Ion Source Operation at GSI

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High Current Ion Sources

During the beamtime in 2016 a wide experimental program has been accomplished (realized) due to the parallel operation. High current ion sources from Terminal North (MUCIS and VARIS) and Penning ion sources from Terminal South were supplying the experiments with various types of ions. The following Table 1 gives an overview of the ion species, which were delivered for physics and accelerator development experiments. A representative value for delivered intensity to the linear accelerator UNILAC is the analysed beam current in front of the RFQ.

Table 1: Ion beam intensities generated with high current ion sources in 2016; filament driven volume type ion sources: MUCIS, vacuum arc ion sources: VARIS, Penning type ion sources PIG.

Ion species	**Duration (days)**	**Ion source**	**Beam for experiment**	**Analyzed intensity (emA)**
$^{15}CH_3^{+}$	18	MUCIS	UNI/SIS/ESR	2.4
$^{50}Ti^{2+}$	7	PIG	UNI	0.04
$^{124}Xe^{3+}$	19	MUCIS	SIS/ESR	2.6
$^{197}Au^{8+}$	23	PIG	UNI	0.07
$^{238}U^{4+}$	27	VARIS	UNI/SIS/ESR	16

The main requested ion species from the Penning Ion Source was gold $^{197}Au^{8+}$ for material research (UMAT) and for biophysics (UBIO) experiments. The PIG source was operated with high duty cycle (50 Hz / 3-4.5 ms) with the lifetime of approximately 24 hours during the beamtime.

One of the main highlights of the beamtime in 2016 was further performance optimization of VARIS ion source with multi aperture (7-holes, ø 4 mm) triode extraction system for $^{238}U^{4+}$ beam. A new record for the beam brilliance in front of the HSI-RFQ has been achieved. An intensity of 13.5 mA (90% from full beam) was obtained inside the beam emittance of 178π mm·mrad horizontally and 175π mm·mrad vertically. Measured beam emittances for both planes are shown in Fig.1. Emittance measurements have been performed in UH1-section. In combination with tuning of the UNILAC high current injector (HSI) and the pulsed gas stripper [1] during the machine experiment campaign that results in a new record intensity of 11.5 mA for U^{29+} beam in the post-stripper section (US4-section) [2].

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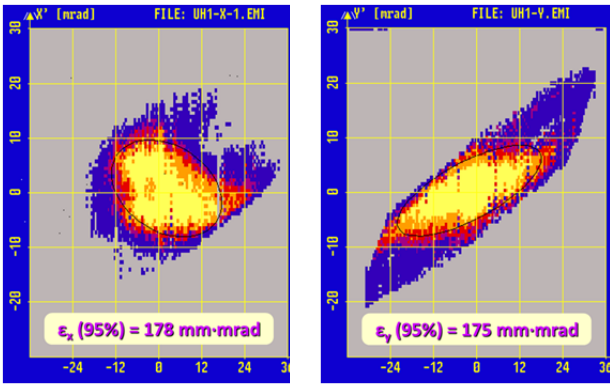

Figure 1: Measured emittances: horizontal (*left*) and vertical (*right*) of intense (15 mA) U^{4+} ion beam in front of the RFQ (UH1-section)

Another notable highlight is further development of molecular ion beams from Terminal North for production of intense proton and carbon beams behind the gas stripper [3]. A new separate gas-exhaust system for flammable gases has been developed and installed on terminal North. Due to this the production of CH_3^{+} molecular ion beam from MUCIS ion source using methane gas has been established as standard operation. The optimization of the operation mode and the ion source parameters results in notably increased lifetime of MUCIS with methane.

In the frame of following elaboration of higher duty cycle (2.7 Hz) uranium operation for FAIR the investigation of possible ways of thermal load reduction of cathodes as well as the concept of using U-W composite materials in the cathodes is ongoing. The first set of test cathodes with U-W(5% Wt.) and U-W(12% Wt.) alloys will be manufactured by AREVA company [4] and delivered in the nearest future to GSI for performance tests with VARIS ion source on terminal North.

In the frame of the program of development of the new projectiles for FAIR experiments seven elements (including four new metals) have been successfully tested in various operation modes on terminal North in 2016 [5].

The further renewing and development of the Penning ion sources is in process. The five sputter PIG sources are completely renewed and successfully put into operation during this beam time. For the gas operation the renewing of PIG sources has been started. The first gas PIG source is ready and will be tested in the new constructed PIG test bench. Also the optimization and performance tests of compact PIG ion source are ongoing on the dedicated new test bench. The first results with argon beams are obtained.

High Charge State Injector HLI

The CAPRICE ECR ion source (ECRIS) at the High Charge State Injector (HLI) experienced a major damage due to a lack of cooling during a test run at the end of 2015. In order to be prepared for the beam time of 2016 starting in April a big effort was made to reconstruct the ion source within the first quarter of the year. Due to the excessive temperature 3 of 6 coils of the ion source solenoids were destroyed, while the permanent magnet hexapole showed an intolerable decrease of magnetic remanence. Consequently these major components of the ion source had to be replaced. Fortunately most of the essential spare components were available for the required replacement. However, a complete disassembly of the ion source was inevitable and further components had to be refurbished or to be re-fabricated.

Table 1 shows the ion species delivered from the ECRIS during the regular beam time.

Table 1: Ion beam operation of the HLI-ECRIS in 2016

Ion species	**Auxiliary gas**	**Duration (days)**	**Analysed intensity (eµA)**
$^{3}He^{1+}$	He	12	500
$^{12}C^{2+}$	O_2	12	160
$^{40}Ar^{9+}$	O_2	19	100
$^{48}Ca^{10+}$	He	40	90-130

After the implementation of the CAPRICE-ECRIS at the HLI-LEBT a $^{40}Ar^{9+}$ ion beam was used for its recommissioning at the HLI before the first beam time period. Subsequently this ion beam was used for tests and experiments scheduled at the cw-LINAC demonstrator [6] at the local experimental area of the HLI working at beam energies of 1.4 MeV/amu. A second period of experiments at the cw-LINAC demonstrator with $^{40}Ar^{9+}$ followed at the end of the beam time block.

Several short periods of biophysics experiments in 2016 were provided with ion beams of $^{12}C^{2+}$, and of $^{3}He^{1+}$, respectively.

A major part of the beam time was occupied by $^{48}Ca^{10+}$ beam which was delivered to various experiments on Super Heavy Element (SHE) research which were performed at TASCA and at SHIPTRAP, respectively. Most of the time a typical ion beam intensity of 90 eµA was provided while maximum intensities of 130 eµA could be achieved. The consumption of ^{48}Ca sample material was as low as 130 µg/h (including material recycling) in the first run and about 440 µg/h (without material recycling) during the high intensity period.

While for most of the elements produced as ion beams from the ECRIS a stable equilibrium can be found for a favourable working point the situation can be more critical for the operation of ^{48}Ca. Occasionally the plasma is characterised by an unstable equilibrium but the response time for optimisation is very slow. For visual control purposes the plasma is continuously observed by means of a CCD camera equipped with a telephoto lens and looking through the straight beam line into the extraction aperture of the ion source which allows a close-up view of the plasma. Experiences obtained from ^{48}Ca beam times in the past years had shown that the colour of the plasma is mainly determined by the amount of Ca in the plasma. This is a critical parameter as it is correlated with the occurrence of instabilities. Moreover it could be verified that a change of colour already appears before an instability occurs. Therefore the monitoring of the colour could be helpful to anticipate instabilities early in order to intervene via re-optimisation. As the human eye is not capable to perceive small changes in colour the RGB values of the CCD-pixels are used. A small software tool has been set up which monitors the averaged RGB values of an area in the image which can be set by the software tool (yellow area in Figure 1a). A diagram visualises the trend of the RGB values over time (Figure 1b).

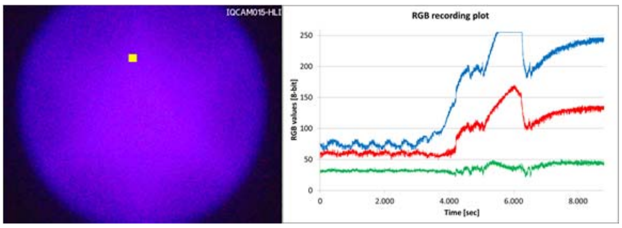

Figure 1: Camera image of the ^{48}Ca-plasma (a, left) and continuous RGB recording plot (b, right).

The application of this software tool during the last phase of the ^{48}Ca beam time showed promising results and turned out to be very helpful to simplify the optimisation of the ion beam.

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