Title

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A Hybrid Ion-Source Concept For A Proton Driver Front-End*

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Abstract. A novel concept for creating intense beams of negative hydrogen ion beams has been devised, and first steps towards its realization have been taken. In this approach, an ECR plasma generator operating at 2.45 GHz frequency is utilized as a plasma cathode, and electrons are extracted instead of ions and injected at moderate energy into an SNS-type multi-cusp H^- ion source. This secondary source is then driven by chopped d. c. power, rather than rf power, but does not need filaments which are the cause for the rather short lifetime of conventional H^- sources. The development of this ion source is primarily aimed at the future beam-power goal of 3 MW for the Spallation Neutron Source (SNS) [1] that will be pursued after the start of SNS operations. The first two phases of this development effort have been successfully passed: assembly of a test stand and verification of the performance of an rf-driven SNS ion-source prototype and extraction of electrons with more than 200 mA current from a 2.45-GHz ECR ion source obtained on loan from Argonne National Laboratory. An electron-extraction chamber that joins these ECR and H^- sources has been fabricated, and the next goal is the demonstration of actual H^- ion production by this novel, hybrid ion source. This paper describes the source principle and design in detail, reports on the current status of the development work, and gives an outlook on future lines of development.

Keywords: Negative hydrogen (H^-) ion source. Proton driver injector.
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INTRODUCTION

The H^- ion source built by LBNL for the Spallation Neutron Source (SNS) project in Oak Ridge has demonstrated excellent peak performance during the commissioning [2] and re-commissioning [3] of the SNS Front End (linac injector). A significant performance improvement overall will be required, however, when the average SNS beam-power goal is going to be raised to 3 MW. In view of future needs of SNS as well as other ring-based proton drivers, the following performance parameters are being aimed at:

- 75 mA peak H- current
- 0.25 p mm mrad normalized rms emittance
- 12% duty factor
- 2 months time-between-services

In spite of significant improvements in the design of the rf antenna implemented during the Front End construction phase, it appears that the approach utilizing an internal antenna and 2-MHz rf power to create the source plasma is not promising enough to pursue further. Instead, a novel approach is described in this paper, with the main source plasma being created by a pulsed d. c. discharge but sustained by a plasma cathode, rather than thermionic filaments which are the cause for the rather short lifetime of conventional H^- sources.

Inspired by the demonstrated durability of Electron Cyclotron-Resonance (ECR) proton sources developed at CRNL Chalk River [4], LANL Los Alamos [5], and CEA Saclay [6], an ECR plasma generator operating at 2.45 GHz frequency is chosen as the plasma cathode, and electrons are extracted instead of ions and injected at moderate energy into an SNS-type multi-cusp H^- ion source.

The first two phases of this development have been successfully passed: assembly of a test stand and verification of the performance of an rf-driven SNS ion-source prototype; and extraction of electrons with more than 200 mA current from a 2.45-GHz ECR ion

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source. An electron-extraction chamber that joins these ECR and H^- sources has been fabricated, and the next goal is the demonstration of actual H^- ion production by this novel, hybrid ion source.

Two- or multi-stage ion sources have been described more than 40 years ago [7, 8], and coupling of an rf driven plasma generator with a conventional dc ion source had been suggested in a review paper [9]. The electrode-less discharge technique associated with Electron Cyclotron Resonance (ECR) ion sources is in principle convenient for H^- ion sources as well, but so far only modest plasma densities have been achieved, allowing to extract beam currents below 5 mA [10] or less [11, 12] as compared to 61 mA needed for 3-MW operation of the SNS. On the other hand, tests of a two-chamber source for positive ions with a microwave-driven plasma cathode were very successful and achieved 110 mA Ar^+ as well as 43 mA of oxygen ions where the discharge could be maintained for 50 hrs [13].

One explanation for the rather weak H^- beam currents so far obtained from conventional ECR discharges could be seen in the presence of copious amounts of energetic primary electrons penetrating into the H^- production region in spite of an installed magnetic filter; these electrons would rapidly destroy the generated H^- ions [14]. The hybrid discharge concept chosen for HYBRIS (HYBRid Ion Source) has a chance to circumvent this loss process because energetic primary electrons should be thermalized in the main discharge before they reach the magnetic filter that separates the H^- production chamber from the main discharge.

LAYOUT AND PRINCIPLE OF OPERATION FOR HYBRIS

The principal idea in the layout of HYBRIS, see Fig. 1, is the combination of a long-life plasma cathode, sustained by an electrode-less ECR discharge, with a stationary, pulsed discharge. A 2.45-GHz ECR ion source described in Ref. 4, complete with ancillary systems, was obtained on loan from Argonne National Laboratory [15] and generates a plasma from which electrons are extracted. The source utilizes up to 1.2 kW of c. w. microwave power, and the resonant magnetic field of 875 kG is generated by two solenoid coils. An electron-extractor tube is held on an adjustable, positive potential, up to 20 kV above the ECR chamber potential, and the extracted beam of primary electrons is decelerated and injected into the cathode flange of the main discharge chamber. The applied voltage between ECR chamber and the cathode flange, in the order of 100 V, determines the actual energy of the injected electrons; the voltage might even be set to negative values if needed to reduce the average electron energy to suitable values for H^- production.

The main chamber consists of the multicusp vessel of the 'startup' SNS H^- source which is equal to the production version [2] except for a few minor technical details. But now the entire rf antenna assembly is replaced by the cathode flange into which the primary electrons are injected, and a pulsed discharge is struck between this cathode and the multicusp chamber acting as the anode. The discharge pulser unit includes a 1-Ω resistor connected in series. For use in the SNS accelerator chain, the ion source would be pulsed at a duty factor up to 7%. The gas supplies for ECR and main chamber can be adjusted separately to provide suitable pressure values for each of the chambers, and the electron-extraction chamber is pumped out through a bypass to the main vacuum tank.

As with the SNS ion source, a magnetic filter separates the H^- production volume inside the cesium collar from the main discharge to prevent energetic electrons from entering; ions and low-energy electrons can penetrate this barrier much more easily, due to collision processes. The negative particles, i. e. ions and electrons, are extracted by an applied voltage of about 35 kV (the nominal SNS beam energy for injection into the RFQ accelerator is 65 keV), and most of the extracted electrons are deflected by a dedicated magnetic dipole field and deposited inside the 'dumping' electrode.

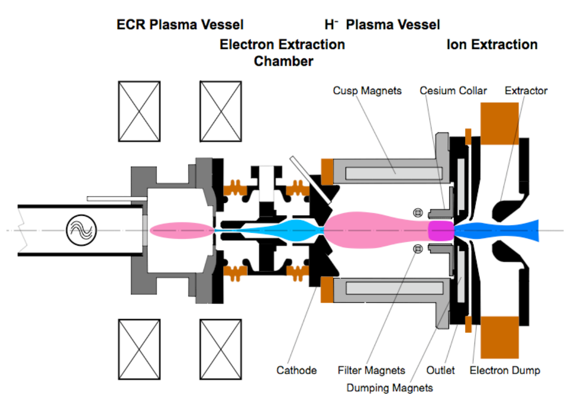

FIGURE 1. Schematic of HYBRIS.

PRELIMINARY TEST RESULTS

As a first test, the SNS ion source was operated in the standard mode with pulsed 2 MHz rf power, 13.56 MHz c. w. power to facilitate pulse ignition, and a capacitive impedance matcher [16]. A substantial H^- beam current was measured in the two-chamber Faraday cup, even without actual cesiation of the collar, and in a test experiment using helium as feeding gas, it was ensured that no extracted electrons were measured in the ion partition of the cup.

In the second phase, the ECR ion source was operated alone on the test stand, and up to 225 mA electrons were extracted at about 1 kW microwave power, but an 85-mA fraction of this beam was intercepted on the inside of the narrow extractor tube. Due to insufficient cooling of this tube, the tests could not be pursued to explore the performance limits of this plasma cathode. The extractor tube inside the electron extraction chamber shown in Fig. 1 is much wider and well cooled, but it had not been available for these tests.

The full HYBRIS assembly is complete, the source has been installed on the test stand, and high-voltage conditioning has been performed. A discharge plasma has very recently been created at moderate microwave power levels around 400 W, but actual beam extraction tests have not yet been performed.

SUMMARY AND OUTLOOK

A novel concept for a hybrid H^- ion source has been created, operating in pulsed d. c. mode and utilizing a microwave-driven plasma cathode. Initial tests of the major components, i. e. plasma cathode and multicusp H^- ion source operated with rf power, have been successfully performed, but the actual production of H^- ions has not yet been attempted. Once the proof-of-principle can be regarded as successful, there are four lines of future developments envisaged:

- Exploring the limits of H^- ion beam production in this novel way.
- Improving the packaging of the assembly to make it into a robust injector component.
- Electron removal at intermediate beam energy [17] to avoid electron deposition on the extractor electrode and development of a new Low Energy Beam Transport section.

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