THE FIRST INTENSE H⁻ BEAM GENERATED BY A MICROWAVE-DRIVEN PURE VOLUME SOURCE *

Haitao Ren[1], Shixiang Peng[1,#], Jie Zhao[1], Yuan XU[1], Jia Chen[1], Ailing Zhang[2], Tao Zhang[1], Yuting Luo[1], Zhiheng Wang[1], Zhiyu Guo[1] and Jia'er Chen[1,2]
[1]State Key Laboratory of Nuclear Physics and Technology, Institute of Heavy Ion Physics, Peking University, Beijing, 100871, China
[2]School of Physics, University of Chinese Academy of Sciences, Beijing 100049, China

Abstract

The 2.45 GHz Electron cyclotron resonance (ECR) plasma generators have demonstrated their efficiency and reproducibility on producing H^+, D^+, O^+, N^+, He^+, Ar^+ [1] and He^{2+} [2] at Peking University (PKU). Recently, modifications on magnet field configuration, discharge chamber structure and extraction system have been carried out to set-up a microwave-driven pure volume H^- ion source. The first experiment was performed on PKU ion source test bench. A 15 mA H^- ion beam has been produced at 40 keV by this prototype source. This paper describes the source principle and design in detail and reports on the current status of the development work.

INTRODUCTION

For the high beam power accelerator, like the large hadron collider, the isotope online separator and the proton synchrotron, an essential desire exits for a reliable and efficient H^- ion production. Surface plasma sources (SPS) with magnetron, Penning and surface converter geometries as well as volume sources are the facilities to provide H^- beams for accelerators [3,4]. Hot and cold cathodes, radio frequency (rf) and microwave are the means of igniting and maintaining magnetically confined plasmas. Those sources operated with hot or cold cathodes are successfully developed in many labs, such as J-PARC, TRIUMF, with current up to several tens milliampere. The limitation of them is the lifetime of their cathodes[3]. Labs like SNS, DESY, etc. use rf to ignite the plasma, the discharge power required to maintain the source plasma and the power efficiency of the beam of this kind of source is about 20kW, even higher [4].

The 2.45 GHz ECR ion sources have already demonstrated its powerful efficiency and reproducibility on producing high density beams for mono-charged high current accelerators. In 1989, Dr. M. M. Marinak, etc., built a H^- volume source driven by 2.45 GHz microwave which produced nearly 1 μA H^- beam [5]. Ten year later, scientists from ANL reported a 5 mA H^- produced by this kind principle source [6,7]. Same test was done at CEA/Saclay with the current of 3.5 mA [8]. Although beam intensity obtained with a microwave–driven source is much smaller than that from cathode or rf driven ones, study is still desirable be done to increase its negative ion beam generation ability because of its specific characteristic. Compared with cathode type, its hollow plasma chamber with no filament or antenna structure promises it does not have a lifetime limitation. Unlike the rf type sources that has a huge power consumption, the total power need by a permanent magnet ECR source is less than 1 kW. Other unique features like compact structure, high reliability, ability to operate in CW/ pulsed mode, good reproducibility and low maintenance, will make this kind of source popular to those high current H^- accelerators once its H^- production ability increased.

For several years, Peking University(PKU) ion source group has undertaken an important research and development program on very high current H^+, D^+, O^+, N^+, He^+, Ar^+ [1] and He^{2+} ion beam[2] with our compact permanent magnet 2.45 GHz electron cyclotron resonance (PMECR) plasma generators. And PKU PMECR source showed a good efficiency for high intensity beam production for several projects. At present, a new 2.45 GHz PMECR source based on pure volume H^- ion production is under development. This negative ion source is working in pulsed mode without cesium (Cs). A 15 mA H^- ion beam has been produced at 40 keV by this prototype source.

A description of the 2.45 GHz microwave-driven pure volume effect H^- source design is given in section II. In Section III, the first experimental results of this source are presented. Lesson we learned and consideration for next H^- source design come up at the end of this paper.

H⁻ SOURCE DESIGN

General Description

Theoretically, within a volume source H^- ion is produced in a two step processes. First is that hydrogen molecules H_2 impact with fast electrons and vibrated to excitation state H_2^*. Secondly, slow electrons interact with excited molecules H_2^* and dissociate the attachment. Those processes can be expressed as following.

$$e(fast) + H_2 \rightarrow H_2^* + e + h\upsilon . \qquad (1)$$

$$e(slow) + H_2^* \rightarrow H_2^- \rightarrow H + H^- \qquad (2)$$

Dominant H^- losses in a volume effect plasma chamber are happened by the electron impact detachment and the mutual neutralization. Therefore, electron heating and separation are practical important within a volume effect

*Work supported by NSFC No.s 11075008 & 11175009.
#Correspondence Author. Electronic mail: sxpeng@pku.edu.cn.

negative source. Besides, the methods of igniting plasmas and electron suppressing within the extracted current to increase H^- current ratio are also important issues for a volume H^- source design.

The principle displayed in Fig.1 is the 2.45 GHz microwave driven pure volume effect H^- ion source developed at PKU. This source is modified from our traditional PMECRIS. We kept the outside dimension with ϕ100 mm × 100 mm and its inner size with ϕ50 mm × 50 mm, but modified the magnet field configuration, discharge chamber structure and extraction system. It is a cesium free source. As one can see on Fig. 1, the most important parts of this microwave driven H^- ion source are microwave matching part, source body and beam extraction system.

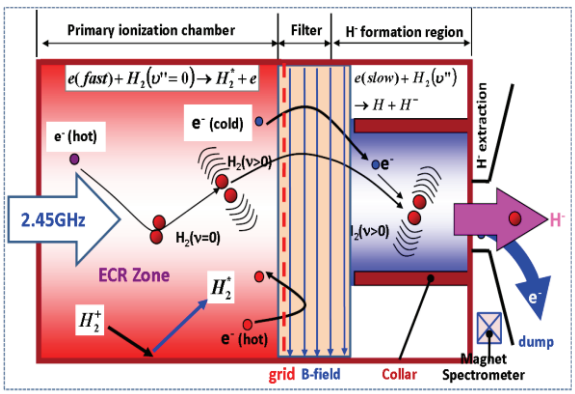

Figure 1: The principle of PKU microwave driven volume H^- ion source.

RF Matching

The 2.45 GHz microwave is used to heat the electrons. Like other sources built at PKU [1], a set of microwave window is used to couple the microwave between the standard rectangle wave guide (JB26) and the cylinder plasma chamber.

Separated Plasma Chamber

The part between the microwave window and the beam extraction aperture is so-called as source body. It is physically separated into three sections with different function in each section, as shown in Fig. 1. The first section is the primary ionization chamber (ECR zone) where high temperature electrons heated by microwave interact with molecules and generate excited H_2^*. The second part is a filter region for electron separation and rf transmission block. The third section is the H^- formation region where H^- is generated.

Within ECR zone the axis magnetic field created by several permanent magnet rings is used to provide the magnet field for ECR. Both excited molecular H_2^* and molecular ion H_2^+ are produced by the interaction of H_2 with energetic electrons heated by microwave. When the molecular ions H_2^+ hit the wall of discharge chamber, it will change into vibrated H_2^*. Experimental results indicate that the magnetic configuration at the surface of microwave window on the axis should not be higher than 875 G. Otherwise, discharge will become difficult.

A transversal magnet field for electron temperature separation and an rf blocking are installed within the filter area. The electron separation magnetic field is generated with a dipole magnet that situates outside the vacuum chamber. The magnetic strength is about 100 Gs. This filter has a high diffusion constant ($D_{e\text{-}slow}$) for slow electrons and a low one ($D_{e\text{-}fast}$) for energetic. In this way, enough slow electrons can penetrate into the third section for H^- ion formation. The function of the tungsten grid (~1 mm wire diameter, 5 mm gap) that installed inside the plasma chamber is used to prevent the microwave penetrating into the negative ion production area in order to limit the electrons within the extraction plasma region absorb energy from microwave. The grid is hold by a cylinder liner. The system of grid and plasma electrode is kept at the same potential. The grid position has been changed in order to optimize the H^- ion production. In the following experimental report, the grid is positioned at 25 mm from the plasma electrode.

In H^- formation region, a stainless steel cylinder is installed as a collar. As mentioned in reference [4,9], collar system has many unique abilities that benefit the H^- ion generation. For example, it has the ability to reduce of electron density at its entrance that will lower the e^- fraction within the extraction beam. And because of less electrons penetrating into this area, H^+ ion generation will be lower. Collar system also has the ability to reduce H^- destruction and increase the vibration excited H_2^* production in the low temperature zone. And the diffusion efficiency of H^- will be increased and the collar forms an easy to extract negative charge in the final part. Besides, an extraction field which penetrates deep into this area improves the operation. Tantalum collar will be used for next source body design.

Electron Dumping

In our design, the electrons are dumped in the gap between the plasma aperture and the extractor. A dipole magnet embedded in plasma electrode is used for $e-$ bending. The advantage of this design is that the electrons do not have full energy before they are absorbed.

There is no actual section to collect the dumping electrons in our design. Part of bending electrons are deposited on the ceramic column, part are stopped on the second electrode. At present all electrons are not cooled.

During our experiment we found that, with or without this magnet spectrometer the e^-/H^- ratio changes from 6 to 15.

ION SOURCE PERFORMANCE

The 2.45 GHz microwave driven pure volume effect H^- ion source prototype test was done on PKU ion source test bench. The structure of this test bench is reported at ref.10. On this test bench, the high voltage platform can be biased to either positive or negative voltage. The maximum extraction voltage is ± 60 kV. A Faraday cup

ISBN 978-3-95450-122-9

equipped with a secondary electron suppressor allows magnetically analyzed beamlet measurements. The electron and negative ion beam separator was removed and a tunable 90° dipole analyzer magnet (DAM) and collected by another faraday day that locates the end of the test bench. With these conditions either positive or negative ion beams were analyzed.

To calibrate the analyzer, positive H^+ ion measurements were made. The ion source was biased to 40 kV while operating with hydrogen. Limited by microwave generator, all measurements were done in pulse mode. A total positive beam of 80 mA has been produced with the following species fraction: H^+ 80%, H_2^+ 18%, and H_3^+ 2%. The H^+ peak reaches a maximum level when the DAM current is set to 13.4 A.

By reversing the DAM current and setting the plasma chamber bias to – 40 kV, a peak rose at the same DAM current, indicating H^- ion extraction. Picture in Figure 2 displays H^- current recorded by a digital oscilloscope when the pressure inside the diagnostic chamber was 4.6E-3 Pa and rf power from the microwave generator was 180 W. The maximum H^- beam obtained during our test is about 15 mA. At steady state an equivalent H^- beam intensity is easy to repeat under the same operation condition.

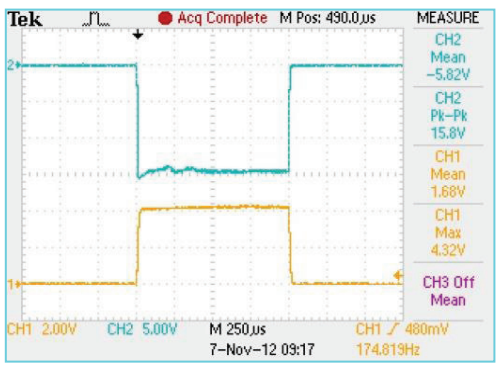

Figure 2: H^- current displayed on a digital oscilloscope. Yellow line is the reference signal from rf generator and the blue one is H^- current.

After several days' operation, sparks occurred inside the acceleration column and source operation condition became worse with time went on. We stopped our experiment and disassembled the ion source body and its extraction system. We found that the stainless-steel electrode used as e^- dump is melt. Figure 3 shows a photograph of the electrode. This is caused of electrons dumping on it. From this point of view, next design of the extraction electrode will be changed. We plan to use tantalum at the cone of this electrode and cool it with water.

CONCLUSIONS AND PROSPECTS

Our microwave driven volume effect ion source prototype has given evidence of the H^- beam production ability on the scale of tens of milliampere. Therefore a decision has been made to copy and upgrade the source which already operated near the required parameters.

To improve H^- production with a 2.45 GHz ECR ion source, we are in the process of designing a new generation ion source. The mechanical structure, the magnet field configuration and distribution, the grid location and its structure, the collar structure and its material, the electron dump material and its cooling method, as well as other parameters will be careful redesigned. More results from that design will be reported in a future paper.

Figure 3: A photograph of the melt electrode heated by the dumping electrons.

REFERENCES

[1] H. T. Ren, S. X. Peng, P. N. Lu, etc., Intense beams from gases generated by a permanent magnet ECR ion source at PKU. Rev. Sci. Instrum. 83, 02B905 (2012).

[2] H. T. Ren, S. X. Peng, Y. Xu, etc., Milliampere He2+ beam generation with PKU compact 2.45 GHz ECR ion source (PMECRIS). Submitted to SCIENCE CHINA Physics, Mechanics & Astronomy, April 2013.

[3] D. P. Moehs, J. Peters and J. Sherman, Negative Hydrogen Ion Sources for Accelerators(invited), IEEE TRANSACTIONS ON PLASMA SCIENCE, 33(6): 1786-1798(2005).

[4] J. Peters, New developments in multicusp H– ion sources for high energy Accelerators(invited), Rev. Sci. Instrum. 79, 02A515(2008).

[5] M. M. Marinak and E. C. Morse, A tandem microwave driven negative ion source: Experimental results, Rev. Sci. Instrum. 61, 508 (1990).

[6] D. Spence, K. R. Lykke and G. E. McMichael, Plasma Modified Production of High-current, High-purity cw H+, D+, and H- Beams from Microwave-driven Sources. LINAC96:71-73.

[7] D. Spence, K. R. Lykke, Production of Negative Hydrogen and Deuterium Ions in Microwave-driven Ion Sources, LINAC98-TU4048.

[8] R. Gobin, O. Delferriere, R. Ferdinand, etc., Development of an H– ion source based on the electron cyclotron resonance plasma generator at CEA/Saclay. Rev. Sci. Instrum. 75, 1741 (2004).

[9] Robert F. Welton, Introduction to Negative Ion Sources (Tutorial), ICIS 2007, Jeju, Korea, Aug 26, 2007.

[10] Y. Xu, S.X. Peng, H.T. Ren, Preliminary results of H2+ beam generated by a 2.45 GHz permanent magnet ECR ion source at PKU. MOPFI035, these proceedings.