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Progress in the Development of a High Current H^- Ion Source for Cyclotron
サイクロトロン用高電流H^-イオン源の開発状況

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A multi-cusp DC H^- ion source has been developed for cyclotrons. In the Cs-free operation, 15 mA of H^- was obtained by increasing the magnetic filter field. To get more understanding of the relationship between H^- production and magnetic field configuration, a numerical analysis of electron energy distribution function (EEDF) has been studied. As the first results of the analysis, decreasing EEDF was observed at magnetic filter field region. And a new ion source has been designed to produce an H^- of 20 mA. The design of this source is changed to improve the source performance especially in the Cs-seeded operation.

1. Introduction

A multi-cusp DC H^- ion source for medical cyclotron has been developed. In the Cs-free operation, H^- beam of 10 mA was obtained stably at an arc power of 3 kW. By increasing the magnetic filter field strength, the saturation of the H^- current at a high arc power was improved and the maximum peak current reached 15 mA at an arc power of 6.6 kW. In the Cs-seeded operation, H^- current reached 16 mA at a lower arc power of 2.8 kW, a low extracted electron current and a low gas flow rate [1]. To get more understanding the relationship between H^- production and magnetic field configuration, a numerical analysis of electron energy distribution function (EEDF) has been studied [2]. Further improvement to enhance the beam current is in progress, a new source has been designed to achieve the next goal of producing an H^- 20 mA. In this paper, the first results of the numerical analysis on the existing source and the concepts for the design of the new ion source are presented.

2. Numerical Simulation on Existing Source

2.1 *Ion Source Structure*

The source consists of a cylindrical plasma chamber, multi-cusp permanent magnets and an extraction system constructed by a plasma electrode (PE), an extraction electrode (EE) and a grounded electrode (GE). Dipole magnets are located near the extraction region of the plasma chamber to produce magnetic filter field which prevents high temperature electrons from entering into the H^- production region. The EE has a pair of dipole magnets which remove electrons from H^- beam trajectory. The internal diameter and length of the plasma chamber are 100 mm and 150 mm respectively. The diameter of the PE’s aperture is 13 mm. There are two arch shape tungsten filaments to generate plasma by arc discharge. The more details of the source are shown in the previous report [1].

2.1 *EEDF Analysis*

In Cs-free operation, H^- ions are mainly produced by volume production via dissociative attachment process between vibrationally excited hydrogen molecules and low temperature electrons [3]. Magnetic filter field has a role to keep electron temperature as low as few electron volts in H^- production region [4]. The understanding of the relationship between H^- production and magnetic field strength is important to optimize magnetic field arrangements, so a numerical analysis on this problem has been studied.

In order to calculate the EEDF, numerical simulation code, “KEIO-MARC” [5] has been applied. In the KEIO-MARC code, equations of motion for electrons are solved by the leap-frog method [6]. Coulomb collision process between electrons is modeled by “binary-collision” [7] and collision between electrons and hydrogen species are treated “null-collision” method [8]. In the simulation, the model of the ion source is based on the real source dimension and the magnets configuration. Figure 1 shows the results of EEDF at an arc power of 2240 kW. It is observed that the number of high energy electrons is reduced by magnetic filter field in the extraction region. This result gives qualitative agreement with the realistic source characteristic. The calculations for different magnetic filter field strengths are underway to study the EEDF dependence of the magnetic field.

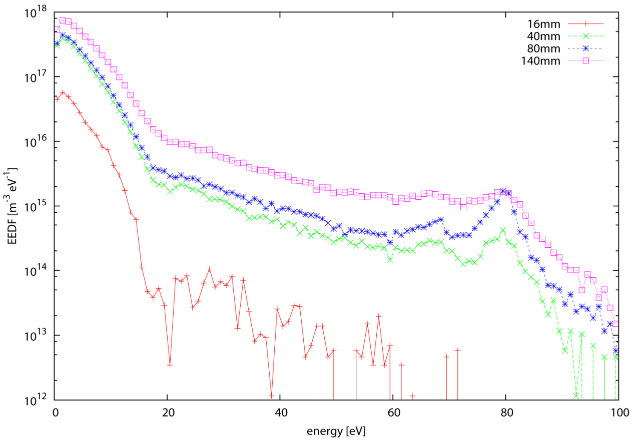
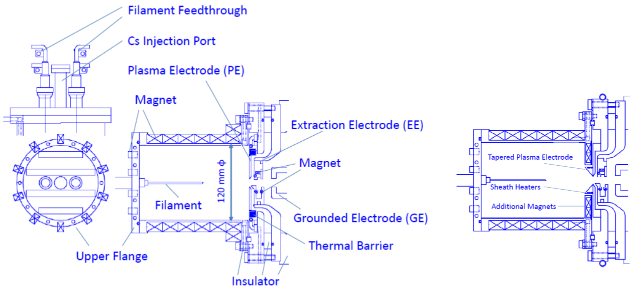


Fig.1. EEDF at each distance from PE.

3. Development of the New Source

A schematic diagram of the new source is shown in Figure 2(a). The source design is based on the existing source. The internal diameter and length of the plasma chamber are 120 mm and 170 mm respectively. Filter magnets located near the PE and can be easily expanded to optimized field strength. Two hairpin tungsten filaments are set to an upper flange via vacuum feedthroughs so as to be easily replaced. Cs injection port is located at the center of the upper flange. These configurations of the source have a better maintainability for practical use.

The PE’s aperture is 14 mm in diameter to increase the extracted H^- ion beam current. Since temperature control of the PE surface is important to increase an H^- production rate on the PE surface in Cs-seeded operation [9], the PE consists of an inner part as a flat plate made of molybdenum and an outer part as thermal barrier to keep its temperature as high as about 250 degrees Celsius by heat input from the plasma. In addition, a tapered-shape PE with sheath heaters has been also prepared to keep actively the PE’s temperature and study the effect of the difference in the PE shape. Additional magnets are arranged radially near the tapered-shape PE to enhance plasma confinement and the filter field strength. Figure 2(b) shows the configuration of the source with the tapered-shape PE and the additional magnets.



(a) (b)

Fig.2. (a) Schematic diagram of new H^- source.
(b) Source configuration with tapered-shape PE and additional magnets.

4. Conclusion

The relationship between H^- production and magnetic field configuration has been studied by the numerical simulation. The first results of simulation of EEDF showed the effect of magnetic filter field on the electrons.

A new 20 mA H^- source has been designed. Two types of PE have been designed to be able to control the temperature of their surface and study the effect of the difference in the PE shape. The design has also a better maintainability. These configurations will be tested and optimized near future.

Acknowledgments

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