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Physics Letters A 372 (2008) 2294–2299
PHYSICS LETTERS A
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Time resolved studies on X-rays and charged particles emission from a low energy plasma focus device

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Received 4 July 2007; received in revised form 21 September 2007; accepted 15 November 2007

Available online 19 November 2007

Communicated by F. Porcelli

Abstract

The time resolved studies on soft X-ray, hard X-ray, electron beam and ion beam emissions from a low energy plasma focus device are carried out simultaneously by employing a photodiode X-ray spectrometer, a scintillator photomultiplier tube, a combination of Faraday cup and Rogowski coil assembly and a biased Faraday cup, respectively. The soft X-ray is seen to be emitted in short multiple pulses corresponding to different pinch stages where as it is a single for hard X-ray, which corresponds to only maximum pinch stage. Similarly, multiple pulses of electron beam is found, which also corresponds to different pinch stages and these pulses are analogous with the soft X-ray pulses. The effective hard X-ray photon energy is estimated by foil absorption technique and found to be around 110 keV, which is consistent with the observed electron beam energy distribution. The simultaneous investigation of the electron and ion beam shows that both are accelerated by the same local field generated during the pinching process. The detailed results of time resolved studies on various radiations are incorporated in this Letter.

PACS: 52.58.Lq; 41.50.+h; 41.75.-i; 41.85.Qg

Keywords: Plasma focus; X-rays; Electron beam; Ion beam; Faraday cup

The short-lived hot and dense plasma of the plasma focus (PF) is a rich source of various radiations such as soft X-ray [1–3], hard X-ray [4,5], electrons [6,7] and ions [8,9]. These radiations strongly relate to the discharge dynamics of the PF device. Therefore, simultaneous time resolved studies of those radiations namely, X-rays and charged particles and their correlation can provide better understanding on various vital features of the PF device such as the temporal evolution of high density and high temperature plasma, acceleration mechanism of charged particles and the production of X-rays. Some of the previous reports reveal the time correlations studies mainly on neutron emission with respect to charged particles and hard X-ray emission [10,11]. The dynamics of plasma along with the various emissions such as hard X-ray, charged particles and neutrons were simultaneously investigated by Hirano et al. [10] from a 18 kJ PF device. They correlated various radiations with discharge voltage and observed that the electron and ion beam signals are appeared just after an interval of 20 ns from the voltage peak, while a sharp hard X-ray signal is noticed nearly at the end of the interval of 20 ns. The neutron signal has a good time correlation with the ion beam signal. In another report, Hirano et al. [12] came into conclusion that the soft X-ray is emitted for a rather long period from the collapse phase up to the disruption of the plasma column, whereas the appearance of hard X-ray coincides with the emission of the electron beam signal. A relativistic electron beam emission has been reported in Ref. [11] and the electron beam emission is correlated with the emission of hard X-ray and neutrons. The estimated electron beam energy lies in the hard X-ray energy range [11]. Gullickson and Sahlin [13] calculated the deuteron energy of a 76 kJ PF by correlating the deuteron emission with the hard X-ray. They found more than 10^9 deuterons per shot with an average energy around 8 MeV. Bostick et al. [8] registered a band of deuteron energy beam 0.3–9 MeV from a 5.4 kJ PF. Their re-

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0375-9601/$ – see front matter
doi:10.1016/j.physleta.2007.11.024

sult shows 10^{14} deuterons with an energy interval 0.3–0.5 MeV and 10^{12} deuterons with energy in the interval 1–9 MeV. They also found strong correlation of the ion beam emission with the neutron and hard X-ray emission. Jakubowski and Sadowski [14] studied simultaneously electrons, ions and X-ray emission from a 45 kJ PF facility and correlated the X-ray emission with the electron and ion beams. Ref. [15] reported the observation of relativistic electron beams by means of Cherenkov detector and the authors found that the evolution of electron beam matched with the hard X-ray emission. The ion and electron beam emissions are observed to be followed similar exponential dependence [16]. Ion, electron and X-ray emissions from a argon filled PF device were studied by Zakaullah et al. [17] and they observed that the intensities of the X-ray, electron and ion beam signals are mutually related. Recently, Patran et al. [18] studied electron beam emission from a PF device and correlated electron beam emission with the simultaneously measured X-ray of different energies.

In spite of earlier efforts on simultaneous studies on various emissions from the PF, a clear picture on the time correlation is still not available. The physical explanation behind the acceleration of electron and ion beam and their inter dependence with the X-ray emission and discharge dynamics are still an important and interesting topic of research. Therefore, we have carried out simultaneous time resolved measurements on the X-rays and charged particles emissions from our PF device and looked into their correlations in order to have a better understanding on their time evolution picture.

The experiments were performed in a 2.2 kJ, 25 kV PF device, which comprises of an evacuated chamber, a co-axial electrode assembly and a capacitive energy storage system. The central electrode was treated as the anode while the squirrel cage type outer electrode was treated as the cathode. The detailed mechanical and electrical parameters of the device can be found in Refs. [3] and [9]. The diagnostics used to monitor the soft X-ray emission was a photodiode X-ray spectrometer (PXS) having BPX-65 photodiode covered with aluminium filters [19]. A scintillator photomultiplier tube (SPMT) assembly was employed for the detection of hard X-ray, which was placed at a distance 3 meters away from the evacuated chamber. A biased Faraday cup (FC) was used to monitor the ion beam signals, whose design and measurement technique was reported in Ref. [9]. In addition, a combination of FC and Rogowski coil [7,20] was used to monitor the electron beam emission. The Rogowski coil is employed to ascertain the electrical performance and discharge phenomena of the PF device. The outputs of those diagnostics were recorded simultaneously on a four channels digital oscilloscope. The schematic of our PF device with various diagnostics is illustrated in Fig. 1. The experiment was performed in nitrogen gas medium at an optimum pressure of 0.3 Torr. The signals of soft X-ray, hard X-ray, electron beam and ion beam were analyzed to look into the time resolved characteristics of various emissions and some time correlations among them were deduced. The results are discussed hereafter.

A typical trace of soft X-ray and hard X-ray signals with the corresponding dI/dt signal is shown in Fig. 2. Multiple spikes and single spike are noticed in soft X-ray and hard X-ray signals, respectively. The width of the soft X-ray spikes varies from 50–100 ns with a total duration up to around 300 ns. The first spike appears just at the moment of the maximum compression and its duration is comparable to the lifetime of the pinch (radial compression) phase as indicated by the dI/dt signal. Hence, the origin of this first spike can be ascribed as due to the soft X-ray emission from the pinch column itself. The first spike is followed by a single/multiple spikes that are appeared just after the maximum compression. Therefore, the origin of these X-ray components may be from the turbulent plasma, which occurs due to the breakup of pinch column. Refs. [12] and [21] have also reported multiple spikes in soft X-ray signals and confirmed that these X-ray spikes are originated from the plasma column as well as from the interaction of electron beam with the anode vapour. Fig. 2 also shows a sharp hard X-ray signal

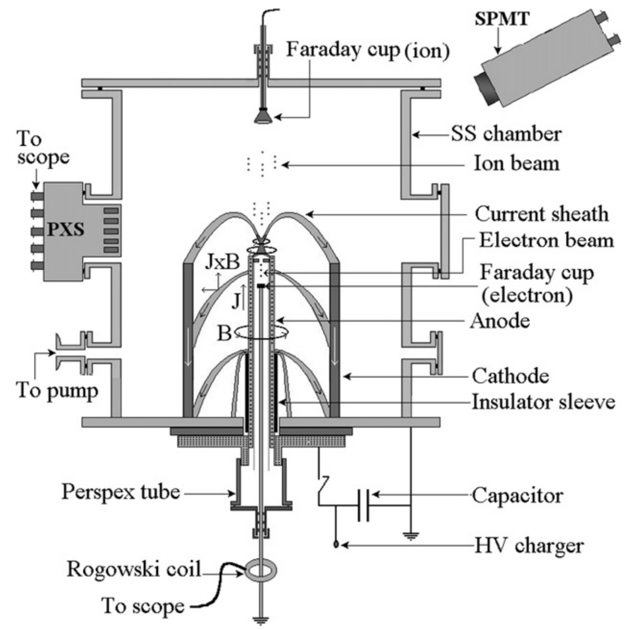

Fig. 1. Schematic of the PF device with PXS, SPMT and FC.

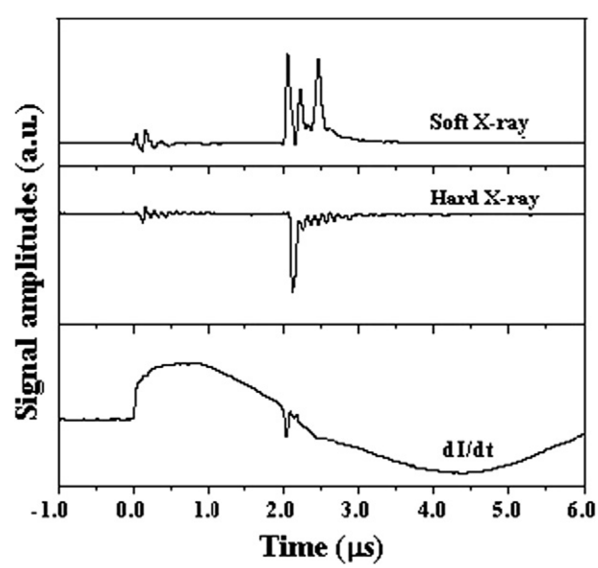

Fig. 2. Soft and hard X-ray signals with dI/dt signal.