Liquid and solid lasers for optimum performance of the Resonance Ionization Laser Ion Source at ISOLDE/CERN

V.N. Fedosseev, CERN, EN department

Workshop on Low-Energy Radioactive Isotope Beam (RIB) Production by In-Gas Laser Ionization for Decay Spectroscopy at RIKEN, 10-11 December 2012, RIKEN-Wako
Outline

- The ISOLDE facility at CERN
- Ionization in a hot cavity
- Evolution of RILIS lasers
- Dual dye-Ti:Sa laser system of RILIS
- New modes of RILIS operation
- RILIS operation in 2012
- Dual narrow-band RILIS
- Outlook
  - *Workshop announcement*
Online Isotope Mass Separator

The Online Isotope Mass Separator (ISOLDE) is a unique source of low-energy beams of radioactive isotopes – atomic nuclei that have too many or too few neutrons to be stable. The facility, located at the Proton-Synchrotron Booster (PSB), is like a small alchemical factory, changing one element into another.
ISOLDE isotope separator on-line facility

Delivers yearly 3200 h of radioactive ion-beams to 30 experiments by means of two target stations

Single charge:
- Surface
- Plasma
- RILIS
- ECR

Mass separation

Post Acceleration
Laser ionization in a Hot Metal Cavity

First RIBs produced in 1990-1991

at PNPI (Gatchina, Leningrad district):

Application of a high efficiency selective laser ion source at the IRIS facility
G.D. Alkhazov, L.Kh. Batist, A.A. Bykov, V.D. Vitman, V.S. Letokhov 1,
V.I. Mishin 1, V.N. Panteleyev, S.K. Sekatsky 1 and V.N. Fedoseyev 1
Leningrad Nuclear Physics Institute, Academy of Sciences of the USSR, Gatchina, Leningrad district 188350, USSR
Received 6 December 1990 and in revised form 25 March 1991

Yb, Nd, Ho - off-line
Ho - on-line

at CERN:

Chemically selective laser ion-source for the CERN–ISOLDE on-line mass separator facility
V.I. Mishin 1, V.N. Fedoseyev 1, H.-J. Kluge 2, V.S. Letokhov 1, H.L. Ravn 3, F. Scheerer 2,
Y. Shirakabe 3, S. Sundell 3, O. Tengblad 3 and the ISOLDE Collaboration
VHE Division, CERN, Geneva, Switzerland
Received 26 November 1992

Yb, Tm, Sn, Li - off-line
Yb - on-line
Efficiency:

\[ \varepsilon = \frac{P_{\text{ionisation}}}{P_{\text{ionisation}} + P_{\text{Effusion}}} \]

\[ \varepsilon = \frac{v_{\text{rep}} \varepsilon_{\text{ion}}}{v_{\text{rep}} \varepsilon_{\text{ion}} + \frac{2dv}{3L^2}} \]

Selectivity = \frac{\text{Laser Ionization Efficiency}}{\text{Surface Ionization Efficiency}}

=> depends on the ionization potentials of isobar atoms

\[ \varepsilon_{\text{laser}} = 2\% - 30\% \]

\[ \varepsilon_{\text{surface}} \begin{cases} > 5\% & \text{alkalies} \\ = 0.1\% - 2\% & \text{In, Ga, Ba, lanthanides} \\ < 0.1\% & \text{others} \end{cases} \]
RILIS at ISOLDE-PSB

Installed in 1993

CVL lasers: \( \nu_{\text{rep}} = 11.000 \text{ Hz} \)
Oscillator + 2 amplifiers
2-3 dye lasers with amplifiers, nonlinear crystals BBO:

\[
\begin{align*}
P_{\text{total} \ Cu} & \leq 75 \ W \\
P_{\text{dye}} & \leq 8 \ W \\
P_{2\omega} & \leq 2 \ W \\
P_{3\omega} & \leq 0.2 \ W
\end{align*}
\]
Copper vapor laser: High peak power (short pulse); high repetition rate, good beam quality (unstable resonator)

Dye lasers: Wide tuning range, ionization schemes with up to 3 steps
RILIS operation since 1994

- Annually increasing demand for RILIS beams
- Feasible ‘hours of operation’ limit reached in 2002
- Increase requires greater reliability and a larger laser installation – RILIS UPGRADE
The 3 stages of RILIS Upgrade

<table>
<thead>
<tr>
<th>Stage</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The pump laser upgrade¹:</td>
</tr>
<tr>
<td></td>
<td>- Change from copper vapour laser (CVL) to commercial Nd:YAG laser</td>
</tr>
<tr>
<td></td>
<td><strong>Aim:</strong> Maintain or improve the dye laser performance whilst increasing the <strong>reliability</strong> of the overall system.</td>
</tr>
<tr>
<td>2</td>
<td>The dye laser upgrade:</td>
</tr>
<tr>
<td></td>
<td>- 3 New state of the art dye lasers to replace the original dye lasers</td>
</tr>
<tr>
<td></td>
<td><strong>Aim:</strong> Improve the dye laser <strong>performance, ease of use and reliability</strong>, make full use of the capabilities of the new pump laser.</td>
</tr>
<tr>
<td>3</td>
<td>Install an independent and complementary Ti:Sa based RILIS laser setup²,³:</td>
</tr>
<tr>
<td></td>
<td>- 2 pump lasers and 3 Ti:Sa lasers plus harmonic generation units</td>
</tr>
<tr>
<td></td>
<td><strong>Aim:</strong> Extend the tuning range of the RILIS setup to enable access to the large number of ionization schemes developed for Ti:Sa lasers.</td>
</tr>
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<td></td>
<td><strong>Reduce switching time</strong> between elements to allow for more condensed scheduling of RILIS runs.</td>
</tr>
</tbody>
</table>

**Additional on-going developments**

- Improve **monitoring** and **automation** of the RILIS parameters
- Implement **machine protection** and alert systems to enable **on-call operation**
- Improve the **selectivity** of RILIS through ion source developments

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¹ The ISOLDE RILIS pump laser upgrade and the LARIS Laboratory

² A complementary laser system for ISOLDE RILIS
*S Rothe et al: Journal of Physics: Conference Series 312 (2011) 052020*

³ Upgrade of the RILIS at ISOLDE: New lasers and new ion beams
Replacement of Copper Vapor Lasers by Solid-State Lasers

“The ISOLDE RILIS pump laser upgrade and the LARIS Laboratory”
CREDO dye lasers made by Sirah GmbH installed in Feb/Mar 2010

- Optimized for 10 kHz EdgeWave pump
- Accept both 355 and 532 pumping beams
- Equipped with FCU (up to 2W of UV)

“Upgrade of the RILIS at ISOLDE: New lasers and new ion beams”
## Dye vs. Ti:Sa lasers

<table>
<thead>
<tr>
<th></th>
<th>Dye</th>
<th>Ti:Sa</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Active Medium</strong></td>
<td>&gt; 10 different dyes</td>
<td>1 Ti:sapphire crystal</td>
</tr>
<tr>
<td><strong>Condition of aggregation</strong></td>
<td>liquid</td>
<td>solid-state</td>
</tr>
<tr>
<td><strong>Tuning range</strong></td>
<td>540 – 850 nm</td>
<td>680 – 980 nm</td>
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<tr>
<td><strong>Power</strong></td>
<td>up to 15 W</td>
<td>up to 5 W</td>
</tr>
<tr>
<td><strong>Pulse duration</strong></td>
<td>8 ns</td>
<td>50 ns</td>
</tr>
<tr>
<td><strong>Power stability</strong></td>
<td>decrease during operation</td>
<td>stable</td>
</tr>
<tr>
<td><strong>Synchronization</strong></td>
<td>optical delay lines</td>
<td>q-switch, pump power</td>
</tr>
<tr>
<td><strong>Maintenance</strong></td>
<td>renew dye solutions</td>
<td>~ none</td>
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</tbody>
</table>

### Efficiency vs. Wavelength

![Graph showing efficiency vs. wavelength for Dye and Ti:Sa lasers.](image)

![Graph showing power vs. wavelength for Dye and Ti:Sa lasers.](image)
Dual RILIS Concept

- **RILIS Dye Laser System**
  - Nd:YAG
  - Dye 2 (SHG)
  - Dye 1 (THG)
  - Narrowband Dye
  - 10 kHz Master clock
  - Delay generator

- **RILIS Ti:Sa Laser System**
  - Nd:YAG
  - Ti:Sa 1 (SHG/THG/FHG)
  - Ti:Sa 2
  - Ti:Sa 3

- **GPS/HRS Target & Ion Source**

- **LabVIEW based DAQ**

- **Faraday cup**

- **λ – meter**

- **pA – meter**

- **12571.486 cm**
The RILIS Ti:Sa lasers

**Pump laser:** Nd:YAG (532 nm), Photonics Industries International
Repetition rate: 10 kHz
Pulse length: 180 ns
Power: 60 W

**Ti:Sa lasers:**
Line width: 5 GHz
Pulse length: 30-50 ns

Wavelength tuning range:
- Fundamental ($\omega$) 690 - 940 nm (5 W)
- 2nd harmonic ($2\omega$) 345 - 470 nm (1 W)
- 3rd harmonic ($3\omega$) 230 - 310 nm (150 mW)
- 4th harmonic ($2\omega$) 205-235 nm (50 mW)

6 resonator mirror sets cover the Ti:Sa range

“A complementary laser system for ISOLDE RILIS”
Third step of RILIS upgrade

 Addition of Ti:Sapphire lasers

Frequency conversion unit
3 steps of RILIS laser upgrade completed

1) Pump laser replacement
2) Dye laser replacement
3) Ti:Sa laser installation

RILIS Dye Laser System
- Nd:YAG
- Master clock
- Delay Generator
- Nd:YAG

RILIS Ti:Sa Laser System
- Ti:Sa 1
- Ti:Sa 2
- Ti:Sa 3

GPS/HRS
Target & Ion Source
Ion beam to Users

λ – meter

Dye 1
Dye 2
Dye 3

SHG
THG
FHG

λ = meter

12571.486 / cm
The complete RILIS Dye + Ti:Sa system

- Sirah dye lasers with 2\textsuperscript{nd} harmonic generation and UV pumping option
- Narrow band dye laser with computer controlled grating and etalon for high resolution spectroscopy or isomer selectivity
- Edgewave Nd:YAG laser for dye pumping or non resonant ionization
- Photonics Industries Nd:YAG pump laser for the Ti:Sa lasers
- 3 Ti:Sa lasers
- Harmonic generation unit for Ti:Sa system

RILIS cabin layout has been redesigned to accommodate the new lasers
100W Nd:YAG laser is available for non-resonant ionization in Ti:Sa only schemes

**Mixed schemes**

**dye and Ti:Sa are exchangeable**

Prerequisite for dual operation: **Temporal synchronization** pulses of the two laser systems

**Backup solution**

**Unique for laser ion sources**

- **Temporal synchronization**
- **Reduction in down time**
- **New elements**
- **Keep one dye set up for future, use Ti:Sa instead**
<table>
<thead>
<tr>
<th>Element</th>
<th>Setting time*</th>
<th>Step 1</th>
<th>Step 2</th>
<th>Step 3</th>
<th>Efficiency off-line</th>
<th>Step 1</th>
<th>Step 2</th>
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<td>λ₁, nm</td>
<td>Dye</td>
<td>λ₂, nm</td>
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<td>4 days</td>
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<td>216.9</td>
<td>YAG</td>
<td>795.4</td>
</tr>
</tbody>
</table>
Double RILIS tuning curves

- TiSa FHG
- Dye THG
- UV-pumped Dye SHG
- TiSa THG
- TiSa SHG
- UV-pumped Dye Fundamental
- Dye Fundamental
- TiSa fundamental
Example of RILIS setup
Ni: Dye-Dye-TiSa

Higher power from TiSa for AIS transition
Example of RILIS setup
Ca: TiSa-Dye-Dye

Step 1

Step 2

Step 3

Higher power from TiSa for Step 1
Example of RILIS setup
Mg: Dye-Dye-YAG

Step 1
Only Dye scheme, TiSa is setting up for next run (Po)

Step 2

Step 3

285 nm Dye SHG
Mg
532 nm Nd:YAG SHG
553 nm Dye fund
Example of RILIS setup
Po: Dye-TiSa-YAG

Step 1
Step 2
Step 3

Higher power from TiSa for Step 2

256 nm Dye THG
532 nm Nd:YAG SHG
843 nm TiSa fund
Example of RILIS setup
At: Dye-TiSa-YAG

Step 1
Step 2
Higher power from TiSa for Step 2
Step 3
Dye and TiSa exchangeable for Step 1

Dye THG
216 nm

Nd:YAG SHG
532 nm

TiSa fund
795 nm
Example of RILIS setup
Au: TiSa-Dye-Dye

Step 1: Higher power from TiSa for Step 1.
RILIS runs in 2012

**ISOLDE GPS SCHEDULE 2012**

Start protons 2012

- March
- April
- May
- June
- July

**ISOLDE HRS SCHEDULE 2012**

Start protons 2012

- April
- May
- June
- July

**Schedule Details**

- **ISOLDE GPS**
  - Proton beams schedule
  - Specific days for experiments and runs
  - Dates for their respective columns

- **ISOLDE HRS**
  - Proton beams schedule
  - Specific days for experiments and runs
  - Dates for their respective columns
Ion beams of 13 elements were produced with RILIS in 2012

Laser ON time in 2012:
- 3000 h – Expected by end of 2012
- 2916 h – by 1 December

Availability of two complementary laser systems (Dye and Ti:Sapphire) has ensured the increase of RILIS beam time in 2011-2012

| Beam | Sm 2 runs | Ca 2 runs | Cd 2 runs | At 2 runs | Au 2 runs | Be 3 runs | Dy 4 runs | Mg 2 runs | Po 2 runs | Ag 2 runs | Zn | Cu | Mn |
|------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|    |    |    |
| Planned | 208 | 272 | 192 | 300 | 172 | 446 | 88 | 296 | 206 | 96 | 198 | 112 | 148 |
| Real   | 212 | 359 | 253 | 345 | 262 | 278 | 111 | 378 | 206 | 113 | 124 | 69  | 208 |
The Dual Etalon Narrow Linewidth TiSa

Addition of a thick etalon to the TiSa cavity
Remote dual etalon control, automatic optimization routine and feedback based frequency stabilization

Reduction of line-width from >5 GHz → <1GHz
Gold Isotopes

178Au HF spectrum 5830 keV
178Au HF spectrum 5915 keV
178Au HF spectrum 5970 keV

→ 1st transition is difficult with dye laser (UV pump beam required)
→ NB-TiSa was therefore advantageous: scanning stability with 3rd harmonic was demonstrated
→ MR-TOF, windmill and FC were used
Beam time was extremely limited!
Astatine Isotopes: scans on both steps

Extensive Ionization scheme development was required
RILIS ion beams

Ion beams of 31 elements are produced at ISOLDE with RILIS

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>H</td>
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<tr>
<td>31 elements ionized with RILIS</td>
<td></td>
</tr>
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</table>

27 ionization scheme tested (dye or Ti:Sa)

<table>
<thead>
<tr>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
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<td>25 RILIS ionization feasible</td>
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Recent new beams: Sm, Pr, At, Ca
RILIS in action
RILIS in action
Outlook, future developments

- Automated protection and remote monitoring of RILIS installation
- Improved RILIS schemes for the Dual RILIS system
- Extension of RILIS cabin
- Installation of a reference atomic beam unit at RILIS
- Fully motorized TiSa – automatic tuning/optimization
- High beam quality laser for non resonant ionization
- Optimizing the LIST and other means of surface ion suppression
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*KTH – Royal Institute of Technology Stockholm, Sweden*

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The main topics of the Workshop are following:

- Lasers and photocathodes for production of high brightness electron beams
- RF and DC photoinjectors
- Hot cavity and gas cell ion sources for radioactive ion beam facilities
- Laser systems for highly efficient resonance ionization
- Optimizing selectivity for resonance ionization laser ion sources
- In-source spectroscopy of rare nuclides