Detection technique with single-ion sensitivity for high-precision mass measurements on superheavy elements*

J. Ketelaer[1], K. Blaum[1,2], G. Eitel[1], S. George[1,2], R. Ferrer[1], Sz. Nagy[1], D. Neidherr[1], and the SHIPTRAP collaboration

[1]Institut für Physik, Johannes Gutenberg-Universität Mainz, Gemany; [2]GSI, Darmstadt, Germany

Introduction and motivation

Mass values contribute to a number of physical models: these range from masses of exotic short-lived nuclides being important for weak interaction studies and the Standard Model of particle physics, to stable masses as means for the definition of fundamental constants [1]. Since the discovery of the superheavy elements from $Z = 102$ to $Z = 117$, the investigations in their masses have become more and more important. They allow for tests of mass models and predictions, which deviate a lot from each other in that region.

Usually, mass measurements on radionuclides with Penning traps are performed using the destructive Time-of-Flight-Ion Cyclotron Resonance (TOF-ICR) method, where the stored and with rf fields probed ions are finally ejected out of the trap. Several hundred ions are needed to get a single spectrum, which takes typically about one hour with a production rate of a few hundred ions per second and a total efficiency of about 1%. Therefore, the TOF-ICR technique is not applicable to rarely produced superheavy nuclides with production rates of less than one per second but rather long half-lives, sometimes even in the order of seconds or minutes. Ideally suited here is the non-destructive Fourier Transform-ICR technique, investigating the image current induced by the ions in the trap electrodes. The newly developed double-Penning trap setup for SHIPTRAP featuring both common techniques is discussed here [2].

Experimental setup and results

The mass spectrometer consists of a cylindrical Penning trap to prepare the ions by buffer gas cooling and mass selective centering of the ion cloud. After that, the particles are transferred through a diffusion barrier channel with 2 mm inner diameter and 47 mm length into the hyperbolically shaped precision trap. The ring electrode of the precision trap is four-fold segmented: two segments are for excitation of the ion motion, while the others are used to detect the induced image current. The detection electrodes are connected to a superconducting helical resonator, forming an LC resonance ciruit with the intrinsic parasitic capacitances of the system. The voltage drop across this tank circuit is then amplified and finally Fourier transformed to obtain the required frequency information. Both traps are situated in a 77 K-environment, whereas the detection inductance as well as the first amplifier are placed in a liquid helium bath at 4.2 K to get the resonator superconducting and to reduce thermal noise. Besides the FT-ICR detection method, the ions can also be ejected from the trap onto a Channeltron or MCP detector to perform a Time-of-Flight measurement.

The properties of the LC detection circuit have been found to meet the requirements for the determination of the current induced by a single singly charged ion in the order of a few hundred fA. The Q-value of the helical coil, defined as the ratio between the resonance frequency and the width, is about 15000 in the unloaded situation and still above 1000 with the trap connected. The inductance of the present coil is $(337 \pm 6)\,\mu$H, which allows for tests with singly charged ^{87}Rb^{+} in a test setup at the University of Mainz. The capacitance can be adjusted around 1224 kHz by a varactor diode to shift the resonance frequency to different mass numbers. The frequency range is about 20 kHz.

Tests with the diffusion barrier channel have also been performed at different buffer gas pressures and with different sealings between the trap tube and the holder of the channel. The best results at 77 K were obtained with a ring-shaped spring covered by a teflon shield, which counteracts the thermal contraction at low temperatures. The pressure ratio between the purification trap region and the precision trap region was about 900 at a typical buffer gas pressure of $5.5 \cdot 10^{-4}$ mbar and a temperature of 77 K [3].

All parts of the setup are ready. The traps and all other electrodes are mounted and cabled. Presently, the ion transport through the trap stack in the superconducting magnet is optimised.

Outlook

For the Mainz test setup, the next steps are to store and detect ions with the conventional Time-of-Flight detection technique as well as with the here developed FT-ICR method. The single-ion sensitivity will be demonstrated soon with singly charged ^{87}Rb^{+} ions delivered by a surface ion source. Finally, the Mainz setup will move to SHIPTRAP at GSI and first mass measurements on superheavy elements, e.g. ^{254}No ($T_{1/2} = 51$ s), will be performed.

References

[1] K. Blaum, Phys. Rep. 425 (2006) 1.

[2] C. Weber, Eur. Phys. J. A 25, S01, (2005) 65.

[3] R. Ferrer et al., Eur. Phys. J. (2006) accepted.

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