HIGHLY POLARIZED ION SOURCE FOR ELECTRON ION COLLIDERS (EIC)

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Abstract

The operation of the RHIC facility at BNL and the Electron Ion Colliders (EIC) under development at Jefferson Laboratory and BNL need high brightness ion beams with the highest polarization. Charge exchange injection into a storage ring or synchrotron and Siberian snakes have the potential to handle the needed polarized beam currents, but first the ion sources must create beams with the highest possible polarization to maximize collider productivity, which is proportional to a high power of the polarization.

It is proposed to develop one universal H^-/D^- ion source design which will synthesize the most advanced developments in the field of polarized ion sources to provide high current, high brightness, ion beams with greater than 90% polarization, good lifetime, high reliability, and good power efficiency. The new source will be an advanced version of an atomic beam polarized ion source (ABPIS) with resonant charge exchange ionization by negative ions, which are generated by plasma interactions with a cesiated surface.

An integrated ABPIS a three-dimensional (3D) computer-aided design model will be prepared based on new materials and an optimized magnetic focusing system. Polarized atomic and ion beam formation, extraction, and transport for the new source will be computer simulated and will be used as a base for the production of a prototype that will be assembled and tested in Phase II.

INTRODUCTION

From a technical point view, although the newly developed technique of stripping charge exchange injection into a storage ring or synchrotron with Siberian snakes offers the potential to provide polarized ion beams with needed currents, the real bottleneck is the development of ion sources which must achieve very high polarization to ensure success. The present proposal is focused on R&D for such an ion source. It is our goal to develop high quality polarized sources to satisfy the worldwide needs of present and future accelerator facilities.

The beam parameters necessary to achieve the design luminosity of the Electron-Ion Collider at JLab are shown in Ref. [1]. The special design of the accelerators and storage rings in this project should provide very good polarization preservation. This means that the final accelerated beam polarization will be determined by the beam polarization extracted from the ion source, which must be as high as possible.

The evolution of polarized ion sources has been presented recently by W. Heberly [2].

Most advanced versions of polarized H^- sources are:

1) Atomic Beam Polarized Ion Source (ABPIS) with polarized atom ionization by resonant charge exchange with negative ions was developed and presented by A. Belov [3];
2) Optically-Pumped Polarized H^- Source (OPPIS) with Rubidium and Sodium targets were developed and presented by A. Zelenski [4].

The BNL OPPIS used for RHIC experiments can inject into the RFQ up to 1.6 mA of H^- with polarization up to P=0.86 in pulses of 0.5 ms [4]. In this ion source, fast protons (2.5-3.5 keV) from an electron cyclotron resonance (ECR) source pick up polarized electrons from optically pumped Rb vapor, pass through a Sona transition region, and pick up a second (unpolarized) electron from Na vapour to create a beam of nuclear-polarized H^- ions. To prevent depolarization in the charge exchange collisions, the optically pumped cell is located inside a strong (25-30 kG) superconducting solenoid.

The efficiency of experiments is proportional to P^2, so high polarization is very important. It has been proposed to upgrade the BNL OPPIS by introducing an optimized version of plasma generation and beam formation, extraction system, neutralization, and reionization system with the hope to increase polarization above 0.9 with acceptable intensity and emittance. OPPIS uses very expensive components such as superconducting solenoid with magnetic field of ~50 kG, very high frequency microwave source, powerful lasers, and a significant quantity of Rubidium and Sodium, which complicate source operation and maintenance. There are many factors which limit the possibility of producing polarization close to 100%.

In our opinion, an ABPIS has more potential for efficient production of different negative $H^-/D^-/T^-$ ions with polarization greater than 95%. It can be less expensive to manufacture and operate and more attractive as a commercial product.

STATUS OF ABPIS

The most advanced version of Atomic Beam Polarized Ion Source (ABPIS) with polarized atom ionization by resonant charge exchange with negative ions was developed at the Institute of Nuclear Research (INR) in Troitsk, Russia [3]. The schematic diagram of this ABPIS is shown in Figure 1.

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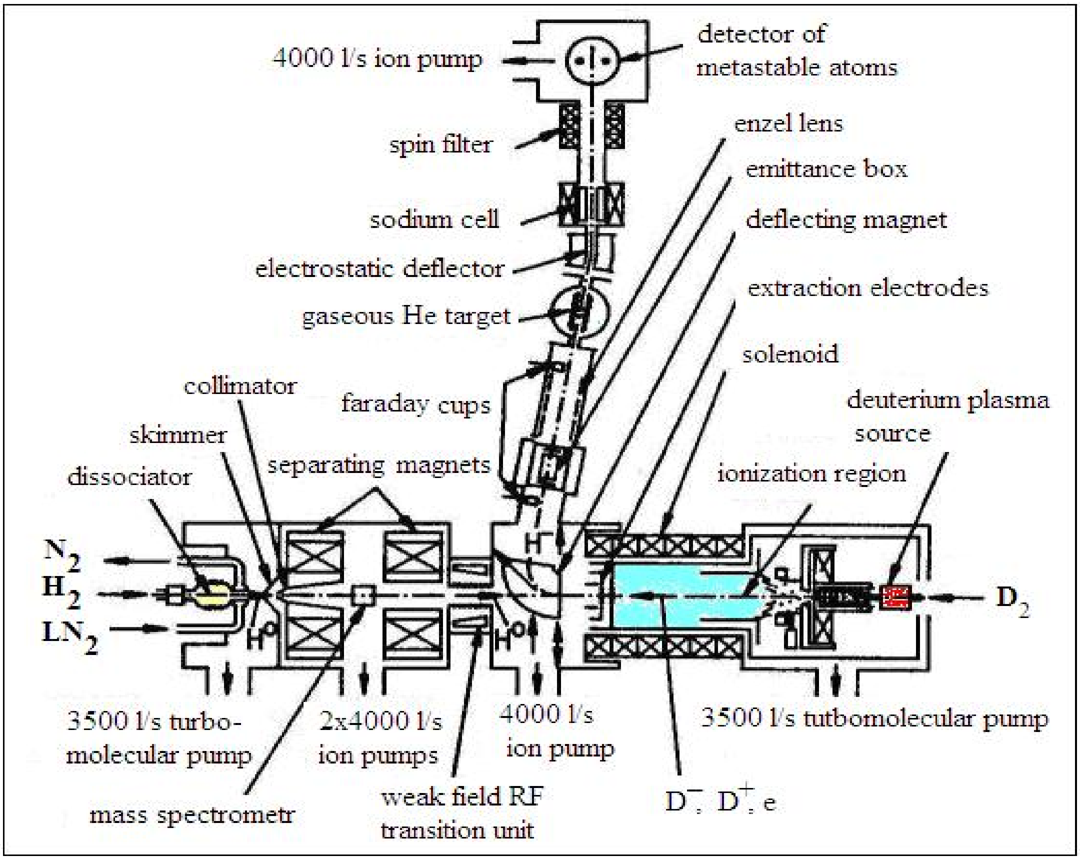

Figure 1: Schematic diagram of atomic beam polarized ion source with resonant charge exchange ionization [5].

The ABPIS with selective resonant charge exchange ionization has a good potential to produce H^-/D^- ion beams with the highest polarization [3, 5-9]. Low energy unpolarized H^-/D^- can transfer an electron only to H or D atoms but not to molecules. This method of ionization helps to produce H^-/D^- beam polarization higher than the polarization of hydrogen in an atomic beam because it eliminates unpolarized molecules from the beam. A pulsed mode of operation is favourable for high intensity and high polarization production. A fast gas valve and a small volume RF discharge dissociator with a helicon antenna in a magnetic field can be used for efficient pulsed operation.

In the ABPIS, hydrogen or deuterium atoms are formed by dissociation of molecular gas, typically in a RF discharge dissociator. The atomic flux is cooled to a temperature of 30K - 80K by passing through a cryogenically cooled nozzle. AlN ceramic can be used for cooling nozzle now. The atoms escape from the nozzle orifice into the vacuum and are collimated to form a beam. The beam passes through a region with inhomogeneous magnetic field created by sextupole magnets where atoms with one projection of electron spin relative to the magnetic field are focused and atoms with the opposite projection of electron spin are defocused. Nuclear polarization of the beam is increased by inducing transitions between the spin states of the atoms. The RF transition units are also used for fast reversal of the nuclear spin direction without changing the atomic beam intensity and divergence.

The main components of this ABPIS shown in Figure 1 are:

1. Source of polarized atomic H or D beam (left part).
2. Surface plasma source of cold negative D^- or H^- ions with an arc discharge plasma source and a surface plasma ionizer with cesium catalysis (right part).
3. Charge exchange solenoid with a grid extraction system (middle part).
4. Bending magnet for separation of polarized and unpolarized H^- and D^- beams (transition to the top part).
5. Beam line and polarimeter (top part). The online measurement of polarization is very important for optimization of many parameters influencing the polarization.

Polarized atomic beam intensity is proportional to the solid angle $\Delta\Omega = \pi.\alpha^2$, which is determined by the magnetic focusing system and magnetic field:

$$\Delta\Omega = \pi.\alpha^2 = \pi.\mu.B/\kappa T.$$

$$B=1.6\ T;\ \Delta\Omega = 1.5.10^{-2}\ sr;\ \alpha = 0.07\ rad$$

$$B=4.8\ T;\ \Delta\Omega = 4.5.10^{-2}\ sr;\ \alpha = 0.21\ rad.$$

For the pulsed atomic beam-type polarized ion source (ABPIS) the most efficient method was developed at INR, Moscow [5-9]. Polarized hydrogen atoms at thermal energy are injected into an ionizer solenoid with an opposing flux of deuterium plasma where polarized protons or negative hydrogen ions are formed due to the quasi-resonant charge-exchange reactions:

$$H0\uparrow + D+ \Rightarrow \mathbf{H+}\uparrow + D0$$

$$D0\uparrow + H+ \Rightarrow \mathbf{D+}\uparrow + H0$$

$$H0\uparrow + D- \Rightarrow \mathbf{H-}\uparrow + D0$$

$$D0\uparrow + H- \Rightarrow \mathbf{D-}\uparrow + H0$$

The ABPIS has a surface plasma ionizer for generation of a low energy D- ion jet from D+ plasma jet from an arc discharge source. The design of the Surface Plasma (SP) ionizer (INR version) is shown in Figure 2.

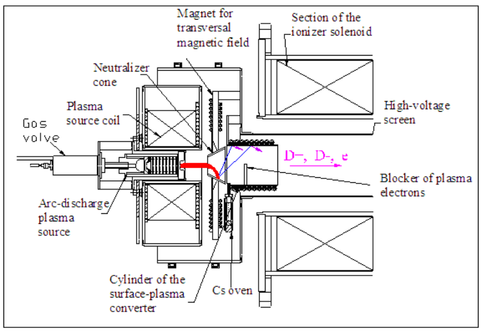

Figure 2: Generation of cold jet of D^- plasma for resonant charge exchange negative ionization of polarized hydrogen atoms (INR version) [3].

By using resonant charge exchange ionization, it is possible to have an efficiency of polarized atom to polarized H^- transformation of up to 12%. The high selectivity of polarized atom ionization allows polarization above 0.9. An arc-discharge plasma source developed at BINP [10] is used as a plasma jet generator. A converter with cesium deposition is used for conversion of plasma flux into negative ions.

Polarized H^-/D^- curren**ts** were increased up to 4 mA with measured polarization P up to 0.95. Unpolarized D^-/H^- currents were 60/100 mA. Coextracted electron current was suppressed by blocker [3].

It is proposed to increase the particle polarization up to the highest level by optimization of the ABPIS components and suppression of depolarizing processes. The ABPIS of INR with highest polarized beam parameters [3] was built nearly 30 years ago using the technology and components available at that time.

In the new ABPIS design, we will use the design of the CIPIOS-CIS ABPIS [8,9] as a prototype improved by the use of the most advanced modern components including 1) a superconducting or strong permanent sextupole magnet; 2) an advanced RF dissociator with helicon discharge with AlN ceramic; 3) a new version of arc-discharge plasma generator; 4) an optimized high-transparency extraction system and 5) an optimized low-aberration bending magnet. A superconducting sextupole will be used for the highest intensity polarized beam production. The advantage of a strong permanent magnet sextupole is reduced cost of manufacturing and operation while still achieving the highest polarization. The existing and easy availability of the main components for the ABPIS construction is a great advantage of this project. Many of the necessary components are now available with very good parameters.

The BNL polarized atomic H jet [11] has an intensity of up to 1.7 10^{17} atoms/s and polarization of ~0.97 in the DC mode of operation and it is possible to have an even higher intensity and polarization in the pulsed mode of operation. An ABS with very good parameters was developed for internal target experiments at BINP [12]. This ABS uses a superconducting sextupole focusing system with magnetic field at the pole tip of up to 4.8 T.

Computer simulations of all involved processes and components are now available and will be used to optimize the suppression of all depolarization processes. It is most important to suppress a surface plasma generation of unpolarized atoms on the cesiated converter.

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