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Status of ISL

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Abstract The Ion Beam Laboratory (ISL), operated by the Hahn-Meitner-Institut, Berlin, is exclusively dedicated to ion beam applications–technologies in materials science and medicine. ISL provides beams of light and heavy ions from various accelerators, and combinations of accelerators, with energies ranging from 10 eV to several 100 MeV. It operates various permanently installed target areas equipped with specific instruments for the different ion beam applications and fundamental ion solid state interaction research.

Key words accelerator operations • ion beam technologies

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Introduction

The Ion Beam Laboratory (ISL) is the Europe's only facility which is exclusively dedicated to fast ion applications in materials science and medicine. This scientific program puts specific goals to accelerator operations comprising the production of different ion species, their acceleration, and the delivery of specifically tailored beams in terms of ion intensity, time structure, stability, and spatial size of the irradiation area.

The needs of the users, the innovations in accelerator technology, and the prospective novel applications of ion beam technologies determine the development program for the instruments and accelerators. Main current activities are:

- the advancement and refinement of all the components of the ion sources, the accelerating structures, the beam transport and diagnostic systems,
- the innovation of the control and monitoring systems to maintain and enhance the efficiency and the reliability of the accelerator facility, and
- the construction of new irradiation areas both for basic research projects and direct ion beam applications.

The following paragraphs describe the current status of the facility in terms of operations and their developments.

Accelerator operations

An artistic view of the facility is shown in Fig. 1. Two injectors, a 5.5 MV single ended Van-de-Graaff with a 5 GHz ECR ion source on the high voltage terminal, and an RFQ-structure can alternatively inject beams into a separated sector cyclotron with a magnetic rigidity of

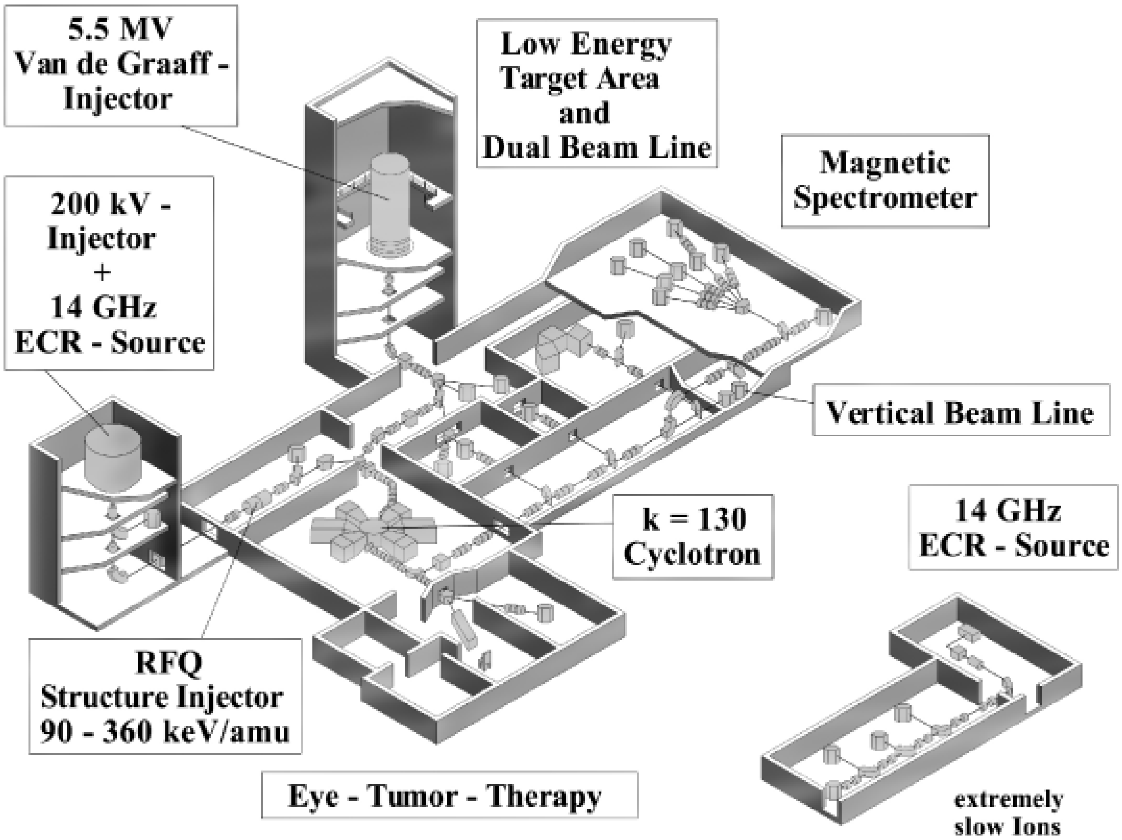

Fig. 1. Layout of the ISL facility. Two injectors, a 5.5 MV Van-de-Graaff and a variable frequency RFQ-structure can alternatively deliver ion beams to a $k = 132$ separated sector, variable frequency cyclotron. More than 15 target stations can be served. Three new target stations are being installed replacing former nuclear physics installations at the area seen at the upper right corner (see text).

$k \sim 132$. Both injectors contribute specifically to ion species and final energies available at ISL. The Van-de-Graaff delivers fast light ions, the RFQ-structure high currents of intermediate and heavy ions. Except for protons, Van-de-Graaff beams have to pass a gas or foil stripper to increase their charge states before injection into the cyclotron. For protons 72 MeV, for light ions with charge to mass ratios of ½, 32 MeV/A, where A is the atomic mass number, are the highest energies to be reached with the electrostatic injector. Ions accelerated by the RFQ-structure are fed directly into the cyclotron. A 14.5 GHz ECR source on a 200 kV high voltage injector platform is used to produce intermediate and heavy ions with charge to mass ratios between 1/8 and 1/5. These ratios amount to final energies between 1.5 and 6 MeV/A. Thus, both injectors are complementary to one another.

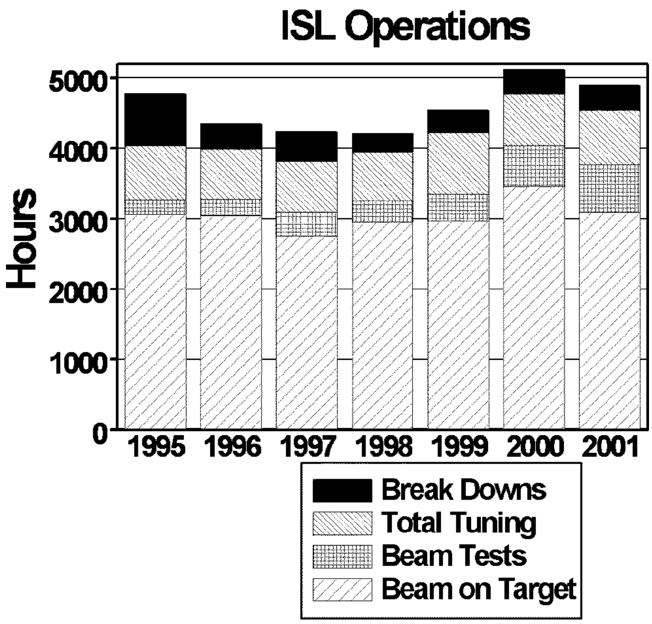

Fig. 2. ISL operations record. ISL has constantly produced about 3000 hours beam on target per year. The increased amount of time used for beam tests reflects the efforts dedicated to the development of high current, very stable heavy ion beams with the RFQ injector.

The accelerators are operated three weeks per month 24 hours per day. Long term service periods are foreseen twice a year. Running this schedule, we were able to produce about 3000 hours of beam on target per year including the development of new beams as seen in Fig. 2. The increased period of time expended on beam development over the last 3 years is attributed to detailed studies of the RFQ-structure described by W. Pelzer in another contribution to this meeting [2].

Though we try hard to reduce the total tuning times the success is not visible in the statistics. New and higher standards for the beam quality and quantity, such as ion current intensity and stability for the irradiation of polymer foils, beam stability for the proton therapy program, and the preparation of high intensity Au beams lead to longer tuning times. Unscheduled shutdowns stayed constantly below 10% of the scheduled beam time. It should be

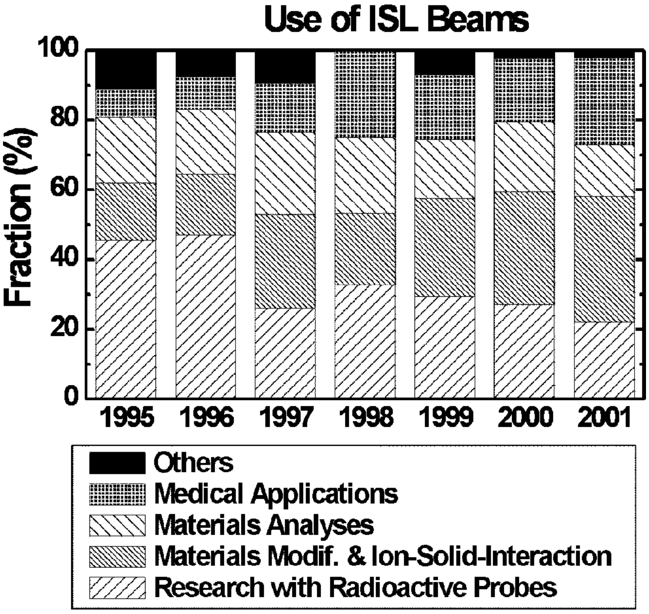

Fig. 3. Scientific activities at ISL. Materials modification, materials analyses, and eye tumor therapy have become the major scientific activities.

mentioned that during four years of operation only one of the 10 eye tumor therapy periods per year had to be postponed for a week due to machine breakdown. In total, about 300 patients have been treated since the start of the therapy program in July 1998.

The graph showing the share of beam time given to the different activities (see Fig. 3) demonstrate a clear trend: medical applications, materials analyses, and materials modifications have become the three main topics. Details of the program can be found in A. Denker's contribution to this conference [1]. The concentration of the activities to these topics is also demonstrated when looking at the ions produced as shown in Fig. 4 where the hours of beam on target depending on ion mass are compared for the last two years. Protons and very heavy masses such as Kr, Xe, and Au are the most demanded ion species. Since we were able to deliver Au beams this has become the most favored beam.

Accelerator and instrument developments

Ion source developments and the control system upgrade have been and still are the main objectives of the R&D program over the last two years. In addition, several new target stations are being installed.

Ion source and beam development

To achieve stable beams of Kr, Xe, and Au ions, the ion source set-up has been rebuilt completely: We installed the latest version of the 14.5 GHz all permanent magnet ECR Source – Supernanogan (delivered by PANTECHNIK S.A. Caen, France) developed a new and fast reacting gas feed, improved the extraction geometry and the vacuum at extraction, and exchanged the analyzing magnet. Main results up to now are very stable Kr and Xe beam up to q/A of 1/5, with currents higher than 4 μA within an emittance smaller than 100 mm mrad after 15 kV extraction from the source. For Au beams we got more than 2 μA for charge state 30 (see Fig. 5) allowing us to produce final energies higher than 600 MeV with currents on the target higher than 200 nA.

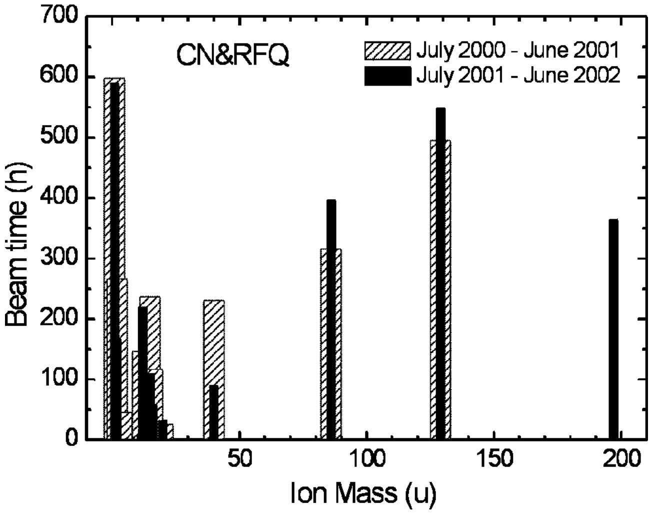

Fig. 4. Ion species run at ISL. The graph compares the ion beam production of the last two years of operation. A clear concentration to very light ions (protons for therapy and high energy PIXE) and to very heavy elements can be observed.

Control system

ISL's control system dates from the late 1970's and was originally designed for the HMI-VICKSI accelerator complex. It is based on a single server processor (PDP11), a CAMAC fieldbus, and software which was developed in-house.

The control system upgrade program has to keep the operating accelerator facility undisturbed. Our choice is

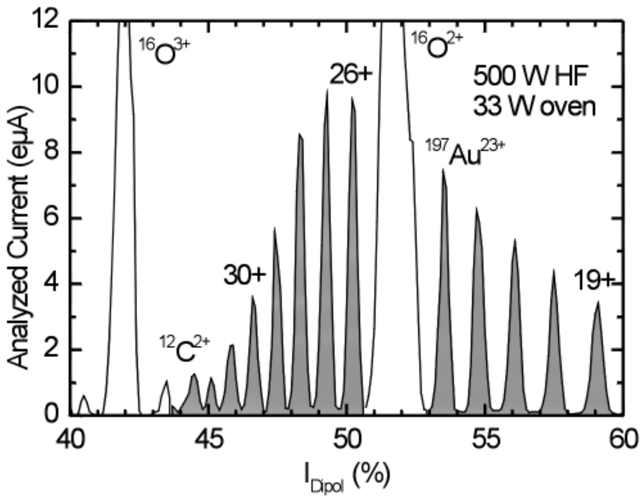

Fig. 5. Charge state spectrum of Au-ions. Since 2001 Au beams are offered in routine operations. The graph shows the beam currents *vs.* the magnetic field (current) of the analyzing magnet. The highest energy reached so far was 680 MeV with Au^{32+}.

the commercial system of VISTA Inc. In combination with real time CAMAC servers like real-time-VAX's and Linux-PC's, a transparent application program interface (API) programming is possible on multiple Operation-Systems-Platforms in a heterogeneous network. In the first upgrade phase, we have implemented graphic user interfaces (GUI's) for operators or machine physicists. Linux Application Servers were installed collecting and archiving machine data, generating 24 h trend charts, accessible on Internet, supporting WAP protocols, and sending alarm messages when requested.

New target areas

For the experimental program we received special funding for basic and applied research on ion tracks. This led to the design of three new target areas which are being installed at the upper floor of the experimental hall (see Fig. 1 upper right corner), where former nuclear physics installations have been removed. These new areas allow specifically:

1. The spectroscopy of electrons, in particular Auger electrons, emitted from atoms in the nuclear track. The special feature of this set-up is an electron spectrometer in an ultra-high-vacuum irradiation chamber where samples can be bombarded with an extremely well focused beam.
2. The *in-situ* analyses of irradiated samples using a four circle X-ray diffractometer. Here, structural changes of crystals or metallic glasses will be studied as a function of the applied irradiation dose of ions with different electronic energy losses.
3. Spectroscopy of neutral atoms emitted after heavy ion impact (sputtered atoms). This will be achieved by post-ionization of the neutrals by a powerful laser. In contrast to charged particle spectroscopy, the analyses of neutrals should provide a more direct access to the mechanisms involved in the energy equilibration process.

Future plans

Au and highly charged Xe beams have become the most frequently used beams at ISL. For these beams the total beam tuning times are determined by ion source tuning times. An additional ion source will increase the performance of the facility allowing the tuning of the beam in parallel to the running experiment. Hence, a second platform with a 14.5 GHz Supernanogan ECR ion source is being installed for the RFQ injector. In addition, another more powerful source with higher RF is foreseen in the long range plan.

In terms of experimental set-ups a medical test beam line is planned to be able to perform research and development for fast dose delivery and verification, avoiding interference with the standard therapy installation.

Conclusions

ISL has successfully managed to apply consequently and exclusively fast light and heavy ions for materials science and medicine. The requirements of the users differ a lot from demands of nuclear physicists in terms of ion species, ion intensities, beam current stability, beam delivery systems and beam diagnostics. This has been a challenge to accelerator operations and still is. In addition, many users need technical support from the laboratory since they are not familiar with ion beam production and ion beam handling. The success of the different research and development projects relies on the interdisciplinary cooperation of researchers from different fields. The accelerator scientists and technicians play an important role at these developments.

References

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2. Pelzer W (2003) Operation of the RFQ-injector at the ISL cyclotron. Nukleonika 48;S2:s25–s28