x}, p_{1y}, p_{1z})$ which was obtained from the following set of equations:

$$\vec{p}_1 \cdot \vec{N} = \cos\beta, \tag{3}$$

$$\vec{p}_1 \cdot \vec{p} = \cos(\beta - \alpha), \tag{4}$$

$$\vec{p}_1 \cdot (\vec{p} \times \vec{N}) = 0. \tag{5}$$

Eq. (3) defined the angle between the new direction and the normal as β while Eq. (4) defined the angle between the new and old directions as (β–α). Eq. (5) imposed the condition that all three vectors $\vec{p}_1$, $\vec{p}$ and $\vec{N}$ were coplanar. A similar set of equations was applied to all refractions that occurred in this problem.

In some cases, total internal reflection occurred on the polygons. Here, somewhat different equations were required to find the new direction $\vec{p}_R$ of the reflected ray. If $\vec{p}$ was the initial direction of a light ray, and $\vec{N}$ was the normal to the polygon, the direction of the ray reflected from that polygon could be found from

$$\vec{p}_R \cdot \vec{N} = \cos\alpha, \tag{6}$$

$$\vec{p}_R \cdot \vec{p} = \cos(\pi - 2\alpha), \tag{7}$$

$$\vec{p}_R \cdot (\vec{p} \times \vec{N}) = 0. \tag{8}$$

For the computer simulations, the points from which the light rays came were sampled randomly using the Monte Carlo methodology.

2.1. Analyses of possible cases

Four different cases were possible when a light ray passed through an etched alpha-particle track. Three of them are schematically shown in Fig. 1.

Case 1: The light ray 1 was totally reflected from the track wall, and returned back into the detector material. It then came to the detector surface where it again underwent total internal reflection. The ray finally returned back into detector and did not contribute to the scoring of light scattered out of the detector (i.e., it was finally directed downwards in Fig. 1).

Case 2: The light ray 2 was refracted at the track interface. Here, the normal $\vec{N}$, incident angle α and the refracted angle β are shown. The ray exited from the track through the track opening.

Case 3: The light ray 3 was totally reflected from the track wall, and exited from the detector surface because the incidence angle there was smaller than the critical angle.