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# On-line commissioning of the HRIBF resonant ionization laser ion source ☆

Y. Liu [a,*], C.U. Jost [a], A.J. Mendez II [a], D.W. Stracener [a], C.L. Williams [a], C.J. Gross [a], R.K. Grzywacz [a,b], M. Madurga [b], K. Miernik [a], D. Miller [b], S. Padgett [b], S.V. Paulauskas [b], K.P. Rykaczewski [a], M. Wolinska-Cichocka [a,c]

[a] Physics Division, Oak Ridge National Laboratory, Oak Ridge, TN 37831, USA
[b] Department of Physics and Astronomy, University of Tennessee, Knoxville, TN 37996, USA
[c] Oak Ridge Associated Universities, Oak Ridge, TN 37833, USA

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ABSTRACT

A highly selective resonant ionization laser ion source has been successfully commissioned at the Holifield Radioactive Ion Beam Facility, Oak Ridge National Laboratory, for the production of pure beams of short-lived nuclei for spectroscopic studies. The laser ion source provided beams of neutron-rich Ga isotopes to the Low-energy Radioactive Ion Beam Spectroscopy Station for beta decay measurements. The radioactive Ga isotopes were produced by 50-MeV proton induced fission of $^{238}$U and ionized by laser radiation using a two-step resonant ionization scheme. Isobarically pure $^{83}$Ga, $^{85}$Ga, and $^{86}$Ga beams were delivered to the experiment at approximate rates of 12,000 ions/s, 100 ions/s, and 3 ions/s, respectively.


## Introduction

The Holifield Radioactive Ion Beam Facility (HRIBF) [1] at Oak Ridge National Laboratory utilizes the Isotope-Separator-On-Line (ISOL) method to produce beams of short-lived radioactive nuclei for research in nuclear physics and nuclear astrophysics. The ISOL method is a multi-step process in which a high-intensity beam of light ions is used to bombard a thick target to produce nuclei far from stability, and those radioactive species are thermally diffused from the target to an ion source, ionized, accelerated, and sent through electromagnets where they are separated according to mass. The desired RIB is then delivered to experiments with or without further acceleration. This method can produce high-intensity RIBs with very good phase-space properties. However, the purity of the RIBs is often limited. In many cases, the isotopes of interest are produced at much lower yields than many neighboring isobars, and the resolution of the mass separators may be insufficient to deliver the desired isotopes with sufficient intensity and low isobaric contamination. To address this problem, various beam purification techniques have been used or investigated at HRIBF to improve the elemental selectivity of the ion source or to add an isobar suppression step in the ISOL process, including molecular side-band [2], selective adsorption [3], selective photodetachment [4], and resonant laser ionization [5,6]; each has its unique advantages and applications.

Resonant laser ionization has been demonstrated as a highly selective, efficient, and versatile means for the production of pure RIBs [7]. In a resonant ionization laser ion source (RILIS), atomic species are ionized by laser radiation via stepwise atomic resonant excitations followed by ionization in the last transition. Since each element has its own unique set of atomic energy levels, the resonant excitation steps can provide nearly 100% elemental selectivity. Such high Z-selectivity is necessary for the production of isobarically pure RIBs. In recent years, there has been significant progress in the development of suitable lasers and RILIS technologies for RIB applications [8–16]. Consequently, RILIS-type sources are increasingly being used or even becoming the primary ion sources at ISOL facilities around the world [9,16–19].

A RILIS has been developed for the HRIBF research program. The RILIS is based on the widely used hot-cavity laser ion source with all-solid-state tunable Ti:Sapphire lasers. The performance of the RILIS has been tested and characterized in off-line studies with stable isotopes. Ionization schemes for 14 elements have been evaluated [5,6,20–23]. The emittance of the RILIS [24] and the temporal profiles of the laser ion pulses [25] have been studied. The overall efficiency of the RILIS has been measured with stable ions for a number of elements, and up to 40% efficiencies have been demonstrated [6].

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* Corresponding author. Tel.: +1 865 574 4761; fax: +1 865 574 1268.
*E-mail addresses:* liuy@ornl.gov, ltuyuan@yahoo.com (Y. Liu).

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For the first on-line commissioning operation, the RILIS was used to provide beams of radioactive neutron-rich Ga isotopes for beta decay studies using the Low-energy Radioactive Ion Beam Spectroscopy Station (LeRIBSS) [26]. In the past, beams of $^{83}$Ga–$^{85}$Ga have been obtained with an electron beam plasma ion source (EBPIS) [27–30], which is the primary ion source used at HRIBF. However, the attempts to study the decay of $^{86}$Ga were not successful due to the overwhelming isobar contaminant $^{86}$Br. Thus, it was hoped that the elemental selectivity of the RILIS would enable the detection of $^{86}$Ga, an isotope that lies in the pathway of the rapid neutron-capture process. In this report, the performance of the RILIS, the experimental setup, and the yields of the radioactive Ga ions are presented.

## Description of the RILIS

### *Hot-cavity ion source*

The RILIS consists of a hot-cavity ion source and three tunable Ti:Sapphire lasers. A schematic view of the ion source assembly is shown in Fig. 1. The ionization chamber of the ion source is a 30-mm long Ta tube of 3-mm inner diameter and 1-mm thick wall, which acts as a capillary cavity and is resistively heated to high temperatures. Such hot-cavity ion sources have been widely used as surface ionization sources for RIBs [31–33]. The hot cavity is connected, via a Ta tube of about 8.5-mm inner diameter referred to as the transport tube, to a target reservoir containing the thick target for RIB production. Radioactive species produced in the target diffuse from the target material and effuse through the transport tube into the hot cavity. There the isotopes of interest are selectively ionized by laser beams entering the hot cavity from the extraction electrode side and traveling in the opposite direction of the ion beam. The ions are subsequently extracted from the hot cavity and transported to the mass separators. To reduce the decay losses of the short-lived species during the diffusion and effusion processes, the target material and the ion source must be heated to high temperatures. The hot cavity and the transport tube are resistively heated by passing an electrical current through them in series. In this way, they can be heated to controllable temperatures exceeding 2000 °C. The cavity is normally hotter than the transport tube, and the highest temperature is located near the middle of the cavity [34]. The target reservoir can be independently heated to temperatures exceeding 2000 °C by a separate Ta heater surrounding the reservoir.

### *Ti:Sapphire laser system*

The laser system includes three Ti:Sapphire lasers, three Q-switched and frequency-doubled Nd:YAG pump lasers, and frequency doubling, tripling, and quadrupling units; all manufactured by Photonics Industries International. This laser system is well suited for two- or three-step resonance photo-ionizations in a hot cavity. Each Ti:Sapphire laser is pumped by an individual Q-switched Nd:YAG laser at 532 nm with maximum output power of 19 W at 10 kHz pulse repetition rate. The fundamental outputs of the Ti:Sapphire lasers are tunable between 715 nm and 960 nm with 2.5 W peak power at around 820 nm. The Ti:Sapphire lasers use a diffraction grating for wavelength selection and can provide continuous wavelength tuning across the entire fundamental spectral range. Moreover, only one mirror set is used to cover the full spectral range. This feature makes the operation of the laser relatively easy. Shorter wavelengths in the blue and ultraviolet regions are obtained by frequency doubling, tripling, and quadrupling of the fundamental laser beam. Two of the three Ti:Sapphire lasers are equipped with units for second-harmonic generation (SHG), third-harmonic generation (THG), and fourth-harmonic generation (FHG). In combination, the lasers can provide two frequency-doubled SHG outputs with 800 mW peak power, one frequency-tripled THG output with 120 mW peak power, and one frequency-quadrupled FHG output with more than 30 mW peak power at 217 nm. Fig. 2 shows the typical tuning curves of the fundamental, SHG, and THG laser outputs.

The outputs of the Ti:Sapphire lasers are pulsed at 10-kHz repetition rates, with pulse widths on the order of 25 ns. In order to obtain efficient resonant excitation and ionization, the laser pulses from different Ti:Sapphire lasers must be synchronized in time to better than several nanoseconds. Since the Ti:Sapphire lasers have individual pump lasers, they can be synchronized by triggering the pump lasers with synchronized external triggers. It should be noted that the Ti:Sapphire lasers initially shared one Nd:YAG pump laser with maximum 100 W average power. With a common pump laser, synchronization could only be achieved by actively

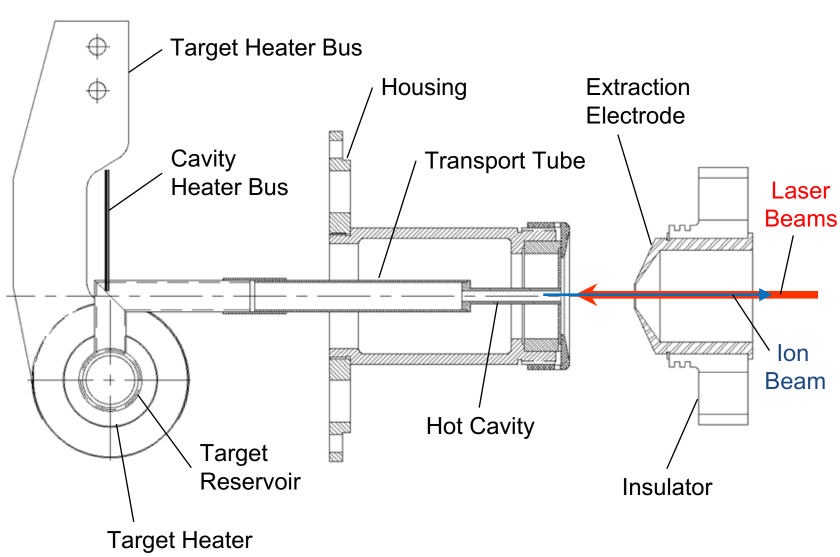


**Fig. 1.** Schematic drawing of the hot-cavity ion source and target reservoir assembly. Atomic species of interest effuse from the target reservoir into the hot-cavity where they are ionized by laser radiation entering from the right.