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The TRIUMF Optically-Pumped Polarized H⁻ Ion Source

C.D.P. Levy, K. Jayamanna, M. McDonald, P.W. Schmor, W.T.H. van Oers,
J. Welz, G.W. Wight and G. Dutto
TRIUMF, 4004 Wesbrook Mall, Vancouver, B.C., Canada V6T 2A3

A.N. Zelenski
INR, Russian Academy of Sciences, 117312 Moscow, Russia

T. Sakae
Kyushu University, Fukuoka 812, Japan

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Abstract

The TRIUMF dc optically-pumped polarized H⁻ ion source (OPPIS) produces 200 μ A dc H⁻ current at 85% polarization within a normalized emittance (90%) of 0.8 π mm mrad, for operations at the TRIUMF cyclotron. As a result of development of the ECR primary proton source, 1.6 mA dc polarized H⁻ current is produced within a normalized emittance of 2 π mm mrad, suitable for high energy accelerators. The OPPIS has also been developed for use in a parity non-conservation experiment which has very severe limits on permissible helicity-correlated changes in beam current and energy.

The dc optically-pumped polarized H⁻ ion source (OPPIS) has been described previously¹. Very briefly, fast protons from an ECR source pick up a polarized electron from optically-pumped Rb vapor, pass through a Sona transition region and pick up an (unpolarized) electron from Na vapor to create a beam of nuclear-polarized H⁻ ions. For operations at TRIUMF, with its small cyclotron acceptance, the performance is 200 μ A dc of 85% polarized H⁻ current within a normalized emittance (90%) of 0.8 π mm mrad. Higher currents are attainable at some cost in polarization. Usually the source is run at lower current, and experimenters further filter the beam to produce extracted beams with high momentum or time resolution. At present the TRIUMF OPPIS delivers beam to a number of experiments for ~40% of the cyclotron running time.

The parity violation experiment (E497) at TRIUMF requires only 0.5 μ A of current extracted from the cyclotron, but has very severe requirements concerning the amount of helicity-correlated changes in beam current, energy and emittance that can be tolerated². To meet these requirements, most of the source intensity must be sacrificed by using a low Rb vapor density, small ion beam diameter, no injection beam buncher, radial flags and slits, and a narrow stripping extraction foil. Typical source parameters in the parity experiment are 30 μ A of 85% polarized beam within a normalized emittance (90%) of 0.8 π mm mrad at a Rb vapor thickness of 2.5 - 3 $\times 10^{13}$ atoms cm⁻².

The ECR proton source that produces the primary proton beam is shown in Figure 1. Microwave power of up to 800 W is produced by a cw extended interaction oscillator and is introduced transversely into the plasma cavity through a quartz tube, which together with boron nitride end cups confines the plasma volume. The tube is sealed at the ends by indium O-rings and is cooled by nitrogen gas flowing around the outside.

Obtaining high polarization requires a 2.5 T solenoidal field in the optically-pumped Rb cell. Despite the 28GHz microwave frequency, the ECR field is only 1 T and the mirror ratio of 2.5 is large compared to other sources. The OPPIS current is sensitive to the magnetic field shape and superconducting solenoid alignment. No multipole magnetic field is used because no advantage was found in previous tests. The magnetic field optimized for polarized current production is shown in Figure 1. It has a very short and shallow ECR zone.

The primary proton beam extraction system (PES) consists of three planar molybdenum electrodes, having multiple 0.95 mm diameter apertures in a hexagonally close-packed configuration. After some optimization the gap between electrodes is 1.2 mm. The electrodes are run in accel-accel mode. During manufacture the electrodes are clamped in a three-layer sandwich and the aperture pattern is drilled by a spark erosion technique, so that the three apertures in each beamlet extraction system are perfectly aligned. Slight differences in aperture size and grid pattern errors do not degrade PES performance. Careful attention to the magnetic field shape and alignment, as well as to PES alignment and gaps, as described above, has resulted in more than a factor 2 improvement in current compared to our previous results.

Another large factor was obtained recently [3] by increasing the number of apertures and increasing the Na ionizer cell aperture diameter. The OPPIS current is nearly proportional to the number of PES apertures, since each aperture's primary proton beamlet results in a polarized H⁰ beam having an emittance much larger than the acceptance of the ionizer cell. Typically a 31-aperture PES is used when running the parity experiment, but we have tried as many as 199 apertures with no loss in proportionality. The OPPIS current is also proportional to the area of the ionizer cell aperture, which for a fixed magnetic field is proportional to the emittance. The TRIUMF injection beamline has a small acceptance, and the ionizer diameter is limited to 12 mm for TRIUMF operations. A 20 mm diameter ionizer with an estimated normalized emittance (90%) of 2.0 π mm mrad at an ionizer magnetic field of 0.14 T is used for the highest current results. Such an emittance would be suitable for high energy accelerator facilities.

Figure 2 shows H^- current and polarization for a 55-aperture PES and 20 mm diameter ionizer. The optical pumping power is 9 W at 795 nm, or a power density of 14 W cm^{-2} across an overall beam diameter of $\sim 9 \text{ mm}$ in the Rb cell. For higher numbers of apertures (and therefore larger diameter Rb columns) the required laser power to optically pump the increased Rb volume naturally increases as well. This limitation could be easily overcome at present using pulsed lasers, producing high current, pulsed polarization of 80–85% suitable for high energy accelerators. The 1.6 mA dc H^- current was obtained at a Rb thickness of $1 \times 10^{14} \text{ atoms cm}^{-2}$ from a 199-aperture PES having an overall diameter of 17.5 mm. The next size up (253 apertures and 19.8 mm diameter) would give still higher currents. In pulsed operation, the grid transparency could also be increased to 70% from the present 60%. Clearly, the intensity limits on the ECR-based OPPIS have not yet been reached. It should be noted that ten times greater polarized H^+ currents could be produced by replacing the sodium vapor negative ionizer with a gaseous He ionizer.

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FIGURE CAPTIONS

1. Schematic of ECR primary proton source extraction system; 1) Quartz tube; 2) ECR cavity; 3) Three plate extraction system; 4) Boron nitride end cups; and 5) Indium seal.

2. H^- nuclear polarization and H^- current dependence on Rb vapor thickness, for a 55-aperture proton extraction system. The polarization was measured at 300 keV beam energy using the ${}^6\text{Li}(p, {}^3\text{He}){}^4\text{He}$ reaction. The H^- current is within a normalized emittance (90%) of $2.0\pi \text{ mm mrad}$.

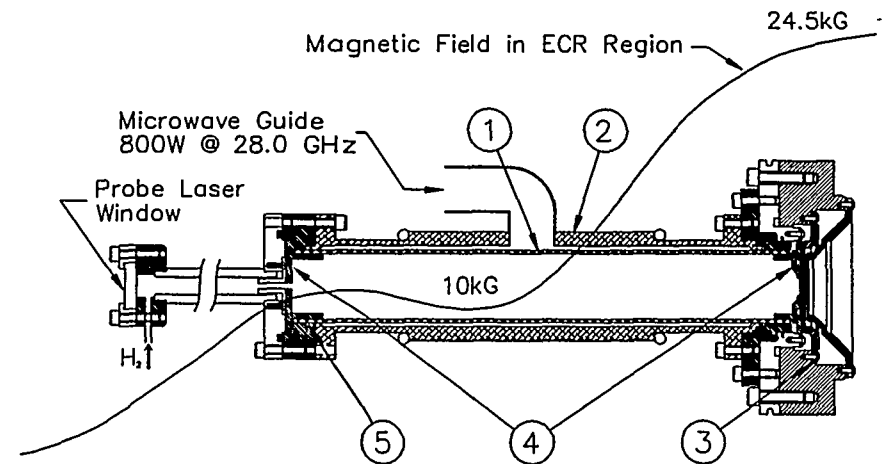


Fig. 1

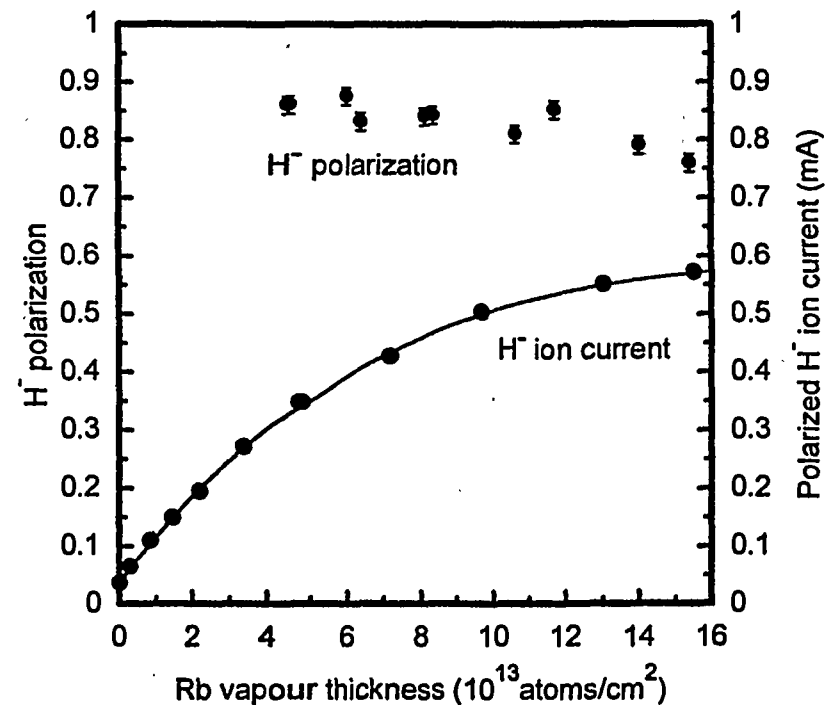


Fig. 2

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