

GAS FLOW INFLUENCE ON NEGATIVE HYDROGEN ION GENERATION WITHIN THE MICROWAVE-DRIVEN NEGATIVE ION SOURCE*

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Abstract

H⁻ ion was generated through two processes within a volume Cs-free source. The density of molecule hydrogen gas will impact on the electron temperature within the primary discharge chamber that will influence the population of vibrational excited H₂^{*}. Within the extraction region, the interaction between molecule hydrogen and H⁻ ion will cause the dissociation of negative ion. To better understand the gas flow influence on H⁻ ion generation within a volume negative ion source, a new Cs-free volume microwave-driven H⁻ source body with two gas inlets was developed at Peking University (PKU). Experiment on gas flow and gas pressure distribution within the plasma chamber was carried out with this source body. In the meantime a two dimensional (2D) model for gas flow was developed. Details will be presented in this paper.

INTRODUCTION

The 2.45 GHz electron cyclotron resonance (ECR) ion source has been developed at many labs.[1, 2] This kind of ion source is widely used mainly for high current single charge state positive ions (H⁺, D⁺, He⁺, O⁺ etc.) generation which shows great performances in high stability, high reliability, easy maintenance and long lifetime. Recently, reliable negative hydrogen ion sources are also demanded in many high current facilities because H⁻ ion has significant advantages in beam transmission or injection into synchrotron. [3] H⁻ ion source is a kind of ion source which needs a lot of theoretical and experimental work. Among all kinds of H⁻ ion source, Penning ion source and the volume ion source operating with Cs are regarded as promising candidates, also ECR source is promising to generate H⁻. [4] Since 2012, a 2.45 GHz microwave-driven H⁻ ion source without using Cs was designed at PKU. This ion source was intended to generate more than 10 mA H⁻ for the injector of SPRESA facility in China at the beginning. [5, 6]. Recently, a 35 mA H⁻ beam with 10% duty factor and a 16.5mA CW H⁻ beam at 35 keV have been produced with this source. However, just like Prof. Horst Klein said at 20 ICFA Workshop summary, "The ion sources, and especially the H⁻ sources, are still somewhat a black magic". [4] Many factors, such as electron density and temperature, molecule hydrogen gas distribution, etc., will influence the generation of H⁻ ions [7]. To better understand the processes within a volume H⁻ source, a series of experiments were carried out on the impaction of gas

distribution. A 2D simulation was performed to study the pressure distribution with different inlets. More simulated and experimental results will be reported in this paper.

EXPERIMENT SETUP

Experiment was done on a compact permanent magnets 2.45 GHz microwave-driven Cs-free volume H⁻ source developed at PKU. The Schematic diagram is plotted in Fig.1. Its outside dimension is $\Phi 116 \text{ mm} \times 124 \text{ mm}$. Detail was described in Ref. 8. 2.45 GHz microwave is fed into discharge chamber through three-layer Al₂O₃ microwave window to heat the electrons confined by ECR resonance magnetic field.

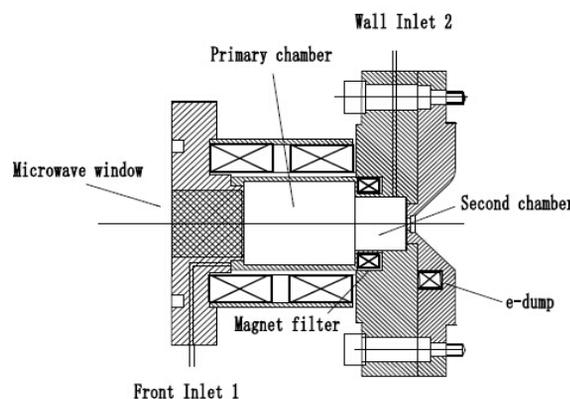


Figure 1: Schematic diagram of microwave-driven negative ion source.

As mentioned in Ref. 9, two processes will happen within this volume source. First, energetic electrons that heated by microwave will impact with hydrogen molecular to generate amount of vibrationally excited H₂^{*} in the primary discharge chamber. Then, H₂^{*} will interact with slow electrons in the second chamber to produce H⁻ ions. A magnetic filter field, which has a high diffusion constant only for slow electrons (<1 eV), is applied between primary and second discharge chamber to lower the electron temperature in the second chamber and prevent fragile H⁻ ions from being destroyed by fast electrons.

The measurements in Ref. 10 & 11 show that T_e will decrease with operation pressure increasing in ECR ion source because the energy transfer between fast electrons and other particles will be enhanced with higher pressure which means high particle density in the chamber. Therefore, it is important to keep a relative higher pressure in the ion source especially in the second

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chamber. For investigating the influence of pressure distribution on negative ion source operation, two gas inlets were designed (Fig. 1): one was located in the front of the source near microwave window named front inlet 1, and another was on the wall of second chamber about 6 mm away from extraction aperture named wall inlet 2.

TWO DIMENSIONAL FLUID MODE

A 2D fluid model based on finite volume method was utilized to simulate the cross section of the inner cavity. It used a commercial computational fluid dynamics program without considering the plasma. The fluid was assumed to behave as compressible, ideal gas, and some structures of the cavity were simplified for building the mesh grid easily. A standard $k-\epsilon$ turbulent model was introduced in our simulation to describe the flow of the gas in the narrow chamber, [12] and energy conservation, momentum conservation and continuity equations were all considered in the simulation. Experiment shows that the pressure in the vacuum chamber after extraction system are nearly the same with certain gas flow from different inlet. Hence, the inlet pressure and outlet pressure were set to be the same in the simulation. It is obvious in Fig. 2 that the pressure with front inlet 1 is about 10~15 Pa which is much higher than using wall inlet 2. This may be explained that wall inlet 2 is much closer to the outlet, so gas fluid may be exhausted very fast leading to a lower pressure in the chamber.

EXPERIMENTAL SETUP

Experiment was carried out on our test bench. [7] A permanent magnet located near the extraction hole of the ion source was used as e-dump to deflect co-extracted

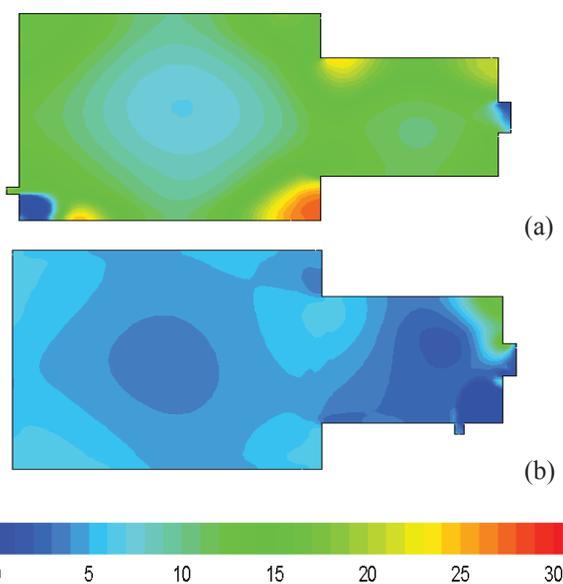


Figure 2: Pressure distribution inside ion source with different gas inlet position (a) front inlet 1, (b) wall inlet 2.

power supply and extraction system. Three-electrode extraction system with $\Phi 6$ mm hole was used to make the ion beam focus better, and electrodes were made of molybdenum with water cooling to prevent them from damaging by electrons. But as there was still some electron emission, a 90° deflection magnet was utilized to analyse the fraction of H^- and electrons. A slid-wire emittance measurement device with Faraday cup before the magnet gave the emittance and total current of the beam.

EXPERIMENTAL RESULTS

Previous experiments have showed some promising results with our microwave-driven H^- ion source. [5, 6] It already delivered 20 mA H^- beam at 35 kV with duty factor of 10% (100 Hz/1 ms) in pulsed mode and 10.8 mA DC beam at 30 kV. The RF power efficiency went up to 11 mA/kW for pulsed beam and 21.6 mA/kW in DC operation.

In the case of volume produced negative ion source, suitable magnet filter is really important which guarantee a low electron temperature area for H^- generation. Besides, Tantalum liner on the inner surface of the ion source can really enhance the yielding of vibrational excited H_2^* . So, after some improvements on magnet filter field, e-dump filed and surface material, experiments were done to explore the influence of gas inlets.

The microwave power was set at 1500 W in pulsed mode (100 Hz/ 10%), and the extraction voltage was - 35 kV with suppressing voltage + 2 kV. The pressure in the vacuum chamber changed from 1.0×10^{-3} Pa to 8.0×10^{-3} Pa with other parameters keeping constant. As introduced before, the inlet flow is nearly the same with same pressure in the vacuum chamber, so the inlet flow can be indicated by the chamber pressure this time. It can be shown in Fig. 3, the pure negative hydrogen ion current increases with pressure increasing from 1.0×10^{-3} Pa firstly and then declines with higher pressure. With pressure

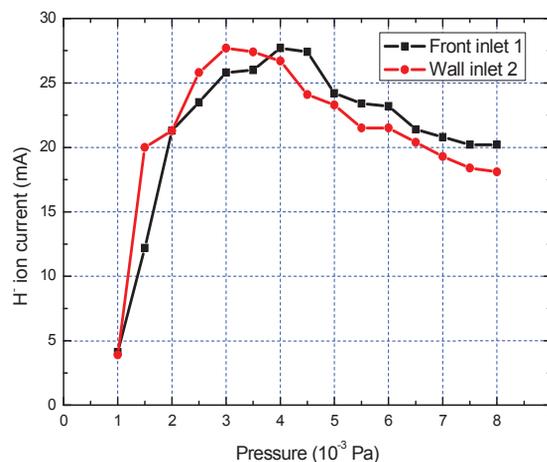


Figure 3: H^- ion current vs pressure with different inlets.

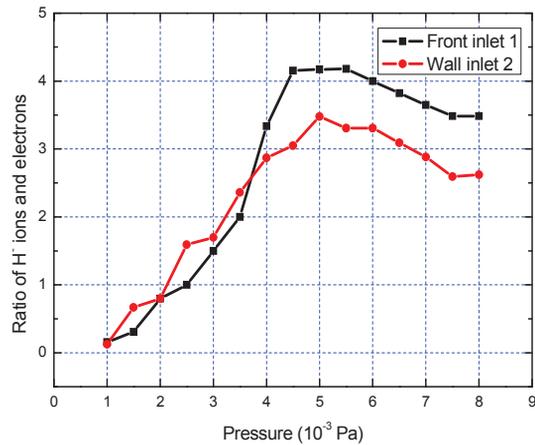


Figure 4: H⁺/e ratio vs pressure with different inlets.

decrease which is advantageous for H⁺ generation, but if the pressure is too high, H₂ molecular will hardly excited as T_e becomes too low. Moreover, it can be seen in Fig. 3, there is minute difference in the optimal pressure of highest H⁺ current with different inlets. Nonetheless, the H⁺/e ratio with front inlet is much better than using wall inlet with pressure varying from 4.0×10^{-3} Pa to 8.0×10^{-3} Pa (Fig. 4). The best H⁺/e ratio can be better than 4 with H⁺ current 27.4 mA at pressure 4.5×10^{-3} Pa. This will be very beneficial for the source operation and reducing the high voltage power load. This may be because, with front inlet 1, the pressure in the ion source can be much higher according to the simulation. Firstly, the electrons will have more opportunities to interact with other particles and be captured; then, as the electron temperature will be lower with higher pressure, low energy electrons can be deflected by e-dump filed much easier before extraction. These two reasons may lead to the decreasing of the number of electrons. Furthermore, the higher pressure operation with front inlet 1 improved the emittance as the T_e as well as co-electrons is decreased. With pressure 4.0×10^{-3} Pa, the emittance was reduced to $0.152 \pi \cdot \text{mm} \cdot \text{mrad}$ with front inlet comparing with $0.198 \pi \cdot \text{mm} \cdot \text{mrad}$ using wall inlet. After these improvements and investigation, the optimal results of our 2.45 GHz microwave-driven H⁺ ion source can be given in Table 1.

Table 1: Optimal Operation Parameters with PKU Cs-Free 2.45 GHz Microwave-Driven H⁺ Ion Source

Operation mode	Pulse	DC
Gas pressure (Pa)	4.0×10^{-3}	4.0×10^{-3}
RF Power (W)	1800	800
Duty factor	10%	100%
Extraction voltage (kV)	35	35
Current (mA)	35	16.5
Power efficiency (mA/kW)	19.4	20.6

The H⁺ current can reach 35 mA in pulsed mode with 10% duty factor, and 16.5 mA with DC operation. Its power efficiency goes up around 20 mA/kW for both cases.

CONCLUSION

A 2.45 GHz microwave-driven H⁺ ion source without using Cs was developed at PKU. As the gas distribution which influences T_e distribution is important for H⁺ generation, simulations and experiments were made after some improvements of the ion source. According to the results, using front inlet shows a lower H⁺/e ratio as about 4 than using wall inlet with pressure 4.5×10^{-3} Pa. This means a relative higher operation pressure is really advantageous for more H⁺ production. However, there is no significant difference between this two kinds of gas inlet methods. After these, the H⁺ current can reach 35 mA in pulsed mode and 16.5 mA with DC mode operation by adjusting operation parameters. Bias voltage experiment and more physical processes study will be carried out for future improvements.

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