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The ion-trap facility SHIPTRAP

Status and perspectives

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Abstract. The Penning-trap mass spectrometer at the ion trap facility SHIPTRAP is in the final stage of commissioning. First on-line mass measurements of neutron-deficient radionuclides in the rare-earth region around $A = 147$ were performed in July 2004. Systematic investigations in order to determine systematic errors are ongoing. Further improvements of the efficiency of the system are in preparation, *e.g.* improved detection schemes and further optimization of the stopping cell. SHIPTRAP will then address exotic nuclides produced in fusion-evaporation reactions at the velocity filter SHIP. This production technique will give access to nuclei not available at ISOL facilities, especially in the transuranium region.

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The ion-trap facility SHIPTRAP [1] at GSI Darmstadt was set up to enable various precision experiments on heavy elements produced in fusion-evaporation reactions at the velocity filter SHIP [2]. In the first stage SHIPTRAP focuses on precision mass measurements of nuclei not available at ISOL or fragmentation facilities with a Penning-trap mass spectrometer. In this respect the region of the elements heavier than uranium is most attractive since the majority of masses in this region is only known from extrapolations to a few hundred keV precision [3]. In addition, the extrapolated mass values are linked to only few α-decay chains [3]. From the measured mass values the nuclear binding energy can be deduced which is an important parameter for nuclear structure theories. Systematic measurements along isotopic or isotonic chains covering shell closures are planned. For the elements heavier than uranium the very low production rates, dropping to only a few ions per week in the extreme case of $Z = 112$, are very challenging.

In the second stage atomic and nuclear structure studies by means of trap-assisted or in-trap nuclear spectroscopy and by laser spectroscopy are envisaged. Isobarically purified low-emittance beams at low energy with the option of pure isomeric beams could be delivered to dedicated spectroscopy set-ups. The advantage of a point-like source could be exploited for instance for X-ray or conversion electron spectroscopy. The laser spectroscopic studies could comprise for instance isotope-shift measurements to determine nuclear charge radii.

A schematic drawing of the setup is shown in fig. 1. The reaction products from SHIP with energies in the order of a few $100\,\mathrm{keV}/u$ are stopped in a buffer-gas-filled stopping cell with an overall efficiency, including the extraction RFQ, of about 5–8% as described in [4]. To improve the beam quality of the ion beam extracted from the stopping cell for an efficient injection into the Penning trap an RFQ cooler and buncher is utilized. In this buffer-gas-filled four-rod structure the ions are cooled within a few milliseconds and extracted as a low-emittance bunched beam. Ions from the stopping cell can also be stacked in the RFQ. A system of two cylindrical Penning traps in one superconducting magnet of 7 T field strength allows for high-precision mass measurements. The first trap with

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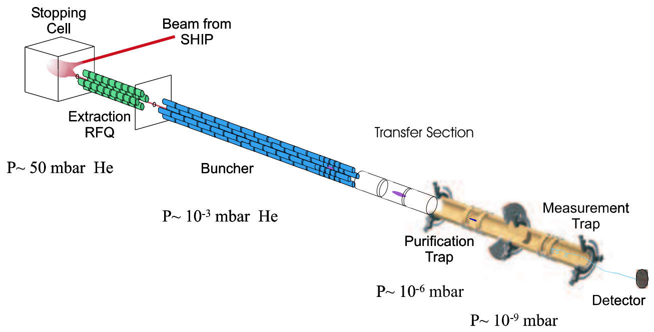

Fig. 1. A schematic overview of the SHIPTRAP facility.

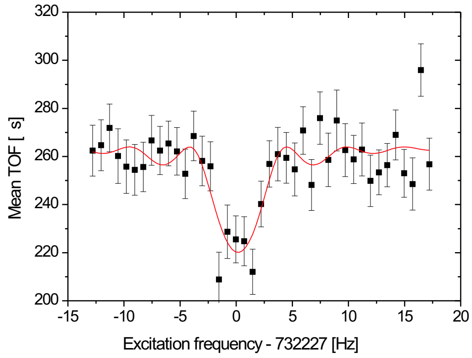

Fig. 2. Time-of-flight resonance of $^{147}Ho^+$ obtained with an excitation time of 200 ms.

a mass resolving power of about 85000 for ^{133}Cs is used for isobaric purification. In the second trap mass measurements are performed by the time-of-flight ion cyclotron resonance method [5]. A mass resolving power of 10^6 is routinely achieved. This allows for the identification of isomeric states and hence an unambiguous mass determination of the ground state.

Extensive off-line tests were carried out in order to characterize all individual components. In addition, on-line experiments at GSI and tests with radioactive ions at the Maier-Leibnitz Laboratory in Garching were carried out to optimize the stopping process in the gas cell.

The overall efficiency of SHIPTRAP of currently about 0.5% is limited by the total efficiency of the gas cell of 5–8% and the detection efficiency of the micro-channel plate detectors of 10–30%. While further improvements are being prepared first mass measurements of radionuclides in the rare-earth region with production rates of some thousand ions per second in front of the stopping cell are already feasible. This was demonstrated with radionuclides around $A = 147$ in July 2004. In this beam time the first on-line mass measurements at SHIPTRAP were performed. Holmium and erbium radionuclides produced in the reaction $^{92}\mathrm{Mo}(^{58}\mathrm{Ni}, xpxn)$ at SHIP were studied. The primary beam energy was chosen to be 4.36 MeV/u yielding the highest production rate in the 3p evaporation channel for ^{147}Ho. The area close to ^{147}Ho is interesting because of the phenomenon of ground-state proton radioactivity, which was discovered at SHIP [6] several years ago. The key parameter is the proton separation energy, which can be derived from atomic masses. Furthermore, important data for nuclear structure studies is obtained allowing for the calculation of two neutron separation energies around the neutron shell closure at $N = 82$. At present, many masses in this region are experimentally unknown. In the run in July 2004 the masses of ^{147}Ho, ^{147}Er and ^{148}Er were measured. The mass of the two erbium nuclides was experimentally determined for the first time. The data analysis is ongoing and the results will be presented elsewhere. As an example a time-of-flight resonance of ^{147}Ho is shown in fig. 2 with a Fourier-limited resolution.

After first on-line mass measurements in July 2004 the systematic errors of the system have to be determined and the overall efficiency has to be improved. A carbon cluster ion source which will enable cross-reference measurements as described in [7] is being tested. This will not only allow for the determination of the systematic error, but also for absolute mass measurements since the atomic mass standard is defined via the mass of ^{12}C. An improvement of the overall efficiency of the the stopping cell may be possible *e.g.* by an increase of the pressure from 40 to about 100 mbar. This will result in a narrower distribution of the stopped ions and hence more ions will be stopped within the extraction volume. In addition, an efficiency increase of the system is expected by using a detector with an extra conversion-electrode combined with a micro-channel plate (MCP) *e.g.* of Daley type [8] instead of the presently used MCP detectors. This will allow for an increased detection efficiency by a factor of 2–3. In the long-term future a cryogenic trap system utilizing the non-destructive Fourier transform ion cyclotron resonance (FT-ICR) detection will replace the current trap system. This will enhance the sensitivity especially for long-lived nuclides with lowest production rates allowing for a mass measurement even with a single ion. A more detailed description of this cryogenic trap system is given in [9].

With all the improvements implemented SHIPTRAP will start a mass measurement program focussed on neutron-deficient heavy ions.

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