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

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HELMHOLTZ ASSOCIATION

Helmholtz Institute Mainz

GSI

- Target materials
- Backing characterization
- Production techniques – Molecular Plating
- Target characterization
- Target performance

Thanks to

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GSI

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Targets for SHE studies

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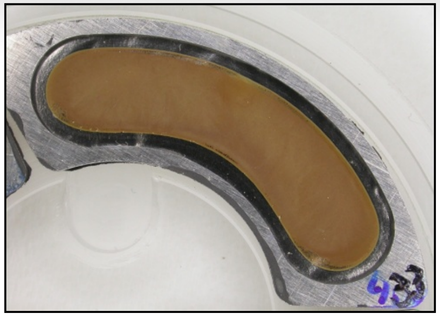
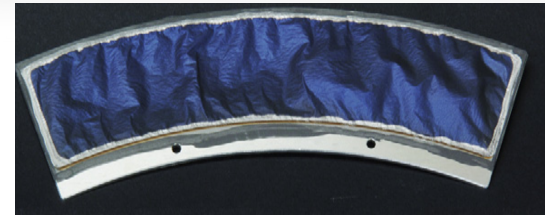


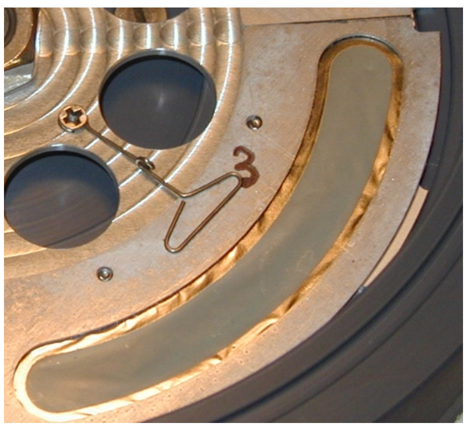
Ti/^{244}Pu-Target

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



C/^{238}U/C-Target [Courtesy GSI Targetlab]

GSI



Ti/^{249}Cf-Target

Ti/^{248}Cm-Target

Different backings, different geometries

Targets for SHE studies

Th	U	Pu	Am	Cm	Bk	Cf

available — radioactive / rare

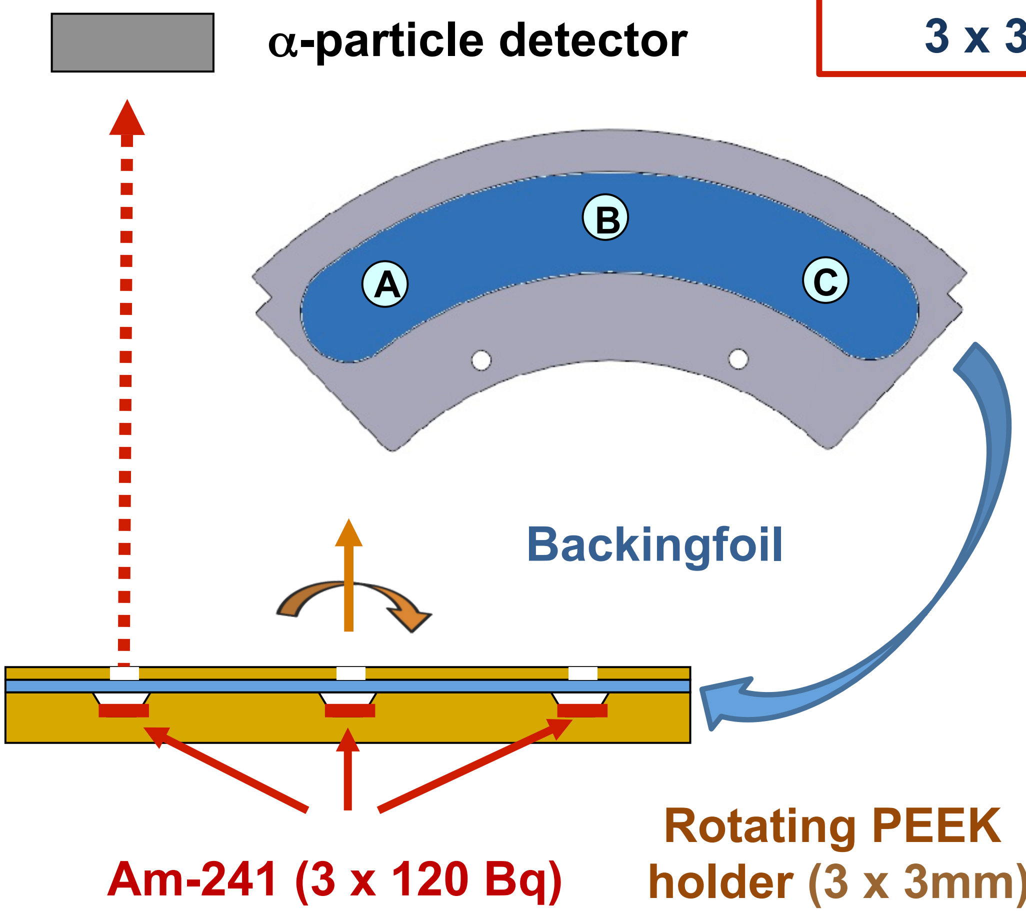
- Unlimited availability
- Thick targets, foils, often self-supporting
- Production techniques:
  - Rolling
  - PVD
  - CVD
  - Sputtering

- Limited availability
- High specific activity (in some cases)
- Production techniques:
  - Painting
  - PVD (^{248}Cm)
  - Electrodeposition

Backing characterization (thin Ti foils)

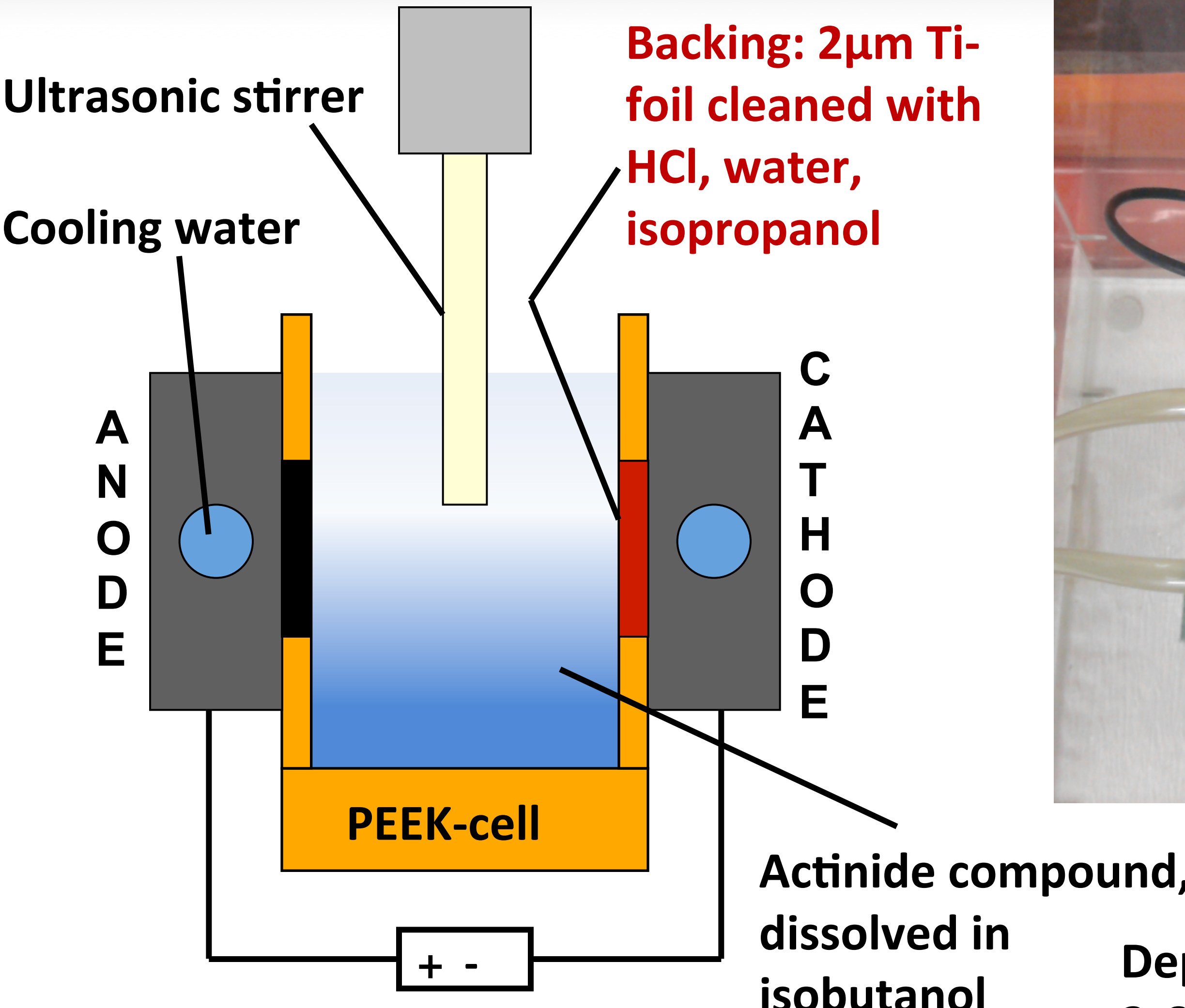
At GSI Targetlab: Backing foils (Ti, 2 μm) produced by cold rolling. Overall foil thickness then determined by weighing. Check for pinholes, cut 20-30 individual backing foils and glue it onto Al-frame

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

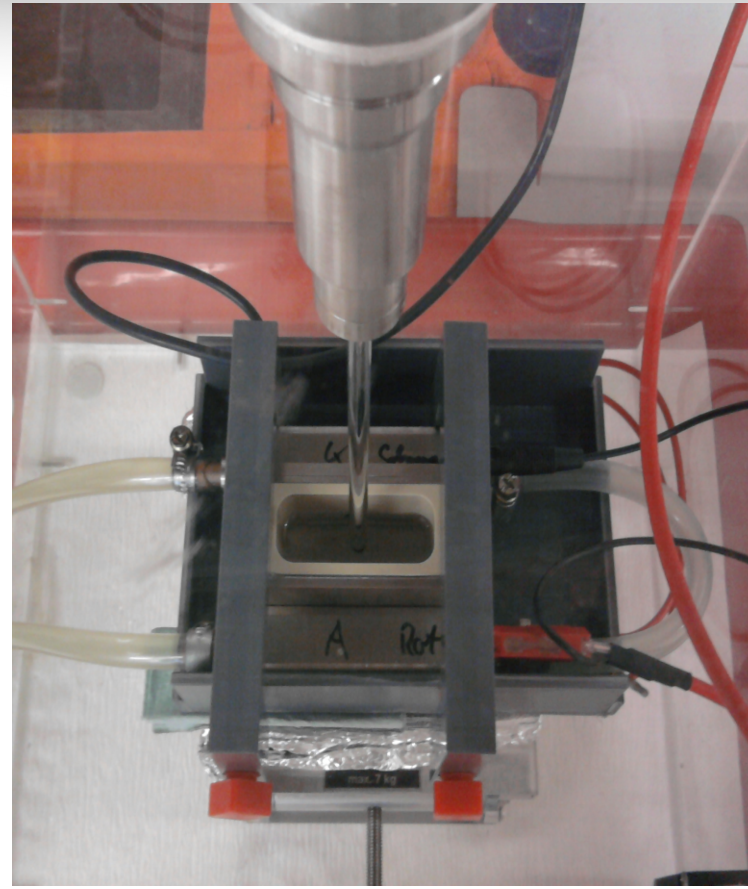


ΔE [MeV]
@ 2.2 μm
0.505
0.514
0.514
0.455
0.484
0.543
0.514
0.553
0.553

Actinide deposition by Molecular Plating



Voltage: 100 V - 1500 V



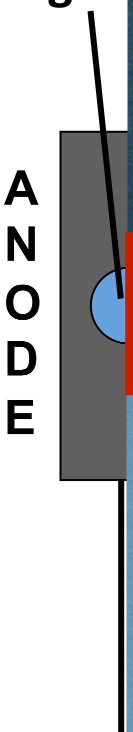
Deposition time: 3-6 hours

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

Actinide deposition by Molecular Plating

Ultrasonic

Cooling w

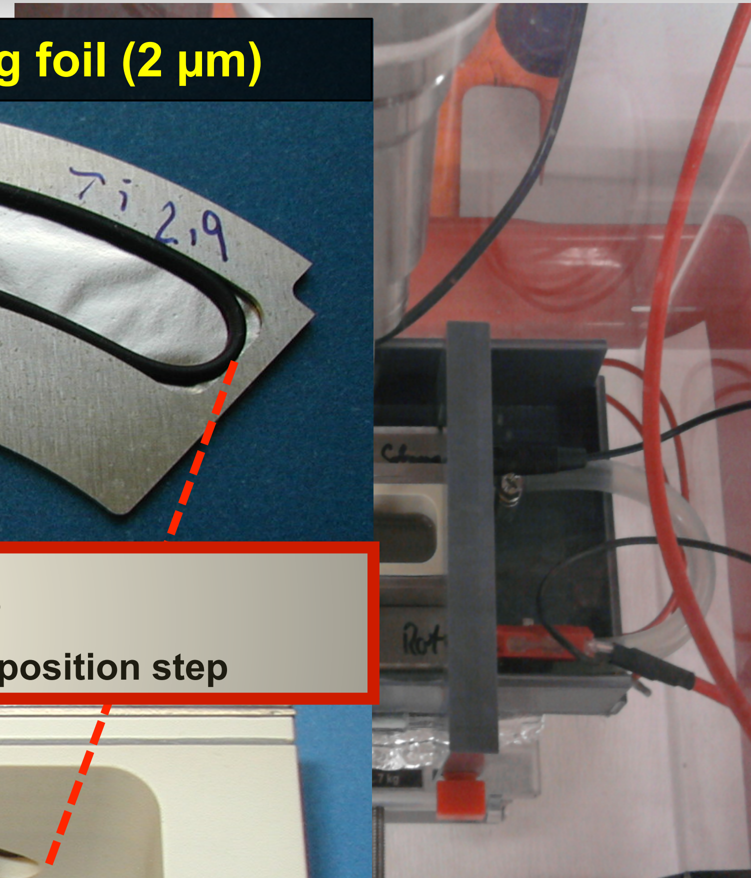


Supporting frame with Ti-backing foil (2 µm)

Deposition yield: up to 90%

Target thickness: mg/cm^2 in a <u>single</u> deposition step

Electrochemical cell assembly (26 ml)



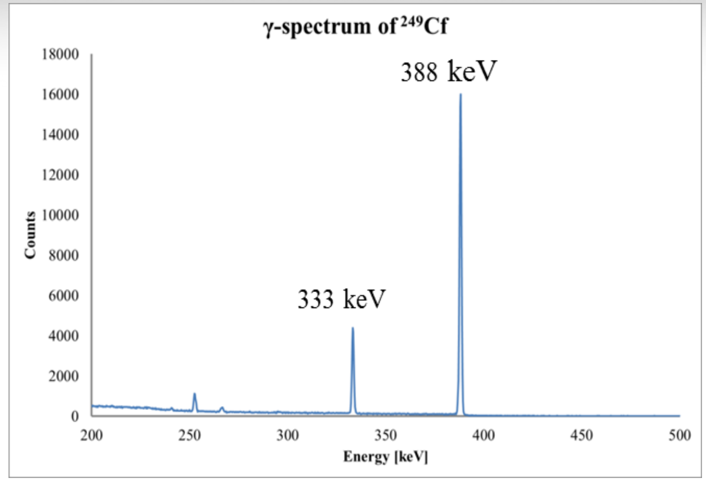
me:

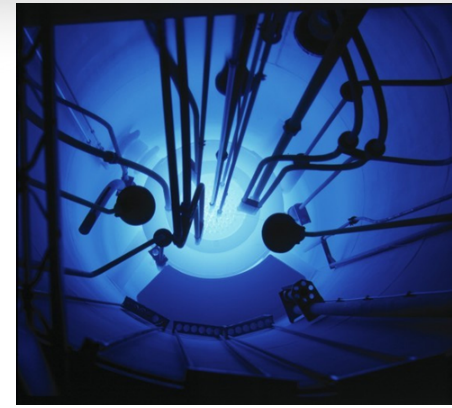
Cell design according to H. Haba [RIKEN], TASCA05, Oslo, Oct. 2005

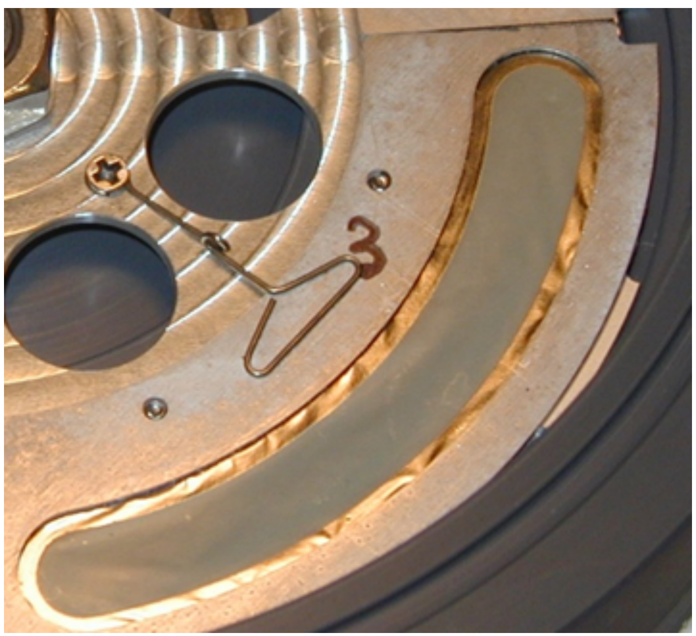
Standard target characterization methods

Target thickness:

- α-, γ-spectroscopy
- Neutron Activation Analysis

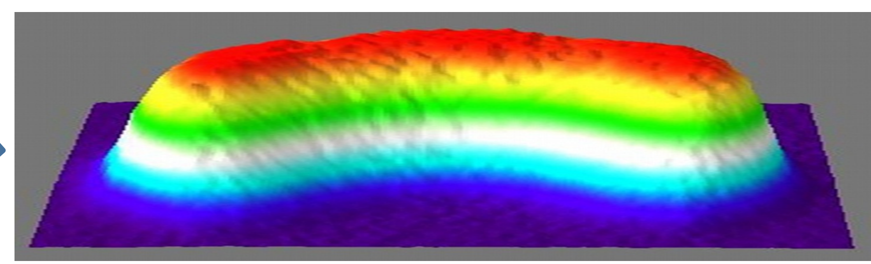






Layer homogeneity:

- α-particle spectroscopy
- Radiographic Imaging



[D. Liebe et al., Nucl. Instr. and Meth. A 590 (2008) 145]

Investigation of layer properties produced by MP

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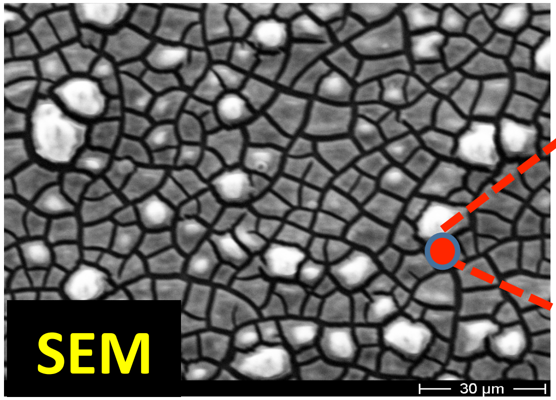
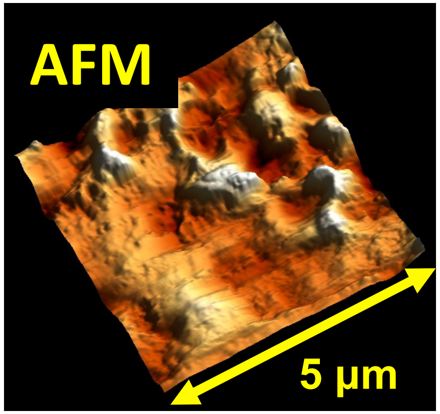
Studies on layer growth mechanism:

- Scanning Electron Microscopy (SEM) ⇒ µm-resolution
- Atomic Force Microscopy (AFM) ⇒ 10-100 nm-resolution

Nd as model element





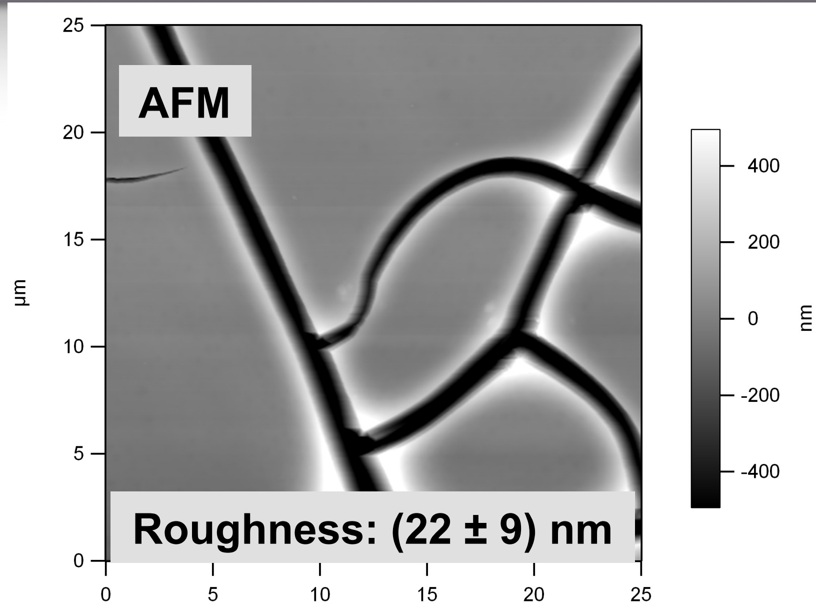
Studies on the chemical composition:

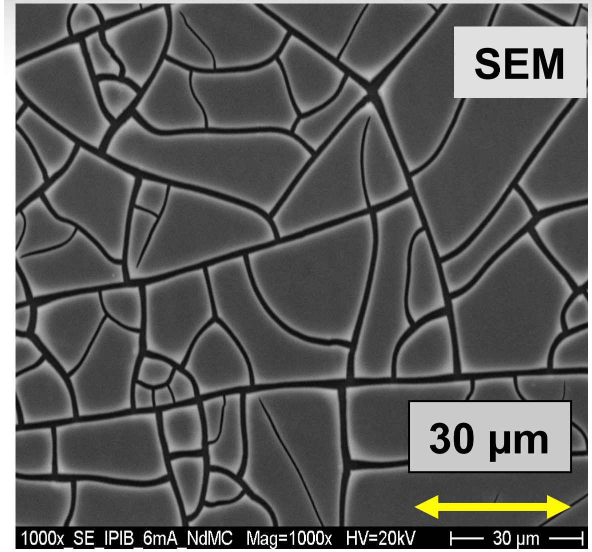
- X-ray Fluorescence (XRF)
- Photoelectron Spectroscopy (XPS)

[A. Vascon et al., Nucl. Instr. and Meth. A 655 (2011) 72]
[S. Sadi et al., Nucl. Instr. and Meth. A 655 (2011) 80]
[A. Vascon et al., Nucl. Instr. and Meth. A 696 (2012) 180]

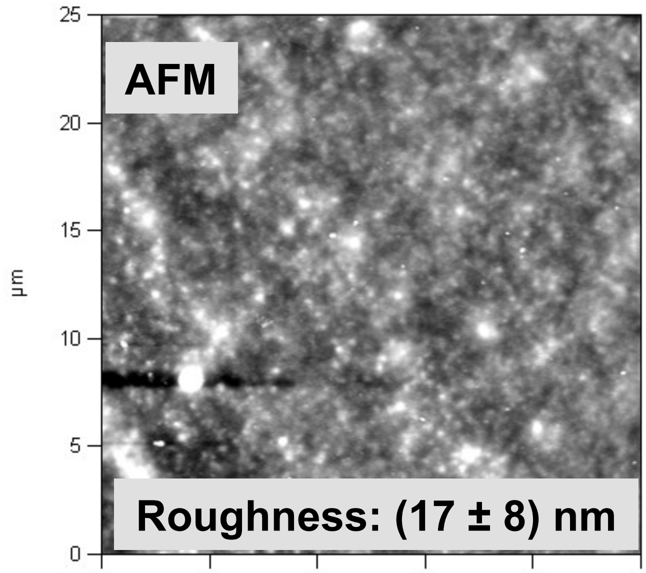
MP investigations: Influence of solvent

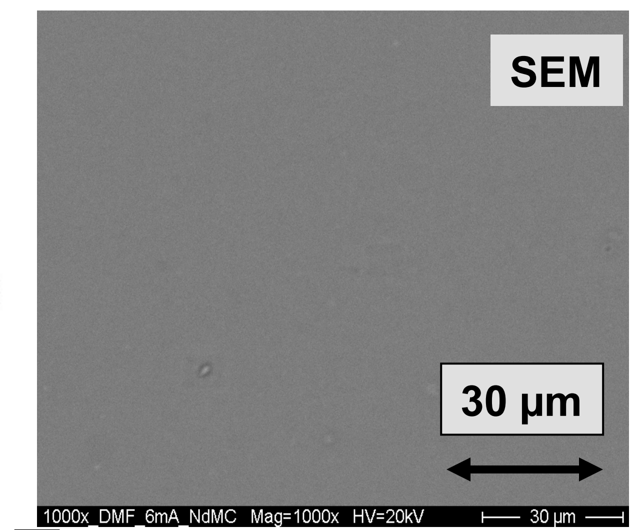
MP of Nd:
Backing:
Ti-coated Si-wafer.
Solvent: Isopropanol/ Isobutanol





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

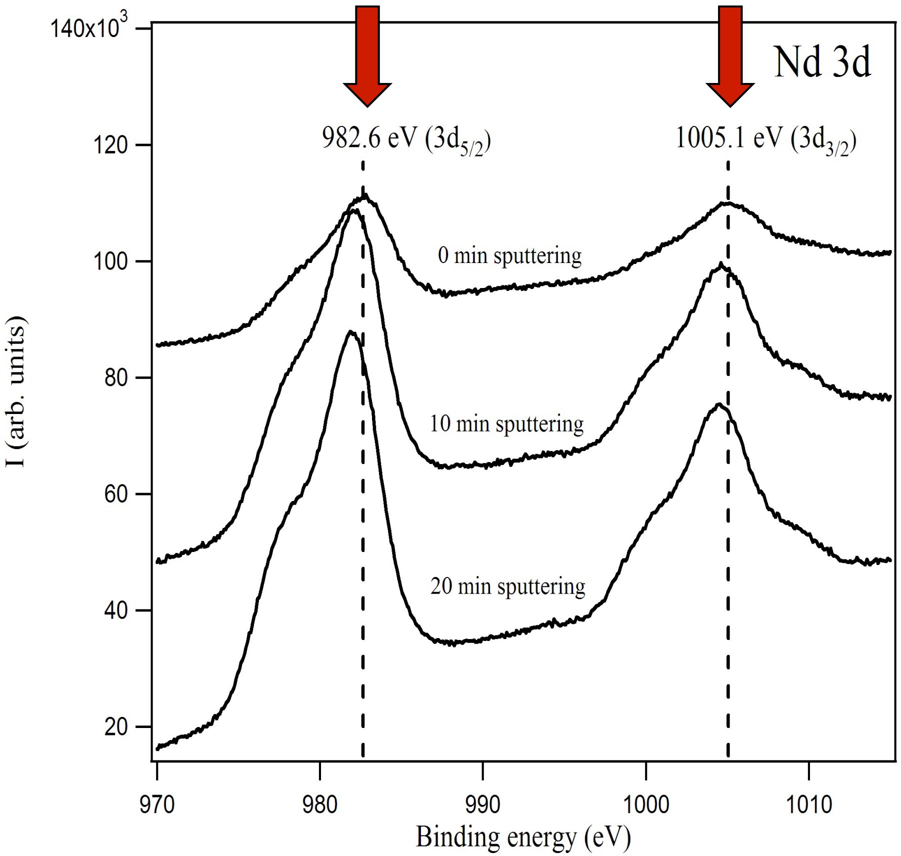


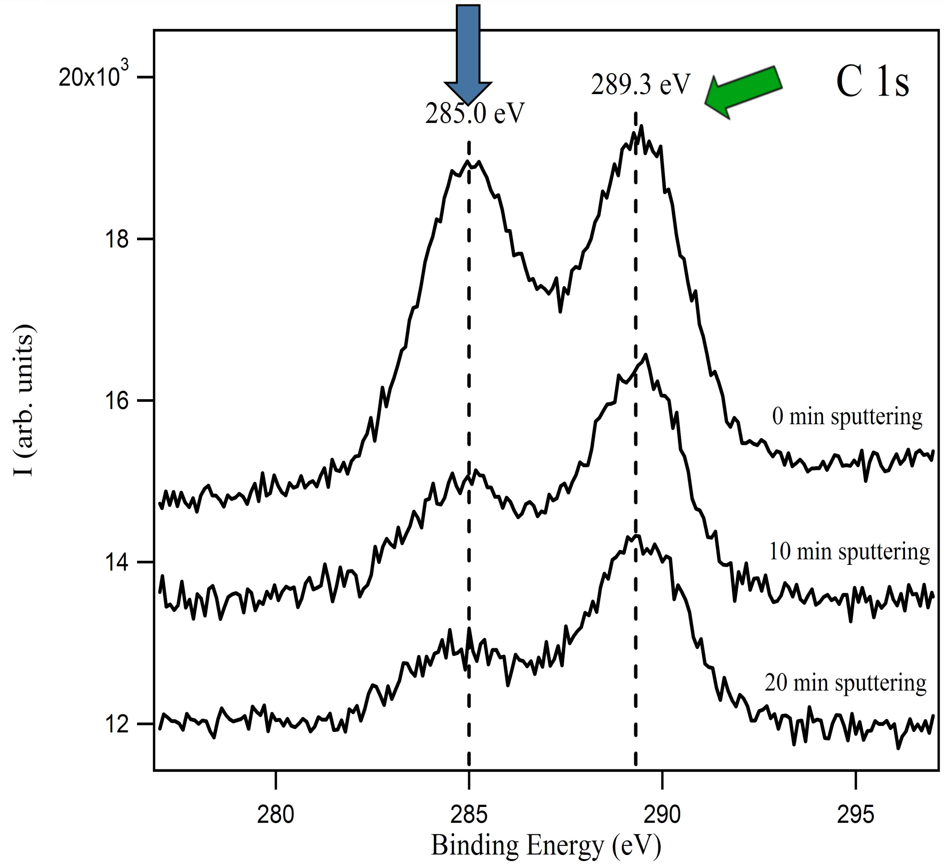


[A. Vascon et al., Nucl. Instr. and Meth. A 696 (2012) 180–191]

XPS-analysis of Nd-layer produced by MP

DETECETD 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

[A. Vascon et al., Nucl. Instr. and Meth. A 696 (2012) 180–191]

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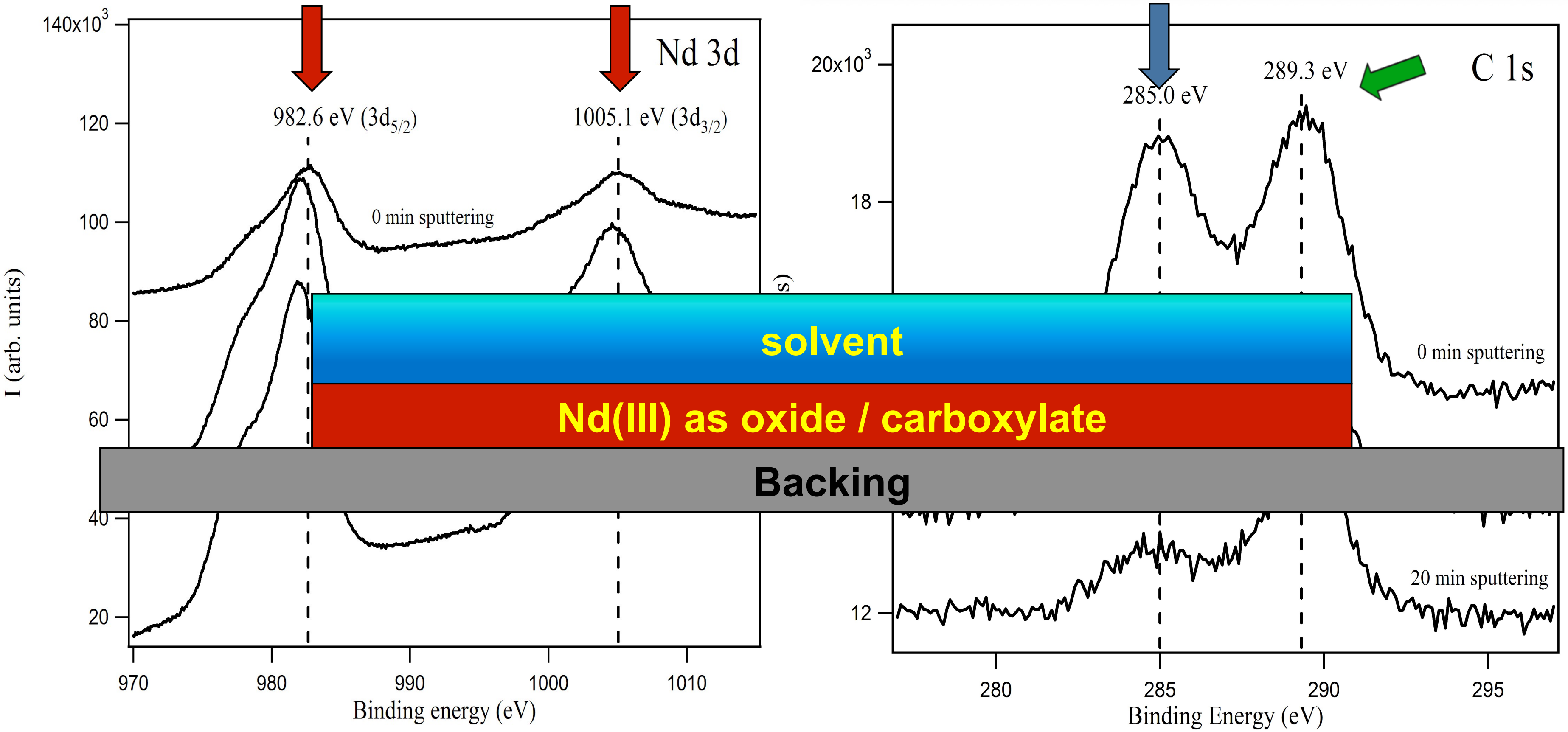

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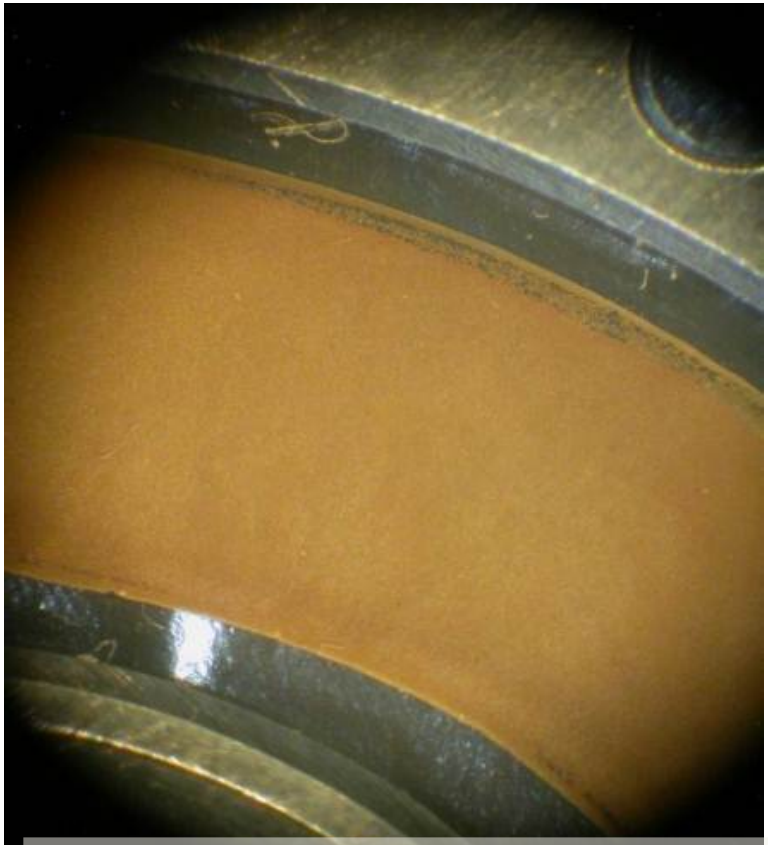
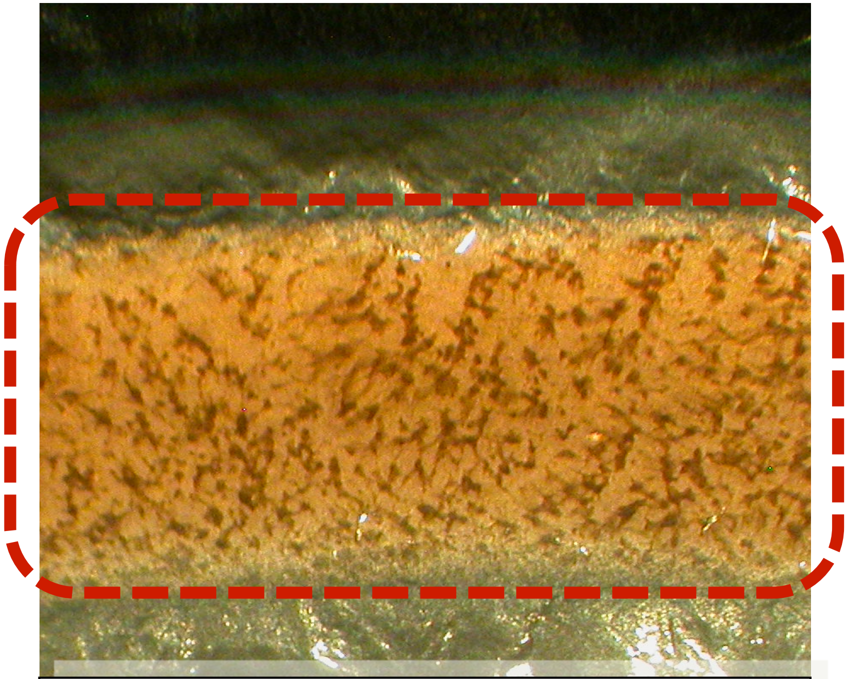
[A. Vascon et al., Nucl. Instr. and Meth. A 696 (2012) 180–191]

In-beam target performance: Morphology change

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



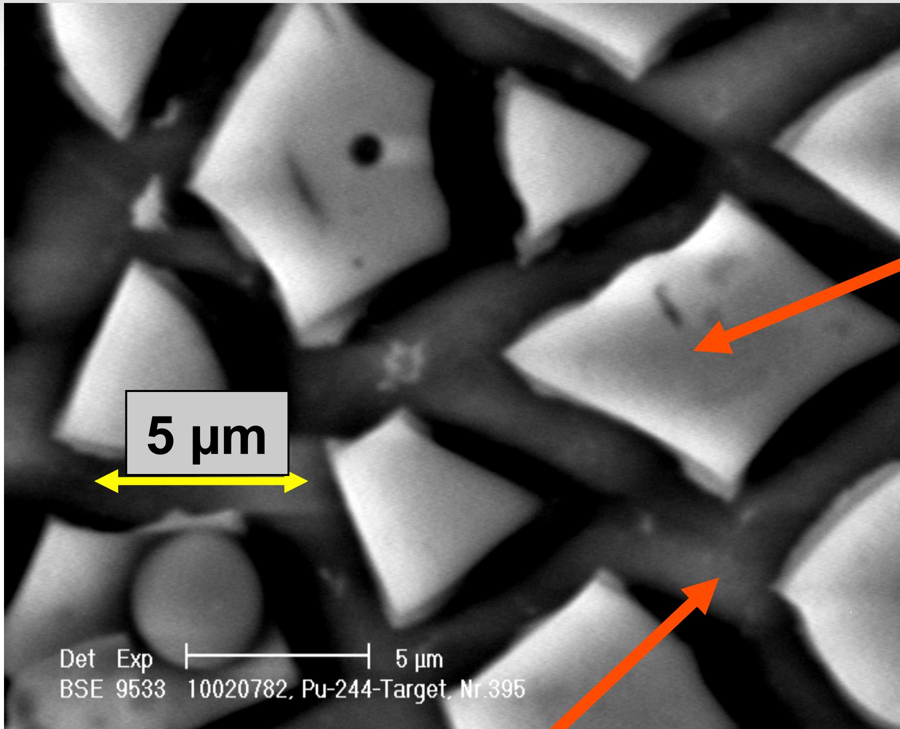
Fresh Pu-244 target layer

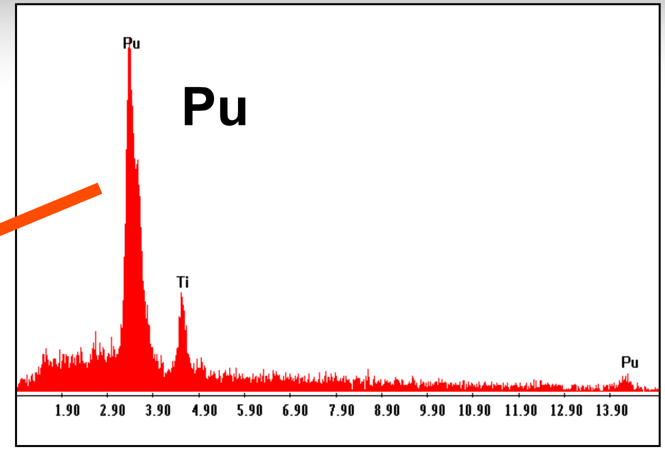


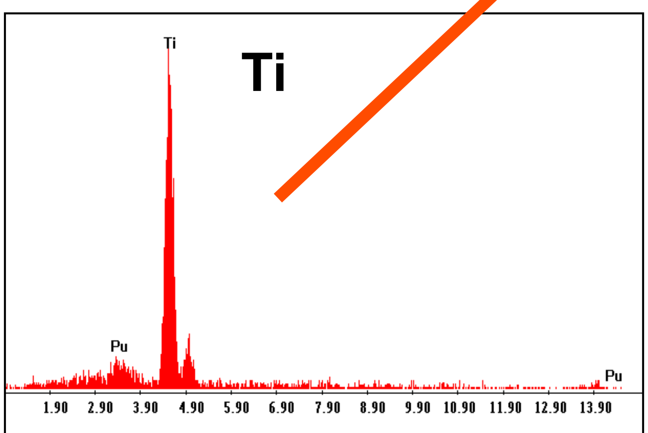
Pu-244 target irradiated with Ca-48. Beam dose > $5x10^{18}$ No material losses but small cracks observed.

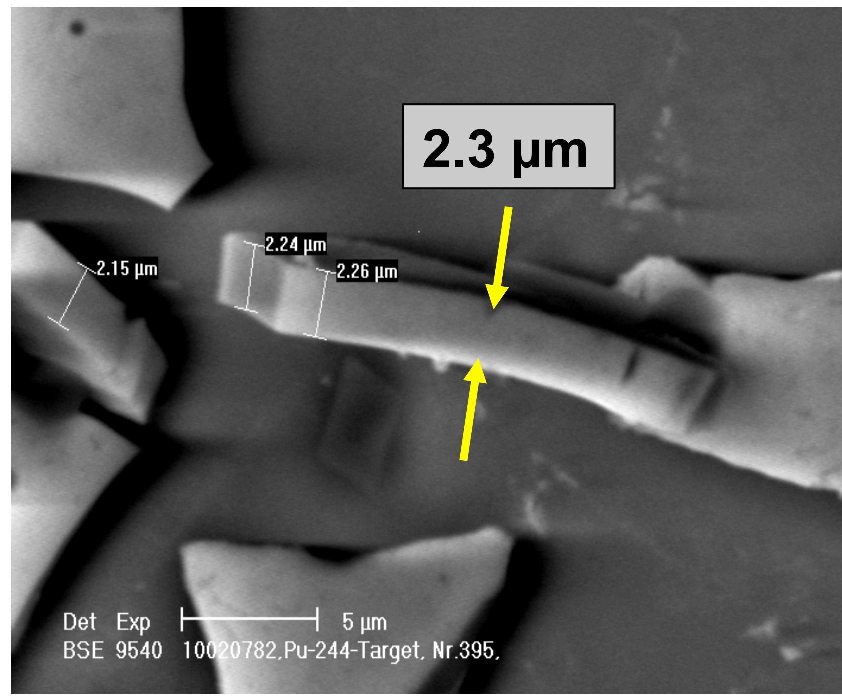
Courtesy: Matthias Schädel, GSI

Fresh target layer





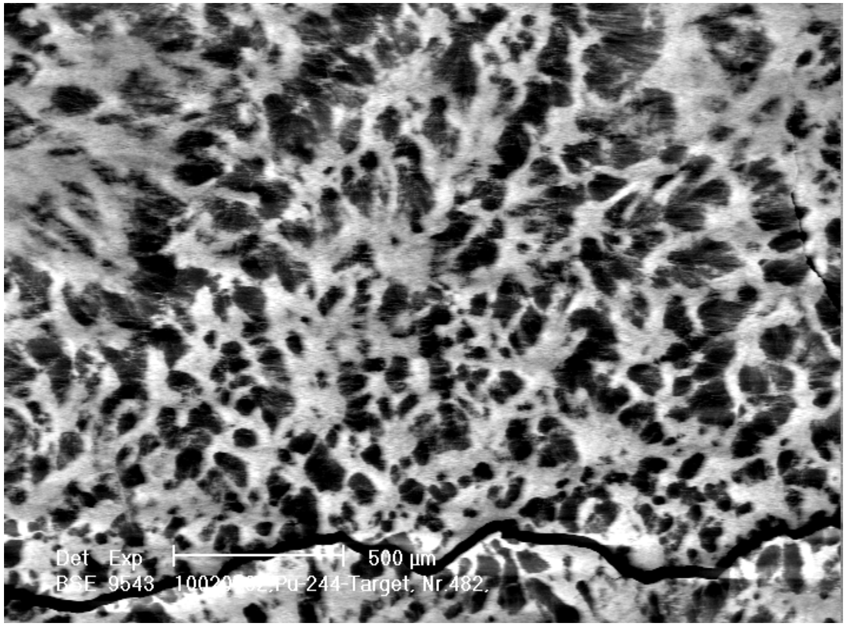


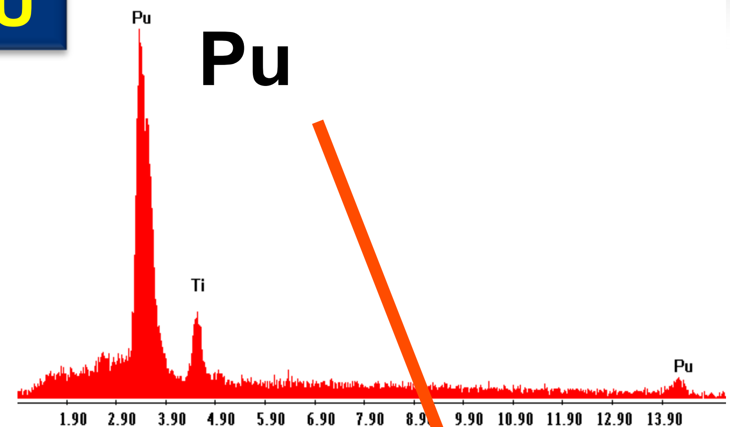


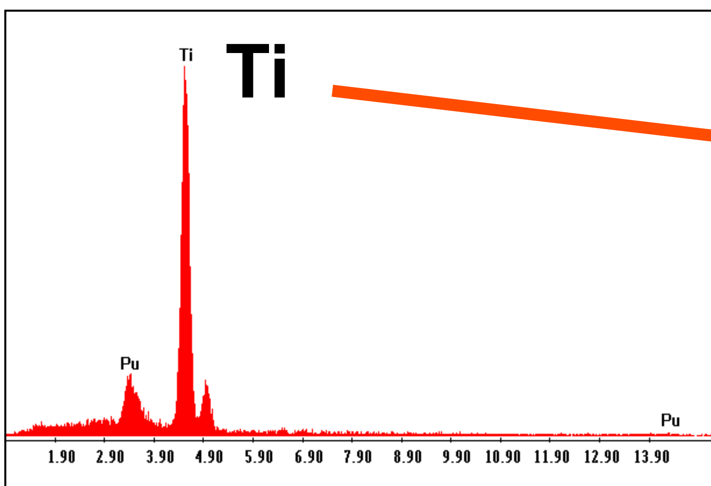
Courtesy: Klaus Lützenkirchen, ITU

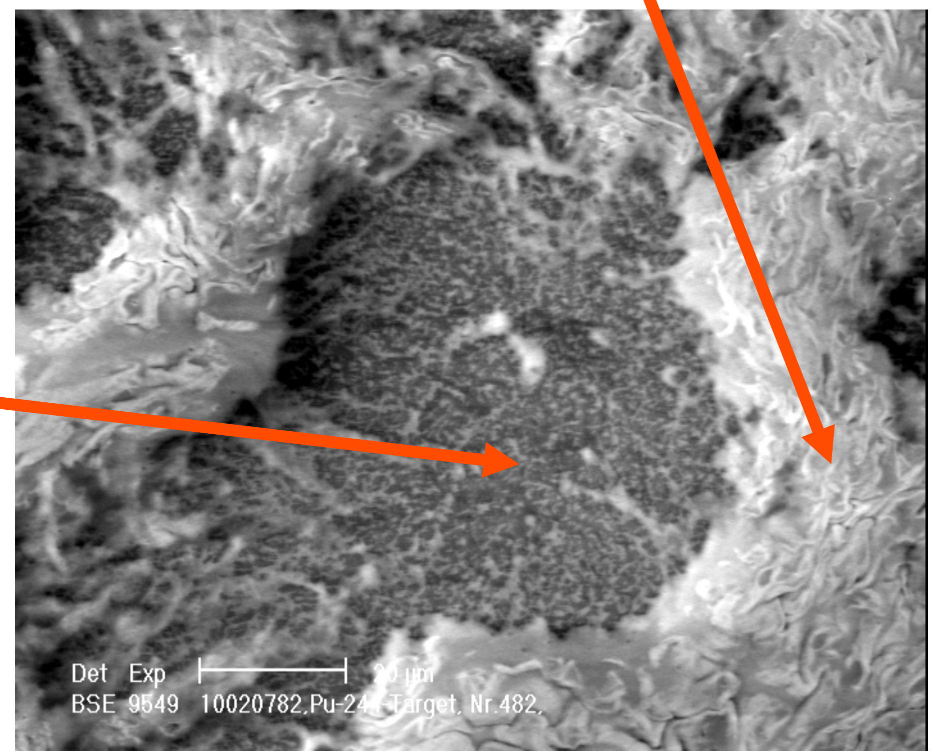
Irradiated target

Courtesy: Klaus Lützenkirchen, ITU



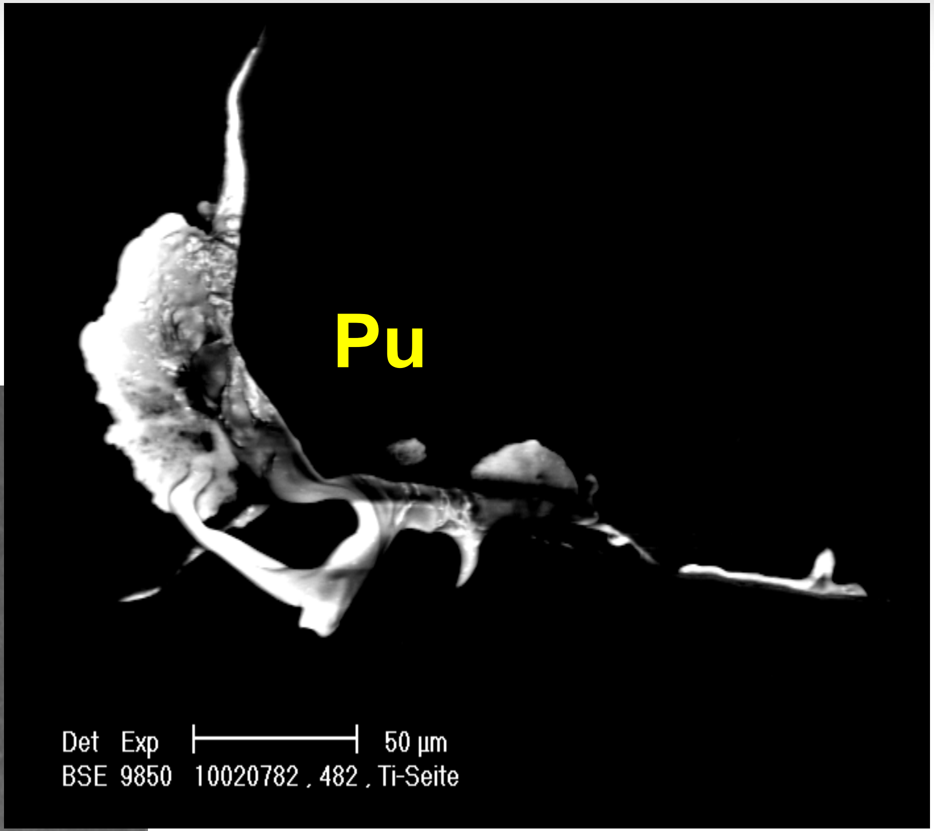


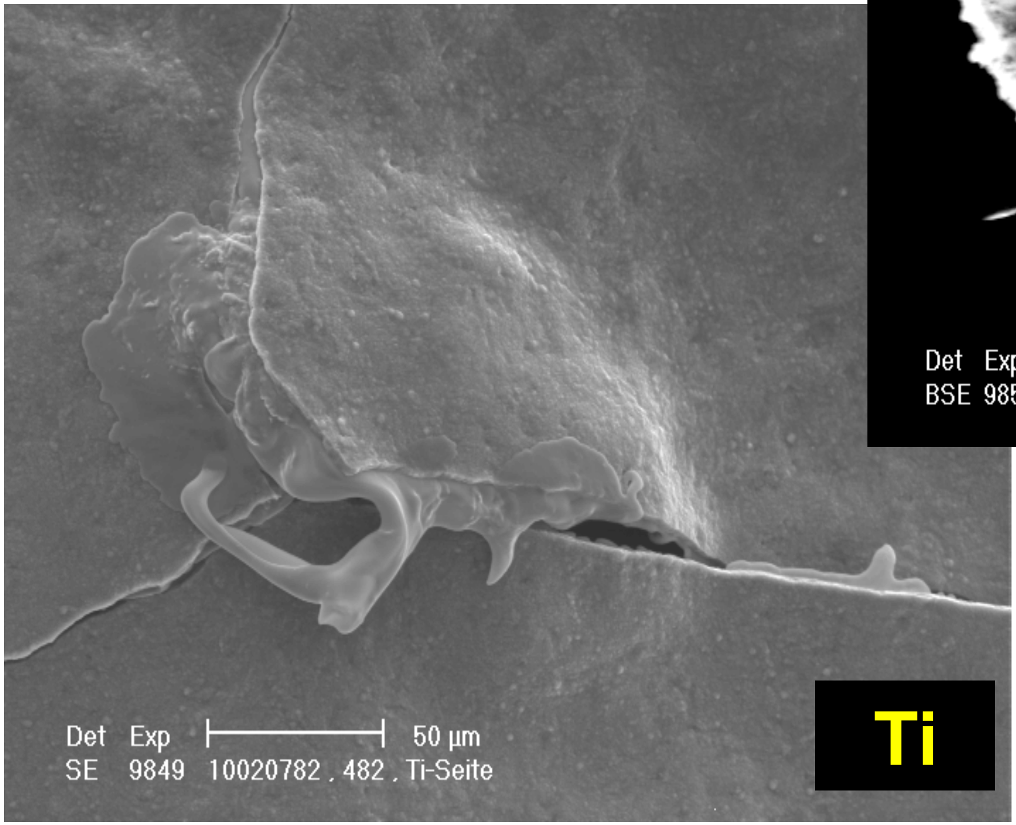




Irradiated target: No Pu-losses but tiny cracks

Courtesy:
Klaus Lützenkirchen, ITU



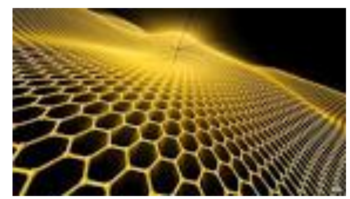


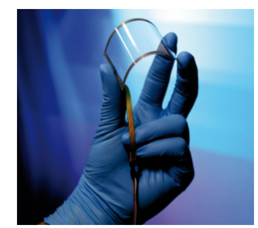
Pu-compound creeps through a small crack to backside of target foil. Crack is closed again….

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

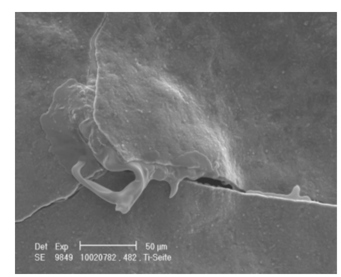
- Alternative backing materials:
  low Z, thin but mechanically stable,
  chemically inert ⇒ <u>Graphene ?</u>





- Alternative production techniques:
  <u>⇒ Ionic liquids, superhydrophobic surfaces</u>

- <u>Actinide</u> target characterization
- Tests of target performance @ 10 pμA



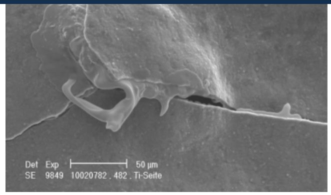
Summary and Outlook

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

Do not forget to adress 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

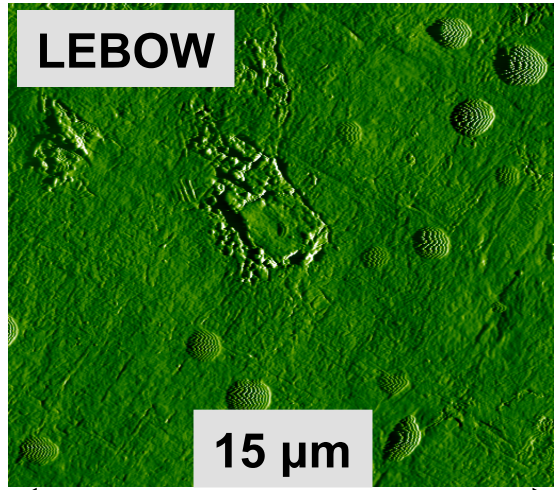


Influence of backing foil

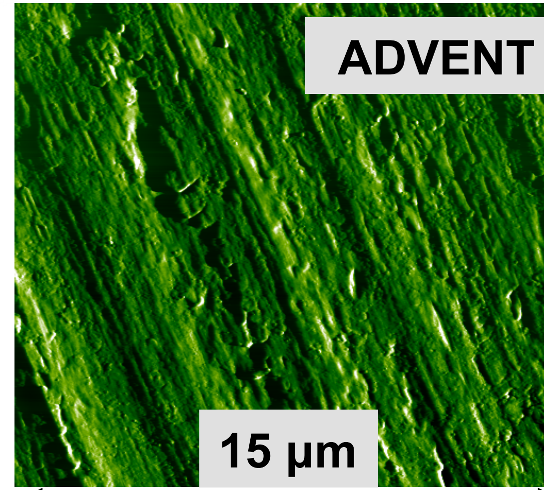
Deposition of Nd (as model element for trivalent actinides) on different Ti substrates.

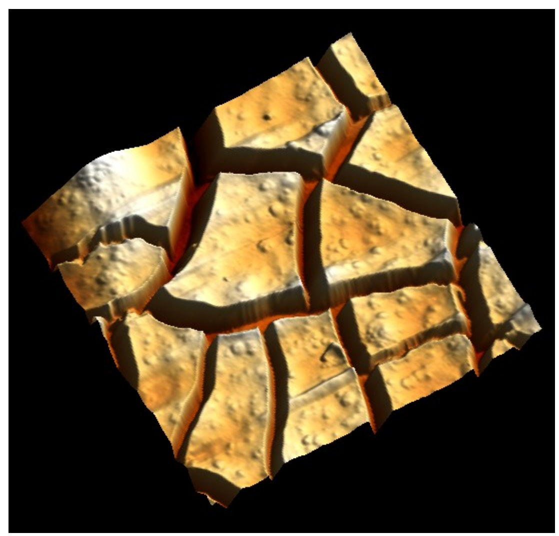
⇒ Surface investigation using Atomic Force Microscopy (AFM)

Roughness: (20 ± 2) nm

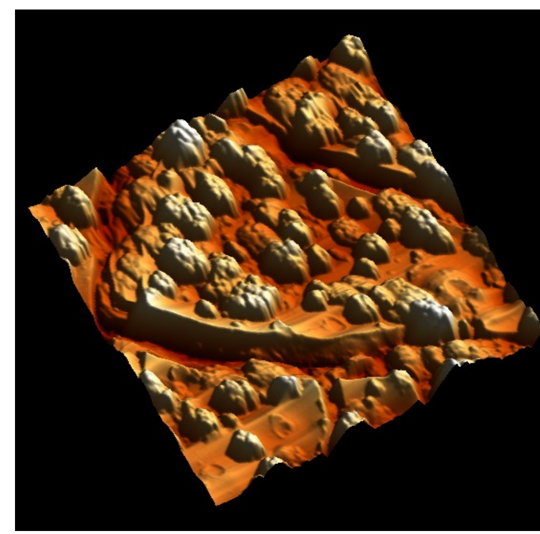


Roughness: (31 ± 3) nm





Roughness: (75 ± 13) nm



Roughness: (92 ± 16) nm