ION SOURCES FOR THE NEW HIGH CURRENT INJECTOR AT GSI

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The new high current injector at GSI will replace the existing prestripper accelerator of Wideröe type by a RFQ and an IH structure [1]. This new accelerator will increase the possible particle currents by 2 orders of magnitude. For the design ion Uranium, the particle current will be increased from presently 20 pμA (U^{10+}) to 4 pmA (U^{4+}). As ion sources for such high currents, a multi cusp ion source (for gases) or a vacuum arc ion source (for metals) are foreseen. The existing Penning ion source, which is well experienced for all elements of the periodic table, will be used in the future as well and has to be improved in current performance for this new operating regime. For these ion sources two 320 kV high voltage terminals are presently used.

1 HIGH CURRENT TERMINAL

The high current terminal will be equipped either with a MEVVA (Metal Vapor Vacuum Arc)[1] ion source (for metals) or with a MUCIS (Multi cusp ion source)[2] ion source (for gases). Because of the high current required from this terminal, we have to replace the existing 320 kV/20 mA high voltage power supply by a new power supply 130 kV/150 mA.

The ion sources are already in use with the existing Wideröe accelerator, however not with the full ion current available from these sources. We had several beam times, mainly for accelerator experiments, with the MUCIS ion source (Ne^{+}, Ar^{2+}, H_3^+, D_3^+) and the MEVVA ion source (Ni^{3+}, Mg^{+}, Mg^{2+}). Total ion currents extracted from the sources were in the order of 100 mA for all ions mentioned above. The preparations and tests of the MUCIS and MEVVA ion sources are performed at a special test bench. Beside the ion source power supplies, the test bench consists of a 8m long beam transport line with two quadrupole triplets, a dipole analyzing magnet and a number of ion beam diagnostic elements. Typical ion beam currents, charge state distributions (CSD) and signal to noise ratios (S/N) measured at the test bench are listed in table 1. The listed values of total current (I_{tot}) depend on the extraction voltage (U_{ex}) applied, and are measured values for ion source settings with minimized beam noise. The S/N ratios listed in the tables are defined by the averaged ion current S and the intensity fluctuations N during a typical beam pulse [repetition rate: 1/s, duration: 1ms]. The listed CSD are for standard ion source settings. For both ion sources it is possible to shift the CSD to lower or higher mean charge state, adjustment parameters are: additional gases, magnetic fields, discharge power.

Table 1: Ion currents from the MUCIS (gases) and from the MEVVA (metals) measured at the test bench.

spec.	I_{tot} /mA	CSD ion : fraction	S/N	U_{ex} /kV
H	≈60	H^+:0.4,H_2^+:0.1,H_3^+:0.5	≤50	10
D	≈60	D^+:0.4,D_2^+:0.1,D_3^+:0.5	≤50	10
Ne	≈50	Ne^+:0.9,Ne^{2+}:0.1	≤50	10
Ar	≈80	Ar^+:0.6,Ar^{2+}:0.3	≤50	25
N_2	≈80	N^+:0.8,N^{2+}:0.2	≤50	25
Mg	≈160	Mg^+:0.5,Mg^{2+}:0.5	≤20	25
Cu	≈100	Cu^+:0.2,Cu^{2+}:0.5	≤10	25
Au	≈80	Au^{2+}:0.4,Au^{3+}:0.5	≈10	25
U	≈80	U^{3+}:0.3,U^{4+}:0.4	≈10	25

During accelerator experiments, we experienced some problems in the transport of the ion beam,whenever the beam was not stable enough along the pulse.Especially we encountered that problem with the MEVVA ion source, whereas the beam transport to the RF structure seemed to be less critical with quiet beams as extracted from the MUCIS. Because the same extraction system was used at both sources, we conclude that the problem is not an emittance problem, but a question of space charge compensation of the beam, which is much more effectiv for quiet beams. Therefore, to reduce the noise of the MEVVA source to the level achieved for the MUCIS is our main development goal.

The higher noise level of the ion beam extracted from the MEVVA ion source compared to the noise level of the ion beam extracted from the MUCIS is strongly connected to the very different plasma generation process. Whereas the homogenious plasma of the MUCIS has its origin in a quiet gas discharge, the plasma of the MEVVA has its origin in a number of non-stationary cathode spots[3, 4]. Moreover the charge state distribution (CSD) of the ions produced in a specific spot scatter during the life time (several μs) of the spot[5]. A number of modifications have been applied to quiet the MEVVA plasma and to influence the CSD[6]. Although the ion beam noise is a principle problem caused by the MEVVA plasma generation process its significance is for some metals (e.g. Al, Cu, U) more pronounced than for others (e.g. Mg, Cr).

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It was possible to produce high intensity Mg^+ and Mg^{2+} ion beams with high stability and low noise comparable to the quality of MUCIS ion beams, whereas Al^+ and Al^{2+} ion beams were very noisy with the same MEVVA setup. Mg and Al have similiar values of ionization energies, electric properties, chemical properties and similiar melting points (Mg: 648°C, Al: 660°C). The vapor pressure of these two metals are very different at the melting point (Mg: ≈ 2 mbar Al: $\approx 10^{-8}$ mbar). The boiling point is 1090 °C for Mg, and 2467 °C for Al.

There are indications from our experiments that for metals used as cathodes in the MEVVA ion source, a lower vapor pressure at the melting point results in more noisy ion beams. In comparison to the pure metals, metaloxides have usually a higher melting point but their vapor pressure curves do not differ too much from the pure metal ones. Experiments have been performed with these pure metal cathodes of Mg, Al and Cu and additional gas flows of O_2 and Ar into the MEVVA. A sufficient gas flow was chosen to allow the cathodes surfaces to be covered by Ar or to be oxidized by oxygen in the time between two MEVVA shots (repetition rate 1/s, pulse width 1 ms).

A preliminary evaluation of the experimental data showed a general decrease in ion beam noise and a shift in the CSD to lower charge states. The latter is well known and results from charge exchange processes in the residual gas (O_2, Ar), additionally, the increased residual gas pressure enhances the space charge compensation in the beam line. It could be shown that in the case of Mg the metal surface could be modifiedby oxygen. The ion beam produced from the oxidized Mg cathode surfaceremained low noisy for about 100 MEVVA shots after switching off theoxygen gas flow, whereas the ion beam noise with Ar auxiliary gasincreased instantly after the disconnection of the Ar gas flow.This measurement showed that a less noisy ion beam could be produced by the use of the higher vapor pressure metal compound MgO compared to pure metal Mg.Presently experiments with U and UO_2 are under preparation.The melting points of U and UO_2 differ drastically(U: 1130 °C,UO_2: $\approx$ 2500 °C), their vapor pressure as functionof temperature behaves similiar. The electrical conductivity of UO_2 should be high enough to make it usable as a cathode in a MEVVA ion source. Measurements of the ion beam noise and ion beam CSD will be performed in the near future.

2 PENNING ION SOURCE TERMINAL

To provide with the PIG source the same beam quality for the new acclerator as for the still existing Wideröe accelerator two general problems have to be solved. First the beam line has to be adapted to the new injection energy of 2.2 keV/u instead of 11.6 keV/u. Second, to make use of the capability of the new injector to accept ions with a m/q-value (m: ion mass, q: ion charge state) of up to 65 instead of 24, one has to improve the already shown capability of the source to produce lower charge states [7].

In the existing beam line there is a multi gap structure for the electrostatic acceleration. Experiments at an energy as low as 2.2 keV/u with the multi gap structure had shown that the focusing strength is too small to transport the beam through the accelerating tube with sufficient efficiency. Therefore a moveable single gap was designed, installed and first tests have been made (see figure 1). The gap width can be varied from 50 mm up to 250 mm without breaking the vacuum. In addition a screening electrode has been installed shortly behind the ground electrode to preserve the space charge compensation of the beam on ground potential.

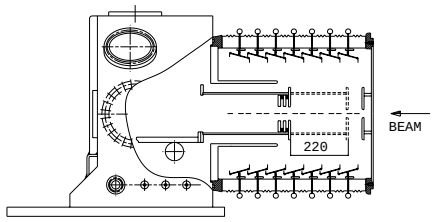

Figure 1: Sketch of the single gap structure. The most right electrode represents the high voltage potential. The moveable electrode is on ground potential. The inner diameter of the electrodes is 50 mm.

The high volatage stability of the movable single gap was tested to be very reliable. Without beam 100 % of the present available acceleration voltage (320 kV) could be applied without any breakdown. The tests with beam at the moveable single gap were carried out with Ar and Bi to have of sample of a light gas and of a heavy monoisotopic solid. For Ar^{2+} the current and emittances were measured for different gap widths. The Faraday cup (FC) and the emittance measurment device were installed about 1 m behind the single gap. The current measured in the FC behind the gap has shown a maximum value in dependence of the gap width (min. 0.9 mA max. 2.2 mA). However, it can be assumed, that this strong variation is just an optical effect (acceptance of the FC), because of the fact that losses in the order of 1 mA would create remarkable sparking in the accelerating tube. The dependence of the emittance from the gap width exhibited a not simple behaviour, created by the superposition of aberations, space charge effects and limitation by apertures. Therefore a final analysis cannot be done before a complete computer simulation is finished, which is in preparation. Furtheron Argon charge states Ar^+, Ar^{2+} and Ar^{3+} at the future injection energy (2.2 keV/u) of the new injector were compared. This showed the technical limits of the system for light ions. For Ar^{2+} the shortest possible gap width was the optimum. For Ar^{3+} the focusing was too small because of the large distance. The beam could not been focused any more. The problems for small m/q-values became obvious. Especially the splitting of extraction voltage U_{ex} and acceleration voltage U_{acc} gets difficult. On one hand one would like to increase the extraction voltage (to extract higher cur-

rents), on the other hand there is not enough voltage for the focusing any more. Further experiments were carried out with $Bi^{6+...9+}$ at optimized gap width (0.55 mA, 0.50 mA, 0.50 mA, 0.20 mA) and with Bi^{8+} with different gap widths (min. 0.25 mA, max. 0.50 mA) at the energy of 2.2 keV/u.

Almost all measured emittances of the above described experiments were within the acceptance of 140 $\pi\, mm\, mrad$ of the new RFQ-structure. Therefore, from the emittance point of view the RFQ should be accept the beam without losses. The use of the screening electrode increased the current in the FC by 5 to 10%. So we can state there is at least a partial space charge compensation. An optimization of the electrode diameters will be carried out in the beginning of the next year.

The maximum m/q-value of 65 for the new injector allows the use of lower charged ions (e.g. Bi^{4+} instead of Bi^{9+}). Therefore several experiments were carried out at the test bench. To apply high enough extraction voltages for the lower charge states the magnetic field had to be increased. The idea of changing the potential of the anti-cathode [8] (by connecting to the anode, by leaving it floating or by connecting via a resistor to cathode) to shift the CSD to lower charge states did not yield good results. With the anti-cathode on anode potential and with floating anti-cathode no ingnition at all was possible. A resistor of about 1 kΩ allowed to shift the maximum of the CSD to Bi^{4+}, but decreased the over all performance of the source. Under normal source conditions it was possible to produce a higher current of Bi^{4+}, but the maximum particle currents were observed for $Bi^{5+...7+}$ depending on the sputter gas used. Currents of about 120 pμA were measured for these ions with the standard extraction system about 1.5 m behind the source. For Au^{6+} 2 mA were measured, which corresponds to ealier measurements [9], in which 4 mA were measured with a by a factor of 2.6 enlarged extraction are. For optimized generation of charge states 5 to 7 of these ions a slightly increased source pressure was necessary. Under these conditions the source discharge was more quiet. Even at a repetition frequency as low as 1/s ignition was no problem with slightly increased heating.

To improve extractable ion currents from the source the increasing of the extraction voltage is one possibility. Because of the insulation distances in our vacuum chamber we are limited to 25 kV. Experiments with additional insulators yielded only small improvements [10]. Therefore we decided to develop an accel-decel extraction system. This gives the possibility to increase the extraction field strength without the necessity of increasing the high voltage at the source. In addition it will help to overcome the above described problem with light ions because it makes high extraction field strength at low beam energy possible. First experiments with a very simple accel-decel design were performed and showed good agreement with raytracing KOBRA3-INP [11] simulations. With +8 kV source potential and -6 kV at the accel electrode, similiar currents could be extracted as with 14 kV extraction voltage with the normal extraction system ($\approx$ 2.5 mA Ar^{2+}). Further development is focused on the cooling and the mechanical stability of the accel-decel extraction system.

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