Ionization efficiency measurements for the SPES plasma ion source

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INTRODUCTION

In isotope separation on line (ISOL) facilities, the target ion source (TIS) system is doubtless one of the most critical objects. In the context of the selective production of exotic species (SPES) facility [1], a uranium carbide target is impinged by a proton beam coming from a cyclotron proton driver (beam energy and beam current up to 70 MeV and 0.7 mA, respectively), generating approximately 10¹³ fissions per second. A large number of radioactive isotopes produced by the ²³⁸U fissions are then directed to the ¹⁺ ion source passing through a tubular transfer line. Here they acquire a charge state and can then be addressed to the mass separator, the charge breeder and the post-acceleration apparatus.

Generally, the target and the ion source constitute a production unit (the TIS system) specifically optimized for a particular group of elements. In the field of radioactive ion beams, ion sources have to be designed and optimized taking into account mainly three specific properties, that are ionization efficiency, selectivity, and optical beam quality.

Since about three years an off-line front end device [2] has been adopted at Legnaro National Laboratories (LNL) to characterize the SPES ¹⁺ ion sources in terms of ionization efficiency and transversal emittance.

In this work, the off-line ionization efficiency measurements for the SPES plasma ion source [3,4], that is a particular case of Forced Electron Beam Induced Arc Discharge (FEBIAD) ion source, are presented in detail, taking into consideration the specific case of a stable Ar beam.

THE SPES PLASMA ION SOURCE

The SPES plasma ion source (SPIS) is a forced electron beam induced arc discharge (FEBIAD) ion source based on the ISOLDE-CERN MK5 design [4]. It is a non-selective device able to ionize a quite large spectra of elements, in particular noble gases. The main components of the source are the Ta cathode and the Mo anode represented in Figure 1. The former is heated at high temperature by Joule effect, allowing the thermionic emission of electrons on the surface facing the anode grid. The latter, usually kept at 150 V with respect to the rest of the source, confines the plasma from which the beam is extracted by means of the extraction electrode represented in Figure 1. The aforementioned components are closed inside the discharge chamber, and positioned in the vacuum vessel thanks to a cylindrical support (see Figure 1). A small axial magnetic field is produced in the anode region by means of a dedicated coil surrounding the ion source. It improves the electron bombardment ionization mechanism, letting electrons spiral along the magnetic field lines. The Ar beam used for the set of measurements presented in this work was generated using a controlled Ar gas flow. It was injected in the vacuum vessel by means of a calibrated leak, passing through the cylindrical cathode cavity represented in Figure 1.

THE EXPERIMENTAL APPARATUS

The SPES front end [2,5] is a test bench able to deliver stable ion beams. It has been manufactured with the main aim to characterize the ion sources of the SPES facility in terms of ionization efficiency and beam emittance. It is composed of five functional subsystems [6]: the ion source complex, the beam optics subsystem, the Wien filter, the diagnostic box 1 and the diagnostic box 2. In the first one
the ion source is housed inside a vacuum vessel able to guarantee pressure levels between $10^{-5}$ and $10^{-6}$ mbar. A platform voltage of 25 kV is set between the ion source and the extraction electrode. The beam optics subsystem allows to shift and focus the ion beam thanks to a set of electrostatic steerers and a quadrupole triplet, respectively. A Faraday cup and a grid-based beam profile detector constitute the beam diagnostic box 1. To separate masses and to perform accurate mass scans, a commercial Wien filter was installed along the beam line [6]. The diagnostic box 2 is composed of a Faraday cup and an emittance meter device (based on two slit-grid type instruments).

**IONIZATION EFFICIENCY MEASUREMENTS**

Before starting with the main operations regarding the ionization efficiency measurement, the ion source was stabilized at its lower power. In particular, the cathode current was gradually increased up to 310 A (the lower heating current capable to produce an electron density sufficient to start the ionization process, and so to produce an ion beam; correspondent voltage drop equal to 3.5 V), and the anode voltage was set at 150 V. In the meantime the magnetic field in the anode region was stabilized at approximately 300 G, and the Ar gas pressure before the leak was slowly regulated at 1 bar, the leak reference value. In this way the flux of Ar atoms entering the ion source was univocally defined (1·10¹⁴ atoms/s, pressures between $10^{-4}$ and $10^{-5}$ mbar). At this point, the procedure for the ionization efficiency measurement started. The ion beam was opportunely focused and monitored in the Faraday cup of the diagnostic box 1 (FC1). Once stabilized the total beam current, its intensity value was opportunely stored. Then the ion beam was focalized in the Faraday cup placed in the diagnostic box 2 (FC2), and an accurate mass scan was performed in order to identify the elements composing the beam and their partial ion beam currents (see Figure 2). Once determined the current percentage associated to the Ar⁺⁺ ions, it was multiplied by the total beam current value previously stored by the FC1, obtaining in this way the total Ar⁺⁺ current.

It is fundamental to refer to the FC1 when a precise absolute value of the beam current is needed (that is the case of ionization efficiency measurements), since the FC2 is placed after the system of slits of the Wien filter, where part of the beam is dissipated (Wien filter transmission efficiency lower than 100%). At this point the Ar⁺⁺ ionization efficiency was easily calculated as the ratio of the total Ar⁺⁺ current and the flux of Ar atoms entering the ion source. The efficiency measurement was repeated for different cathode current values (and consequently, for different electron density values), up to 370 A.

The sets of measurements reported in figure 3 present a good agreement with data reported in [7]. The Ar⁺⁺ ionization efficiency increases gradually with the cathode current, reaching the saturation value of approximately 8%, when the cathode current is equal to 360 A and the cathode temperature level is approximately equal to 2200 °C (anode electron current equal to 120 mA, with the anode voltage set at 150 V). Efficiency measurements with other gases (mainly Kr and Xe) are currently ongoing at LNL.

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