Fabrication and characterization of actinide targets for super-heavy element studies

Klaus Eberhardt

- Target materials
- Backing characterization
- Production techniques – Molecular Plating
- Target characterization
- Target performance
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Targets for SHE studies

- FL \( \Rightarrow \) \( {}^{244}\text{Pu} \left( ^{48}\text{Ca}, \text{xn} \right) \)
- E115 \( \Rightarrow \) \( {}^{243}\text{Am} \left( ^{48}\text{Ca}, \text{xn} \right) \)
- Lv \( \Rightarrow \) \( {}^{238}\text{U} \left( ^{50}\text{Ti}, \text{xn} \right) \)
- Lv \( \Rightarrow \) \( {}^{248}\text{Cm} \left( ^{48}\text{Ca}, \text{xn} \right) \)
- E117 \( \Rightarrow \) \( {}^{249}\text{Bk} \left( ^{48}\text{Ca}, \text{xn} \right) \)
- E119 \( \Rightarrow \) \( {}^{249}\text{Bk} \left( ^{50}\text{Ti}, \text{xn} \right) \)
- E120 \( \Rightarrow \) \( {}^{248}\text{Cm} \left( ^{54}\text{Cr}, \text{xn} \right) \)
- E120 \( \Rightarrow \) \( {}^{249}\text{Cf} \left( ^{50}\text{Ti}, \text{xn} \right) \)

Different backings, different geometries

Ti\(^{244}\text{Pu}\)-Target
Ti\(^{249}\text{Cf}\)-Target
C/\(^{238}\text{U/C}\)-Target
[Courtesy GSI Targetlab]
### Targets for SHE studies

<table>
<thead>
<tr>
<th>Element</th>
<th>Availability</th>
<th>Production Techniques</th>
</tr>
</thead>
<tbody>
<tr>
<td>Th</td>
<td>available</td>
<td>Rolling, PVD, CVD</td>
</tr>
<tr>
<td>U</td>
<td>available</td>
<td>Sputtering</td>
</tr>
<tr>
<td>Pu</td>
<td>radioactive / rare</td>
<td>Electrodeposition</td>
</tr>
<tr>
<td>Am</td>
<td>radioactive / rare</td>
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<tr>
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<td>radioactive / rare</td>
<td></td>
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</tbody>
</table>

- **Unlimited availability**
- **Thick targets, foils, often self-supporting**
- **Production techniques:**
  - Rolling
  - PVD
  - CVD
  - Sputtering

- **Limited availability**
- **High specific activity (in some cases)**
- **Production techniques:**
  - Painting
  - PVD (\(^{248}\)Cm)
  - Electrodeposition
At GSI Targetlab: Backing foils (Ti, 2 µm) produced by cold rolling. Overall foil thickness then determined by weighing. Check for pinholes, cut 20-30 individual backing foils and glue it onto Al-frame.

⇒ thickness deviations for each foil measured by α-particle energy loss. 3 x 300 s counting time (each foil)

<table>
<thead>
<tr>
<th>ΔE [MeV] @ 2.2 µm</th>
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<tbody>
<tr>
<td>0.505</td>
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<tr>
<td>0.514</td>
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<td>0.514</td>
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<tr>
<td>0.455</td>
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<td>0.484</td>
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<td>0.543</td>
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<tr>
<td>0.553</td>
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</table>
Actinide deposition by Molecular Plating

- Backing: 2μm Ti-foil cleaned with HCl, water, isopropanol
- Actinide compound, dissolved in isobutanol
- Deposition time: 3-6 hours
- Voltage: 100 V - 1500 V

Cell design according to H. Haba [RIKEN], TASCA05, Oslo, Oct. 2005
Actinide deposition by Molecular Plating

Supporting frame with Ti-backing foil (2 μm)

Deposition yield: up to 90%
Target thickness: mg/cm² in a single deposition step

Electrochemical cell assembly (26 ml)

Cell design according to H. Haba [RIKEN], TASCA05, Oslo, Oct. 2005
Target thickness:

- $\alpha$, $\gamma$-spectroscopy
- Neutron Activation Analysis

Layer homogeneity:

- $\alpha$-particle spectroscopy
- Radiographic Imaging

Investigation of layer properties produced by MP

Studies on layer growth mechanism:
- Scanning Electron Microscopy (SEM) ⇒ µm-resolution
- Atomic Force Microscopy (AFM) ⇒ 10-100 nm-resolution

Nd as model element

Studies on the chemical composition:
- X-ray Fluorescence (XRF)
- Photoelectron Spectroscopy (XPS)

[A. Vascon et al., Nucl. Instr. and Meth. A 655 (2011) 72]
[S. Sadi et al., Nucl. Instr. and Meth. A 655 (2011) 80]
MP investigations: Influence of solvent

MP of Nd:
Backdrop: Ti-coated Si-wafer.
Solvent: Isopropanol/Isobutanol

Roughness: (22 ± 9) nm

[AFM Image]

MP of Nd:
Backdrop: Ti-coated Si-wafer.
Solvent: DMF

Roughness: (17 ± 8) nm

XPS-analysis of Nd-layer produced by MP

DETECTED ELEMENTS: C, O, Pd (from the anode), and Nd

- **Nd 3d signal:** grows after Ar\(^+\) sputtering

- **C 1s signal:** 285.0 eV is aliphatic carbon → removed after sputtering: physisorbed

  289.3 eV is C(O)OR or COOM group → not removed after sputtering: chemisorbed

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Small (old) TASCA target wheel. Small target spot results in high heat load in center of target. ⇒ Change of target morphology might occur

Fresh Pu-244 target layer

Pu-244 target irradiated with Ca-48. Beam dose > $5 \times 10^{18}$
No material losses but small cracks observed.

Courtesy: Matthias Schädel, GSI
Fresh target layer

5 µm

2.3 µm

Ti

Pu

Courtesy: Klaus Lützenkirchen, ITU
Irradiated target

Courtesy: Klaus Lützenkirchen, ITU
Irradiated target: No Pu-losses but tiny cracks

Pu-compound creeps through a small crack to backside of target foil. Crack is closed again....

Courtesy: Klaus Lützenkirchen, ITU
Summary and Outlook

• Target materials range from U to Cf (Es, Fm)
• Backing characterization prior to target fabrication
• Production techniques – Molecular Plating
• Target characterization using various methods
• Target performance under irradiation conditions

• Alternative backing materials:
  low Z, thin but mechanically stable, chemically inert ⇒ Graphene?

• Alternative production techniques:
  ⇒ Ionic liquids, superhydrophobic surfaces

• Actinide target characterization
• Tests of target performance @ 10 μA
Summary and Outlook

• Target materials range from U to Cf (Es, Fm)
• Backing characterization prior to target fabrication

Do not forget to address target issues:

• Development of new techniques
• Characterization of actinide targets
• Beam time needed for performance tests
• Development of a standard target wheel

• Actinide target characterization
• Tests of target performance @ 10 pµA
Influence of backing foil

Deposition of Nd (as model element for trivalent actinides) on different Ti substrates.

⇒ Surface investigation using Atomic Force Microscopy (AFM)