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Release Properties of Ag, Pd and Sn in an Upgraded Hot Cavity Laser Ion Source

Motivation

- Initially dedicated to the fast, efficient extraction and study of ^{94m}Ag (N=Z), $t_{1/2}$ (21+)= 0.39 s, achieved in 2023
- Mass and laser spectroscopy data on short-lived, neutron-deficient isotopes in this region is scarce due to the challenges of producing and efficiently extracting them
- The upgraded inductively heated hot-cavity laser ion source (HCLIS) at IGISOL acheived reasonable extraction efficiency and release time for Sn, Ag, and Pd isotopes, enabling laser spectroscopy and mass measurements near the N=Z line
- Crucial for key nuclear structure concepts like pairing, isospin symmetry, single particle vs collective behaviour

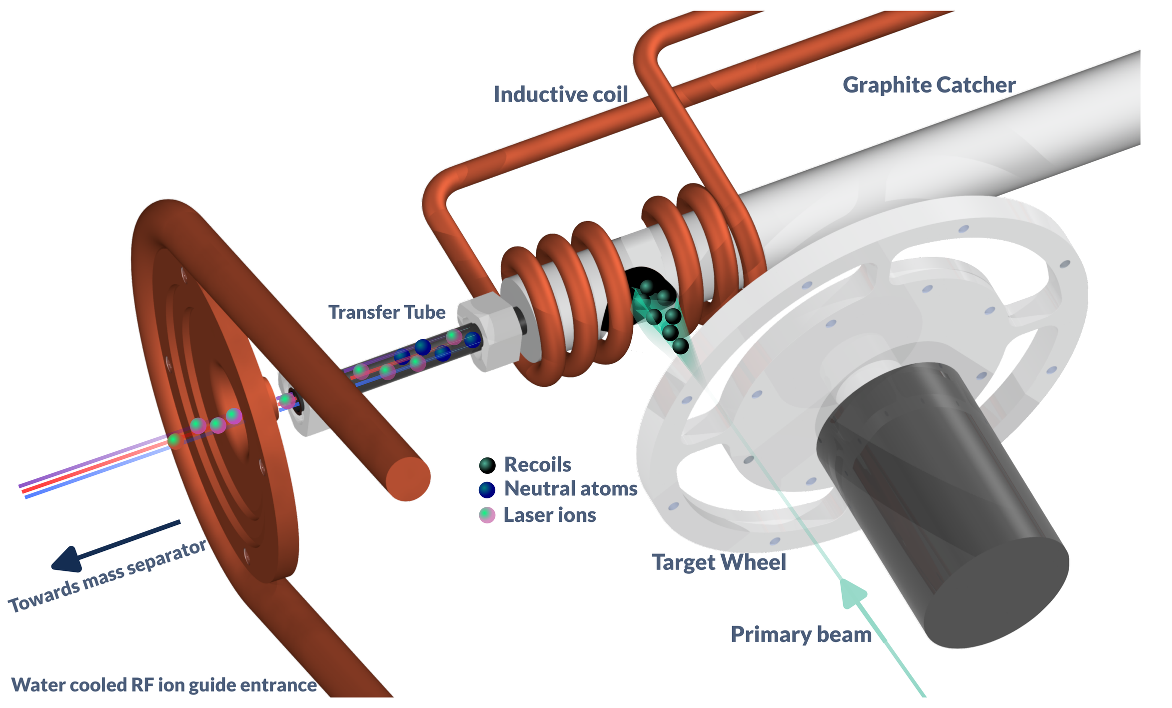


Fig. 1 : 3D drawing of hot cavity catcher with various parts illustrated

Design

- Catcher geometry optimized for heavy-ion fusion evaporation reactions [1] , Eg: ^{58}Ni(^{40}Ca,p3n)^{94}Ag
- Inductively heated (<2kW) graphite catcher in Mo crucible[2]
- Resistive heating for hollow sigradur transfer tube forming a potential gradient (9 V)
- Integrated target wheel and collimator on a separate platform
- Water cooling for heated components and RF ion guide entrance
- Highest stable operating temperature ~ 1800 K

Release Tests with Stable Ag

- Implantation of 495 MeV Stable ^{107}Ag^{20+} beam from K130 cyclotron into graphite catcher
- Neutralization in catcher and effusion into transfer tube
- Resonant three-step laser scheme for Ag used to selectively ionise the atoms [3]
- Ions via RF guide accelerated to 30 kV before mass separation using dipole magnet (M/ΔM(FWHM) ~ 250)
- Overall efficiency = beam current after dipole magnet/beam current from cyclotron
- Pulsed cyclotron beam is used for extraction time measurement
- ~30% efficiency for ^{107}Ag ; fast extraction time ~ 30 ms

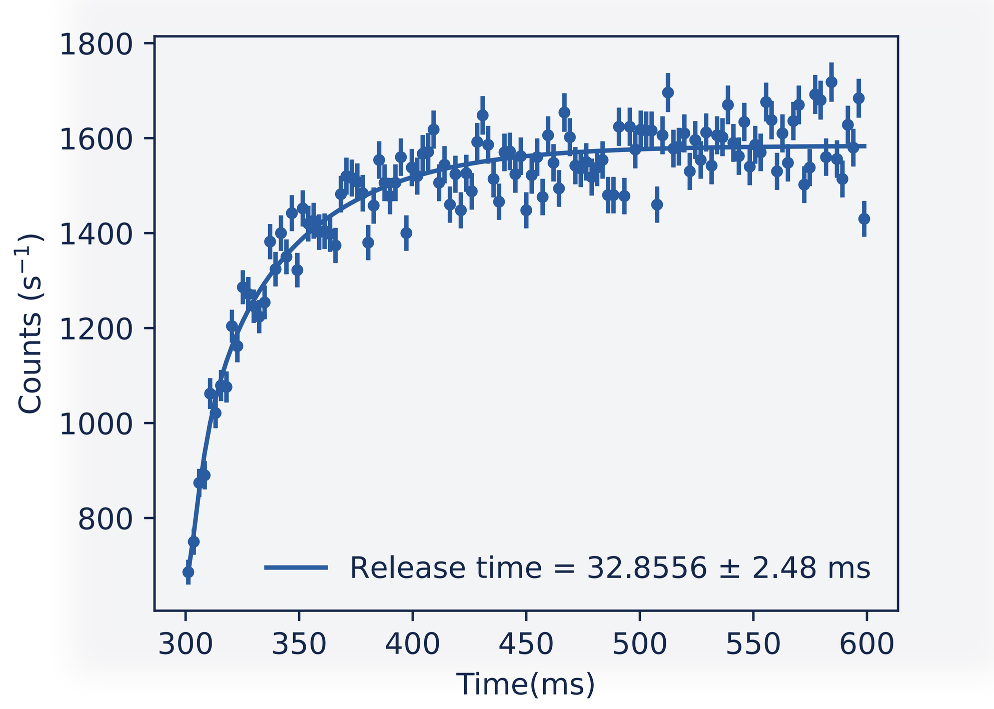


Fig. 2:Rise time curve measured for ^{107}Ag stable implanted beam in the hot-cavity. The catcher and tube temperature are approximately 1500 K and 1770 K respectively

In-source Laser spectroscopy of ^{94}Ag(N=Z) with MR-ToF MS

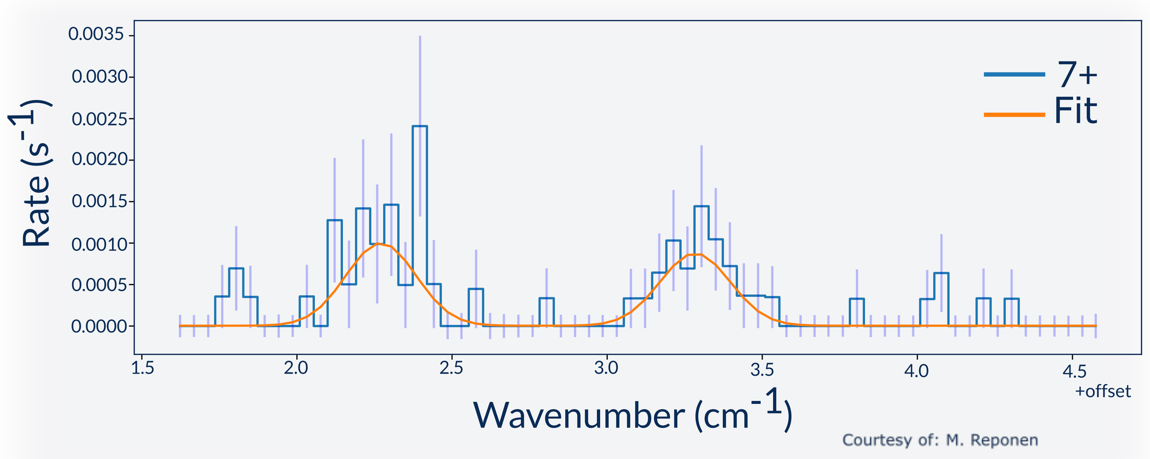


Fig. 3: MR-ToF assisted hyperfine scan of ^{94}Ag(7+). Both tube and the catcher temperature is about 1300K

Nucleus	Count rate (s^{-1})	Half-life
^{94}Ag (7+)	0.03	0.55 s
^{94}Ag (21+)	0.003	0.4 s
^{103}Ag	80000	65.7 min
^{104}Ag	75000	69.2 min

Table 1. Count rate for various radioactive Ag isotopes after mass separator with ^{14}N (185 MeV, 300 pnA) +^{92}Mo (125 μm) target and ^{40}Ca (100 pnA, 185MeV) +^{58}Ni (3 μm) target for ^{94}Ag from an experiment conducted in 2025

Release Tests with Stable Sn

- 550 MeV Stable ^{120}Sn^{23+} beam fromK130 cyclotron implanted into graphite catcher
- Neutralization in catcher and effusion into transfer tube
- Resonant three-step laser scheme for Sn used to selectively ionise the atoms [5]
- Ions via RF guide accelerated to 30 keV before mass separation using dipole magnet (M/ΔM(FWHM) ~ 250)
- Detected on a MCP after the mass separator
- ~5% efficiency for ^{120}Sn ; extraction time < 1 s
- Part of ongoing efforts to study ^{100}Sn (N=Z)

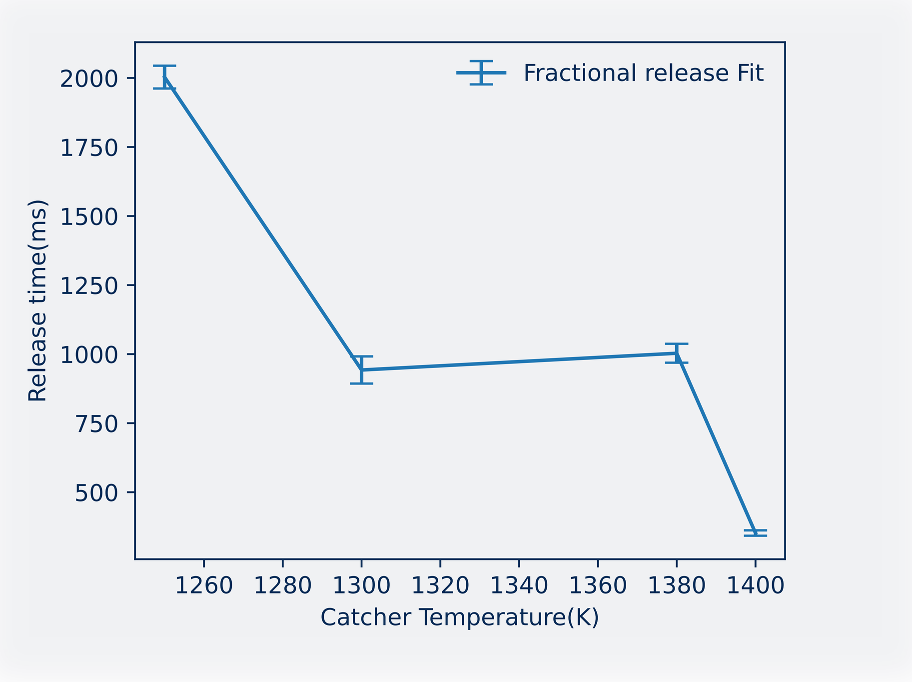
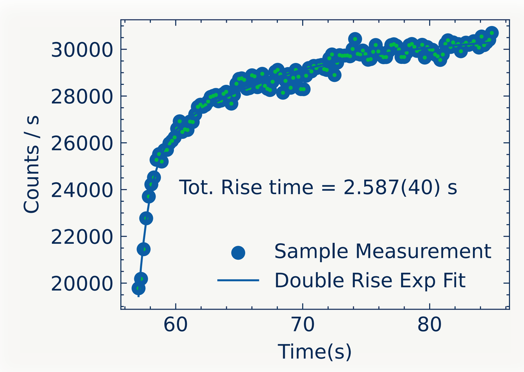


Fig. 7: Release time variation of ^{120}Sn from the hot cavity catcher. Tube temperature is about 1100K

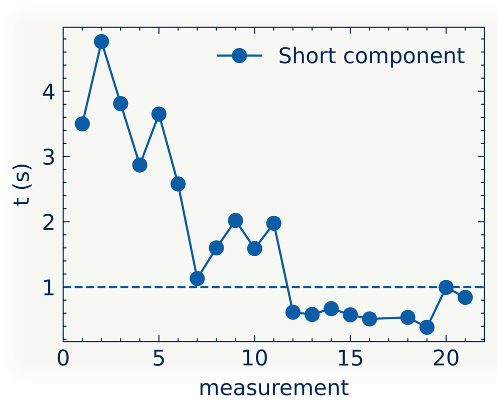
Resonant Laser Ionisation of Pd and Extraction Measurements

- Three step resonant ionization scheme used to ionize Pd atoms
- ^{14}N (148 MeV, 100pnA) + ^{92}Mo (0.03 mm) for ^{97,98,99,100}Pd used in tuning and optimisation of beam transport & lasers
- ^{40}Ca (230 MeV, 70 pnA) + ^{58}Ni (3.3 μm) for ^{92,93,94}Pd used for mass measurements in IGISOL MR-ToF MS



- Study of release time at different heating parameters
- Double exponential fit to rise time curves, where the short component corresponds to laser ionisation

Fig. 4: Double exponential fit to rise time curve for an arbitrary heating parameters



- Threshold heating parameters to obtain release time < 1 s are Induction = 1900 W(~1400K), DC=50.59 A, 9.9 V (~1300K)
- Average total extraction efficiency of around 4%

Fig. 5: Variation of release time with different heating parameters

Mass measurement of ^{92}Pd(N=Z) with MR-ToF MS

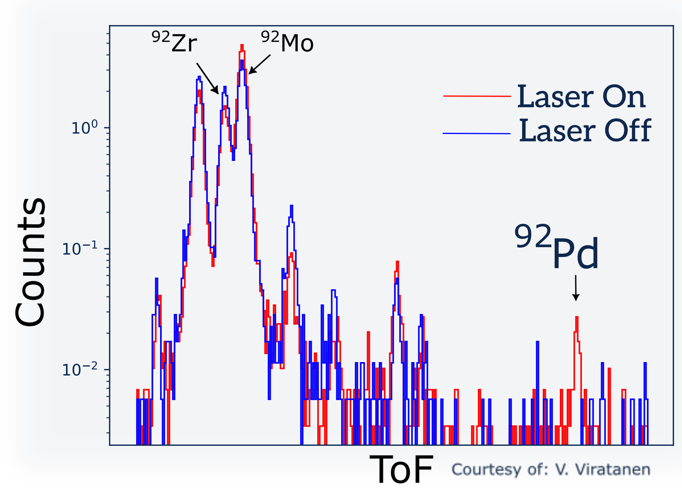


Fig. 6: ToF spectrum from MR-ToF contrasting both laser off and laser on spectra for A=92 nuclei

Nucleus	Count rate (s^{-1})	Half-life
^{97}Pd	1800	3.10 min
^{98}Pd	8200	17.7 min
^{99}Pd	30000	21.4 min
^{94}Pd	10	9 s
^{93}Pd	0.4	1.07 s
^{92}Pd	0.02	1 s

Table 2. Experimental count rate for various radioactive Pd isotopes observed after mass separator

Outlook

→ Modelling effusion using MonteCarlo simulations - helps in determing fitting bounds for fractional release curve, test combinations of effusing species and materials

→ COMSOL simulations for DC heating focusing on temperature distribution and potential gradient along the transfer tube

→ Possible In-source laser spectroscopy of ^{94}Ag(21+) and mass measurement of ^{94}Ag(0+) with improved total extraction efficiency

→ Extraction tests of lanthanides, ceasium and other elements around Sn

References

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Acknowledgments
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