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OPTICALLY PUMPED POLARIZED ION SOURCE WITH 16.5-GHz ECR ION SOURCE

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Summary

A new type of polarized H^- ion source which uses electron pick-up reactions of a low energy H^+ ion beam from electron-spin polarized sodium atoms has been developed at KEK. We have obtained 10 ∿ 25 μA polarized H^- ion beam when the electron-spin polarization of sodium atoms was about (46 ∿ 100) ± 8 %.

1. Introduction

Since 1980, a new 750 keV preinjector has been under construction for the acceleration of a polarized proton beam at KEK.[1] A new type of polarized H^- ion source which aims to produce an intence polarized H^- ion beam has been developed. Recently, we have made two large improvements on the previous apparatus[2] of polarized H^- ion source; one is to replace the duo-plasmatron by a 16.5 GHz ECR ion source as an H^- ion source, and the other is to use single frequency ring dye lasers as an optical pumping source instead of broad band dye lasers. Fig. 1 shows a set-up of a new KEK optically pumped polarized ion source. By these improvements we could substantially increase the beam intensity of polarized H^- ion beam and the electron-spin polarization of opically pumped sodium atoms. In this paper we will describe mainly about these two improvements and also some experimental results which we have obtained so far.

2. Apparatus and Experiment

2.1 16.5 GHz ECR ion source

The ECR ion source consists of a cylindrical plasma chamber and three solenoid coils. Microwave power of 1 ∿ 2 kW was produced by a coaxial magnetron (JRC, M1408) which was modified for tolerating long pulse width (∿ 1 msec) and high repetition rate (20 Hz) operations. The microwave power was fed into the plasma chamber through a thin microwave window for vacuum sealing. The plasma chamber is made of stainless steel. Three solenoid coils form magnetic mirrors (mirror ratio ∿ 2) and the field at the beam extraction and Na cell region is 0.9 T. Low energy (2 ∿ 5 keV) H^+ ion beam was extracted by multi-slit electrodes forming accel.-decel. system. Total extracted ion current was 220 mA at 3.7 keV and the beam current of 50 ∿ 60 mA was measured at the exit of Na cell (10 cm apart from the extracting electrodes) by a 1 cmϕ Faraday cup as shown in Fig. 2. Hydrogen pressure in the plasma chamber was less than 1×10^{-4} Torr in normal operation. It affected strongly proton ratio. Fig. 3 shows the measured values of proton ratio as a function of the hydrogen gas pressure which was measured at the head of a turbomolecular pump. As the pressure increased, the proton ratio decreased. A higher proton ratio of 70 % was obtained by optimising the source paramters.

KEK POLARIZED H^- ION SOURCE

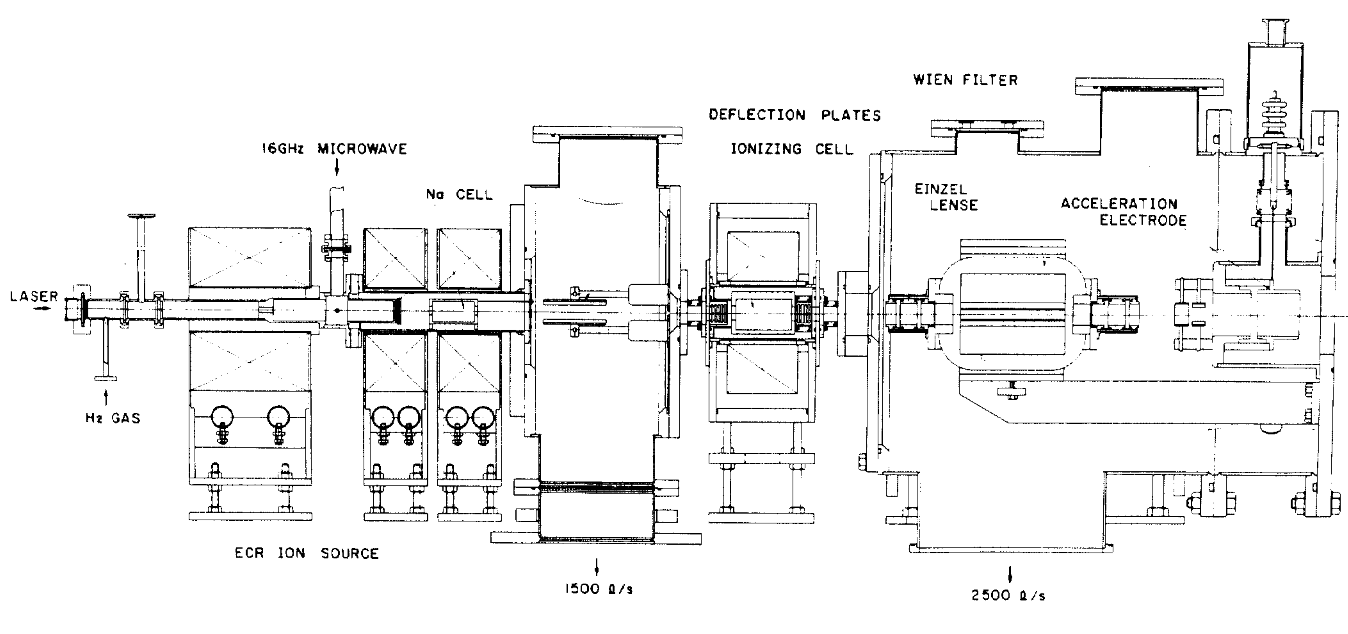

Fig.1 Schematic arrangement of optically pumped polarized H^- ion source.

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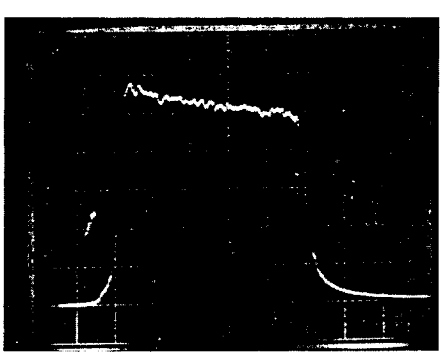
Langmuir probe for the measurement of plasma parameters was placed at 10 mm from the center of plasma chamber. The electron temperatures and the palsma densities were measured for the two plasma chambers; one is of introducing the microwave transversely to the magnetic field and the other of longitudinally. The results are summarized in Fig. 4. The plasma densities in were separately calculated from the electron saturated current (Ies) and the ion current (Ii). As seen in figures, the electron temperature decreased abruptly as the hydrogen pressure increased. In normal operation, the electron temperature and the electron density were 23 eV and 10^{12} n/cm^3 respectively. We have also measured the plasma confinement time (τ) by a resonant cavity method. In normal operation, τ is $\sim$ 30 μsec and it decreases gradually as the hydrogen pressure in the plasma chamber increased.

The beam emittance from the ECR ion source is very important to obtain an intense polarized H^- ion beam. So, we have measured beam emittance of the ECR ion source. The measurements were performed at the distance of 18 cm from the edge of the magnetic field. The detector head consists of a ceramic plate with thirty two gold segments and the beam current detected by the each segment is integrated and multiplexed. Data are digitized by a transient recorder (Biomation 8100) and averaged for 128 beam pulses by a data processer (Iwatsu SM1330) and then, sent to a micro computer (HP-85).

Typical emittance configurations are shown in Fig. 5. The value of the emitance shown in the figure is normalized (Area × $\beta\gamma$). The beam emittance was strongly affected by the beam extraction system. Figs. 5-(a) and (b) show the measured beam emittance configurations in the cases of using multi-slit electrodes and single-hole electrodes respectively. The normalized beam emittance for the multi-slit case was 1.3 π mm•mrad. This value was about a half that of the case with single-hole electrodes and the aberrations also disappeared. The fringing field of the solenoid coils affects largely upon the beam emittance. Assuming a linearly decreased fringing field, the beam in the Na cell region is considered to be small (6 $\sim$ 8 mmϕ) and less divergent from simple calculations using the measured emittance configuration. We found that the 16.5 GHz ECR ion soruce was very useful for the optically pumped polarized ion source.



V: 10mA/div.

H: 50μsec/div.

Fig.2 Ion beam current from ECR ion source.

2.2 Measurement of electronspin polarization of optically pumped sodium atoms

Electron-spin polarized sodium atoms are produced by optical pumping with two single frequency dye lasers which are tuned to the wavelength of the sodium D_1(589.593 nm) line. Electron-spin polarization of

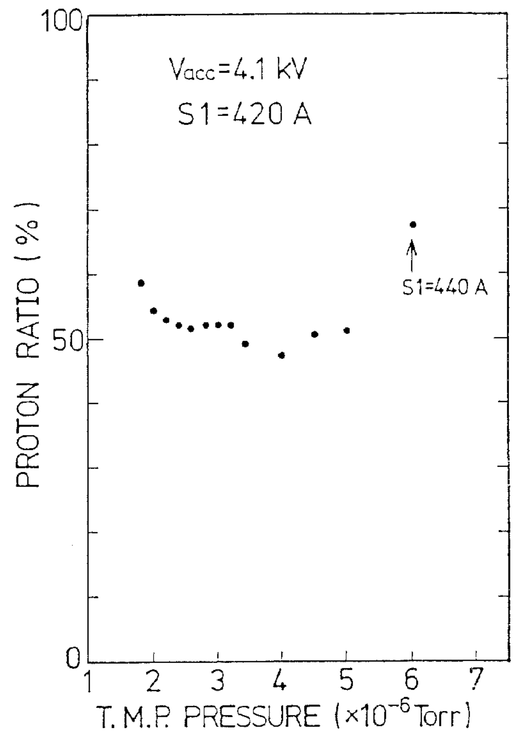


Fig.3 Proton ratio of extracted ion beam as a function of hydrogen pressure.

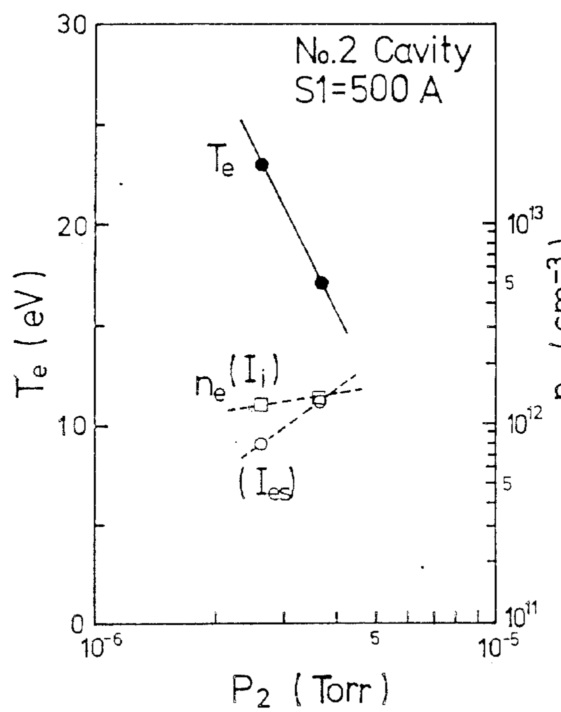


Fig.4 Electron temperature and plasma density as a function of hydrogen pressure.

sodium atoms is strongly affected by the laser power and the sodium target density. It is quite important to measure the electron-spin polarization of optically pumped sodium atoms for the development of this polarized ion source. A very usefully, scheme for this purpose has been proposed and experimentally confirmed recently.[3] This scheme utilizes Faraday rotation based on an optically anomalous dispersion at the edges of a resonance line. It has no deteriorating effects target cell length.

The amount of Faraday rotation comes from the difference of the refractive indices for left and right circularly polarized light.

$$\theta = \frac{\pi \ell}{\lambda}(n_+ - n_-) \quad , \qquad (1)$$

where n_+ and n_- are the refractive indices for left and right circular polarization respectively, λ is the wavelength of the light and ℓ is the target length. Refractive indices are affected by the magnetic field and the electron-spin polarization. So, θ can be written as follows.

$$\theta = \theta_0 + \alpha P \theta_0 \quad , \qquad (2)$$

where P is the electron-spin polarization of the optically pumped sodium atoms and θ_0 is the Faraday rotation angle for the unpolarized sodium atoms and α can be obtained theoretically.[3,4] If θ and θ_0 are measured, the electron-spin polarization can be obtained from eq. (2).

The laser system for our polarized H^- source is schematically shown in Fig. 6. For one pumping laser, at a target thickness of 2×10^{13} atoms/cm^2, the polarization was 58 ± 7 % at the maximum and for two pumping lasers, it was 100 ± 8 % at 1.4×10^{13} atoms/cm^2 and 76 ± 7 % at 2.3×10^{13} atoms/cm^2. These values almost agreed with the theoretically predicated polarization values.[5] The beam current of polarized H^- ion beam was about 10 ∿ 15 μA at the sodium target thickness of 2×10^{13} atoms/cm^2. When the target thickness increased to 5×10^{13} atoms/cm^2, the output H^- ion current increased to 20 ∿ 25 μA, however, the polarization decreased to 46 ± 8 %. We are now assembling this polarized ion source in the 750 keV high voltage terminal. The test of beam acceleration will be done in this spring.

Acknowledgement

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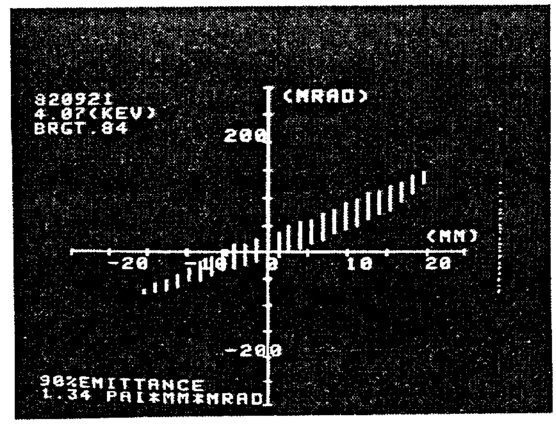

Fig.5 (a) Beam emittance for the case with multi-slit electrodes.

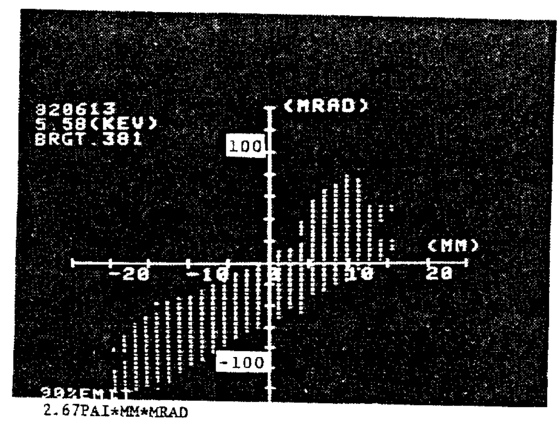

Fig.5 (b) Beam emittance for the case with single-hole electrode.

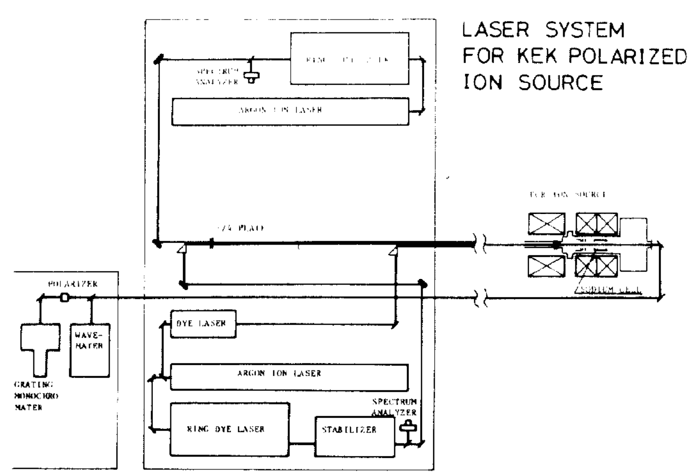

Fig.6 Laser system for the optically pumped polarized H^- ion source.