Progress of Resonant Ionization Laser Ion Source Development at GANIL[a)]

J.L. Henares[1,b)], Y. Huguet[1], T. Kron[2],N. Lecesne[1], R. Leroy[1], B. Osmond[1], F. Schneider[2], A.M. Sjödin[1], K. Wendt[2]

[1]*GANIL, BP 55027, 14076 Caen Cedex 5, France*
[2]*Johannes Gutenberg-Universität Mainz, Staudinger Weg 7, 55099 Mainz, Germany*

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SPIRAL2 is a research facility under construction at GANIL for the production of Radioactive Ion Beams (RIB) by Isotope Separation On-Line (ISOL) methods and low-energy in-flight techniques. A Resonant Ionization Laser Ion Source (RILIS) will be one of the main techniques to produce the radioactive ion beams. GISELE (GANIL Ion Source using Electron Laser Excitation) is a test bench developed to study a fully operational laser ion source available for Day 1 operations at SPIRAL2 Phase 2. The aim of this project is to find the best technical solution which combines high selectivity and ionization efficiency with small ion beam emittance and stable long term operation. Latest results about the new ion source geometry will be presented.

I. INTRODUCTION

GANIL will host in the near future the new SPIRAL2 [1] facility for the production of on-line accelerated radioactive ion beams. One way to produce the radioactive ion beam for SPIRAL2 is based on the ISOL (Isotope Separator On-Line) method [2]; radionuclides are produced by nuclear reactions during the interaction between an incident beam and a thick target. The produced radioactive atoms diffuse out of the high temperature target and effuse into a hot cavity ion source where they are ionized. The ionized atoms are extracted and mass selected through a magnetic separator and can then be post accelerated into the existing CIME (Cyclotron pour Ions de Moyenne Energie) cyclotron or sent directly to various experimental installations [3].

The resonant ionization laser ion source (RILIS) has emerged as an important technique in many facilities to selectively generate RIBs [4]. RILIS combines Z-selectivity with an efficient ionization process [5]. It is based on step-wise resonant photo-ionization of the elements of interest. RILIS is one of the priority ion sources which should be operational for the commissioning and very first physics runs at SPIRAL2 Phase 2 to satisfy beam requests from a large part of the submitted Letters of Intent.

GISELE (GANIL Ion Source using Electron Laser Excitation) is a RILIS off-line test bench created to develop a fully operational laser ion source for SPIRAL2 Phase 2. The objective of the GISELE project is to find the best technical solutions which combine high selectivity and ionization efficiency with optimum beam parameters such as small ion beam emittance and long term operation.

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b)Electronic mail: henares@ganil.fr.

II. LASER ION SOURCE SETUP

A detailed description of GISELE has been presented in a previous publication [6]. The on-line production target is replaced by an atomizer in the off-line test bench. A sample of the stable element is evaporated in the atomizer in order to produce a flux to the ionization tube. The atoms are ionized by resonance photo-ionization using 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) [7], based on an upgrade of the University of Mainz design as described in [8]. The frequency of the Ti:Sa lasers can be doubled, tripled and quadrupled to greatly expand the accessible wavelength range to achieve the correct ionization scheme. Higher harmonics are generated in two frequency conversion units designed and manufactured at the University of Mainz [9]. In these experiments, 10 kHz repetition rate pulsed laser was used to minimize any possible duty cycle losses. The laser beams are transported into the hot cavity ion source and the ionization takes place inside the ionization tube, where the atoms and laser beams overlap (figure 1).

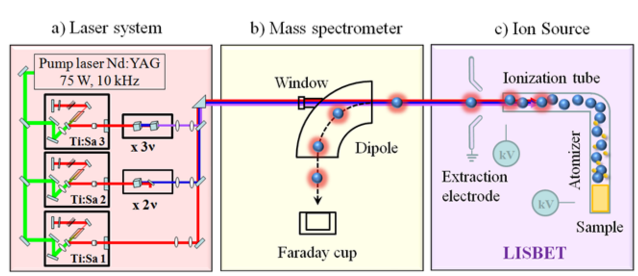

FIG. 1. (Color online). General setup for GISELE test bench: a) laser system, b) mass spectrometer c) LISBET ion source.

The created ions are extracted by an electrical field and separated by a magnetic sector field mass spectrometer. The ion beam current is detected with a Faraday cup.

The first requested beams for the first day of SPIRAL2 Phase 2 concerning RILIS are Sn, Zn, Ga, Y and In. The production of a Gallium ion beam was already successfully demonstrated in June 2011 in collaboration with the University of Mainz. In this paper we want to test the production of ion beams from LISBET using zinc as the element of choice.

A concept ion source LISBET (Laser Ion Source Body using Efficient Techniques) was designed to investigate new geometries for the future on-line ion source layout. LISBET consists of two tantalum tubes forming an angle of 90 degrees (figure 2). The elbow shape will be used in the on-line ion source to transport the atoms between the target (transfer tube) to the ionization area (ionization tube) while shielding the ionization area from the main cyclotron beam. For the off-line experiments the transfer tube will be used as atomizer. Both tubes have an external diameter of 7 mm and a thickness 0.15 mm. The atomizer is 83.5 mm long and the ionization tube is 61.5 mm long. A diameter of 7 mm was selected in order to be able to fit a ceramic material inside the ionization tube in an attempt to reduce isobaric contaminants. The temperatures of the atomizer and ionizer tubes are controlled separately. To avoid atoms sticking to the walls, high temperature is needed to ensure desorption time inside the cavity of less than 1 s for later on-line application. For the test measurements the stable material is placed in the end of the atomizer inside a boron nitride container.

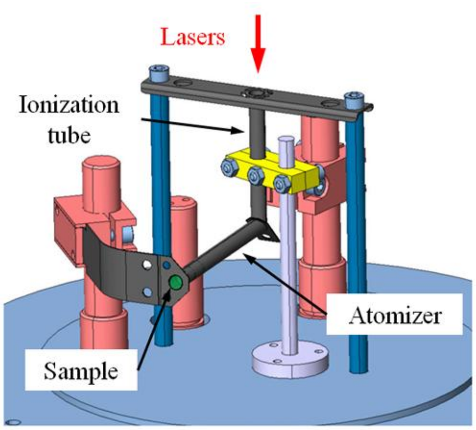

FIG. 2. (Color online). General view of LISBET ion source.

To measure the efficiency of the method, 0.8 µg of natural zinc was placed in the container. Lasers were set to photo-ionize zinc using the three-step scheme shown in figure 3. For the first and the second excitation steps saturation was reached while the saturation powers were determined to be 29 mW for the first step and 250 mW for the second step. For the ionization step no saturation behavior was observed with an output power of 3 W. The atomizer and the ionization tube were heated to create a constant atom release flux from the sample. For this purpose during the experiment, the temperature was slowly increased from 300 K to 2000 K to evaporate the sample. The ionized particles were extracted with a high voltage of 15 kV. During efficiency measurements, the mass spectrometer was set on ^{64}Zn mass region. The total integrated ion current was compared with the amount of atoms in the original sample to give the efficiency of the process [10]. A background correction was done using the ion current measured while the laser beams were blocked.

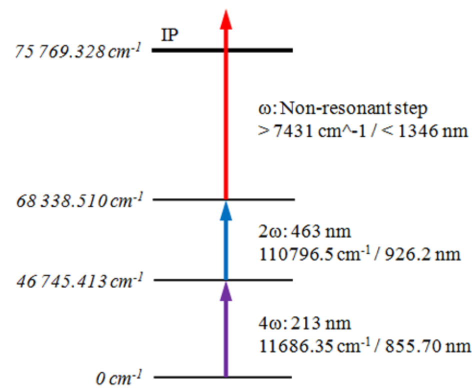

FIG. 3. (Color online) Ionization scheme for zinc atoms with a non-resonant third step transition.

III. RESULTS

Different species were found in the mass range of the spectrometer (figure 4), most of them created by surface ionization in the ionization tube like Na, Al, K or Ba. The surface ionization occurs by thermal desorption when the atoms touch the walls of the hot cavity. The intensity of the surface ionization signal decreases over time. However, the natural isotopes of zinc generated by multi-step photo-ionization were detected as major components almost free of any reasonable background. An overall efficiency of 0.52 ± 0.05 % was obtained for the zinc signal, composed of the partial efficiencies from atomization, ionization, transport and detection. The ion current during the course of one efficiency measurement is shown in figure 5. The signal peaks correspond to increases in the hot cavity temperature. The efficiency was calculated with the integrated ion current compared with the amount of atoms in the sample. It is observed that the sample was not fully evaporated due to time restrictions, consequently, the efficiency only could be considered as a lower limit. As comparison, ISOLDE RILIS measured an efficiency of 4.9% with a dye laser system, different ion source geometry and different ionization scheme [11]. The possible causes of the relative lower efficiency are: Only the first and the second ionization steps were saturated, less overlap between photons and ions was expected due to the relative large volume created by the diameter of the ionization tube, and efficiency losses caused by relative low high voltage extraction could have happened.

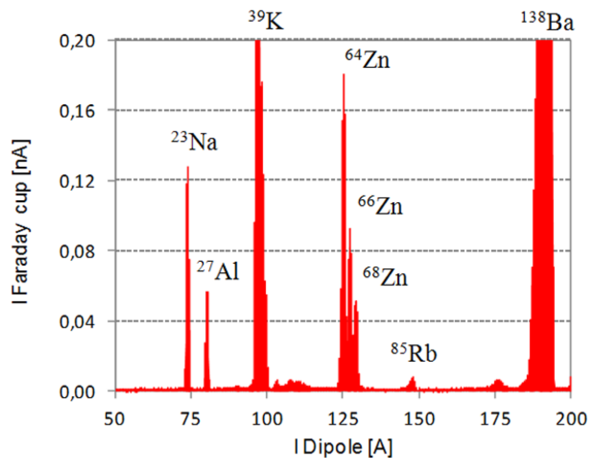

FIG. 4. The complete mass spectrum of ions coming out the ion source. All peaks except zinc are produced by the surface ionization.

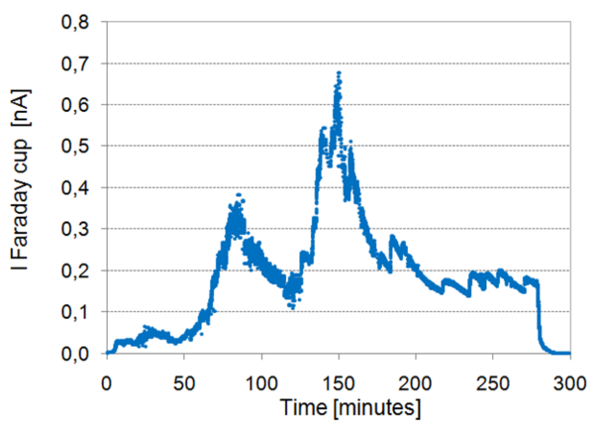

FIG. 5. Ion current detected for ^{64}Zn during the efficiency measurement.

IV. IMPROVEMENTS

LISBET has been designed as a modular system to investigate different solutions by varying the geometry and the tube design parameters (diameter, thickness or length) to compare and to develop the future on-line laser ion source. Furthermore, to improve the selectivity of the ion source, tests will be carried out by using new ceramic materials with a low work function. Carbide tubes will be tested in cooperation with the SPCTS laboratory “Science des Procédés Céramiques et de Traitements de Surface” from the Université de Limoges [12]. Also the saturation of the third step should be reached by using a higher power Nd:YAG laser, this could substantially increase the ion source efficiency. The feasibility of employing the electric field, generated by the heating current, to eliminate contaminants will additionally be investigated in combination with the ceramics. Finally, in order to characterize the time profile of the ion beam [13] an electronic system for time resolved data acquisition is under development.

V. CONCLUSION

The GISELE test bench is now fully operational for spectroscopic as well as efficiency measurements. A zinc ion beam was generated with the efficiency of ≥0.52%. A significant improvement of this value is expected after full optimization of the ion source parameters and conditions.

VI. ACKNOWLEDGMENTS

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