1st Topical Workshop on Laser Based Particle Sources

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Book of abstracts

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Laser R&D and Researcher Training within LA^3NET

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Lasers can be used for the generation of high brightness electron and exotic ion beams, the acceleration of particles with the highest accelerating gradients, as well as for the characterization of many complex particle beams by means of laser-based beam diagnostics methods.

Without constant progress in laser technology and close collaboration between laser experts and accelerator scientists, many of today's most advanced experiments would simply be impossible.

The LA^3NET consortium combines developments into laser technology and sensors with their application at advanced accelerator facilities, providing complex beams ranging from highest brightness electron beams to high intensity proton beams.

In this talk I will present the consortium's broad, yet closely interconnected experimental program with a focus on laser based particle sources and will summarize the network-wide training program consisting of Schools, Topical Workshops and Conferences that will also be open to participants from outside the consortium.

Normal-conducting RF photoinjectors for Free Electron Lasers

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Free electron lasers operating at short wavelength require very high beam quality which is mainly defined at the electron source. To fulfill the specifications normal-conducting (NC) RF photoinjectors have been developed at different groups around the world.

After a short introduction to SASE-FELs and a motivation, why electron sources are so important for them, the talk will present the design of different NC RF photo injectors. Emphasis will be set on the developments at the photoinjector test facility at DESY in Zeuthen (PITZ) which demonstrated very good beam quality in a wide range of electron bunch charges.

Laser systems for the low emittance injector of the future SwissFEL X-ray source

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Future free-electron laser (FEL) light sources based on LINAC are demanding high quality electron beams for X-ray production. The SwissFEL laser group at Paul Scherrer Institute at PSI is working on the development of photo-injector laser systems and cathode studies to achieve the lowest possible emittance both in transverse and longitudinal planes and to meet the requirements for the future SwissFEL electron source [1,2]. The group is also responsible for delivering THz sources and pump lasers for the experimental stations of SwissFEL.

The currently operating SwissFEL Test Injector Facility is delivering 250MeV electron bunches with up to 200pC charge at 10Hz repetition rate, with a compression scheme downstream the booster cavities. The requirements for the laser, in order to achieve low emittance, include wavelength tuneability of the source to lower the intrinsic (thermal) emittance from the copper cathodes used [3], as well as transverse and longitudinal shaping of the laser beam to reduce space charge induced emittance degradation. For the production of ultrashort X-ray pulses stability of the laser system is crucial [4]. Synchronization of the laser pulses to the machine RF system with extreme high accuracy of 40fs is required. A terawatt class Ti:Sapphire oscillator followed by chirped pulse amplifier system provides the primary synchronized source and allows for ~25nm tuneability range at the 3rd harmonic (~260nm) [5]. An optical parametric amplifier together with frequency mixing stages added to the system enables larger tuning range for thermal emittance studies. The broad bandwidth of the Ti:Sapphire amplifier system also supports the temporal shaping requirements for the injector and with a stacking scheme based on birefringent crystals, delivers 4 and 10 ps nearly flat-top temporal profile in the deep-UV with sub-ps rise- and falltime. A second, directly diode pumped Nd:YLF laser system provides the backup for operation, and is limited to Gaussian pulse shapes. In the future a hybrid fiber-solid-state system is considered.

The presentation will give a general overview of the group's work on the gun lasers with a focus on recent studies of emittance optimization via laser wavelength tuning. Laser and electron-beam based measurements of timing jitter will also be discussed.

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Laser ion source of the ISAC/TRIUMF on-line radioactive ion beam facility

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Resonant ionization laser ion sources (RILIS) have become an important type of ion source for on-line ISOL radioactive ion beam facilities due to the unique capability of element-, and at times even isotope selective-, ionization of the RILIS.

The operating principle of RILIS operating at ISOL facilities will be presented, followed by the particular implementation at TRIUMF's Isotope Separator and Accelerator facility (ISAC). Recent advances in beams, ionization schemes, RILIS operation, and new developments will be discussed.

The Alto laser ion source

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The Resonant Ionization Laser Ion Source (RILIS) is an element selective, highly efficient and versatile tool to generate pure radioactive isotope beams at Isotope Separators on-line (ISOL) facilities. The laser ion source at ALTO consists of a dye laser system at 10 kHz pumped with a 532 nm Nd:Yag laser. ALTO RILIS was successfully put into its first operation in 2011. The 79Ga isotope was resonantly ionized with a 287-532 nm scheme and an enhancement factor of 15 was observed, compared to surface ionization with a tantalum cavity.

Recently two new commercial grating tuned high repetition dye lasers have been procured and installed. Each dye laser has a laser resonator, a power amplifier and a single-pass doubling unit. The typical power of the lasers, for a pumping power of ~30 W, is ~8 W after the amplifier and ~ 500 mW after frequency doubling with a convention efficiency of ~6%. The pulse width of the lasers is ~10 ns and the linewidth is ~3 GHz. The on-line laser ionization of Ga with the new dye laser system was then repeated in Nov 2012 with a 287/294-532 nm scheme.

Meanwhile to support on-line RILIS operation, the design and the building of an off-line reference cell are in process.

Development status of GANIL ion source GISELE

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The future SPIRAL2 will be a new radioactive ion beam facility. A resonant ionization laser ion source is under development at GANIL, in collaboration with University of Mainz (Germany) and TRIUMF, Vancouver (Canada). Here the status of the project and the latest improvements are presented. Current work is carried out in a test bench where the design of the ion source body can be tested, including low work function materials used as hot cavity in order to increase selectivity. It will be equipped to allow time profile measurements of the ion bunch. Ionization schemes are also evaluated for efficiency. The aim of this project is to find the best technical solution which combines high selectivity and ionization efficiency with good ion beam emittance and stable long term operation.

Photocathodes for high brightness electron beams

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Photocathodes are key elements in high brightness RF photoinjectors. A proper selection of the photocathodes has a relevant impact on the properties of the generated electron beam. In this presentation the main photocathode parameters are introduced and their effect on generated beam discussed. Moreover, a review of the production process, characterization and use of these materials is presented.

Photoinjector activities at CERN

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The Compact Linear Collider (CLIC) is under study at CERN in a collaboration between many institutes. For developing the technology needed for CLIC a dedicated test facility (CLIC test facility 3, CTF3) is currently in operation at CERN, which contains also two RF photoinjector installations. The CALIFES photoinjector for the CTF3 main beam provides beam for two-beam acceleration experiments on a daily basis, whereas the PHIN photoinjector was installed at an off-line test stand for studying its feasibility as an electron source for the CTF3 drive beam. Having reached most of the CTF3 drive beam requirements, the focus of the studies at PHIN has now shifted towards feasibility studies for the CLIC drive beam, which requires a high bunch charge of 8.4 nC and 0.14 ms long macro pulses with 50 Hz repetition rate and 2 ns bunch spacing. This corresponds to a total charge of 0.59 mC per macro pulse, which is challenging with respect to the photocathode lifetime. Therefore, an extensive photocathode R&D program is in progress, for which a dedicated photoemission laboratory including a DC electron gun and a test beam line is available. This talk will give a general overview of the photoinjector activities at CERN with a focus on the PHIN studies and the photocathode R&D.

Photocathodes for Rossendorf SRF gun

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Rossendorf SRF gun is an electron source for high current electron beams based on superconducting RF technology and laser driven photocathode. Semiconductor Cs2Te photocathodes are the standard electron sources. Up to now eight Cs2Te photocathodes have been operated in the SRF gun. Quantum efficiency (Q.E.) of 1% and life time of months satisfy the gun operation. Besides the present Cs2Te photocathode, GaAs(Cs, O) attracts a lot of attention because of its high QE in the visible light range and the probability to produce high polarization beams. A new preparation system for GaAs is developing, and we will later examine the activation and performance of GaAs photocathodes in SRF gun.

InnoSlab Lasers and their Applications in Science and Industry

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Diffractive limited high energy 1.0 µm nano-second laser pulse and the efficient green and UV radiation by second harmonic generation and third harmonic generation are widely used in industry and science. A lot of laser applications in industry and research require laser sources having high energy, short pulse width, high repetition rates, high beam quality and compact size. It is difficult or impossible for rod, disc solid lasers and fibre lasers to have all the features at the same time. The InnoSlab lasers with a stable-unstable hybrid resonator have been verified to be successful for the generation of laser radiation with diffraction limited beam quality at high power level. As far as we know, it is still a challenge for the generation of Gaussian beam with several ten's mJ energy and below 10ns pulse width at multi kHz repetition rate by robust and compact resonator design. In case of rod and disc solid state lasers and fibre lasers huge effort is required to build up lasers of several mJ pulse energy with Gaussian beam quality and with pulse length shorter than 10ns at multi ten´s kHz.

To scale power and energy oscillator and amplifier systems (MOPA) are often used. The main problem in most MOPA designs is to obtain efficient amplification with a large amplification factor due to the controversial behavior between the saturation for high efficiency and the achievable gain for a large amplification factor. Furthermore, the high power/energy scaling combined with high beam quality is always the aim of the amplifier system. The key point of the beam quality control at high power level is to reduce the thermal effects. Those problems are addressed by the InnoSlab amplifier design. Laser materials supporting short pulses require high pump intensities throughout the crystal. Good thermal management is essential to avoid failure by thermo-mechanical stress and to support nearly diffraction limited beam quality at high average power. An InnoSlab laser or amplifier consists of a longitudinally, partially pumped slab crystal. Grinding of the mounting surface of the slab suppresses parasitic oscillations across the line-shaped, homogeneously pumped cross-section inside the crystal. The short distance between the pumped gain volume and the large cooled mounting surfaces allow for efficient heat removal.

In this talk, we present InnoSlab oscillator and amplifier design for short pulse and ultra-short pulse lasers. Performances and favorable applications of short pulse and ultra-short pulse lasers in science and industry will be discussed.

Burst mode pulse generation from fiber lasers for accelerator facilities

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This talk will report on development of a burst-mode Yb-fiber amplifier, generating bursts of pulses with up to 500 MHz intra-burst repetition-rate and total burst energies of ~1 mJ (e.g., 25 pulses of 40 µJ each). The pulses are compressible to ~1 ps. All essential parameters of the amplifier are controllable using custom-developed FPGA-based electronics. The talk will summarize other relevant developments in our lab, including ultrafast material ablation experiments achieved with the burst-mode laser, the development of a 100-W, 5-ps fiber laser system, and a Cs atomic-locked Yb-fiber frequency comb, achieving excellent short (<1 s) and long-term (>1 s) timing jitter with potential applications to optical synchronization in accelerators.

Recent operation and outlook for the ISOLDE Resonance Ionization Laser Ion Source (RILIS)

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As the most commonly used ion source of the ISOLDE facility, the RILIS is in a virtually uninterrupted cycle of setup and operation during the on-line period. In 2012, for example, RILIS ionized beams of 13 elements were produced for 24 separate runs. This required approximately 3000 hours of on-line operation for which 344 RILIS operator shifts were scheduled. This intensity of use is unique among laser ion sources worldwide and requires at least 4 laser operators per run, a highly reliable laser system, and careful scheduling of ISOLDE experiments. Recently, efforts have been made to facilitate the setup and maintenance of optimal RILIS parameters through the integration of remote laser control, monitoring and data acquisition tools. To complement these developments, a project is underway to build and install a comprehensive RILIS machine protection and status monitoring system. This should enable a transition to on-call operation for many RILIS runs and is a pre-requisite for any future increase of annual operating hours.

A summary of the 2013 operating period will be given and details of future improvements of the RILIS installation, including the RILIS control, monitoring and machine protection system, will be shown.

A development platform for Ti:Sa lasers

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The tunability and reliability of solid-state Ti:Sa lasers meets the requirements for their application at laser ion sources based on resonance laser ionization.

The prototype of the Ti:Sa lasers now used at laser ion sources world-wide was initially developed at the University of Mainz as a replacement of the dye laser system used for ultra trace analysis.

Since then the laser cavity design underwent several revisions to become a compact, transportable laser system. The requirements for application of the Ti:Sa lasers at on-line laser ion-sources (TRILIS, RILIS) have have led to increased set-up speed and user friendliness at the expense of degrees of freedom and space in the resonator.

However, these highly specialized designs are not suitable for testing new concepts or for laser developments for specific applications that require, for example, more output power or continuous tuning while in narrow linewidth mode.

In this presentation, a short review of the history of the Mainz-Ti:Sa design and its branching will be given. A breadboard based Ti:Sa development platform will be presented and future Ti:Sa developments will be discussed.

Photocathode lasers for driving RF guns with Cesium Telluride photocathodes (FLASH, XFEL, ELBE)

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Various photocathode lasers for Cesium Telluride photocathodes will be described. These diode-pumped solid-state lasers generate picosecond pulses, which are finally converted to the ultra violet spectral range by means of two nonlinear optical crystals. The laser systems have been developed at the Max-Born-Institute and are now being used for driving the photo injectors at the FLASH-FEL (DESY Hamburg), as well as the facilities of PITZ (DESY Zeuthen) and ELBE (Forschungszentrum Dresden-Rossendorf, FZDR).

The generation of trains (burst) of ultraviolet pulses will be discussed in more detail. These pulse trains drive the photo injectors of linacs with superconducting cavities of the TESLA type, e. g. at the FLASH FEL and at PITZ. This special operational mode of the laser will be compared to the more common quasi-CW mode, which is used for driving the superconducting RF guns at the FZDR.

Finally, a novel method for generation of shaped ultraviolet pulses, in particular flat-top pulses with sharp rising and falling edges, will be explained. The method is based on a multicrystal birefringent filter. It is being developed as a major component for the photocathode laser of the upcoming European XFEL.

Laser driver for CTF3 photo-injectors

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Future compact linear electron-positron collider (CLIC) is under development at CERN in collaboration with many institutes worldwide. CLIC test facility (CTF3) is now under operation at CERN and it is a test bench for CLIC feasibility studies. Two RF photo-injectors are operated at CTF3: prototype for CLIC main beam – CALIFES, and prototype for CLIC drive beam – PHIN. Both photo-injectors are driven by one Nd:YLF laser installation which is described in present talk. The laser consists of a passively mode-locked oscillator which delivers 8ps pulses with 1.5GHz repetition rate synchronized with 3GHz klystron, 10W output preamplifier and final diode pumped amplifiers operated in a burst mode - one for CALIFES (5mm diam, 6 kW 500 µs pump) and two for PHIN (7mm diam, 16 kW 500 µs pump and 10mm diam, 22 kW pump). CALIFES photo-injector requires pulse trains with a duration 1-200 ns with an UV energy up to 2µJ/pulse, PHIN photo-injector can be operated either on 2nd harmonic (green light) or 4th harmonic (UV light) and requires pulse trains from 50ns to 5µs with an energy up to 1µJ/pulse.

Photoinjector laser activities in IAP RAS

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Photoinjector laser activities in IAP RAS started in collaboration with the High Energy Accelerator Research Organization, KEK institute (Japan) in 2008. At that time under the project of the International Linear Collider (ILC) by means of the Super-conducting Test Facility (STF) functioning in KEK the technology of cryogenic RF accelerator modules production was being refined and demonstrated. As an electron source in its RF electron gun served a photoinjector based on a laser driven CsTe cathode. So that in IAP RAS the prototype of such a laser system was build and delivered to KEK in 2010. Requirement of a 3.2 nC charge per injected electron pulse corresponds to the 8-picosecond UV (λ = 262 nm) laser pulse (micropulse) energy of 1.5 µJ. 2437 micropulses running with the frequency of 2.708 MHz (subharmonic of accelerator klystrons) form an exactly rectangular 900µs-long train (macropulse), repeated in turn with the frequency of 5 Hz. High energy stability both for micropulses inside a macropulse and for macropulses themselves is required.

Following the strict specification for the micropulse repetition rate we have chosen an Yb-doped fiber master oscillator (λ = 1047 nm) with self-mode-locked operating regime without Q-switching. Subsequent amplification in the Yb-doped fiber is limited by the cubic nonlinearity effects distorting the radiation spectrum. Thus the final

amplification system is embodied as a two pass two cascade Nd:YLF solid state amplifier with flash lamp pump. Pumping pulses of two cascades are shifted in time in order to amplify the macropulse more uniformly. To compensate temporal inhomogeneity of the gain the macropulse is previously modified in the fiber fast acousto-optic modulator (AOM) so that its amplified envelope become exactly rectangular. The time dependent AOM transmittance mask is calculated in the feedback algorithm. The 2nd and the 4th harmonics are generated in KTP and BBO crystals respectively. Utilizing the decreasing segment of the 4th harmonic generation efficiency curve allows reducing the mean power fluctuation to 2.3%.

The 2nd stage of the photoinjector devoted collaboration is tightly connected with the Joint Institute for Nuclear Research (JINR) in Dubna. As a linear accelerator project with characteristics similar to those in KEK shortly after started in JINR, the second laser system of the type was made in IAP RAS to drive its photocathode. Comparably cheap and reliable solution for a photocathode laser driver has done well again. Laser system for JINR exceeds the KEK project more than six times in power due to raising micropulse repetition rate up to 10 MHz and macropulse repetition rate up to 10 Hz. Micropulse and macropulse repetition rates, micropulse number within a macropulse tuning options are added. The micropulse energy of 1.85 µJ is achieved. Due to additional feedback stabilization algorithm adjusting the fiber preamplifier current the mean power fluctuation drops down to 0.8%. The laser system for JINR has been transported to Dubna and at the moment is being installed on its final location.

At the 3rd stage the most challenging problem was attacked. It was theoretically shown that for the electron beam transverse emittance minimization the photo injector laser driver micropulse must have a 3D ellipsoidal shape. Such an exotic requirements are imposed on a laser system started in 2012 in IAP RAS for the Photo Injector test facility at DESY, Location Zeuthen (PITZ), where the developing of the electron source for the European X-ray Free Electron Laser (XFEL) is being carried out. In the output of the photocathode laser for PITZ 7-picosecond 3D ellipsoidally shaped UV micropulses (3DESP) with the energy of 30 µJ must run with the frequency of 1 MHz inside 300-microsecond long macropulses with rectangular envelope repeated in turn with the frequency of 10 Hz.

The project concept consists of four main terms. The 1st task is 3DESP creation by means of two liquid crystal Spatial Light Modulators (SLM) (for amplitude and phase masking) in the mixed spatial-frequency domain. The experiment with one amplitude masking SLM has already been done along this line. Then these wide-band pulses must be amplified without dramatic distortion of the shape. The thin-disk Yb:KGW multi-pass (18 V-passes) imaging amplifier is aligned and tested in small signal and working regimes. Thirdly the second and the fourth harmonics in thin LBO and BBO crystals respectively have to be generated utilizing the angular chirp technique to achieve high efficiency of conversion without shape degradation. And finally for the micropulse shape diagnostics an ultra fast 3D cross-correlation scanner has been developed. The probe micropulse noncollinearly interacting in BBO crystal with the micropulse under study gives the cross-correlation function that contains the information about temporal micropulse distribution. Each scanning slice gives 2D intensity distribution in the corresponding cross-section. Engineering decision for time dependent delay line of the probe channel represents 80 m of single-mode polarization-maintaining fiber coiled up on a piezo ceramic disk. This devise is able to scan the micropulse during one macropulse. The cross-correlation scanner is realized to the 1st harmonic diagnostics. The thorough investigation of its resource is done.

Gas jet laser ionization: developments towards high selectivity for RIB production and high resolution studies of exotic atoms

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Selective resonant laser ionization for the production of radioactive ion beams at gas cell-based facilities was pioneered by KU Leuven and more recently has been integrated at the IGISOL facility, Finland [1,2]. In an extension of this technique, a novel approach has been demonstrated in which neutral radioactive atoms are selectively ionized upon exit from the gas cell within the expanding gas jet [3,4]. This adaptation of the Laser Ion Source Trap method, proposed originally to improve the beam quality from a hot cavity ion source, aims for ultra-high purification of low-energy radioactive ion beams.

For ensuring the high efficiency of an on-line resonance ionization laser ion source, powerful pulsed lasers often operating in a high repetition mode (~kHz regime) with small duty cycle losses, are most suitable. These laser systems, whether dye or solid state, need to deliver sufficiently high power in order to saturate each individual excitation step. Standard broadband laser systems have spectral linewidths of a few GHz, which often masks sensitivity to hyperfine structure and isotope shifts, thus prohibiting a measurement of fundamental ground state nuclear structure (nuclear spins, moments and changes in mean-square charge radii).

Nevertheless, new opportunities have arisen and exciting results have been now been obtained via in-source spectroscopy on candidates with larger hyperfine parameters such as copper [5]. Currently, one of the most topical developments in the field is the application of resonance ionization in a gas jet. Both Doppler and pressure effects, which convolute and broaden the atomic linewidth, are substantially reduced thus making the environment attractive for a much wider range of short-lived nuclei. In this presentation I will summarize a variety of studies to improve the efficiency of the technique which thus far has been limited by the gas jet expansion [6]. The improvement in spectral resolution will be demonstrated by comparing with in-source spectroscopy.

The limitation to the resolution of in-jet laser ionization is the bandwidth of the pulsed laser systems. This presentation will also look at the novel developments which are currently being applied to solid state Ti:sapphire laser systems in order to specifically address this issue. Two approaches are being pursued: the first, an intermediate solution, utilizes synchronized control of a double-etalon laser cavity to achieve a linewidth <1 GHz. The second involves a more complicated technique of injection-locking the pulsed cavity to a cw master laser. This has been demonstrated to reduce the linewidth from a few GHz to tens of MHz [7]. I will show the latest results from JYFL, Mainz and RIKEN/Nagoya to illustrate the international efforts in this work.

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Recent laser developments at the IGISOL facility

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The quest for efficient and selective laser ionization and spectroscopy of new elements and isotopes requires advances of the currently used laser systems in terms of several key parameters including power, wavelength coverage and resolution. To enhance the specifications of the currently employed Ti:sapphire laser systems at IGISOL and other international facilities, several new techniques have been employed. For each technique a short review as well as an application will be presented.

- A grating-based Ti:sapphire laser for wide range wavelength scanning has been built and used for ionization scheme development in samarium.
- The power of the second and fourth harmonic was greatly improved using intra-cavity frequency doubling, a technique which is now routinely used in experiments.
- A first test of difference frequency mixing has been carried out to check the viability of filling in the "wavelength gap" between the fundamental and the second harmonic for the Ti:sapphire laser in the range of 500-700 nm.
- Fiber transport for high power pulsed lasers is currently under investigation and may be used for convenient optical distribution to different ion sources, reducing the need for tedious alignment procedures.
- The intrinsic resolution of the Ti:sapphire laser has been improved from 5 GHz to below 1 GHz by introducing a second thick etalon into the cavity. First measurements with this system have been carried out on the stable isotopes of copper in a collimated atomic beam reference cell as well as inside the gas cell and gas jet of the IGISOL laser ion source.
- An even further reduction of the laser linewidth is possible using the technique of injection locking. Currently, such a system is being set up at IGISOL using a continuous wave master laser to seed a pulsed pumped bow-tie ring cavity. In optimal conditions the linewidth of such a laser is only determined by the Fourier-transform limit and the stabilization performance and can reach to below 20 MHz.

Comparison of Resonant Ionization of Yb in high- and low-voltage mass separators

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Resonant Ionization Spectroscopy is a very efficient method for generating element-pure ion beams. The development of the necessary ionization schemes for use in online ion sources with acceleration voltages between 30 and 60 kV is usually done at more compact and inexpensive offline mass spectrometers with much lower acceleration voltages. This is possible because this difference generally does not affect the resonant excitation. In contrast, measurements on Ytterbium show differing excitation strengths in ion sources with high and low acceleration voltages if a multi-step scheme involving a Rydberg state as highest excitation is used. The transition into the ionization continuum is then possible by non-resonant absorption, collisions between atoms, or by electric fields that perturb the coulomb potential. Since the different excitations strengths still occur while using the same atomization crucibles with the same temperatures and laser powers, they have to originate from the different field strengths.

DC electron sources for polarized beams

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Spin-polarized beams of high brightness may be produced by photoemission from semiconductor superlatices, e.g. GaAs/GaAsP. A negative electron affinity (NEA) state of the semiconductor has to be provided to make photoemission energetically possible. This is achieved by a modification of the cathode surface, in particular by a sub-monolayer of Cs:0 compounds. The challenge for an accelerator application is to maintain the NEA state under running conditions. The implications for design and operation of the spin-polarized source are discussed.

Generation and investigation of spinpolarized electron bunches and GaAs-photocathode cleaning and performance studies at the S-DALINAC

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A source of polarized electrons has recently been implemented at the superconducting Darmstadt electron linear accelerator S-DALINAC. Photo-emission from strained layer superlattice-GaAs (SSL) and bulk-GaAs photocathodes are obtained from using either 3 GHz modulated diode lasers at 780 nm and 405 nm or a short-pulse Ti:Sapphire laser system at 780 nm with the possibility of frequency doubling to 390 nm to achieve a high degree of polarization or a high quantum efficiency, respectively.

Measurements were done with varying laser pulse lengths and electron bunch lengths from 90 ps to 40 ps using a pulse stretcher system and a single-mode optical fiber. The electron bunch length was determined using a chopper rf cavity and a slit system. The dependence of the electron polarization from the rf phase was studied over the electron bunch both for SSL and bulk cathodes.

To enhance the availability and performance of the polarized source with respect to quantum efficiency, a separate atomic-hydrogen cleaning system for the cathodes is presently being set up which will allow one to treat cathodes after several Cs-O activation cycles and to optimized preparation procedures.

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Solid state laser system for SPES radioactive isotopes ionization

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Nowadays the resonant ionization by tunable lasers (also known as LIS, laser ion source) is the most suitable ionizing system to assure a good selectivity directly in the initial phase of the ion production in an ISOL (Isotope Separation On Line) facility

Keeping into account the other experiences from all the ISOL facilities spread into the world, this ionization technique is planned to be used also in SPES (Selective Production of Exotic Species) facility, that will be built in Laboratori Nazionali di Legnaro (LNL – National Laboratory of Legnaro) in Italy by INFN (Istituto Nazionale di Fisica Nucleare – National Institute of Nuclear Phisics).

Studies of laser ionization technique in support of SPES project has started in 2009 in Laser Spectroscopy Laboratory of Pavia with dye lasers and nowadays, at the beginning of 2013, an offline laser laboratory will be constructed in LNL to continue studies of photoionization using an all solid state lasers solution.

The all solid state solution is a recent approach respect to the dye laser to develop a ionization laser system and has to be investigated to reveal its strength points and also its weakness; this will be the aim of the new laser laboratory in LNL.

All this efforts are finalized to be ready with an operative solution and equipment for the first SPES ion beam for the users planned for 2017.

In-gas-cell and in-gas-jet laser ion sources: Resonance ionization spectroscopy of radioactive atoms

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New approaches to perform efficient and selective step-wise Resonance Ionization Spectroscopy (RIS) of radioactive atoms in a gas cell and in supersonic gas jets are discussed.

In the ion source, the nuclear reaction products recoiling out of the thing target are thermalized and neutralized in a high pressure noble gas (helium or argon), then resonantly ionized by the laser beams in a two-step process, extracted from the ion source, accelerated and mass separated [1-3]. In this way isobaric and isotopic selectivity can be achieved. The laser ion source made it possible to perform β-decay studies of nuclei that are produced in proton-induced fission of 238U and in light/heavy ion-induced fusion evaporation reactions.

A number of innovative techniques that were implemented to improve the performance of the laser ion source and also open new opportunities for high-precision laser spectroscopy of radioactive isotopes.

• In a dual chamber gas cell, the laser ionisation chamber is separated from the stopping chamber [4]. In this geometry the recombination of laser-produced ions due to the plasma created by the primary accelerator beam is reduced and allows to increase the ion source efficiency. This reduced plasma density opens the possibility to collect ions coming from the stopping zone with electrical fields thus increasing the ion source selectivity above 2000.

• High efficiency and selectivity of the ion source allows to perform in-gas cell resonance ionization spectroscopy of exotic atoms. Using this method the nuclear magnetic moments of copper and silver isotopes produced in heavy-ion-induced fusion-evaporation reactions have been measured [5].

• Implementation of resonance ionization in the supersonic gas jet [6,7] allows to increase the spectral resolution by one order of magnitude in comparison with in-gas-cell ionization spectroscopy. Properties of supersonic beams, obtained from the de Laval and the free jet nozzles that are important for the reduction of the spectral line broadening mechanisms in cold and low density environments are discussed. First results of high-resolution spectroscopy in the supersonic free jet are presented.

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Gas Cell Based Laser Ion Source for Production and Study of Neutron Rich Heavy Nuclei

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A new setup for synthesis and study of new heavy nuclei, based on gas cell laser ion source is under construction at FLNR JINR (Dubna). A creation and a launch of this facility will open a new field of research in low-energy heavy-ion physics, and new horizons in the study of unexplored "north-east" area of the nuclear map will become possible.

This unexplored area of heavy neutron rich nuclei is very important for nuclear physics investigations and for the understanding of the r-process in astrophysical nucleosynthesis. Just in this region the closed neutron shell N=126 is located which is the last "waiting point" in the r-process .The half-lives and other characteristics of these nuclei are important for the r-process scenario of supernovae explosions. Study of the properties of nuclei along the neutron shell N = 126 could also contribute to the present discussion of the quenching of shell gaps in nuclei with large neutron excess.

During the last several years a combined method of separation based on stopping nuclei in gas and subsequent resonance laser ionization of them has been intensively studied and developed. This method was used up to now for separation and study of light exotic nuclei and fission fragments. Now it is proposed for production of heavy neutron rich nuclei by low-energy multi-nucleon transfer reactions. Such techniques allows one to extract nuclei with a given atomic number, while a separation of the single ionized isotopes over their masses can be done rather easily by a magnetic field. Half-lives of heavy neutron rich nuclei, which we are interested in (as a rule, β-– decaying), are much longer than the extraction time of ions at such a setup.

The status of laser ionization schemes and the scope for improving efficiencies

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The addition of 3, Nd:YAG pumped, titanium sapphire (Ti:Sa) lasers to the ISOLDE resonance ionization laser ion source (RILIS) presents an ideal opportunity for a full evaluation of the ionization schemes currently used at RILIS. The purpose of this is to determine if there are any possibilities for utilising this broadening of the available wavelength range to reach autoionizing states and more generally increase the efficiency of the laser ion source. The general status of ionisation schemes will be discussed, along with methods for scheme development.

Spectral linewidth control of broadly tunable high repetition solid state lasers

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Resonance ionization is the key for the efficient production of highly pure beams produced with laser ion sources at Isotope Separator On-Line (ISOL) facilities. The high element selectivity is achieved by applying a multi-step resonant excitation and ionization scheme via optical transitions unique for every element. To ensure access to a maximum number of elements wide-range tunable laser systems like Ti:sapphire or dye lasers are required. The frequency selection of the Ti:sapphire lasers operated at the leading on-line laser ion source facilities worldwide (i.e. ISOLDE-RILIS at CERN, ISAC-TRILIS at TRIUMF and few others) is based on a combination of a birefringent filter and a thin etalon which limits the spectral line width to typically 6 GHz, which almost perfectly matches the Doppler width of the thermal atom ensemble inside a hot cavity. For applications like direct in-source laser spectroscopy addressing hyperfine structure and isotope shift investigations as well as isomer selection a further considerable reduction of the experimental line width is required. This is achieved by utilization of a second, thick etalon within the laser resonator implying simultaneous control. The resulting laser line width well below 1 GHz expands the applications of this solid state laser system and enhances generation of higher harmonics to access the blue and ultra-violet spectral range. The operation principle, wavelength selection, line width reduction and automated wavelength control of the dual-etalon laser are discussed in this presentation. The actual performance at Mainz as well as at the CERN ISOLDE/RILIS is analyzed and the steps towards a reliably tunable, fully automated narrow band width Ti:sapphire laser are given.

Generation of electron beams with superconducting photoinjectors

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The production of beams with low emittance as well as high average current is one of the key techniques for future electron accelerators and next generation light sources. The superconducting radio-frequency photo electron source (SRF gun) has the potential to fulfill the requirements for these new accelerators. The presentation will give an introduction and overview of this type of modern electron injector. The main issues such as niobium cavity design and fabrication, cryomodule, radio-frequency system, photocathodes, and drive laser will be discussed. The status of the various R&D project for SRF guns will be presented, and a comparison to alternative high-current injector concepts like DC photo guns and low-frequency, normal-conducting RF guns will be given.

Photoemission studies of Copper

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Breakdowns in high-gradient RF cavities, as used e.g. in the CLIC project, are a major limit of the cavity performance. A new approach to explain these breakdowns based on a locally varying work function has been investigated at the CERN photoemission laboratory. The response of copper photocathodes to different wave lengths has been measured and compared with the data measured in a similar facility. An explanation of the difference between the two data sets will be proposed and further measurement steps outlined.

Time-of-flight technique for RILIS selectivity improvement

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In a resonance ionization laser ion source (RILIS) lasers produce ions in a time equal to the laser pulse width about 10 ns. In principal, the width of extracted from the RILIS cavity ion bunches can be the same order as the laser pulse width. Then, the RILIS selectivity could be significantly increased with a gating technique as many as the ratio of the laser pulse-repetition interval to the laser pulse width. It is reasonable to expect that the RILIS selectivity may be as much as 10^4 with high repetition rate lasers (10^4 pps).

This report discusses the possibility of the creation a single- or dual-stage time-of-flight system makes possible the compression of ion pulses in the region between the target and the extraction electrode.

In addition, the preliminary results will be presented for testing of a hot graphite cavity, in which laser ionization occur, operating at the voltage about 40 V. At these extraction voltage small width ion bunches can be created and yet the mass-separator resolution will not reduced by the ions kinetic energy distribution.

High Purity Radioactive Ion Beam (RIB) Production at ISOLDE by the Laser Ion Source and Trap (LIST)

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ISOLDE, the radioactive ion beam (RIB) facility at CERN, takes a top position among the world´s leading isotope production plants, allowing for all kinds of investigations on exotic nuclides far off the valley of β-stability. Most of these experiments require highest ion beam purity in respect to isobaric beam contaminations as well as contributions from neighboring isotopes. On the other hand a high production yield as well as ionization probability for the isotope of choice is crucial, even when dealing with isotopes of shortest half-life. Both conditions are most perfectly met by using the selective ionization method of the well-established resonant ionization laser ion source (RILIS) which ensures considerable ionization efficiency for the element of interest and, in theory, only for that. In addition to existentially supporting user experiments the ISOLDE RILIS meanwhile has become an independent research unit for laser spectroscopic studies and isomer selection. However, under real working conditions, also the RILIS technology does not eliminate all disturbing contaminants in the RIB, stemming from surface or thermal plasma processes within the hot ion source cavity. Hence, one specific upgrade of the ISOLDE RILIS concerned the introduction of the laser ion source and trap (LIST). It ensures unrivaled suppression of isobaric contaminations already within the ionization process by decoupling the atomization process on the hot ion source surfaces from the laser ionization region, which takes place inside a radiofrequency ion guide structure.

As has been demonstrated under realistic on-line conditions, the LIST suppresses isobaric contaminations by more than a factor of 1000 in respect to the conventional RILIS. However, the gain in ion beam purity is obtained at the expense of a reduced ionization efficiency, typically by about a factor of 20 to 50. Nevertheless, by running the LIST in one of the two possible modes of operation, i.e. the high purity LIST-mode or the high efficiency ion guide-mode without suppression, respectively, the best of both worlds can be chosen in accordance with the needs and a broad variety of investigations becomes feasible.

The principle of the LIST, the technical premises for the on-line operation at ISOLDE, which had to be met, and the necessary adaptations will be presented. These were based on methodic developments and investigations, as carried out off-line at the Mainz University RISIKO mass separator, as well as on the results from the on-line LIST runs 2011 and 2012. Rather similar activities are also under way at ISAC, TRIUMF, confirming the usefulness of the LIST ion source unit.

In-source laser spectroscopy of isotopes far from stability: new possibilities and results (ISOLDE, IRIS)

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Application of in-source laser spectroscopy for isotopic shifts and hyperfine structures investigations of the far from stability isotopes is discussed. New possibilities for such studies at ISOLDE (CERN) and IRIS (Gatchina) mass-separators are described. Preliminary results of the IS and hfs measurements for isotopes in the lead region (78<Z<86) are presented.

In-Source Photoionization Spectroscopy: Methods of data analysis

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The laser ion source is not only a very effective in its normal use as an element-selective tool for producing intense ion beams, but it can be used as a very powerful atomic-spectroscopy tool due to the resonance character of the photoionization (In-Source Laser Resonant Photoionization Spectroscopy). In contrast to other laser spectroscopic techniques, in that case the laser frequency scanning procedure is applied directly within the mass-separator ion source. The main advantage of this technique is its very high sensitivity, nevertheless its spectral resolution is Doppler-limited, therefore the accurate data analysis is of great importance.

The method of analysis of the data obtained in the recent In-Source Spectroscopy experiments at ISOLDE will be presented. This method incorporates different types of corrections for the obtained optical spectra and solving the rate equations for the given photoionization scheme to take into account the saturation of transitions, pumping processes between hyperfine structure (hfs) components and a population redistribution of the hfs levels.