BEAM MEASUREMENTS AT THE ECR-RFQ SYSTEM FOR MATERIALS RESEARCH WITH HIGHLY CHARGED IONS*

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ABSTRACT

The RFQ accelerator for the production of highly charged heavy ions, installed at the Institut für Kernphysik, consists of a 14 GHz ECR ion source in combination with an energy-variable RFQ post-accelerator. It is designed to deliver highly charged ions in the energy range between 1 keV/u (the ECRIS beam) and 100-200 keV/u with the VE-RFQ. Beam measurements have been done with Ar^{8+} beams. The status of the project and results of beam measurements will be presented.

1 INTRODUCTION

Slow highly charged ions, due to the potential energy stored in their atomic shells, are able to induce eletronic transitions in collision with atoms or solids even at kinetic energies far below the treshold for dynamic ionization. Dependent on the charge state, this potential energy can exceed several 10 keV, enabling the liberation of numerous target electrons during collisions of one such ion with surfaces or single atoms (gas targets). At low ion velocities these electron transfer and emission processes only depend on the stationary properties of the colliding ion-atom/ion-surface system. If the ion velocity exceeds that of the electrons bound at the surface or in the bombared atom, the dynmical aspects become more and more important. Thus, being able to vary the ion velocity over a sufficiently wide range (.1 to 3 a. u.) both aspects of the ion-surface or ion-atom interaction can be studied. For these investigations a novel accelerator has been constructed and is almost completed at the Institut für Kernphysik, Frankfurt (IKF) [1,2]. This facility consists of the combination of a 14.4 GHz-ECR ion source (IKF) and a **v**ariable-**e**nergy **r**adio **f**requency **q**uadrupole accelerator (VE-RFQ).

The faclity is show in fig. 1. The first analyzing magnet is designed to simultaneously analyze two charge states from the charge-state-spectrum delivered by the ECR source. One of the charge states is injected into the RFQ, while a higher charge state can be deflected simultaneously into the low-energy beam line. There are two electric quadrupole tripletts in the beamline as focussing elements, one before and one behind the analyzing magnet. Two electrostatic einzel lenses are used for the injection into the RFQ.

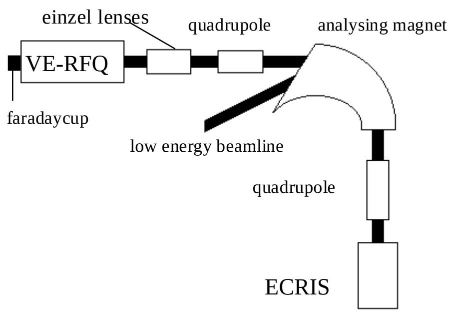

Figure 1: Scheme of the ECRIS/VE-RFQ facility

2 THE 14 GHZ-ECR ION SOURCE

This source was developed in close cooperation with a number of other groups [3,4,5,6], especially the support by the group of C. Lyneis at LBL has to be acknowledged here.

In the present design all inner parts of the source like plasma chamber, hexapole, disk, etc. can be dismounted without opening the structure of the magnetic solenoid.

As radial electron trap, a magnetic hexapole was constructed following a design of Halbach [7]. It is a closed structure of 24 pieces [8,9] optimized for maximum field strenghts. The field measured at the inner surface of the hexapole of our source amounts to

* supported by the BMBF

1.3 Tesla. The system has a total lenght of 190 mm, the inner diameter of the plasma chamber is 58 mm.
Insulation is achieved via two epoxy pipes of 150 mm length seperating the extraction region and the pump of the injection region from the high voltage components of the source. One large pipe seperates the plasma region from the solenoid. Altough all insulators are designed to allow source voltages of U>60 kV, the operation voltages are limited at U=30 kV because of the microwave insulator. Two 360 l/s turbomolecular pumps are used on the injection side and in the beamline. In addition, during operation of the source the extraction region is pumped via a 800 l/s cryogenic pump. After maintanance a vacuum of better than $3x10^{-7}$ mbar is reached using only the two turbo pumps.
The X-ray emission of the source was minimized distinctly below permitted values by inserting special absorbers into the injection chamber.
At to points of the beamline emittance measurements were carried out. The first one was done directly behind the ECR source. The ECR source was able to produce charge states for Argon from q=2+ to q=16+; the maximum was reached at Ar^{8+}. The lowest value of the emittance measured was $\varepsilon = 102.14\ \pi$ mm mrad. This measurement was carried out with a beam energy of $T=q \times 20$ keV. These results are very good also if compared with measurements at other ECR sources e. g. at GSI and LBL. The second group of measurements were done behind the analyzing magnet at the entrance of the einzel lenses. Used charge states were Ar^{3+} to Ar^{8+} extracted with 30 kV. The emittances measured varied between 17 and 50 π mm mrad (The normalized emittance ε_N was $\varepsilon_N < 0.3\ \pi$ mm mrad) with currents between 30 and 40 µA.

3 THE VE-RFQ

The RFQ is basically a homogenous quadrupole transport channel with additional acceleration. The mechanical modulation of the electrodes adds an acceleration axial field component, resulting in a linac structure which accelerates and focuses with the same rf fields [10, 11].
Usually the operating frequency of an accelerator is fixed. This means a fixed input energy per nucleon and a fixed output velocity. In order to provide the large range of ion velocities at different charge states the RFQ structure is designed to allow a variation of the operation frequency between 80 and 110 MHz, which corresponds to an energy variation of a factor of 2 [12]. The resonance frequency of the system is adjusted by changing the effective length of the driving conductor by means of movable shorts. The structure is designed for a minimum specific input charge of q/A=0.15 and input energies between 2 and 4 keV/u. It will provide ion energies between 100 and 200 keV/u. For the highest energy the electric power consumption will be 60 kW. The maximum electrode voltage is 72 kV and length of the electrodes is 138.6 cm. The number of cells of the structure is 158, the length of the cells is growing from 3.9 mm at the beginning of the structure to 13.975 mm at the end of the structure. The diameters of the electrodes are between 4.5 mm and 8.6 mm, while the apertureradiuses are between 3 and 5 mm. Accepted normalized emittances of the RFQ are between 0.2 and 0.5 π mm mrad. The structure is mounted in a vacuum chamber wich has a length of 150 cm and a diameter of 50 cm. The parameters of the RFQ are shown in table. 1.

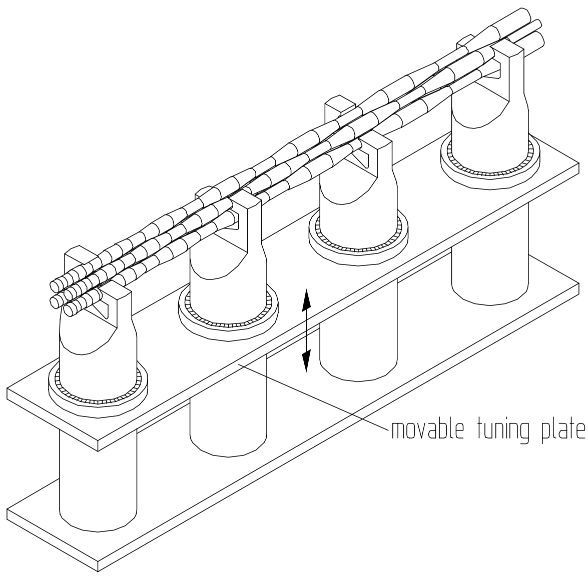

Figure 2: The VE-RFQ

In december 1995 first beam measurements were carried out behind the RFQ. The resonance frequency was adjusted to 94.89 MHz, the used duty cycle was 11.1 % while the rf power was 15 kW corresponding to an electrode voltage of 36 kV. For this frequency an input energy of 2.84 keV per nucleon is necessary. This means an output energy of 5.68 MeV (142 keV per nucleon). The first measurements were done with an Ar^{8+} beam with a current of 10 µA which was extracted from the ECR source with an extraction voltage of 14.2 kV. After optimizing the adjustments at the electrostatic quadrupoles and the single lenses a transmission of 96 % could be reached.
To exactly determine the output energy a Rutherford backscattering diagnostic unit was mounted on the end of the vacuum chamber. This device consists of a thin gold layer target (100 $\mu g/cm^2$) and a semiconductor detector.

Table 1: RFQ parameters

Length of tank [mm]	1548
Diameter of tank [mm]	500
Number of stays	10
Number of cells	158
Lenght of cells [mm]	3.9...13.975
Length of electrodes [mm]	1386
Diameter of electrodes [mm]	4,5...8,6
Apertureradius [mm]	5,0...3,0
Modulation	1...2,25
Injection energy [keV/u]	2,0...4,0
Ion energy [keV/u]	100...200
Specific charge	0,2...1
Rf frequency [Mhz]	80...110
Maximum electrode voltage [kV]	72
Maximum Rf power [kW]	60
Duty cycle [%]	25
Normalized acceptance [π mm mrad]	0,2...0,5

The detector was mounted with an angle of 170° to the beam direction. For this angle and the used target an energy loss of 55.9 % is expected for the backscatterd ions. This means an expected energy of 2.5 MeV for the backscatterd ions of the extracted Ar^{8+} beam. Figure 3 shows the backscattering spectrum of this beam.

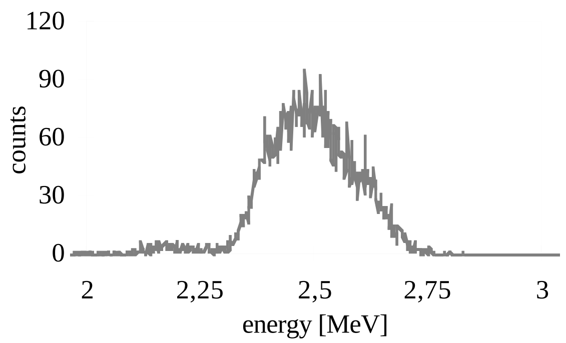

Figure 3: Backscattering spectrum

The maximum of the peak is located at an energy of 2.5 MeV. The width of the peak is caused by the different energy losses of the particles into the gold layer and the energy sharpness of the beam. Accelerated particles could also be registrered at higher rf power. The output energy of these particles was higher than 5.68 MeV, but the width of the peak was growing.

Next steps are to improve the rf transmitter and to carry out emittance measurements behind the RFQ. Subsequent to this the beam line behind the RFQ will be set up and first atomic physics experiments will be done.

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