Report on novel techniques for the production and selection of ECR-ionized radioactive ions beams

Different novel techniques were studied or tested for the production of pure metallic radioactive ion beams from ECRIS. The results of these investigations were reported in the associated Milestone reports attached to this document. These investigations concerned:

- The production of metallic ion beams by combining an upgraded Phoenix charge breeder for providing beams of better purity, and of a state of the art FEBIAD source (MS110 and MS114)
- The production of metallic ion beams of carbon from the miniature COMIC ion source at ISOLDE (MS 111)
- The comparison of production of multiply charged carbon beams using a Phoenix charge breeder at LPSC and the Nanogan 3 ECRIS at GANIL (MS112)
- The possible use of the ARC ECRIS concept as a versatile and efficient charge breeder (MS113)

Outlook

The first study (MS110) and experimental work (MS114) should lead to the future production of pure metallic ion beams from light elements at SPIRAL by the beginning of 2017. At LPSC, the COMIC source is being further developed. A 5.6GHz version should soon be tested. The production of carbon beams (MS111 and MS112) is still of high interest at GANIL and ISOLDE, and should soon be tested on-line with the upgraded SPIRAL 1 facility.

In the following, a compilation of milestone reports is given which summarizes the work done in PREMAS for the production and selection of ECR-ionized radioactive ions beams.

MS110

Task 3: Sources of Pure and Intense Radioactive Ion Beams (GANIL)
Short report on the Milestone JRA03-MS110: Radioactive beams of condensable elements: evaluation of ECR- ionization methods for GANIL / SPIRAL 1

Performances of the present SPIRAL

SPIRAL makes use of the ISOL technique: the intense heavy ion beams of GANIL impinge on a thick graphite target where the fragments are stopped. The radioactive atoms diffuse out of the hot target and effuse via a transfer passage to the Nanogan III Electron Cyclotron Resonance (ECR) ion source. The radioactive ions are then separated and accelerated in the Cyclotron d'Ions de Moyenne Energie (CIME) [1]. Fig. 1 presents the current Target – Ion Source System (TISS) used at SPIRAL.

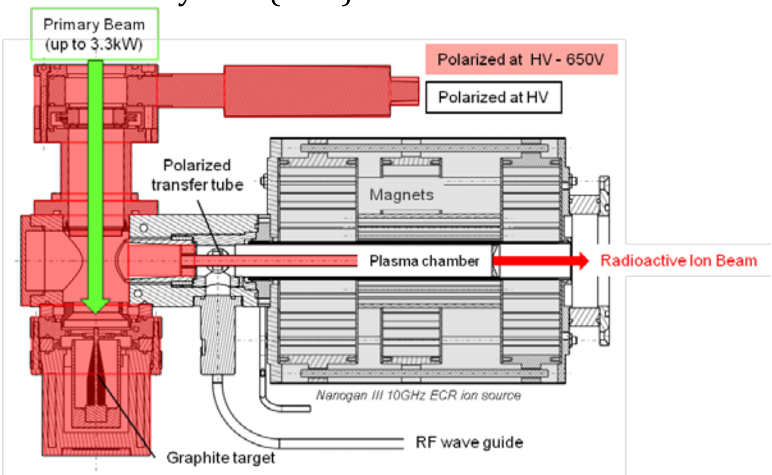

Figure 1: Present target –ion source system used at SPIRAL. It couples the Nanogan III ECR with a graphite target via a cold transfer tube.

During the past decade a number of physics highlights were obtained with the very intense and pure radioactive ion beams available at SPIRAL [2]. However the present ionization technique is limited to gaseous elements: it prevents the ionization of condensable elements as the transfer tube and the Electron Cyclotron Resonance (ECR) source is a cold assembly that stops the effusion of radioactive isotopes of condensable elements from the hot target to the ion source plasma.

Evaluation of methods of condensable beam production

Compared to rare gases, radioactive atoms of condensable elements produced by the ISOL method suffer from comparatively longer sticking times on surfaces that they encounter during their transport from the target to the ion source volume. As high temperature reduces the sticking time, the condensable elements are traditionally produced using hot target and ion source assemblies [3]. Typical ion sources used in this case are hot surface sources, such as surface ionization sources, Forced Electron Beam Induced Arc Discharge sources (FEBIAD sources also called "hot plasma" sources), and Resonant Ionization Laser Ion Source (RILIS). An alternative to this scenario was tested at GANIL in the past by a coupling directly ECR sources to targets at the SIRa test bench

[4,5]. Due to the diversity of the beams requested in letters of intent submitted to the GANIL PAC by the user community, a FEBIAD source developed recently at ISOLDE, the so-called VADIS [6], and of a surface ionization source previously tested at SIRa [7] were found to be the ion sources of condensable elements to be coupled in priority with the SPIRAL targets. Last year, during two successive test beam times, the SPIRAL target - VADIS source combination has been shown to be an effective solution for the diversity of beams it could produce. The results of the corresponding tests will be detailed in a forthcoming publication and are shown for record in Table 1. Using such ion sources, radioactive isotopes of 9 new elements have been already ionized during on-line tests: radioactive isotopes of the alkali Na, K, metallic Al, Fe, Cu, Mn and halogen Cl elements were all produced from the VADIS while the alkali ions Li, Na, K, have been produced with high selectivity and higher efficiency from the MonoNaKe surface ionization source. This list is non exhaustive as more elements can in principle be ionized by the VADIS. The production of molecular beams, such as CO^+, or AlF^+, which is commonly used for easing transport (effusion and diffusion) processes within the target and ion source or for purification purpose, is an additional possibility offered by such an ion source.

Table 1: Preliminary results of the two test beam times for the new target – ion source prototype using a VADIS at SIRa. The column to the right shows intensities when scaled to the nominal power (1.5kW for ^{36}Ar and 750W for ^{58}Ni). In the case of the ^{36}Ar run, a lack of conditioning of the ion source resulted in a lower ionization efficiency (monitored during the two tests with a tracer of stable Ne). Intensities were therefore also scaled to the nominal ionization efficiency as routinely achieved at ISOLDE and verified during the ^{58}Ni run.

Isotope	Half life	Primary beam	Power (W)	Measured 1+ intensity	Extrapolated to nominal power and ionization efficiency
23Mg	11.3s	36Ar	~13	1.73E+03	2.0E+06
25Al	7.18s	36Ar	~13	2.60E+02	3.0E+05
33Cl	2.5s	36Ar	~13	6.93E+03	8.0E+06
35Ar	1.775s	36Ar	~13	8.67E+03	1.0E+07
37K	1.226s	36Ar	~13	1.10E+04	1.3E+07
38K	6.3min	36Ar	~13	1.30E+04	1.5E+07
38K	6.3min	58Ni	4	3.80E+04	7.3E+06
38mK	923ms	36Ar	~13	1.30E+04	1.5E+07
38mK	923ms	58Ni	4	-	-
53Fe	8.51 min	58Ni	34	6.60E+04	1.4E+06
53mFe	2.526min	58Ni	34	1.40E+04	3.0E+05
58Cu	3.204s	58Ni	37	4.30E+03	9.0E+04
58Mn	3s	58Ni	37	5.70E+04	1.2E+06
59Cu	81.5s	58Ni	38	7.30E+04	1.5E+06
60Cu	23.7min	58Ni	35	2.50E+03	5.00E+04

As both the FEBIAD and the surface ionization source will produce singly charged ion beams, the SPIRAL upgrade shall make use of another source to elevate the charge state of the radioactive ions. Such technique, known as charge breeding, is described in Fig. 2 as it should be implemented in the SPIRAL upgrade. The upgraded Phoenix ECR ion source which shall perform such process and which is described in the next section is the heart of the upgrade. It is the key technology whose relevant aspects shall be studied by GANIL within the task 3 of PREMAS.

Complementary to the test of the quite universal method of charge breeding, the use of molecules with the present ionization system of SPIRAL shall be tested for producing radioactive ion beams of Carbon beams, as with the COMIC ion source. The obtained results shall eventually be compared.

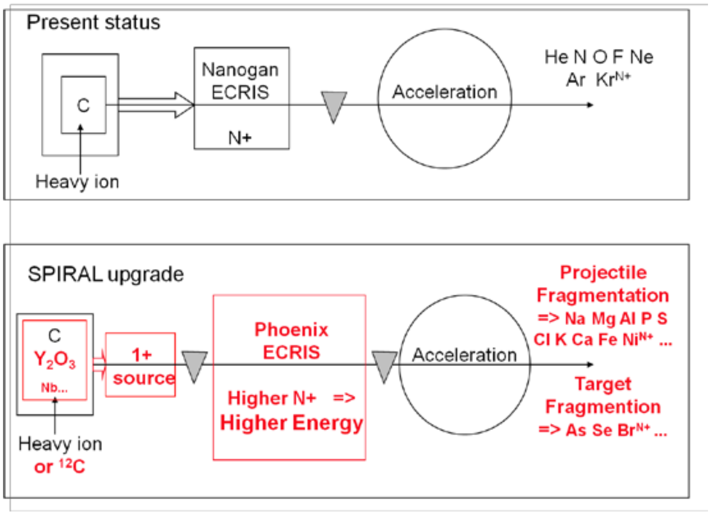

Figure 2: Principle of the charge breeding upgrade. In the production cave, the present ionization system is replaced by a 1+ (or low N+) ion source. After separation, the 1+ (or low N+) beam is injected into a charge breeder situated out of the cave which performs the multi-ionization to an N+ charge state prior to post-acceleration. Eventually the graphite target may be replaced by heavier materials.

Charge breeding of radioactive beams with an ECR ion source

At reacceleration facilities, charge breeding is a technique consisting in the injection of a 1+ beam into the plasma of an Electron Beam Ion Source (EBIS) or ECRIS and of its subsequent multi-ionization for reaching the charge state required by the post-accelerator. The charge breeding is a competitive and cost effective solution compared to the stripping foil technique. It has benefited from multiple studies within FP5 and FP6, and from the development of facilities using this technique at ISOLDE, TRIUMF or more recently ANL. Because of the continuous mode of operation and of the intrinsic resolving power of the cyclotron CIME, an ECR charge breeder is naturally better suited than a pulsed EBIS. The ECR charge breeder of the SPIRAL upgrade is a Phoenix booster donated by the Daresbury Laboratory and which was tested at ISOLDE from 2003 to 2008 [8,9]. A number of aspects of such charge breeder are being improved before being put on-line. Recent tests undertaken at ANL – which is a collaborator for the SPIRAL upgrade - demonstrate that a factor varying from 3 to 4 in 1+ to N+ conversion efficiency could possibly be achieved with such technique compared to the results obtained at ISOLDE and LPSC in the region of mass available at SPIRAL, provided that a special care is taken in the injection optics and in the design of the booster. Charge breeding efficiencies measured at ANL from 1+ to a given N+ charge state range from about 8 to 15% from mass 20 to mass 80 [10].

Within the task 3 of PREMAS, one shall especially study and improve the aspects concerning beam purity. To this aim, UHV standards were used in the design of the upgraded charge breeder to reduce the residual pressure which is the source of high stable beam background. The plasma chamber, extraction and injection electrodes will be made of pure Al. Support gas injection is performed directly within the plasma chamber. The details of the upgraded charge breeder will be given in an forthcoming publication. Fig. 3 presents a scheme of the upgraded booster, whose design now includes a number of improvements.

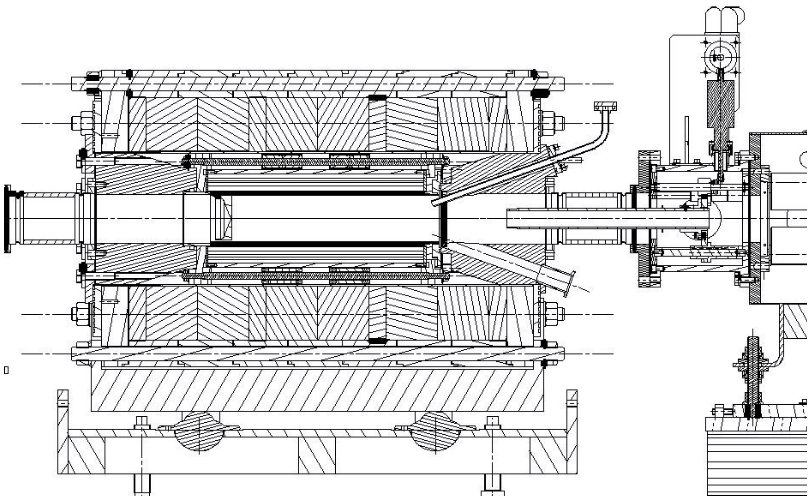

Figure 3: Upgraded Phoenix charge breeder to be installed at SPIRAL. A number of improvements have been made including tunable injection optics, ultra-high vacuum components, double RF injection etc.

Perspectives

According to the schedule of the upgrade, the design of the upgraded charge breeder will be achieved in June 2012. The upgraded Phoenix will be assembled during the first semester of 2013, and then installed at SPIRAL late 2013. In 2014 first off-line tests and then on-line charge breeding tests shall be performed, before SPIRAL becomes operational again end of 2014.
An application for a test beam time in 2013 will be done to test the production of radioactive C beams from the present ionization system.
Results of high interest for the task 3 of PREMAS using the selected methods of ECR - ionization should therefore be obtained during 2013 and 2014. A delay in achieving the milestone M-JRA03-3.5 at GANIL is probable. The deliverable is still within reach within the allocated time.

References

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