Status report of the ECR ion sources at the KVI

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Introduction.

At the moment three ECR ion sources are in operation at the KVI. One of these is being used as the ionizer section of the polarized ion (protons and deuterons) source POLIS; it runs at 2.5 GHz. In this paper the emphasis will be on the other two ECRISs, both being used for the production of highly charged ions.
These two sources have a 14 GHz generator, a coaxial Rf power input *à la CAPRICE* [1], room – temperature coils, a permanent hexapole magnet made of NdFeB alloys. In the mechanical set-up both sources have a cylindrical center part, comprising the plasma chamber, the hexapole magnet, and the two axial pole plugs; this center part is connected to the source high voltage supply. The RF wave-guide is connected to a coupling bloc, onto which the coaxial inner tube, the gasfeed and the vacuum pump is mounted. The plasma chambers are thin walled stainless steel chambers, without special coating, surrounded by a second thin walled chamber in order to cool the plasma chamber with water at low pressure from a dedicated cooler. The distance from the inside of the plasma chamber to the hexapole tips is about 2.5 mm.

The complete magnetic field configuration, including the coils, the pole plugs together with the hexapole magnet can slide around the plasma chamber. In this way the position of the plasma electrode and puller with respect to the magnetic configuration can be optimized, without the need to break the vacuum, while for the beam guiding system the ion optics remains fixed.

ECRIS3

ECRIS3 is connected to the AGOR super-conducting cyclotron. The operation characteristics after commissioning were reported earlier [2].
Beams of $^{12,13}C^{6+}$, $^{14}N^{7+}$, $^{15}N^{5+}$, $^{16}O^{6+,8+}$, $^{36}Ar^{11+,12+,14+}$, $^{40}Ar^{8+}$ and $^{3}He^{2+}$, $^{4}He^{2+}$ have been produced at various source voltages (16 – 29 kV), corresponding to a range of beam energies for experiments. The source is operating satisfactorily with sufficiently high beam intensities (from the user point of view). *Gas mixing* is important for high charge state ions. In the case of argon the best results have been obtained with ^{18}O as a mixing gas [3].
During an experiment of ten days with isotopic ^{36}Ar high charge states, the *consumption* amounted 0.6 scc/hr, while the mixing gas consumption was about 6 scc/hr. In this case, the gas inlet was immediately above the turbo pump on injection side, at ground potential, which results in an inefficient usage, as about ¾ of the gas will be pumped away. At a different occasion a low intensity $^{3}He^{2+}$ was needed; in order to reduce the consumption of ^{3}He, natural helium gas was used as a mixing gas, such that a stable source operation could be obtained for the relative low required beam current.

Since the AGOR cyclotron is used for the larger fraction of available beam time with (polarized) protons, the ECRIS3 set up is quite often available for test runs.
A list of best results is given in table 1. The two columns are for different exit holes; the smaller hole was installed for atomic physics experiments.

		ECRIS 3	ECRIS 3	ECRIS4	ECRIS4	ECRIS4	ECRIS4	ECRIS4	ECRIS4	ECRIS4
			$=E^{upstairs}$					$=E_{downstairs}$	$=E_{downstairs}$	$=E_{downstairs}$
axial configuration				"3"	"5"	"5"	"8"			New plugs
coil distance (mm)				65	58	58	52	52	52	52
intermediate coil		No	No	No	No	No	No	Yes	Yes	Yes
extr hole diam (mm)		7	3.7	5.7	5.7	3.7	3.7	3.7	6.1	3.7
Status:		1995-98	1998	1995	1997	1998	1998	Jan-99	Feb-99	Apr-99
O^{6+}	μA	220			110	90	93			
O^{7+}	μA	55		13	13	13	12	16		25
Ar^{8+}	μA	70				55	55	60	64	82
Ar^{9+}	μA	74				25	25	41		59
Ar^{11+}	μA	52				8	12	26		34
Ar^{13+}	μA	15				1.7	2.5	8		9.4
Ar^{14+}	μA	4.7				0.6	0.7	3.9	4.1	4
Ar^{16+}	μA	0.27				0.003	0.014	0.22	0.21	
$^{nat}Xe^{19+}$	μA	3								
$^{129}Xe^{19+}$	μA		5				0.5			
$^{nat}Xe^{28+}$	μA	0.1								
$^{129}Xe^{28+}$	μA		0.9							
$^{nat}Xe^{31+}$	μA	0.02								
$^{129}Xe^{31+}$	μA		0.03							

Table 1. Best results obtained (in μA) with ECRIS3, and at various stages with ECRIS4.

ECRIS4
ECRIS4 is connected to the five experimental set-ups of the Atomic Physics group. It is very intensively used to deliver all kinds of high and low charged ions (all "gaseous"), in the mass range of A= 1 – 131, at source voltages from 1-25 kV. This source is equipped with a strong Halbach type hexapole magnet, designed by the Giessen group [4].
The performance for O^{7+} and Ar^{14+} beams was, until modifications at the end of last year, about a factor 5 lower as compared to the currents of ECRIS3, see table 1. It was tried to optimize the source by modifying the axial magnetic configuration, e.g. by increasing the pole plug lengths, by decreasing the distance of the coils, by shifting the location of the

hexapole magnet with respect to the coils and plugs. These changes did not result in any improvement of importance. A discussion in terms of the effect of the (very) strong hexapole magnet is given in a separate paper [5]
The greater part of the beam intensity usually is lost at the small diaphragms used in the specific target chambers. It was considered to substantially decrease the exit hole of the source (to 3.7 mm), such that those losses would occur already in the source. The advantage would be that various aberrations in the beam could be reduced. These aberrations could easily be picked up during beam formation in the fringing field of the narrow and strong hexapole magnet. Lower aberrations would then result in a better transmission and a higher beam current on target.
Indeed, a smaller exit hole gave slightly higher currents on target. With respect to the currents produced by the source itself, these maximum currents - in spite of the considerably smaller exit hole - did not change too much.
Although the high charge state currents (e.g. of argon and xenon) are low, experiments have even been performed with Xe^{19+} beams, even at 1 kV source voltage.

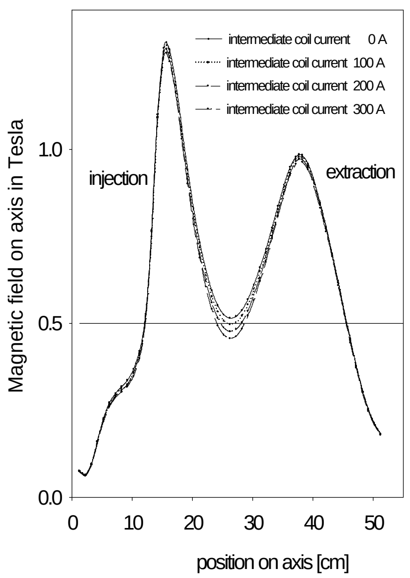

Fig. 1 Effect of intermediate coil

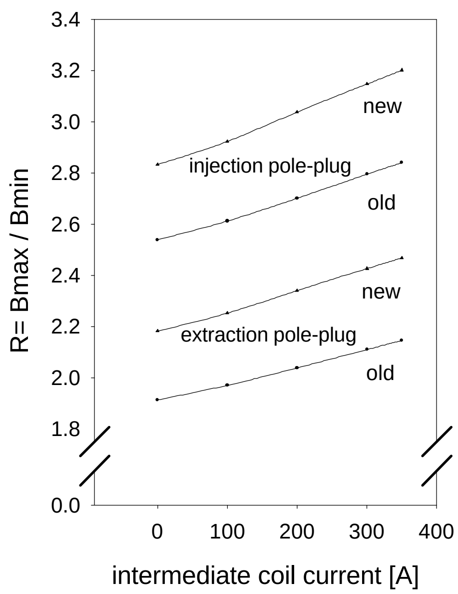

Fig. 2 Effect of optimization of pole plugs

Further optimization

The availability of the ECRIS3 set up has given the opportunity of interchanging the central part (i.e. hexapole magnet, pole plugs and vacuum chamber) of the two sources, with the aim to improve the moderate operation of ECRIS4. In the new situation, the best part is being used in the Atomic Physics area, indicated as $ECRIS^{upstairs}$. The part, which needs to be optimized further, is installed in the set-up for AGOR (called $ECRIS_{downstairs}$), where time for upgrading is available.

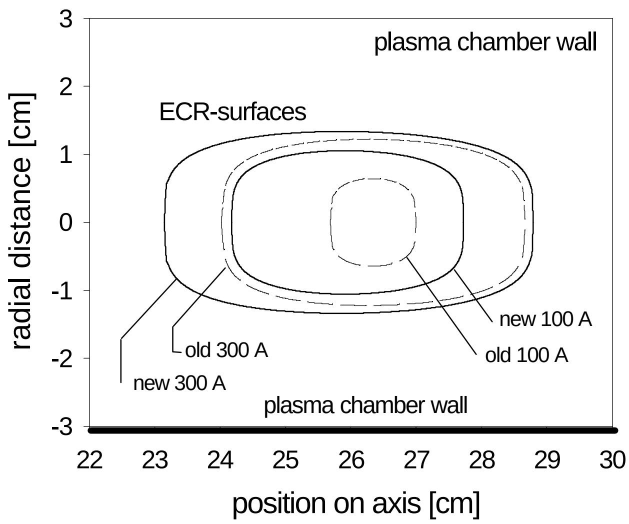

Fig. 3. Location of various ECR surfaces for different currents through the intermediate coil, with "old" and "new" pole plugs

A substantial improvement was obtained by reshaping the axial magnet configuration. Firstly, this was realized by the installation of an *intermediate* coil with reversed current between the two major coils; it resulted in a *reduction* of the *minimum* axial field by 10 % and at the same time in a substantially increase of the ECR resonance zone length. Figure 1 shows the results of the measurements. In this way the performance of ECRIS4 has greatly improved, as can be seen in table 1, results of January 1999 and later. In particular, the shape of the charge state distribution is much better, indicating that the obtained electron temperatures and densities are much closer to the desired situation.
Secondly, by reshaping the pole plugs, according to model calculations, the two field *maxima* could be *increased* by about 10 %. In figure 2 the measured effect on the axial mirror ratio is given for the new pole plugs in comparison with the old pole plugs; the effect of the intermediate coil is also shown. Figure 3 gives the locations of the ECR surfaces, which are deduced from various measurements.
Table 1 gives a few results, see column April 1999. From these new results it becomes clear that the performance of the ECRIS4 is now about similar to that of ECRIS3.

Summarizing: The two ECR ion sources at KVI have reached the same level of performance, close to that of a CAPRICE type ion source. Further improvements by using other techniques like "two frequency" heating or Aluminum coating are possible.

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