

PRELIMINARY RESULTS OF H_2^+ BEAM GENERATED BY A 2.45 GHZ PERMANENT MAGNET ECR ION SOURCE AT PKU*

Yuan Xu, Shixiang Peng[#], Haitao Ren, Jie Zhao, Jia Chen, Tao Zhang, Ziheng Wang, Yuting Luo, Zhiyu Guo and Jiaer Chen, SKLNPT & IHIP, School of Physics, Peking University, Beijing 100871, China
Ailin Zhang, School of Physics, UCAS, Beijing 100049, China

Abstract

To obtain high-yield H_2^+ ion beam, experimental and theoretical study was carried out on the 2.45 GHz Peking University permanent magnet electron cyclotron resonance ion source (PKU PMECRIS). With PMECR II [1], studies on the size of discharge chamber and the operation pressure were carried out to increase H_2^+ ion fraction. Beam analysis results prove that the H_2^+ can reach 47.7% with suitable operation parameters. More details will be presented in this paper.

INTRODUCTION

The creation of molecular ion H_2^+ is an essential process in hydrogen gas plasma. For proton ion source, H_2^+ ions are undesirable in the final extract beam. But recently, the demand to build an ion source to generate high current hydrogen molecular ion H_2^+ beam has been growing rapidly. For example, H_2^+ ion can be used as a pilot beam of the intense deuteron beam during the commissioning of linear accelerators to minimize the activation of components.[2][3] Also it is an effective way to improve the output current of cyclotrons by accelerating H_2^+ and stripping it into H^+ at the exit of accelerator, instead of accelerating H^+ beam directly.[4][5] R. F. King *et al.* proposed a one-dimensional plasma model for a volume arc source, which is expected to produce 140 mA of ion beam with H_2^+ species ratio around 73% in theory, but it wasn't realized.[6] N. Joshi *et al.* developed a volume type ion source at Frankfurt University, and about 91% H_2^+ was extracted with current intensity of 2.84 mA.[7] Obviously, the fraction of H_2^+ is definitely high, but the current is not enough for some applications.

With a 2.45 GHz permanent magnet ECR ion source PMECR II [1][8][9] (Fig. 1), the fraction and current intensity of molecular ion H_2^+ were improved at PKU. Theoretical study indicates that, to optimize the production of H_2^+ , it is helpful to increase the electron temperature in the source and avoid attachment with neutral H_2 which lead to fast destruction of H_2^+ . [6] In our PMECRIS, these were achieved by changing the size of discharge chamber and operation pressure in the source. The experimental results will be presented.

EXPERIMENT SETUP

The test bench (Fig. 2) consists of a microwave system, an ECR ion source, a Faraday cup (FC1) to measure the

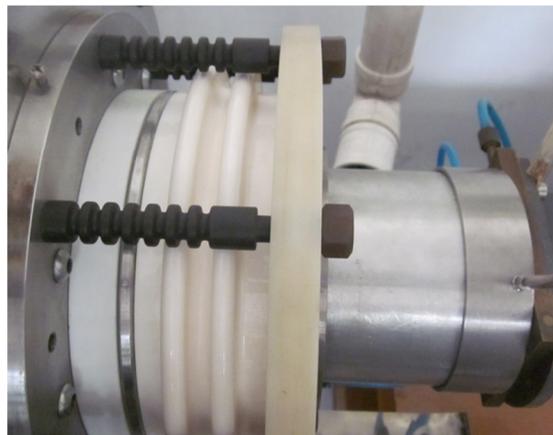


Figure 1: Photograph of PMECR II.

total current and an emittance measurement device(EMU).

The vacuum is kept by a turbomolecular pump, and the ion fraction is measured with a 90° deflection magnet with another Faraday cup (FC2) behind by using the similar method before.[10] Consequently, the intensity of each ion beam is the product of the total current and the corresponding fraction.

The outline diameter of our ion source is 11.5 cm with a maximum $\Phi 64$ mm discharge chamber, and its length is about 11 cm. Through a three-layer dielectric window and a protective disk, microwave is fed into the source and coupled with plasma. Magnetic field is generated by several NdFeB permanent magnet rings, which provide a wide electron cyclotron resonance zone. With this source, a peak current of 100 mA pulsed proton beam can be easily obtained through a $\Phi 6$ mm hole with three-electrode extraction system at 50 kV.

EXPERIMENTAL RESULTS

In order to investigate the production and destruction mechanisms of H_2^+ , discharge chamber's diameter was set at 30, 35, 40, 45 and 64 mm respectively by putting different liners in the source. The pressure of the chamber was 1.1×10^{-3} Pa, and the beam was extracted at voltage of 50 kV with about 200 W pulsed rf power feeding in the chamber. Extracted beam analyses were performed versus the chamber diameter while other operation parameters kept constant (Fig. 3). It shows that the current of H_2^+ increased from 8.3 mA to 21.9 mA as the diameter decreased from 64 to 30 mm.

*Work supported by NSFC NO. 11175009 and 11075008.
#sxpeng@pku.edu.cn

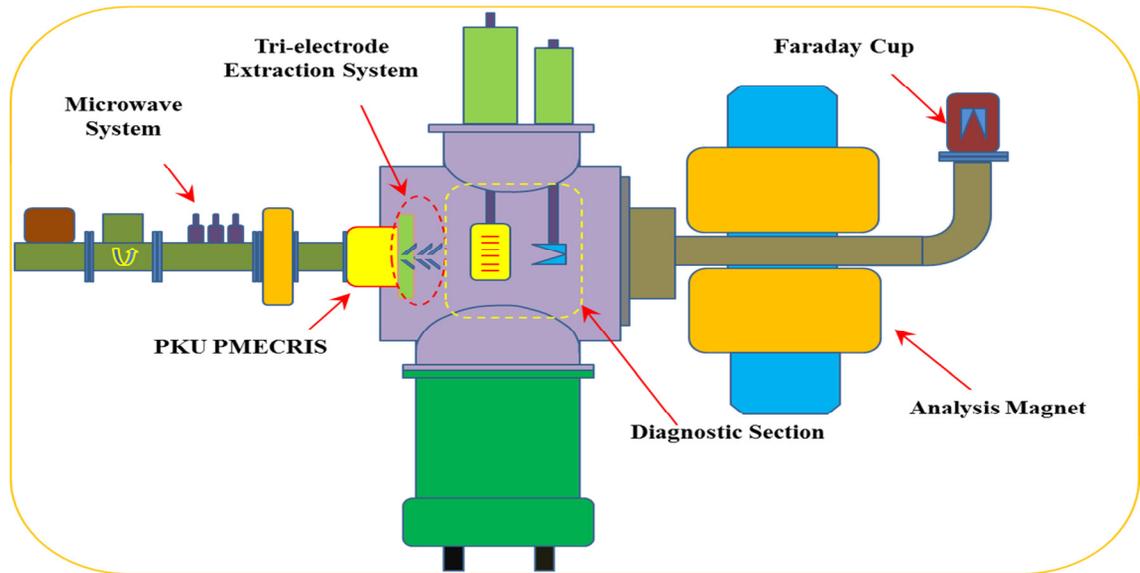


Figure 2: Schematic diagram of the short beam line.

Moreover, a H_2^+ species fraction of 40.5% was obtained at diameter 64 mm. The possible reason is that a large chamber means low gas density under the same gas flow rate, which leads to decreasing of dissociative attachments with neutral molecules.[6] But due to a low total current, the current of H_2^+ is only 8.3 mA at $\Phi 64$ mm. The profiles of H^+ , H_2^+ and H_3^+ in a pulse were also measured by a digital oscilloscope (Fig. 4). When the chamber is small, there may be not enough energy to further ionize H_2^+ ion due to the plasma chamber is not couple well with the microwave. Therefore, the fraction of H_2^+ ion is also comparatively high with smaller diameter.

Because of the high species ratio of H_2^+ ion at $\Phi 64$ mm, more experiments were performed by changing the pressure at this condition. The H_2^+ fraction increased as the discharge pressure decreased from 2.0×10^{-3} Pa to 3×10^{-4} Pa (Fig. 5). An 85 mA total beam with 47.7% H_2^+ fraction was already extracted at 45 kV with pressure

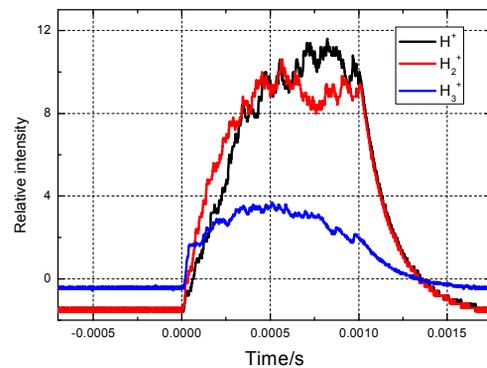


Figure 4: Profiles of H^+ , H_2^+ and H_3^+ beam pulse.

4×10^{-4} Pa, and the intensity of H_2^+ was more than 40 mA. H_2^+ and other ions were also detected by changing the current of analysis magnet (Fig. 6). It can be noticed that H_2^+ ion already has a comparable peak with H^+ . As the

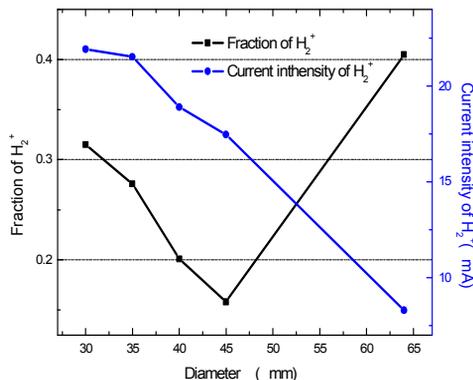


Figure 3: H_2^+ fraction and current intensity vs diameter of discharge chamber.

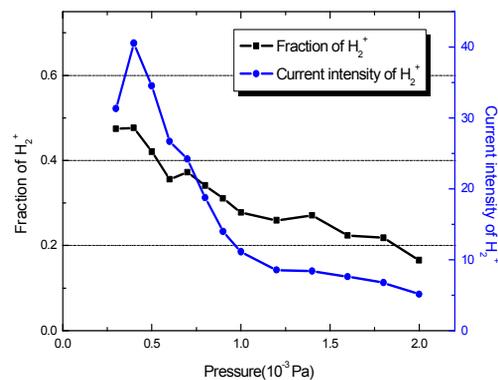


Figure 5: H_2^+ fraction and current intensity vs discharge pressure ($\Phi 64$ mm)

pressure was too low for discharge at 3×10^{-4} Pa, both the total and H_2^+ current dropped down.

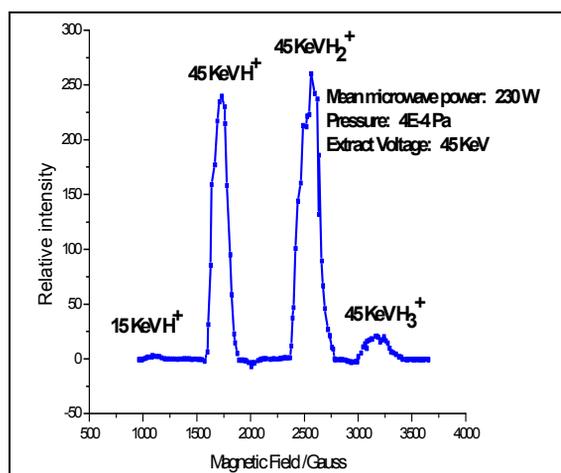


Figure 6: Mass spectra of hydrogen beam (Total current: 85 mA, H^+ :48.5%, H_2^+ :47.7%, H_3^+ : 3.8%).

Furthermore, when we decreased the rf power feeding into the source and increased the pressure, a high fraction H_3^+ beam was achieved. And more than 15 mA H_3^+ beam was extracted with corresponding fraction of 54.8% in our preliminary experimental study (Fig. 7). More research will be done on H_3^+ beam in the near future.

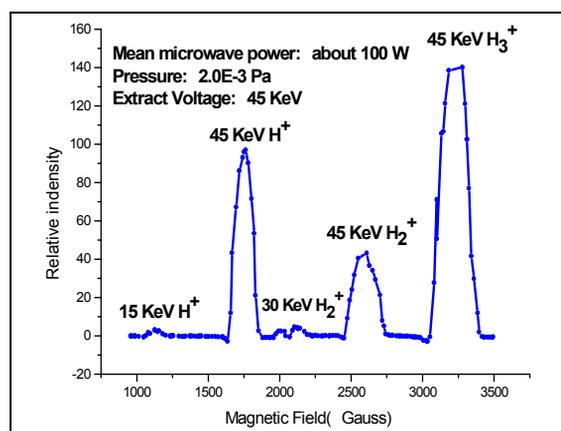


Figure 7: Mass spectra of hydrogen beam (Total current: 28 mA, H^+ :30.7%, H_2^+ :14.5%, H_3^+ : 54.8%).

CONCLUSION

Experimental study was carried out on PKU PMECRIS anticipating H_2^+ ions, and more than 40 mA H_2^+ ion beam was extracted with a $\Phi 6$ mm extraction hole. Beam analysis results look promising to produce high current H_2^+ ions as well as H_3^+ . As a whole, the production of H_2^+ ion strongly depends on operation pressure, and dissociative attachment process need be reduced. More study concerning the production of molecular ions is in progress, and more results will come up with future improvements.

ACKNOWLEDGMENTS

This work is supported by the National Science Foundation of China (Grant Nos. 11175009 and 11075008).

REFERENCES

- [1] Zhizhong Song, Shixiang Peng, Jinxiang Yu, Jianchuan Ming, Zhongxi Yuan *et al.*, Rev. Sci. Instrum. **77**, 03A305 (2006)
- [2] R. Gobin, P.-Y. Beauvais, O. Delferrière, D. De Menezes, O. Tuske, G. Adroit, Y. Gauthier, and F. Harrault, Rev. Sci. Instrum. **79**, 02B303 (2008).
- [3] Zhiyu Guo, Yubin Zou, Yuanrong Lu, Xueqing Yan, Shixiang Peng, Kun Zhu, Guoyou Tang, Dawei Mo, and Jiaer Chen, Physics Procedia. **26**, (2012) 70 – 78.
- [4] D. Campo, A. Calanna L. Calabretta, D. Rifuggiato, M. Maggiore and L. A. C. Piazza, Proceedings of IPAC2011, San Sebastián, Spain WEPS073.
- [5] L. Calabretta, M. Maggiore L. A. C. Piazza, D. Rifuggiato and A. Calanna, A multi megawatt cyclotron complex to search for CP violation in the neutrino sector, <http://arxiv.org/ftp/arxiv/papers/1010/1010.1493.pdf>.
- [6] R. F. King, E. Surrey, and A. J. T. Holmes, Fusion Eng. Des. **83**, 1553 (2008).
- [7] N. Joshi M. Droba, O. Meusel and U. Ratzinger, Physics Research A, **606** (2009) 310–313
- [8] H. T. Ren, S. X. Peng, M. Zhang, Q. F. Zhou, Z. Z. Song, Z. X. Yuan, P. N. Lu, R. Xu, J. Zhao, J. X. Yu, Y. R. Lu, Z. Y. Guo, and J. E. Chen, Rev. Sci. Instrum. **81**, 02B714 (2010).
- [9] S. X. Peng Z. Z. Song, J. X. Yu, H. T. Ren, M. Zhang, Z. X. Yuan, P. N. Lu, J. Zhao, J. E. Chen, Z. Y. Guo and Y. R. Lu, Proceedings of ECRIS2010, Grenoble, France.
- [10] R. Xu, J. Zhao S. X. Peng, Z. X. Yuan, Z. Z. Song *et al.*, Rev. Sci. Instrum. **79**, 02B713 (2008).