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Helium ion distributions in a 4 kJ plasma focus device by 1 mm-thick large-size polycarbonate detectors

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ABSTRACT

Helium ion beam profile, angular and iso-ion beam distributions in 4 kJ Amirkabir plasma focus (APF) device were effectively observed by the unaided eyes and studied in single 1 mm-thick large-diameter (20 cm) polycarbonate track detectors (PCTD). The PCTDs were processed by 50 Hz–HV electrochemical etching using a large-size ECE chamber. The results show that helium ions produced in the APF device have a ring-shaped angular distribution peaked at an angle of $\sim \pm 60^\circ$ with respect to the top of the anode. Some information on the helium ion energy and distributions is also provided. The method is highly effective for ion beam studies.

1. Introduction

Plasma focus devices (PFD) have attracted attention as copious source of radiations such as intense X-rays, neutrons (with deuterium gas) and beams of energetic electrons and ions with potential applications in many fields by using different gases [2,18,9,10,4]. The PFDs generate ions during the progress of sausage ($m = 0$) instability towards the top of the PFD chamber in a conical fashion with energies ranging from tens of keV to few MeV [11,17]. The comprehensive mechanism behind the ion beam production in PFDs is still not well understood due to its complex nature. Studies of characteristics of ion beams emitted from PFDs provide valuable information on the ion acceleration mechanisms which are also important for industrial applications [21]. In order to better understand production and acceleration mechanisms and perform a comprehensive ion beam analysis and diagnosis, it is necessary to obtain reliable experimental data on the ion flux beam profile, ion energy spectrum, ions angular distribution and mechanisms involved in particular for helium ions.

Angular distribution and characteristics of ion beams of gases such as deuterium, nitrogen and argon as well as neutrons in PFDs have been investigated by many researchers using different detection methods such as activation foils [14], magnetic analyzers [25], Faraday cups (FC) [15,20,16,8,24], Thomson spectrometers [1], solid state nuclear track detectors (SSNTDs) like CR-39, LR-115 and polycarbonate [26,34,5,23,30–32]. The SSNTDs like CR-39, LR-115 and polycarbonate track detectors provide relatively simple methods with a number of advantages over other methods including simplicity, low cost, high spatial resolution, sensitivity to even lower-LET ions (e.g. protons, deuterons and alphas depending on the type of polymer and etching method used) and heavier ions as well as neutrons, insensitive to low LET ionizing radiations (e.g. x, γ and electrons), insensitive to non-ionizing radiation at low intensities (e.g. light, UV, IR, microwave), insensitive to environmental conditions (e.g. ambient or higher temperatures, moisture, pressure) and requiring every little electronics. In particular, polycarbonate track detectors (PCTDs) when processed by electrochemical etching (ECE) provide additional advantages of analysis and diagnosis of the ion distributions by the unaided eyes, possibility to measure diameter of track sizes for ion spectrum analysis, availability in very large sizes and thicknesses at a low cost, simplicity of cutting any desired sizes from large PC masked sheets, availability in different thicknesses in particular in 1 mm thicknesses in common daily appliances markets at a relatively low cost, resistant to high vacuum and electromagnetic fields, flexible to bend and match with any experimental conditions, being free from post-irradiation fading specially at room temperature and in particular

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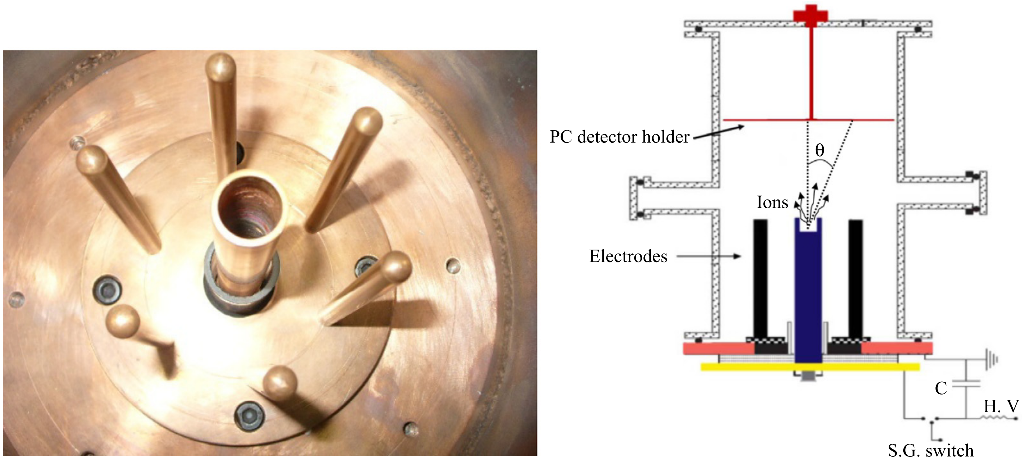

(a) (b)

Fig. 1. Inner electrode, outer electrodes (cathode) and insulator arrangement of the APF device (a), schematic diagram of the APF device and direction of accelerated ions (b).

the possibility to etch large size detector for prompt ion beam measurements and diagnosis [27,31,33].

The studies of helium ions in a PFD are rather limited and no studies seem to have been performed with the PCTDs. Rhee [22] studied energy spectrum of helium ions constructed from helium ion track analysis in CR-39 from a high voltage pulse powered PFD. The results of that study showed that the number per unit energy interval is the highest at low energies which decreases as energy increases to ∼3.5 MeV. El-Aragi et al. [3] studied scattered radiation dose intensity as a function of pressure of different gases including helium gas in a 0.1 kJ PFD using TLD-500. They found that radiation level has a minimum for different gases, when the gas pressure is between 0.66 and 1 mbar. Only helium gas was deviated from this phenomenon as it gave maximum radiation level at 0.8 torr pressure. Zhang et al. [35] reported electron beam emission within a 2 kJ PFD with helium gas with the maximum average electron charge obtained at 8.44 ± 2.68 mC at 12 kV and 12 mbar. El-Kashef [6] established the optimum operating pressures and good focusing with best spike voltage of 4 kV at time of maximum discharge current pressure to be 0.4 mbar for nitrogen gas, 2 kV at time of maximum discharge current pressure 0.3 torr and 1 kV at time of maximum discharge current pressure from 0.3 torr for helium gas. El-Kashef and Soliman [7] studied the distribution of magnetic forces in axial, radial and azimuthal direction for a 4.4 kJ plasma focus device and their dependence on helium gas pressure in the range from 0.5 to 1.5 torr.

Our recent studies on the detection of nitrogen ion tracks in 1 mm-thick large-size PCTDs by 50 Hz–HV ECE process provided a powerful approach for studying ion beam profiles, 2 and 3 dimensional and hot-spot distributions for prompt diagnosis of beam characteristics at a glance by the unaided eyes [27,31,33]. In order to apply this new approach for detection of helium ions and to study helium ion beam characteristics in the APF device, track registration characteristics of alpha particles representing helium ions at different ECE durations and applied field conditions as well as alpha energies have been performed [33,28]. The optimum ECE processing conditions for alpha particle tracks in 1 mm-thick large-size PCTD in PEW solution at 26 °C was found to be 10 hours duration for 50 Hz–4 kV field conditions [31,33]. The alpha track registration efficiency and mean track diameter as functions of alpha energy under different field conditions were also studied [28]. The method provided an alpha energy registration range from about ∼15 keV to ∼4.5 MeV with an efficiency response resembling a Bragg-type response [28]. Having very limited information on helium ion detection and ion angular and energy distribution characteristics in a PFD, this new research was carried out to:

1. Study helium ion detection, beam profile and angular distributions in the 4 kJ APF device by applying 50 Hz–HV ECE method of 1 mm thick large-area (20 cm) PCTDs,
2. Demonstrate direct, prompt and efficient diagnosis of helium ion beam profile and ion angular distributions and hot spots by the unaided eyes and/or direct photography,
3. Determine ion track density, diameter and energy distributions of helium ions in the central beam axes of the APF device and/or in 2 and 3 dimensional iso-ion density contours, and
4. Explore the possibility of helium ion track diameter and energy distributions.

2. Instruments and methods

The studies were performed by using a 4 kJ APF device filled with helium gas. The APF device was charged by a 40 μF capacitor up to 15 kV. Total external inductance of the device is 115 nH. As shown in Fig. 1(a), the APF device consists of a central solid copper anode of 148 mm length and 20 mm diameter, and six copper rods each 9 mm in diameter forming the cathode. A Pyrex glass tube with an effective length of 48 mm acts as the insulator sleeve. The vacuum in the APF device chamber was maintained at about 10^{-5} mbar in all experiments performed. A Rogowski coil was used to record the current signal.

The detectors used to register helium ion tracks to obtain information on the ion beam characteristics in the APF device were 1 mm-thick large-area PCTDs, masked on both sides. The PCTD is an organic polymer ($C_{16}H_{14}O_3$) used as passive track detectors with high potential for time-integrated particle detection in particular in pulsed ion beams [27,31]. Helium ions/alpha particles when impinge on a PCTD surface break the polymer bonds along their ionization density path and leave a trail of damage which forms latent tracks. These latent tracks in a PCTD can be easily amplified by an ECE process to a point observable by the unaided eyes [27]. The characteristics of the PCTDs under the ECE process makes it unique for ion beam detection, beam profile and angular distribution studies in a PFD [31,32].

The ECE method requires a specially designed ECE chamber which usually consists of two semi-chambers. The semi-chambers hold in place one or more PCTDs tight by rubber washers to insulate them from each other. A stainless steel electrode rod is fixed in each semi-chamber for HV connection. ECE chambers have been