Nuclear Inst. and Methods in Physics Research, A 877 (2018) 118–123

Contents lists available at ScienceDirect

Nuclear Inst. and Methods in Physics Research, A

journal homepage: www.elsevier.com/locate/nima

The laser and optical system for the RIBF-PALIS experiment

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ARTICLE INFO

Keywords:
Laser Ion Source
Gas cell
Gas jet
Laser resonance ionization
Laser spectroscopy

ABSTRACT

This paper describes the laser and optical system for the Parasitic radioactive isotope (RI) beam production by Laser Ion-Source (PALIS) in the RIKEN fragment separator facility. This system requires an optical path length of 70 m for transporting the laser beam from the laser light source to the place for resonance ionization. To accomplish this, we designed and implemented a simple optical system consisting of several mirrors equipped with compact stepping motor actuators, lenses, beam spot screens and network cameras. The system enables multi-step laser resonance ionization in the gas cell and gas jet via overlap with a diameter of a few millimeters, between the laser photons and atomic beam. Despite such a long transport distance, we achieved a transport efficiency for the UV laser beam of about 50%. We also confirmed that the position stability of the laser beam stays within a permissible range for dedicated resonance ionization experiments.

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1. Introduction

A gas-cell-based low-energy RI-beam production system, PALIS [1,2], is being developed at the RIKEN Radioactive Isotope Beam Factory (RIBF) SLOWRI facility [3]. PALIS is designed to enable low-energy RI-beam experiments by parasitic operation during the RIKEN in-flight separator (BigRIPS) [4] experiments. This system, using a gas catcher cell, collects unused RI-beams removed at the slits in the BigRIPS second focal plane (F2), extracting a low-energy RI-beam. The produced low-energy RI-beams can be used to study the ground-state properties of exotic nuclei using low-energy RI-beam experimental techniques, such as laser spectroscopy and ion trapping, whenever BigRIPS is in operation. The resonance ionization technique is applied in PALIS with the following three advantages. The first advantage is the selectivity for attaining extremely high purity of low-energy RI-beams. During the process of resonance ionization, atomic transitions are resonantly excited by laser photons. Because the atomic transition discretely depends on the element, it leads to a high degree of element selectivity. In the PALIS experiment, separation is performed by the ratio of the mass number (A) to the atomic number (Z) at BigRIPS, by Z via laser ionization, and by A (charge state:1+) at the mass separator. In this way, isobaric and isotopic selection can be achieved. The second advantage is its high stopping efficiency, owing to the use of a heavier buffer gas, typically argon, which can stop high-energy RI-beams even in a small gas catcher cell. The selection of the gas type is related to the neutralization probability of RI-ions in a gas. For helium gas, its high ionization potential promotes the survival of RI-ions in a singly or doubly charged state after thermalization. This phenomenon results in non-element selective extraction for all RI-ions stopped in the gas cell, namely the IGISOL method [5,6]. On the other hand, if argon gas is used instead of helium, this leads to neutralization of more than 99% of RI-ions [7]. The combination of neutralization by using argon gas and re-ionization by using laser resonance ionization is suitable for stopping high-energy RI-beams. The third advantage is its potential for resonant ionization spectroscopy. During resonant ionization process, the hyperfine splittings and the isotope shifts can be measured to determine the nuclear spins, moments and charge radii. Novel spectroscopy experiments such as in-gas-cell laser spectroscopy [8–10] and in-gas-jet laser spectroscopy [11–13] will be performed in future PALIS experiments.

Fig. 1 shows an overview of the laser beam transport line. The radiation levels in the beam line area prohibit free access to PALIS

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https://doi.org/10.1016/j.nima.2017.09.055
Received 15 May 2017; Received in revised form 10 September 2017; Accepted 21 September 2017
Available online 28 September 2017
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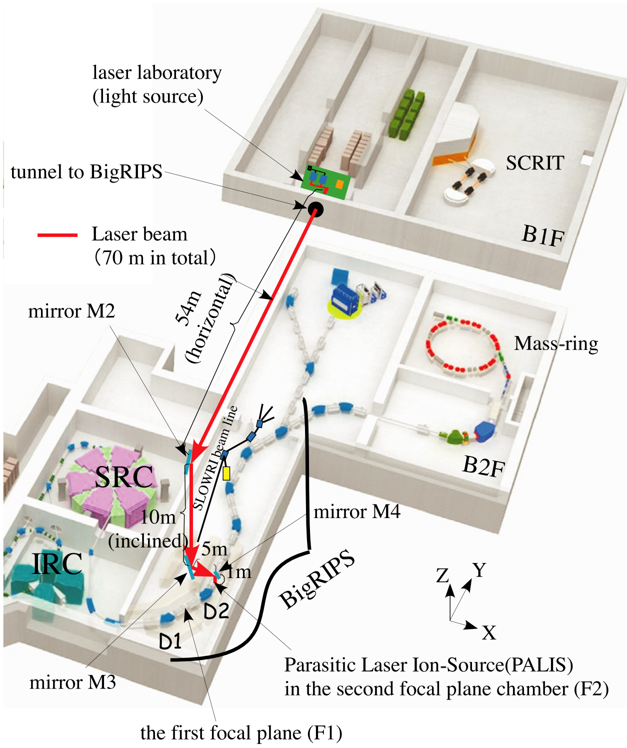

Fig. 1. Overview of the 70 m laser beam transport line in the RIBF laboratories. Multi-color laser beams are sent from the laser laboratory (B1F) to PALIS located at the second focal plane chamber in the BigRIPS fragment separator(B2F-F2).

during on-line operation. The laser system itself, however, must be located in an unrestricted area. Thus, the laser laboratory is located in an adjacent building, resulting in a required optical path of 70 m for the laser beam transport to PALIS. This long distance means that even a small fluctuation in the beam may cause it to miss the downstream optics. Additionally, because the PALIS gas cell moves horizontally on the x-axis perpendicular to the BigRIPS beam direction, the laser beam must follow the gas cell position precisely. The technical difficulties in this setup are in tuning the laser and the extracted ion beam under complete remote control. The control parameters encompass those for the laser system (such as mirror angle, mirror position, spot monitoring and power detection over a long laser beam-line) along with those for the RI-ion beam (such as gas cell position, degrader position and angle, vacuum condition and the electric field for ion beam extraction). The reliability of the laser beam transport and monitoring system should be compatible with the parasitic nature of this experiment: the scope for intervention, maintenance and repair work will be restricted during normal operation of the BigRIPS experiments.

We established a 70 m long laser beam transport system for the PALIS experiments. The number of optical elements used for laser beam transport was minimized to avoid power loss caused by imperfect reflection from mirrors and to make tuning the system easier. By using a dichroic mirror and a polarizing cube beam splitter, laser beams with different wavelengths are combined at the starting position in the laser laboratory, and the combined beam is transported to the ionization volume where the laser photons and atoms overlap. In this article, we describe the structure and characteristics of the laser and optical system for the RIBF-PALIS experiment. Preliminary results of PALIS off-line experiments are also presented.

2. The laser and optical system for PALIS

2.1. The laser light source

A high-power and high-repetition rate laser system was installed for PALIS experiment as shown in Fig. 2. Two types of laser system; liquid state using dye solution and solid state with a Titanium:sapphire gain medium ensure a wide tuning range.

In the dye laser system, two pulsed dye lasers are pumped by one Nd:YAG InnOSlab laser (EdgeWave GmbH). The radiation of the Nd:YAG laser is split to each dye laser by using a 1:1 or 1:2 beam splitter. When using the 1:2 beam splitter, two-thirds of the power of the Nd:YAG laser is used to pump the dye laser for excitation from an intermediate state to an auto-ionization level, whose saturation requires a higher laser power than is required for a transition from the ground state to an intermediate state. The maximum repetition rate for the YAG laser is 15 kHz. Its average output power depends on its mode: one is a single-color mode, whose power is 90 W at 532 nm with a second harmonic generation (SHG) module, and the other is a multiple-color mode, whose power is 36 W at 355 nm with a third harmonic generation (THG) module and is 40 W at 532 nm with an SHG module. The typical pulse length is 8 to 10 ns. The two pulsed dye lasers (Credo, Sirah Lasertechnik GmbH) provide a wide wavelength range, from 215 to 900 nm, typically with a power of 10 W at the fundamental frequency and 1 W at a frequency doubled by SHG. In order to use a green or UV pump wavelength, both dye lasers have a grating lift option that allows a selection from either grating of 1800 lines/mm or 3000 lines/mm inside the laser cavity. The typical spectral bandwidth is 2.4 GHz and 1.5 GHz respectively, which can be increased by a factor of four by changing an intracavity prism expander. During continuous operation of the dye laser, the dye solution tends to degrade because of exposure by high power pump laser light. Therefore the conversion efficiency, i.e. the power ratio of dye and YAG laser is frequently checked by using power meters pneumatically moved in/out of both dye lasers.

While the Ti:sapphire system, a high-repetition rate laser system with a broad bandwidth was installed in 2009 in collaboration with Nagoya University. This system consists of one Nd:YAG pump laser (LDP-100MQG, Lee Laser Inc.), whose maximum power and repetition rate are 50 W and 10 kHz, respectively, and a Ti:sapphire laser with a Z-shaped resonator that has a broad spectral bandwidth of about 4 GHz and a pulse length of 35 ns. The fundamental wavelength of this laser can be tuned over a range of 690 to 990 nm. SHG and THG are performed outside the cavity, allowing for light to be produced in the UV region and in the visible violet region. Recently, an injection locked Ti:sapphire laser [14] is also being developed, pumped by the same Nd:YAG laser at the use of an alternative pump laser beam path. This laser cavity is injection locked by a narrow-bandwidth laser beam from a cw external cavity diode laser(ECDL). Its spectral linewidth of 20 MHz will benefit high precision laser ionization spectroscopy in the gas-jet [10].

The laser wavelength can be measured by a high-precision wavelength meter(WS7, HighFinesse). The timing signals for laser pulses from the dye laser and the Ti:sapphire laser are monitored by photodiodes, and the laser pulses are synchronized by a gate delay generator that adjusts the trigger time of the Nd:YAG laser. In order to check the matching of the resonance wavelength, the reference cell located near the optical table can be used to produce atomic beams of stable isotopes.

With one broad bandwidth Ti:sapphire laser and two dye lasers, three different wavelengths can be prepared simultaneously for RI-beam production. One narrow bandwidth laser can also be used when performing high-resolution spectroscopy in the gas-jet.

2.2. Optical path and beam diagnostics

Fig. 3 shows a schematic of the flight path of the laser beam between the laser light source and PALIS. The total path length is about 70 m. The beam transport system is designed to be simple: the only optical

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