Nuclear Instruments and Methods in Physics Research B 317 (2013) 422–425

Contents lists available at SciVerse ScienceDirect

Nuclear Instruments and Methods in Physics Research B

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

The FURIOS laser ion source at IGISOL-4

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ARTICLE INFO

Article history:
Received 14 March 2013
Received in revised form 24 May 2013
Accepted 27 May 2013
Available online 19 June 2013

Keywords:
Lasers
Resonance ionization
Gas cell

ABSTRACT

The FURIOS laser ion source at the Accelerator Laboratory of the University of Jyväskylä has been moved to a new location as a part of the IGISOL-4 facility. The laser ion source project had a high priority which allowed the transport of laser light to be optimized during the design phase. The laser resonators have been upgraded with a dual etalon configuration leading to greatly reduced laser linewidth. The transport efficiency of the dual-chamber gas cell has been determined using an alpha recoil source, with efficiencies ranging from a few percent in the beam interaction chamber to nearly 20% in the ionization chamber. In addition, we present recent results from the re-commissioning of the laser system on stable copper isotopes.

1. Introduction

The IGISOL facility at the Accelerator Laboratory of the University of Jyväskylä, Finland, is used for the production of low-energy beams of exotic nuclei. The facility utilizes the so-called ion guide method to stop and transport radioactive ions. A primary beam impinges on a thin target producing radioactive nuclei via reactions including fission or fusion. The reaction products recoiling from the target are stopped in a noble gas, typically helium, where they promptly thermalize primarily to a +1 charge state. The ions are extracted using gas flow from the ion guide into vacuum via a small exit orifice. They are subsequently captured in a radio-frequency sextupole ion guide (SPIG), accelerated to 30 keV, mass separated and delivered to a variety of experimental stations.

In 2004, construction of a laser ion source facility commenced at IGISOL [1]. The Fast Universal Resonant laser IOn Source, FURIOS, was designed to address the lack of selectivity in the ion guide method and, in some cases, a low efficiency. Later, the possibility of using the laser ion source for in-source resonance ionization spectroscopy was investigated. Recently, the FURIOS laser system has been moved to a new laboratory as part of the IGISOL-4 move. This has allowed the facility to be re-designed for efficient laser transport to the target area. This article discusses the new FURIOS facility and recent re-commissioning results.

2. FURIOS upgrade

The laser ion source project was first constructed at the IGISOL-3 facility thus the design was severely restricted with compromises made with respect to the laser transportation and coupling into the gas cell. The optical path comprised of several mirrors, many of which were placed at non-optimal angles, leading to transport losses of more than 80% for deep ultra-violet light. In addition, access to ionization in the gas jet was hampered by an inaccessible high-loss optical window on the mass separator delivered from the old ISOL facility at GSI.

For the operation of an efficient and reliable laser ion source the optimization of the laser transport path is vital [2]. Therefore, the new IGISOL-4-facility, presented in Refs. [3,4], was designed in such a manner that would allow a simple and optimal positioning of the laser transport mirrors. Furthermore, up to three laser beams can be transported separately to the target area for coupling into the target chamber. This allows the dielectric mirror coatings to be chosen specifically for the given wavelength. Fig. 1 presents the second floor of the IGISOL-4 facility, with the location of the new laser cabins and the laser transport paths.

The FURIOS laser system consists of multiple high repetition rate pulsed lasers (see Fig. 2). These include two Nd:YAG lasers (Lee Laser LDP-200MQG) operating at 10 kHz with output powers of 80 W and 40 W, respectively. The 80 W Nd:YAG is used to pump three Ti:sapphire lasers that form the backbone of FURIOS. The second Nd:YAG is reserved for the development of an injection-locked Ti:sapphire laser [5] as well for the pumping of a grating-based Ti:sapphire laser. A Copper Vapour Laser (CVL, Oxford Lasers LM100X(KE)) with a typical output power of 30 W is used mainly for non-resonant ionization. In general, the laser system is capable

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http://dx.doi.org/10.1016/j.nimb.2013.05.061

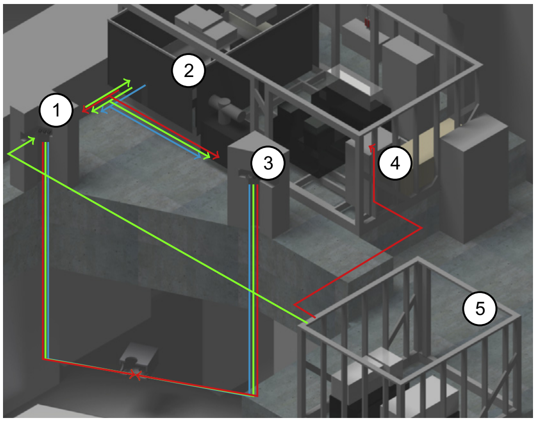

Fig. 1. The FURIOS facility: (1) In-source laser access, (2) Primary laser cabin and the solid state pulsed Ti:sapphire laser system, (3) In-jet and hot cavity laser access, (4) CW optical path, (5) Secondary laser cabin containing the CVL laser and the future CW Ti:sapphire and pump laser. The laser paths are presented in red, blue and green. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this article.)

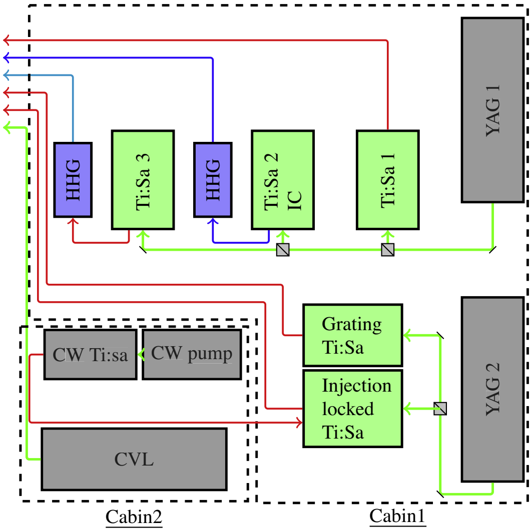

Fig. 2. Layout for the FURIOS lasers. Cabin 1 contains the primary Ti:sapphire lasers and higher harmonic generation units used for laser ionization. A secondary optical bench serves as a platform for the grating-based Ti:sapphire and the injection-locked bow-tie ring resonator. Cabin 2 contains the CVL and the new CW Ti:sapphire and pump laser. IC: Intra-cavity second harmonic generation, HHG: Higher harmonic generation.

of covering wavelengths ranging from ~690 nm to 1000 nm and from ~500 nm to 205 nm with higher harmonic generation.

Currently, a major development program is under way to reduce the laser linewidth in order to increase the sensitivity to isotope shifts and hyperfine structure of atomic levels. Two approaches are being utilized to realize this goal. First, a 6 mm thick undoped YAG crystal with a reflectivity of 8% has been installed in a standard Z-shaped Ti:sapphire laser resonator, acting as a thick etalon. This dual etalon configuration has resulted in a reduction of the laser linewidth from typically >5 GHz to ~1 GHz. A second, more advanced approach for reducing the linewidth involves injection-locking of a bow-tie Ti:sapphire ring cavity [5–9]. In this technique, the narrow linewidth light of a CW Ti:sapphire laser (Master laser) is amplified in a pulsed resonant optical amplifier (Slave laser). Additional laser-related developments are discussed in Refs. [10,11].

3. Recent milestones

3.1. Laser ionization of silver

The initial re-commissioning of the FURIOS facility was performed on metallic silver using a dual-chamber gas cell originally designed in Leuven [12]. A long-standing motivation for the study of silver is related to the intense discussion about the existence of the two-proton decay channel from the spin-trap (21^+) isomer in the isotope $N = Z$ ^{94}Ag [13]. At IGISOL, a programme has been initiated to selectively and efficiently produce a low-energy ion beam of neutron deficient silver isotopes, including ^{94}Ag, using heavy-ion induced fusion-evaporation reactions. To effectively stop the recoils, two approaches are being pursued. The first involves the development of a hot cavity catcher device, the advantage of which lies in the fast release time of several ms and a high extraction efficiency for silver (see [14] and references therein). Secondly, the dual-chamber gas cell will be used, successfully demonstrated at Leuven for the application of in-source laser spectroscopy [15].

An efficient laser ionization scheme for silver has been characterized and tested, using a non-resonant final transition into the continuum performed with the CVL [14]. This bottleneck of the ionization scheme has been somewhat alleviated following a recent comparison between different non-resonant ionization lasers. Despite the lower power, a Ti:sapphire laser operating at ~800 nm provided considerably higher count rates than either the CVL or a Nd:YAG laser operating at 532 nm.

In August 2012, the dual chamber gas cell was utilized in an attempt to produce neutron-deficient Ag isotopes using the reaction ^{36}Ar $(^{nat}$Zn,pxn$)^{101-97}$Ag. This unfortunately failed due to the high intensity, well focused Ar beam damaging the zinc target. Nevertheless, prior to installation the target was coated with a thin layer of stable silver which acted as a source of sputtered atoms as the ^{36}Ar beam passed through the gas cell. Lasers were introduced into the gas cell through the rear window and thus ionized silver atoms along the extraction axis of the cell within the so-called “ionization chamber” (see Fig. 4). In this experiment the ion collector plates were not used.

The selectivity of the dual-chamber laser ion source (defined as the ratio of ion count rate with lasers on compared with lasers off) was then studied using both helium and argon buffer gases as a function of primary beam intensity, the results of which are presented in Fig. 3. Although the absolute count rates in helium were larger (26,000/s in argon compared with 82,000/s in helium at a primary beam current of 0.8 eμA), the selectivity of the laser

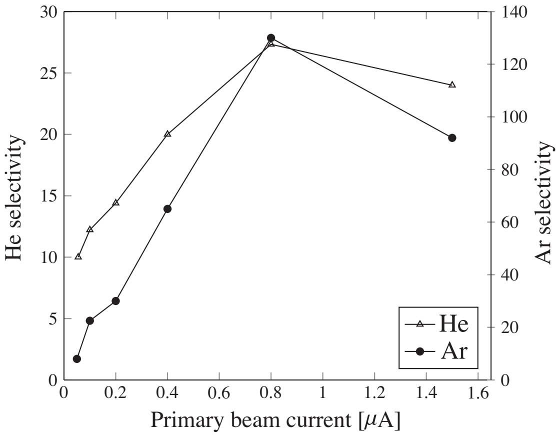

Fig. 3. The selectivity of the laser ionization process for silver using helium and argon. The silver atoms were sputtered from the back of a zinc target via the passage of a 190 MeV beam of ^{36}Ar.