Laser Ion Source Development for ISOL Systems at RIA

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Introduction

The key to the success of the proposed Rare Isotope Accelerator (RIA) is its ability to combine the advantages of conventional thick-target isotope separation on line technique and transmission-target projectile fragmentation/fission technique to provide ion beams of higher intensities and a wide range of rare isotopes for a wide variety of applications in basic sciences, applied sciences, and medicine. To many applications, the purity of the radioactive ion beams (RIBs) is of crucial importance. One of the main technical challenges facing current Isotope Separation On-Line (ISOL) facilities is to obtain isobarically pure RIBs from various isotopes produced in the target. Laser ion sources based on resonant photoionization [1] have been used for on-line production of radioactive species at several ISOL facilities around the world [2-5] and it has been demonstrated that these ion sources are highly selective, efficient and versatile. In these sources, ions of a selected isotope are produced using laser radiation via stepwise atomic resonant excitations followed by ionization in the last transition. Since each element has its own unique atomic energy levels, the resonant photoionization process can provide elemental selectivity of nearly 100%. Such high elemental selectivity is necessary for the production of pure radioactive ion beams.

There has been excellent progress in the development of resonant ionization laser ion sources and more than 20 RIBs can now be routinely provided at CERN-ISOLDE using a copper vapor laser pumped dye laser system with average overall efficiencies on the order of 10% [6]. However, the obtainable isobar selectivity of present laser ion sources is reduced by non-selective surface ionizations within the laser interaction region and the overall efficiencies are limited by insufficient laser power to saturate the transitions. Further development of these laser ion sources is needed to achieve the ultimate selectivity and efficiencies of resonant laser ionizations. The goal of this R&D project is to improve target and laser ion source coupling, explore new laser technologies for more powerful, reliable, easy-to-use and almost maintenance-free laser systems, and develop ionization schemes for more elements. Our effort toward this end is described below.

Improve target and laser ion source coupling

The most widely used laser ion sources at present are the hot-cavity types that use a high temperature, resistively heated capillary metal cavity connected to the target chamber. Laser beams are focused into the cavity where radioactive reaction products, diffused out of the target and effused into the cavity, are irradiated, and the ionized species are then extracted out of the cavity. The cavity is typically heated to high temperatures (up to 2700 K) in order to prevent short-lived isotopes from sticking to the wall. The performance of these laser ion sources are often limited by

1. non-selective surface ionizations that can occur efficiently at such elevated high temperatures, reducing the obtainable selectivity of the sources,
2. limited amount of laser power that can be focused into the cavity, and
3. inefficient extraction of ions out of the capillary cavity.

Therefore, one objective of this R&D project is to investigate different means to achieve the ultimate selectivity and efficiency of resonant photoionization processes.

Extensive research has been conducted to study different cavity materials with low work functions [6], as surface ionization depends strongly on the work function of the cavity material in relation to the ionization potential of the particular element. In order to further improve the hot cavity laser ion source, theoretical and experimental studies will be carried out to study various processes inside the hot cavity (such as thermal and laser generated plasmas, potential barriers, charge recombination and charge exchange processes, surface adsorptions, etc.) which may play important roles in creating or destroying ions as well as extracting ions out of the cavity. It is expected that the results of these studies will be important for us to choose optimal cavity materials and geometries for optimum source performance. More important, these studies are required to develop alternate coupling arrangements that can provide fast extraction of all ions inside the laser interacting region.

Lowering the temperature of the capillary cavity can significantly reduce the surface ionization efficiencies, but will also increase decay losses of short-lived isotopes. Solutions may be found to use molecular carriers for faster release of desired isotopes while keeping the cavity temperature sufficiently low; the desired isotopes may then be photoionized into molecular ions or photo-dissociated and ionized in atomic form. Some elements are difficult to release from the target even at elevated temperatures and using

more volatile molecular carriers may be the only way to bring them out. Molecular carriers have often been successfully used at HRIBF, the best examples of this technique are the production of ^{17}F and ^{132,134}Sn beams. Such on-line chemistry methods will be explored for use with a laser ion source.

The ionization efficiency of the hot-cavity laser ion sources is often limited by insufficient laser power to saturate the transitions. One of the main problems that have been reported is that less than half of the available laser power can be focused into the capillary hot cavity. This problem can be minimized by using state-of-the-art solid-state lasers, as discussed in the next section, which can offer beams of TEM_{00} transverse mode. With such superior beam quality, it is possible to focus most of the laser power into the capillary cavity. We may also investigate the possibilities of multiple beam passes to increase spatial overlapping or multiplexing laser beams with different time delays to increase temporal overlapping.

Explore state-of-the-art laser technology

Narrow-bandwidth widely tunable dye lasers have played the most prominent role in atomic and molecular spectroscopy. Using different dyes with frequency doubling and tripling, these lasers provide tunable coherent radiation throughout the wavelength range from the near ultraviolet to the near infrared. At present, the most widely used laser ion sources are based on copper vapor laser (CVL) pumped, pulsed dye laser systems, due to the high power and high repetition rate of the CVL pump lasers. However, these laser systems are not easy to operate, require high maintenance and constant supervision. Another objective of this R&D project is to explore commercially available state-of-the-art laser technologies such as all-solid-state tunable lasers for more laser power, better beam quality, as well as better reliability and almost maintenance-free operations. Various tunable lasers, such Ti:Sapphire, dye lasers and optical parametric oscillators (OPOs) will be considered for wavelength diversity and tunability.

Nd:YLF or Nd:YAG pumped Ti:Sapphire lasers provide an all-solid-state alternative to dye lasers. Ti:Sapphire lasers are very attractive because they are all solid-sate, highly reliable, easy to use, and low-maintenance. They are tunable over the range of 700 to 1000 nm. By optical harmonic frequency generation, the accessible spectral region can be extended to 350-500 nm (frequency doubling), 233-330 nm (frequency tripling), and 200-250 nm (frequency quadrupling). Pulsed Ti:Sapphire lasers with comparable output

power as the CVL pumped dye lasers and TEM_{00} transverse mode output (i.e., best beam quality) with 10 kHz repetition rates and <20ns pulse width are now commercially available [7]. A disadvantage is that there are gaps, especially between 500-700nm, in their spectral output range. The mission wavelength range can be filled with a Nd:YLF pumped dye laser or an optical parametric oscillator. A commercially available diode-pumped Nd:YLF laser system [8] is shown in Fig. 1. It can generate 30 W average power of 20-30 ns pulses with 10 kHz repetition rate at 523 nm, which is comparable to the performance of the CVL pump lasers. Substantial improvements in power and repetition rate of solid-state laser systems can be expected in the future.

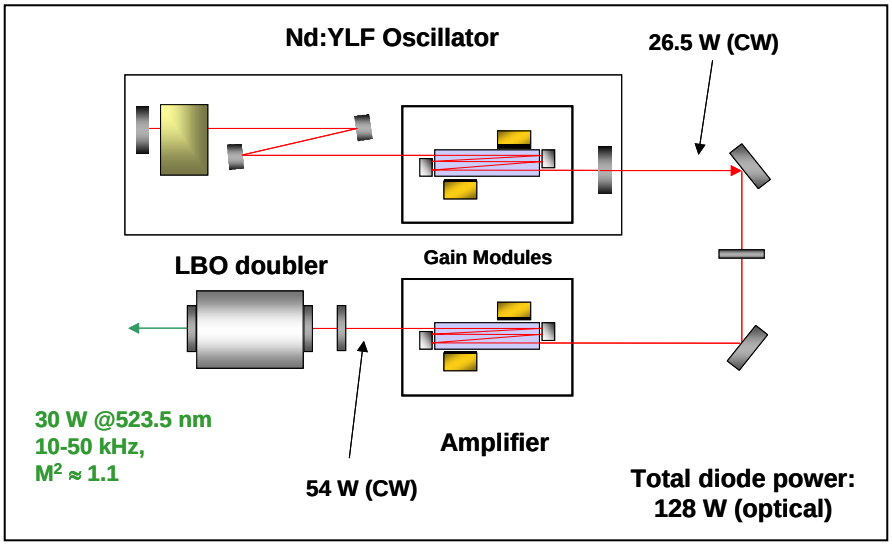

Fig.1. A commercial diode-pumped Nd:YLF laser with output power comparable to the copper vapor lasers and is suitable as a pump laser for tunable Ti:Sapphire and dye lasers.

Develop new ionization schemes

The efficiency of photoionization depends on finding the most efficient excitation and ionization schemes and choosing lasers with sufficient intensity to saturate each transition. For each element there may be many possible ionization schemes. As a major problem with RLIS has always been related to the high power requirements of the ionization step, it is important to find efficient transitions to ionize an excited atom resonantly through an auto-ionization state or a Rydberg state since they require much less laser power to achieve high ionization efficiencies than that of non-resonant

ionization through the continuum. Although more than 20 RIBs can now be produced with laser ion sources, more than half of them are non-resonantly ionized. Therefore, a further objective of this project is to carry out a systematic search for auto-ionization states, Rydberg states, and strong transitions to them for more elements. With state-of-the-art laser technology and optimum ionization schemes, it is possible to achieve selective photoionization with efficiencies close to unity for many elements in the periodic table (ionization potential < 10 eV).

Summary

We have proposed to carry out an R&D project for the development of laser ion sources for the ISOL system at RIA. The proposed research can be accomplished at the Holifield Radioactive Ion Beam Facility (HRIBF) in an operating ISOL environment with both stable isotopes and with short-lived radioactive isotopes. HRIBF has made significant contributions to the ISOL technology of producing radioactive ion beams, including innovative ion sources and highly effective production targets.

References

1. Vladilen S. Letokhov, Laser Photoionization Spectroscopy, Academic Press, Orlando, 1987.
2. V.N. Fedoseyev, G. Huber, U. Koester, J. Lettry, V.I. Mishin, H. Ravn, V. Sebastian, Hyp. Int. 127 (2000) 409.
3. P. Van Duppen, Nucl. Instr. Meth. B 126 (1997) 66-72.
4. Yu. Kudryavtsev, et al., Nucl. Phys. A 701 (2002) 465c-469c.
5. M. Koizumi, et al., Nucl. Instr. Meth. B 204 (2003) 359.
6. U. Koester, V.N. Fedoseyev, V.I. Mishin, Spectro. Acta Part B 58 (2003) 1047.
7. Private communications, Photonics Industries International, Inc., 25 East Loop Road, Stony Brook, NY 11790.
8. Q-Peak Inc., 135 South Road, Bedford, MA 01730.