

BEAM EXPERIMENTS WITH THE GRENOBLE TEST ELECTRON CYCLOTRON RESONANCE ION SOURCE AT ITHEMBA LABS

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Abstract

At iThemba Laboratory for Accelerator Based Sciences (iThemba LABS) a new electron cyclotron ion source (ECRIS) was installed and commissioned. This source is a copy of the Grenoble Test Source (GTS) for the production of highly charged ions. The source is similar to the GTS-LHC at CERN and named GTS2. A collaboration between the Accelerators and Beam Physics Group of CERN and the Accelerator and Engineering Department of iThemba LABS was proposed in which the development of high intensity Argon and Xenon beams is envisaged. In this paper we present beam experiments with the GTS2 at iThemba LABS, in which the results of CW, pulsed and afterglow operation are compared.

INTRODUCTION

iThemba LABS is administered 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 figure 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 three external sources [1]. In 2006 the decision was made that, due to the requirements of nuclear physics for new ion species and higher particle energies, a new ECRIS should be procured. A source, based on the design of the Grenoble Test Source (GTS) [2], which is similar to the GTS-LHC at CERN, has been constructed and installed. 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 that was designed and constructed by Grand Accelerator National d'Ions Lourds (GANIL) [3] and originally built for the Hahn-Meitner-Institute (HMI) in Berlin [4], with its beam line elements, was donated to iThemba LABS and is in operation since 2009.

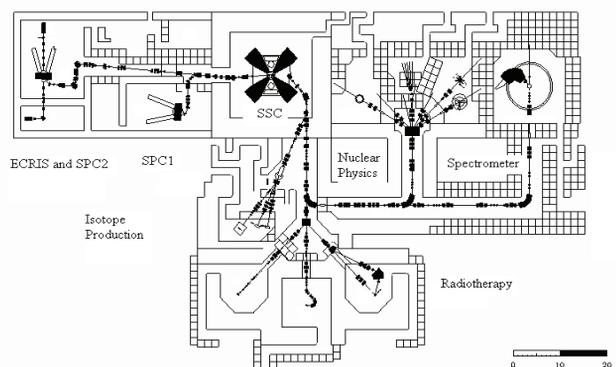


Figure 1: Layout of the iThemba LABS facility

The NA61 experiment at CERN studies the production of quark-gluon plasma. The light ion beam for the reaction is produced via the fragment method in which the primary lead beam hits a target which releases the secondary beam of lighter ion fragments. For experiments with heavier ions like Argon which are planned for 2014, a direct beam from the SPS is needed [5]. This beam is to be produced in the GTS-LHC and injected into LINAC3 which operates at a pulse length of 200 μ s with a maximum repetition frequency of 5 Hz. Direct injection into the RFQ requires $^{40}\text{Ar}^{11+}$ ions from the source with a source potential of 9.6 kV.

THE GTS2 ECRIS

The coils, the permanent magnet assembly, the plasma chamber and all mechanical parts of the GTS2 were manufactured by different companies in Europe, which were also involved in manufacturing the GTS-LHC. For the vacuum system of the source three 700l/s turbo pumps (one at injection and two at extraction), one 70l/s turbo pump for the oven system and two dry roughing pumps are used. The longitudinal magnetic field is produced by three coils, namely the injection-, centre-, and extraction coil. The power supplies for the injection- and extraction coil can deliver 1300 A at 60 V leading to a maximum B-field of 1.6 T. A 600 A bipolar power supply is connected

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to the centre coil. The permanent magnet array in the Halbach configuration produces 1.27 T at the plasma wall surface [6]. Two 2.3 kW micro wave generators operating at 14.5 and 18 GHz are connected to the source via WR62 wave guides. The active plasma chamber volume which is manufactured from Aluminium is 1430 cm³ at an active length of 30 cm and a diameter of 7.8 cm. The triode extraction system consists of a plasma electrode which is positioned at the end of the permanent magnet array in the plasma chamber, an intermediate electrode at a distance of 30 mm to the plasma electrode, and a ground electrode at 8 mm distance to the intermediate electrode. The aperture diameters of the electrodes are 12, 17, and 17 mm, respectively. The source can be operated with two resistive ovens which were not installed during the experiments. The bias disc (BD) has a surface of approximately 12 cm² and is positioned at 189 mm distance from the injection chamber exit flange which roughly corresponds to a position at the beginning of the permanent magnet array in the plasma chamber. Figure 2 shows a schematic of the source set-up.

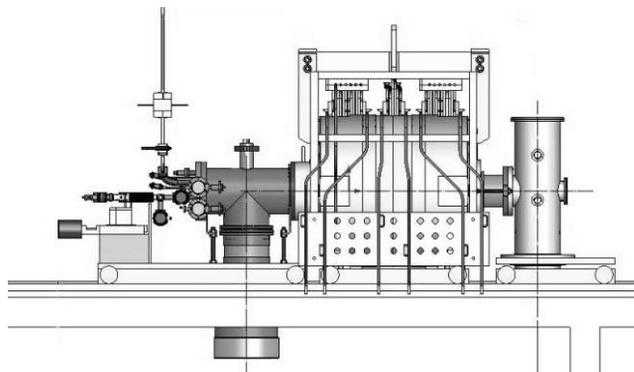


Figure 2: Schematic drawing of the set-up of the GTS2. On the left side the injection chamber with the micro wave guides, the oven feed through, and gas inlet systems are shown. The centre part contains the three coils for the generation of the longitudinal field. On the right side the extraction chamber concludes the set up.

The source is connected to the transfer beam line via a 104° bending-magnet. This set up of the beam lines in the ECRIS vault with the new diagnostic beam line for the GTS2 allows for simultaneously operation, i.e. the required beam for cyclotron acceleration will be delivered from one source, while the second source can be used for beam development. The diagnostic beam line of the GTS2 has an einzellens which focuses the beam on the double-focusing distance in front of the 90° magnet. Behind the magnet a horizontal slit is installed on the double-focusing distance to ensure sufficient mass resolution. The diagnostic line is completed with a chamber containing a slit-harp emittance device for both transversal planes and a Faraday cup. The set-up of the two sources in the ECR vault is shown in Fig. 3.

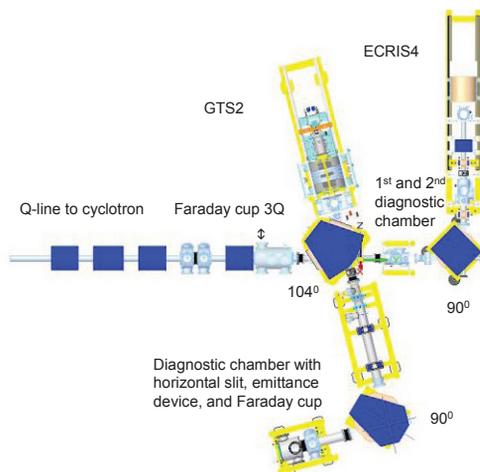


Figure 3: Layout of the beam lines in the ECR vault, in addition the position of Faraday cup 3Q is indicated.

ARGON BEAM MEASUREMENTS

After conditioning the source experiments in CW operation were performed which are important for the injection into the injector cyclotron SPC2. The Argon charge state spectrum was measured in the first Faraday cup (3Q) in the Q beam-line behind the 104° bending magnet (see Fig. 3).

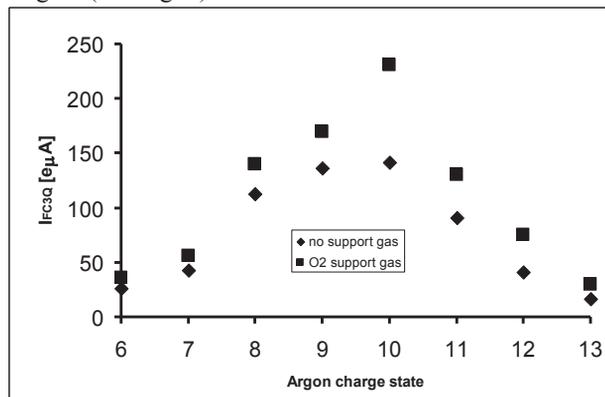


Figure 4: The Argon charge state distribution for CW operation with and without O₂ supporting gas. Note that the Ar¹⁰⁺ intensity includes O⁴⁺.

The source was optimized for charge state 11+ for all measurements. Fig. 4 shows the measured spectrum. Typical values of the source parameters are: Extraction voltage U_{ex}=9.6 kV, Intermediate electrode voltage U_{int}=-2 kV, Bias disc voltage U_{BD}=-200 V, Injection coil current I_{inj}=1100 A, Centre coil current I_{cen}=300 A, Extraction coil current I_{ext}=1050 A, and Argon gas flow F_{Ar}=1.1 ml/h producing a pressure at the injection side of the source of p_{inj}=2*10⁻⁷ mbar and at the extraction side of p_{ext}=3*10⁻⁷ mbar, 14.5 GHz RF power P_{RF}=500 W. A current of 90 eµA for Ar¹¹⁺ was obtained. The maximum of the distribution is around charge state 9+ to 10+. The figure shows further the influence of Oxygen supporting

gas (gas flow $F_{O_2}=1.5\text{cm}^3/\text{h}$). The intensity of the beam for the different charge states is increased by approximately 40 %.

In pulsed operation of the source (no supporting gas) with a duty cycle of 50% (50ms RF pulse on, 50ms RF pulse off) the current of the Ar^{11+} ions was slightly increased to 110 μA during the pulse compared to CW operation.

For the injection into the RFQ accelerator at CERN, pulses with a pulse length of only 200 μs at a maximum repetition frequency of 5Hz are required which can be produced from the source in the afterglow regime.

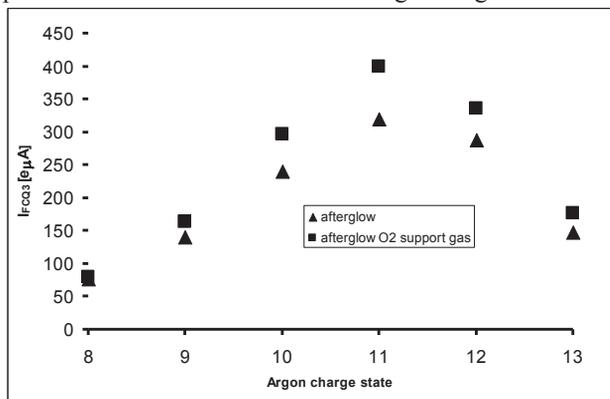


Figure 5: The Argon charge state distribution for afterglow operation. Compared are the results without and with Oxygen as supporting gas.

For the afterglow operation the plasma was generated with 50 % duty cycle (RF power 50 ms on, 50 ms off) for thermal stability reasons. The bias disc was pulsed with pulse lengths between 1 and 3 ms. The pulse were delayed with respect to the end of the RF pulse between -1 and +3 ms. The best results (pulses which are stable in intensity and repeatability) were obtained for a delay time of 0.5 ms and a pulse length of 1 ms (see Fig. 6). In this mode an intensity of 320 μA without supporting gas and 400 μA with Oxygen supporting gas was achieved. It is also clear from Fig. 5 that the maximum of the distribution is shifted to higher charge states compared to CW operation. The source parameters were chosen to ensure stable operation over several hours. Fig. 6 shows a picture taken from the oscilloscope for afterglow operation with Oxygen supporting gas. Traces 1 and 2 show the end of the RF pulse. Trace 4 shows the pulse for the bias disc switch (delay 0.5 ms, pulse length 1 ms) and trace 3 shows the Faraday cup signal measured across 1 k Ω . In this example the current amounts to 80 μA during the RF pulse. When the RF is switched off, the current increases linearly to 130 μA over 0.5 ms. At the instant the bias disc voltage is applied the current increases to 400 μA in 0.1 ms and stays constant during the bias disc pulse length. Experiments carried out without bias disc potential and with bias disc potential in DC operation resulted in much lower intensity compared to pulsed operation.

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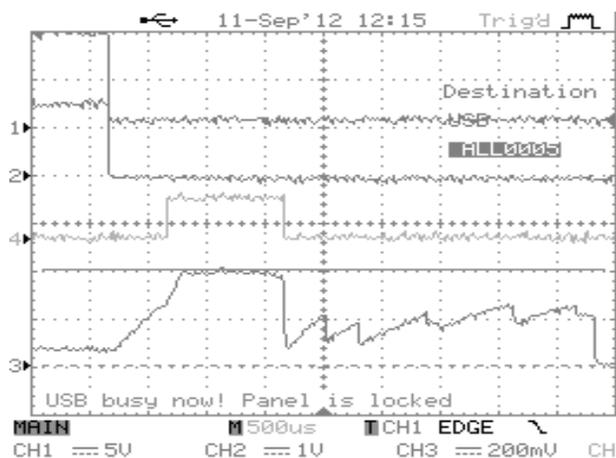


Figure 6: The oscilloscope signal for afterglow operation. Trace 1 shows the end of the RF trigger pulse. Trace 2 is the read back of the RF generator (1 V corresponds to 240 W). Trace 4 shows the pulse for the bias disc switch (delay 0.5 ms, pulse length 1 ms) and trace 3 shows the Faraday cup signal measured across 1 k Ω .

Experiments with Helium as supporting gas resulted in the same beam intensities for the different charge states, but the pulse stability was noticeably reduced.

Experiments using the new diagnostic beam line showed that the transmission decreases when compared to the transmission into the Q-line. This effect needs further investigation.

CONCLUSION

The experiments with the GTS2 show its capability to produce intense Ar^{11+} beams. The source parameter for stable beam generation in different operation modes could be determined and the influence of He and O_2 supporting gas was studied. The experiments will be continued to further optimize the source performance.

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