CALIBRATION AND APPLICATION OF NUCLEAR TRACK DETECTORS FOR HIGH-TEMPERATURE PLASMA DIAGNOSTICS

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Abstract

The paper reports on features of so-called solid-state nuclear track detectors (SSNTDs), their calibration measurements performed with known ion beams, and their different applications for detailed studies of charged particle emissions from various high-temperatures plasma facilities.

1. Introduction

In 1959 E. Silk and R. Barnes revealed nuclear tracks induced by fission fragments in solid-state (mica) [1]. Ever since nuclear tracks were observed in many others solid-state materials, e.g. in plastics, some glasses, and crystals. Very soon these materials have found application as solid-state nuclear track detectors (SSNTDs).

Taking into account sensitivity, resolution, and variability of their response, the best SSNTD materials appeared to be optically clear amorphous, thermoset plastics (polymers), which have high homogenity and isotropy, high optical transparency and uniformity. A plastic material fulfilling those requirements was synthesized in 1978, and it was called CR-39 (Columbia Resin) [2]. Others, more sensitive SSNTDs (improved versions of CR-39) were manufactured in the eighties and they are commercially available as PM-355, PM-500, PM-600 plastics.

It should, however, be noted that a thermoset material (such as CR-39) is usually made within the extrusion and quenching process. Therefore, its quality and especially its particle detection characteristics depend strongly on the applied technological procedures. Hence, every newly acquired batch of SSNTD sheets should be carefully calibrated before using for quantitative measurements of ions.

The main aim of this paper was to report on calibration of selected SSNTDs and to present some examples of their applications, which might be of interest for many plasma laboratories.

2. Calibration of SSNTDs

At the Andrzej Soltan Institute for Nuclear Studies (IPJ) various SSNTDs have been used for several years as convenient tools for high temperature plasma corpuscular diagnostics. Therefore, detailed calibration measurements of different types of SSNTDs have been performed. The applied calibration procedure was as follows: Beams of selected ions, as provided by different particle accelerators, were scattered by a suitable thin foil target (made of pure Au, C, Al, etc.). The scattered ions were used to irradiate samples of the investigated track detectors, and simultaneously they were monitored by Si-detectors (for determination energy spectra and counting rates). After irradiation the samples were etched under controlled conditions (in a 6.25 N water solution of NaOH, at 70^{o}C) for different etching times. The etching process was stopped every two hours, track parameters (mainly their

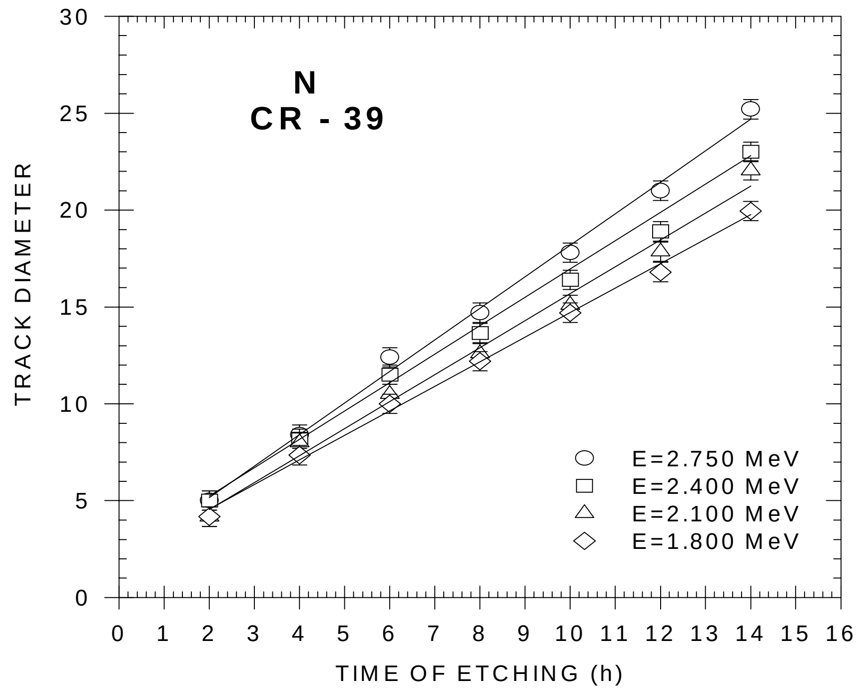

Fig. 1. Evolution of track diameters (in μm) of different energy nitrogen ions as a function of etching time.

diameters) were measured with an optical microscope, and the etching process was renewed for next 2 hours.

Some results of the calibration studies concerning the CR-39 and PM-355 plastic track detectors, irradiated with protons of energy changed from 0.9 MeV to 4.5 MeV in 0.2 MeV steps, were presented in a paper [3], where a detailed description of the irradiation and etching was also given. It should be noted that similar calibration measurements were performed in our laboratory sixteen years ago for SSNTDs of the cellulose-nitrate (CN) type. The CN samples were then irradiated with deuterons of energy from 0.1 to 1 MeV [4].

The calibration diagrams of the CR-39 and PM-355 type track detectors exposed to monoenergetic deuterons and ^{4}He ions were presented in later papers [5-6]. Recently, the SSNTDs mentioned above as well as the modern PM-500 and PM-600 plastics (together with CN-films for a comparison), were irradiates by heavier ions, such as N^+, N^{+2}, N^{+3}, O^+, and C^+. Parameters of the tracks induced by those ions were measured as a function of the etching time, ion energy, and its electric charge (e.g. Fig.1.). We have also performed some calibration measurements with fast monoenergetic neutrons. The SSNTD samples were irradiated with neutrons of energy 14.9 MeV and 5.2 MeV. Some of those samples were equipped with an additional converter layer (neutron – proton) fixed in front of them. Neutron registration efficiencies were determined for the CR-39, PM-355, and PM-500 plastic detectors, without and with a converter layer of a different thickness (Fig.2.)

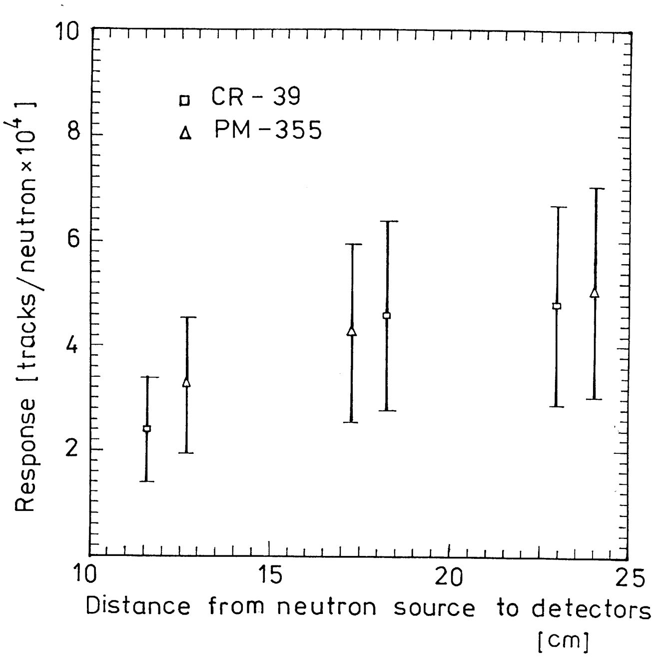

Fig. 2. Responses of CR-39 and PM-355 nuclear track detectors to 5.2 MeV neutrons at different distances from the neutron source (detectors without a converted layer).

3. Applications of SSNTDs

The SSNTDs described above appeared to be reliable efficient, and convenient tools for quantitative measurements of energetic charged particles emitted from high-temperature plasmas. In such experiments there usually appear strong electromagnetic interferences and there are observed short emission times of pulsed particle beams accompanied by intense pulses of the X-ray radiation. The SSNTDs can cope very well with such problems and therefore they have found applications in many plasma facilities. The SSNTD samples were installed, e. g. inside a Thomson-type ion analyzer, in order to register ion parabolae obtained when primary ion beams are deflected by magnetic and electric fields of the spectrometer [7-8]. The samples of plastic SSNTDs were also installed, upon a semi-circular support placed in front of the electrode outlet within PF type facilities. Those SSNTDs were placed at different angles to the electrode axis in order to measure angular distributions of fast ions, emitted from PF discharges [9-10] .

The SSNTD were also applied to register “ion pictures” formed within an ion pinhole-camera [8-9]. Pieces of a SSNTD covered with absorption filters of different thickness were used to determine energetic spectra of the D(d,p)T nuclear reaction protons generated within PF devices [11-12].

4. Conclusions

The calibration characteristics of different SSNTDs, as obtained in our laboratory, make those detectors more convenient for diagnostic purposes and detailed experimental studies of primary ions, emitted from high temperature plasmas. Such calibrated SSNTDs can be used e.g. for measurements of different nuclear reactions products, i.e.fast fusion protons, energetic tritons, He-ions, and fast neutrons.

The calibrated SSNTDs can also be applied for energy and flux measurements of pulsed plasma-ion streams generated by different plasma facilities including those used for technological purposes, e.g. for ion implantation, surface treatment, metallic coating etc.

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