The Gas Cell and Extraction RFQ for SHIPTRAP ◊

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1. Improved set-up of cell and RFQ

Based on tests with a first prototype setup [1], the design of the buffer gas stopping cell and the extraction RFQ for the SHIPTRAP facility at GSI [2] has been optimized. Special attention has been paid to be able to accept the full SHIP beam dimensions of about 50 x 30 mm^2, resulting in a significant enlargement of the actual setup.

The cell is designed to be able to stop heavy ions at energies between 10 keV/u and 500 keV/u in He gas pressures between 10 and 100 mbar. The lower energy limit is given by the availability of large area (60 mm diameter), pinhole free metallic (Al, Ti, Ni) and thin (< 2.5 μm) entrance windows. Since any impurities inside the cell drastically reduce the extraction efficiency via molecule formation and recombination, purity inside the cell is a prime prerequisite. UHV conditions ($< 10^{-9}$ mbar) have to be achieved by effective pumping, heating and the usage of only metallic and ceramic components. During operation it is necessary to use very clean gas (He 7.0) combined with an effective purification system (< 1 ppb).

For the transport of the stopped ions inside the SHIPTRAP gas cell (length: 330 mm, diameter: 250 mm) RF and DC fields are used to guide the ions towards the nozzle where they are extracted via the gas flow. In addition to the cylindrical DC electrodes a funnel shaped system of 40 ring electrodes is installed in front of the nozzle. The voltage applied on the funnel consists of both an RF (alternating by π) and a DC component to combine focussing and acceleration more efficiently.

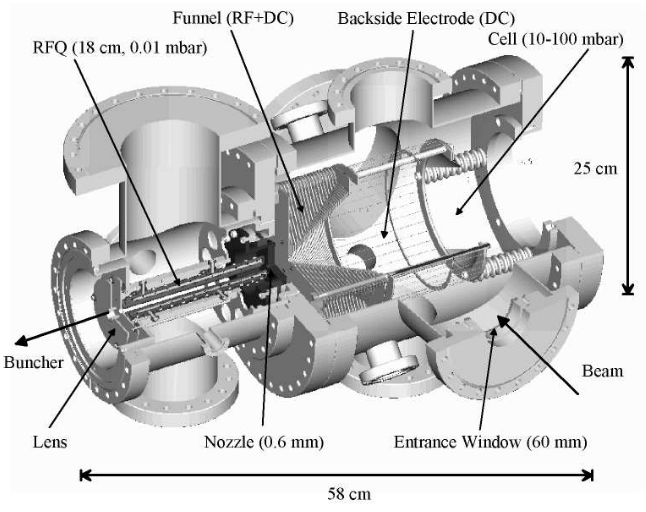

Fig. 1: The Munich part of SHIPTRAP with the buffer gas cell and the extraction RFQ connected by the nozzle. Inside the cell the RF/DC-funnel electrode and the DC back electrode are visible. The entrance window into the cell has a diameter of 60 mm (20 mm for the actual tests).

The nozzle has an inner diameter of 0.6 mm, where both sides of the nozzle throat have a conical shape that has been optimized with gasdynamical simulations (see also section 2) [2]. The convergent subsonic nozzle entrance was optimized to achieve gas velocities high enough to drag the ions through the nozzle, while the divergent nozzle exit was optimized to the transfer into the extraction RFQ as well as for the transversal cooling within the first RFQ segments.

In the segmented extraction RFQ the ions are separated from the neutral gas and cooled transversely for the following transfer into the buncher RFQ. Each rod of the extraction RFQ consists of 12 segments with a total length of 180 mm. The diameter of the rods is 11 mm with an aperture (diameter) of 10 mm.

2. Simulations

The new gas cell with the RF ion funnel inside have been investigated in detailed computer simulations with the codes VARJET [3] (gas dynamic simulations based on full time-dependent Navier-Stokes equations) and SIMION [4] (ion trajectory simulations in electric and magnetic fields). Some results of the buffer gas flow simulation are presented in Fig. 2. Taking into account that the gas velocities in the cell at large distances from the supersonic nozzle are negligible (about 1 cm/s) the calculations were made for the area which includes the last eleven RF funnel rings (out of 40) and the nozzle (see Fig. 2). The effect of considerable increasing of the gas velocity in the vicinity of the nozzle is clearly visible.

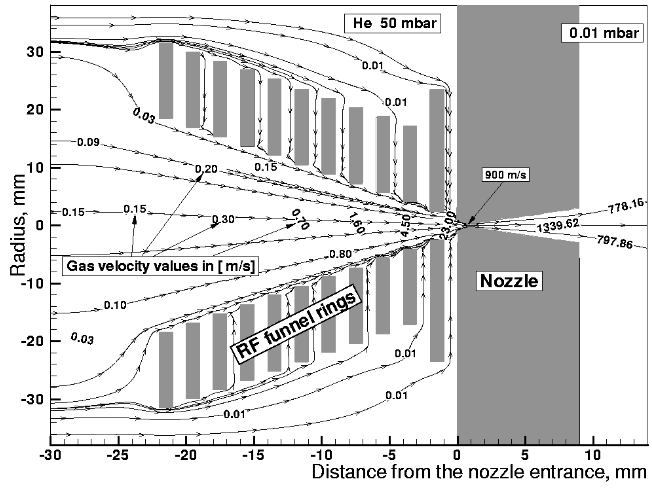

Fig. 2: Plot of the buffer gas velocity flow field in the exit region of the SHIPTRAP gas cell for He pressures of 50 mbar in the cell and 0.01 mbar in the extraction chamber. The arrowhead lines show the He gas streamlines and the numbers indicates the gas velocity values in m/s.

The results of this gas dynamic calculations (flow fields of gas velocity components and density) then have been used in SIMION simulations where the mobility of ions in the gas is used to simulate the effect of ion-atomic collisions as a frictional force. The results of SIMION simulations are presented in Fig. 3. Such simulations allow to get a realistic description of the ion transport through the cell under the combined action of gas dynamics and electric fields.

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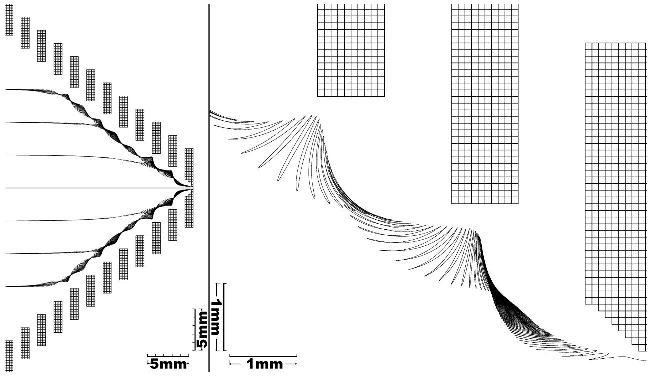

Fig. 3: Simulation for ion trajectories in the vicinity of the nozzle including electric fields and gas flow. The left picture shows the motion of several ions along the funnel plates towards the nozzle. On the right hand side the motion of one ion influenced by the RF field at 400 kHz is visible in an enlarged view.

3. Test setup and measurements

The Munich test setup allows both off-line and on-line tests. For off-line measurements the test ions can be produced inside the cell by a pulsed (25 - 50 Hz) Nd-YAG laser. A moveable lens makes it possible to vary the place of the ion creation. Tests were performed to optimize the extracting and guiding fields and for measurements of extraction times as a function of the gas pressure. The extraction times were measured between the laser pulse as start trigger and the ion detection signal as stopping signal. Besides the extraction characteristics the second main issue was the stopping behaviour of ion beams. This was studied using ion beams (Ag, Au, I) from the Tandem accelerator in Garching at different energies ramping from 0.6 to 0.8 MeV/u entering the gas cell through a 5.5 μm thick Ni entrance window.

In all cases the extracted ions are mass selectively detected with a QMS [5] and a subsequent MSP (Micro Sphere Plate) [6].

In first tests with laser induced Er ions measurements of extraction times at different He gas pressures and electric fields were performed. In Fig. 4 a spectrum of extracted masses is shown. Clearly visible are the peaks of the four most abundant mass-peaks of ^{166}Er, ^{167}Er, ^{168}Er and ^{170}Er with an indication of their natural abundances.

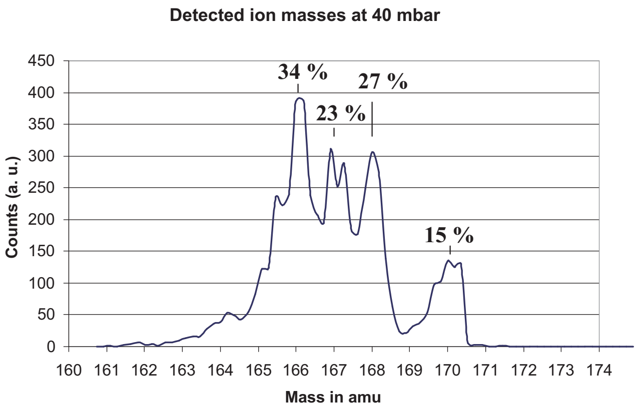

Fig. 4: Plot of detected ion masses at a He pressure of 40 mbar inside the cell. Clearly visible are the peaks of ^{166}Er, ^{167}Er, ^{168}Er and ^{170}Er. Indicated are the natural abundances of Er isotopes. The substructure in the mass-peaks is a measurement artefact of the QMS.

For these tests DC fields between 10 and 20 V/cm at the funnel and a voltage between 150 V and 360 V at the backside DC electrode were applied. The RF frequency inside the gas cell was set to 400 kHz at an amplitude of 170 V_{pp}. The ions were produced near the longitudinal axis in the region where the stopped ion cloud from accelerator measurements would be expected. The extraction RFQ was operated with an RF-voltage of 80 V_{pp} at a frequency of 800 kHz in addition to a 6V dragging ramp between the first and the last segment. Fig. 4 shows the measured extraction times as a function of the gas pressure at fields of 20 V/cm at the funnel and 180/280 V at the back side electrode. Typical extraction times between 3 and 5 ms could be achieved, thus easily matching the design specifications for SHIPTRAP applications

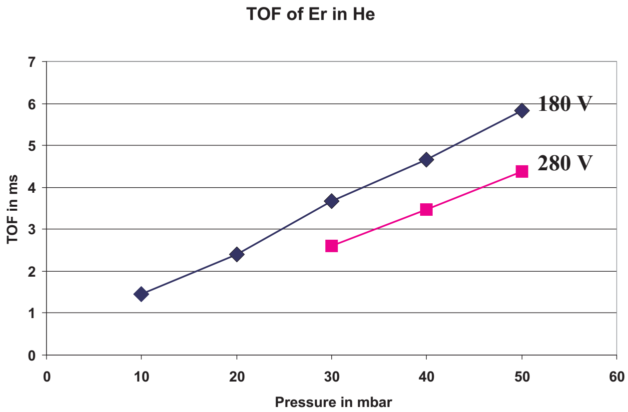

Fig. 5: Extraction times of laser induced Er ions in dependence of the He pressure at different DC voltages applied at the back side electrode.

Online tests at the Garching tandem accelerator with Ag beams succeeded in detecting the stopped and extracted beam ions, however, contamination contributions potentially from the entrance window foil will require further studies.

The gas cell/extraction RFQ combination was successfully operated in the first commissioning beam-time of the complete SHIPTRAP setup with a ^{40}Ca-beam. Further on- and off-line tests will focus on the optimization of the extraction efficiency and extraction time as well as on the characterization of the ion beam emittance after the extraction RFQ.

References

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