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Facile production of atomic and molecular actinide ions

J. Stricker(1, 2), K. Gaul(1,2), L. M. Arndt(1), Ch. E. Duellmann(1, 2, 3), D. Renisch(1,2), J. Velten(1) and the TACTICa Collaboration(1, 2, 3). (1) Johannes Gutenberg-University Mainz, 55099 Mainz, Germany. (2) Helmholtz Institute Mainz, 55099 Mainz, Germany. (3) GSI Helmholtzzentrum für Schwerionenforschung GmbH, 64291 Darmstadt, Germany.

Trapped atomic and molecular actinide ions are considered to be ideal for a variety of fundamental physics experiments designed to explore physics beyond the standard model [1]. Molecular actinide ions with one unpaired electron are promising probes of fundamental physics, for example in the search of parity and time-reversal symmetry violations [1]. These molecules can also be used as quantum sensors in the search for ultra-light bosonic dark matter [2].

Laser ablation is one of the most common ion-production methods. We report on the production of ions of thorium- and uranium-containing species in different charge states by laser ablation using a modified commercial ion gun. The produced ions are extracted and analyzed by a time-of-flight mass spectrometer. The modularity of the setup facilitates easy coupling with ion traps, where it is possible to investigate trapped actinide ions of interest using precise spectroscopy. This approach allows us to study signatures that may hint at novel physics. We performed a systematic study on the dependence of the generated ion species, ranging from atomic to tetratomic actinide ions. For this purpose, different chemical actinide compounds were used as target materials for laser ablation in combination with specific laser ablation fluences.
Our systematic approach enables a selective production of tailored actinide ion species. We successfully generated thorium fluoride ions ($ThF_x{}^{n+}$, where x = 0–3, n = 1–3) [3] and uranium oxide ions ($UO_x{}^{n+}$, where x = 0–1, n = 1–4) [4]. Of these molecular ions, the species with a single unpaired electron (ThF^{2+}, UO^{3+}) or closed electronic shells (ThF^{3+}, UO^{4+}) may be particularly interesting for precision spectroscopy and tests of fundamental physics.

We will apply this method to produce oxides and fluorides of further actinides in the future. Once coupled to an ion trap we will focus on the investigation of physics beyond the standard model with the produced ions using precision laser spectroscopy.

[1] G. Arrowsmith-Kron et al., Rep. Prog. Phys. 87, 084301 (2024)
[2] D. Antypas et al., Sci. Technol. 6, 034001 (2021).
[3] J. Stricker et al., arXiv:2503.05759 (2025).
[4] J. Stricker et al., to be submitted (2025).

Author: STRICKER, Jonas (JGU / HIM Mainz)

Co-authors: Prof. DÜLLMANN, Christoph E. (GSI, JGU and HI Mainz); Dr RENISCH, Dennis (JGU and HI Mainz); Mr VELTEN, Jean (JGU Mainz); Dr GAUL, Konstantin (JGU and HI Mainz); Mr ARNDT, Lennard (JGU Mainz)

Presenter: STRICKER, Jonas (JGU / HIM Mainz)

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