A Radio Frequency Ring Electrode Cooler for Low-Energy Heavy Ion Beams

S. Heinz, D. Habs, S. Hegewisch , A. Nieminen , M. Schumann , and J. Szerypo

The phase space cooling of low-energy (10 - 100 eV) ion beams can be performed by frictional forces while the ions interact with the atoms of a buffer gas. During the cooling process the ions have to be confined in transverse direction by oscillating electric fields. A conventional method for ion confinement is the application of Radio Frequency Quadrupoles [1] which generate an oscillating harmonic pseudo potential and operate in the typical pressure range of 0.01 - 0.1 mbar.
Presently we are investigating another concept for the ion confinement where the RFQ structure is replaced by a stack of thin Radio Frequency ring electrodes with varying inner diameters (RF funnel) surrounding the buffer gas volume. Other than with RFQs the potential created by the RF funnel is box shaped.

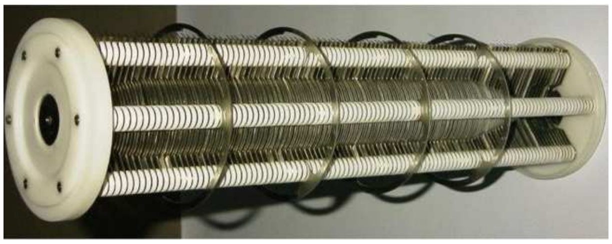

Fig. 1: Photo of the RF ring electrode cooler (RF funnel).

We have built a 450 mm long RF funnel cooler [2] which is composed of 223 single ring electrodes with a maximum inner diameter of 60 mm (Fig. 1). The thickness of each RF ring is 1 mm and the gap between adjacent electrodes is 1 mm as well. The construction is enclosed by a stainless steel cylinder which is designed with beam entrance and exit apertures. In its interior a Helium buffer gas pressure of about 0.2 mbar is kept for stopping and cooling the ions. Each electrode is supplied by an RF field at a frequency of 2.3 MHz and an amplitude of 100 V_{pp} while the phase difference between adjacent electrodes is π. The RF field generates an average repelling short-range force close to the electrode surfaces pointing toward the funnel axis and causing a reflection of the ions when they approach the electrodes. Additionally a DC electric field gradient of about 0.5 V/cm is applied along the funnel to compensate friction losses and to drag the ions toward the exit.

Following detailed Monte Carlo simulations we have carried through first experimental investigations on the RF funnel in June 2003 at the IGISOL facility in Jyväskylä (Finland) where we replaced the Jyväskylä double RFQ-cooler by our RF funnel. The transmission behavior of the funnel in dependence of the beam current was investigated with a beam of singly charged ^{129}Xe ions up to currents of 20 nA (this limit was given by the ion source). The obtained output current versus input current characteristics is shown in fig. 2.

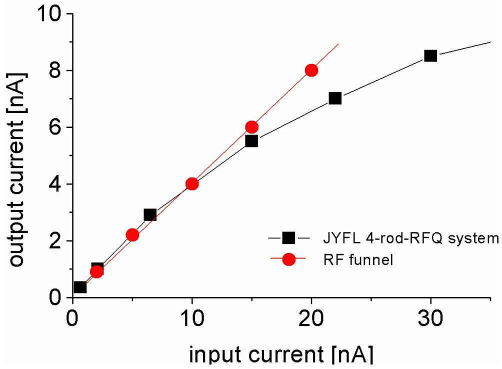

Fig. 2: Transmission characteristics of the RF funnel (dots) in comparison to the transmission behavior of the Jyväskylä RFQ cooler (black squares).

The dots correspond to the RF funnel while the black squares show the transmission behavior of the JYFL 4-rod-RFQ system measured with a ^{84}Kr beam in an earlier beam time. To obtain the real transmission values one has still to take into account a 30 % ion loss in the deceleration system in front of the cooler entrance. These losses are not included in fig. 2 but have been taken into account in the numbers given below.
For the RF funnel we found a very promising behavior of the transmission characteristics since the transmission of 65 % proofed to be independent of the beam intensity (I_{max} = 20 nA) over all the investigated range which revealed the applicability of the RF funnel as high-current cooler. This observation can on one hand be explained by the funnel electrode structure leading to a smooth focusing of the ion beam during the cooling process. On the other hand, the box shaped pseudo potential reduces ion losses due to field distortions which concerns especially particles on trajectories far off the cooler axis. Moreover, the RF funnel has a particular high solid angle acceptance at its entrance of 1.2 π which is a factor of 3 more than for the RFQ cooler.
In comparison, the transmission value of the IGISOL RFQ system is also about 65 % for input currents up to $\sim$ 10 nA. For higher currents, however, the curve is no longer linear but is approaching a saturation value which clearly points to increasing ion losses with increasing beam currents.
The performance of the RF funnel as beam cooler has up to now only been studied by Monte Carlo simulations. We assumed an ion beam with an energy of (100 $\pm$ 40) eV and an emittance of 173 π mm mrad at the funnel entrance, according to the experimental conditions in Jyväskylä. For a buffer gas pressure of 0.2 mbar we found for optimized funnel paramters (U_{RF} = 100 V_{pp}, U_{DC} = 0.5 V/cm) an emittance reduction by a factor of 10 which corresponds to a value of 20 π mm mrad (for 100 eV ions) for the cooled beam at the funnel exit. The beam energy and its half width have been reduced by a factor of 20 to (4.7 $\pm$ 2.2) eV.

References

[1] A. Nieminen *et al.*, NIM **A469** (2001) 244
[2] S. Heinz *et al.*, J.Phys.B: At.Mol.Opt.Phys. **36** (2003) 971