

Ion emission study using visible spectroscopy and ToF method in a plasma focus device of two kilojoules

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Abstract. Different studies have been developed in order to understand the dynamics and processes involved in the particle emission from plasma focus devices operating in the kilojoule range. The use of chemical compound gasses and noble gas mixtures has proven to produce different charged particles, as well as increase the neutron yield from deuterium plasma discharges. Nevertheless, the processes and parameters involved in these discharges are not fully understood. In this work we will present results of visible spectroscopy and “time-of-flight” observations of the different ion species and ionization levels obtained in a 2kJ plasma focus device, when using deuterium or hydrogen with small percentage impurities.

1. Introduction

It is an interesting phenomenon that high energy ions with energy of more than 1 MeV are produced in plasma focus devices [1]. The energy of these ions is sometimes larger than hundred times the charging voltage of the capacitor bank. These 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 [2, 3]. The determination of ion beam characteristics is very important not only in understanding the mechanism of production of high-energy ion or neutron, but also for their potential applications.

In general, the studies of ion beams have been performed in plasma focus devices that operate with energies from 1kJ to 1MJ [4]. In this work, preliminary results of some characteristics of the emitted ions from a plasma focus device of 1.6 kilojoules, PEPUTNIK, will be presented. In particular, the ion energy and flux is measured with a biased graphite ion collector. Furthermore, to characterize the ionization degree evolution of the gas impurities present in the plasma we used a visible spectrometer, ANDOR Shamrock-500i-B1.

2. Experimental setup

The experiments presented here were conducted in a plasma focus device operating at a kilojoule energy level (PEPUTNIK: 8000nF, 20-30kV, 1600-3600J, ~960ns time to peak current, $dI/dt \sim 2.7 \times 10^{11}$ A/s) (see figure 1), which has been designed and constructed at the Chilean Nuclear Energy Commission, CCHEN. In table 1 the dimensions and parameters of the device are shown. Discharges



in different gasses like hydrogen, deuterium and a mixture of 98 % hydrogen and 2% neon at pressure of 9mbar to 10mbar were done. A charging voltage of 20 kV was used.

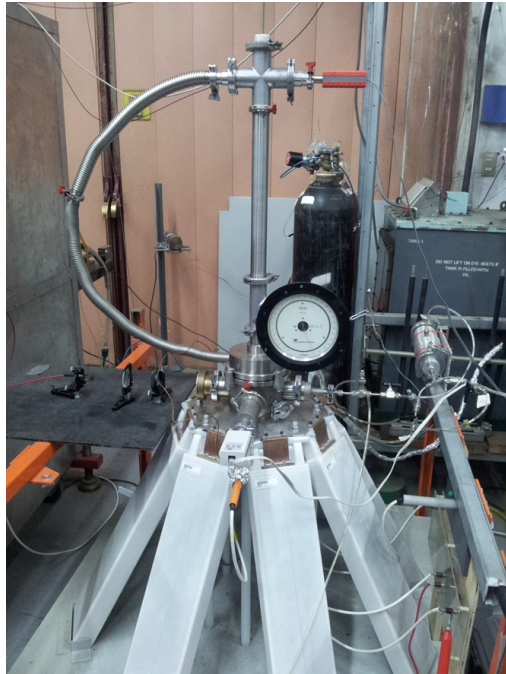


Table 1. Electrical parameters of the PEPUTNIK device.

Parameter	Value
C_0 [nF]	8000
L_0 [nH]	47
E [J]	1600
V_{op} [kV]	20
I_{max} [kA]	260
$T/4$ [ns]	960
r_a [mm]	12
z_{eff} [mm]	27

Figure 1. Image of the experimental setup of the 2kJ plasma focus device, PEPUTNIK.

3. Electrical and spectral diagnostics

Regular voltage divider probes and current derivative probes, as well as a Faraday Cup (FC) for ion collection, were used. The ion collector is a conical probe designed to maintain an impedance of 50Ω [5, 6]. It is composed of a graphite conical inner electrode of 15mm in length with a base diameter of 7mm to reduce the secondary electron emission (SEE) and a brass external electrode separated by a Teflon insulator (figure 2). The graphite collector inside the drift tube was used to detect the axial ion beams emitted from the PF and it was placed 66 cm away from the anode tip. The collector is negatively biased to a dc voltage between -150 to -200V. The negative voltage also removes the secondary electrons from the surface of the collector that are generated at the collector surface by the incoming ion beams. Thus, a suitable biasing voltage on the collector is essential for proper interpretation of the collector signal. Due to the negative biasing, the ion probes also act as X-Ray Diode (XRD).

The characterization of the ionization stages of the gas impurities present in the plasma is being done by means of the visible spectrometer: ANDOR Shamrock-500i-B1. With the use of an ICCD available in the laboratory, time resolved images of the spectra emitted by the discharge are acquired and processed. To be able to have a spatial resolution we use a system involving two plano-convex lenses that allow focusing a small volume of the plasma sheath into the fiber optic (FO) that connects to the spectrometer. A 300 groove/mm diffraction grating was used due to the broad spectral region available and good response to the observed region, which in this report spans from ~ 620 nm to ~ 705 nm. Two plano-convex lenses were used to focus the plasma emission into a 19 circular-to-linear fiber optic bundle connected to the entrance of the spectrometer (see figure 3). The ICCD-Spark gap system was synchronized externally, allowing the acquisition of time resolved measurements with integration times of 20 ns.

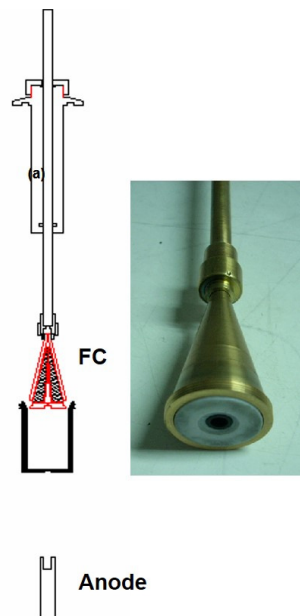


Figure 2. Picture and scheme of Faraday cup.



Figure 3. Picture and scheme of the experimental setup for the spectroscopy measurements.

4. Results and discussion

In general it is possible to observe of the voltage and current derivative signals that the dip is seen to coincide with both the x-ray pulse in the FC. This kind of peak on these detectors has been reported earlier as x-rays emitted during pinching [5, 6]. Time of flight (TOF) measurements performed using two ion probes indicate that the time delay between probes for the different beam components with simultaneous emission at a time which, within the time resolution, coincides with the emission of the x-ray pulse. These facts allow single ion probe signals to be used for the ion energy spectrum measurements [6]. The time correlation between x-ray and ion beam emission indicates that in PF discharges ion acceleration takes place at some time close to the maximum radial compression phase. Therefore, it is reasonable to assume that ion acceleration takes place in existing plasma, with a multi-charged ion composition. Under these conditions, all ions are accelerated by the same electric field and the energy gained in the acceleration process is proportional to the ion charge [7, 8].

Figure 4 shows the distribution of the ions energies for all data obtained in hydrogen (H_2) at 9 mbar. It is clearly observed, in this case, that the ions energies are distributed in two regions with a maximum energy around 370keV. The region of higher energy corresponds to the ion species with the highest ionization stages, Al^{+5} , Al^{+6} (from the alumina insulator), and O^{+5} . On the other hand, the region of lower energy corresponds to the ion species with lower ionization stages, H^+ , Al^+ and Al^{+2} , N^+ , Cu^+ and Cu^{+2} (from the anode), and O^{+2} .

Spectral measurements were done in order to identify the elements present and their ionization degree. Figure 5 shows the spectra acquired during the whole current pulse at the pinch volume. As seen from the image, only some ionic species are detected, as Al^+ and Al^{+2} , Cu^{+2} and Cu^{+3} , and O^+ . Similar ionization stages and flux level have been observed in devices of the same energy range operated with methane and nitrogen [6, 9, 10].

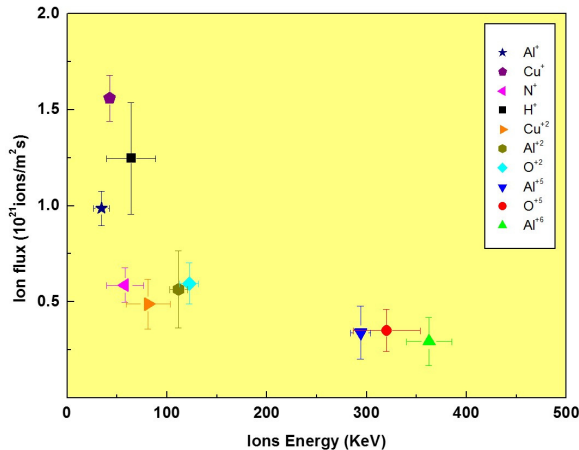


Figure 4. Graph of ion flux vs ion energy at 9 mbar in hydrogen

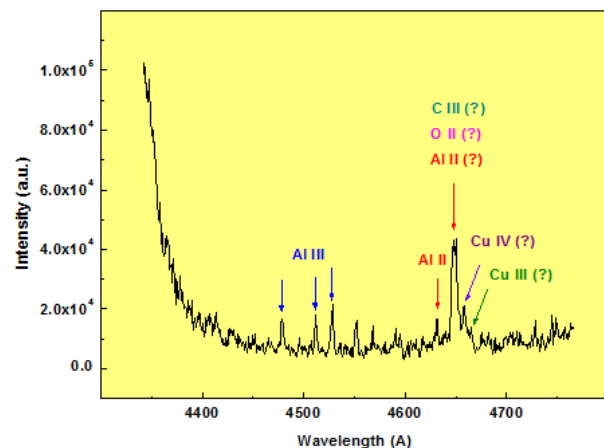


Figure 5. Spectral evidence of the presence of some ion species obtained at 9 mbar in hydrogen.

These results show some agreement between both diagnostics, ToF and spectrometer, but it is necessary to extend the range of measurements to other pressure using mixture of gases and improving the method of time of flight to determine the ionization degree.

5. Conclusion and future work

The results obtained with ions ToF method using a Faraday Cup show the presence of several ion species with energies between 40 keV and 370 keV. The comparison of the results of both diagnostics shows a small agreement between the ionization degree and type of species present in the discharge. It is necessary to increase the number of shots for each experimental condition. It is necessary to measure at the axial position with the spectroscopic diagnostic to directly compare the results and enhance the measuring conditions in case some radiation absorption is present.

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