A complementary laser system for ISOLDE RILIS

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Abstract. The Resonance Ionization Laser Ion Source (RILIS) is a powerful tool for efficient and selective production of radioactive ion beams at Isotope Separator On Line (ISOL) facilities. To avoid isobaric background, highly selective stepwise resonant ionization is applied, using up to three different laser wavelengths. Due to their advantages in terms of stability and reliability, an all solid-state titanium:sapphire (Ti:Sa) system is used or is planned to be installed at the majority of on-line facilities worldwide. Such an all solid-state Ti:Sa laser system is going to be installed at the ISOLDE RILIS at CERN alongside the well-established dye laser system.

1. Introduction

One major prerequisite to study shorter lived or lower yield radioisotopes at ISOL facilities is the availability of ion beams without isobaric interference. The conventional ionization mechanisms of surface or plasma ion sources can be very efficient, but are chemically non-selective. The resulting degree of isobaric contamination would render many experiments impossible. The resonance ionization laser ion source [1, 2] addresses this problem by applying the highly selective and efficient technique of stepwise resonant ionization of the element of interest using up to three laser beams of different wavelengths overlapping in the ionizer tube of the ISOLDE target unit. On account of the high degree of selectivity achieved, RILIS operation is requested by the users for over 2000 hours per year, amounting to over 50 % of the total ISOLDE beam-time [3]. The ISOLDE RILIS currently uses up to three dye lasers, two Credo broad-band lasers from *Sirah Laser- und Plasmatechnik GmbH* and one narrow-band laser from *DMK Laser Microsystems Co., Ltd.*. The lasers are optically pumped simultaneously by one *EdgeWave GmbH* Nd:YAG laser which provides 8-10 ns pulses at a repetition rate of 10 kHz with a total output power of typically 100 W in the second harmonic. If necessary, a third harmonic beam of up to 20 W can be generated for blue to green dyes that require UV pump beam. A reserve pump laser offering the same operating parameters is available to ensure that downtime in the event of laser malfunction or urgent maintenance is minimized. This is an important consideration due to the complexity and inflexibility of the busy ISOLDE experiment schedule. The RILIS dye laser system has so far been applied for ionizing 28 of the elements produced at ISOLDE [3]. Up to three days of preparation are needed if a different element is requested, this includes a change of the dye solution (more than ten different dyes are used), laser set-up and alignment of the beams into the ion source.

If the increase in demand for RILIS beams is to be met, a second laser system, installed alongside the existing dye laser system would be of great benefit, particularly for a reduction in the time taken for switching between elements requested by ISOLDE users. As one system

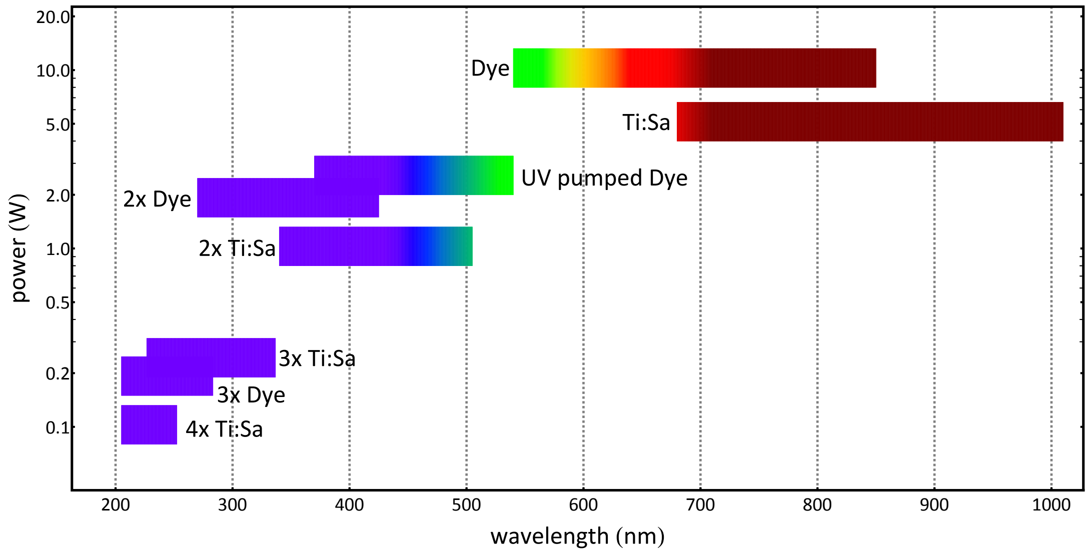

Figure 1. Overview of the achievable wavelengths using dye lasers and Ti:Sa lasers and their higher harmonics. Given power values are a guide for comparison only.

is in operation, the other could be prepared for the ionization scheme of the next element on the beam time schedule. Switching time is estimated to be just hours. To some extent, the systems also serve as a backup for each other. The idea is now to install not only a second laser system, but a complementary system of all solid-state titanium:sapphire (Ti:Sa) lasers that extends the accessible wavelength range to the near infra-red, where dye lasers do not perform very well. Figure 1 shows the wavelength ranges and powers that can be produced using the dye laser and the Ti:Sa laser systems. The Ti:Sa system could bring benefits such as long-term power stability and an almost maintenance-free operation. As early as 2003 the potential advantages of a RILIS Ti:Sa system were discussed [4], but it was also noted that the gap in the tuning range from 500 nm to 700 nm renders such a system incompatible with more than 50 % of the RILIS ionization schemes available at that time. The use of Ti:Sa lasers for Resonance Ionization Spectroscopy (RIS) and Resonance Ionization Mass Spectrometry (RIMS) [5, 6] has led to the development of excitation and ionization schemes for many more different elements. Operation of the Ti:Sa based laser ion source TRILIS at TRIUMF, Canada was reported in [7]. To date, 38 ionization schemes have been developed or tested at the University of Mainz (Germany), University of Jyväskylä (Finland), Oak Ridge National Laboratory (USA) and TRIUMF (Canada) using Ti:Sa lasers. The periodic table of RILIS elements (2) gives an overview of the availability of ionization schemes using the different laser systems for the different elements. Ionization schemes for elements requested by ISOLDE users could be developed rather quickly at the off-line mass separator RISIKO [8] and the refined Mainz Atomic Beam Unit (MABU) at the University of Mainz using their Ti:Sa laser system. The specifications of this laser system are given in Table 1, taken from [9]. Values presented are typical, output powers are wavelength dependent.

2. The Ti:Sa laser system

The laser system to be installed alongside the dye laser system will consist of one commercial Nd:YAG pump laser, three Ti:Sa lasers and two units for frequency conversion (FCU) to generate up to the fourth harmonic of the fundamental Ti:Sa laser beams, extending the available spectral range into the UV-blue region. Furthermore a commercial system for pointing stabilization of

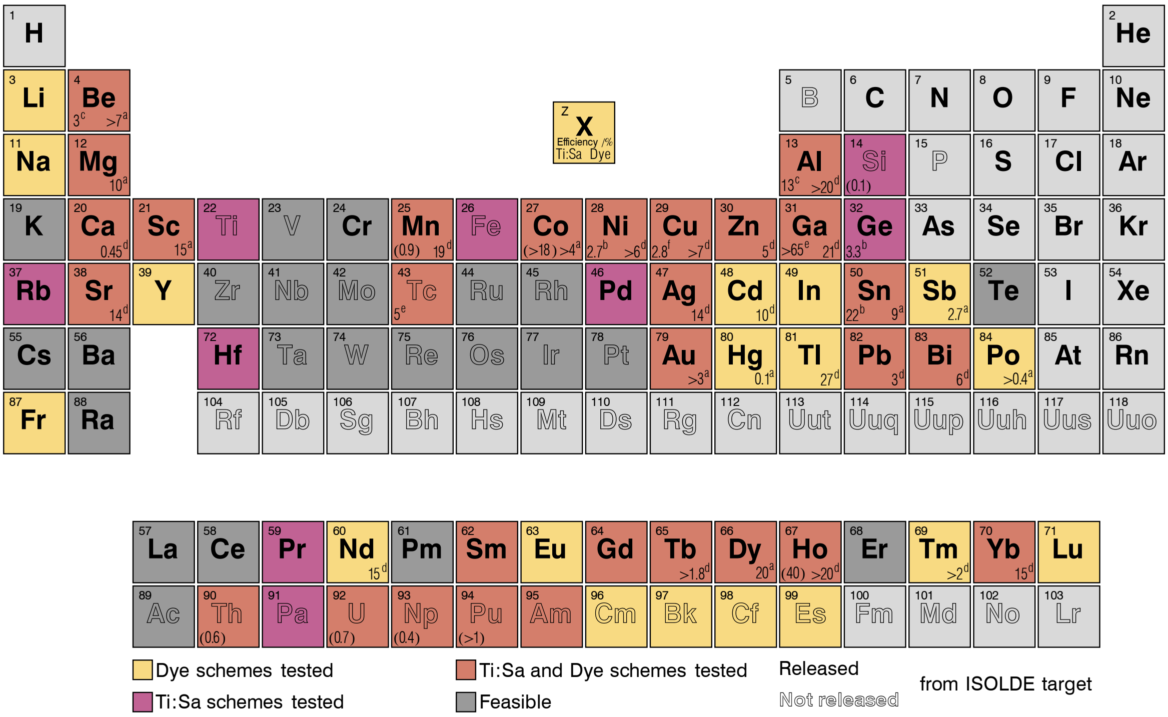

Figure 2. Periodic table of RILIS elements. Ionization efficiency data is taken from a[10], b[11] c[12], d[4] e[13], f[14], values given in brackets are preliminary. Dark gray boxes indicate elements with feasible multi-step ionization schemes according to the Kurucz line database [15].

Table 1. Specifications of the Mainz Ti:Sa laser system

Operating range (fundamental)		680 - 960 nm
Tuning range		100 GHz
Repetition rate		1 - 15 KHz
Pump power (10 kHz)		22 W
Lasing threshold		2 W
Pulse duration		40 - 60 ns
Average power (10 kHz)	- fundamental	5 W
	- frequency doubled	1 W
	- frequency tripled	150 mW
	- frequency quadrupled	150 mW
Spectral width		3 GHz
Beam quality		$M^2 < 1.15$
Temporal synchronization		< 3 ns

three laser beams has been purchased from *TEM Messtechnik GmbH.*

2.1. Pump laser

Two DM60-532 frequency doubled Nd:YAG pump lasers with a nominal output power of 60 W at a repetition rate of 10 kHz were purchased from *Photonics Industries International Inc.* One of the pump laser requirements was a small laser head footprint on the laser table since the existing system already occupies most of the available space on the optical tables and an extension of the laser cabin is currently not feasible. One pump laser will be permanently installed in the RILIS laser cabin whereas the second laser, which can be temporarily installed at RILIS if extra pump power is needed, can be moved to other laser laboratories such as the LARIS lab [10], the laser development lab or the ISOLDE off-line mass separator.

2.2. Ti:Sa laser
The design of the Ti:Sa lasers was adopted from the University of Mainz. Modifications were made to meet the requests for on-line operation i.e. fast setup, stable operation and on-line monitoring of timing, wavelength and output power. A sketch of the laser is shown in Figure 3. The resonator part (1) incorporates the Brewster-cut titanium:sapphire crystal, in which the pump beam (green line) is focused using the pump optics (g). A recent development from the group at the University of Mainz lead to a different pumping geometry, where the focus of the pump beam is on the end-facet of the laser crystal, allowing high pump powers of up to 30 W, without any damage to its surface [16]. The mirrors (b) form the actual resonator and define the laser mode (red line). In collaboration with the University of Jyväskylä, the approach of intra-cavity second harmonic generation (SHG) has been tested successfully, leading to a design modification to leave space in the resonator for the SHG crystal and a dichroic mirror (f). Another development is the fixed setup for the alignment laser (2). The alignment laser (He-Ne or diode laser) is coupled into an optical fiber (i) which can be attached to any of the Ti:Sa laser modules. The two exchangeable mirrors (k) allow switching from alignment mode to monitoring mode where a small fraction of the Ti:Sa laser light is transported to a second fiber coupler followed by a fiber splitter, to allow simultaneous monitoring of timing and wavelength. Initially wavelength stabilization as well as on-line monitoring of the output power, crystal temperature and water flow will be implemented using a programmable micro-controller.

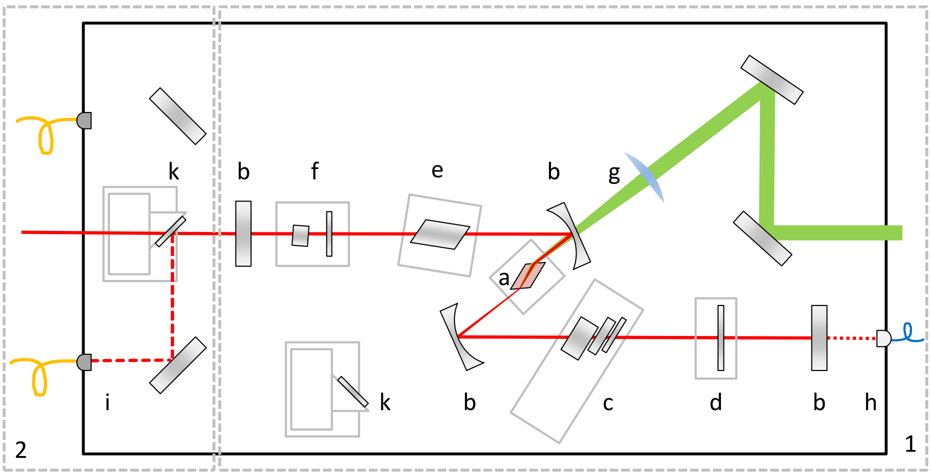

Figure 3. Sketch of the CERN Ti:Sa layout. 1. Resonator part: (a) Ti:sapphire crystal, (b) resonator mirrors, (c) birefringent filter, (d) stepping motor actuated etalon, (e) Pockels cell, (f) intra-cavity SHG, (g) optics for pump beam, (h) photo-diode for power monitoring; 2. Arrangement for alignment and monitoring: (i) fiber couplers, (k) inter-exchangeable mirror mounts.

The prototype of the CERN Ti:Sa, whose base plate was machined at the mechanical workshop at the University of Mainz, has been successfully tested in Mainz and at the laser development laboratory at CERN. The fixed alignment setup for the alignment laser described above, worked satisfactorily. The slope efficiency of the laser was measured to be 25.5% at a wavelength of ≈ 735 nm and the lasing threshold was observed at 5 W pump power.

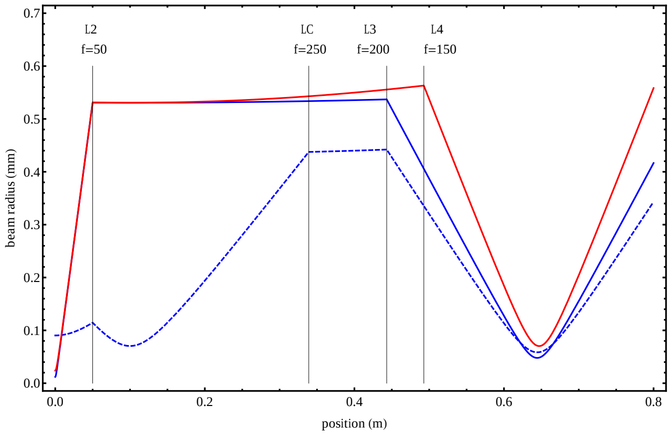

Figure 4. The graphic shows the beam size of the laser beams (red: fundamental beam; blue: second harmonic, dashed: horizontal, solid: vertical) as they propagate through the FCU, beginning after SHG crystal at position 0 m. L2 to L4 are spherical lenses with the given focal length f in mm. LC is a cylindrical lens.

2.3. Frequency conversion unit

The subsequent frequency doubling, tripling and quadrupling of the fundamental laser emission of the Ti:Sa laser will be done using a refined version of the frequency conversion unit (FCU) developed at the University of Mainz. The use of a new beam shaping arrangement allows a simplified alignment of the tripling setup. Furthermore, the astigmatism of the SHG beam produced in the tripling process is reduced from ≈ 5 to < 1.5. The prototype was successfully tested at CERN. Figure 4 shows the result of the ABCD matrix calculations for the beam shaping setup. The graphic shows the development of the beam radius along the direction of propagation in the FCU, beginning at the exit of the SHG crystal. The SHG beam and the fundamental beam are focused into the third harmonic crystal at position ≈ 0.65 m. The setup also allows difference frequency mixing as well as summing of two Ti:Sa lasers. Two FCU modules will be constructed as part of the collaboration CERN-Mainz-GANIL for the GANIL Ion Source using Electron Laser Excitation project (GISELE) [17].

3. Outlook

In 2010 the laser beam stabilization system will be delivered to CERN. Tests and stepwise installation to the RILIS are scheduled during the winter shutdown period. In September/October 2010 a test of the laser ion source trap (LIST) [18, 19] is planned at the ISOLDE off-line mass separator. The CERN Ti:Sa system will be moved from the laser development laboratory to the separator site to provide laser beams needed for this test. Novel pulse control electronics will be tested together with the on-line monitoring setup. One of the two pump lasers will be installed in the RILIS laser cabin during the 2010/2011 shutdown period. The limited space in the laser room necessitates a carefully planned rearrangement of the existing lasers on the laser table, allowing the Ti:Sa system to be placed next to the current dye laser system. Installation of the Ti:Sa system in the on-line laser cabin is foreseen as a step-wise process.

Acknowledgments

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