Charge-State Boosting for Post-Acceleration

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Post-acceleration of low-energy rare isotope beams available directly from the ISOL stations or from the gas-stopping of fast beams is an important aspect of RIA. It will provide RIA beams with energies up to 10 MeV/u for example for low-energy Coulomb excitation experiments, transfer reaction studies or for the study of astrophysical reactions. An alternative to brute-force post-acceleration starting with singly charged ions and subsequent stripping is the implementation of charge-state boosting as a first step of the post-acceleration. This alternative is cost-effective and needs therefore to be considered in view of the financial constraints in realizing RIA. For the same reason charge breeders are already in use for post-acceleration at REX-ISOLDE/CERN [1] or are discussed for other rare isotope facilities. Even if the 1+ post-acceleration scheme is realized, the availability of a charge state booster will have the positive aspect of being able to bypass the first accelerator section and to use this section for the post-acceleration of another beam up to energies relevant for nuclear astrophysical studies.

There are several concepts that can be used for charge state boosting. One of the concepts most strongly promoted is the usage of ECR ion sources [2, 3]. There exists a lot of experience with ECRs due to their usage as primary sources of high intensity, moderately charged ion beams for accelerators. Various tests have been made for their charge-state boosting performance for ions delivered from 1+ ion sources. A dedicated system is the PHOENIX source developed in collaboration between ISN/Grenoble and TRIUMF/Vancouver. The result of performance tests with stable beams has been reported recently [4]. A breeding efficiency for $Sn^{1+} \rightarrow Sn^{22+}$ of η = 4 % has been achieved and the breeding time for Sn^{19+} was found to be τ = 20ms. A rather large beam emittance of $\varepsilon_{90\%}$ = 50 π mm mrad was measured for 12-keV Ar ions. A problem with ECR sources may turn out to be the large current (> mA) of stable ions that come along with the beam of interest. So far, no rare isotope beam experiment has really been performed with post-accelerated beams involving an ECR ion source as charge state booster.

Alternatives for charge state boosting are Electron Beam Ion Traps (EBIT) [5] and Ion Sources (EBIS) [6]. In these devices ions are trapped within the space charge of an intense electron beam and ionized to high charge states by electron impact. The main differences between EBIS and EBIT are the length of the trapping region and the electron current density. The EBIT systems typically use a much shorter trapping region and a much higher electron beam density than the EBIS devices. A common feature is their operation at ultra-high vacuum which results in a very small background current. Furthermore, the emittance of the extracted beam is significantly lower than that of ECRs.

The only charge state booster that already operates on the EBIS/EBIT principle is REX-EBIS [7], which is part of the REX-ISOLDE post accelerator project [1] at

ISOLDE/CERN. REX-ISOLDE has come into operation recently and first experiments with post-accelerated rare isotope beams have already been performed. For REX-EBIS, operated at half its nominal electron current density, a breeding time from Na^{1+} to Na^{8+} (peak charge) of ~18 ms was found. Peak-charge boosting efficiencies of 8-10% have been verified [7].

EBITs are today widely spread and mostly used for spectroscopy studies on trapped highly charged ions and it has been demonstrated that they can be used as very efficient sources for highly-charged ions. An advanced design is that of the LLNL high intensity EBIT which has a 6 Tesla magnetic field, an electron beam energy up to >100 keV, and a maximum beam current of 5A. The magnetic field focuses the electron beam to a radius of 50μm, resulting in a very high central electron beam density of 10^5 A/cm^2 (for 30 keV electrons). The latter feature is the key for very short charge boosting times and high accumulation efficiency.

A few years ago Marrs and Slaughter evaluated the potential of using such or a similar device as charge-booster [8]. Their findings indicate that a high intensity EBIT will have properties superior to any other device mentioned above. Ion beams with low emittance can be accumulated in an EBIT continuously with very high efficiency and the breeding times are very short. For Sn^{40+} an upper limit for the beam intensity of 10^{10} to 10^{11} ions/s is expected. For $Sn^{1+} \rightarrow Sn^{40+}$ (Ne-like) and for $Sn^{1+} \rightarrow Sn^{48+}$ (He-like) the breeding times are calculated to be τ = 3 ms and 34 ms, respectively. The breeding efficiency can reach 90% for closed shell configurations. Away from closed shells a typical abundance of 25% has been measured.

Therefore, in order to be able to evaluate the performance of EBIT charge state boosters and to compare it to that of ECRs we propose to design and build a high intensity EBIT, which is optimized for the breeding of high intensity rare isotope beams.

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