Ion source operation at GSI

R. Hollinger, K. Tinschert*, A. Adonin*, R. Berezov*, D. Agahi, M. Brühl, M. Endermann, B. Gutermuth, F. Heymach, V. Ivanova, S. Jung, R. Lang, J. Mäder, F. Maimone, K. Ochs, P. T. Patchakui, M. Raupach, P. Schäffer, S. Schäffer, C. Vierheller, A. Wesp, S. Zulauf*
GSI, Darmstadt, Germany

High Current Ion Sources

The experimental program in 2015 has been focused on UNILAC experiments. The operation with high duty cycle (50 Hz) had the lion's share of a beam time. 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 current in front of the RFQ.

Table 1: Ion beam intensities generated with high current ion sources in 2015; filament driven volume type ion sources: MUCIS, Vacuum arc ion sources: VARIS, Penning type ion sources: PIG

Ion species	Duration (days)	Ion source	Analyzed intensity (emA)
$^{12}CH_3^+$	7	MUCIS	2.5
$^{12}C_3H_7^+$	3	MUCIS	0.8
$^{50}Ti^{2+}$	4	PIG	0.04
$^{197}Au^{8+}$	34	PIG	0.07
$^{209}Bi^{4+}$	4	VARIS	6
$^{238}U^{4+}$	11	VARIS	14

Mostly gold ion beam (Penning Ion Source) from the high current injector (HSI) was requested in 2015. The $^{197}Au^{8+}$ beam was operated with high duty cycle (50 Hz / 3 ms) and was used for material research (UMAT) and for biophysics (UBIO) experiments. The lifetime of the PIG source during the beam time was approximately 24 hours.

One of the main highlights of 2015 was the further development of molecular ion beams from Terminal North for production of intense proton and carbon beams behind the gas stripper [1,2,3]. Several molecular substances including alkane gases and volatile liquids have been tested using different ion source setups. Various plasma chambers, extraction systems and electrical connections (different plasma potential) have been tried out in order to achieve the best ion source performance and the maximum yield of protons behind the gas stripper. The best results have been achieved with methane (CH_4) and isobutane (C_4H_{10}) gases, providing molecular ion species CH_3^+ and $C_3H_7^+$ correspondingly. On Fig.1 a rather complicated mass-spectrum of isobutane is shown. One could see that the distribution maximum lies on propyle molecules (C_3H_X). The beam intensity in front of the RFQ reached 2.5 mA for CH_3^+ and 0.8 mA for $C_3H_7^+$, respectively [1]. As the result, the new record intensities of up to 4.3 mA for protons as well as of up to 10 mA for $^{12}C^{6+}$ ions in the post-stripper section have been achieved [3].

* Corresponding authors

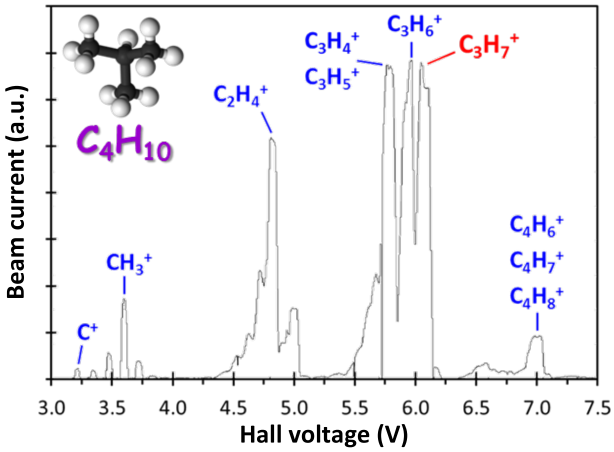

Figure 1: Mass spectrum of isobutane gas

Another notable highlight is the performance optimization of VARIS ion source with the new multi aperture (7-holes, ø 4 mm) extraction system for $^{238}U^{4+}$ beam. That results in combination with a pulsed gas stripper in a new record intensity for uranium in the post-stripper section (behind HSI) [5].

Further development of higher duty cycle (2.7 Hz) uranium operation for FAIR is ongoing. The new inductance free (L=0 H) resistances have been implemented into the discharge circuit of the ion sources at the Terminal North. That allows reducing the minimum operation pulse length of the VARIS ion source, which in turn reduces the thermal load on the cathode and generally could improve the ion source performance with duty cycles higher than 1 Hz. Also the concept of using U-W composite materials in the cathodes to increase the operation duty cycle for uranium is going to be proved. The recent investigations of the AREVA company have shown the possibility of manufacturing U-W(5% Wt.) and U-W(10% Wt.) alloys.

The further renewing and development of the PIG sources is in process. The four sputter PIG sources were successfully put into the operation after complete renewing and another two ion sources will be ready for the next beam time in 2016.

The construction of the new test bench for further investigation and development of compact PIG ion source is finished. The first test with Argon beam has been already performed. As a next step it is planned to measure

DOI:10.15120/GR-2016-1

the current performance, the lifetime and the beam emittance.

High Charge State Injector HLI

The CAPRICE ECR ion source (ECRIS) at the High Charge State Injector (HLI) delivered the ion species listed in table 2 for various physics experiments in the regular beam time schedule as well as for dedicated ion beam development.

Table 2: Ion beam operation of the HLI-ECRIS in 2015; additional time for ion beam development in brackets.

Ion species	Auxiliary gas	Duration (days)	Analyzed intensity (eμA)
$^{3}He^{1+}$	He	2	320
$^{12}C^{2+}$	He	10	60
$^{40}Ar^{7+,8+,9+}$	He	15	30-140
$^{48}Ca^{10+}$	He	72	90
$^{84}Kr^{13+}$	O_2	7	30
($^{84}Kr^{6+...19+}$	O_2	1	2-33)

A $^{40}Ar^{7+}$ ion beam was used for machine commissioning at the HLI at the beginning of the beam time period. Subsequently this ion beam was used for two experiments scheduled at the local experimental area at the HLI working at beam energies of 1.4 MeV/amu. First emittance measurements as preparation for the commissioning of a prototype device of the cw-LINAC were performed followed by investigations on emittance transfer. In addition further charge states of Ar ($^{40}Ar^{8+}$,$^{40}Ar^{9+}$) were requested from the experiments for comparative measurements.

Several short periods of biophysics experiments in 2015 were provided with ion beams of $^{12}C^{2+}$, and of $^{3}He^{1+}$, respectively.

Two-thirds of the complete beam time were covered by $^{48}Ca^{10+}$ beam and were dedicated to various experiments on Super Heavy Element (SHE) research mainly performing experiments on the chemistry of element 114 at TASCA and on laser spectroscopy of Nobelium at SHIPTRAP, respectively. Two corresponding long $^{48}Ca^{10+}$ runs were characterized by good beam stability and the typical low material consumption of ^{48}Ca sample material.

After the implementation of new TWTA-based microwave transmitters as upgrade measure in the last year [6] this equipment was utilized during a part of the $^{48}Ca^{10+}$ beam time and during the $^{84}Kr^{13+}$ beam time, which had been requested as further ion beam for the experiments on emittance transfer at the local experimental area at the HLI.

This operation opened the opportunity to perform further investigations on microwave frequency tuning at the CAPRICE ECRIS under operating conditions using the ^{84}Kr ion beam with its broad charge state distribution. In fact by tuning the microwave frequency to 14.464 GHz up to 40% more current of $^{84}Kr^{13+}$ was provided at the entrance of the RFQ with respect to 14.5 GHz, the normal operating frequency. The charge state distributions shown in figure 1 confirm that the frequency tuning can be used for operating conditions with the aim to increase the intensity of higher charge states (i.e. $^{84}Kr^{n+}$ with n>11). At the operating frequency of 14.444 GHz the highest intensity of the highest detected charge state, $^{84}Kr^{19+}$, was measured and a current gain of 16 times was obtained with respect to the normal operating frequency.

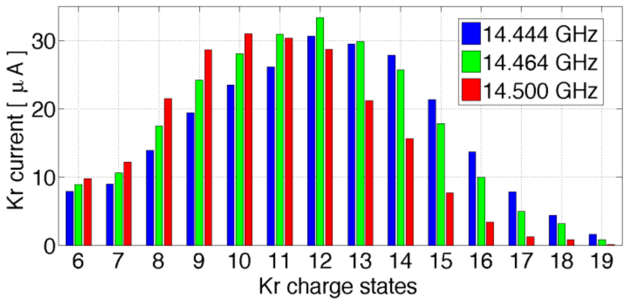

Figure 1: Charge spectra of ^{84}Kr with frequency tuning.

References

[1] A. Adonin, R. Hollinger, this report.
[2] W. Barth et al., Heavy ion linac as a high current proton beam injector, Phys.Rev.STAB, **18**, 050102 (2015).
[3] M. Heilmann et al., this report.
[4] W. Barth et al., U^{28+}-intensity record applying a H_2-gas stripper cell, Phys.Rev.STAB, **18**, 040101 (2015).
[5] W. Barth et al., this report.
[6] K. Tinschert et al., GSI Scientific Report 2013, GSI Report 2014-1 (2014) 302

DOI:10.15120/GR-2016-1