

METHOD FOR EFFICIENCY AND TIME RESPONSE MEASUREMENT ON DIVERSE TARGET ION SOURCES WITH STABLE ALKALI

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Abstract

Developments of new setups for radioactive ion beam production by the isotope-separator-on-line (ISOL) method are underway at GANIL in the frame of the SPIRAL (Système de Production d'Ions Radioactifs Accélérés en Ligne) and SPIRAL-II projects. The measurement of total efficiency and time behaviour of these new target/ion-source systems (TISSs) is a crucial step for these devices which aims to produce short-lived isotopes with high intensity. The overall atom-to-ion transformation efficiency depends on several processes: diffusion of the atoms out of the production target, effusion towards the ion source and ionization. The efficiency can be extracted using the ratio between the emerging yield and implanted flux in the TISS. Several methods have already been developed to achieve these measurements: the use of stable or radioactive beams, gas injection, or the introduction of solid material into the TISS. This paper focuses primarily on a method that uses stable alkali. A pulsed/CW alkali ion gun has been built and will be used to optimise diverse TISSs: NanoNaKE [1] a compact multi-charged alkali ion production system for SPIRAL-I; SISTHE a surface ionisation source prototype to study the alkali ion source for SPIRAL-II; and one TISS for SPIRAL-II.

INTRODUCTION

All particle acceleration originates in ion sources. Due to the constant increase of their intensities various important nuclear physics research projects have been successfully completed. Most ion beams produced are stable. However to achieve optimum results the ion source must provide a high-intensity, high- charged state. For radioactive ion beam (RIB) production by ISOL method, the source feed material is limited since it is produced on-line by nuclear reactions occurring in a target. Also, the species of interest are often short-lived compared to the time spent in the target/ion-source system (TISS). Therefore, the ion source must have a high efficiency and a short delay time.

The total efficiency of TISSs depends on numerous parameters such as target design (conditioned by the energy and intensity of the primary beam), diffusion out of the target material, effusion toward the ion source and ionization. To delineate how to improve the total efficiency of a TISS we need to separate and characterize each of these processes.

In this paper, one method suggested to measure efficiency and time response of TISSs with stable alkali is presented and compared to other existing methods. The

method will be applied to the SPIRAL-I and SPIRAL-II TISS development at GANIL.

EFFICIENCY MEASUREMENT METHODS

The total efficiency of a TISS is simply given by the ratio of the current leaving the source to the flux entering the system. Diverse methods for measurement of efficiency and time response are now presented. Several parameters of these methods will be qualitatively compared, such as the sensitivity, the perturbation induced and the chemical form of the species ionised.

Gas Injection

This method, easy to set up, and is mostly used with electron-cyclotron-resonance ion sources (ECRISs). The gas is injected into the ECRIS through a calibrated leak and then ionized. Time response measurements can be achieved using a pulsed valve [2,3].

Condensable Effusive Jet

External ovens heating a sample [4] allow evaporation and introduction of solids into an ECRIS or surface ion source (SIS), much like a gas. The injected flux can be found beforehand by calibrating the flux, using a piezoelectric quartz for example, or afterwards by mass measurement of the evaporated sample: neither method is very sensitive (of the order of mA).

Sputtering and Plasma Heating

Direct ion sputtering or plasma heating can be used to introduce solid materials into an ECRIS.

For ion sputtering [5], a negatively biased solid sample is placed just outside of the ECRIS plasma. Positive ions from the support gas are accelerated toward the sample, impact upon it and sputter solid material into the plasma.

A crucible or wire can be positioned at the plasma boundary, such that the sample is heated and evaporates by the plasma itself [6].

Laser Ablation

A laser is used to evaporate a small amount of material into the plasma of an ECRIS [7]. Laser pulses are sent onto the sample with peak energy densities about 10^7 W/cm². The solid atoms ablates from the samples and recoil into the plasma before being ionised.

Stable Ion Beam as Primary Beam

Implantation of stable isotopes ion beams in the target can be used to measure the release characteristics of a TISS. The radioactive ions produced by nuclear reactions or the ions of the implanted beam can be detected

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Table 1: Comparison of several efficiency-measurement methods. The second row presents the quantity measured at the entrance and exit of the source: F for Flux, I for Intensity, M for Mass. In the third row the measured processes for each method are listed: P for Production, D for Diffusion, E for Effusion and I for Ionisation. The last row describes the perturbations induced by the efficiency measurement on the production process

Injection Method	Efficiency evaluation	Process	Time resolution	Perturbation
Gas injection through calibrated leak	F_{in}/I_{out}	E.I	~ms	
Condensable effusive jet from solid evaporation	M_{in}/I_{out}	I	~100ms	Design (large radial port)
Sputtering of solid sample	M_{in}/I_{out}	I	~ms	
Plasma heating of solid sample	M_{in}/I_{out}	I	/	Design (large radial port) / ECR tuning coupled to evaporation
Laser ablation of solid sample	Difficult	I	< ms	
High intensity ion beam for nuclear reaction	$I_{in}/\text{Decay rate}$	P.D.E.I	/	Heating of the target if high impinging current is required
Stable ion beam implantation	I_{in}/I_{out}	D.E.I	< ms	Heating of the target
Radioactive ion beam implantation	$I_{in}/\text{Decay rate}$	D.E.I	< ms	

downstream of the TISS. In both cases, time response measurements are achieved switching the primary beam on and off. For radioactive ions, the evolution of the decay rate of a particular radionuclide is monitored either in the target or after ionisation [8]. The time response is directly bound to the efficiency measured in CW mode, owing to the life-time of the element.

Radioactive Ion Beam as Primary Beam

This method [9] is quite similar to the ion beam method but the ions of the primary beam are radioactive. They are implanted in the target and the decay rate of the same isotope is detected downstream from the TISS after diffusion, effusion, ionisation and mass separation. The beam intensities of the primary beam can be much lower than with the previous method, limiting local modification of target heating.

ALKALI ION GUN

A pulsed alkali ion gun has been built to measure efficiency and time response of diverse TISS: NanoNaKE, a compact $1^+/N^+$ alkali production system for SPIRAL-I; SISTHE a surface ionisation source to study the alkali ion source for SPIRAL-II; and the target/ion-source prototype for SPIRAL-II. This method is related to the ion implantation presented previously but is much simpler to implement. In fact, most of ion beams used arise from particle accelerators with very costly and limited beam time. This compact device (8 cm long, diameter 15 cm) can provide mono-isotopic continuous or pulsed alkali ion beam for hundreds of hours with a high intensity (15 μA). The chosen beam energy is lower than 1 keV to implant the ions on the surface of the target, restricting the efficiency measurement to the diffusion and ionisation. The low error on the current measurement and the possibility to measure the current injected in and

extracted from the TISS on line make this method interesting.

Technical Description

Our device is composed of three main parts (part a, b and c of fig 3): a stable alkali ion source, an extraction lens and a focusing lens. A Faraday cup is added to measure the extracted beam current and its transport efficiency. The alkali ion source is provided by Heat Wave Labs [10].

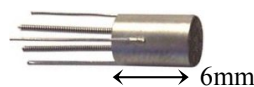


Figure 1: Photo of the stable alkali ion source used in the ion gun.

Their operational principle relies on thermionic emission of positive ions from a porous tungsten layer doped with alkali heated by an isolated molybdenum heater wire. Temperatures of about 1100°C are reached.

Characterisation

The alkali ion gun has been characterised with a potassium source. The first tests have shown the reliability of the device. The ion gun delivers currents of about 15 μA for an extraction potential of 400 V and 9 W on the heater wire. At 8 cm from the emission point, the beam can be focused to a diameter less than 6 mm. The current emitted is measured with an error rate about 10%. A pulsed beam of 1ms has been obtained for time response measurement.

NanoNaKE

The compact multi-charged alkali ion source NanoNaKE developed at GANIL [1] is composed of MonoNaKE, a SIS for radioactive singly-charged ions production, associated with the multi-charged ECRIS Nanogan III currently used on SPIRAL-I. On-line tests carried out in April 2007 shown evidence for 1^+ to N^+

conversion but with an efficiency lower than expected. Since performance of the 1^+ ionization source MononaKE has already been measured on-line, it has been replaced with the ion gun to measure the transport and the $1^+ \rightarrow N^+$ conversion efficiency of the system restricted to the 1^+ beam line associated to Nanogan III.

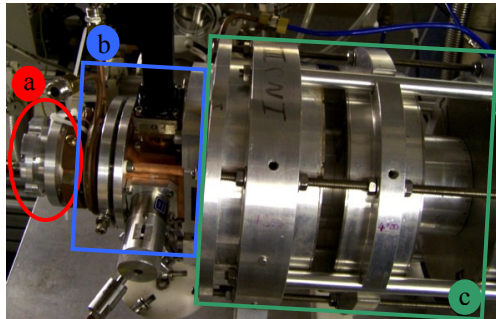


Figure 2: Photo of the ion gun assembled on NanonaKE for transport and conversion measurement: a-ion gun, b-transfer line, c-Nanogan III multi-charged ECRIS.

First results have already been obtained on the effect of the residual gas on the transport of the beam in the 1^+ beam line, and also evidence for losses induced by effects not observable during on-line tests (Penning and RF discharges, secondary electron emission, unexpected influence of the extraction voltage on the transport efficiency). These results have led to a new version of the 1^+ beam line, with an improved pumping speed. More detailed results will be published later.

SISTHE

SISTHE is a source dedicated to the study of the surface ionisation process. It will allow us to acquire fundamental knowledge to develop a future surface ion source for the SPIRAL-II project. Temperature measurements of the carbon ionizer tube have been carried out during June 2007. The next step is to measure the ionisation efficiency and the effect of the pollution over a period of up to three months for different alkali elements, using the ion gun.

The beam delivered by the ion gun is stopped on a carbon sheet placed into a cavity upstream of the ioniser tube. As the energy of the ions (1 keV) is low, they are implanted on the surface (a range of 2 nm for sodium in C). Heating this cavity leads to the release in atomic or ionic form of the implanted ions outside the surface and the cavity. Assuming that:

- ions or atoms collide at least once with the ionizer, and
- the probability to become an ion after a contact with the ionizer is the same for ions and atoms,

the state of the atom (neutral or ionized) at the entrance of the ionizer does not affect the state of the atoms at the exit of the source and thus our measurement. The proportion of atoms exiting from the cavity toward the ionizer tube is

easy to calculate through the conduction ratio or by a Monte-Carlo simulation (code RIBO [10]).

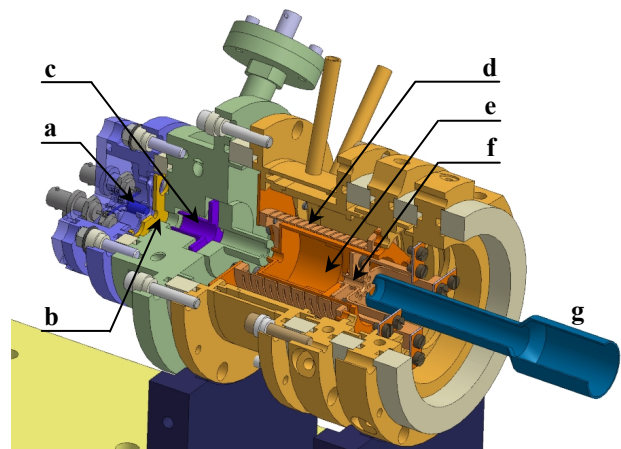


Figure 3: Technical design of the ion gun on SISTHE for efficiency and time response measurements: a-stable alkali ion source, b-extraction lens, c-focusing lens, d-oven, e-cavity, f-ioniser tube, g-extraction lens.

Time response measurements are achieved with the pulsed beam of the ion gun. The volume of the cavity has been kept as small as possible to limit the contribution of the cavity to the time response.

SPIRAL 2 Prototype

With the results from SISTHE, a SIS prototype will be developed for SPIRAL-II. This source will be linked to the production target through a transfer tube. The beam from the ion gun will be injected into the surface of the target at the opposite end of the transfer tube. In this case, measurement of effusion efficiency into the target cavity toward the ion source will be possible, and also of the ionisation efficiency and the time response.

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