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Hot-cavity studies for the Resonance Ionization Laser Ion Source

J.L. Henares [a,*], N. Lecesne [a], L. Hijazi [a], B. Bastin [a], T. Kron [b], J. Lassen [c], F. Le Blanc [d], R. Leroy [a], B. Osmond [a], S. Raeder [b,e], F. Schneider [b], K. Wendt [b]

[a] GANIL, BP 55027, 14076 Caen Cedex 5, France
[b] Johannes Gutenberg-Universität Mainz, Staudinger Weg 7, 55099 Mainz, Germany
[c] TRIUMF, 4004 Wesbrook Mall, Vancouver, BC, Canada V6T 2A3
[d] IPN Orsay, BP 1-91406 Orsay, France
[e] KU Leuven, Oude Markt 13, 3000 Leuven, Belgium

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ABSTRACT

The Resonance Ionization Laser Ion Source (RILIS) has emerged as an important technique in many Radioactive Ion Beam (RIB) facilities for its reliability, and ability to ionize target elements efficiently and element selectively. GISELE is an off-line RILIS test bench to study the implementation of an on-line laser ion source at the GANIL separator facility. The aim of this project is to determine the best technical solution which combines high selectivity and ionization efficiency with small ion beam emittance and stable long term operation. The ion source geometry was tested in several configurations in order to find a solution with optimal ionization efficiency and beam emittance. Furthermore, a low work function material was tested to reduce the contaminants and molecular sidebands generated inside the ion source. First results with ZrC ionizer tubes will be presented. Furthermore, a method to measure the energy distribution of the ion beam as a function of the time of flight will be discussed.

1. Introduction

The Resonant Ionization Laser Ion Source (RILIS) has emerged as an important tool for several applications including Radioactive Ion Beam (RIB) generation [1], spectroscopy [2] or ultra-trace analysis [3]. The production of RIBs far from stability using the RILIS technique is of major interest in on-line nuclear facilities due to its inherent Z-selectivity and efficiency [4]. GISELE (GANIL Ion Source using Electron Laser Excitation) is an off-line test bench to develop, study and eventually implement RILIS for the production of on-line accelerated Radioactive Ion Beams in a future ISOL facility at GANIL (Grand Accélérateur National dÍons Lourds) [5]. The future target and ion source system require a 90° turn between the production area and the extraction area due to design restrictions. In the ISOL (Isotope Separator On-Line) process, radionuclides are generated by nuclear reactions during the interaction between a highly energetic beam and a thick target [6]. The produced radioactive atoms diffuse out of the high temperature target and effuse into a hot cavity ion source where the elements of interest can be ionized. The ionized atoms are extracted and mass selected by means of a magnetic spectrometer and can then be post-accelerated or sent directly to various experimental installations. The objective of the GISELE project is to find the best technical solution which combines high selectivity and ionization efficiency with optimum ion beam parameters such as small beam emittance and stable long term operation.

RILIS is based on a step-wise resonant excitation process where the elements of interest are ionized via atomic resonant excitation followed by ionization in the last transition by radiation from up to three available titanium sapphire lasers [7]. The electrons are excited when the laser radiation frequency matches the atomic transition frequency. Since each element has its own unique energy level structure the ionization process has a higher atomic selectivity compared to other ion source techniques. However, detailed laser spectroscopy information on atomic spectra and excitation schemes is required to access the elements of interest and drive the ionization process efficiently.

2. Laser ion source setup

GISELE is composed of an ion source and the laser system as described in [8]. To characterize and study the ionization process, the on-line production target is replaced by an atomizer in the off-line test bench, where a sample of the stable element is evaporated in order to produce a flux of neutral atoms to the ionization tube. LISBET (Laser Ion Source Body using Efficient Techniques) is an ion source prototype designed to investigate the geometries of

* Corresponding author.
E-mail address: henares@ganil.fr (J.L. Henares).

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the on-line ion source layout. LISBET consists of two tantalum tubes forming an angle of 90°, the first is used as transfer/atomizer cavity and the second as ionization tube where the laser light interacts with the atomic vapor. Both tubes are resistively heated by an electrical current to high temperatures of about 2000 K, to ensure fast desorption of atoms from the surface. The design allows the independent selection of the polarity and the magnitude of the heating current for the transfer tube and ionization tube. To study the impact of the geometry two versions of the ionization tube were tested: 3 mm and 7 mm diameter. Both versions are of 35 mm length, while the transfer/atomizer tube has an invariable diameter of 7 mm and 85 mm length.

The resonance photo-ionization is performed using up to three tunable solid state titanium:sapphire (Ti:Sa) lasers, pumped by a frequency doubled Nd:YAG laser. The Ti:Sa lasers were manufactured by the TRILIS group at TRIUMF (Vancouver, Canada) [9], and based on the design of Mainz University. A 10 kHz repetition rate laser system was used to minimize any possible duty cycle losses. The frequency of the Ti:Sa laser light can be doubled, tripled, and quadrupled to expand the accessible wavelength range. Higher harmonics are generated in two frequency conversion units designed and manufactured at the University of Mainz [10]. The overlapped laser beams are transported to the ion source through the mass separator and the extraction system, and the ionization takes place inside the ionization tube. The created ions are extracted by an electrical field of 19 kV and separated by a magnetic sector field mass spectrometer. The ion extraction line consists of two extraction electrodes and an Einzel lens. The extraction voltages and distances were optimized using SIMION^{TM} [11] simulations to maximize the extraction efficiency of ions from the ion source and to obtain minimum emittances. Finally, the ion beam current is detected with a Faraday cup and a low energy beam profiler (Fig. 1).

3. Contaminant reduction

Nowadays, the RILIS technology is used worldwide and the number of accessible elements increases each year. One of the drawbacks of hot cavity RILIS is non-selective surface ionization of unwanted isobaric contaminants due to the high temperature of the hot cavity. The surface ionization occurs during thermal desorption, when the atoms desorb from the walls of the hot cavity. The electric current used to heat the ion source by the Joule effect also generates also an electric field from the voltage drop from 4 to 6 V along the ionizer and the atomizer. This electric field can modify the direction of the surface ion motion and that of the laser ionized atoms. Therefore the ionizer and the atomizer are independently heated. Four solutions are proposed to control the electric field direction. A scheme of the different solutions is given in Fig. 2. A surface ionizable element was chosen to measure the total current by placing a sample with a known number of atoms into the atomizer. ^{85}Rb was chosen because it is not present as an impurity in our setup. For the test a 7 mm diameter and 35 mm length ionizer tube LISBET version was used.

Option A was chosen as reference because of the surface ions drift forward in both the atomizer and the ionizer giving the highest ion extraction efficiency, referred as Δ. Solution B gave a reduction factor of 2 compared to Δ, as the surface ions are captured by the electric field and half of them cannot reach the electrode extraction potential. C produced a reduction factor of 1.4 compared to Δ. Finally, the most interesting alternative is option D, since the direction of the electrical current for the ionization tube was chosen such that the resulting electric field pushes the ions generated in the ionization tube toward the extraction region, whereas the direction of the electrical current for the transfer tube repels back the surface ions generated in the transfer tube. However this option provided a reduction factor of only 1.7 compared to Δ. Nevertheless the atomizer has a cap that prevents the sample from falling down. This has the effect of recycling the surface ions. In the on-line behavior the cap is replaced by a target container which acts as a hole, so a greater reduction factor is expected without the cap. A prototype ion source will be built to measure the reduction factor under conditions similar to those on-line.

3.1. Low electron emission work function materials

Recently several publications concluded that low electron emission work function materials can reduce the surface ion production [12]. The number of suitable materials is limited by their mechanical properties and the required high work temperatures. In collaboration with the University of Limoges a specially designed ZrC ionizer was tested as low work function material [13]. The ZrC was designed as a rod of 3 mm of inner diameter and 7 mm outer diameter that fits into the 7 mm ionizer tube LISBET. A test was performed with the configuration *D* of the electric field (repelling backwards the ions generated in the transfer tube and pushing forwards the ions generated in the ionization tube) to determine the expected reduction in surface ionization. The implementation of the low work function

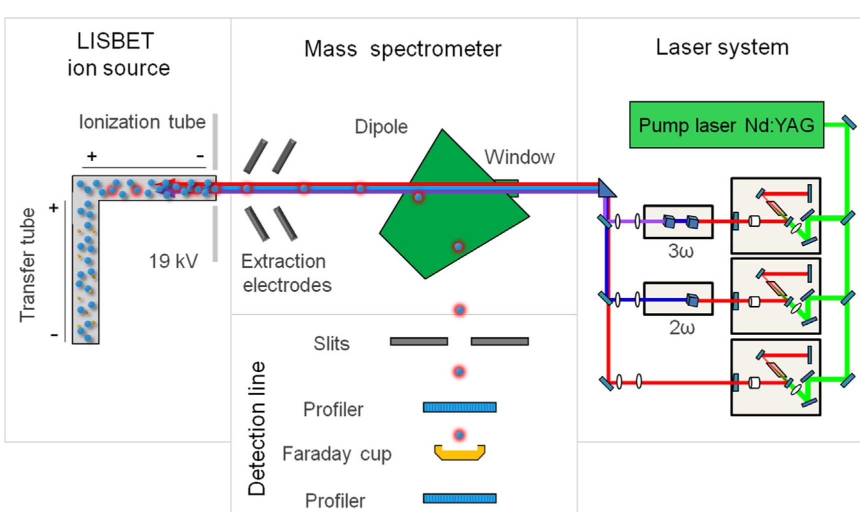

Fig. 1. Setup of GISELE off-line test bench indicating LISBET ion source, laser system, mass spectrometer and detection line.

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