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A novel method for observation by unaided eyes of nitrogen ion tracks and angular distribution in a plasma focus device using 50 Hz–HV electrochemically-etched polycarbonate detectors

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HIGHLIGHTS

► A novel method for detecting ion tracks observable by unaided eyes was developed.
► Nitrogen ions and angular distribution in a plasma focus device (PFD) were detected.
► The ECE of PC detectors with 50 Hz–HV generator proved efficient for such applications.
► The ion tracks, angular distribution, 2- and 3-dimensional iso-ion distributions were obtained and demonstrated.
► This method is highly applicable for ion detection in PFDs and other dosimetry applications.

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ABSTRACT

A novel ion detection method has been developed and studied in this paper for the first time to detect and observe tracks of nitrogen ions and their angular distribution by unaided eyes in the Amirkabir 4 kJ plasma focus device (PFD). The method is based on electrochemical etching (ECE) of nitrogen ion tracks in 1 mm thick large area polycarbonate (PC) detectors. The ECE method employed a specially designed and constructed large area ECE chamber by applying a 50 Hz–high voltage (HV) generator under optimized ECE conditions. The nitrogen ion tracks and angular distribution were efficiently (constructed for this study) amplified to a point observable by the unaided eyes. The beam profile and angular distribution of nitrogen ion tracks in the central axes of the beam and two- and three-dimensional iso-ion track density distributions showing micro-beam spots were determined. The distribution of ion track density along the central axes versus angular position shows double humps around a dip at the 0° angular positions. The method introduced in this paper proved to be quite efficient for ion beam profile and characteristic studies in PFDs with potential for ion detection studies and other relevant dosimetry applications.

1. Introduction

A plasma focus device (PFD) is a well known intense source of heavy ions, neutrons, electrons, X-rays, etc. as discovered by Filippov et al. (1962) and Mather (1964). In order to have a clear insight into the ion-target interaction mechanism for PFD in different areas of ion source applications, one needs to have an efficient and accurate investigation of ion beam characteristics in terms of energy, flux, spatial distribution and ion compositions. Studies of characteristics of ion beams in particular for nitrogen ions, as it is also the case in this paper, are numerous by using time-resolved and time-integrated detection methods in particular solid state nuclear track detectors (SSNTDs) (Sadowski et al., 1988, 1999; Kelly et al., 1997, 1998; Takao et al., 2001; Ahmad et al., 2003; Szydlowski et al., 2004; Mohanti et al., 2005; Skladnik-Sadowska et al., 2005; EL-Aragi, 2010; Etaati et al., 2010; Bhuyan et al., 2011; Roshani et al., 2011). Kelly et al. (1997, 1998) applied Faraday cups and a Thomson spectrometer equipped with CR-39 to obtain the spectra of nitrogen ions in a Mather-type PFD (4:75 kJ, 30 kV, operated at $p = 0:4$ Torr of N_2-gas). They demonstrated that $^{14}N^{+1}$, $^{14}N^{+2}$ and $^{14}N^{+3}$ ions exist with a 170 keV–3.5 MeV nitrogen ion energy range. Takao et al. (2001) evaluated nitrogen ion energy spectra from a 19.5 kJ PFD using a Thomson parabola spectrometer demonstrating the energy range of nitrogen ion beams to be from 0.2 to 1 MeV and the spectrum of N^+ with a peak around 0.4 and 0.5 MeV. Mohanti et al. (2005), using a multiple Faraday cup assembly, measured pulsed nitrogen ion beam of a 2.2 kJ PFD and demonstrated the energy spectrum of nitrogen ions with a maximum energy at ~700 keV, the most

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probable ion energy of ~25 keV, a maximum ion flux at an angle of 5° and a minimum at an angle of 0°.

Since PFDs can generate short lived (10–100 ns) but high temperature (0.1–2.0 keV) and high density (10^{18}–10^{20} cm^{-3}) plasma, SSNTDs like polymer track detectors provide good time-integrated detection methods. A charged particle incident on a polymer track detector such as CR-39/PM-355, cellulose nitrate (e.g. LR-115, CN), polycarbonate (PC), etc. leaves a dense trail of damage along its path forming a latent track which can be revealed either by chemical (Fleischer et al., 1975) or electrochemical etching (ECE) (Tommasino and Armellini, 1973; Sohrabi 1974).

Sadowski et al. (1999) used SSNTDs in their studies and discussed many of their advantages and shortcomings for ion time-integrated measurements in PDFs over time-resolved measurements (which result into pileups of time-resolved signals). Ahmad et al. (2003) studied the characteristics of nitrogen ion beams from a 2.3 kJ PFD with CR-39 and reported a track density of 1.1 × 10^6 tracks/cm^2. Bhuyan et al. (2011) measured the ion fluxes from a 1.8 kJ PFD, operating in methane by CR-39, and demonstrated maximum fluxes for the energy range of 15–40 keV, 50–100 keV and 100–300 keV, for H^+, C^{+4}, and C^{+5}, respectively.

The ion beam characteristic studies using SSNTDs, some of which were stated above, have all used chemical etching of polymer track detectors such as CR-39/PM-355 and cellulose nitrate (e.g. LR-115, CN). No studies so far have applied either the ECE method or PC detectors to ion beam characteristic studies in PFDs. The ECE method of charged particle tracks was originally introduced by Tommasino and Armellini (1973) using a high frequency–high voltage (HF–HV) generator. This method with further development and improvements soon lead to immediate discovery of fast-neutron-induced recoil tracks (carbon, nitrogen and oxygen) in 250 μm PC detectors to a point observed by unaided eyes (Sohrabi, 1974; Sohrabi and Morgan, 1978), the invention of a simplified fast-neutron dosimeter (Sohrabi, 1979) and efficient detection of alpha particles in PC using optimized field conditions of 2 kHz and 800 V (Sohrabi and Khajeian, 1981, 1984). An HF–HV generator to process a polymer track detector in an ECE chamber requires specific designs which are not readily available to all laboratories. Hassib and Piesch (1978) used the ECE method but applied 50 Hz–220 V from electricity main upgraded by a transformer to higher voltages and amplified fast-neutron-induced recoil tracks in PC detectors with thicknesses up to 500 μm. The 50 Hz–HV ECE attempt however seems not having resulted to any further development for near four decades.

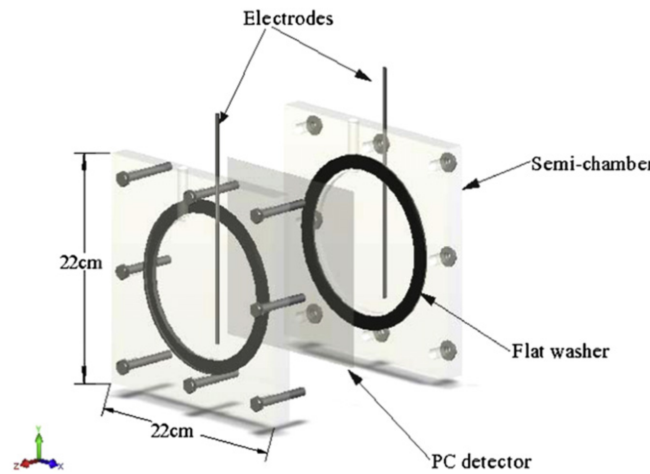

Fig. 2. A three-dimensional view of the large ECE chamber used in this study.

The purpose of this study is twofold; (1) to develop a novel method for ion beam characterization and other applications in order to observe ion tracks and angular distributions by unaided eyes in 1 mm thick large area PC track detectors using 50 Hz–HV generators developed in this study, and (2) to characterize nitrogen ion beam profiles in the Amirkabir 4 kJ PFD filled with nitrogen gas.

2. Experiments and methods

The Amirkabir PFD, which is a Mather-type device (Mather 1964), was used in this study. The device is energized by a 36μf

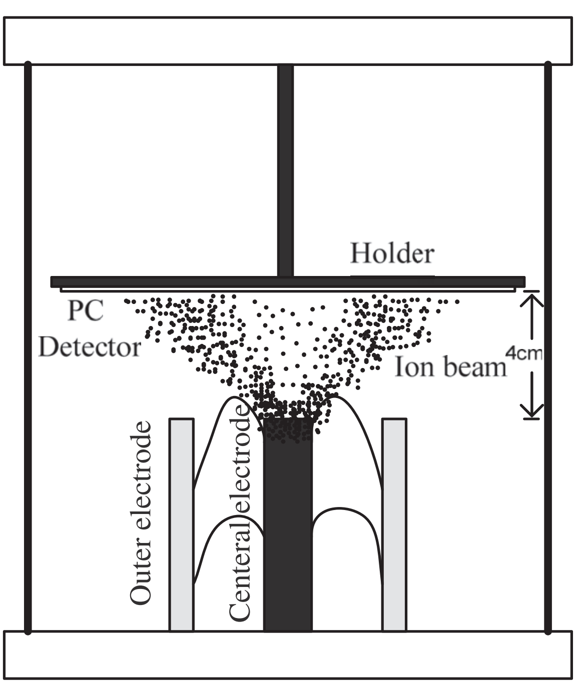

Fig. 1. Schematic diagram of the PFD with the PC detector fixed on top of the anode tip.

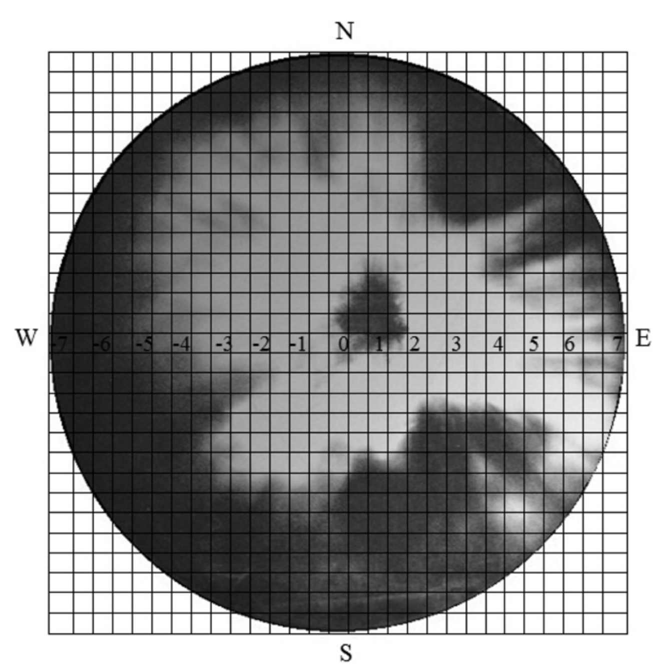

Fig. 3. A direct photograph of the nitrogen ion tracks and their distribution in a large PC detector (15 cm effective etched diameter) applying ECE conditions of 48 kV cm^{-1} at 50 Hz, PEW solution at 25 °C, and for 10 h ECE time.