Wide-band mass measurements with a multi-reflection time-of-flight mass spectrograph†

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The multi-reflection time-of-flight mass spectrograph (MRTOF-MS), first proposed more than 20 years ago[1], uses a pair of electrostatic mirrors to compress a flight path of several hundred meters (or even many kilometers in some cases) within a reflection chamber of ≈1 m length. The MRTOF-MS can achieve mass resolving powers of $R_{\rm m}$>10^5 while operating at rates of 100 Hz or more[2)3)4)].

Recently, these devices have begun to prove useful for online measurement of nuclear masses[5)6)]. The technique has been demonstrated to accurately provide mass precision of $\delta m/m \sim 5\times10^{-7}$ or better.

However, the multi reflection nature of the measurement has made analysis of rich, wide-band mass spectra difficult or impossible. Much like runners of widely varying skill racing on a circular track, after some time ions with sufficiently differing mass-to-charge ratios make different numbers of laps and create a difficult to interpret spectrum. By developing an analytic method to interpret such spectra, we believe the device could eventually provide wide-band measurements of nuclear masses much in the way of storage rings[7)]. The device could also be useful in analytic chemistry, providing wide-band analysis much like FT-ICR Penning traps, but with greater sensitivity.

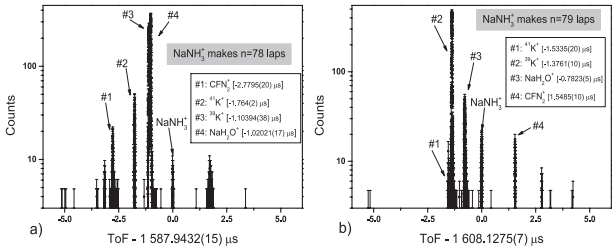

Fig. 1. Example spectra with n_{m1}=78 and 79 laps. Abscissa reflects the time-of-flight of the $NaNH_3^+$ reference.

As reported[8)], using a time-of-flight peak corresponding to a reference ion with known mass-to-charge ratio that makes a known number of laps in the reflection chamber it is possible to determine the mass-to-charge ratio corresponding to any other peak as

$$m_2 = m_1^{(n)} \left(\frac{\zeta + n_{m_1}}{\zeta + n_{m_1} + \Delta n} \right)^2, \qquad (1)$$

where reference ions with mass-to-charge ratio $m_1^{(n)}$ make n_{m_1} laps and unknown ions with mass-to-charge ratio m_2 make $n_{m_1} + \Delta n$ laps, while ζ is a system-dependent constant; for our system ζ=0.686 893(20).

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Determining Δn requires a pair of spectra with different values of n_{m1}. Using this method, it is possible to determine the mass-to-charge ratio of ions over a wide range with a relative mass accuracy of ∼10^{-6}, which is typically sufficient to uniquely identify the ions. Such a pair of spectra with ion identity determined is shown in Fig. 1 using $NaNH_3^+$ as a reference.

Once Δn is known, a more precise determination of the ion's mass-to-charge ratio can be determined using the time-of-flight of the reference and unknown with each undergoing the same number of laps, as previously demonstrated online for $^8Li^{+}$[6)]. If there exist isobars, one isobar can be used as a reference while the others are treated as unknown masses and simultaneous accumulation of reference and unknown can be performed, removing possible drift-related errors.

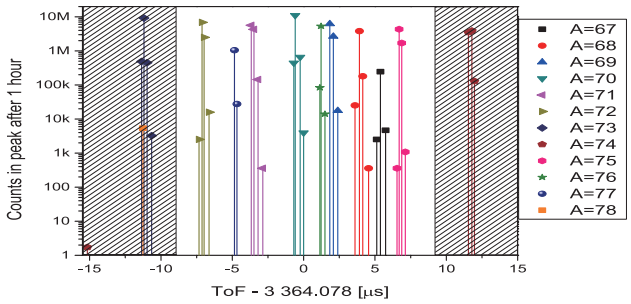

Fig. 2. Calculated spectra at SLOWRI from nuclei produced by in-flight fission of Uranium. In the hashed region, ions will experience time-dependent electric fields from extraction switch and cannot be analyzed.

We foresee the possibility of performing such wide-band mass measurements of r-process nuclei at SLOWRI. As demonstrated in the calculated spectra shown in Fig. 2, it should be possible to measure masses of 20 or more nuclei simultaneously. This would allow the entire region from ^{78}Ni to ^{132}Sn to be investigated with less than 10 tunes of BigRIPS.

References

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