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COMPACT H$^+$ ECR ION SOURCE WITH PULSE GAS VALVE

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Abstract

We are developing a compact ECR H$^+$ ion source with a fast pulse gas valve. In the case of high current ion linac, the distance between the ion source and the first accelerating tube such as RFQ must be as short as possible to reduce the space charge effect, while operation in a high electric field a good vacuum condition is desirable. Since hydrogen gas always flows out from ion sources when the plasma chamber is filled with the gas, vacuum pumping systems have to evacuate the gas enough before the first accelerating tube. The quick pulse gas injection system achieved by a fast piezoelectric gas valve can reduce the gas load to the vacuum evacuation system and is suitable for installing the ion source close to RFQ. In order to optimize the operating parameter of the ion source, a multi-collector mass analyzing system is developed. The current status is reported together with the preliminary measurement data of the quick mass analysis and spectroscopy of the emitted lights from the plasma.

INTRODUCTION

In an ion source using gas discharge, not only ion beam but also neutral gas flows out from extraction hole. Most of the neutral gas is pumped out by the vacuum pumping system in the Low Energy Beam Transport (LEBT), and a part of the gas diffuses to the accelerating tube. Conventionally, even in the case of a pulsed ion source, neutral gas is constantly supplied and ion beam is extracted from the ion source during the pulse period, while neutral gas continues to flow out of the plasma chamber. In a high-intensity ion accelerator, it is desirable that the length of the LEBT is as short as possible in order to reduce the adverse effect of the space charge effect. However, if the LEBT is short, the effect of the inflow neutral gas to the acceleration tube increases. Then, frequent discharges in the accelerating tube may happen, which may interrupt operation. Chopping the supply of the gas into the plasma can reduce the gas flow. Therefore, we have developed ECR ion source with less gas load [1].

COMPACT H$^+$ ECR ION SOURCE WITH PULSE GAS VALVE

Currently, we have developed a compact ECR H$^+$ ion source with pulse gas valve and test its performance. Since it is assumed to be used for small neutron sources based on proton linac, H$^+$ was chosen as the ion species. In order to achieve high H$^+$ ratio in the extracted beam, the ECR method was adopted. The pulse gas injection system achieved by a fast piezoelectric gas valve can reduce the gas load to the vacuum evacuation system and is suitable for a close installation of the ion source to RFQ.

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Desgin

The source is build on a ICF203 flange. There are two radial permanent magnet rings at the upstream and downstream of the chamber. Each magnet ring consists of twelve trapezoidal pieces and their magnetic holder. The extraction system consists of a plasma electrode and a set of three electrodes with a negative potential inserted between the two grounded electrodes, and up to 25 kV can be applied to the plasma electrode. The high voltage assembly is insulated and supported from ground potential by polyethylene insulators. The ion source unit is covered by an iron magnetic return yoke that reduces the stray magnetic field around the ion source. The structure of the ion source is shown in Fig. 1.

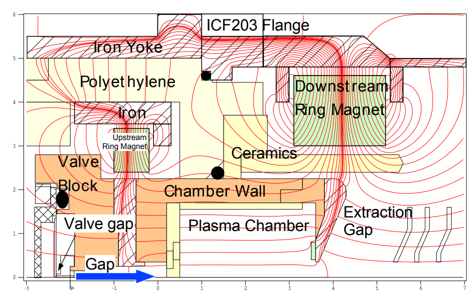

Figure 1: Schematic drawing of the ion source structure. Red lines indicate magnetic flux.

Gas Valve

We developed a fast pulse gas valve using a piezoelectric element KBS-27DA-5A to chop gas supply to ion source [2]. If positive voltage is applied to the piezoelectric element, the gas entrance into the chamber is blocked by the piezoelectric element, so that the gas does not flow into the chamber. However, when negative voltage is applied to the piezoelectric element, the piezoelectric element curves oppositely to open the flow path, and the gas flows into the chamber. By applying a quick pulse voltage to the piezoelectric element, it is possible to inject and chop gas quickly. Figure 2 shows a schematic diagram of the operating principle of the pulse gas valve using the piezoelectric element.

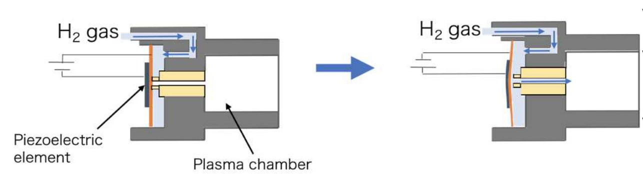

Figure 2: Operating principle of the pulse gas valve.

Magnetic Field

The magnetic field strength satisfying the ECR condition at 6 GHz is about 220 mT. For the generation of the magnetic

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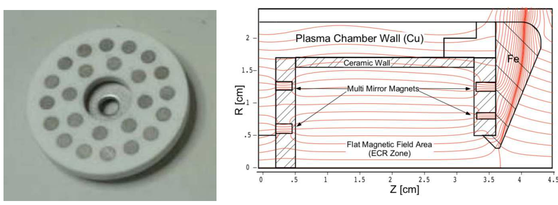
field, the miniaturization is aimed at by using a permanent magnet. In addition, a multi-mirror magnetic field scheme is adopted for the purpose of flattening the magnetic field strength distribution on the beam axis and widening the ECR region [3]. Figure 3 shows a photograph of a disk-shaped ceramic with small magnets embedded in it, and the magnetic field distribution when it is loaded in the chamber. Figure 4 shows the measurement result of the axial magnetic field strength on the beam axis. While there is a room to improve the magnetic field distribution by adjusting the shape of the magnet, the magnetic field is well flat on the axis of the chamber position.



(a) (b)

Figure 3: (a) downstream cylindrical magnet columns embedded in a ceramic disc with the diameter of 34 mm. The diameter of each magnet column is 3 mm. (b) schematic flux plot with multi-mirror field.

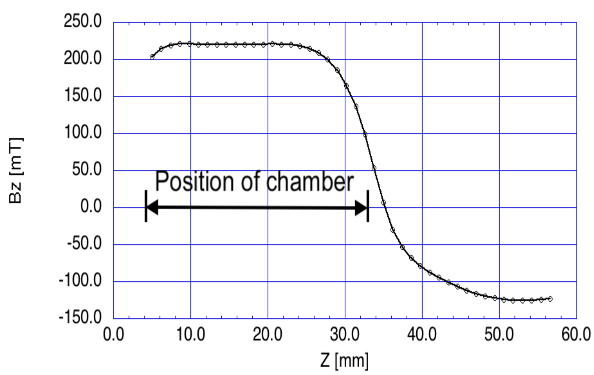


Figure 4: Magnetic field distribution on the beam axis.

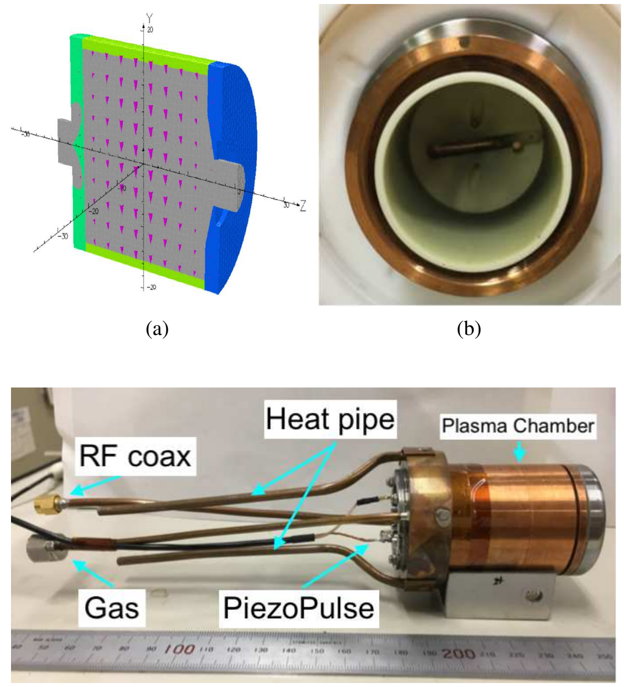
Plasma Chamber

Because the plasma chamber volume should not exceed 50 cc to keep the time constant of the gas stay in the chamber small enough, 34 mm inner diameter 28 mm length cavity was fabricated and the operating frequency is at around 6 GHz. Due to the small volume allowed, the cavity is operated at single mode. Because of the small space available for RF feeding, an antennae coupling through a coaxial line is used instead a waveguide (Fig. 5).

PERFORMANCE TEST

Experimental Setup

A test bench has been constructed to evaluate the beam generation performance of the ECR ion source. The 6 GHz RF power of up to 200 W can be supplied by amplifying the



(a) (b)

(c)

Figure 5: (a) Calculated RF mode of TE111 in a cavity. (b) Picture of the inside of the plasma chamber viewed from the downstream side. All the inner cavity walls are covered with ceramics, and an antenna coupling through the coaxial line is seen in the center back. (c) The plasma chamber and the piezoelectric valve assembly.

RF power generated by a signal generator with a solid state amplifier. The amplified RF power is fed to a waveguide with a coaxial-waveguide conversion adapter at both the ends of the waveguide. A DC blocker inserted in the waveguide blocks the HV. Hydrogen gas is generated by a hydrogen gas generator for gas chromatography. The generated gas is stored in a gas buffer tank, and the gas flow rate to the plasma chamber can be adjusted by changing the gas supply pressure to the pulse gas valve. The gas flow rate is measured by a mass flow meter.

In order to know the ratio of ion species in the extraction beam, we installed a mass analyzer with an analysis magnet and multiple collector electrodes [4] just after the ion source. The feature of this mass analyzer is that it can analyze multiple kinds of ions in the extraction beam simultaneously and almost in real time. This greatly improves the efficiency of examining the properties of the beam generated by the ECR ion source, which is determined by complex involvement of many parameters such as magnetic field distribution, gas pressure, and RF power and frequency. The signals from multiple electrodes are scanned by a fast multiplexer and the multiplexed signal is sent to the outside and then digitized by a PC based oscilloscope. In addition, a lens for a spectrometer was installed at downstream position of the beam line for spectroscopy of light emitted from the plasma in the ion source. Schematic diagram of experimental setup is shown in Fig. 6.

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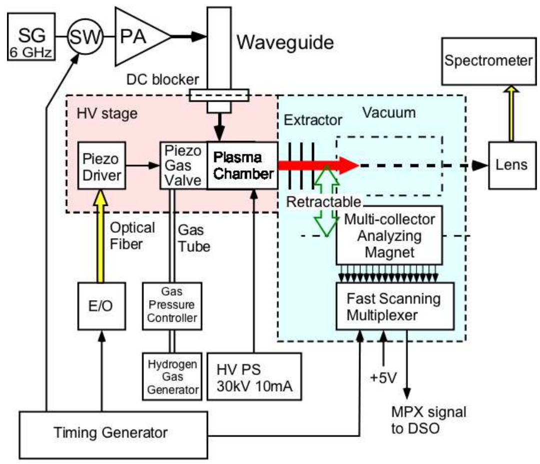

Figure 6: Schematic diagram of experimental setup. The mass analyzer can be retractable from the beam line and can switch between mass analysis and spectroscopy configuration.

Preliminary Results

Mass analysis Figure 7 shows a measurement result of extracted beam current using the mass analyzer (with 0.6 % gas pulse duty; 2 ms pulse duration with 3 pps , RF power; 6.16 GHz, 67 W, 2ms). Pressure in the plasma chamber estimated from $\phi 6$ mm extraction hole conductance and average mass flow was 32 mTorr. Total extracted beam current at peak was about 8 mA, and H^+ current was about 1 mA. The highest was H_2^+ current, in addition, heavy ions considered to be not hydrogen-derived were also detected more than H^+ in this trial case.

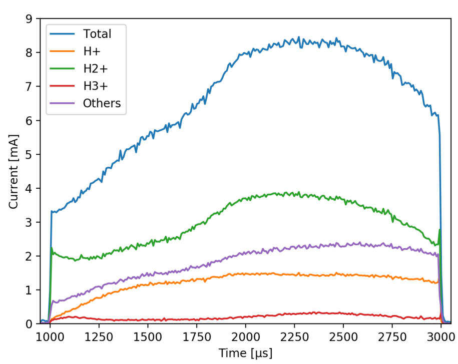

Figure 7: The horizontal axis is time, and the vertical axis is current. RF power is fed from 1000 to 3000 µs and the gas valve is open from 0 to 2000 µs.

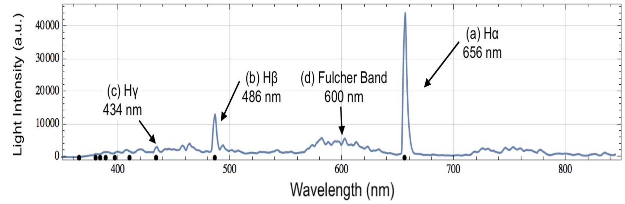

Figure 8: Typical spectrum obtained by a spectrometer where Balmer series and Fulcher band are shown.

Spectroscopy Figure 8 shows a typical visible light spectrum obtained by spectroscopy of a plasma generated by the ion source. The Balmer series H-alpha (a) at 656 nm, H-beta (b) at 486 nm, H-gamma (c) at 434 nm lines and Fulcher band (d) are shown. It is expected that we can grasp the details of the plasma generated by the ion source by investigating the data obtained by spectroscopy in detail.

CONCULUSION

We are developing a compact ECR H^+ ion source with pulse gas valve and testing its performance. Fast pulse gas valve reduces gas load to evacuation system. The real-time mass analysis of the extracted beam enables us to optimize the parameters. The less amount of proton beam current for now may be requiring us to make some modification to the structure in addition to the parameter optimizations. A fast shutter before the spectrometer may enable us to investigate the time structure of the pulse plasma.

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