

CRITICAL ANALYSIS OF NEGATIVE HYDROGEN ION SOURCES FOR CYCLOTRONS

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Abstract

The negative hydrogen ion sources found applications as injectors for cyclotrons. The efficiency for internal and external ion sources is one important question for industrial cyclotrons, which are used for production of medical isotopes. The short critical analysis of PIG and MULTICUSP ions sources for production of negative hydrogen ions is given in this paper.

INTRODUCTION

The industrial cyclotrons for production of medical isotopes found large number of applications [1]. The Positron Emission Tomography requires radioactive markers, which are produced using irradiation of target by proton beam from cyclotron [2]. The industrial cyclotrons use negative hydrogen ions with following converting to protons before input of beam to target [3]. The ion source is important device of cyclotrons, which determines physical parameters of beam for injection to accelerating and magnetic fields.

The history of R&D for ion sources is long. The ion source consists from plasma emitter with required ions and extraction electrode system. The general structure of negative hydrogen ions source is given on Fig. 1. The more detail structure of negative hydrogen ion source is presented on the Fig. 2. The generation of hydrogen negative ions in plasma emitter is complex task. The selection of type of electrical discharge determines by applications of ion source. The focus of this paper is negative hydrogen ion source for industrial cyclotrons.

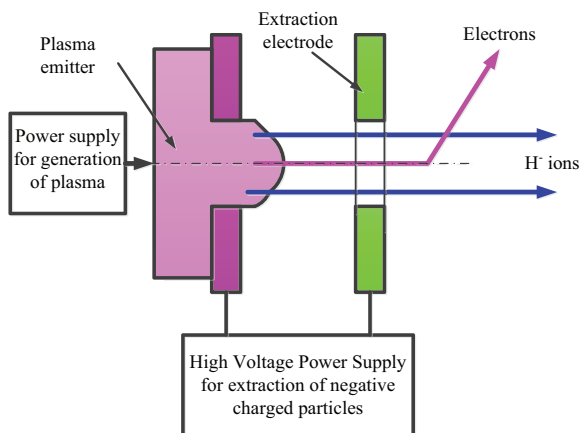


Figure 1: The general structure of H⁻ ion source.

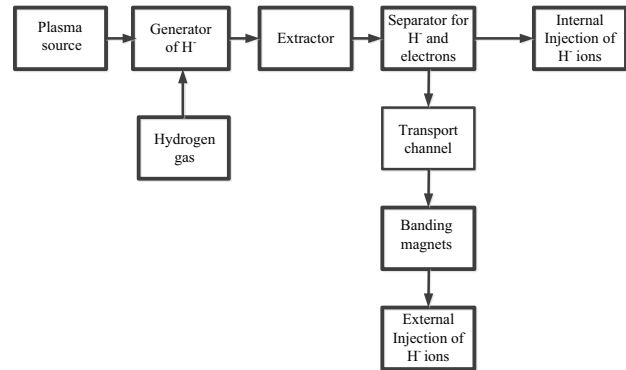


Figure 2: The structure of H⁻ ion source.

PHYSICAL MECHANISMS FOR GENERATION OF H⁻ IONS

The main question for negative hydrogen ion source is acceptable and effective method for production of these ions. The adding of second electron on the orbit of hydrogen atoms leads to forming negative hydrogen ions. The logical solution for production of hydrogen negative ions is plasma chemical reactions in plasma with hydrogen gas [4]. The methods for forming of gaseous plasma with negative ions are very broadly and known [5]. The plasma chemistry for generation of hydrogen negative ions is complicated [6]. The physical processes in plasma emitter of ion source are following: i) the forming of gaseous plasma and ii) the generation of negative hydrogen ions using plasma chemical reactions. The forming of gaseous plasma is simple task and presents the standard solution based on glow electrical discharge. The second task is complex and has different solutions, based on the plasma chemical reactions for production of negative hydrogen ions. The basic principle of production negative hydrogen ions is combination of ionization and dissociation processes.

The common basic mechanism for production of negative hydrogen ions is following:

1. The forming of excited positive charged hydrogen molecule by electron impact:



2. The capture of low energy electron by



3. The dissociation of these excited hydrogen molecules on the negative hydrogen ions:



The input of vapor material such as Cs (material with low work function) leads to surface ionization and dissociation:



This approach allows increasing the extraction negative hydrogen ion beam current. The using of Cs is limited for some ion sources in cyclotrons, especially for internal ions source. Analysis of this mechanism shows that these physical processes present the combination of volume and surface ionizations with dissociation are complicated. The using of Cs is not acceptable for some ion sources.

However, in spite on using and understanding of basic mechanism for forming of hydrogen negative ions, the other physical mechanisms are acceptable for negative hydrogen ion sources and are interesting. The two potential physical mechanisms and processes are given bellow for example. The first mechanism is dissociative attachment of electrons to hydrogen molecules can be considered by [7]:



The cross sections for dissociative electron attachment to molecules of H₂ are given on the Fig. 3 for example from [7]. The second mechanism is the creation of negative hydrogen ions at during of dissociative recombination of electrons with molecular hydrogen by [8]:

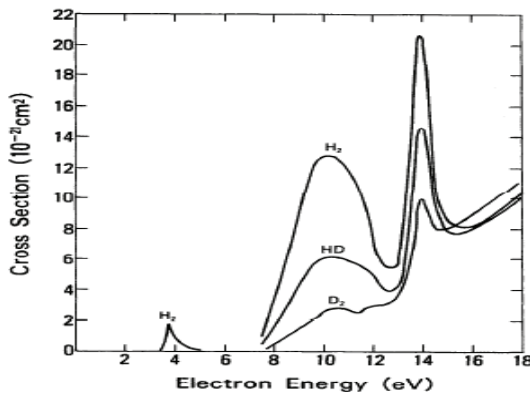


Figure 3: The cross section of dissociative electron attachment to molecules of H₂.

These mechanisms have range for energy of plasma electrons from 3 to 20 eV. Analysis of these examples shows, that using of these physical processes is complicated. The main reason of it is absent of simple method for control and regulation of kinetic energy for plasma electrons.

The main conclusions regarding physical mechanism for generation of negative ions are following:

- a) the process of generation of negative hydrogen ions is not fully controlled;

- b) the method for regulation and control of kinetic energy for plasma electrons is the task for research.

INTERNAL ION SOURCE

The ion source of negative hydrogen ions based PIG (Penning Ion Gauge) is a main type of internal ion source for cyclotron. The general structure of PIG H⁻ ion source is given on Fig. 4.

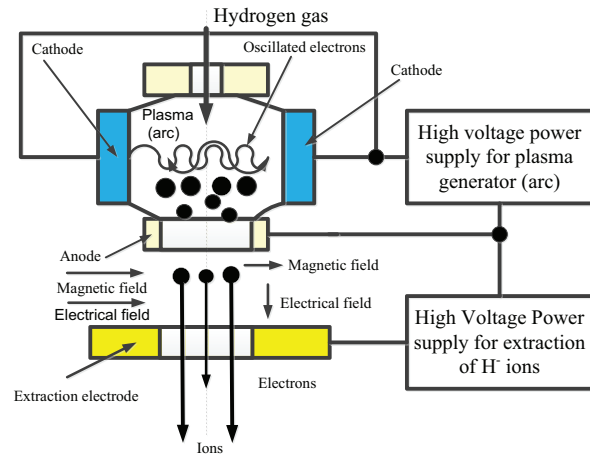


Figure 4: The PIG negative hydrogen ion source.

This ion source uses cold cathodes (cathode and anti-cathode), that leads to arc low power. The main advantages of PIG ion source are following: i) the effective ionization and plasma chemical reactions for production of negative hydrogen ions in parallel electrical and magnetic fields and ii) the simple separation of electrons and negative ions at during of extraction for ion and electron beams in perpendicular magnetic field to extraction electrical field. Analysis of this type of ion source shows, that instability of plasma gives high noise in the extraction beam current.

The evaporation of cathode material as a result of bombardment by positive ions leads to change of surface morphology for cathodes and electrical field. The change of electrical field is critical for field emission. The life time of cathodes decreases as a result of these physical processes. The flow rate molecular hydrogen gas leads to increasing of local pressure in the area between cathodes. The conditions for forming of electrical discharge determines by Paschen Law. The following processes for generation of hydrogen negative ions link with non-stability of glow discharge in the extraction beams area. The serious problems for using of PIG ion source in cyclotrons are stability of current and emittance of beam. These two parameters give limitation for production of high quality beam for injection to accelerator.

EXTERNAL ION SOURCE

The external ion source based on MULTICUSP allows solving problems if internal ion source and forms the high current ion beams with high quality for next generation of industrial cyclotrons. The general structure MULTICUSP ion source is given on Fig. 5.

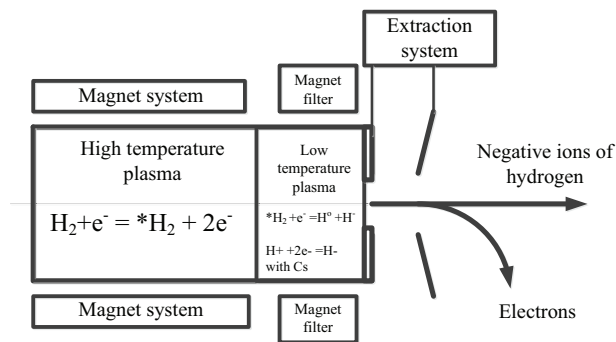


Figure 5: The structure of MULTICUSP ion source.

The MULTICUSP ion source has three innovations:

1. Two areas of plasma emitter with high and low temperature plasma, that allows to reduce emittance of beam.
2. Magnetic filter.
3. Cs for increasing of beam current.

As a result of these main innovations the beam current was increased and emittance was decreased. The high quality hydrogen ion beam was acceptable for new generation of industrial cyclotrons. The different types of MULTICUSP ion source have different methods for forming of plasma emitter with extraction of negative hydrogen ions and separation of electrons and ions.

The critical analysis of the ion source shows, that this type of external ion source is complicated and expensive in compared with PIG. The vacuum chamber with magnetic field systems has large dimensions in compared with PIG ion source that is limit for using as an internal ion source for cyclotron. The forming of high temperature plasma in plasma emitter requires of high power from power supply. It leads to limitation of lifetime for this type of ions source. The new approaches using RF, pulsed discharges present interesting and promising ways. The design of magnetic filter also is complicated task, especially for using of permanent magnets. The permanent magnets have limit on working temperature that leads to cooling system. The forming of high quality of ion beam requires few electrodes for plasma and extraction systems, that leads to additional high voltage power supply sources. The progress in R&D of this type ion source belongs to research Laboratories in spite on the large number of applications for industrial cyclotrons.

CONCLUSION

Analysis of ion sources for industrial cyclotrons shows the complex task. In spite on the high efficiency of external ion sources, these ion sources continuous to be complicated in compare with internal ion source. Critical short analysis shows, that both types of ion sources can be used in the industrial cyclotrons. The focus of negative hydrogen ion sources addresses to the quality for beam, parameters and applications of cyclotrons. The production of medical isotopes is one from many directions for applications of industrial cyclotrons at present and interest to ion source is understanding and important.

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