ISL-BERLIN, AN ION BEAM LABORATORY FOR APPLICATIONS

H. HOMEYER

Bereich Festkörperphysik, Hahn-Meitner-Institut Berlin
Glienicker Straße 100, D-14109 Berlin, Germany

The nuclear physics activities at the former accelerator facility VICKSI have been ceased. Within a 3-years program which began in 1993, the facility is being converted into an ion beam laboratory (Ionen-Strahl-Labor) for solid state physics and medical applications. The old CN-van de Graaff-injector has been improved by the installation of a small ECR-source. The tandem injector will be replaced by an RFQ linear accelerator. With the two injectors running separately or each in combination with the cyclotron, ISL offers ions with energies over a range of 5 orders of magnitude. A survey of the different activities using ion beams, such as basic research in solid state physics, materials analysis, and medical applications, - in particular the proton therapy project for intraocular melanomas - is presented.

1 Introduction: from VICKSI to ISL

The VICKSI-facility (**V**an de Graaff **I**sochron **C**yclotron **K**ombination für **S**chwere **I**onen) went into operation by the end of 1978. For more than 16 years it has produced light and heavy ion beams for nuclear physics. In 1984, a second injector, an 8 MV tandem, was installed which extended the range of ions and the maximum of available energies.

According to the recommendations of the scientific advisory committees in 1988 the nuclear physics program lost its funding and a shutdown of the whole facility was intended by the end of 1994. However, a rather substantial and continuously increasing amount of beam time of VICKSI had been given to solid state physics, especially nuclear solid state physics. Short-lived nuclear probes were used in order to investigate the interior of solid state samples on atomic scales. Though VICKSI had attracted most German users of this technique, this field alone was not strong enough to guarantee a survival of the facility.

By the end of 1991 another committee, reviewing the *„applications of nuclear methods with the special aspect of accelerators"*, proposed, among other recommendations, *„that existing accelerator laboratories should provide a broad spectrum of ion beams, a user-friendly instrumentation and an infrastructure for materials research and other applications"*[1]. Another important supporter showed up by the end of 1991: The ophthalmologists from the Benjamin Franklin Klinik of the Freie Universität Berlin asked if we could provide proton beams with energies higher than 65 MeV to be used for proton therapy of ocular melanomas.

With strong solid state physics groups on the site, the neutron scattering activities at the reactor, the solar energy research program, and the ophthalmologists at the close distance of less than 12 km, the Hahn-Meitner Institute was a favored place to establish an ion beam laboratory for applications - applications of ions in other fields than nuclear physics.

In 1993, the new facility **ISL** (Ionen-Strahl-Labor) Berlin was founded. It started officially January 1994. Within a 3-years program, the conversion of a nuclear physics oriented accelerator facility to an ion beam laboratory dedicated to materials research, solid state physics, and medical applications will be completed. In this contribution we present a survey on the main research activities and on the implications in the machine and the beam delivery system.

2 Improvements and the new equipment

Major efforts have been put into the machine development. The main tasks were improvements on ion sources and other accelerator components to potentially reduce the necessary manpower for maintenance and system handling.

Two years ago we implemented two new ECR-sources. The first one is BECRIS[2], a 5 GHz source, fully equipped with permanent magnets. This source replaced the axial penning source on the terminal of the 6 MV van de Graaff injector. With a maximum RF power of 160 W, the total power consumption of the source is less than 1 kW. This source, now in operation for more than two years, means a quantitative and qualitative improvement of the van-de-Graaff. Quantitatively, the currents for highly charged ions are substantially higher, ions we could never think of before such as $^{20}Ne^{5+}$, $^{40}Ar^{6+}$ or $^{129}Xe^{7+}$ are produced with sufficient intensities. Qualitatively, the source requires much less service and runs much more stable. In general, if there is the choice between a higher terminal voltage *or* a higher charge state to reach a certain injection energy, we can take the higher charge state. Thus, by decreasing the terminal voltage on the average, the risk of sparks is drastically reduced. Last but not least, the source delivers stable hydrogen beams without special adjustments as they were necessary for the old penning source.

The second ECR-source is a replica of the Ganil ECRIS4 14 GHz source. It has been set up at a different small accelerator complex with 3 target positions for highly charged ions at extremely low energies. The ions are extracted with a voltage of 15 kV from the source at ground potential. The whole beam transport line is mounted insulated from ground potential. Right in front of the sample chamber the ions are decelerated in two steps to energies of some ten eV (see fig.1)[3]. The transmission through the deceleration system is about 10 %. This source will also be the workbench for ion source development[4].

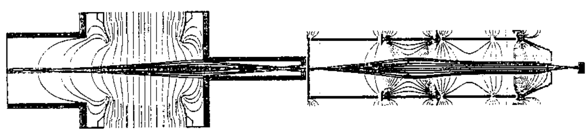

Figure 1: Deceleration system for extremely slow highly charged ions.

The ions are extracted from the source with 15 kV. In front of each of the three target positions the energy can be decreased in two steps. The first stage, a tube module of the Van de Graaff decelerates down to 1.5 kV. The second part, a 4-stage lens, allows a deceleration down to some 10 V. The transmission is about 10 %.

The most important innovation is the new RFQ injector for the cyclotron which is described in detail in another contribution to this conference[5] and ref. 6. It will replace the tandem injector. This replacement has two major issues: It should deliver ion beams with lower energies per mass unit and much higher currents than the tandem. In combination with the ECR source, the system should require considerably less maintenance.

Ions, energies and beams currents available at ISL are summarized in fig. 2. The stand alone ECRIS4 source covers another three orders of magnitude on the low energy side.

When operating in combination with the cyclotron the CN and the RFQ are complementary: The CN covers the light ions and high energies per mass unit, the RFQ the heavy masses and ion species which otherwise are very difficult to be produced in a pressurized tank on a high voltage terminal. As stand alone machines each of the injectors has its special features: The CN delivers beams with high stability and low energy spread. A change of the energy or the ion species is fast and easy. The RFQ is a high current machine, very convenient for high dose irradiation.

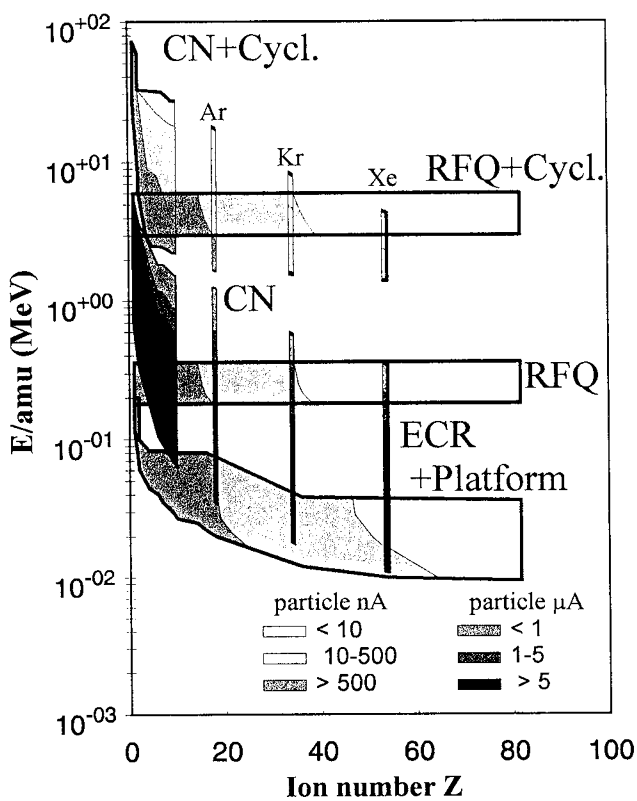

Figure 2: Ions and energies available at ISL.

With the two injectors running either as stand-alone machines or in combination with the cyclotron a broad range of ions and particle energies are offered at ISL.

3 Experimental area

The rearrangement of the target area has nearly been completed. The most important changes are: low energy beam lines at the van de Graaff injector, a cave for medical applications, and dual beam lines to bombard samples with low and high energy beams simultaneously. Figure 3 shows the new layout of the target area: The set up for proton therapy is under construction and should be finished by the middle of 1996, the two dual beam lines, position 7 and 8 will be ready in spring 1996, the RFQ will be delivered in summer 1996.

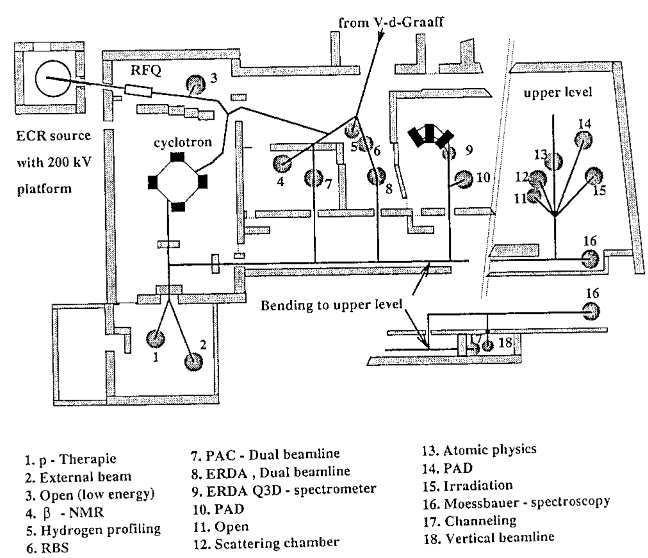

Figure 3: Main target hall.

Most of the target posititions are already installed. They are dedicated to specific experimental setups and open for outside users.

Table 1: Beam properties and experimental setups at the different target positions

Position	Name	Beam Properties and Special Equipment	Activity
1	Proton Therapy	spread-out homogeneous beam, exit foil, accurate beam intensity measurement at low doses	dosimetry, preparation of the therapeutical beam
2	External Beam	exit foil, spread out or well focused beam, single ion delivery	dosimetry, single event upset, irradiation
4	β-NMR	high intensity low energy beams, millisecond pulsing system	recoil implantation of ^{12}B produced via $^{11}B(d,p)^{12}B$
5	Hydrogen-Profiling	^{15}N-beam with low energy spread, computer-controlled fast energy variation in small steps, shielded big BGO detector	measurements of hydrogen contents in thin layers and interfaces
6	RBS	light and heavy ions for Rutherford Backscattering analysis	thickness and stoichiometry of thin layers
7, 10, 14	PAC/PAD	high intensity beams for nuclear probe production, fast wobbling system for homogeneous irradiation, PAD magnets (one of them superconducting), nanosecond pulsing	recoil implantation of short- (PAD) or long-lived (PAC) isotopes
8	ERDA	nanosecond pused beams of heavy ions	thickness and stoichiometry of thin layers, especially determination of light element
9	Q3D-magnetic spectrometer	pulsed heavy ion beams with exact emittance matching, high resolution magnet spectrometer with kinematic compensation	surface analysis
13	Atomic physics	large μ-metal shielded scattering chamber, window free gas target	electron spectrometry
5	Irradiation	homogeneous large area irradiation (wobbling system), temperature control, 4-900° K, of the samples during irradiation	irradiation of samples
16	Mößbauer-Spectroscopy	high intensity well focused pulsed beams (pulse width 1 ns, rep. rate 2 Mhz) Mößbauer drive	production and recoil implantation of excited ^{57}Fe ions
17	Channeling	very parallel beam of fast heavy ions	sample chamber with goniometer
18	Vertical Beam	well focused or spread out beams, exit through foils possible	irradiation of liquid samples, i.e. bacteria

The different target positions are more or less dedicated to experimental setups for specific ion beam applications. Table 1 summarizes more details than the names in figure 3. The survey of activities shows that besides a specific ion, the beam delivery system is very important for the different types of activities.

4 Scientific program

The research program covers a broad range of scientific topics in atomic, solid state, and applied physics.

In *atomic physics* the lowest and the highest energies available at ISL attract a great deal of interest. At the lowest energies the interaction of highly charged ions with surfaces is a new and exciting field of research. Experiments at ISL contribute to the understanding of the basic mechanisms taking place when highly charged ions approach a solid state surface. The idea of hollow atoms penetrating the solid has been corroborated in a recent experiment[7]. At the highest energy, the measurement of double-ionization cross sections allows to uncover the role of correlation in ion-atom collisions, one of the current hot topics in atomic physics[8].

Talking about the activities in *solid state physics* one has to bear in mind that the application of ions in this field is only one step of the experimental procedure. Sample preparation and characterization with alternative or complementary methods is equally essential.

Though ion implantation plays an important role in semiconductor technology many basic questions are open. The often neglected effects of high electronic energy losses can become very important and can lead to macroscopic changes of the material[9]. These results started a whole experimental program to study the importance of the contributions of the electronic and nuclear energy losses to defect formations in different materials. Apart from this more or less fundamental part of research heavy ions with high energy losses are used for the pinning of flux lines in high temperature superconductors or for the controlled modification of parts of electronic components.

In nuclear solid state physics heavy ion or proton beams of high energy are used to produce specific radioactive isotopes which are recoil implanted into different materials. The interaction of the radioactive nuclei with their electronic environment can be investigated with highly developed techniques. The electronic environment is determined by the local structure, the electronic charge density distribution. The study of the structure and of the mobility of defects in semiconductors[10] is one of the major tasks at ISL. A detailed description of the experimental methods and the different research activities can be found in ref. 11.

Last but not least, the analytical part of the ion beam applications should be mentioned. Since a couple of years the ^{15}N-beam of the Van de Graaff has been used to measure hydrogen contents and their distribution in all kinds of different samples. Examples are given in ref. 12.

The more or less standard RBS analysis is done on a regular basis. There is a big advantage to use a rather complex machine like the CN van de Graaff at ISL because the mass of the incident ion can be adjusted to the analytical problem, i. e. to the necessary resolution which depends on the composition of different elements on the sample. This part of the analysis will be extended. Energetic very heavy ions from the cyclotron will be used for the new ERDA (Elastic Recoil Detection Analysis) setup.

5 Medical applications

Due to the increase of the cyclotron D-voltage from 100 to 140 kV, protons can be accelerated up to 72 MeV, the limit given by the RF-system. This energy is high enough to treat uveal melanomas. The project to install a therapeutical proton beam started in 1992. It was finally funded in the beginning of 1995. This project will be realized together with ophthalmologists of the Benjamin Franklin Klinik at the Freie Universität Berlin. The treatment of the first patients is planned by the end of 1996. Together with the clinical program, some groups use protons and other energetic ions for dosimetry standards of charged particle beams.

6 Changes in Accelerator Operation

For the accelerator personnel things changed a great deal. Beam times are much shorter compared to the times when most of the activities were nuclear physics experiments. This means that much has to be done to reduce the time necessary for a beam change. We have tried hard on this problem during the last two years but the success is still marginal.

It is not just a stable beam that has to be produced. The beam delivery system is equally important. Reliable calculations for the different target areas are necessary and the beam diagnostic system has to be adapted. To give two examples: Dose monitoring via residual gas ionisation has been installed at places where the beam intensity on target can not be measured. At another area an emittance measurement has to demonstrate that the beam is correctly prepared.

7 Conclusions

ISL is in operation for nearly two years. Already by now, it has become evident that the decision to establish an ion beam laboratory for users other than nuclear physics was a step into the right direction. The request for beamtime at the first meetings of the Program Advisory Committee was a factor of two higher than what we could offer. There is an increasing demand of beamtime because many new users have learned how to make use of ion beams.

We observe, however, that many new users are not very familiar with accelerators and beam lines. Many things have been and still have to be learned to meet the new demands until the ISL facility really offers a user-friendly installation.

References

1. Bericht des adhoc Ausschusses des BMFT zur Anwendung kernphysikalischer Methoden 1990/91, 5 (1992)
2. P. Arndt, N. Golovanivski, H. Homeyer, M. Martin, *NIM* B **89**, 14-16 (1994).
3. B. Martin et al., Proc. 11th Int. Workshop on ECRIS, ed. A.G. Drentge, 188 (1993)
4. H. Waldmann, B. Martin, *NIM* B **98**, 532-535 (1995)
5. B. Martin et al., contribution to this conference
6. W. Pelzer, A. Schempp, *NIM* A **346**, 24-30 (1994)
7. R. Köhrbrück et al., *Phys. Rev.* A, Vol. **50**, No. 2-B, 1429-1434 (1994)
8. G. Schiwietz et al., *Europhys. Lett.* **27** (5). 341-346 (1994)
9. S. Klaumünzer, A. Gutzmann, *Nukleonika* **39,** 125-140, (1994)
10. R. Sielemann, L. Wende, and G. Weyer, *Phys. Rev. Lett.* Vol. **75**, No. 8, 1542-1545 (1995)
11 H.-E. Mahnke, *Nucl. Phys.* A **588**, 221c-228c (1995)
12. S. Blässer, J. Steiger, A. Weidinger, *NIM* B **85**, 24-27 (1994)