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Charge breeding ions for nuclear physics with the PHOENIX ECRIS

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Abstract

At ISOLDE, CERN, an online PHOENIX ECR charge state breeder is being tested for the investigation of the $1^+ \rightarrow n^+$ scenario for the next generation ISOL postaccelerators. As the program of tests reaches an end, the possible physics experiments with multiply charged radioactive ion beams are being investigated. Especially the use of the ECR charge breeder in combination with a high voltage platform would permit an acceleration of the radioactive ions produced at ISOLDE to total energies up to a few MeV. This opens up possibilities for nuclear astrophysics experiments such as various studies of low energy radiative capture reactions. Experiments requiring the implantation of radioactive ions in a substrate at varying depth can also be conceived. This contribution presents the various aspects of the current performances of the PHOENIX ECR charge breeder that could benefit physics applications.

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1. Investigation of the ECR charge breeding

The PHOENIX ECR Booster is installed as a test bench on the heavy masses beamline after the general purpose separator (GHM) at ISOLDE [1], as shown in Fig. 1.

The current program for tests [2,3] is meant to provide relevant information about ECR charge breeding [4] for next generation postaccelerators in radioactive ion beam (RIB) facilities. Lately, it has also been considered as a stand-alone device for preparing beam for nuclear physics experiments, purifying the beam, either by using the charge state distribution [5] for ions of different Z values, or by injecting and breaking up molecular sidebands from the ISOLDE target and ion source as mentioned in Section 3. A test of the trapping of the daughter nuclides has been recently performed [6], which could open possibilities for the production and study of new RIBs. In this context, many immediate issues in physics require the intensification of ECR charge breeders development (see for instance [7–9]).

2. Charge breeding for a full electrostatic postacceleration

The efficient, rapid, clean charge breeding of intense beams constitutes a key issue for next generation ISOL postaccelerators. ECR charge breeding appears like a promising solution as no intensity limitation has been observed yet up to a few μA of beam injected [7–9]. In case of a full electrostatic postacceleration, the charge state distribution in the ECR gives a range of various beam energies between which one could switch easily. Therefore, physics experiments that require low to medium energy beams could benefit in some cases from pure electrostatic acceleration out of the ECR.

Recent developments [10] of the PHOENIX ECR Booster should now allow the handling of all beam energies available at ISOLDE, from 30 to 60 kV. With an optimal

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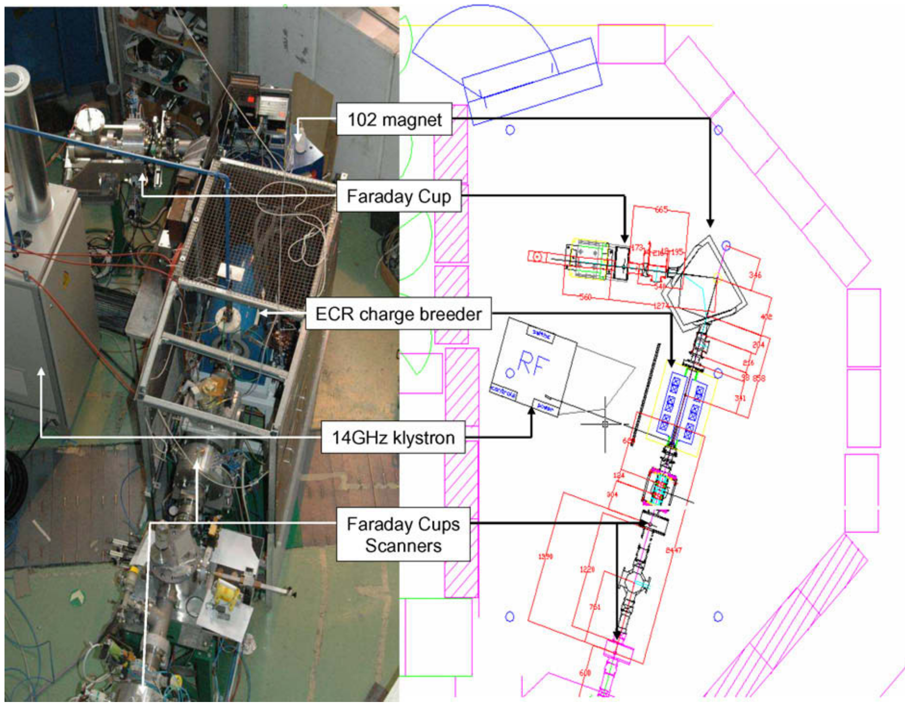

Fig. 1. Layout of the PHOENIX ECR Booster test bench in ISOLDE hall.

charge breeding for $4 < A/q < 8$ and a 60 kV operation, energies up to 15 keV/u can be reached. This would suffice to perform some direct implantation experiments with the current setup.

There are physics issues where the control of the implantation depth into a target material is critical. For instance, models for electron screening in dense astrophysical plasmas [11] can be tested experimentally by implanting an alpha-emitter into various materials and by measuring its half-life at various temperatures [12]. As mentioned in [13], one wishes for an homogeneous depth distribution of the alpha-emitters inside the target. Such an experiment could be imagined with the current PHOENIX ECR test bench. Enough statistics to reach a final precision of a few 10^{-3} on the half-life measurement of ^{224}Ra [14] could be produced for the implantation of $^{224}Ra^{28+}$ at, respectively, 0.35 and 0.1 μm depth into quartz and gold, and the study of the two separate alpha lines emitted with less than 1% energy loss.

However, most applications require much higher energies, and one should consider the possibilities coming with the installation of an additional high voltage platform after the ECR charge breeder. With an additional 340 kV acceleration potential, energies up to 100 keV/u would then be available. This would allow ion implantation into denser materials, such as semi-conductors, offering much interest in solid states physics [15]. The development of light isotopes ECR charge bred beams [7] would also open possibilities to measure the astrophysical cross section factor $S_{17}(0)$ in inverse kinematics, using high intensity ^{7}Be beams as proposed in [16]. ^{7}Be beams are produced at ISOLDE with intensities of a factor 1000 higher [17] than at some other facilities [18]. However they cannot be accelerated with REX-ISOLDE [19] due to actual space charge limitations of the EBIS preparation trap [20]. The ECR could be used to produce intense beams of $^7Be^{4+}$ in the low-energy range of interest. Finally, the study of low-lying resonances in radiative capture reactions in a similar manner was already mentioned as a possible application in a previous contribution [21].

3. Charge breeding for beam purification

The production of clean beams becomes a main concern as one goes further from stability, towards lower yields and shorter half-lives. Especially, the question of isobaric contamination is crucial for the proper measurement of nuclear structure properties.

One of the current main limitations of the PHOENIX ECR Booster is the residual gas stable contamination that induces charge exchanges in the extraction region [7]. Technical developments were initiated to solve this problem, including vacuum improvements and the project of installing a new two-step isotopic separator [10] similar to the one installed in TRIUMF, Vancouver [22]. In spite of this limitation, two means of beam manipulation with the ECR charge breeder exist, that can be advantageously used to enhance beam purity.

The first one is the use of the charge state distribution generated inside the ECR plasma to extract ions with an optimized A/q-value so that the proportion of multiply charged contaminants is strongly suppressed. This method

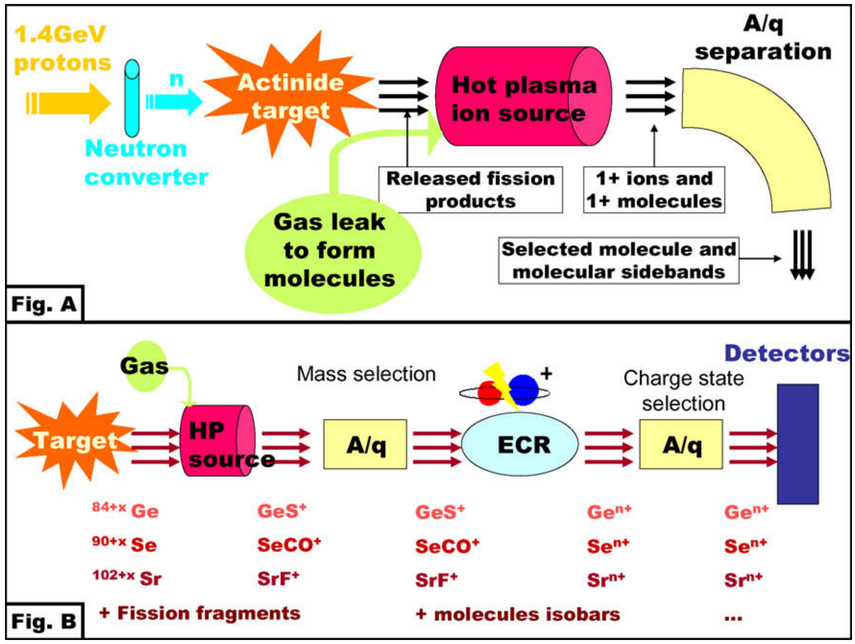

Fig. 2. (A) Production of neutron-rich isotopes as molecular beams at ISOLDE. (B) Injection of the molecules into the ECR charge breeder to remove the sidebands.

was already applied at ISOLDE to perform the study of ^{48}Ar decay [5].

The second method is the injection of the wanted species as molecules into the charge breeder where they are broken, extracted and mass selected, thus removing the molecular sidebands. Some elements are extracted from the ISOLDE target with a higher yield and less contamination as molecular beams. Such a method was used in a similar way at Oak Ridge National Laboratory (ORNL) [23], where $^{80-86}$GeS^{+} beams were produced with a target-ion source set comparable to what is used at ISOLDE. The molecules were broken in a charge exchange cell, and their fragments postaccelerated in a tandem before undergoing an additional separation in mass and in energy.

Although a resonant laser ion source can be used at ISOLDE for selective ionization of many metallic elements, many non-metallic and some metallic elements can be better separated in molecular form with a plasma ion source. This is particularly true for the production of neutron-rich isotopes. Therefore, a proposal was submitted [24] to study the ground-state properties of neutron-rich Ge, Se and Sr isotopes close to the r-process path, using the PHOENIX Booster charge breeding for molecular breakup. The principle of this method is illustrated in Fig. 2.

4. Conclusion

Although much effort was put into ECR ion sources for stable beam production, ECR charge state breeders still require some technical improvements to take full advantage of their performances. Some suggestions were provided in another contribution to this conference [7] for the development of an optimal ECR charge breeder for the production of multiply charged RIBs.

At the same time, existing results show very encouraging leads for physics applications. Among the mentioned experiments, some can be performed with the current setup at ISOLDE. Even more experiments of interest in solid state physics or nuclear astrophysics can be proposed with relatively little development of the PHOENIX ECR Booster. In many cases, ECR charge breeding might offer various opportunities for the development of new beams, or for the production of beams with a higher level of purity.

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