Characteristic Observation of the Ion Beams in the Plasma Focus Device

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The proton emission from the plasma focus device with the H_2 filling was analyzed. The ion beam characteristics, particle pinhole image and pinch plasma image were obtained with an aluminum filtered pinhole camera with CR-39 film and x-ray pinhole camera with Beryllium (Be) filter respectively. Ring-shaped of ion bunches were observed and also on the pinched plasma column same shape was attributed.

Keywords: plasma focus, ion beam emission, pinch plasma

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1. Introduction

The determination of the ion beam characteristics is very important not only in the understanding the mechanism of the production of high-energy ions or neutrons, but also for their applications. Hence, The investigation of the ion emission from plasma focus device (PFD) and their mechanisms is still under consideration by many groups. Different kinds of acceleration mechanisms for charge particle were identified [1–3]. General characteristics of the ion beams were studied in different laboratories. [4–12]. High energetic ions are considered to play an important role in the production of the intense neutron flux in the plasma focus device when using deuterium gas [13]. Experimental observations with ion pinhole camera were performed with different plasma focus device at different condition by SADOWSKI *et al.* 1983, 1985, [14], JERZYKIEWICZ *et al.*, 1984; and there was shown ring-shape of the ion bunches, but the mechanism or circumstance of the production of these ions with these shape are not reported so far. Part of this results were published by our group in 2001 and recently, 2006 [10, 15] but the main attention is paid to new understanding of the previous results. Hence, the main aim of this work has been to extend the previous research of ion beam. In this study, the ion beam characteristics, particle pinhole image and pinch plasma image were obtained with aluminum filtered pinhole camera with CR-39 film and x-ray pinhole camera with Beryllium (Be) filter respectively.

2. Experiments

Our Mather-type plasma focus is energized by a capacitor bank of 44.8 μF/30 kV [16]. In this experiment the anode and cathode were of length 242 and 230 mm respectively. The oxygen-free copper inner electrode with a diameter of 50 mm. Outer electrode (cathode) is composed of 24 copper rods with diameter 10 mm, which forms the shape of a squirrel cage with an inner diameter of 100 mm as Fig. 1 shows the experimental setup. The electrode chamber and the analyzer chamber separated by a partition plate, which has a 150 μm pinhole for introducing ions (Fig. 2) and in the other experiment, 300 μm pinhole in different angles, respect to the center were used (Fig. 5). H_2 gas was introduced to the electrode chamber at 2.3 Torr, while analyzer chamber differentially was evacuated up to 8×10^{-5} torr using rotary and diffusion pump. Particle pinhole camera placed in the analyzer chamber. An ion track detecting film of CR-39 was used in the particle pinhole camera. The particle pinhole camera was used to obtained the radial distribution of ions and evaluate the ion production area in the pinched plasma column. In the particle pinhole camera, the CR-39 film was covered with 15 μm thick aluminum foil to eliminate heavy ions and low energy protons with an energy of less than 1 MeV. The electrode was placed 100 mm downstream of the pinhole and x-ray pinhole camera mounted in the side-on direction. The x-rays from the focus region and anode tip after passing through the pinhole covered with Be foil filter (300 μm in thickness) fall on the photographic film which is fixed in a holder.

3. Experimental Results

Figure 3 shows the typical pinhole image that obtained with the particle pinhole camera. In the measurement, the CR-39 film was placed 400 mm downstream of the first pinhole (see Fig. 2), and CR-39 film was covered with the 15 μm thick aluminum foil as filter to eliminate heavy ions and low energy protons. The ion pinhole picture shows ring-shaped (tubular) ion bunches, with the concentric circle pattern of many small spots. These localized emission regions are positioned roughly along the PF column and they could be observed as a bright spots. In the other ex-

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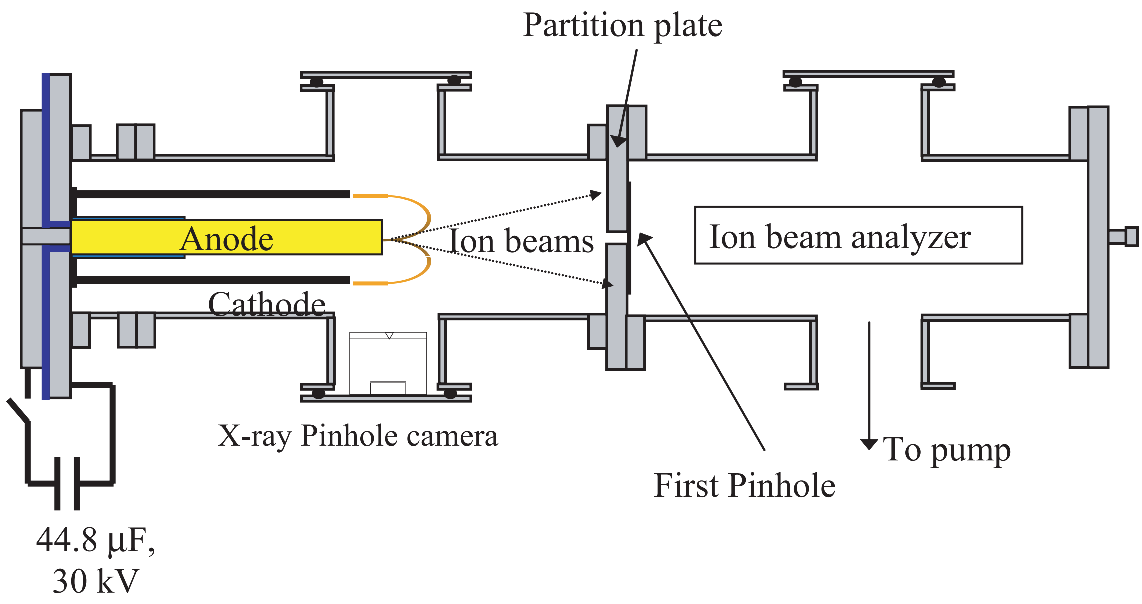

Fig. 1 Experimental setup.

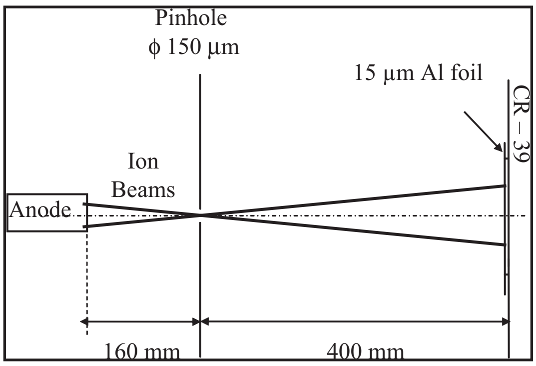

Fig. 2 Schematic of the pinhole camera (one pinhole).

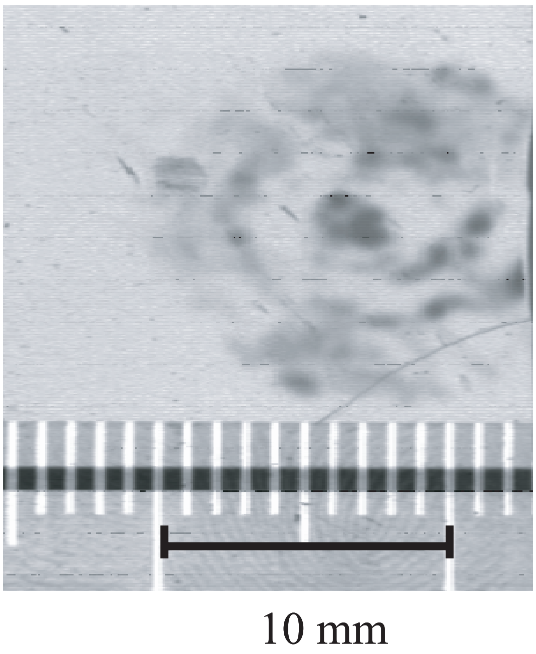

Fig. 3 Particle pinhole image obtained with the aluminum filtered pinhole camera with CR-39 film.

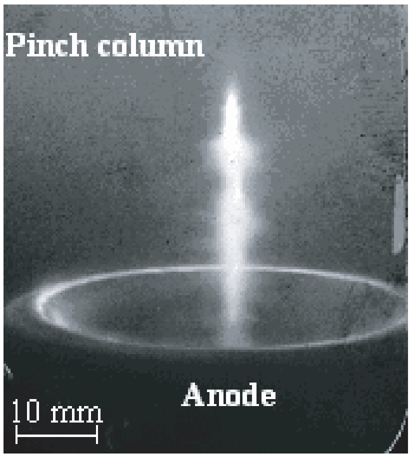

Fig. 4 X-ray pinhole images of pinched plasma column.

periment (see Fig. 5), particle pinhole camera without and with filter in center and off-center was used to show radial distribution of ions and comparison with the one pinhole camera. Another important point to note is seen by comparing Figs. 6 (a) and 6 (b); low and high energy ions images, without and with filter. In the center, density of ions is higher than the off-center in both cases. Figure 6 (b) presents a homogeneity and symmetry of ions shape. In 20-deviation of the center, a necking shape of ions were observed. On the other hand one could observe in the plasma column (Fig. 4), a ring-shape around the dense plasma column (necking) that it can be attributed to the ion shape in the pinhole image which obtained in the Fig. 3. In fact, it seems that, $m = 0$ instability (necking) cause the ions acceleration with periods of few to tens of nanoseconds but as we reported [17], there is another acceleration mechanism for ions a part from of $m = 0$ instabilities. Of course In general, various acceleration mechanisms are probable

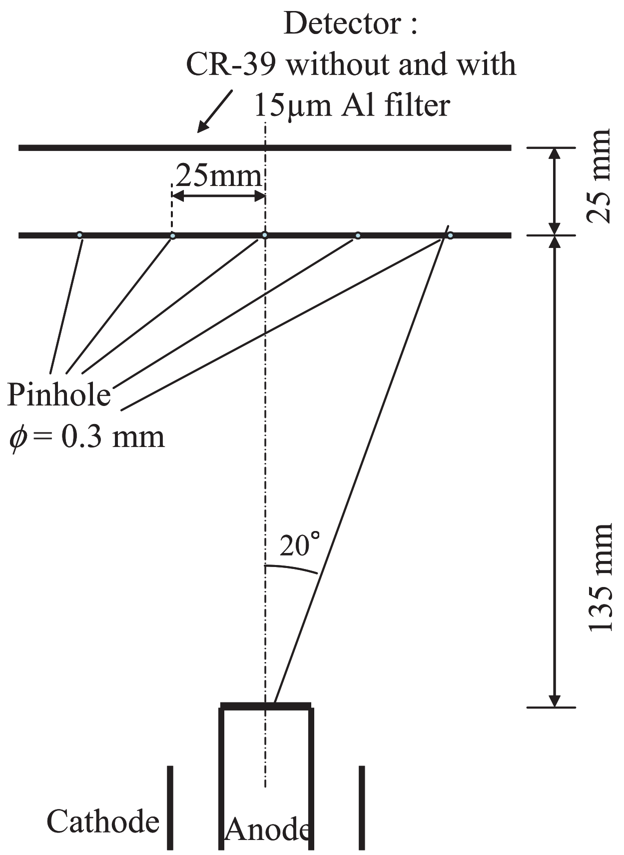

Fig. 5 Schematic of the Pinhole camera in center and off-center.

during different phases of PF discharge, but they cannot be unequivocally identified on the basis of the experimental data collected so far. However this hypothesis, in which ring-shape of the pinched plasma column is implied to ion beam shape is not free of doubt but can help us to knowing more on the ion production mechanisms. To getting clear image of the pinched plasma column we need high speed camera as was taken by Poland group [18] they could show ring shape of the pinched plasma column clearly with high speed camera and may be it will be our future work. The same results also were obtained by PF-PACO and PF-20. We counted the densities of the proton tracks at each point

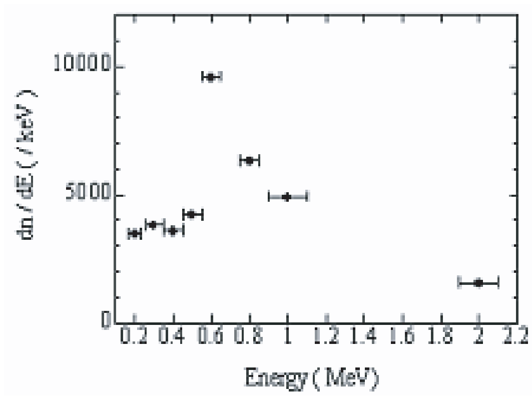

Fig. 7 Energy spectrum of protons.

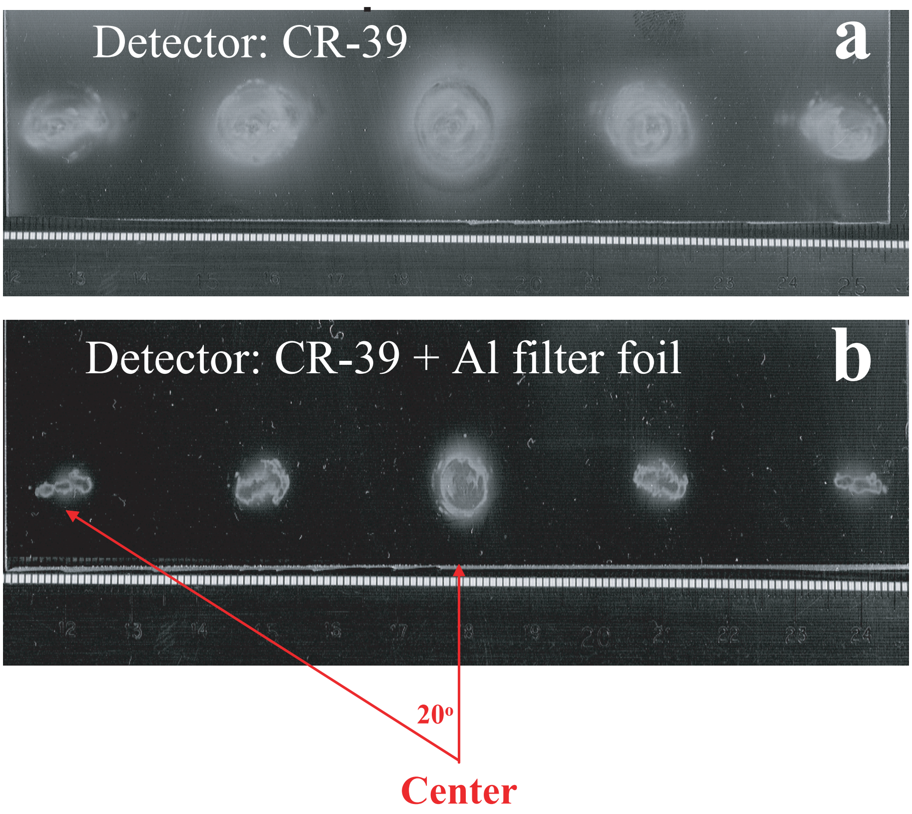

Fig. 6 Particle pinhole image obtained in center and off-center, without and with Al filter.

on the CR-39 film to evaluate the energy spectrum [10]. Figure 7, shows the energy spectrum of protons. As seen in the figure, the spectrum has a peak at 0.6 MeV and decrease with increasing energy. the spectrum is almost flat below 0.5 MeV. Same results were reported by Bhuyan *et al.* [19] for a 2.2 kJ nitrogen filled plasma focus device with hollow copper anode the energies of accelerated nitrogen ions in ion beam at the height of 5.0 cm from the top of the anode ranges from 7 to 500 keV. Their Faraday cup measurements showed that the ion number density of lower energy ions (≤ 50 keV) was in excess of $4{\times}10^{18}\,\mathrm{m}^{-3}$, whereas the number density of high energy ion ≥ 300 keV) was of the order of $5\times10^{17}\,\mathrm{m}^{-3}$. This can be explained by the fact that a pinch column is surrounded by an azimuthal magnetic field, lower-energy protons are stronger trapped within the pinch column, while the higher-energy protons can easily escape from the dense plasma region. Distinct emission dip in the deuteron angular distributions were reported by Sadowski *et al.* [11], and he suggest that an ion emission dip might correspond to the lack of accelerated particle, but exact mechanism for this event is not clear so much.

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