STATUS OF NEW ELECTRON CYCLOTRON RESONANCE ION SOURCES AT ITHEMBA LABS

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Abstract

iThemba Laboratory for Accelerator Based Sciences (iThemba LABS) is a multi-disciplinary accelerator facility. One of its main activities is the operation of a separated-sector cyclotron (SSC), which provides beams of various ion species at energies ranging from 5 to 220 MeV/amu. These beams are used for fundamental nuclear physics research in the intermediate energy region, radioisotope production and medical physics applications. During the last 16 years the heavy ion beams at iThemba LABS were produced in a 10 GHz Minimafios Electron Cyclotron Resonance Ion Source (ECRIS). In 2006 the decision was made that, due to the requirements of nuclear physics for new ion species and higher particle energies, a new 3rd generation ECRIS should be procured. Therefore a source, based on the design of the Grenoble Test Source (GTS), is under construction. It is a room temperature source that uses two microwave frequencies, 14.5 GHz and 18 GHz, to deliver highly-charged ions of sufficient intensity to be accelerated in the separated-sector cyclotron to energies in the GeV range. At the same time a 14.5 GHz ECRIS4 with its beam line elements that were designed and constructed by Grand Accelerator National d'Ions Lourds (GANIL) and originally built for the Hahn-Meitner-Institute (HMI) in Berlin was donated to iThemba LABS and has recently been installed. The status of the projects and future plans will be discussed.

INTRODUCTION

iThemba LABS is operated by the National Research Foundation (NRF) of South Africa. It provides accelerator and ancillary facilities for: research and training in the physical, biomedical and material sciences; treatment of cancer patients with energetic neutrons and protons and related research; production of radioisotopes and radiopharmaceuticals for use in nuclear medicine, industry and related research. At the heart of the iThemba LABS accelerator complex is the variable-energy, separated-sector cyclotron, which provides beams with a maximum energy of 200 MeV for protons. Beams are directed to vaults for the production of radioisotopes, proton and neutron therapy and nuclear physics experiments as shown in Fig. 1. Light ions, pre-accelerated in the first solid-pole injector cyclotron (SPC1) with a K-value of 8 are used for therapy and radioisotope production. For radioisotope production and neutron therapy a high-intensity 66 MeV proton beam is used, while a low-intensity 200 MeV beam is used for proton therapy. The second solid-pole injector cyclotron (SPC2) with a K-value of 10 is used for pre-acceleration of light and heavy ions as well as polarized protons from the two external sources shown in Fig. 2. With the 3:1 available RF frequency range and the different harmonic numbers that can be used, the particle energy of all three cyclotrons can be varied over a wide range for a large variety of ion species. Beams are delivered to the different user groups for 24 hours per day and seven days per week. The 66 MeV proton beam is available for radionuclide production and neutron therapy from Mondays until midday on Fridays. Patients are treated during daytime and between treatments the beam is switched to the radionuclide production vaults within seconds, and the intensity increased to 250 μA. During weekends a 200 MeV beam is used either for proton therapy or nuclear physics research using beams of light and heavy ions, as well as polarized protons [1, 2].

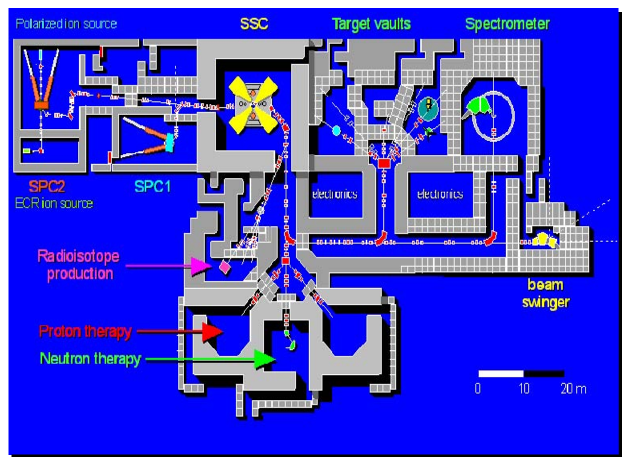

Figure 1: Layout of the accelerators at iThemba LABS.

ACCELERATORS AT ITHEMBA LABS

The Injector Cyclotron for Heavy Ions

The solid pole injector cyclotron SPC2 with a K-value of 10 has four radial magnet sectors and an extraction radius of 48.6 cm. Beams are accelerated with two 90º-dees operated at a maximum voltage of 60 kV. The RF-system can be tuned over the frequency range 8.6 MHz to 26 MHz with movable short-circuit plates in quarter-wave transmission lines. Harmonic numbers 2 and 6 are used. The beam is extracted with an electrostatic channel and two active and one passive magnetic channel. The ion sources are external and the beam is injected axially with three spiral inflectors corresponding to the three orbit geometries that are being used. At present heavy ions with mass numbers up to that of xenon are delivered by our

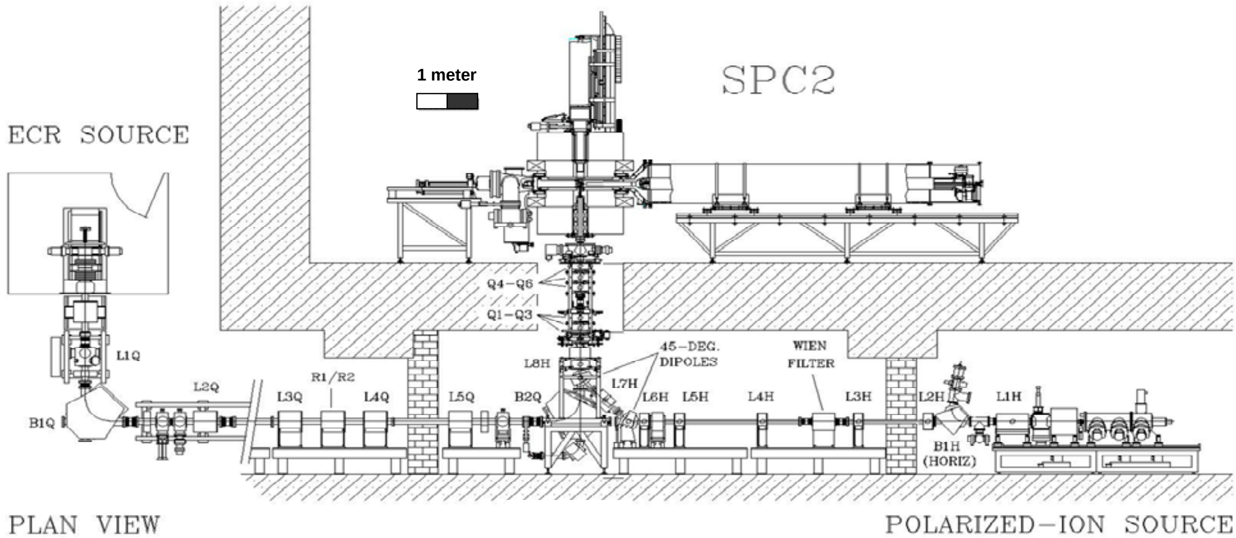

Figure 2: The beam lines that transport beams from the Minimafios and polarized proton ion source to the SPC2.

Minimafios ECRIS. Proton beams from an atomic beam polarized ion source are also accelerated with this injector cyclotron. Beams have been delivered since 1994 [3]. The position of the two sources and the beam lines towards SPC2 are shown in Fig. 2.

The Separated-Sector Cyclotron

The SSC has four separate magnet sectors with an overall diameter of 13 m with a sector angle of 34°. The RF-system consists of two vertical half-wave resonators that operate in the frequency range 7 MHz to 26 MHz. The maximum dee voltage is 220 kV at a power level of 80 kW per resonator [4]. The beam is inflected with two bending magnets and a magnetic inflection channel. Beam extraction is obtained with an electrostatic extraction channel and two septum magnets. A flat-topping system, operating at the third harmonic, has been installed in one of the valley vacuum chambers. Typically, the cyclotron delivers a 250 µA beam of 66 MeV protons for radioisotope production with 99.8% transmission through the machine.

The Minimafios Ion Source

A MINI Machine for Ion Stripping (Minimafios) Electron Cyclotron Resonance Ion Source (ECRIS) [5] was purchased in 1987 from the Centre d'Etudes Nucleaires (CEN) Saclay. This source operates at a RF frequency of 10 GHz with an RF power of up to 1 kW. Typical values for the injection and extraction coil currents are around 1000 A at 50 V to obtain a magnetic induction of approximately 0.8 T. The operating pressure varies for different ion species from 10^{-6} mbar to 10^{-5} mbar. Supporting gases like helium or oxygen are sometimes used. The extraction voltage applied to the source varies from 10 to 20 kV. For electron density enhancement a biased disc at -50 V is introduced to the injection side of the plasma chamber. Examples for beam currents in eµA (not necessarily optimized for intensity) obtained with the source are: up to 800 for H^+, 800 for He^{2+}, 18 for N^{5+}, 16 for O^{6+}, 40 for Ar^{8+}, 4 for Kr^{15+} and 3 for Xe^{22+}. Table 1 lists the beam energies for particle species which have been required by users and accelerated with the SSC, using the internal PIG (Penning or Philips Ion Gauge) source of SPC1 and the Minimafios ECR ion source of SPC2.

Table 1: Beams delivered at iThemba LABS.

Element	**Mass**	**Energy range (MeV)**	
		From	To
H	1	11.5	227
He	4	25	200
B	11	55	60
C	12	58	400
C	13	75	82
N	14	140	400
O	16	73	400
O	18	70	110
Ne	20	110	125
Ne	22	125	125
Al	27	150	349
Si	28	141	141
Cl	37	205	250
Ar	40	280	280
Zn	64	165	280
Kr	84	450	530
Kr	86	396	462
I	127	730	730
Xe	129	750	790
Xe	136	750	750

THE ECRIS4 SOURCE OF THE HAHN MEITNER INSTITUTE

This ECRIS4 with its beam line, shown in Fig. 3, that was originally built by GANIL for the Hahn Meitner Institute (HMI) [6, 7], was recently installed at iThemba LABS and linked up to the existing Q-line. This source consists of a water-cooled plasma chamber (length 18cm, diameter 7 cm) surrounded by FeNdB permanent magnets which produce a hexapole field of 1T (at the wall of the chamber) for radial plasma confinement. Two solenoid coils produce an axial field which confines the plasma axially. The field on the axis typically varies from 0.4 to 1.1 T. The microwave power is coupled into the source via a wave guide. The generator can deliver up to 2 kW of microwave power at a frequency of 14.5 GHz. The source is designed to operate with an oven and sputter target techniques, but was used in Berlin mainly for the beam production from noble gases, hydrogen and nitrogen. Typical values of intensities and charge states for argon are: 25, 6 and 3 eμA for Ar^{11+}, Ar^{13+}, and Ar^{14+} respectively. These values demonstrate the advantages of this source when compared with the existing ECR source at iThemba LABS. Not shown in the picture is the second diagnostic chamber which connects this beam line to the existing Q beam-line.

Figure 3: The Hahn-Meitner-Institute ECRIS4 source and the new beam-line, consisting of a solenoid, a diagnostic chamber and 90º-degree bending magnet.

Because of the different beam heights at iThemba LABS and the HMI a new support structure was designed and constructed. The source with its extraction system, the solenoid lens and the first diagnostic chamber are placed on it. The 90º bending magnet is mounted on a separate stand. The connection to the existing Q-beam line is done with the second diagnostic chamber and an Einzel lens which is positioned in the entrance of the bending magnet B1Q, shown in Fig. 2. The diagnostic chambers each contain horizontal and vertical pairs of slits and a Faraday cup. The ion source and all beam transport components are aligned, using an optical telescope system. The installation of the necessary infrastructure like water cooling, compressed air, and electrical connection is completed and the equipment is under vacuum. The additional AC power required to feed the power supplies is provided from a new transformer. First beam experiments are expected to take place in the beginning of 2009.

THE GTS ECRIS

The existing Minimafios will be replaced by this new modern room temperature source which is a replica of the CERN ion source that was built by the CEA in Grenoble [8, 9]. Various companies in Europe were involved in the construction of parts for the source. The source will be coupled to 14 GHz and 18 GHz microwave generators. Provision is made for two ovens. The axial field can be varied between 0.5 T and 1.2 T by means of three solenoid coils and the radial field has a value of 1.3 T using FeNdB permanent magnets. The source is expected to deliver a beam current of 60 eμA for Xe^{30+} ions. The coils, permanent magnets, all mechanical parts and the RF generators have been delivered.

The expected improvements in beam performance by means of the HMI [10] and GTS [11] sources in beam intensity, charge states and final particle energy (after acceleration with SPC2 and SSC) are listed in table 2 and compared with the experimental results obtained with the existing Minimafios for the examples of ^{40}Ar and ^{129}Xe.

Table 2: Expected beam currents, charge states and final particle energies for the HMI, GTS and Minimafios sources.

Ion Source	Element	Charge State	Beam Current eμA	Final Energy MeV
Minimafios	Ar	11	1	665
HMI	Ar	14	1.5	1078
GTS	Ar	17	4.2	1590
Minimafios	Xe	22	3.4	825
HMI	Xe	26	5	1153
GTS	Xe	37	5.4	2335

It is clear from the table that with the new sources, especially with respect to the achievable final energies, a new area of nuclear physics experiments at iThemba LABS will be possible.

NEW BEAM LINE LAYOUT

The two new sources are part of the infrastructure upgrade process at iThemba LABS. A schematic layout of how these sources will be connected to the injector cyclotron SPC2 via the existing Q-beam line is shown in Fig. 4. The beam extracted from the HMI ECRIS4 is focused with a solenoid of 0.2 m length and a maximum magnetic induction of 0.75 T into the position of a horizontal and vertical slit system in the front of the double focusing 90º bending magnet which has a rigidity of 0.1 Tm. The magnet focuses the beam at the second pair of slits in the second diagnostic chamber. The beam current can be measured before and behind the bending magnet. The beam then drifts to the entrance of the existing Q-line where it is focused by means of an electrostatic Einzel lens. This reduces the beam envelope during the drift to the first solenoid of the Q line.

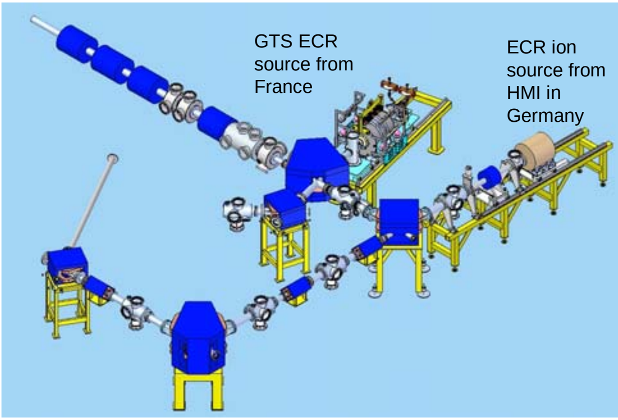

Figure 4: Low-energy beam lines connecting the two new ECR ion sources to SPC2.

The beam of the GTS ECRIS is focused by an Einzel lens and injected into the existing Q-line by a double focusing 104º bending magnet. This setup allows for simultaneous operation of both sources which is important for developing new ion beams from elements like lithium, vanadium, or calcium. When the GTS source is used to inject beam into SPC2 for nuclear physics experiments, the beam of the HMI source is stopped at the second Faraday cup before the 104º magnet. Alternatively, when the HMI source delivers beam the 104º magnet is switched off and the beam from the GTS source can be diagnosed in a diagnostic chamber after an additional 60º-bending magnet as shown in Fig. 4.

The beam line of the HMI source is insulated from ground potential and can be biased to a potential of -20 kV. This allows for experiments with very low energy ions as was demonstrated at the HMI for many years [12]. At a later date a similar beam line will be constructed. As shown in Fig. 4 this line will consist of two quadrupole magnets transporting the beam to a 90º-bending magnet, followed by another quadrupole magnet and a 60º bending magnet to focus the beam on the target. All components needed to build up this beam line are available.

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