Preliminary Design of a Hybrid Ion Source for $^7Li^{3+}$ Generation

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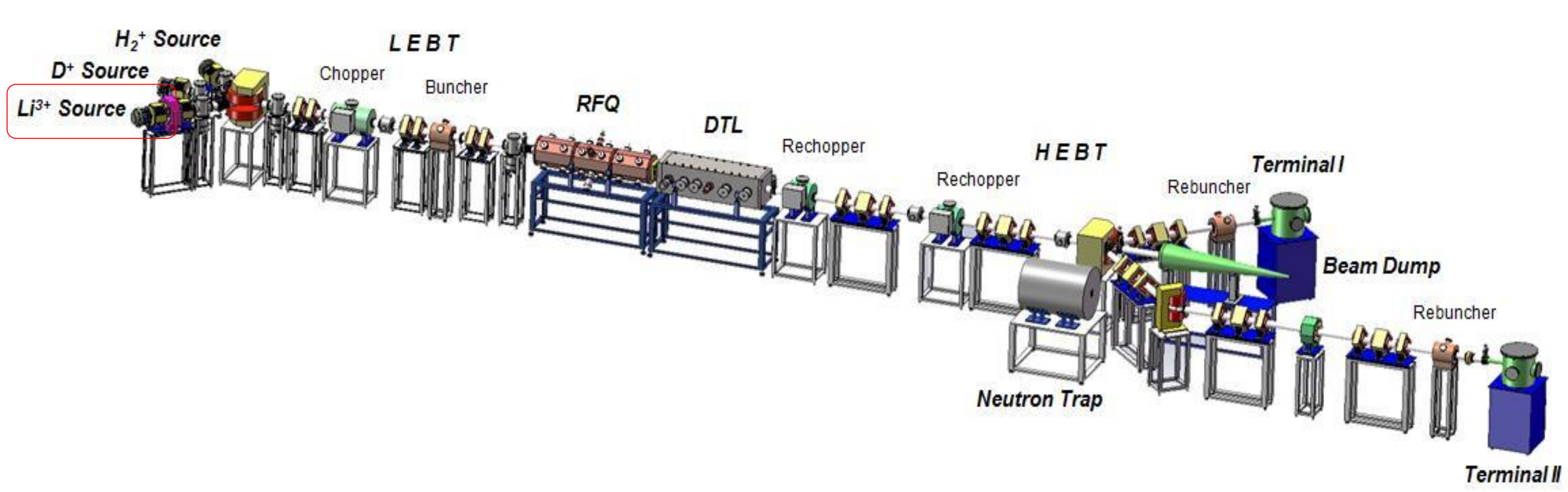
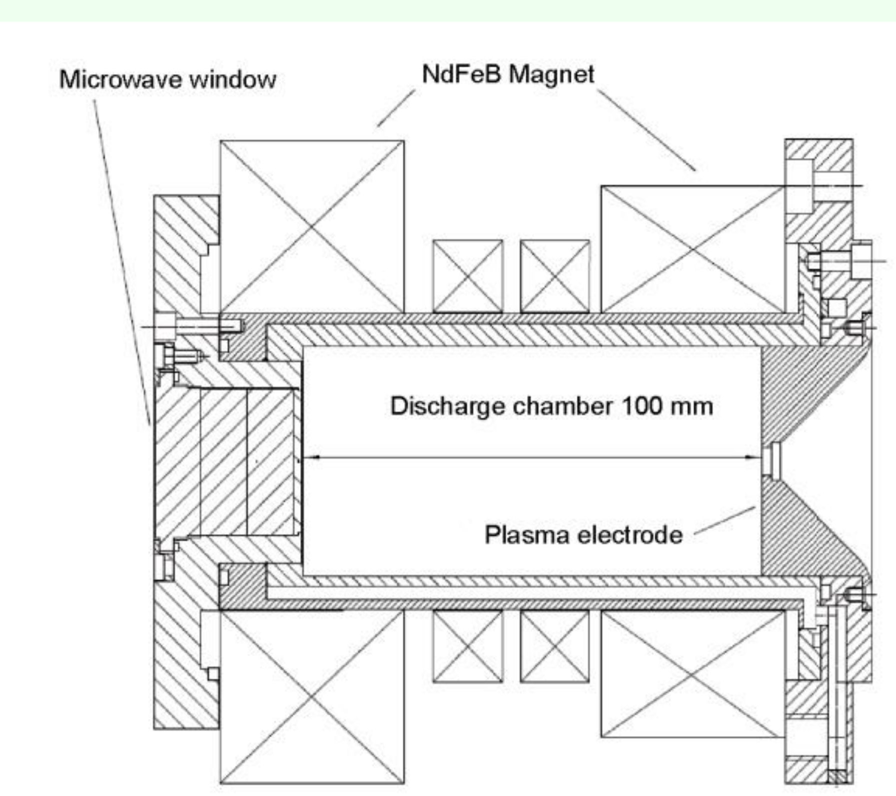
Abstract: The p(^{7}Li,n)^{7}Be reaction can be used to produce forward neutron beam based on the principle of inverse kinematics, which is useful to reduce the background of the measurement of prompt fission γ-ray emission from fast neutron induced fission of ^{235}U and ^{238}U. Based on inverse kinematics reaction, a hybrid $^7Li^{3+}$ ion source is going to be adopted to produce 10 eμA beam for the project of CIFNEF (Compact Intense Fast NEutron Facility) proposed by Peking University (PKU) and China Institute of Atomic Energy (CIAE). To qualify the possibility of producing multi-charged ions with a 2.45 GHz microwave source, a high B field 2.45 GHz ion source has been built at PKU. Oxygen gas was used for the source test. About 200 eμA O^{3+} and 400 eμA O^{2+} were produced with the high B field ion source. This indicates the feasibility of producing high charge state ions with lower frequency and high B field. Based on these results, a tandem-type hybrid ion source with the combination of a 2.45 GHz ECR ion source and a hot surface ionization source was developed for Li^{3+} ion generation at PKU. An oven will be used to produce lithium vapor and the surface ionization source converts the lithium atoms into Li^+ ions. Then Li^+ will be striped into Li^{3+} in ECR region. The configuration of magnetic field is min-B. Details will be presented in the paper.

Compact Intense Fast NEutron Facility (CIFNEF)

Recently, Peking University (PKU) and China Institute of Atomic Energy (CIAE) plan to build a Compact Intense Fast NEutron Facility (CIFNEF). In CIFNEF, $^7Li^{3+}$ ions are accelerated to bombard the hydrogen target to produce neutrons through the p(^{7}Li,n)^{7}Be inverse kinematics reaction for the study of the peculiar structure of the neutron-rich fission fragment nucleus. The p(^{7}Li,n)^{7}Be reaction can produce forward neutrons so the measurement background can be reduced effectively. To meet the requirement of the CIFNEF, an ion source which has the ability of producing 175 keV/10 μA $^7Li^{3+}$ is needed.



Preliminary experiment of a high B field 2.45 GHz ion source using oxygen gas



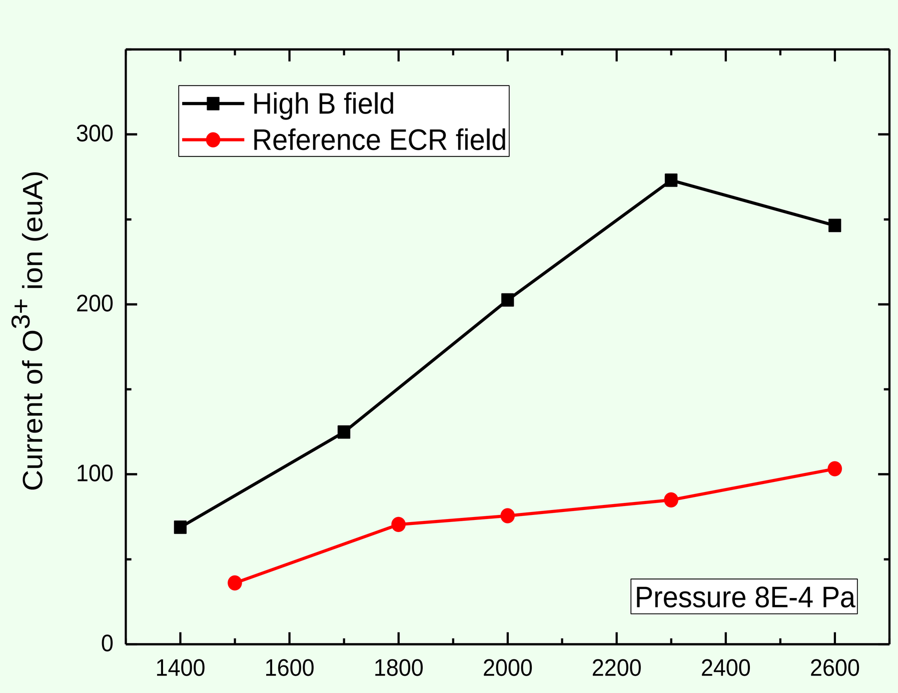
Schematic view of the high B field ion source

Usually 14 GHz or even higher microwave frequency is used for the ECR ion source to produce high charge state ions, but we intend to produce $^7Li^{3+}$ with 2.45 GHz ECR source. A high B field prototype ion source was developed at PKU to investigate the possibility of multi-charged ion generation of a 2.45 GHz ECR ion source. A mirror shape magnetic field with the highest strength of 2700 Gs and a minimum one of 880 Gs was supplied with permanent magnets. The mirror ratio was about 3. The discharge chamber was 100 mm in length and 50 mm in diameter. A three-electrode extraction system with emitting aperture of 6 mm in diameter was used to extract the beam.

The maximal currents of O^{2+} and O^{3+} that this ion source could get were 446 eμA and 273 eμA, respectively.

Figure in the right is a comparison of O^{3+} current produced by the high B field ion source and normal ECR ion source with magnetic field of 875 Gs and mirror ratio of 1.24 in different microwave power. Obviously, the current of O^{3+} produced by high B field ion source was higher than by normal ECR source under the same operation conditions.

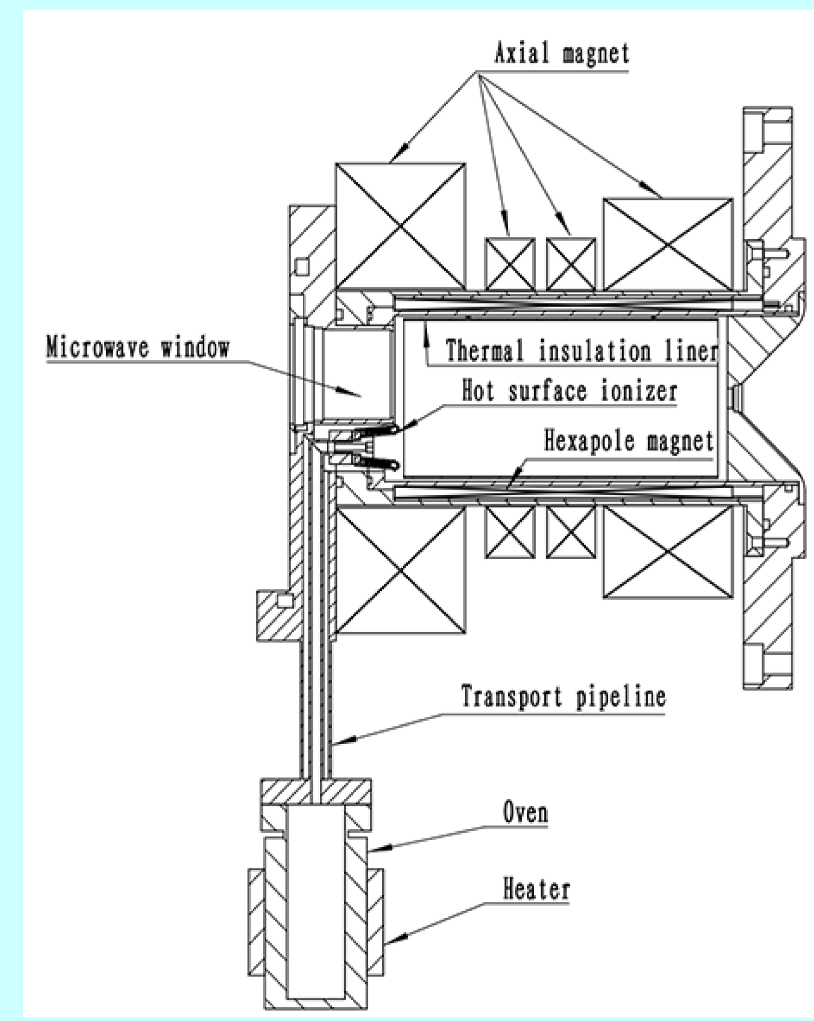
The experiments proved that 2.45 GHz ECR ion source could produce high charge state ions in high magnetic field.



O^{3+} currents for high B field and normal ECR field, vs microwave power

The preliminary design of a tandem-type hybrid ion source for $^7Li^{3+}$ generation

The schematic view of the hybrid ion source for $^7Li^{3+}$ production is showed in the right. Generally, it is composed of a hot surface ionization ion source and a 2.45 GHz ECR ion source. Based on the results of the high B field 2.45 GHz ion source, the frequency of 2.45 GHz is feasible for the production of some multiply charged ions in ECR ion source with high B field. So 2.45 GHz is selected as the frequency of the $^7Li^{3+}$ ion source. Also noteworthy, it has a lower cost of the 2.45 GHz magnetrons compared with the higher frequency ones. In addition, only low-cost magnetic field structure (B~875 Gs) is needed.



The schematic view of the hybrid ion source

Microwave window

Like the traditional PKU ECR ion source, 2.45 GHz microwave is introduced into the plasma chamber through a three-layer Al_2O_3 microwave window. A BN disc mounted between the ceramic disc and the plasma chamber is used to protect the window from bombardment of electrons.

Heating system

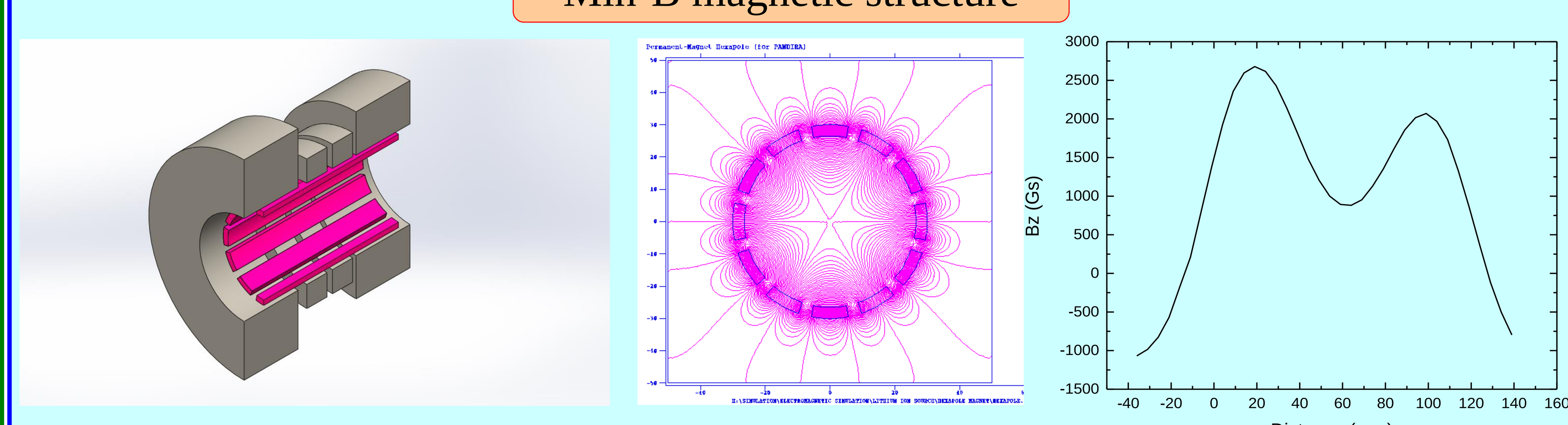
As the elemental lithium is in solid state at room temperature, an oven and a heater are needed to heat it up into lithium vapor. In order to avoid the condensation of the lithium vapor, the transport pipeline and the liner are adiabatic. And the hot surface ionizer can also facilitate the maintaining of the gas state of lithium.

Hot surface ionizer

Design drawing of the hot surface ionizer and the illustration of the hot surface ionizer mounted in the ion source

Lithium vapor transferred from the oven will be ionized into Li^+ ions first in the surface of hot surface ionizer. Then the Li^+ ions get into the 2.45 GHz ECR zone where they are striped into Li^{3+} through stepwise ionization.

Min-B magnetic structure



A min-B magnetic structure which is composed of axial mirror fields and hexapole fields is used. The axial mirror magnet is formed by four permanent magnet rings used in the high B field ion source. The magnetic field produced by hexapole magnet near the wall of plasma chamber is about 2000 Gs. The axial mirror magnets and radial hexapole magnets are all made of Nd-Fe-B.

Extraction system

A three-electrode extraction system will be used. The diameter of the plasma electrode emission aperture will be 6 mm. All the electrodes will be well cooled. In addition, pollution of the ceramic caused by the lithium vapor will be carefully treated.

Conclusions and outlook

To meet the requirement of Compact Intense Fast NEutron Facility (CIFNEF) project, a hybrid $^7Li^{3+}$ ion source combined of a hot surface ionization ion source and a 2.45 GHz ECR ion source is designed based on the preliminary experiments of the high B field ion source at PKU. A min-B magnet configuration which is formed by axial mirror magnets and radial hexapole magnets will be used. The hybrid $^7Li^{3+}$ ion source is now machining in factory. After all the machine work is done, beam experiments will be carried out.