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The SPES Laser Ion Source: Time Structure and Laser Enhancement Measurements with Sm^+ beam

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Abstract. A two-step resonance photo-ionization scheme has been used to ionize samarium atoms in the SPES tantalum hot-cavity ion source. The effect of the ion load on the ion beam time structure and the laser enhancement of the ion yield has been studied at different ion source temperatures. Generally, the introduction of more positive ions (ion load) affects negatively the overall confinement of the laser ions inside the volume of the ion source. Possible enhancement of the laser ion confinement through the introduction of neutrals is observed as well. The ion load is also observed to affect the confinement in the transfer line much more than in the hot cavity. Measurement of the time structure with inverted polarity of the cavity DC heating supply confirmed the significance of the longitudinal potential for ion extraction. The laser enhancements of the ion yield are found to be sensitive to the ion load at low operating temperature of the ion source i.e. 1800°C, whereas at 2050°C and 2200°C, they are relatively stable till an ion load value of 1.2 µA.

1. Introduction

"Selective Production of Exotic Species" (SPES) is a second-generation ISOL facility which is in the final stage of construction at Legnaro National Laboratories (LNL) [1]. A multi-foil target system of uranium carbide will be irradiated by a proton beam with an energy of 40 MeV and a current intensity up to 200 µA. This is expected to provide a fission rate of approximately 10^{13}/s inside the target. The fission fragments effuse and diffuse through the pores of the target material and eventually reach the heated transfer line which is designed to transport the species to the hot cavity, where they can be ionized and extracted for subsequent delivery to the experimental areas.

The SPES laser ion source (LIS) is based on the surface ion source, reported in [2]. Detailed characterization of this ion source as a hot cavity LIS has been performed with gallium ion production [3].

2. Radial confinement of ions in a hot cavity

In a hot cavity ion source, a "thermal plasma" is formed as a result of the presence of ionized atoms and the thermionic electrons emitted from the heated walls. The potential of this plasma is negative with respect to the wall and can be calculated as [4],

$$\phi_p = \frac{k_B T}{2e} ln \frac{n_{is}}{n_{es}} \tag{1}$$

where k_B is the Boltzmann constant, T is the absolute temperature and, n_{is} and n_{es} are the densities of the ions and the electrons respectively near the surface of the hot cavity.

The negative potential of the plasma provides the confinement of the ions inside the volume of the ion source by preventing collisions of the ions with the wall [4, 5].

The increase of neutral density can also provide a great improvement in the confinement of the ions. The efficiency can be increased if the mean free part of ions is reduced to the order of the cavity dimensions. However, very high neutral densities are required in these cases [5].

3. Experimental Set-up

Two frequency-doubled Ti:Sa lasers tuned at 435.71 nm are used to achieve the photo-ionization of samarium atoms [6], as per the indicated scheme in Figure 1. The combined power was measured around 2.4 W (above saturation) with a repetition rate of 10 kHz.

The experiment was performed at the ISOLDE Offline 2 facility [7] in CERN, Geneva. A schematic representation of the set-up is shown in Figure 2. Two tantalum capillaries, one loaded with samarium sample and the other with potassium, are connected to the beginning of the transfer line. The surface ion current produced by the potassium sample was used to manipulate the total ion current in order to study the ion load effect on the samarium laser ion yield.

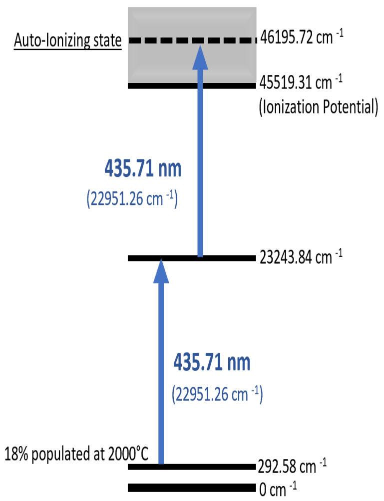

Figure 1. Photo-ionization scheme of samarium. Transition wavelengths are given for vacuum.

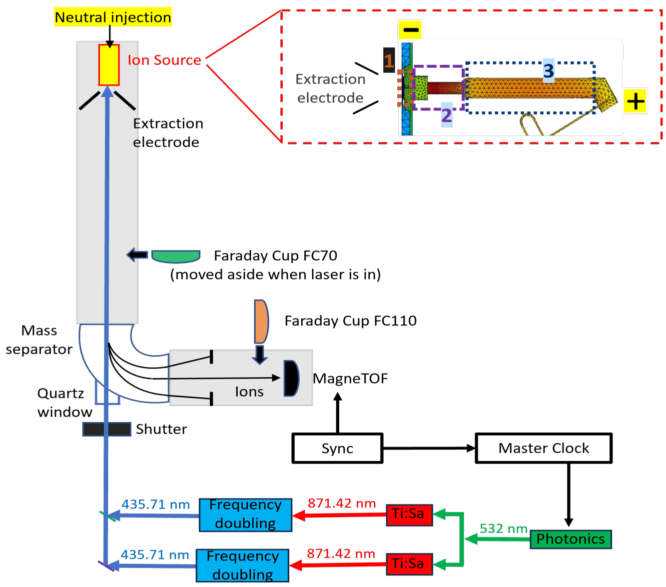

Figure 2. Schematic representation of the experimental set-up. The dotted red box shows the orifice, the hot cavity and, the transfer line of the ion source indicated as 1, 2 and 3, respectively.

4. Time Structure Profiles of the Extracted Ion Beams

When a laser pulse simultaneously creates ions along the whole ion source volume, the resulting temporal profile of the extracted ion beam is determined by the source internal extraction mechanisms. Measurements of temporal structure of the ion beam can, therefore, reveal details about the ion confinement properties of the ion source. In particular, reduced population of ion bunches originating from the hot cavity or transfer line implies a reduction of ion confinement in the respective space.

To obtain such time structures, a MagneTOF™ detector, synchronized with the trigger of the laser pulses, is used in single ion counting mode to investigate the isotope beam after mass separation. The data acquisition module is described in [7].

4.1. Conventionally polarized laser ion source

Conventionally, the polarity of the ion source is applied in such a way that the voltage potential gradually drops in the direction towards the exit/orifice of the hot cavity. This provides an axial electrostatic field that allows the drifting of the ions towards the exit for extraction [3, 8, 9].

Figure 3a, 3b and 3c shows the time structure profile of the extracted ^{144}Sm ion beams for various ion loads at ion source temperatures 1800°C, 2050°C and 2200°C, respectively. In the time structure profiles, the ion bunches originating from the orifice of the ion source, the hot cavity and the transfer line, are labelled 1,2 and 3, correspondingly. The origin and identification of such peaks from similar ion sources are well-presented and simulated in literature, see for example the paper of Y. Liu [10].

The bunch 1 is immediately extracted as the orifice is penetrated by the applied extraction field until a depth equal to the diameter of the orifice. In the plots, the bunch 3 is seen before 1 and it is because in the temporal window of only 100 µs, there is an overlap of ion bunches from the previous laser pulse on the succeeding one. Figure 3d shows the ratio of the total ions from region 2 and 3 versus the ions just from the region 1 of the ion source (which should not be affected by the confinement inside the ion source as they are immediately extracted once formed).

Two important observations from these plots are:

1) At ion source temperatures of 1800°C and 2200°C, a similar behaviour is observed. The confinement of the laser ions seem to increase briefly with the increase in the total ion current and, there appears to be a maximum confinement of laser ions at total ion current of around 1.7 nA for 1800°C, and 60 nA for 2200°C. After these values, the overall confinement starts to drop. However, the difference is that the confinement at 1800°C is highly sensitive to the increase in the total ion current and it is almost completely depleted at the total ion current value of 230 nA. Whereas in the case of 2200°C, the confinement is less sensitive to the total ion current and remains at a good level till a total ion current value of around 1.2 µA. In the case of 2050°C, the increase in the total ion current results in the decrease of the laser ion confinement straight away.

2) Once the laser ion confinement has achieved its maximum, the confinement in the hot cavity (region 2) remains very stable for certain ranges of the total ion current, depending on the ion source temperatures. These ranges of total ion current are 1.7-7.8 nA, 1.4-225.3 nA and 59.7-762.0 nA for ion source temperatures of 1800°C, 2050°C and 2200°C, respectively. In these ranges of total ion current, the confinement in the transfer line (region 3) drops consistently with increase in the total ion current.

These observations indicate the following points respectively.

a) From Equation 1, the introduction of more positive ions should weaken the confinement of the ions. However, it is observed that the increase in total ion current can provide a better confinement in certain ranges. We must keep in mind that, to increase the total ion current, more potassium neutrals have to be injected and the surface ionization efficiency is roughly 50%

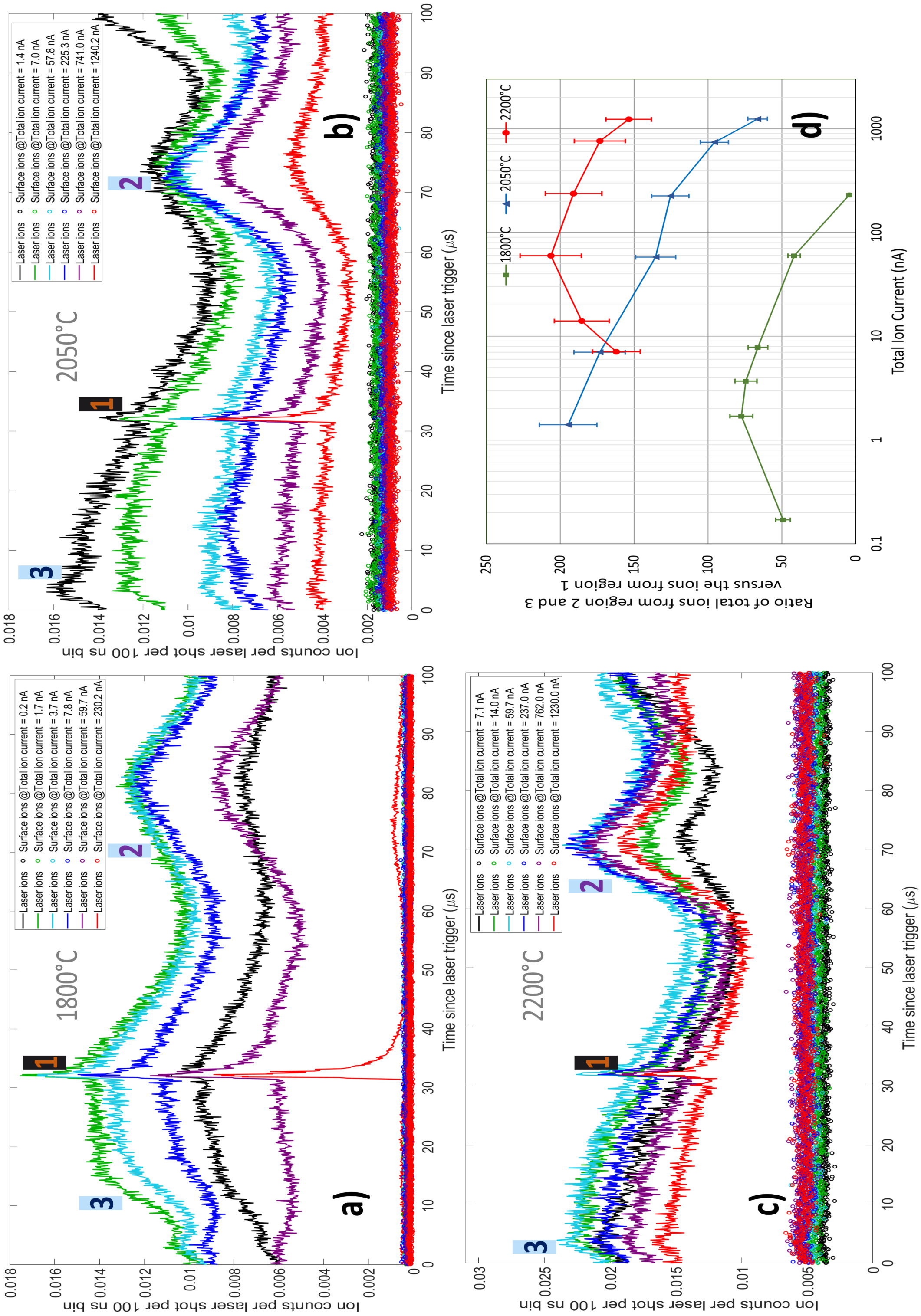

Figure 3. Time structure measurement of ^{144}Sm ions from the SPES-LIS a) 1800°C, b) 2050°C and, c) 2200°C. d) shows the ratio of total ions from region 2 and 3 versus the ions from region 1.

at 2200°C [2] and, even lower at lower temperatures. So, this observation could be possibly explained by the effect of the increased neutral potassium density, as mentioned in [5].

b) The laser ion confinement in the transfer line is more prone to be depleted by increase in the total ion current w.r.t. the hot cavity. The geometry and the temperature profile of the transfer line could be optimised to provide a more resistant ion confinement as in the hot cavity.

4.2. Inverse polarized laser ion source

We measured the time structure of the extracted laser ion beams in the "inversely polarized" configuration of the ion source. It means that the Joule heating of the ion source still remains the same but the direction of the potential drop is now inversed. Figure 4 shows the measured time structure profile and it is evident that only the laser ions formed in the orifice of the ion source (region 1) are extracted, while the laser ions formed in the hot cavity and the transfer line are drifted away from the exit and are therefore unable to be extracted.

5. Laser Enhancement of the Samarium Ion Yield

In a hot cavity laser ion source, the ions produced due to the hot surface (surface ions) are unavoidable. The ratio of the ions produced by the resonant laser interaction (laser ions) to the surface ions is termed as the laser enhancement ratio (LER) and, it determines the selectivity of the laser ion source.

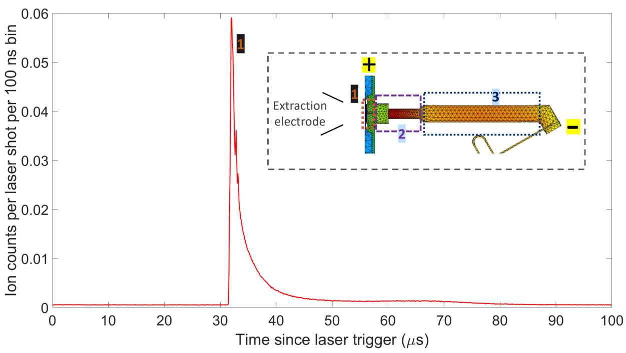

Figure 4. Time structure of the ion beam from an inversely polarized ion source.

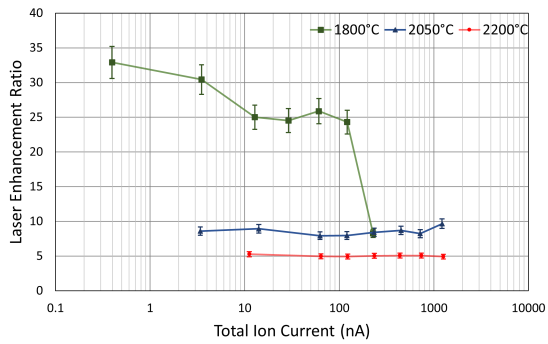

Figure 5. LERs at different ion source temperatures versus the total ion current.

Figure 5 shows the measured LER values of samarium ionization for different ion source temperatures at various values of total ion current. The laser enhancement remains fairly constant for different levels of total ion current at ion source temperatures 2050°C and 2200°C. At ion source temperature of 1800°C, the laser enhancement is highly sensitive to the total ion current and drops rapidly. This could also be correlated to the time structure profile where it is clearly seen that the laser ion confinement at this temperature drops fast with the increase in total ion current.

6. Conclusion

At ion source temperatures of 2050°C and 2200°C, the SPES-LIS can provide a very good confinement of laser samarium ions till a total ion current value of 1.2 µA. The laser enhancement of the samarium ion yields also maintain a relatively stable value in this range of ion source temperature and total ion current. The transfer line of the SPES-LIS could be further optimized to provide a laser ion confinement more resistant to the total ion current like the hot cavity.

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