POLARIZED ION SOURCE WITH RESONANT CHARGE–EXCHANGE PLASMA IONIZER

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Atomic beam–type polarized ion source with resonant charge–exchange plasma ionizer developed at the Institute for Nuclear Research produces high–intensity beams of polarized protons and polarized negative hydrogen ions. In this paper new results of experimental test of storage of polarized atoms in the charge–exchange region of this source are presented. Polarized proton beam with peak current of 11 mA, polarization 0.8 and normalized emittance $\sim 1\ \pi\ mm\ mrad$ has been obtained.

The source of polarized hydrogen ions developed at the Institute for Nuclear Research is atomic beam–type source in which almost resonant charge–exchange reaction between polarized hydrogen atoms and deuterium ions is used for polarized ion production:

$$D^+ + H^0 \uparrow \rightarrow D^0 + H^+ \uparrow \tag{1}$$

$$D^- + H^0 \uparrow \rightarrow D^0 + H^- \uparrow \tag{2}$$

The use of the reaction (2) for a direct production of polarized H^- ions has been proposed by W.Haeberli [1].

In the polarized ion source under discussion the resonant charge–exchange reaction takes place in plasma. Using of plasma generated by an ion plasma source for ionization of polarized atomic hydrogen has been proposed by V.V. Nizhegorodtsev [2]. Method used in the INR source is a synthesis of the proposals by W. Haeberli and V.V. Nizhegorodtsev.

This new approach has several advantages: large cross–section of the resonant charge–exchange reaction at low relative energy of colliding particles in plasma (the cross–section of reaction (1) at relative energy of colliding particle $\sim 10\ eV$ is equal to $4 \cdot 10^{-15} cm^2$, the cross–section of reaction (2) is $1.2 \cdot 10^{-14} cm^2$ for the same relative energy), absence of a space–charge problem due to plasma quasi–neutrality, a possibility to get plasma with very large ion density (up to $10^{14} cm^{-3}$) by modern plasma sources, a simplicity of plasma transport in a longitudinal magnetic field where the charge–exchange takes place.

Pulsed polarized proton beam with peak current of 6 mA, polarization 0.76 and normalized emittance $2\ \pi\ mm\ mrad$ has been obtained from the polarized ion source with free atomic hydrogen beam in the resonant charge–exchange ionizer based on the reaction (1). The source was described in detail in ref.[3].

The same source has been used later for a direct production of polarized negative hydrogen ions from a polarized hydrogen atomic beam. In order to use reaction (2) a deuterium plasma in the charge–exchange region has been enriched with unpolarized deuterium negative ions. A special converter has been developed for that purpose. Positive deuterium ions and neutral atoms were converted into negative deuterium ions on the converter surface. Pulsed polarized H^- ion beam with peak current of 1 mA, polarization 0.87 and normalized emittance 1.8 π mm $mrad$ had been obtained from this source [4]. Figure of merit of the polarized beam $P^2 \cdot I = 0.76$ mA exceeds relevant figure of any other polarized H^- ion sources.

For some projects even higher intensities of polarized H^- sources are desirable. One way to increase intensity of polarized proton and H^- ion beams obtained from an atomic beam–type source is the use of storage of polarized hydrogen atoms in ionization region [5,6]. It was demonstrated [7] that storage of polarized hydrogen atoms in a charge–exchange region of polarized proton source gives again about 9 in comparison with a free atomic hydrogen beam. But this result has been obtained with low intensity deuterium plasma flux through the storage cell (the unpolarized D^+ ion current extracted was ~ 5 mA). In this paper we present new results of experimental test of storage of polarized hydrogen atoms in the polarized ion source which have been obtained with one order of magnitude more intense plasma flux through the storage cell.

The experimental setup is described in detail in ref. [7]. In the present study we have used storage cell made from alluminum alloy with uncoated walls at room temperature. Its length was equal to 250 mm and its internal diameter was 15 mm. The polarized hydrogen atoms were injected into the storage cell from one open side and deuterium plasma was injected into the cell through a diaphragm 3 mm in diameter from opposite side. In order to increase the plasma flux through the storage cell magnetic field in the plasma source has been increased from 400 G to 800 G, and an ion extraction system has been redesigned. The modification of the extraction system became necessary because of strong radial inhomogeneity of deuterium plasma in the storage cell. In order to minimize influence of the plasma inhomogeneity on the divergence of the ion beam the gap between plasma and second electrode of the extraction system has been increased to 15 mm. Quasi Pierce optics of the plasma electrode has been used in order to compensate the divergence of the ion beam due to space charge forces in the acceleration gap. Due to these improvements unpolarized D^+ ion beam with peak current up to 45 mA has been obtained downstream a mass analysing magnet.

As a result the polarized proton beam with peak current up to 11 mA, polarization 0.8, normalized emittance about 1 π mm $mrad$, pulse duration 200 μs at repetition rate 5 Hz has been obtained from the source with this deuterium plasma flux. Brightness of the polarized beam $P^2 \cdot I/Em^2_{norm} = 7\ mA/(mm\ mrad)^2$ is almost one order of magnitude larger than the brightness of the polarized proton beam obtained from the same source without the storage cell.

Intensity of the polarized proton beam can be increased further by increase of deuterium plasma flux througth the storage cell and by cooling the storage cell walls to a temperature about 100 K.

Conclusion

Use of storage of polarized hydrogen atoms in ionization region of an atomic beam–type polarized proton source with resonant charge–exchange plasma ionizer resulted in production of pulsed polarized proton beam with peak current of 11 mA, polarizaton 0.8, normalized emittance $\sim$ 1 π mm $mrad$, pulse duration 200 μs at repetition rate 5 Hz.

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