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RESonance laser Ionisation techniques for SeparaTors (RESIST)

Deliverable 12.2 - Report on Task 1

PRE-LIST TECHNIQUES TO ENHANCE ION BEAM PURITY

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LIST OF ACRONYMS AND ABBREVIATIONS

RESIST	RESonance laser Ionisation techniques for SeparaTors
RILIS	Resonance Ionization Laser Ion Source
IGLIS	In-Gas Laser Ionisation and Spectroscopy
LIST	Laser Ion Source and Trap
RIB	Radioactive Ion Beam
ISOL	Isotope Separator On-Line
RIS	Resonance Ionisation Spectroscopy

Executive Summary

This report summarises the deliverable due in month 24 of ENSAR-2. It focuses on the status of Task 1 of the RESIST Joint Research Activity.

Introduction

The RESIST (RESonance laser Ionisation techniques for SeparaTors) Joint Research Activity of ENSAR2 aims to refine the highly successful Resonance Ionisation Laser Ion Source (RILIS), the In-Gas Laser Ionisation and Spectroscopy (IGLIS) and Laser Ion Source Trap (LIST) technologies. These techniques are coupled to both approaches currently in use, i.e. hot cavities and gas cells at on-line facilities, for the production and study of radioactive ion beams (RIBs).

Our goal is to obtain RIBs of the highest purity regarding selection of isobaric as well as isomeric species, which otherwise are indistinguishable for conventional mass spectrometers. We propose to implement, for the first time, laser techniques not only at « traditional » ISOL facilities, but also at existing and upcoming in-flight facilities. This approach will enable dedicated studies on the shortest-lived exotic and specifically refractory isotopes far from stability and will result in spectroscopy of exceptional sensitivity and significance, aiming at the coupling of new laser systems (of dramatically reduced linewidth) which are tailored to exploit optimised experimental environments. Radionuclides produced in the rarest quantities will thus be accessed, extending and complementing earlier nuclear and laser spectroscopic techniques.

Task 1 focuses on efforts to enhance the ion-beam purity prior to the so-called LIST devices and is led by CERN, with contributions from JOGU Mainz, KU Leuven, GANIL and INFN. This task aims to find solutions for the optimal configuration of electrical fields to reduce non-resonant ionization processes when coupling the LIST with the target both in hot cavity ion sources as well as gas-cell based sources, and to investigate low work-function materials resistive to the high-temperature conditions. Task 1 has three deliverables, namely a series of reports due at the end of the first 12 months, after 24 months and finally after 48 months. This task is led by ISOLDE CERN and is divided into three sub-tasks.

This document herein reports on the second 12 month period of activity of the RESIST partners involved in Task 1. We refer to Deliverable 12.1 (reported at the end of the first 12 month period) for a more detailed background to the different sub-tasks which are discussed independently in the following sections.

Section 1: A reduction of secondary electron ionisation processes pre-RF structure. Minimisation of radioisotope deposition on the RF structure which leads to isotope-dependent ionisation mechanisms

<u>JOGU Mainz: Implementation of Fast Beam Gating and Two-Photon Spectroscopy in the Perpendicular-Illuminated Laser Ion Source and Trap PI-LIST</u>

The Laser Ion Source and Trap (LIST) is a tailored upgrade of the well-established, highly element-selective resonance ionisation laser ion source RILIS. It comprises additional suppression of non-laser ionised contaminants produced in the hot atomisation cavity immediately at its exit by an electrostatic repelling electrode, providing a clean laser – atom interaction volume within a radially confining rf quadrupole structure. During previous application of the LIST, electron impact-induced ionisation processes inside the rf structure had been identified as an additional source of contamination. In Deliverable 12.1 we highlighted the effect of introducing a second repelling electrode operated on negative potential to suppress electrons from entering the LIST which are created by the hot source material [1]. On-line operation of such a LIST unit, additionally comprising reduced surface deposition by a reduced overall length, is foreseen at CERN-ISOLDE at the beginning of the physics campaign in 2018 for the production of pure Mg RIBs.

For further surface ion suppression and preservation of the desired nuclides laser-ionized in the hot cavity before entering the LIST structure, which would otherwise be lost at the repelling electrode, a fast polarity switch to control the heating current applied to the atomizer is currently under development [2]. The voltage gradient induced by the heating current may then either guide ions out towards the extraction or back into the source, where they can re-neutralize on the walls. Therefore, four high current IGBT switches in an H-bridge configuration operated by home-built TTL-controllable electronics allow in-situ polarity switching of up to 100 A on a sub-µs timescale. Adaption of this system to higher currents used at on-line facilities is ongoing. Later on, this development can be utilized to improve the performance for time-of-flight technique-based laser ion source concepts [3].

More recently, a significant reduction of beam contamination from interfering species in the Laser Ion Source as well as the LIST unit has been obtained by rapid switching of a beam gate in perfect synchronization with the sequence of laser pulses. This technology was demonstrated in holmium to enhance the suppression of dominant stable isotopes and long-lived isomers with respect to a desired radioisotope. The pronounced tailing of the mass peak towards lower mass, caused by ionization processes taking place inside the acceleration field and leading to interfering contributions on lower masses, as visible for a sample of ^{163,166,166m}Ho in Fig 1. (red line), could be strongly reduced (green line). A gain in selectivity and corresponding ion beam purity by up to two orders of magnitude was achieved depending on the load of higher mass ions escaping from the hot cavity and LIST structure.

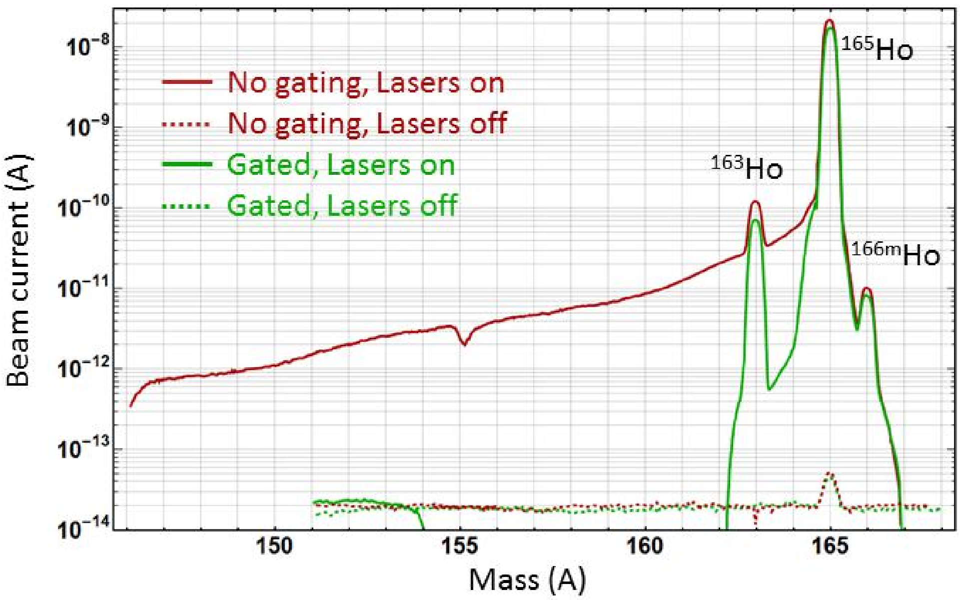

Figure 1: Mass scans in the holmium mass region for comparison between standard operation (red line) and fast ion beam gating (green line) on a sample of ^{163,165,166m}Ho. Non-specific background at the lower mass side stemming from ionization in the acceleration region is clearly suppressed (dotted lines show negligible surface ionization background).

[1] R. Heinke *et al.*, Hyperfine Interact. **238** (2017) 6
[2] S. Rothe *et al.*, Nucl. Instr. Meth. B **376** (2016) 86
[3] V.I. Mishin *et al.*, AIP Conference Proceedings **1104** (2009) 207

SECTION 2: OPTIMISATION OF LASER-IONISATION GEOMETRY IN THE GAS JET TO MINIMISE OR EVEN PRECLUDE PHOTO-ION CREATION IN THE GAS CELL VOLUME AND MINIMISING THE DEPOSITION OF RADIOISOTOPES ON THE RF STRUCTURE

We refer to Deliverable 12.1 for the introduction to this topic. This work is related to Sub-task 1.2 and the development of a new off-line setup for gas-jet research in the HELIOS laboratory of KU Leuven. Since our previous report the laboratory has been taken into full use for supersonic gas jet research, discussed further in Deliverable 12.3. In parallel, work has proceeded at KU Leuven into studying the transmission efficiency of the radiofrequency quadrupole ion guides, and comparing the results with different models available in the literature. Figure 2 illustrates schematically the S-shaped and linear rf guides used to transport the ions from the gas cell to the mass separator. Stable copper ions are created following laser ionization in the gas cell and by monitoring the ion current on the first electrodes of the S-RFQ as well on a downstream Faraday cup, the transmission was determined to be 90(5)%. The experimental data were compared with a hard-sphere model, Stokes model and a combined model as illustrated in Fig. 3. As shown, the transmission efficiency is rather well reproduced using the hard sphere model.

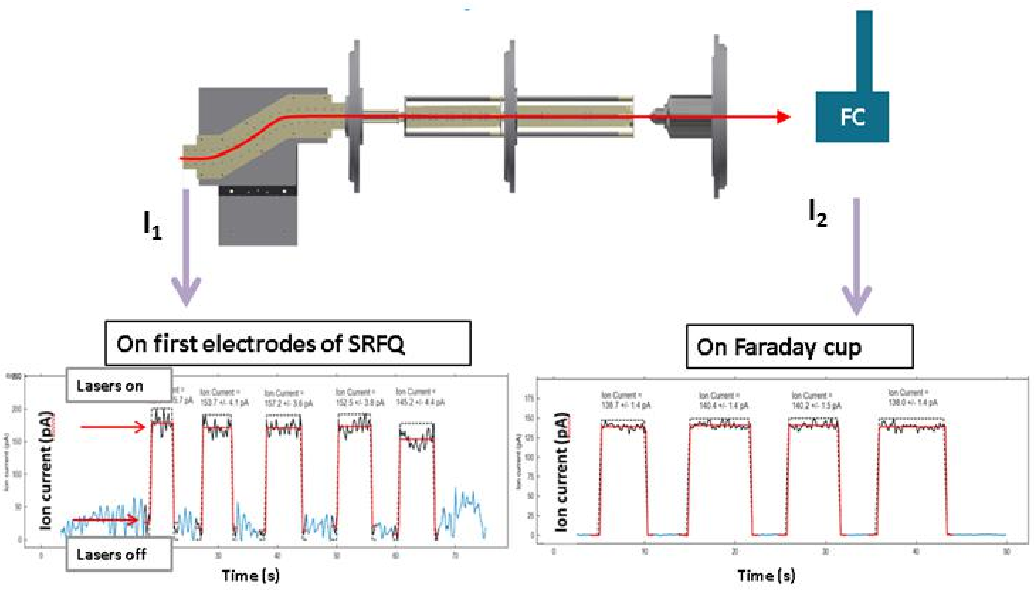

Figure 2: Schematic representation of the HELIOS rf ion guides (S-shaped and linear), installed at KU Leuven. By monitoring the currents I_1 and I_2, the transmission efficiency of the system can be measured.

In addition to the transport efficiency, the beam emittance of the extracted ion beams is another of the main properties that characterize a RFQ ion guide system. Experiments have beam performed to determine the longitudinal emittance of the ion beams transported through the ion guides by gradually applying a blocking voltage on one of the small apertures through which ions travel in the ion guides. These measurements resulted in a value for the longitudinal emittance of 1.4(5) eV. This value is also in agreement with ion optical simulations (see Fig. 4) considering the hard sphere model. Currently we are performing experiments to measure the transverse beam emittance to fully characterize the optical properties of the extracted ion beams.

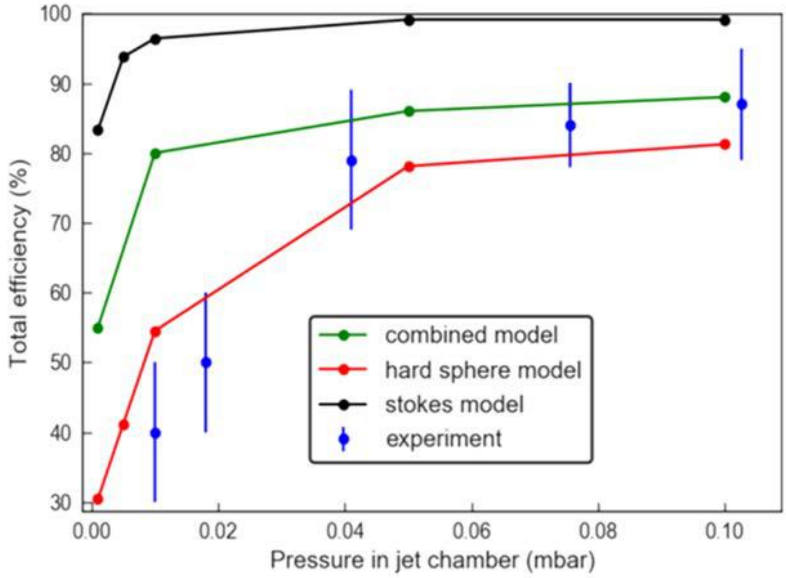

Figure 3: Comparison between the experimental transmission efficiency and different simulations for the radiofrequency ion guides at KU Leuven.

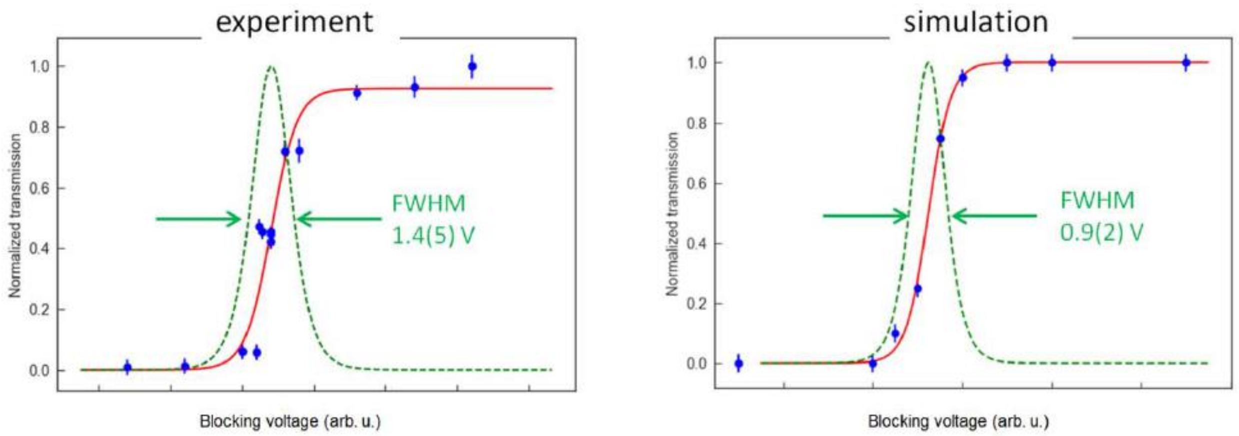

Figure 4: Measurement (left) and simulation (right) results of the longitudinal emittance of the ion beams transported through the RFQ ion guides.

SECTION 3: HIGH TEMPERATURE MATERIALS RESEARCH FOR THE TRANSFER LINE AND THE LASER IONISATION CAVITY FOR SURFACE ION SUPPRESSION

GANIL: Studies at the GISELE test bench

The off-line RILIS test bench at GANIL, named GISELE (GANIL Ion Source using Electron Laser Excitation) was built to study ionisation processes and to optimise ion source parameters, in particular for surface ion suppression. A new ion source prototype, LISBET (Laser Ion Source Body using Efficient Techniques) has been designed to be a modular system in order to investigate different experimental approaches by varying the design parameters. It consists of two tantalum tubes forming a 90° elbow shape, used as a transfer/atomiser cavity and an ionisation tube where the laser light interacts with the atomic vapour. Both tubes are resistively heated by an electrical current to high temperatures of about 2000 K. The design allows an independent selection of the polarity and the magnitude of the heating currents.

The efficiency, the emittance and the time structure were analysed with a Sn ion beam as a function of the ioniser tube diameter and length. An increase of the ioniser diameter substantially improved the ion beam production. The electric potential gradient along the tube, generated by the heating current, together with the reduction of neutralisation due to the decrease of the contact surface, produced an increase of the ion extraction. In the case of the ioniser diameter, an efficiency of approximately 24% was obtained for 7 mm and 8% was obtained for 3-mm diameter ionisers, respectively. The simulations showed that an ioniser with a diameter of 7 mm should provide the best transport efficiency. An increase in the ioniser length was expected to ameliorate the efficiency, however, no improvement was observed.

In order to study and optimise the selectivity of the ion production, two methods have been studied to decrease the production of contaminants (due to the surface ionisation) with an alkali marker (Rb). The first technique is based on changing the electric field potential directions in the transfer tube and/or the ionisation tube. The option where the electrical potentials are directed towards the entrance aperture for the transfer tube and towards the exit aperture for the ionization tube was found to yield the highest reduction in contamination without compromising the production rate. The second technique utilized the insertion of ZrC ceramics into the ioniser tube. Further reduction of contamination at high temperatures was expected in this case. As described in the literature, ZrC materials could have a low work function property that diminishes the alkali contamination. However, no significant improvement was found with the inserted material configuration. Preliminary work on the microstructure of ZrC has to be carried out in order to reduce the work function before new investigations continue.

LNL-INFN: cavity development for isobaric suppression

Taking as a reference the techniques developed at RILIS (ISOLDE), the team of engineers in charge of developing the ionisation source for SPES, Legnaro, has recently started a dedicated study based on Finite Element Methods (FEM) simulations, in order to optimise the ionisation efficiency of the SPES RIB. In particular, the study of the temperature distribution inside the laser cavity should be uniform along the cavity line. This aspect is paramount to avoid the presence of cold zones, which become condensation surfaces (traps) for the isotopes coming from the production target.

U-Mainz: Optimisation of Temperature Distribution and Reliability of the Laser Ion Source Hot Cavity

For thoroughly optimising design details, materials and heat distribution in the hot cavity ion source, heat transport and dissipation was analysed by a finite element code (Fig. 5a). This refinement led to a further gain in reliability and reproducibility of the hot cavity laser ion source unit. Holmium was used to test the system, verifying the previously measured overall ionization efficiency (from 2015) of 41(6) %, (Fig. 5b).

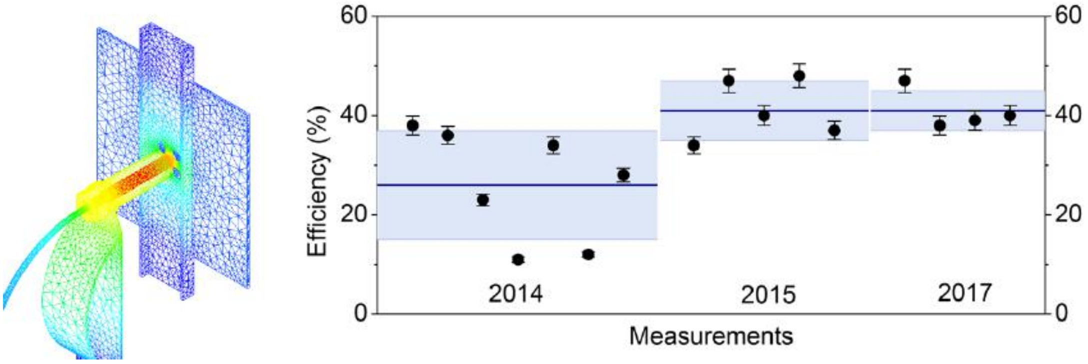

Figure 5: (Left figure) Finite element simulation of the hot cavity laser ion source, (right figure) development of experimental ionization efficiencies for holmium with reproducibility achieved in recent years (grey range).

Conclusion

Resonant laser ionisation enjoys a dominant position as the most fruitful and in-demand ionisation mechanism for the production of radioactive ion beams worldwide. The partners within the RESIST collaboration bring complementary expertise to the forefront of this field, developing advanced techniques not only to improve the efficiency and selectivity of RIB production, but also to use state-of-the-art laser systems for the study of exotic nuclei produced at the source for nuclear structure studies. The objectives of RESIST aim to support the Transnational Access Facilities of ENSAR2, while in parallel provide a rich research programme of development and spectroscopy which will ensure that Europe continues to lead the field in resonant laser ionisation and spectroscopy.

As highlighted in this report, the partners of RESIST are making good progress in the development of techniques to enhance radioactive ion beam purity.