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MONO 1000 : A SIMPLE AND EFFICIENT 2.45 GHz ECRIS USING A NEW MAGNETIC STRUCTURE CONCEPT

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The production of singly-charged atomic and molecular ions with a new 2.45 GHz ECR (Electron Cyclotron Resonance) ion source has been studied. The ion source Mono 1000 uses a new magnetic confinement structure. The elements Ne, Ar and Kr are ionised with efficiencies close to 100%, while 45% has been achieved for He. In the case of the molecules SO_2 and SF_6, more than 90% overall efficiency has been observed with more than 40% of sulfur atoms leaving the source under the form S^+. A total extracted yield of 4 x 10^{12} singly-charged fulleren (C_{60}) ions per second has also been observed.

I. INTRODUCTION

Important efforts are constantly required to develop new radioactive ion production systems[1,2,3]. As we look for radioactive nuclei ever farther from the valley of stability, the production rate decreases, implying that a more efficient ionization process is needed. Moreover, their short half-lives require the use of a rapid ion production system. The last strong constraint comes from the dose rates which arise during irradiation, and which limit the life of the equipment. The production system must therefore be simple, reliable and as cheap as possible[4]. In the frame of the SPIRAL project ("Système de Production d'Ions Radioactifs en Ligne") at GANIL, an alternative solution to the Radioactive Ion Beam System (RIBS) has been proposed[5,6]. The new target ion-source equipment, called $1^+/n^+$ charge breeding, consists of two parts. The first part includes the target and an ion source producing singly-charged ions. The type of ion source is chosen in accordance with the chemistry of the element to be produced. It is located in the production cave and, since it is exposed to high radiation levels, it is often replaced. The second component is a multi-charged ECR ion source, installed outside of the cave, and into which the singly-charged ions are injected. In order to ionize radioactive gases in a 1+ charge state with good efficiency, a new ECR ion source has been designed. Compared with a standard ECR ion source that uses different magnets to confine the plasma longitudinally and perpendicularly to the source axis, the new magnetic structure is greatly simplified, while providing a confinement which leads to an ionization efficiency close to 100%.

II. DESIGN

A. Magnetic structure

A new magnetic confinement structure[7] has been employed in the Mono 1000 source. The magnetic field is obtained with two rings of permanent magnets. The two minimum fields are equal to zero Tesla (Fig. 1). Equipotentials of the magnet are plotted every 0.02 T, from the center to outside, except for 0.23 T, which is the last closed equi-potential field surface. The outermost surface is at 0,4 T. The magnetic field is very sensitive to the orientation of the magnets.

B. Mechanical design

Due to the absence of multipole between the rings (Fig. 2), it is possible to have access to the plasma perpendicularly to the source axis from four flanges, making the source as flexible as possible during the tests. Without these flanges, the chamber of the source could be reduced to a very simple pipe without a "double-skin cooling chamber", provided that the RF power remained below one hundred watts. Including the flanges, the external dimensions of Mono 1000 are 330 mm x 330 mm x 315 mm. Its mass is 33 kg.

C. Extraction

The plasma electrode is 7mm diameter and is made from aluminum. The extraction electrode material is stainless steel and has an external diameter of 30 mm and an inner diameter of 12mm. The maximum current extracted is proportional to the area of the plasma electrode hole, up to a maximum diameter of 7.5 mm. The plasma electrode hole is 7 mm in diameter for all the results presented, except for emittance measurements.
The perfect cylindrical symmetry of the beam is due to the cylindrical symmetry of the magnetic field Fig. 3 shows an emittance of 26 π.mm.mrad for a $^{4}He^{+}$ beam at 11 kV.

D. Radio frequency

The working radio frequency (RF) was 2.45 GHz, corresponding to a magnetic field of 0,087 T. However, owing to the high magnetic field closure at 0.23 T, it is possible to use RF over a large range, between 0 and 4 GHz, while conserving a mirror ratio higher than 1.5. For optimizing reflected power (below 10%), efficiency and maximum extracted current, a coaxial cable/wave guide transition offers the best solution (Fig. 2). It can be mounted perpendicularly to the source axis or on the rear flange. The aperture dimensions of the radial source flanges are 90 mm x 58 mm.
The available RF power during the tests was in the 0 to 200W range. The tuning of the source depends only on RF power and gas flow control. The reduced number of parameters makes the ion source ideal for automated tuning.

E. Gas injection

For an extracted current of 200μA, if the residual gas is not sufficient to act as a support gas, it is necessary to add ^{4}He to produce Ne^{+}, Ar^{+} and Kr^{+} ions. To measure the ionization efficiency of $^{4}He^{+}$, ^{3}He is added. The precision of the gas pressure measurement is better than 10%, and then the results are given with this error bar.

III. RESULTS (Table I)

A. Ionization efficiency of noble gases

Values of the maximum current and of the maximum efficiency (Table I) are obtained in two different measurements (except for SO_2). All the efficiency measurements were made while using a calibrated leak of 36.7pμA (for Ar), or a pre set micro-valve. For other gases, the corresponding leak is a function of the square root of the mass ratio. For Ne^{+}, Ar^{+} and Kr^{+} ions, the total ionization efficiency is close to 100%. For Ar^{+}, this efficiency has been verified for different values of a leak, between 36.7pμA and 321pμA, obtained by varying the upstream pressure of the calibrated leak. The 45% ionization efficiency of ^{4}He has been obtained by injecting ^{3}He or H_2 as a support gas.

B. Beam intensity

The maximum intensities are corrected for the transport efficiencies of the beam line. One can observe that the evolution of the maximum current of ^{3}He, ^{4}He, $^{20}Ne^{+}$ and $^{40}Ar^{+}$ ions through the same plasma electrode hole and at similar energies depends on the square root of the masses, as for a gas emerging from a chamber through a hole.

C. Ion beams of condensable elements

$^{32}S^{+}$ was obtained by injecting SO_2 or SF_6 into the source through a micro valve. The system is calibrated by injecting argon simultaneously through this valve and through the calibrated leak. Measurements of Ar^{+} current with and without the calibrated leak allow the control of the ionization efficiency at different working points and determine the aperture of the micro-□□□valve. The injection of SO_2 (285pμA) or SF_6 (105pμA) in place of argon, led to a 97% conversion of sulfur to atomic or molecular ions at the exit of the ion source. More than 40% of sulfur atoms were extracted

as S^+ ions. In order to eliminate contribution of O_2^+, measurements were performed for $^{34}S^+$; the yield of $^{32}S^+$ ions was deduced from the natural ratio between ^{32}S and ^{34}S isotopes.

D. Molecular ion beams

Results of molecular ion beams produced by SO_2, SF_6 and C_{60} ionization and/or fragmentation are also given. To obtain these results, the RF was reduced to a power lower than 10W.

IV. OUTLOOK

These tests validate the new magnetic confinement structure achieved with only two permanent magnet rings. This allows the construction of very simple ECR singly-charged ion sources, which nevertheless present a high efficiency for gases and sulfur. Moreover, the beam emerges from the source with cylindrical symmetry.

Using the same magnetic principle, an ECR singly-charged ion source has been built and tested for a plasma that is 700mm long and 90mm in diameter. It performed similarly to the Mono 1000. This"ion guide" source has the ability to transport ions with various mass-to-charge ratios. For gases or condensable elements, the ionization efficiency was close to 100%, which suggests a transport efficiency close to 100%.

Good ionization efficiency and simplicity of design qualify Mono 1000 as a singly-charged ion sources for the 1+/n+ proposal. Moreover, its apertures allow one to install a radioactive isotope production target very close to the source plasma, thus increasing the transfer efficiency towards a maximum. Nevertheless, for radioactive ion production, the use of magnetic coils is preferred over the use of permanent magnets which are sensitive to neutron irradiation. A new singly-charged ion source based on the same magnetic structure but equipped with coils is presently under consideration.

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[5] R. Geller, Rev. Sci. Instrum. **71**, 612 (2000).

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[7] Patent CEA/CNRS n° B 12544.3, licence Pantechnik

Figures captions

		U_{source}	I_{max}	Calibrated leak	Transport Efficiency	Eff.	Eff_{tot}
		kV	μA	pμA	%	%	%
Noble gases							
$^{3}He^{+}$		18.5	2830	134	64	38	39
$^{4}He^{+}$		18.5	2360	116	66	45	46
$^{20}Ne^{+}$		18.1	1120	52	68	92	96
$^{40}Ar^{+}$		17	820	36.7	50	93	100
Kr^{+}		7.2	185	25.3	45	94	100
Condensable elements							
$^{40}Ca^{+}$		10,7	46				
From $Fe(C_5H_5)_2$	$^{56}Fe^{+}$	10,1	85				
From SO_2	$^{32}S^{+}$	8,6	121	285	92	42	97
$^{32}S^{2+}$		‘’	~5	‘’	‘’	2	‘’
SO^{+}		‘’	99	‘’	‘’	35	‘’
SO_2^{+}		‘’	~52	‘’	‘’	18	‘’
From SF_6	$^{32}S^{+}$	17	48	105	29	46	≥91
$^{32}S^{2+}$		‘’	47	‘’	‘’	45	‘’
Molecular ions							
C_{60}^{+}		0,75	0.7		2		
From SF_6	$^{19}F^{+}$	3,7	0.3	105			
$^{32}S^{+}$		‘’	1	‘’			
SF^{+}		‘’	1.3	‘’			
SF^{2+}		‘’	3.5	‘’			
SF^{3+}		‘’	20	‘’			
SF^{4+}		‘’	0.45	‘’			
SF^{5+}		‘’	7	‘’			
SF^{6+}		‘’	0.17	‘’			

Table I : Results obtained with Mono 1000 for ^{3}He, ^{4}He, ^{20}Ne, ^{40}Ar, ^{84}Kr. The efficiency measurements were made with a calibrated leak of 36.7pμA of Ar for noble gases and with a micro-valve for condensable elements. Eff. and Eff_{tot} correspond respectively to the ionization efficiency for the ion given in the first column, and to the total ionization efficiency. Corrections for transport efficiency of the beam line and for total ionization efficiency were included.

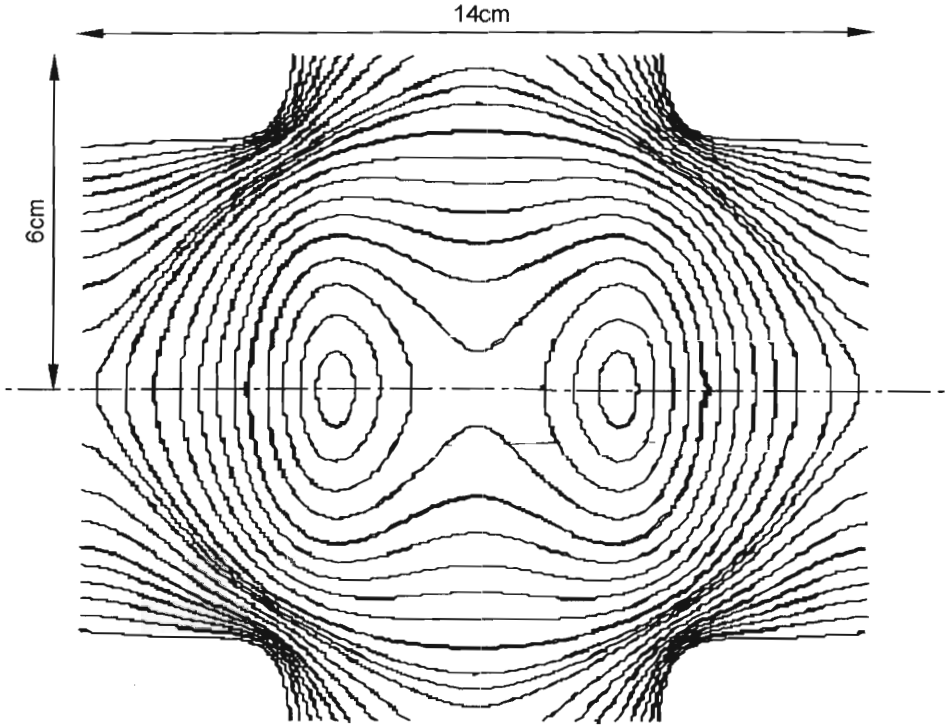

Fig. 1. Magnetic field equipotential surfaces of Mono 1000. The two minimum fields are equal to zero Tesla. The potentials are plotted every 0. 2 T, from the center to the outside, except for 0.23 T, which is the last closed equipotential field surface. The last surface given is for 0.4 T.

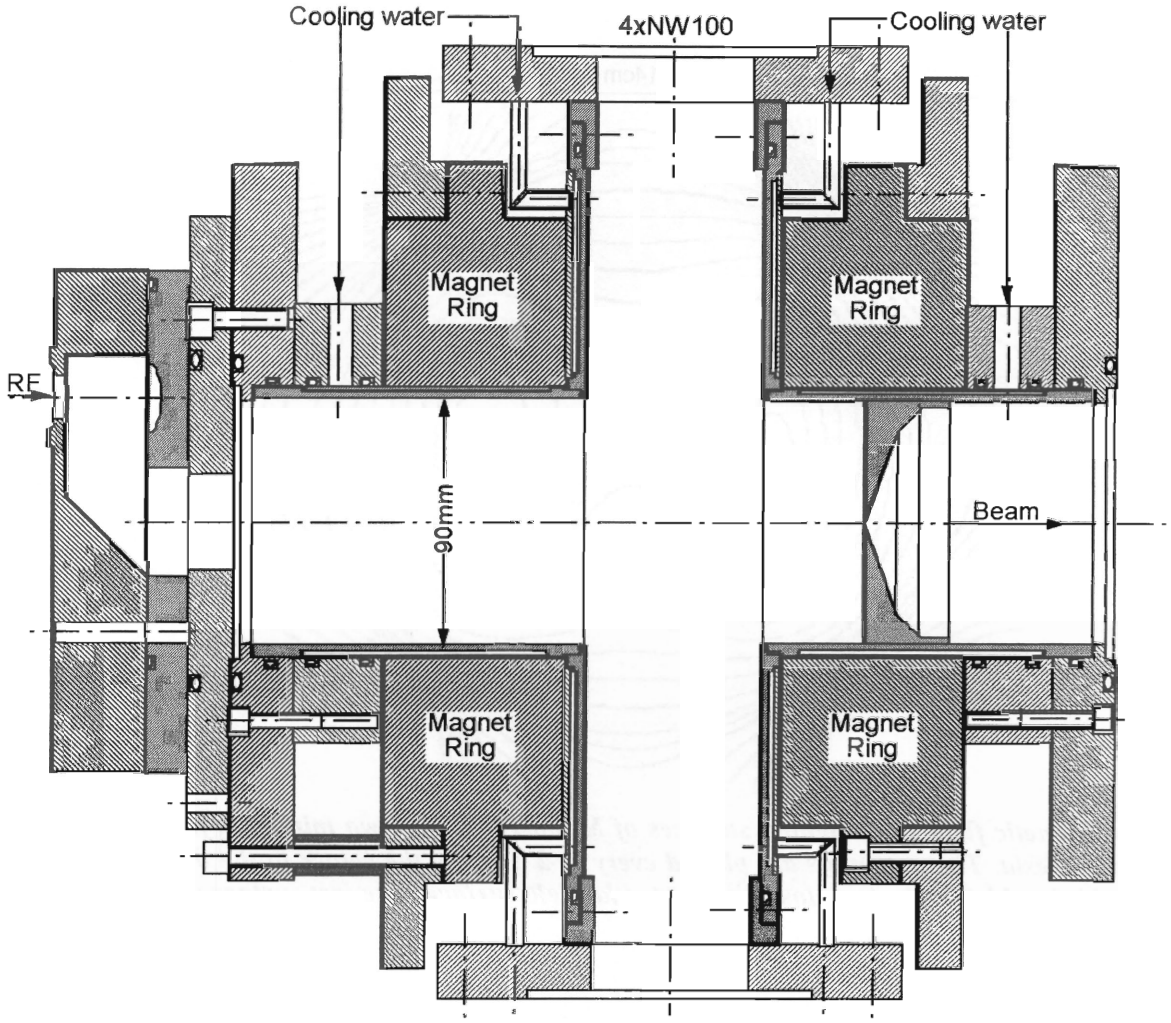

Fig. 2. Mechanical design of the Mono 1000 ion source, equipped with permanent magnet rings.

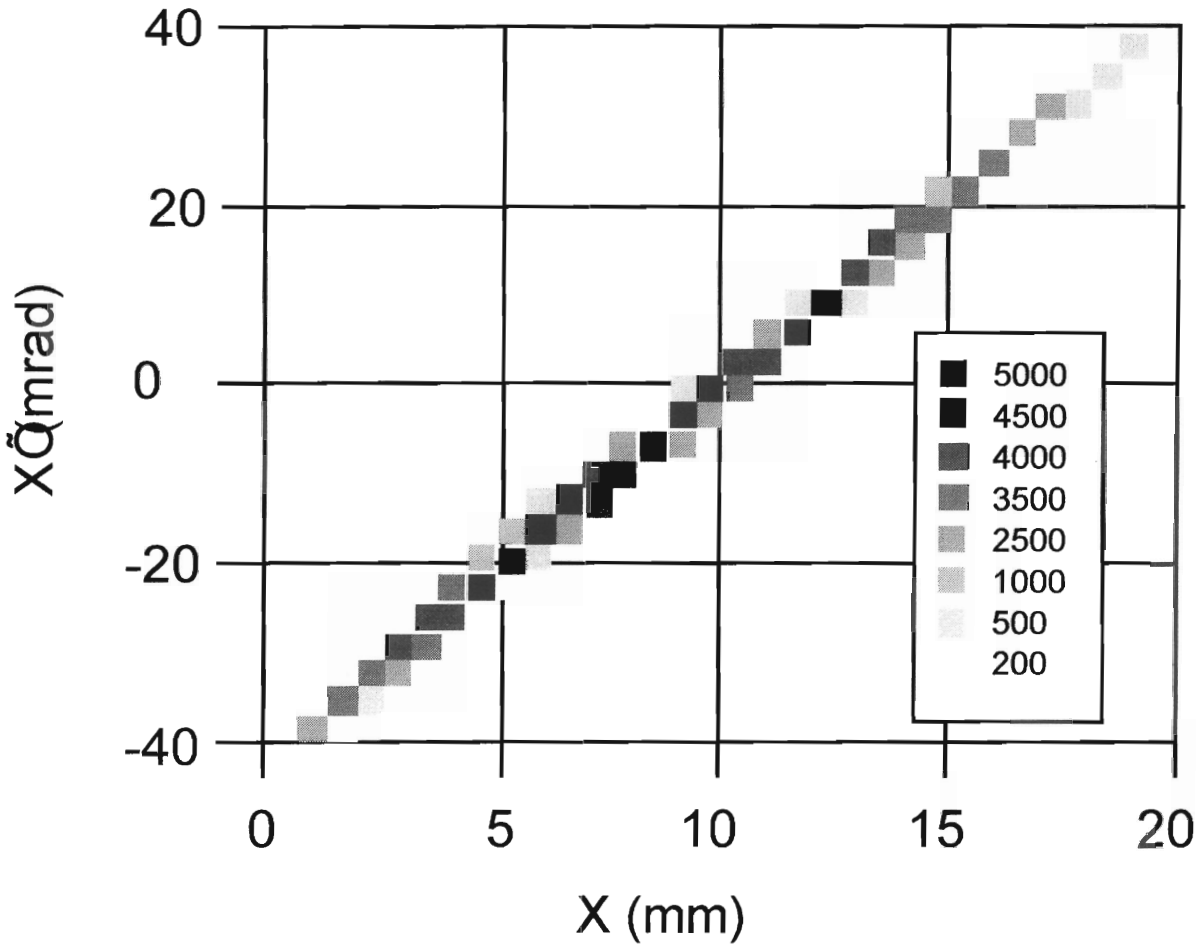

Fig. 3. Emittance of Mono 1000 obtained with 90μA of He^+. HV source : 11kV. Plasma electrode hole : 2mm. Extraction electrode hole : 12mm. Geometrical emittance : 26 π.mm.mrad, corresponding to 92% of the beam.