ION SOURCE DEVELOPMENT AT THE AGOR FACILITY*

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Abstract

This paper discusses the present status of ion source development at KVI. Work is mainly focussed on increasing the beam intensity of the ECRIS injector and to optimize the beam transport and injection into the AGOR cyclotron. The ultimate goal is to deliver a 1 kW beam of heavy ions on target. Recent progress towards this goal is discussed. We also present the first results of beam extraction and transport simulations. In order to test these simulations and to improve the beam matching between ECRIS and cyclotron we have designed and built a new pepperpot emittance meter. Finally, a simple method is described to produce a low-energy $^6Li^+$ beam using an alumino-silicate ion source inside a multicusp source.

INTRODUCTION

Ion source development at KVI is mainly driven by the intensity demands for the TRIμP project, i.e. a 1 kW heavy-ion beam on target [1]. In order to meet these objectives we have upgraded the existing CAPRICE type Electron Cyclotron Resonance Ion Source (ECRIS) into the AECR design of LBL [2] and JYFL [3]. To increase the performances of the ion source further we are implementing two-frequency rf heating. In addition we have started a program to improve the ion extraction from the ECRIS and transport to the cyclotron.

An important aspect in improving beam extraction and transport is the availability of adequate beam diagnostics. As an addition to the existing set of Faraday cups and beam profile monitors we have recently designed and built a versatile emittance meter capable of measuring the full 4-D phase-space distribution of the beam. This new device will be used to benchmark simulation studies of beam extraction and transport and to study emittance growth with increasing beam intensities.

Finally, a simple method is described to produce a beam of $^6Li^+$ ions using a small, commercially available aluminosilicate ion source. This source was placed just in front of the extraction hole of the existing multicusp source used for the production of light-ion beams (p, d and α's). The paper concludes with a brief summary and outlook.

THE KVI-AECR ECRIS

The TRIμP objectives require us to deliver beam currents at the inflector of the cyclotron of around 150 μA, with charge over mass ratios of $Q/A = 1/4$ for the lighter ions (up to ^{40}Ar) and $Q/A = 1/8$ for the heavy ions (up to ^{208}Pb). In order to meet these objectives we have upgraded the existing CAPRICE-type ion source into the AECR design as mentioned above, reusing the solenoids and power supplies, 14 GHz rf generator and the extraction system. A cross section of the upgraded ion source, called KVI-AECR, is shown in Fig. 1. The ion source is equipped with an aluminum plasma chamber with inner diameter of 76.2 mm and a length of 320 mm. The plasma chamber also holds the six NdFeB permanent magnet bars producing the hexapole field, which together with the axial mirror field produced by the two solenoids yields the minimum-B configuration. The magnetic field configuration is characterized by maximum values of 2.1 T and 1.1 T of the axial injection and extraction fields, respectively, a minimum field of 0.36 T and a maximum hexapole field at the radial wall of 0.9 T. The plasma chamber is radially accessible through six slits located between the magnet bars. We use these slits for enhanced pumping of the plasma chamber with a 410 ls^{-1} turbo pump, but they also allow the insertion of e.g. sputter probes and plasma diagnostics.

A tungsten biased disk is located on the central axis at the injection side of the plasma chamber. The plasma is heated with 14.1 GHz radiofrequency waves generated by a 2 kW klystron amplifier. The rf waves are launched into the plasma chamber from the injection side via a rectangular waveguide. We are presently installing two-frequency heating by combining the 14.1 GHz rf waves with rf waves from a 11-13 GHz, 500 W traveling wave tube amplifier using a star-point combiner. More detailed information on the KVI-AECR can be found in Refs. [4] and [5].

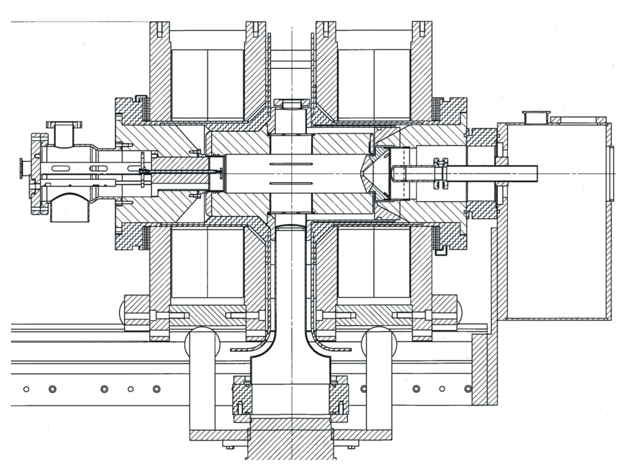

Figure 1: Cross section of the KVI-AECR

* Work supported by the "Stichting voor Fundamenteel Onderzoek der Materie" (FOM), the State University of Groningen and by the European Union through EURONS under contract No. 506065.
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Recently we have significantly improved the ion source performance by carefully eliminating small vacuum leaks and by modifying the extraction system. The background pressure in the plasma chamber was reduced from a few times 10^{-7} to a few times 10^{-8} mbar. The extraction system was modified by replacing the ground electrode (inner diameter=29 mm, length=190 mm) behind the puller with one having an inner diameter of 53 mm and length of 160 mm. These changes resulted in a more than three-fold increase of extracted beam currents, e.g. 260 μA of Ne^{6+} extracted at a source potential of 22.5 kV and measured with an electron-suppressed Faraday cup behind a 20 mm diaphragm placed in the image plane of the analyzing magnet. We can meet the TRIμP objectives for the light-ion beams, but further work needs to be done on the heavy-ion beams.

BEAM EXTRACTION AND TRANSPORT

In order to better understand beam extraction from the ion source and transport to the cyclotron we have started detailed particle trajectory simulations using various codes. Only the latest results obtained with the KOBRA-3d code [6] will be discussed here. Figure 2 shows the electrostatic fields in the extraction region of KVI-ECRIS calculated with KOBRA-3d. The calculation reveals that the region between plasma electrode and ground electrode is shielded from secondary electrons by the electric field between puller and ground electrode. This frustrates the space-charge neutralization of the beam in the extraction zone, which leads to increase of the beam emittance. This effect can be mitigated by decreasing the distance between the ground electrode and the entrance of the puller electrode. An ion trajectory calculation shows that 25% of the beam is lost to the walls of the beam pipe between the extraction region and the object plane of the analyzing magnet.

The transport of the ion beam from the object plane of the analyzing magnet to the matching section of the AGOR injection line is tracked using COSY-INFINITY [7] starting with the beam phase-space distribution calculated with

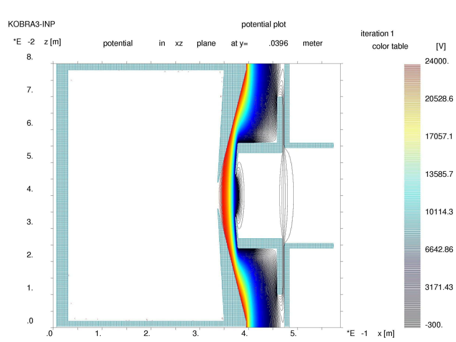

Figure 2: Electric fields in the extraction region of KVI-ECRIS.

KOBRA-3d. This simulation agrees well with the experimental settings and measurements of the beam widths with beam profile monitors. The beam transport efficiency from the image plane of the analyzing magnet to the matching section is typically 75%.

EMITTANCE METER

With increasing beam intensity it becomes more and more important to carefully match the low-energy beam to the acceptance of the cyclotron and to avoid beam losses as much as possible. This can only be done when the beam emittance is known with a reasonable accuracy. In addition, measured beam emittances also serve as sensitive benchmarks for the simulation studies discussed above.

We therefore have designed and constructed a versatile emittance meter which is capable to measure the full four-dimensional transverse phase-space distribution $\rho(x, y, x', y')$ of a low-energy ion beam. Our instrument is compact and can be inserted at different locations along a beam line. It will also be used to measure the beam emittances of the superconducting MS-ECRIS, who's commissioning will start at the end of 2007 at GSI [8]. One of the design specifications requires the instrument to be able to measure beam emittances with in one plane a large divergence of ± 50 mrad and a narrow width of 5 mm, and in the perpendicular plane a small divergence of ± 6 mrad and a large width of 40 mm. The emittance meter therefore combines the pepperpot and scanning techniques, i.e. a linear array of holes aligned in the direction of small divergence is scanned in the perpendicular direction of small beam width.

A schematic view of the emittance meter is shown in Fig. 3. The pepper plate is a thin tantalum foil with a vertical row of small holes (Ø 20 μm) mounted on a water-cooled copper block which can absorb 150 W of beam power. This assembly can be scanned through the beam in the horizontal direction by a steppermotor driven translation mechanism. The ions transmitted through the pepper plate are detected with a position-sensitive detector consisting of two multi-channel plates and a phosphor screen. A mirror and lens system images the light from the phosphor screen onto a CCD camera mounted outside the vacuum. More detailed information on the design can be found in Ref. [9].

As an illustration of the capabilities of the emittance meter Fig. 4 shows x-x', y-y' and x'-y cuts through the phase-space distribution of a 111 keV Ne^{6+} beam. This measurement only took 10 seconds. This emittance measurement shows a clear correlation and substructure in the x'-y cut, a feature that can not detected with conventional Allison-type scanners.

^{6}LI^{+} ION SOURCE

We have developed a very simple method to produce a low-energy $^{6}Li^{+}$ beam by modifying the existing mul-

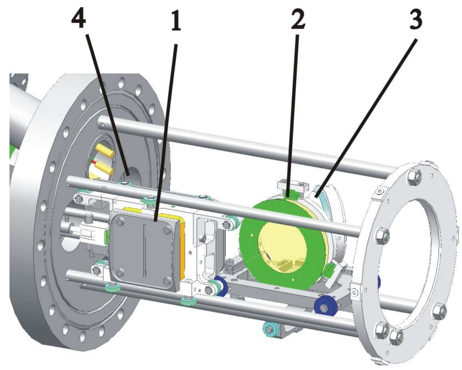

Figure 3: Layout of the emittancemeter: 1) pepper plate, 2) multichannel plate, 3) mirror, 4) view port to CCD camera.

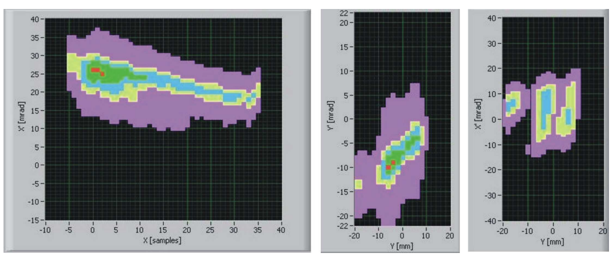

Figure 4: Left: Phase-space profiles of a 111 keV Ne^{6+} beam. Right: x-x' emittance. Middle: y-y' emittance. Right: x'-y correlation.

ticusp ion source which is normally used for the production of p, d and α beams. This is done by removing the tungsten filament and installing instead two copper rods on which a small, commercially available alumino-silicate $^6Li^+$ source is mounted. The length of the copper rods is such that the emission area of the alumino-silicate ion source is positioned just in front of the extraction electrode of the multicusp source. A photo of this assembly is shown in Fig. 5. The Li^+ beam is extracted using the extraction system of the multicusp source and focussed onto the object plane of the 90° bending magnet. The alumino-silicate ion source is equipped with an internal heater that heats the ion source to a maximum temperature of 1100 °C using 65 W of electrical power. The extracted $^6Li^+$ current strongly increases as a function of the heating power as is also shown in Fig. 5. Alumino-silicate ion sources are available for all alkali and alkaline-earth elements.

SUMMARY AND OUTLOOK

Ion source development at KVI is driven by the intensity demands for the TRIμP project, i.e. a 1 kW heavy-ion beam on target. For neon beams this corresponds to injecting approximately 180 eμA Ne^{6+} into the matching section of the low-energy beam transport line of the AGOR cyclotron. As a first step to realize this goal we have upgraded the ECRIS according to the AECR design of LBL and JYFL. So far we

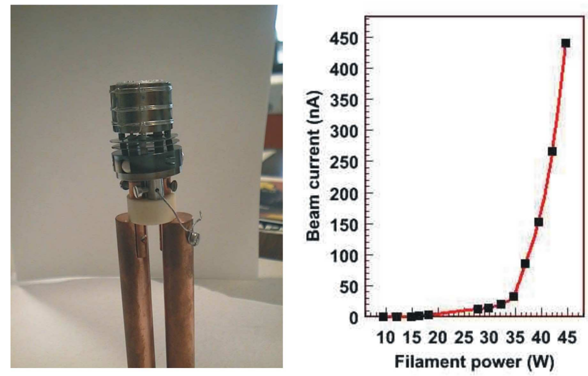

Figure 5: Left: The $^6Li^+$ ion source fixed on its mounting rods. Right: Li^+ current as a function of the heating power.

succeeded in extracting 260 eμA Ne^{6+} from this source. We are implementing two-frequency rf heating and an optimized accel-decel extraction system. In addition we have started a program to improve the ion transport from ECRIS to cyclotron. Our approach is based on extraction and transport simulations and measuring the full 4-D phase-space distribution of the beam. We have therefore developed a versatile emittance meter based on a hybrid pepperpot and scanning technique and using optical detection with a CCD camera. This compact device can be mounted at various locations of a beam line and can determine the beam's phase-space distribution within a few minutes and with an accuracy between 10 and 20%. Finally, we discuss the application of a small alumino-silicate ion source mounted inside a multicusp source to easily produce low-energy beams of singly-charged alkali and alkaline-earth ions.

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