The Leuven isotope separator on-line laser ion source

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Abstract

An element-selective laser ion source has been used to produce beams of exotic radioactive nuclei and to study their decay properties. The operational principle of the ion source is based on selective resonant laser ionization of nuclear reaction products thermalized and neutralized in a noble gas at high pressure. The ion source has been installed at the Leuven Isotope Separator On-Line (LISOL), which is coupled on-line to the cyclotron accelerator at Louvain-la-Neuve. ^{54,55}Ni and ^{54,55}Co isotopes were produced in light-ion-induced fusion reactions. Exotic nickel, cobalt and copper nuclei were produced in proton-induced fission of ^{238}U. The b decay of the $^{68-74}$Ni, $^{67-70}$Co, $^{70-75}$Cu and $^{110-114}$Rh isotopes has been studied by means of $\beta-\gamma$ and $\gamma-\gamma$ spectroscopy. Recently, the laser ion source has been used to produce neutron-deficient rhodium and ruthenium isotopes ($^{91-95}$Rh, ^{98}Rh, ^{90,91}Ru) near the $N = Z$ line in heavy ion-induced fusion reactions. © 2002 Elsevier Science B.V. All rights reserved.

1. Introduction

The development of efficient and element-selective ion sources is a key point in studies of exotic nuclei far from stability. Such nuclei are produced in nuclear reactions in very

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small quantities and usually are covered by much more abundant isobars. Laser resonant ionization can provide a very efficient and highly selective way to ionize the exotic atoms only.

An on-line laser ion source has been developed at the Leuven Isotope Separator On-Line (LISOL) for the production of purified beams of exotic nuclei [1–4]. The mass separator is coupled on-line to the cyclotron CYCLONE at Louvain-la-Neuve. The operational principal of the ion source is based on element-selective multistep laser resonance ionization [5,6] of nuclear reaction products thermalized and neutralized in a high-pressure noble gas.

The laser ion source allowed to collect nuclear spectroscopic data for exotic nuclei produced in light ion-induced fusion reactions: $^{54-55}$Ni [7], $^{54-55}$Co, in proton-induced fission reactions: $^{68-74}$Ni [8], $^{67-70}$Co [9,10], $^{70-77}$Cu, $^{110-114}$Rh and in heavy ion-induced fusion reactions: $^{91-95}$Rh, ^{98}Rh, $^{90-91}$Ru, $^{42-43}$Ti.

2. Description of the laser ion source

Fig. 1 shows a general view of the laser ion source for heavy ion-induced fusion reactions and of the SextuPole Ion Guide (SPIG). A number of improvements have been carried out to obtain stable and reproducible operational conditions. The overall efficiency of the ion source has been improved by incorporating the SextuPole Ion Guide (SPIG) [3] to separate laser-produced ions from the gas jet and to transport them to the acceleration stage of the mass separator. This allowed us to improve essentially the ion beam quality and the stopping efficiency by increasing the buffer gas pressure inside the ion source. A gas purifier (MonoTorr Phase II 3000) has been installed on the gas handling system allowing a reduction of the impurity level in the buffer gas down to ppb level. These improvements
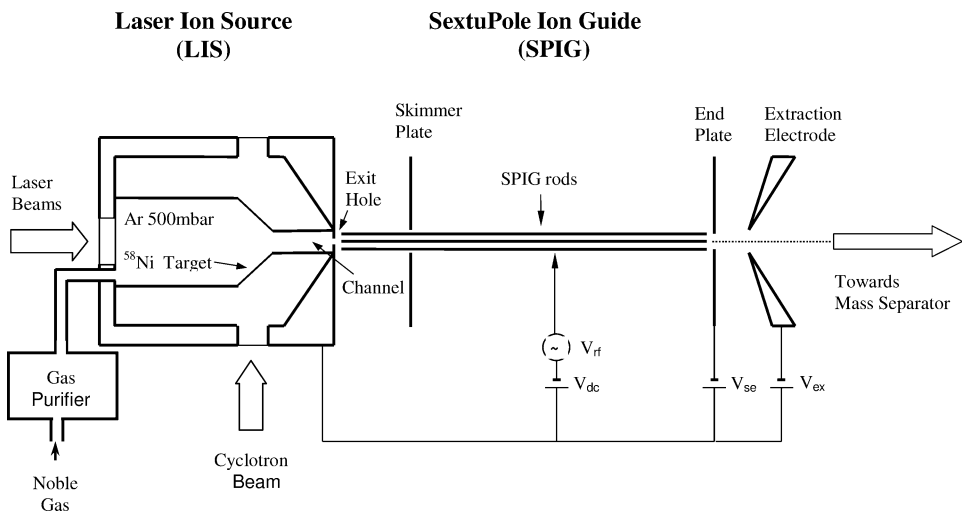

Fig. 1. General layout of the laser ion source and the sextupole ion guide (SPIG).

allowed detailed studies of the ion—impurity molecule interaction and of the ion—argon or helium atom interaction in on- as well as off-line conditions. These results are important for the new ideas on the production of postaccelerated radioactive ion beams whereby the fragments will be stopped in a buffer gas cell.

Recently the first on-line results with the laser ion source were obtained using the ^{58}Ni(^{40}Ar^{11+}, xpyn) and ^{58}Ni(^{36}Ar^{10+}, xpyn) fusion evaporation reactions. The enriched nickel-58 target (3.14 mg/cm^2) was tilted at 45° relative to the cyclotron beam path. The nuclear reaction products recoiling out of the target are thermalized and neutralized in the Ar buffer gas (500 mbar) and move together through the channel toward the exit hole (0.5 mm). This design of the ion source has been used to provide fast evacuation of reaction products. The inner diameter of the cell is equal to 28 mm and the diameter of the channel is equal to 6 mm. At 500 mbar Ar gas pressure around 80% of the reaction products are thermalized. The laser beams enter the cell longitudinally and ionize the neutralized reaction products in the channel. The atoms spent around 15 ms in the channel.

The optical system consists of two tunable dye lasers pumped by two XeCl excimer lasers. The laser pulse repetition rate is 200 Hz; the atoms are irradiated on average three times during the evacuation process. Two-color, two-step schemes are used to ionize rhodium and ruthenium atoms through autoionizing states. The first-step laser wavelengths are equal to 228.538 nm for Ru and 232.258 nm for Rh. The second-step wavelengths are equal to 553.09 nm for Ru and 572.55 nm for Rh.

Stable rhodium atoms can be produced inside the source by resistive heating of a rhodium filament. The stable ions were used to tune the separator beam optics. The ions leaving the source are captured by the SPIG and transported towards the extraction electrode (Fig. 1). The SPIG has been described in [3]. It consists of 6 rods (124 mm long and a diameter of 1.5 mm) cylindrically mounted on a sextupole structure with an inner diameter of 3 mm. The buffer gas is pumped out efficiently through the gaps between the rods, while the ions are confined and transported to the extraction electrode with the gas jet velocity. The skimmer plate separates the high vacuum chamber of the separator and low vacuum part around the gas jet. The main difference from the previous skimmer setup consists in the fact that ions can be guided towards the mass separator without applying a DC voltage in a high-pressure zone between the ion source and the SPIG rods.

Fig. 2 shows β-gated γ-spectra at mass 92 with lasers tuned on-resonance (top panel) and without lasers (bottom panel). The experimental production rate of ^{92}Rh was 11 at/μC. These nuclei were produced in the ^{58}Ni(^{36}Ar^{10+}, 1p1n) reaction at an incident beam energy of 130 MeV in the middle of the target. A comparison between the two spectra in Fig. 2 shows new γ lines belonging to the decay of ^{92}Rh. The half-life value obtained from the TDC spectrum gated by the most intense lines (817, 865 and 990 keV) equals 5.6 ± 0.3 s.

Table 1 shows the parameters of the laser ion source obtained in different nuclear reactions. Two-step ionization schemes through autoionizing levels have been developed for the following elements: Ni, Co, Rh, Ti, Cr, Mn, Cu, Fe, Mo, Cd, Hf, Ta, W, Re, Pt, Pb.
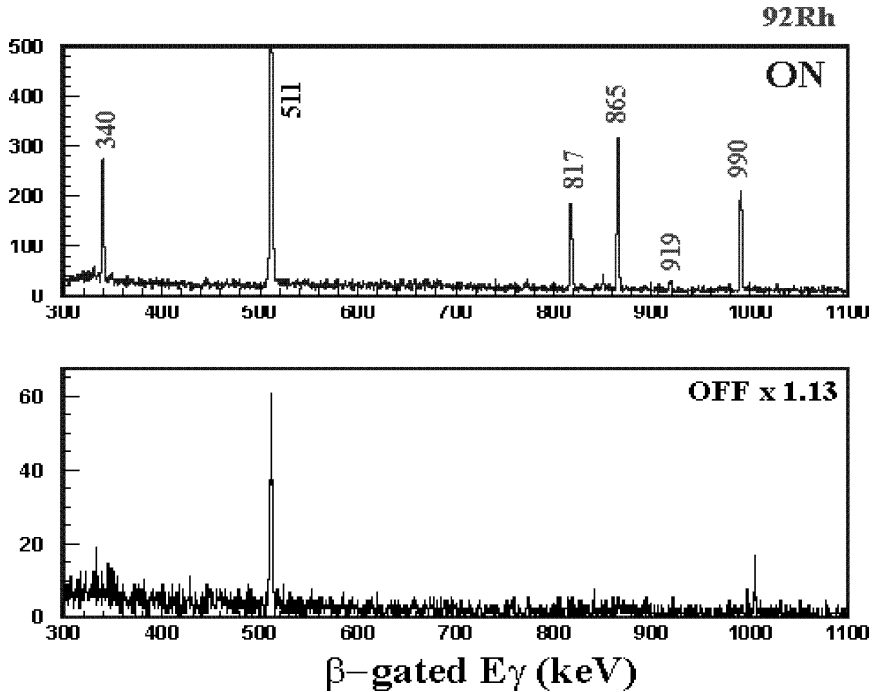
Fig. 2. β-gated γ-spectra of rhodium-92 with lasers tuned on resonance (top panel) and without lasers (bottom panel). The bottom spectrum was multiplied by 1.13 to account for the difference in beam dose between the two spectra. The γ-rays indicated with their energy in keV and are identified as belonging to ^{92}Rh.

Table 1
Parameters of the laser ion source

Reaction and products	Efficiency[a] %	Selectivity[b]
Light ion-induced fusion ^{54,55}Ni, ^{54}Co	5	300
Proton-induced fission of ^{238}U, $^{68-74}$Ni, $^{66-70}$Co, $^{110-114}$Rh	0.2	50–80
Heavy ion-induced fusion $^{90-95}$Rh, ^{98}Rh, $^{89-91}$Ru, $^{42-43}$Ti	0.04	80

[a] [ions/s in mass separated beam]/[atoms/s recoiling out the target] (%).
[b] [ions/s in mass separated beam (lasers on resonance)]/[ions in mass separated beam (lasers off resonance)].

Acknowledgements

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