WALL DISTRIBUTION OF IONS EXTERNALLY INJECTED FOR CHARGE –BREEDING IN ECRIS

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Abstract

We have investigated the ion loss distribution in an electron cyclotron resonance (ECR) ion source. The ions, radioactive and singly charged ^{111}In, were injected into the ECR ion source (ECRIS) for breeding their charge states at the Tokai Radioactive Ion Accelerator Complex (TRIAC). The residual radioactivity on the wall of the ECR plasma chamber of the source was measured, giving a two-dimensional distribution of the ions failed to be re-extracted during charge breeding. The distribution was decomposed, according to azimuthal symmetry, into three components, asymmetric, 120-degree symmetric, and isotropic ones, whose origins were quantitatively discussed for clarifying ion-losses in the course of charge breeding in ECRIS.

INTRODUCTION

The radioactive ion beam (RIB) facility TRIAC [1] has been jointly constructed under the collaboration between KEK and JAEA and operated for experiments since November, 2005. The facility is based on an isotope-separator on-line (ISOL) technique. The radioactive nuclei are produced by means of proton-induced fission of ^{238}U or heavy-ion reactions with the primary beams from the JAEA tandem accelerator. The produced radioactive nuclei are singly ionized and mass-separated by the JAEA-ISOL [2]. They are fed to the 18 GHz ECR ion source for charge breeding (KEKCB), where the singly charged ions are converted to multi-charged ions with the mass-to-charge ratio (A/q) of around 7. The charge-bred radioactive ions are extracted again and fed to the post-accelerator [3] for further acceleration.

Several RI beams as well as stable ion beams have been successfully charge-bred to A/q~7. Recently, we have accelerated to 178keV/A the medium-mass charge-bred radioisotopes of Kr and In. The acceleration of RI beams charge-bred by ECRIS was the first time over the world. Details on the charge breeding experiments for the KEKCB can be found elsewhere [4].

In charge breeding experiments using KEKCB at TRIAC, we observed large differences in charge breeding gaseous and non-gaseous ion species, i.e. in the injection optics and the resultant charge breeding efficiencies [5]. In order to understand the differences we investigated how the ions, which were externally injected to the ECR plasma of KEKCB for breeding their charge states but failed to be re-extracted, were distributed on the wall (surface) of the plasma chamber.

EXPERIMENT

For the measurement of ion distribution on the wall of the plasma chamber, we injected into KEKCB and charge-bred radioactive singly-charged ^{111}In ions with a half-life of 2.8 days. After charge breeding, we measured the distribution of the ^{111}In by detecting the residual activity on the wall of the chamber. We here just introduce the experiments for measuring the residual activity since detailed experimental procedures for charge breeding can be found elsewhere [5].

As shown in Figure 1, after charge breeding, we removed the inner tube (a 350mm-long cylindrical tube with a diameter of 76mm) from the plasma chamber and measured two γ-rays emitted from ^{111}In (after beta-decay to ^{111}Cd) deposited on the wall of the inner tube by a Ge(Li) detector. In front of the Ge(Li) detector, a 20mm-thick lead shield with a hole of 20 mm in diameter was placed as a collimator. In addition, we placed a cylindrical lead block inside the inner tube to prevent γ rays from the opposite side of the tube. By changing the azimuthal angle and longitudinal position on the inner tube, around and along the axis of injection and extraction in a cylindrical coordinate, the measurements were performed at several tens of points on the tube. (Lower part of Figure 1 and Figure 2)

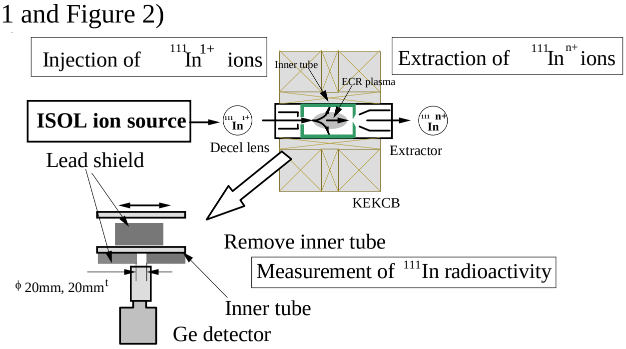


Figure 1: Experimental set-up for charge breeding and measuring the residual radioactivity of ^{111}In on the surface of the inner tube.

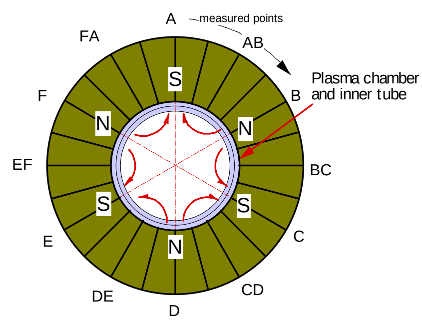
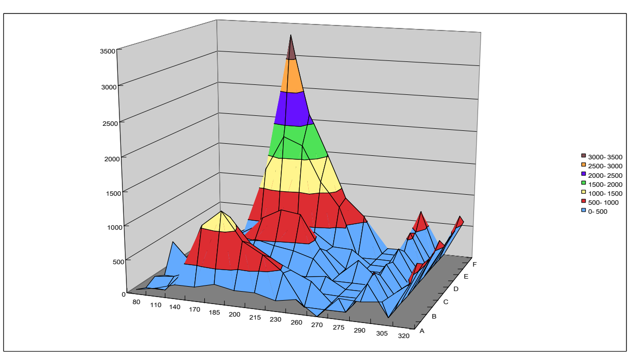


Figure 2: Hexapole radial magnetic field and definition of measured points around the chamber. Viewed along the ion beam direction.

EXPERIMENTAL RESULTS

Figure 3 shows a two-dimensional distribution of the radioactivity of ^{111}In ions deposited on the surface of the inner tube, which is efficient to overview the distribution although the interpolation, not rigorous, can cause a misunderstanding because of the limited number of data points. From the overview, we could identify azimuthally asymmetric distributions around the longitudinal position with B_{min} of axial field, i.e. around z~200mm in the configuration shown in the lower part of Figure 3, and rather symmetric and isotropic distribution at the extraction side close to the position with B_{max}.



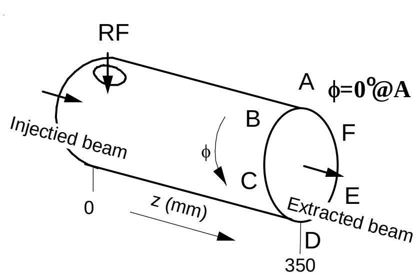


Figure 3: Contour plot of ^{111}In deposited on the surface of the inner tube. The interpolation is not rigorous, just for eye-guiding.

A typical azimuthal distribution around the B_{min} is given in Figure 4. We assumed that the distribution consisted of three components, azimuthally isotropic, 120-degree symmetric and asymmetric ones. At each longitudinal position, as indicated in Figure 4, we decomposed the distribution according to the azimuthal symmetry; asymmetric and symmetric components. The symmetric includes isotropic and 120-degree symmetric components. Integrating over azimuthal angle, the longitudinal distributions were extracted and compared in Figure 5, where axial magnetic field configuration is also given. The asymmetric component is localized around B_{min}, while the symmetric component is concentrated around the B_{min} as well as at the extraction side.

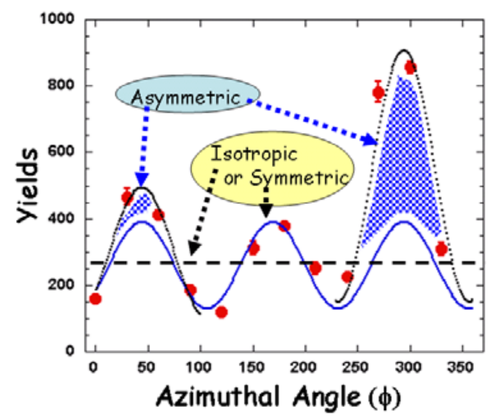


Figure 4: Azimuthal distribution of ^{111}In around B_{min}. Decomposed into 3 components; azimuthally isotropic, 120-degree symmetric, asymmetric ones.

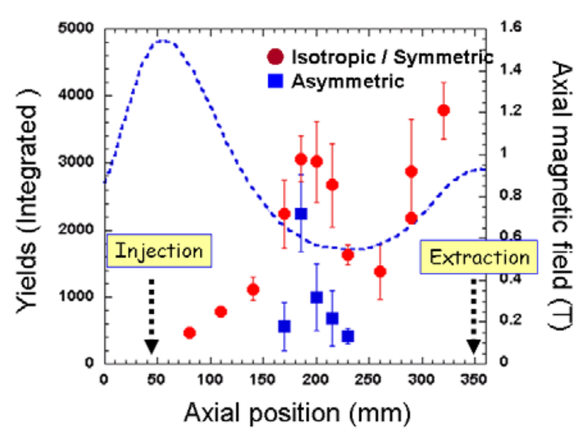


Figure 5: Longitudinal distribution of the symmetric and asymmetric components, as defined in Figure 4. The symmetric include both the isotropic and 120-degree symmetric components. Axial magnetic filed configuration is also given for comparison.

The asymmetric component representing 13.5 % of the total activity residual on the surface might be associated with ions injected in a rather asymmetric manner since the (axial and radial) magnetic field configuration for the confinement of electrons in ECR plasma cannot produce such asymmetry. More careful optimization of the beam optics for the injection is necessary for the elimination of the asymmetric component in the ion-losses in the course of charge breeding.

The 120-degree symmetric distribution of ions reminds us of the electron losses due to the combined field configuration of the axial and the radial magnetic field for electron confinement[6]. Although the behavior of ions in ECR plasma has not yet been studied in detail both experimentally and theoretically, we can expect that both electrons and ions should show a quite similar behavior. Therefore, the 120-degree symmetric distribution can be considered as a characteristic behavior of ions in ECR plasma. When considering the charge-breeding process as two successive processes, i.e. stopping and ionizing processes [7], the ions with the 120-degree azimuthal symmetry would correspond to those lost during the second, ionizing process. In the ionization process, those ions, though successfully captured by ECR plasma in the stopping process, are supposed to be lost to the wall of plasma container along the hexagonal radial magnetic field. The fraction, i.e. how many ions are lost in the ionization process, is nothing but the ionization efficiency for the ions in ECRIS.

As shown in Figure 4, the 120-degree symmetric component is on the top of the isotropic one. The isotropic one is actually the main component of the symmetric distribution, which is observed all over the wall as shown in Figure 3. The 120-degree symmetric component was observed only around B_{min}, even where the isotropic component amounts to a large fraction (refer to Figure 4). Along the discussion given above for the 120-degree symmetry in the distribution, the isotropic component could be also associated with the incomplete confinement of ions, i.e. the losses simply by the ambipolar diffusion of plasma constituents.

The symmetric component, including isotropic and 120-degree asymmetric components, represent 86.5% of the total. The 38% of the symmetric component were observed at the extraction side. The large fraction of ion losses around the extraction side could be understood quantitatively by a weak confinement field. The weak radial field caused by the geometrical limit of permanent magnets at the extraction side, as well as the weak axial field for efficient ion extraction, could lead rather poor radial confinement of electrons and consequently large loss of ions along the radial direction.

SUMMERY AND OUTLOOK

We have injected radioactive ions of ^{111}In into the KEKCB and, after charge breeding, measured the residual activity to investigate how ions externally injected for charge breeding be lost in the course of charge breeding. By analyzing the distribution, we found three components, asymmetric around B_{min}, 120-degree symmetric, and isotropic ones. The asymmetric one could be removed by further tuning the injection optics. About 38% of the second and the third component were observed around the extraction side, implying that the ions were strongly influenced by the weak confinement field both for the radial and axial direction.

Further measurements using the gaseous element ^{140}Xe are scheduled. Comparison between the distribution of the ^{111}In distribution and the one of the ^{140}Xe will give a hint to understand the difference of charge-breeding efficiencies for gaseous and metallic elements, i.e. the element-dependent efficiencies observed so far in the charge breeding experiments using ECRIS.

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