Element Selective Laser Ion Source for On -Line Mass Separator.

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Abstract. First results obtained with a new type of an element-selective laser ion source for an on-line mass separation are presented. The concept of the ion source is based on laser resonance ionization of nuclear reaction products thermalized in a high-pressure noble gas. The fast and universal thermalization of reaction products in combination with high selectivity and high efficiency of resonance photo ionization allows to develop an element-pure source of short lived exotic nuclei.

Many interesting nuclear physics phenomena are only revealed by studing nuclei far from stability. Such nuclei can be produced by an energetic beam from an accelerator in a target connected to an ion source of an on-line mass separator [1]. For the study of short-lived exotic nuclei the target-ion source system should have a short delay time, a high ionization efficiency and a high selectivity. Since in most cases the nuclear reactions are only partly selective the lack of selectivity in the ion source is the limiting factor.

The way to obtain an extremely high degree of selectivity is using laser resonant photo ionization [2]. Stepwise excitation of the atoms of interest followed by ionization in the last step provides element selectivity and together with subsequent mass separation delivers element and isotope pure ions. With today's commercially available laser systems it becomes, in principle, possible to obtain an

ionization efficiency near unity for about 80% of all elements. So far only pulsed lasers can deliver the high power needed to achieve a high efficiency. These lasers have one major drawback, namely their low duty cycle. To solve this duty cycle problem, Andreev et al. [3] and Kluge et al. [4] proposed to store the atoms of interest in a moderately heated cavity connected to a target or an external oven. This technique has now been used at several on-line mass separators [5-7] showing its high potentiality. But the target - storage system has its limitations : only elements fastly diffusing out of the target and volatile in the cavity are efficiently ionized and secondly, unwanted thermo-ionization sometimes seriously contaminates the ion beam.

The laser ion source described here combines the fast and universal thermalization of nuclear reaction products in a high pressure noble gas, used in He-jet and ion-guide techniques [8], the high selectivity of resonance photo-ionization and, to overcome the low-duty cycle problem, the ion-storage capacity of noble gases.

A lay out of the target - ion source system is given in fig. 1. The cyclotron beam enters the source through a 5 μm Havar window (3) and hits the target (4). The reaction products recoil out of the target and thermalized to a 1^+ charge state in the helium gas (typically 500 mbar pressure). After a few milliseconds all the ions are neutralized [9]. This short ion survival time, which forms a major limitation for the efficiency of the ion-guide technique, is believed to be due to the plasma induced by the cyclotron beam [9]. The ion survival time in a gas cell without cyclotron beam is much longer. Therefore the cyclotron beam is bunched in 50 ms on and 50 ms off periods. About 5 ms after the end of the cyclotron beam pulse, the source is free of charged particles and a laser pulse is fired axially into the laser ion source. Atoms of interest in the laser beam path (ϕ=2 mm) are

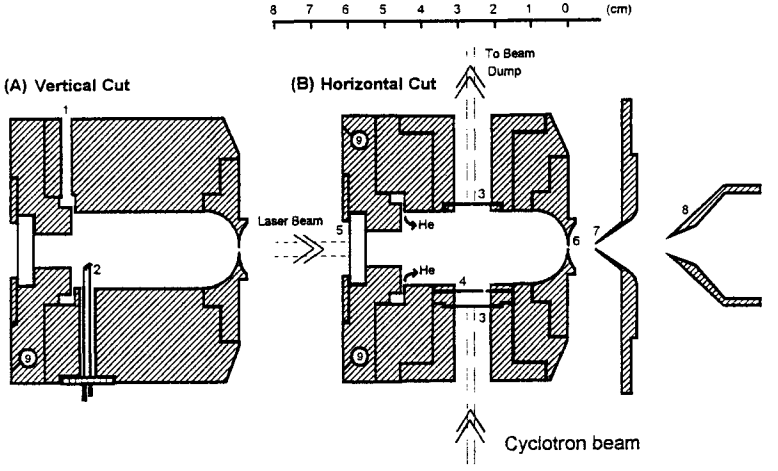

Fig. 1. A schematic lay-out of the laser ion source; 1-helium inlet, 2-nickel filament, 3-5μm havar windows, 4-target, 5-quartz window, 6-exit hole (Ø 0.5mm), 7-skimmer (Ø1.5mm), 8-extraction electrode (Ø5.5mm), 9-water cooling.

selectively ionized and are transported by the helium flow (0.12 l/s) as ions through the exit hole (6). The ions are accelerated towards the skimmer (7), (negatively polarized by a few hundred volts relative to the gas cell) where most of the helium is removed by differential pumping. The ion beam is further accelerated towards the extraction electrode (8) and the analyzing magnet of the mass separator.

This ion source was used for production of a pure beam of radioactive ^{55}Ni ions. Here we used a two-step one colour photo-ionization technique, whereby the same laser wavelength is used for the excitation and the subsequent ionization of nickel atoms. About 4.5 mJ per pulse of UV laser light (10ns pulse duration) was obtained after frequency doubling of the output of a pulsed dye laser operated with DCM, which was pumped by the 532nm output of a Q-switched 10 Hz Nd:YAG laser. For the strongest transitions observed (λ=322.698nm, λ=324.846nm,...) the ionization step was readily saturated with the available laser power density (for more details see [10,11]).

The performance of the laser ion source was tested with stable nickel atoms produced in the cell by heating a Ni filament (2) in fig.1 as well as with ^{55}Ni produced on-line using a 27 MeV ^{3}He beam on an enriched ^{54}Fe (3mg/cm^2) target. Fig. 2 shows the signal of stable nickel ions produced in the gas cell by resonant laser light and detected in the collection chamber of the mass separator. The amplitude of the ion signal is shown versus the time elapsed since the impact of the laser pulse in the gas cell. Note that the time scale can be related to a position inside the gas cell: for example, the ions created at the crossing point of the laser and cyclotron beam (2.5 cm from the exit hole) are detected 20 ms after the laser has fired. This figure demonstrates the long ion-survival time in the absence of the cyclotron beam. The recoil energy of the ^{55}Ni atoms was 1.4 MeV leading to an effective target thickness of 0.43 mg/cm^2 and a primary production rate of 4.2x10^4 atoms/μC of ^{55}Ni atoms recoiling out of the target was estimated on the basis of cross section calculations [12]. After mass separation, the radioactive isotopes were implanted in a tape behind which a detector was positioned for the detection of the β particles.

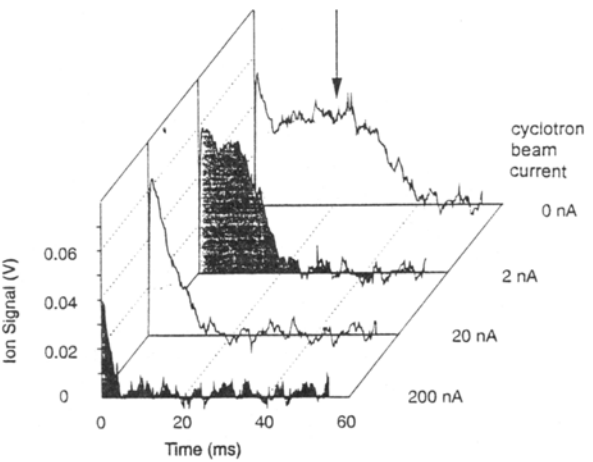

Fig. 2. The resonant photoion signal of stable Ni (M=58) as a function of the time elapsed since firing of the laser for different cyclotron beam currents.

A production rate of 54 atoms/μC was measured when the laser was tuned at the 322.698 nm line and with a target chamber pressure of 500 mbar. This corresponds to a total efficiency of 0.13%. A lower limit of 64 for the selectivity, defined as the ratio of the production rates with the laser on and off resonance, was measured, a limit which was almost exclusively determined by the ambient radioactivity seen by the β detector. To clarify the 0.13% total efficiency, we summarize in table 1 the different processes that determine the efficiency in our laser ion source.

TABLE 1. The estimated efficiency (%) of the relevant processes that contribute to the total efficiency of the laser ion source.

stopping efficiency	85
survival against diffusion	44
laser ionization efficiency	90
metastable-state production	<80
spatial overlap with the laser beam	<10
time overlap (duty cycle) [a]	31
transmission through the separator [b]	20
molecular sidebands	<100
total estimated efficiency	<0.18
experimental efficiency [c]	0.13

a Only ^{55}Ni atoms produced in the last 15 ms of the cyclotron beam on period are still in the ion source at the moment of the laser pulse.

b The low transmission through the separator is not related to the laser ion source but is a purely technical problem.

c Since the nuclear reaction cross section enters directly in the experimental efficiency, the quoted value for this efficiency has a large uncertainty.

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