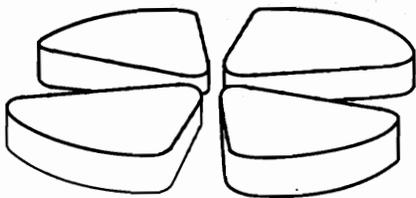


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Abstract

The first on-line production system for SPIRAL/GANIL (Radioactive Ion Production System with Acceleration on-Line) phase-I has been commissioned on the SIRA (Radioactive Ion Separator) test bench. Exotic multicharged noble gas ion beams have been obtained during several days. In parallel, a new ECRIS (Electron Cyclotron Resonance Ion Source) for monocharged ions has also been developed. Preliminary off-line results are presented.

The efficient production of radioactive nuclear beams by the ISOL (Isotope Separation On-Line) method is intrinsically related to the efficiency of the ion source employed in the production system. The use of ECRIS (Electron Cyclotron Resonance Ion Source) [1] is particularly interesting due to its high plasma density and good confinement, which allow efficient ionisation of almost all elements of the periodic table. Moreover, ECRIS is well suited for production of highly charged ions, which is an important ingredient for producing accelerated beams in a wide range of energy. The development of ECRIS for on-line production [2] at GANIL/SPIRAL [3] is undertaken following two different directions. The first one allows an optimum production of radioactive multicharged ion beams of noble gases directly inside the production cave (NANOGAN-III). The second one searches an optimum system for producing radioactive monocharged ions of any element in the production cave (MONO1000), with subsequent transformation in multicharged ions

somewhere else. Following these two different directions two different ECRIS are presented in this contribution.

The NANOGAN-III (Figure 1) is a compact permanent magnet ECRIS developed for the SPIRAL project. The magnetic circuit consists in a sextupolar magnetic structure for radial confinement superposed by two axially and one radially magnetised permanent magnet rings. The total permanent magnet weight of the source is 47.7kg. This ion source has been designed for operation with a 10GHz transmitter. Its power consumption is of 200W when tuned for the best charge state distribution performance. NANOGAN-III is an evolution of the preceding model NANOGAN-II [4] which worked at 14.5GHz. The new version, even working at lower frequency, has several advantages. In order to lower the magnetic field in the center of the plasma chamber, one of the permanent magnet rings has been removed. This decreased the cost and the weight of the ECRIS to 4/5 of the preceding one. The transmission of the beam through the separator has been improved, which could mean that the emittance of NANOGAN-III is smaller than the preceding version. The ion source is linked to a carbon target by a cold and short transfer tube. This allows efficient production of noble gas elements with reasonable suppression of condensable contaminants.

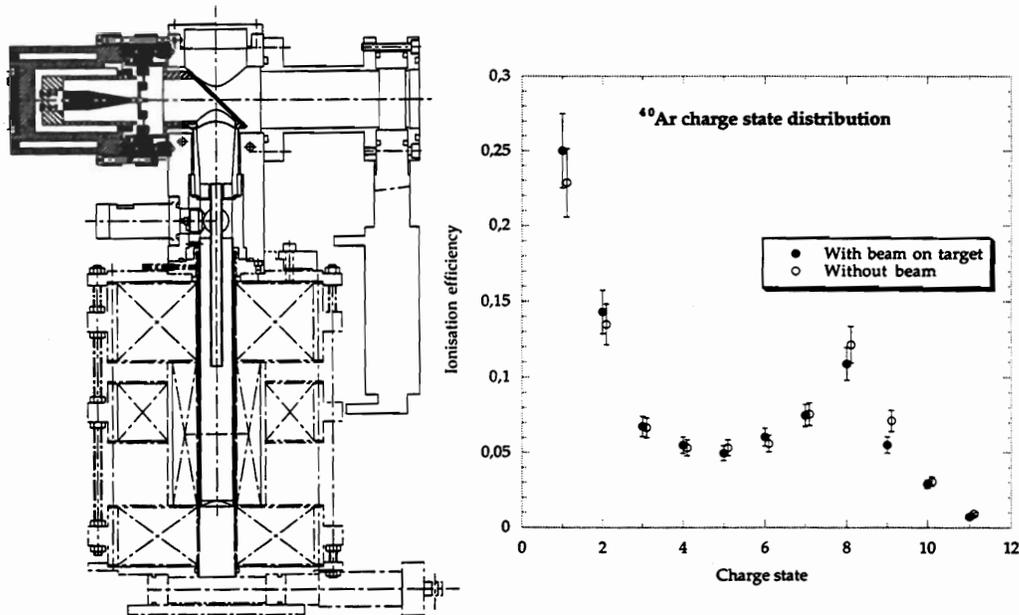


Fig. 1. NANOGAN-III system and charge state distribution of ⁴⁰Ar with and without beam in target.

The overall transmission of an extracted beam of 1 milli-Ampere at the SIRa separator is approximately 90% at 20kV extraction voltage. The ionisation efficiency - all charge states - of Ar ions has been measured to be better than 95%. This measurement is made by injecting a calibrated leak of Ar gas inside the ion source chamber off-line as well as during the on-line tests. The

Table 1

Selected yields for the commissioning of SPIRAL. Primary beams of ^{13}C , ^{20}Ne , ^{36}Ar and ^{78}Kr of 2.0kW, 0.4kW, 2.0kW and 0.2kW have been considered.

<i>Beam</i>	<i>Charge</i>	<i>Yield</i>	<i>Beam</i>	<i>Charge</i>	<i>Yield</i>
$^6\text{He}(0.8\text{s})$	1+	$3.2 \cdot 10^8$	$^{34}\text{Ar}(0.84\text{s})$	(6 – 8)+	$1.2 \cdot 10^7$
$^8\text{He}(0.12\text{s})$	1+	$2.0 \cdot 10^6$	$^{35}\text{Ar}(1.78\text{s})$	(6 – 8)+	$3.0 \cdot 10^8$
$^{17}\text{Ne}(0.11\text{s})$	(3 – 6)+	$3.0 \cdot 10^4$	$^{72}\text{Kr}(17\text{s})$	(13 – 16)+	$8.0 \cdot 10^1$
$^{18}\text{Ne}(1.7\text{s})$	(3 – 6)+	$3.0 \cdot 10^6$	$^{73}\text{Kr}(27\text{s})$	(13 – 16)+	$2.0 \cdot 10^3$
$^{19}\text{Ne}(17\text{s})$	(3 – 6)+	$5.0 \cdot 10^7$	$^{74}\text{Kr}(11\text{m})$	(13 – 16)+	$1.0 \cdot 10^5$
$^{31}\text{Ar}(15\text{ms})$	3+	7.0	$^{75}\text{Kr}(4\text{m})$	(13 – 16)+	$7.0 \cdot 10^5$
$^{32}\text{Ar}(98\text{ms})$	(6 – 8)+	$1.5 \cdot 10^3$	$^{76}\text{Kr}(14.8\text{h})$	(13 – 16)+	$3.0 \cdot 10^6$
$^{33}\text{Ar}(0.17\text{s})$	(6 – 8)+	$1.7 \cdot 10^5$	$^{77}\text{Kr}(74\text{m})$	(13 – 16)+	$2.0 \cdot 10^7$

charge state distribution of ^{40}Ar ions when NANOGAN-III is tuned in order to maximise the 8+ charge state is shown in Figure 1. The comparison between the off and on-line distributions attests that the ion source is almost insensitive to the heating and the to presence of the beam on the target. It should be noted that before the irradiation of a new target, one should degas the complete system for approximately 48 hours. The production yields obtained on-line at SIRa with NANOGAN-III is shown in table 1. The presented numbers have been extrapolated from 0.4kW to 2.0kW for ^{13}C and ^{36}Ar primary beams.

At GANIL, the development of ECRIS for monocharged production is intrinsically related to the charge booster project, i.e. the reinjection of the beam into another ion source for charge multiplication before the injection into the accelerator. This important condition fixes not only the required efficiency but also the characteristics of the beam provided by the 1+ ECRIS. Another important aspect of the problem is the functioning cost. It is evident that a monocharged ion source is cheaper than a multicharged one. If one consider that the life time of the production system is limited, a smaller and cheaper ion source is needed inside the production cave - very close to the irradiation point.

The MONO1000 ECRIS (Figure 2) has been designed in order to have a large magnetised chamber of approximately 1 liter of volume, allowing one to place a target and/or a heating internal wall system with external cooling. The magnetic structure is made with two permanent magnets rings (total weight of 22.2 kg), which allows to create a closed 2000 Gauss surface at the wall of the plasma chamber. The plasma electrode is located in a 1800 Gauss magnetic field. It has to be pointed out that no specific radial structure is used - the

magnetic field is on revolution symmetry - and that the magnetic field in the extraction area presents a cylindrical geometry. During the first commissioning tests, the 2.45 GHz microwave was injected into the large diameter (90 mm) cylindrical plasma chamber through a coaxial transition ended by an antenna.

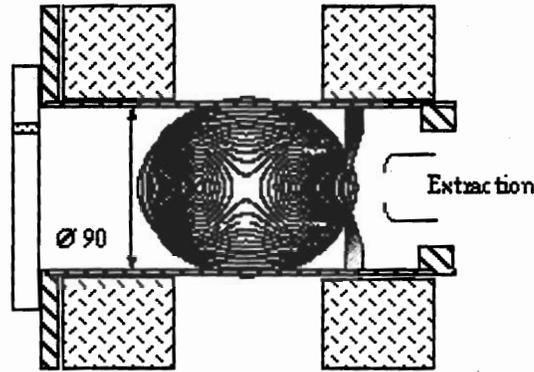


Fig. 2. The MONO1000 ion source.

The first tests of the ion source have been made with Argon and Helium gas. The pressure inside the source was around $2 \cdot 10^{-6}$ mbar and the injected microwave power did not exceed 20 W. The ionisation efficiency of the source has been measured injecting a quantity of Ar gas through a calibrated leak and tuning the source with He as support gas. The measured ionisation efficiencies for ^{40}Ar at 1+ and 2+ states were respectively 90% and 9%, inside a root mean squared emittance of 27π mm mrad at $E = 14\text{keV}$. Moreover, ^{32}S beam production has been also studied injecting a calibrated quantity of the gaseous molecule of SO_2 in the source. This test - also made with a maximum injected power of 20W - revealed an overall efficiency of ionisation for the compounds of ^{32}S of around 95%. This efficiency is distributed on 43 % of ^{32}S (1+), 1.8 % of ^{32}S (2+), 35 % of ^{32}SO (1+) and 24 % of the mixture $^{32}\text{S}_2$ (1+) with $^{32}\text{SO}_2$ (1+). It is clear that several different molecules are still present on the spectrum of the extracted ions. The ratio between the yield of this molecules and the ^{32}S (1+) beam varies strongly with the microwave power. Presently we are limited to around 20W due to our microwave coupling. A new coupling is being developed which could allow one to deliver one order of magnitude more power in the ion source.

In conclusion, we presented two different ECRIS for on line radioactive ion beam production. The first one, NANOGAN-III 10 GHz, is used at the SPIRAL project, allowing one to produce efficiently multicharged radioactive beam of rare gases. The second one, MONO1000, is a low cost monocharged ECRIS working at 2.45 GHz. The first off line tests producing beams of He, Ar and S have shown excellent efficiencies.

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