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The study of discharge characteristic of the cold-cathode negative hydrogen PIG-type ion source ☆

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ABSTRACT

The cold-cathode Penning ion gage (PIG)-type ion source is designed for the internal ion source of the compact cyclotron. This kind of ion source has been used for generation of the negative hydrogen (H^-) ions for many decades. The discharge characteristics of the ion source are investigated systematically for hydrogen operation at different discharge currents, gas flow rates and magnetic fields, respectively. In this paper, optical emission spectroscopy measurement is carried out to diagnose the parameters of the hydrogen plasma in the ion source. The preliminary optimization of the H^- formation with the gas flow rates is discussed and analyzed. Current experimental results can provide useful information for the design and operation of the negative ion source.

1. Introduction

The compact cyclotron was designed for the production of the short half-life medical isotopes. The external proton beams with particle energies up to 11.2 MeV are obtained by the H^- ions stripped off their two electrons in a carbon stripper foil. A kind of cold-cathode PIG-type ion source has been widely used to generate the H^- ions [1–4]. For installed in the central region of the cyclotron, the ion source should be extremely compact, perform at small working gas flow, have a sufficiently long life-time, easily changeable, at a high ion beam current, and not contaminate the accelerating system of the cyclotron [5–8].

PIG ion source was originally proposed by Penning as a low-pressure manometer [9] and later been used for a variety of applications, such as the sputtering and evaporation of surfaces, electromagnetic separation of isotopes, sealed-tube neutron generator and fusion applications [10–14]. In a typical ion source, electrons oscillate between two cathode electrodes inside a hollow anode to establish a high-voltage, low-pressure plasma discharge. An axial magnetic field increases the path length of ionizing electrons, making plasma production more efficient. The special limitation in the central region makes the size of the plasma chamber only about a few centimeters.

Our main task in the designing of H^- PIG-type ion source is the optimization of H^- ions formation in the hydrogen plasma. Therefore, the diagnostics of the plasma parameters turn out to be much more essential. However, standard diagnostics are electrical measurements of extracted ion and electron currents, which depend on a variety of external parameters such as the geometry of the extraction system, the beam optics and the extraction voltage. The conventional Langmuir probe measurements are hard to provide the plasma parameters, for the strong magnetic fields in the PIG-type ion sources. Emission spectroscopy represents a non-invasive and in-situ diagnostic tool for line of sight averaged plasma parameters, which has been already successfully applied to the H^- ion sources [15,16]. The relationship between the H^- production and the plasma parameters should be studied systemically.

An internal PIG-type ion source was designed and tested on a test-stand. The discharge characteristics of the ion source were studied and discussed for different parameters. The relative intensity of the Balmer series lines H_α, H_β and H_γ were measured and analyzed. The plasma electron temperature was determined from the two line radiance ratio method and the steady-state coronal model. The preliminary results of the H^- extraction measurements with dc voltage are presented in this paper. Correlations between the plasma parameters and the extracted H^- current are discussed.

2. Experimental setup

An internal PIG-type H^- ion source was designed and made for a compact medical cyclotron at China Academy of Engineering

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Physics (CAEP). The ion source consists of two main components: the cathode and the hollow anode. A couple of cylindrical cathodes located at either of the hollow anode ends within an axial magnetic field. The cathode was made of tantalum because of its low sputtering coefficient. The hollow anode with an ion exit slit ($6 \times 0.4\ mm^2$, 0.51 mm thickness) in the middle part (by height), is made of copper. Electrons emitted from either cathode are accelerated into the hollow anode and trapped axially by an electrostatic well and radially by the magnetic field. The cathodes are heated by ion impact and there is no need of additional filament heating, so it is possible to minimize the ion source dimensions to 50 mm (high) and 13 mm (wide). The ion source was inserted into a vacuum chamber and tested on a test-stand. The test-stand uses a room temperature electromagnet which produces magnetic fields of about 0.7 T excited by a 75 A coil current. There is an almost linear relationship between the magnetic field and the coil current. The fluctuation of the magnetic field strength is slightly and cannot affect the ion source

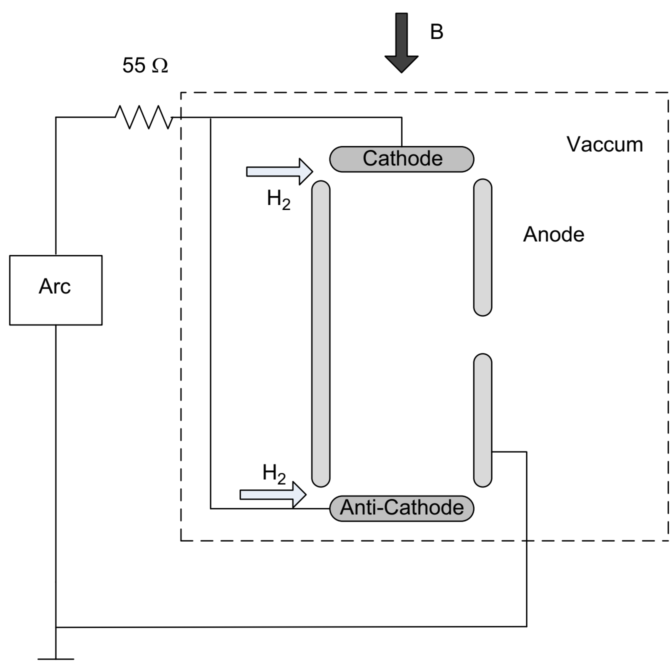

Fig. 1. Schematic diagram of the electrical setup of the PIG-type ion source.

operation, the spectroscopic diagnosis and the measurements of the extracted beams.

A schematic diagram of the electrical setup is shown in Fig. 1. The anode is grounded. The cathodes are powered by a −2 kV 2 A pulsed/dc power supply and a 55 Ω resistor is connected in-line to protect the power supply when discharge. The schematic diagram of the spectroscopic system for the ion source is shown in Fig. 2. The plasma emission spectra in the visible spectral range are easy to be obtained with the quite simple experimental setup. The optical fiber is equipped with a collimator lens in such a way that the plasma volume with diameter 6 mm is imaged. The spectra during the ion source discharge are recorded with a PI (Princeton Instruments) SP2756A spectrometer and a PIXIS CCD. The resolution of the spectrograph is about 0.06 nm for $\lambda = 200$–1050 nm.

The hydrogen was injected directly into the ion source. The pressure of the vacuum chamber increases as the gas is inputted into the ion source. The relationship between the gas flow rates and the vacuum chamber pressures for this investigation is similarly linear. The pressure of the vacuum chamber at 10 SCCM (SCCM denotes cubic centimeter per minute at STP) is 3.62×10^{-5} Torr and the pressure increment per 1 SCCM is about 2.5×10^{-6} Torr. Generally, the pressure of the cyclotron is of the order of magnitude 10^{-5} Torr for using an internal ion source. The pressure inside the ion source is hard to measure for the extremely small dimension. A calculation shows the pressure inside the ion source is approximately the order of magnitude 10–100 larger than the chamber pressure. A first-order calculation also shows the similar result [14]. The ion source is operated in a large vacuum chamber which can maintain a lower background pressure. All results presented here are for hydrogen injection directly into the source.

3. Results and analysis

The operation and discharge characteristics of the ion source were studied on the test-stand. For each continuous discharge, the arc voltage, the arc current, the gas flow rate, the vacuum system pressure and the magnetic field were recorded seriatim. Visual observation shows bright pink plasma inside the ion source during the discharge. As the arc current or gas flow rate increases, the plasma becomes visually brighter. The plasma parameters of the ion source such as electron temperature can be got from the line emission measurements.

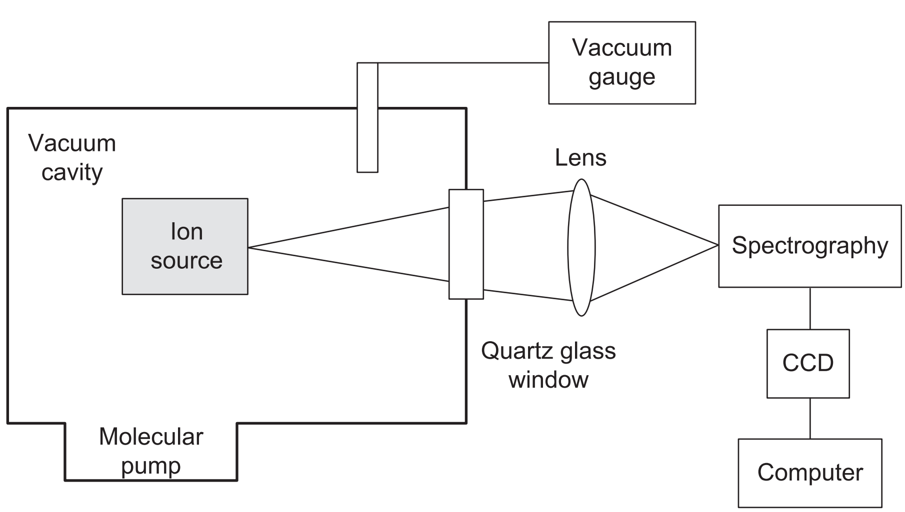

Fig. 2. Schematic diagram of the spectroscopic system for the ion source.