HIGH DUTY CYCLE ION SOURCES AT GSI AND FAIR

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Abstract

Future heavy ion experiments at GSI and FAIR demand for high current as well as highly brillant ion beams of various metallic and gaseous ions produced by the GSI accelerator facility. Therefore GSI's Ion Source Group is continously developing and operating various types of ion sources feeding the UNIversal Linear ACcelerator (UNILAC). In this contribution a status overview of operated high duty cycle ion sources including important ion source data as beam current and beam spectrum as well as future perspectives for the ion source operation for FAIR is presented.

INTRODUCTION

GSI Helmholtz Center for Heavy Ion Research is providing beams of almost every chemical element up to the heaviest stable ions like Uranium to users of the worldwide scientific community. Among others [1] two types of ion sources are dedicated for operation in the high duty cycle regime, namely the Penning Ionisation Gauge (PIG) placed at the high current injector and the Caprice-type Electron Cyclotron Resonance Ion Source (ECRIS) placed at the high charge state injector.

STATUS OF ION SOURCES

During the last years, apart from regular continuous operation of GSI's injectors, the performance of the high duty cycle ion sources has been improved. The operational results and improvements are shown in the following subsections.

Penning Ionisation Gauge - PIG

The PIG is in use for more than 30 years at GSI [2]. This type of source is the working horse especially for experiments carried out at the experimental hall of the UNILAC. Therefore the main feature is the 50 Hz operation with duty factors up to 25%. For the PIG a combination of extraction and post-acceleration is used in order to deliver the injection energy of 2.2 keV/u to the beam injected into the radio-frequency quadrupole (RFQ) for all available elements. The low energy beam transport line (LEBT) from post-acceleration towards the RFQ is about 10 m long and consist of several magnetic focussing quadrupole doublets and triplets, steerers, beam diagnostic stations (profile grids, faraday cups, beam transformators) as well as an analysing magnet for mass separation of multi-isotopic elements. Finally the beam is bend to the axis of the UNILAC via a 12.5 degrees magnetic switchyard, where also the high current beam is inclined to the linac.

The PIG is used for producing beams of gaseous as well as for metallic elements. Depending on experimentalists request development of new elements and isotopes has been done in the recent years. Most common and recent elements from the PIG source are shown in Tab. 1.

It is obvious that for metallic ions using a sputter electrode the lifetime of the source is normally not longer than a day with 25% duty cycle and reasonable currents whereas the sources with gaseous elements have lifetimes of more than just a few days. For the sputter as well as sources for gaseous elements a general refurbishment campaign is ongoing which is almost a general setup of a new source. 90% of the parts are replaced and only about 10% are carefully cleaned.

Table 1: Selections of ion beam species with corresponding beam currents in front of the RFQ.

Ion species	Intensity (eμA)	Ion species	Intensity (eμA)
$^{12}C^{+}$	300	$^{74}Ge^{4+}$	20
$^{12}C^{2+}$	60	$^{84}Kr^{3+}$	40
$^{12}C^{3+}$	73	$^{86}Kr^{2+}$	26
$^{20}Ne^{+}$	150	$^{86}Kr^{3+}$	200
$^{20}Ne^{3+}$	35	$^{92}Mo^{4+}$	5
$^{22}Ne^{+}$	200	$^{97}Mo^{4+}$	6
$^{40}Ar^{+}$	22	$^{98}Mo^{4+}$	3
$^{40}Ar^{2+}$	250	$^{124}Sn^{5+}$	8
$^{40}Ca^{+}$	80	$^{132}Xe^{5+}$	60
$^{40}Ca^{2+}$	100	$^{132}Xe^{6+}$	30
$^{40}Ca^{3+}$	50	$^{136}Xe^{3+}$	250
$^{46}Ti^{2+}$	20	$^{136}Xe^{4+}$	6
$^{50}Ti^{2+}$	70	$^{152}Sm^{3+}$	60
$^{51}V^{2+}$	55	$^{197}Au^{4+}$	500
$^{52}Cr^{2+}$	70	$^{197}Au^{7+}$	200
$^{56}Fe^{2+}$	200	$^{197}Au^{8+}$	20
$^{56}Fe^{3+}$	60	$^{208}Pb^{4+}$	100
$^{58}Ni^{2+}$	100	$^{208}Pb^{5+}$	10
$^{58}Ni^{3+}$	200	$^{208}Pb^{9+}$	20
$^{58}Ni^{4+}$	50	$^{209}Bi^{4+}$	200
$^{60}Ni^{2+}$	18	$^{209}Bi^{5+}$	300

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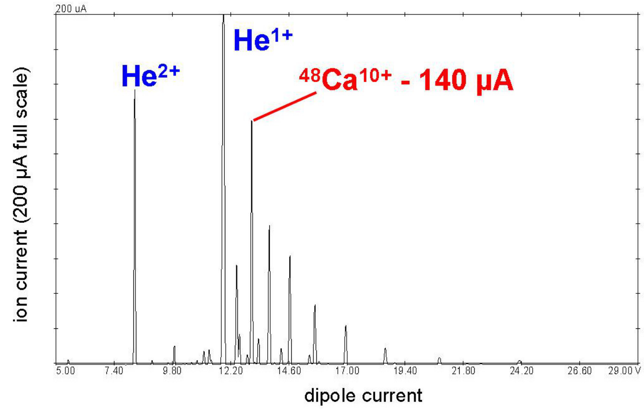
Electron Cyclotron Resonance Ion Source (ECRIS)

The High Charge State Injector (HLI) with its 14.5 GHz CAPRICE ECRIS had been established as an injection line for the UNILAC at GSI two decades ago. It has been in operation since then. The large number of experiments served with UNILAC beams require a great variety of highly charged ion species including isotopically enriched samples for ion beam production.

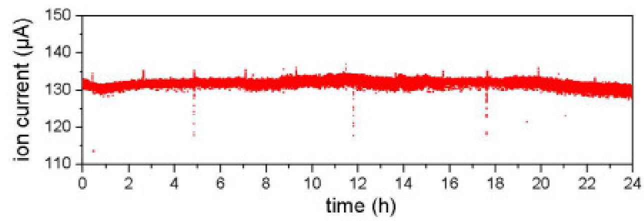
An ECRIS had been chosen as ion source for the HLI because it can work without limitation of duty cycle in CW mode as well as in different pulsed modes with enhanced intensities [3, 4]. In the ECRIS plasma long ion confinement times are possible so that very high charge states can be extracted. This makes post-acceleration avoidable and facilitates the direct injection into a compact linac consisting of an RFQ and an IH-structure. One major advantage of an ECRIS is the use of microwave injection to sustain and to heat the plasma electrons very effectively instead of using electron emitting filaments and arc discharge. So it can work over long time periods without maintenance. Furthermore ECRIS operation has a very low material consumption implying a high operation efficiency. Due to these characteristics the ECRIS turned out to be perfect for providing C^{2+}-beams for the cancer therapy project at GSI with good stability and high reliability. Patient treatment started in 1997 and initiated the concept for the dedicated Heidelberg Ion Beam Therapy Center (HIT), which took over the patient treatment in 2007.

While elements generated from gases or gaseous compounds can easily be transported into the plasma, materials in the solid state must be transformed into this state to be fed into the plasma. The method of thermal evaporation has been established and used at GSI for many years, because it resembles closely the operation with gases and provides higher intensities as the sputtering method and lower contaminations compared to the MIVOC method (Metal Ions from Volatile Organic Compounds). A sophisticated technology using resistively heated ovens was developed [5]. The effective thermal evaporation of metallic elements leads to long oven lifetime while the use of a load-lock system facilitates an easy maintenance for exchange or refilling of the oven and is perfectly adapted to the needs of long beam runs at the accelerator.

One of the frequently provided ion species is the rare isotope ^{48}Ca which is produced from highly enriched isotopic material. Fig. 1 show a charge state spectrum and the corresponding beam stability for ^{48}Ca, which is a good example for the efficiency of ion beam production. A low material consumption rate of 200 μg/h was observed for ^{48}Ca when optimized on 10+. Up to 43% of the evaporated ^{48}Ca could be analyzed behind the dipole magnet spectrometer as ions of the non-desired charge states 3+...11+ while 12.6% of the material could be provided as ion beam of the requested charge state 10+. While most of the solid elements are directly produced from the pure elemental material in some cases it is necessary to evaporate compounds as ZnO or SiO. These applications in most cases are the result of dedicated development work. As the increase of available ion beam intensities is one of the most desired goals several methods have been investigated like gas mixing, the use of electron-donors, or of biased probes at the injection side of the plasma chamber. The availability of wide range microwave generators based on travelling wave tube amplifiers made it possible to apply frequency tuning and multiple frequency heating of the ECR plasma. Thus it is possible to excite different RF mode distributions in the plasma chamber which can provide more efficient microwave coupling and therefore enhanced ion beam intensities extracted from the plasma [6].



(a) charge state spectrum



(b) intensity stability over 24 hours

Figure 1: Recorded data of ^{48}Ca. (a) charge state spectrum of ^{48}Ca + He optimized on $^{48}Ca^{10+}$, (b) intensity of the analyzed $^{48}Ca^{10+}$-beam versus time over a period of 24 hours.

ION SOURCE DEVELOPMENTS TORWARDS FAIR

For the high current injector respectively the PIG source first steps are already undertaken in order to increase the stability while extracting higher currents out of the plasma. Due to mechanical design of the source the distance between high voltage potential and the dipole vacuum chamber is only a few milimeters. Due to this fact regular sparking was occuring in this region. By replacing the safety covers at the top end of the anode with a large insulator,

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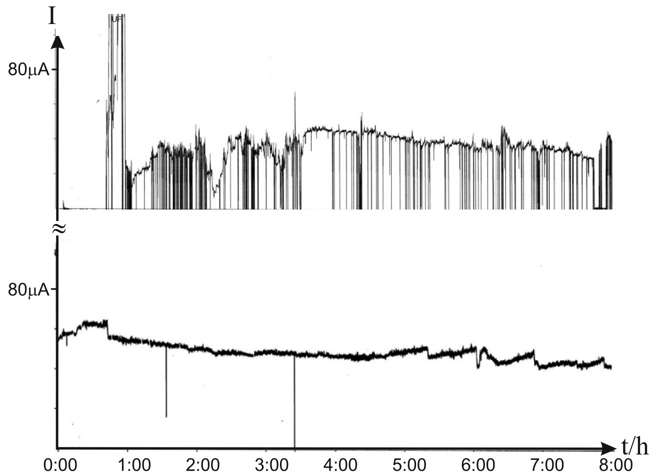

Figure 2: Top: Current vs. time plot without insulator, bottom: Current vs. time plot with insulator. Each vertical line in both graphs indicate at least one sparking event. Each plot represents a period of 8 hours.

it was possible to reduce sparking by orders of magnitude (see Fig. 2). The evaluation of remaining sparks is still ongoing. Also beam transport from the source towards the RFQ is going to be evaluated again in the near future. The long term perspective also includes an upgrade of the Penning ion source while preparing for GSI being an injector for the FAIR facility.

The requirements to ion beams for FAIR are characterized by highest beam intensities but at rather low duty cycles in pulsed operation with comparably short pulse lengths. Besides developments to expand the number of available ion species as ion beams and to improve the extraction from the ECRIS and low energy beam transport of the ion beams dedicated research will be performed towards the special requirements for FAIR. The main issue will be the optimization of pulsed modes based on investigations previously performed [4]. The pulsing is effectively achieved by modulating and switching the microwave generators by means of arbitrary waveform generators. Thus a synergy can be obtained with the optimization of the microwave-plasma coupling which is a further important issue as described above.

Multipurpose Superconducting ECR Ion Source (MS-ECRIS)

An increased microwave frequency allows for enhanced plasma densities and ion currents in an ECRIS. According to semiempirical scaling laws the electron density is directly related to the square of the microwave frequency. Considering the electron cyclotron resonance condition the increased microwave frequency requires an increase of the magnetic field. A useful frequency of 28 GHz requires magnetic flux densities above 2.2 T implying the use of superconducting magnets. In cooperation with European institutions GSI initiated a project to build a prototype of an

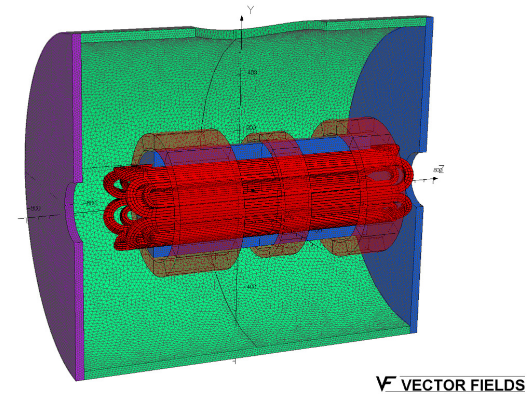

Figure 3: Model for the magnetic coil design.

advanced Multipurpose Superconducting ECR ion source (MS-ECRIS) to achieve a considerable improvement of the performances [7]. The most challenging issue is the very high level of magnetic field, so far never achieved for similar magnet systems. Therefore the realization of the magnet system for MS-ECRIS turned out to be very demanding. Its design utilizing iron collars requires a sophisticated clamping which has been subject to several modifications and is presently under investigation at the manufacturer's site [8].

CONCLUSION AND OUTLOOK

Since the FAIR project is demanding for higher intensities optimisation of the two high duty cycle injectors will be forced. First steps are already done and more of them will follow in the upcoming years. For the PIG source there is the goal of increasing extraction and transport efficiency to the RFQ, while after final tests of the magnet system production and assembly of the new MS-ECRIS will take place at GSI.

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