CUSP MIRROR FIELD ION SOURCE FOR RADIOACTIVE ION BEAM PRODUCTION

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Abstract

One very remarkable fact is that Cusp Electron Cyclotron Resonance Ion Source (CECRIS) can be designed without having any permanent magnet. Now it is possible to place single CECRIS near the thick target for ionising the effusing out radioactive fragments to high charge-state for use or further acceleration after isobaric separation. It may remove the requirement of decelerating the beam for charge breeding. Simultaneously, the radioactive ion beam (RIB) will not be degraded too in terms of intensity and emittance. It can be used both in continuous or pulsed mode of operation. There may be a requirement of dedicated separate cooling system for the coils, as they will be affected violently by radiation. Emphasis is then given to a discussion of the technique applied to fulfil the particular new requirements set to the radioactive ion sources in order efficiently match modern accelerators. A simple design and scheme of obtaining highly charged RIB is to be finally discussed herein.

INTRODUCTION

Facilities that make use of isotope separators on line (ISOL) in which high intensity primary ion beams (PIB) are used to produce low energy secondary beams of nuclei far from stability have now been operational for some decades at many places around the world. The interplay between the four involved issues: nuclear reactions, target, ion-source A and Z separation and post-acceleration have shown that the target and ion-source are the most crucial links of the chain.

The ISOL separator, the RIB facilities in particular, presents a unique and challenging environment for ion source operation. Ion sources are required to ionise short-lived isotopes, in a very high radiation environment, efficiently, rapidly and reliably so that beams with high intensity and small emittance can be formed, mass separated, and transported to experiments and accelerators. Today, the conventional ECRIS provides the impetus for a new era in the PIB and/ or RIB. Two ion-sources, a single-state ioniser (with or without permanent magnet) and another a multi-state ioniser (charge breeder with permanent magnet sextupole) are used in the case of RIB production online.

The number of stable atoms available is around 200, while the radioactive atoms are more than 6000. Furthermore, people are interested in the RIB because of many special application features, associated with it. For example, the features of RIB can be listed as under briefly.

- Element can be selected freely.
- The implantation depth and position can be controlled in high precision.
- The detection technique is very high because the radiation technique is used.
- The lifetime can be selected in wide range.
- The spin of radioactive nuclei can be selected freely.

Some initial theoretical and sound attempts have been done at our centre to understand the loss of plasma taking place in unsuccessful old CECRIS and mitigate, or at least reduce, the loss by reconfiguring the cusp field by adopting a simple, novel and cost-effective technique [1]. It is possible to achieve sufficient and symmetric cusp magnetic field for higher frequency of microwave also for the condition of high-B mode superb operation of a CECRIS. It may be used to produce highly charged RIB with/without its use as single-state ioniser.

ISOL ION SOURCE PRINCIPLE

Many different nuclear reactions may be used for production and with few exceptions they are very complex with many exit channels leading to a variety of short-lived and rare nuclei. When a light energetic PIB falls on a thick refractory target, a large number of radioactive ions are produced and they effuse out of the hot target. These radioactive particles have to be continuously produced and transferred to an ion-source. But the production method and choice of target are dictated by the physical and chemical properties of the individual elements. Now RIBs of almost all elements in the periodic table are produced because of tremendous development in method and understanding of the processes. But the variety and intensity of beam depend strongly on the PIB [2].

Given the considerable radioactive atom losses and low initial production rates each target/ ion source must therefore be designed to operate with the highest possible efficiency in order to provide enough RIB intensity for physics experiments: at least 10^5 ($<10^9$) ions per second is usually desired.

The future of (C)ECRIS will mainly depend upon new interests in fundamental or applied physics. The accumulation time in conventional (C)ECRIS is linear up to 1 sec, charge boosting $>10^{11}$ ion and bunching is efficient, very low duty cycle 2% of rf cycle can be efficiently utilized for ISOL beams. Radioactive nuclei have very short life (T(1/2)=10 msec to 2 sec) and the formation time is around 10 to 50 msec. The (C)ECRIS must cook them rapidly (10 msec, 5 to 15% efficiency and 60% trapping in charge breeder). They should never hit solid wall since adsorpted particles are released too late. It can be post accelerated up to 15 MeV/M before the radioactivity decays. The energy attained by an ion is proportional to charge state Q in

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LINAC and electrostatic accelerators and varies as Q^2 in cyclic accelerators. From this argument, it is apparent that a (C)ECRIS can be very efficiently used to ionize radioactive nuclei also to breed superbly its charge for post acceleration.

ION SOURCES

It has been a customary method first to ionise the radioactive nuclei to single charge-state and secondly to boost the charge-state to higher values by powerful ionising device like ECRIS, EBIS, LIS etc.

Other Ionisation Sources

Other than the CECRIS to be discussed in this report are listed below for the sake of completeness.

- High temperature surface ionisation sources [3].
- High energy protons (PIB) falls into a cylindrical target with a tapered hole, it creats 1+ radioactive nuclei in an attached tantalum tube heated by the proton beam itself [4].
- Hot cathode discharge ionisation sources [5].
- Resonant laser ionisation sources [6].
- Ion guide laser ionisation sources (IGLIS) [7].
- Laser ionisation sources with hot cavity [8].
- Conventional ECR ionisation sources [9].
- Penning trap and EBIS ionisation sources [10,11].

Cusp ECR Ionisation Sources (CECRIS)

People are using two ion-source systems. The first ion source works in rough vacuum of the order of 10^{-3} mbar as the radioactive particles are carried by the technique of helium jet and continuously dumped into the ion source. In this vacuum the ion source is capable to ionise the radioactive product to single-state. Various types of ion sources are used for this purpose. But conventional compact ECRIS (NANOGAN) made of permanent magnet also being used at GANIL [12]. Presently most people opt for high frequency ECRIS for HCHI radioactive beam production. This works at high vacuum of the order of 10^{-7} mbar. The total general scheme of the current target-ion-source system in use is shown in Fig. 1.

Elaborate design calculations for the optimised cusp field (CECRIS) has opened up new avenues for its use in producing single-state or multi-state stable or radioactive ion production [13]. The CECRIS uses only a system of a pair of coils. A smaller CECRIS can be designed for industrial rf frequency. It can be very easily set near the target and can be operated at rough vacuum to provide appreciable current of the radioactive single-charge ions. Another bigger CECRIS can be used to accept the single charge ions and breed them to very high charge state. In figure 1, small and big both the two ion sources can be replaced by properly designed and constructed CECRIS to perform the similar job.

The CECRIS does not use any permanent magnet (sextupole magnet). That's why it becomes compact, more powerful and cost-effective additionally because of using mid iron technique. Furthermore, if some how the pressure of the gas containing the radioactive debris after the thick target is controlled to lower values, the CECRIS can be put in such a way that it accepts directly the neutral or singly charged radioactive nuclei to produce HCHI radioactive beam. Then the system will be simpler and more economical. The requirement of a decelerator, which affects vigorously the quality of the RIB to be injected into the breeder ion source, in between the two ion sources is eliminated. Additional cooling system for the ion source is required because of working in high radiation area. In this case, the figure 1 can be modified to get figure 2. The connecting thin walled tube in between the target and the ion source can be made of very refractory material like tantalum. It can be heated to near about 2000 deg C by passing current through it for prohibiting the settlement of radioactive particles on it as well as effecting possibly some singly charged radioactive particles. These particles will diffuse into the plasma chamber immersed in the cusp field generated by the oppositely energised co-axial coils wound over the plasma chamber. In this condition, the system will be built very economically.

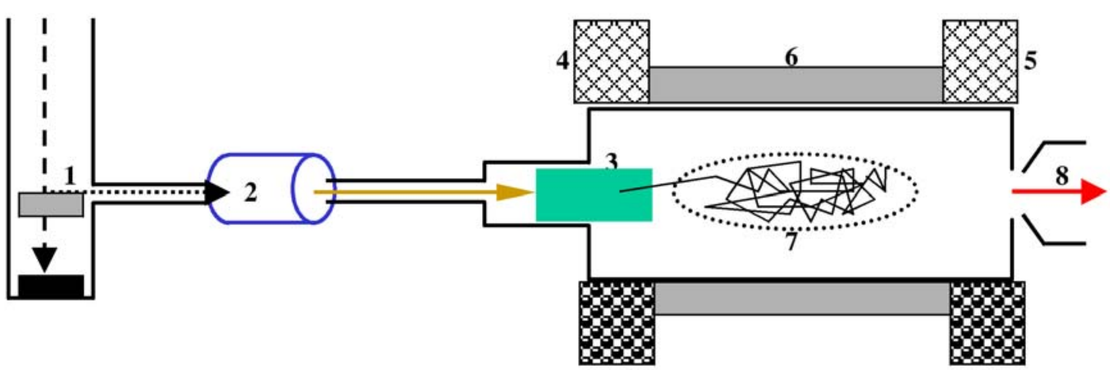

Figure 1: Schematic of the target-ion source system of a general ISOL system. The light particle PIB is falling on the thick target (1). The produced radioactive nuclei are carried to the single-state ion source (2). The extracted beam from it decelerated at (3) to the energy of few eV and injected into the chamber containing the ECR discharged plasma (7). The radioactive HCHIs are extracted from it and form a RIB to be used immediately or accelerated. The coils (4), (5) and the sextupole (4) also are used.

CONCLUSION

There is optimism among the people involved with ion-sources that the novel idea of the low and high frequency CECRIS will work. But some are sceptical about the idea as the cusp field utilises the modified minimum-B field configuration instead of perfect minimum-B field as in conventional ECRIS. This possibly will be solved introducing a weak highly rotating radial dipole field making zero field point dynamic. But it should be remember that the field at the line (ring) cusp at the mid-plane is made sufficiently strong to act superbly as a magnetic mirror. Furthermore, the loss of plasma particles are reduced by putting negatively biased electrodes at the point cusp on the central axis and at the ring cusp at mid-plane at chamber surface. It will create a juxtaposed electrostatic potential over the scaler potential normal to the cylindrical vector potential due to the coils. The action of the electrostatic potential will be to redistribute the plasma potential and enhance the electrostatic confinement of plasma.

The source constructed with the propounded technique can be used in producing PIB as well as RIB. The scheme of producing RIB by directly injecting the produced radioactive nuclei also seems to be very promising and cost-effective. The requirement of the decelerator can be eliminated entirely.

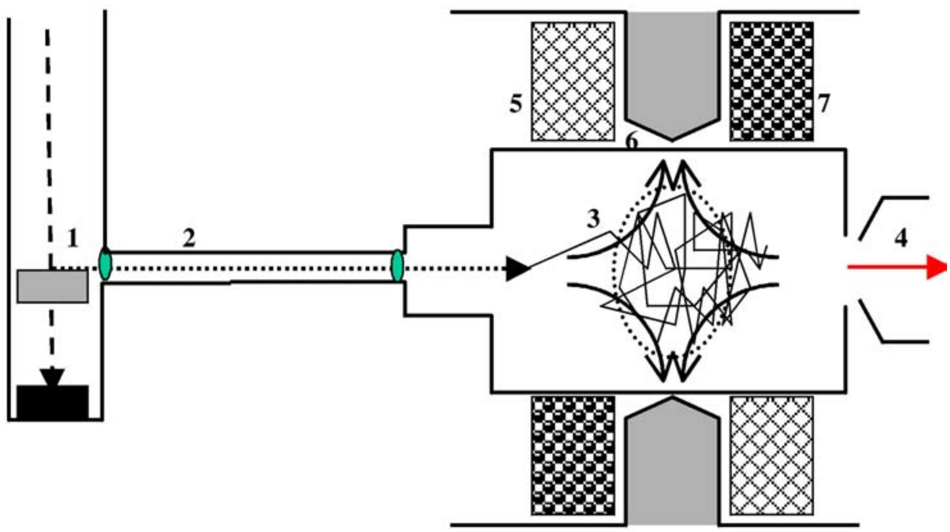

Figure 2: Schematic of the target-ion source system (CECRIS). The energetic light particle PIB is falls on the thick target (1). The produced radioactive nuclei or singly charged ions are carried through the heated tantalum tube (2) and injected into the chamber containing the ECR discharged plasma (3). The radioactive HCHIs are extracted from it and form a RIB to be used immediately or accelerated. The cusp field generated by the oppositely energised coils (5) and (7) are shown as curved arrows at the centre of the chamber. The field is optimised at the centre plane by the mid iron (6) to prohibit plasma loss.

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