SEM analysis of morphology changes in D irradiated W assisted by FIB

M. Balden, S. Lindig

Max-Planck-Institut für Plasmaphysik, EURATOM Association, Boltzmannstraße 2, D-85748 Garching, Germany

Contributions:

A. Manhard, O. Ogorodnikova, J. Roth

Max-Planck-Institut für Plasmaphysik, EURATOM Association, Boltzmannstraße 2, D-85748 Garching, Germany

V. Alimov*, T. Yamanishi*

Tritium Technology Group, Japan Atomic Energy Agency, Tokai, Ibaraki 319-1195, Japan

Motivation

- **Knowledge of morphology changes of tungsten at high D fluences** *(> 10^{24} m^{-2})* **with seeding impurities and at low** *(RT – 1000 K)* **and high** *(>1000 K)* **temperatures**

  ⇨ **Impact on T retention assessment**

  ⇨ **Material degeneration: Erosion and safety aspects**

Which is the best W grade to withstand plasma loading?

What is the history of the W surface?

Martin Balden@ipp.mpg.de

Content

- **Material analysis with SEM assisted by FIB & EBSD**

- **Surface morphology:**
  Blistering of W and other surface extrusions
  Examples: dependence on W grade, temperature, flux

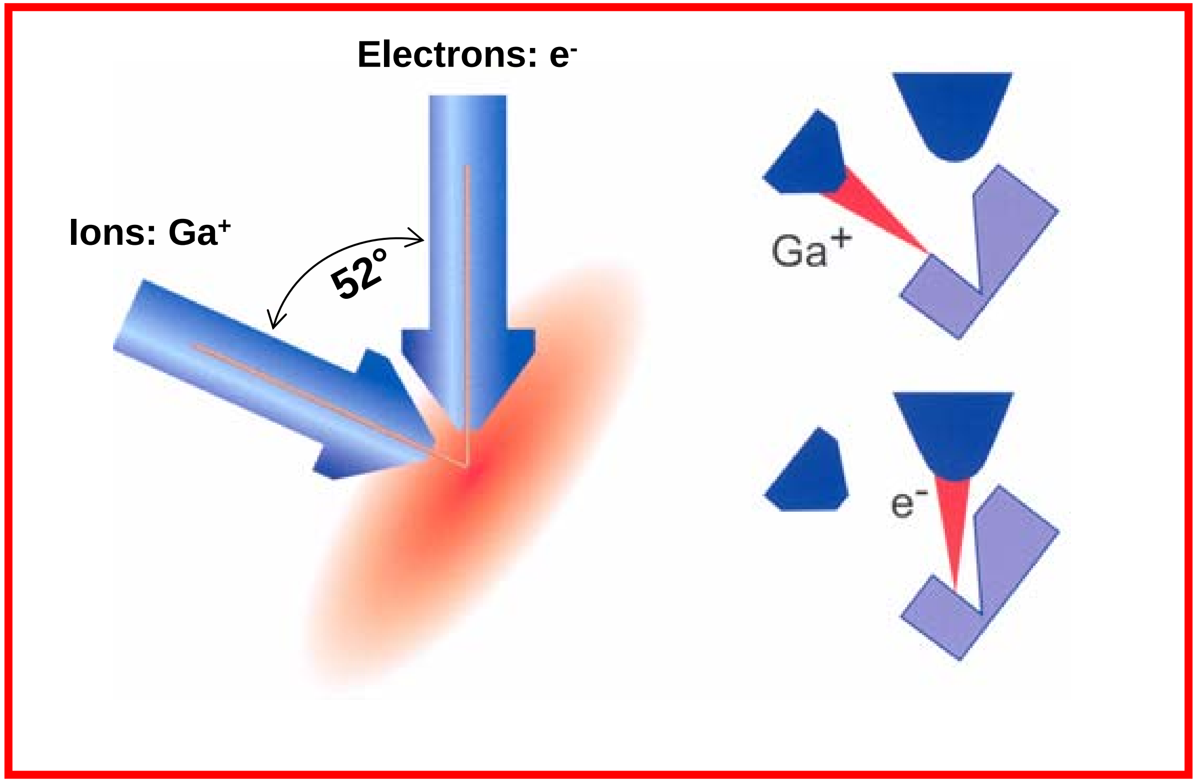
- **Mechanistic explanations for some observations**
  supported by analysing the subsurface morphology by FIB

- **Classification and mechanisms**
  of blister/surface extrusions

- **Conclusion / outlook**

Martin Balden@ipp.mpg.de

Material analysis with SEM assisted by FIB & EBSD



- **3D structure of features by** **sequential FIB cutting** *(nm precision)* **and** **SEM imaging** *(nm resolution)*
- **Grain orientation by EBSD** *(diffraction technique)*

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Material analysis with SEM assisted by FIB & EBSD

LN-Reservoir for EDX detector

Electron column

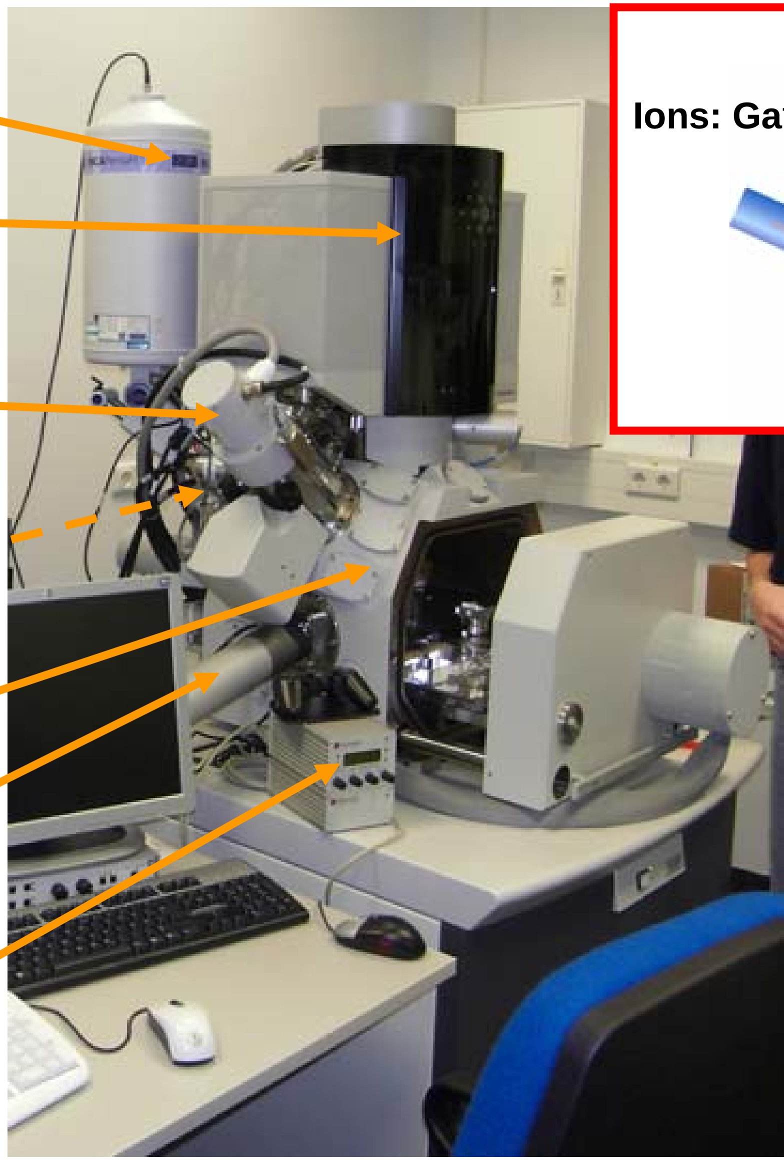
Gallium ion column

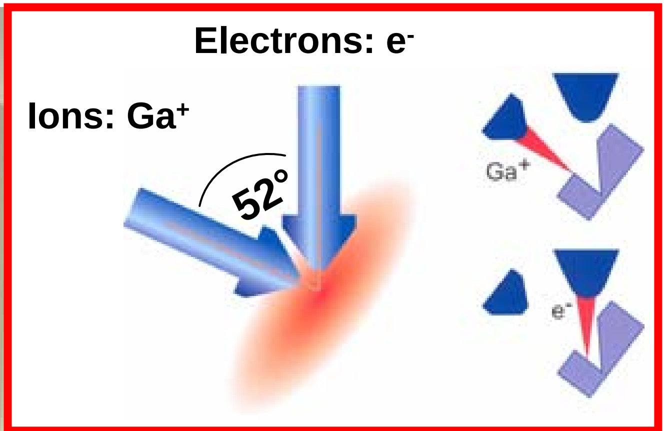
Gas injection system for coating with Pt-C layer

Vacuum chamber

EBSD detector

Nano manipulator control





Helios NanoLab 600 FEI

more

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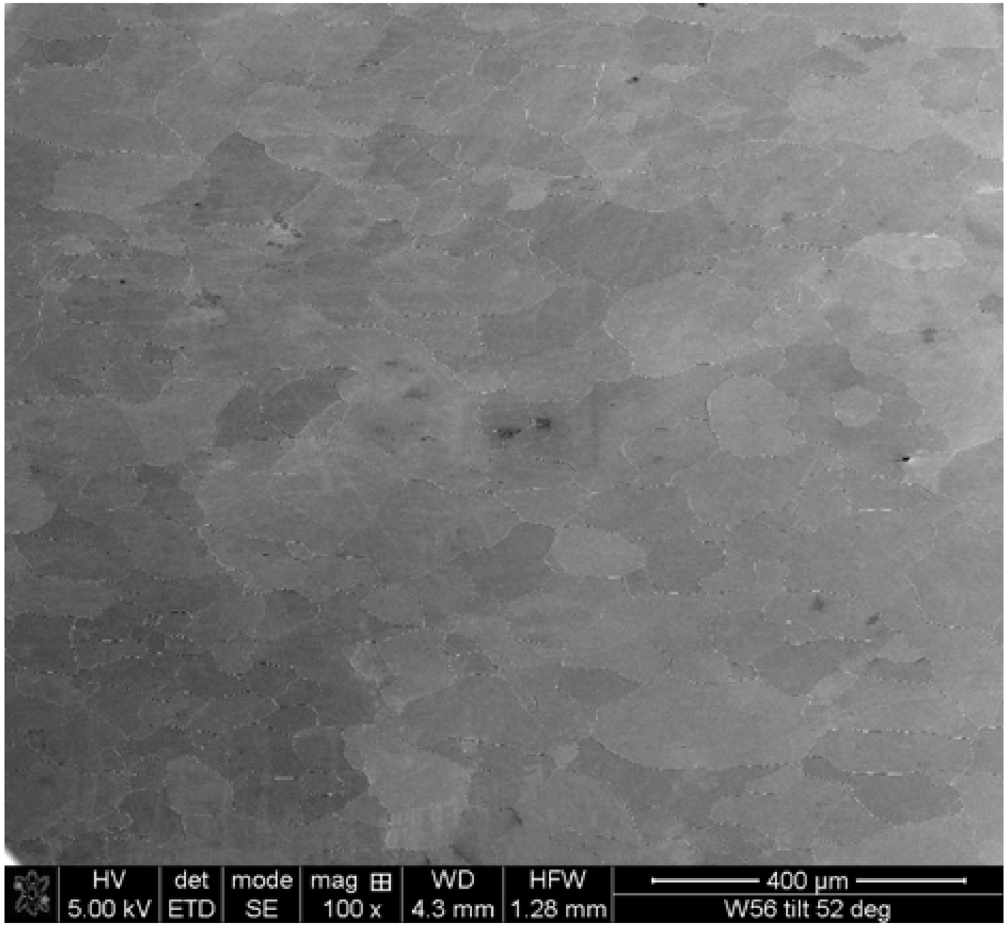
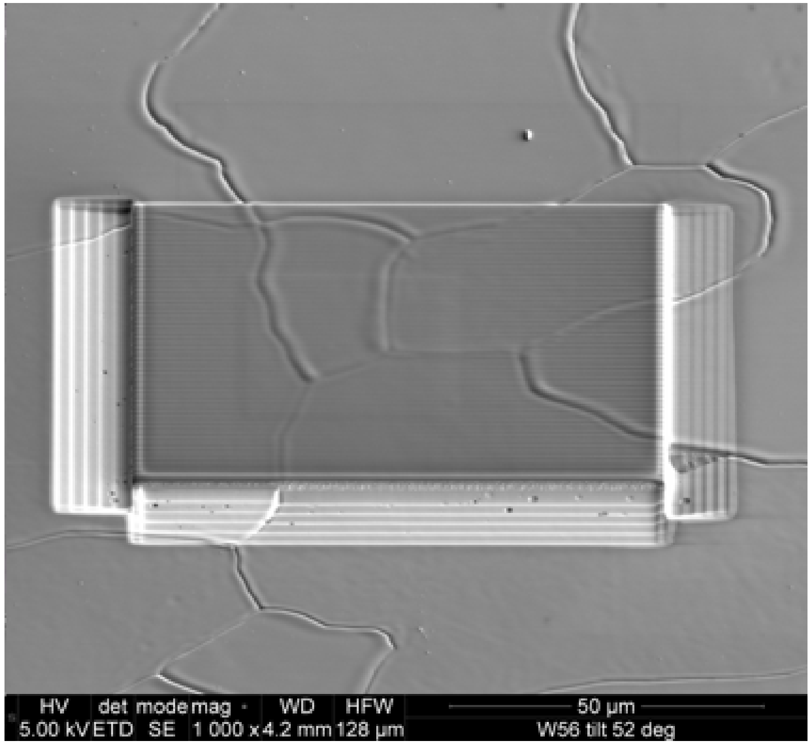
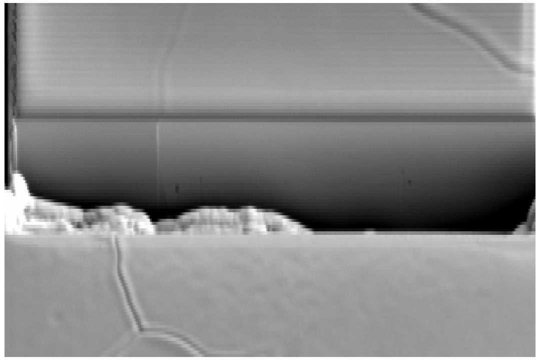
Re-crystallized W: initial







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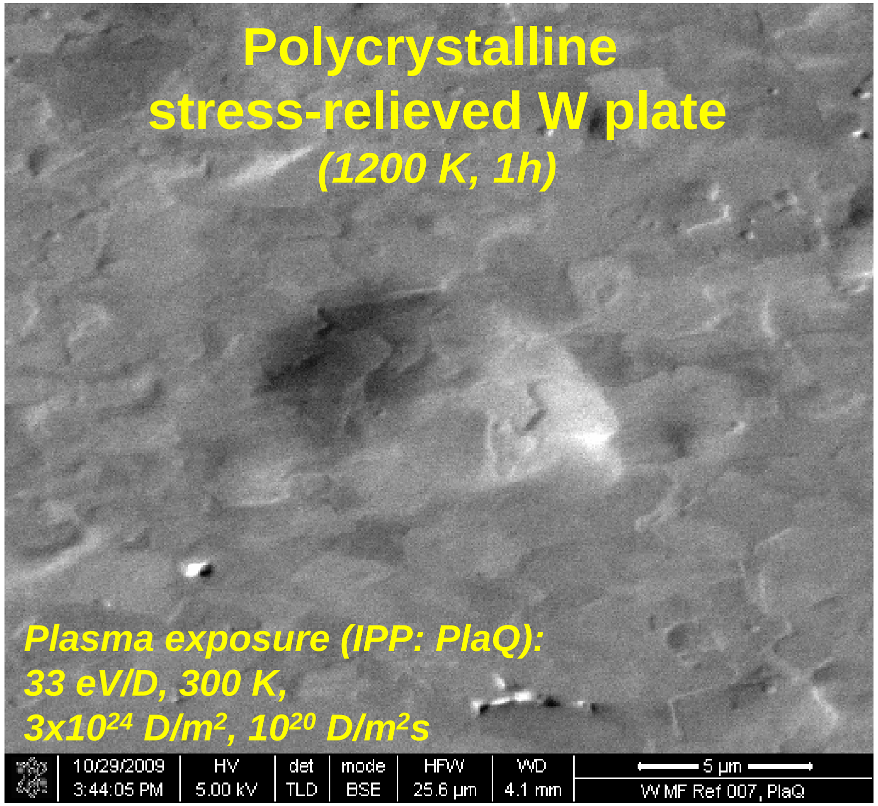
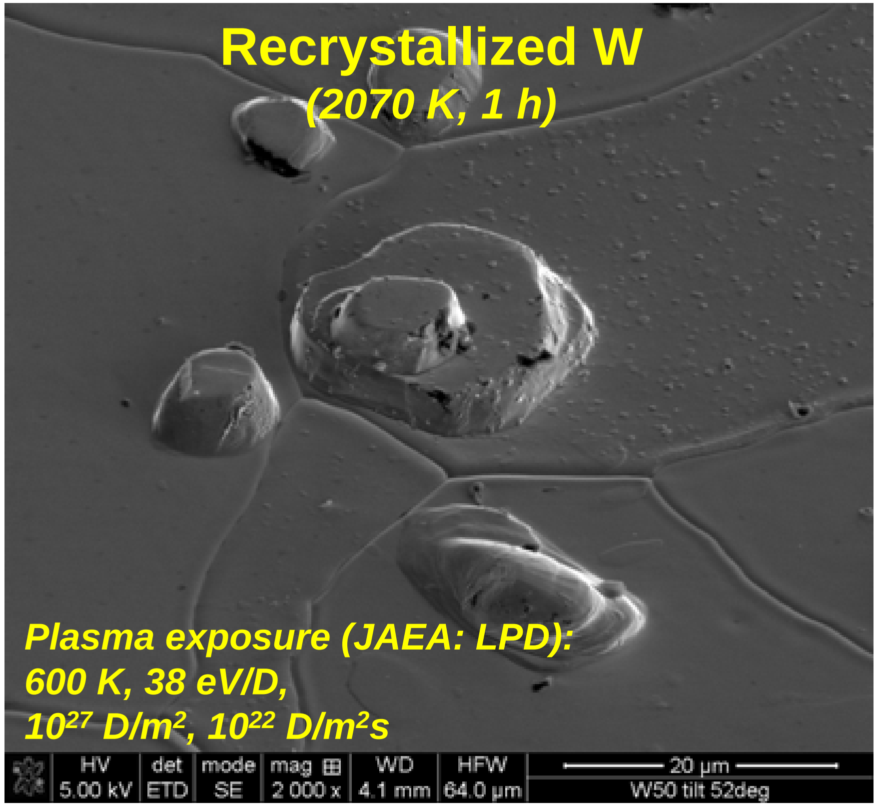
Surface morphology dependence on W grade

- ➢ **Blistering & other surface extrusions**

⇨ **Strongly differing morphology ⇨ other mechanism**





- ➢ **Note: W expected to get hot**

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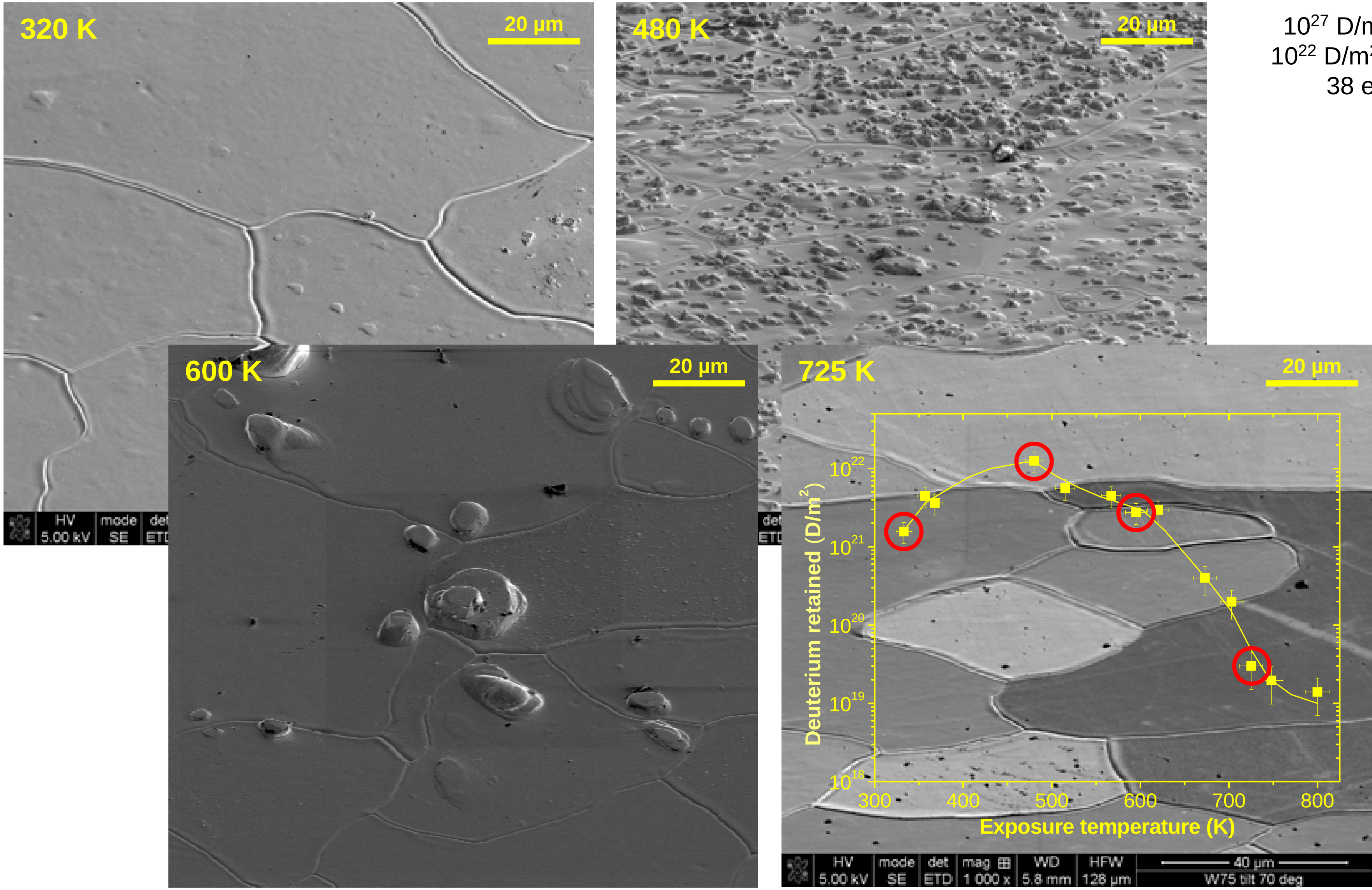
Temperature dependence on recrystallized W



10^{27} D/m^2
10^{22} D/m^{2}s
38 eV

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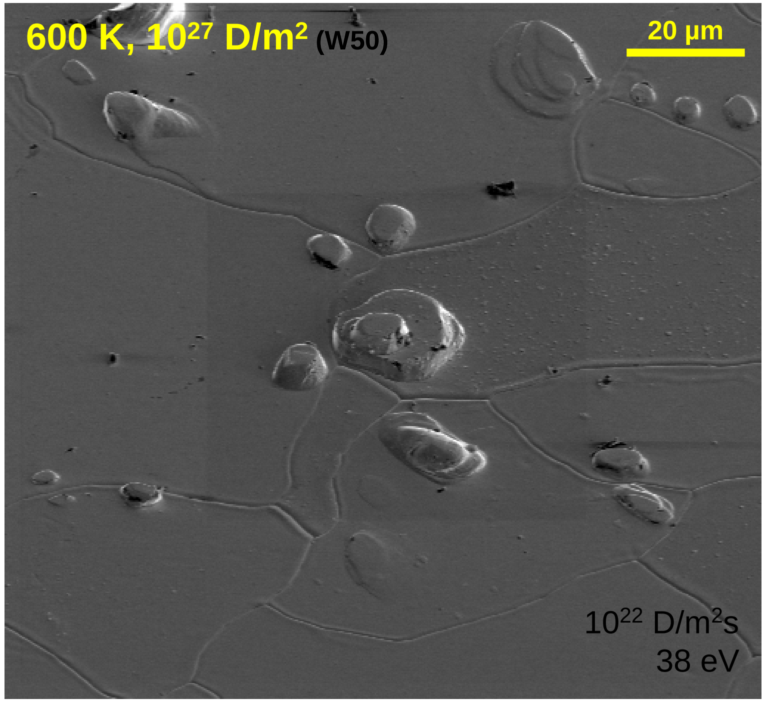
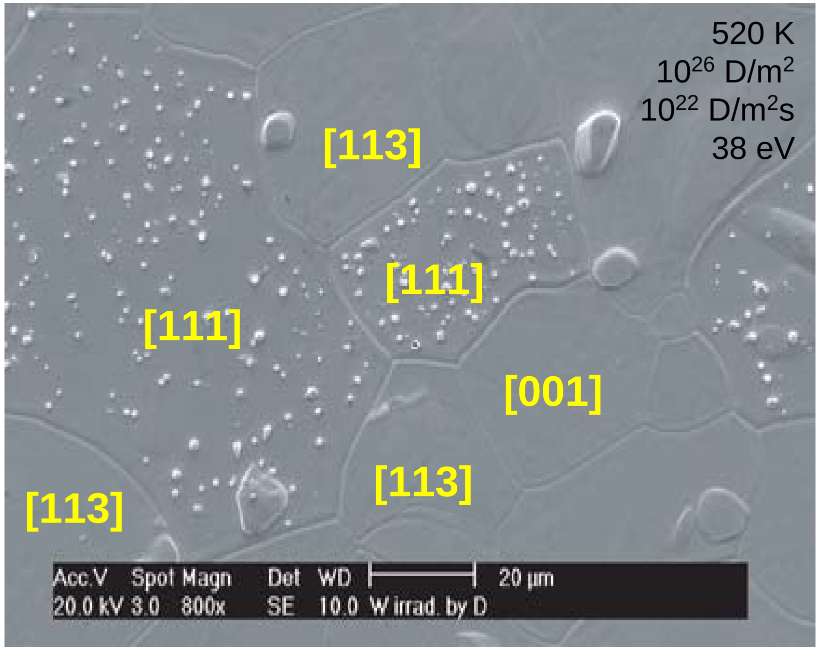
- **Morphology of extrusions depends on crystal orientation** *(features mostly restricted to one grain)*

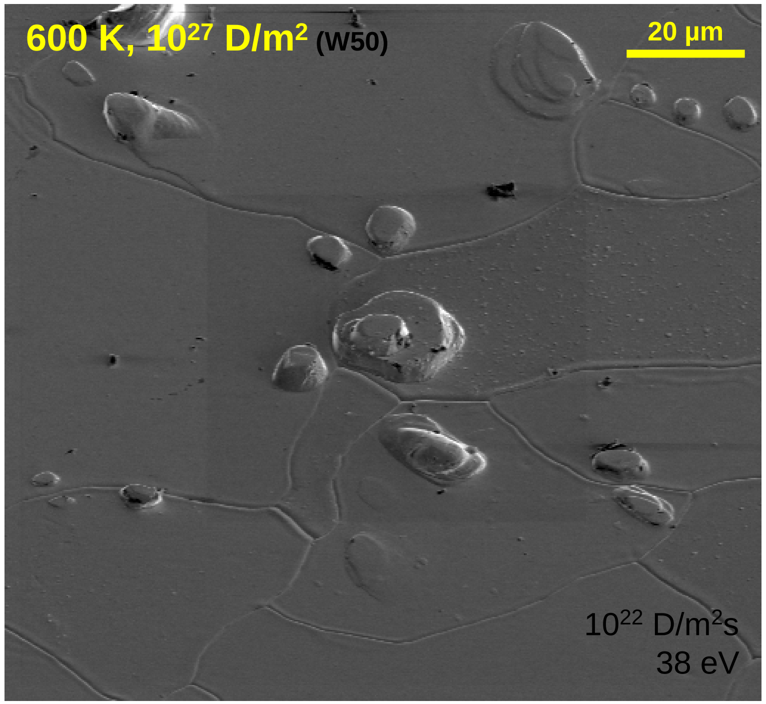


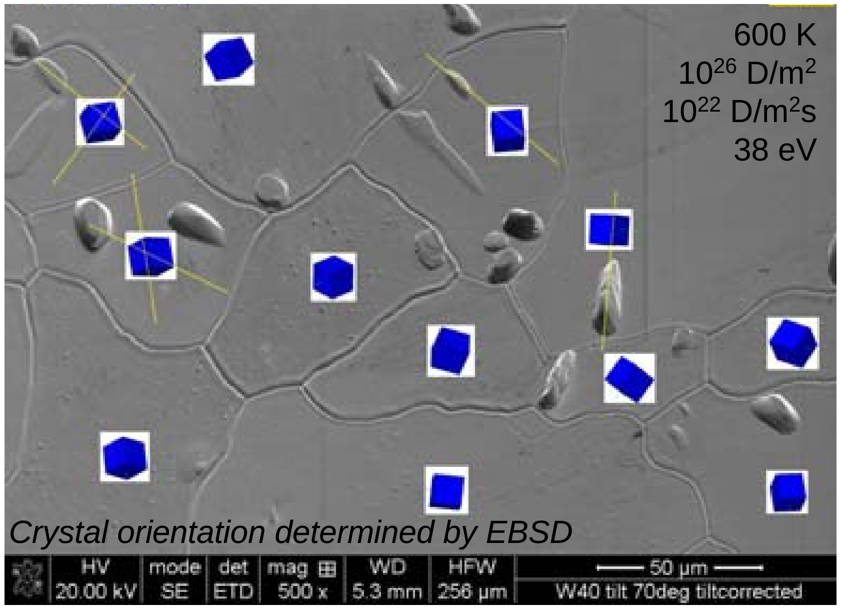


W.M. Shu et al., Physica Scripta T128 (2007)

Recrystallized W

- **Morphology of extrusions depends on crystal orientation** *(features mostly restricted to one grain)*
- **Stepped extrusions formed by <u>gliding</u> along slip system {110} ⟨111⟩ in tungsten ⇨ <u>ductile</u> behaviour** *(even at <600 K)*





S. Lindig et al., Phys. Scripta T138 (2009)

Martin Balden@ipp.mpg.de

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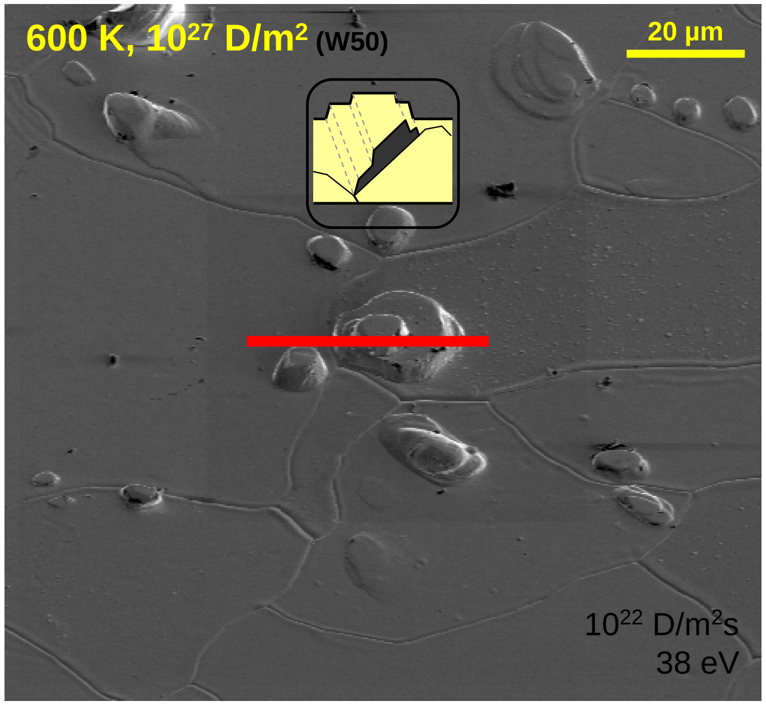
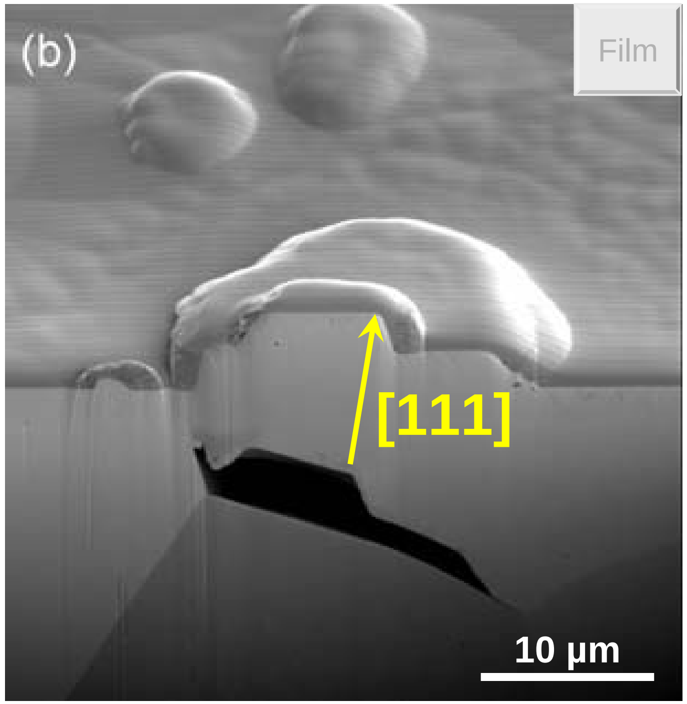
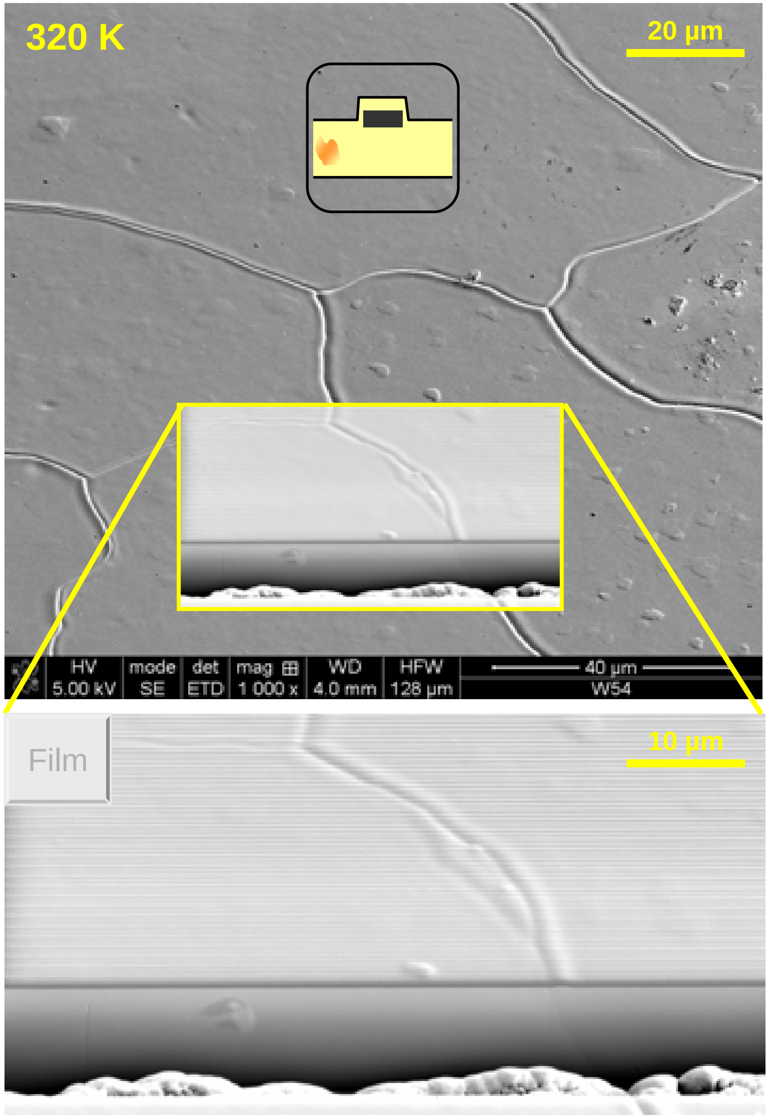
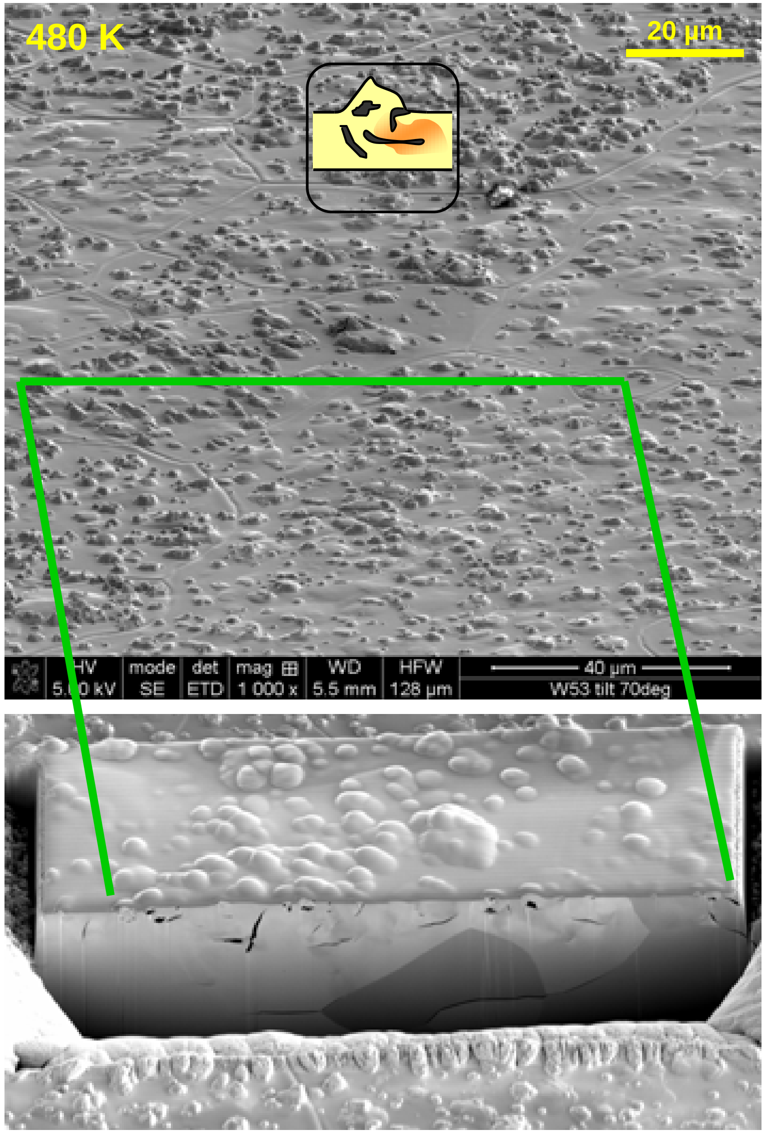




Morphology investigations: Subsurface





10^{27} D/m^2
10^{22} D/m^{2}s
38 eV

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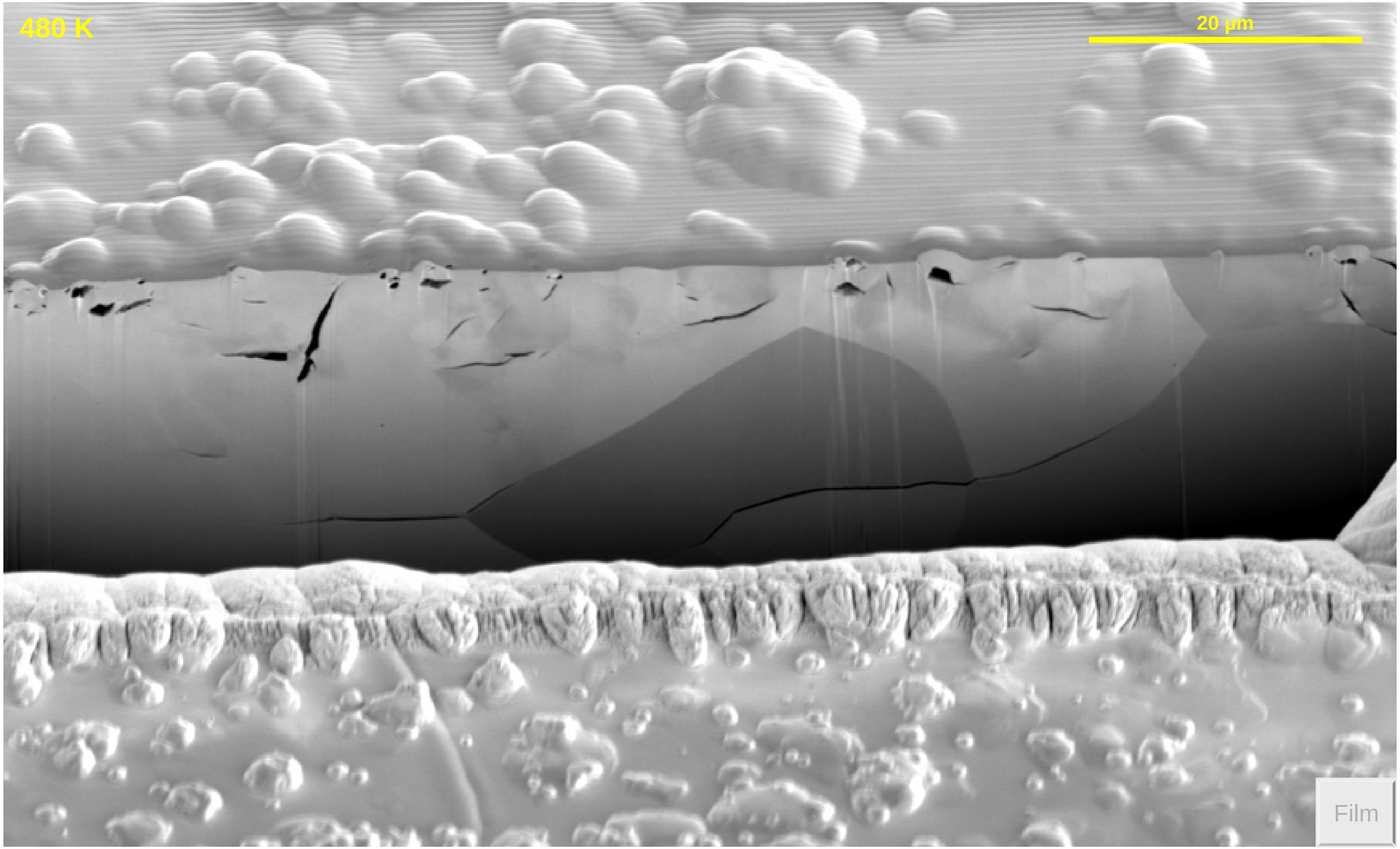
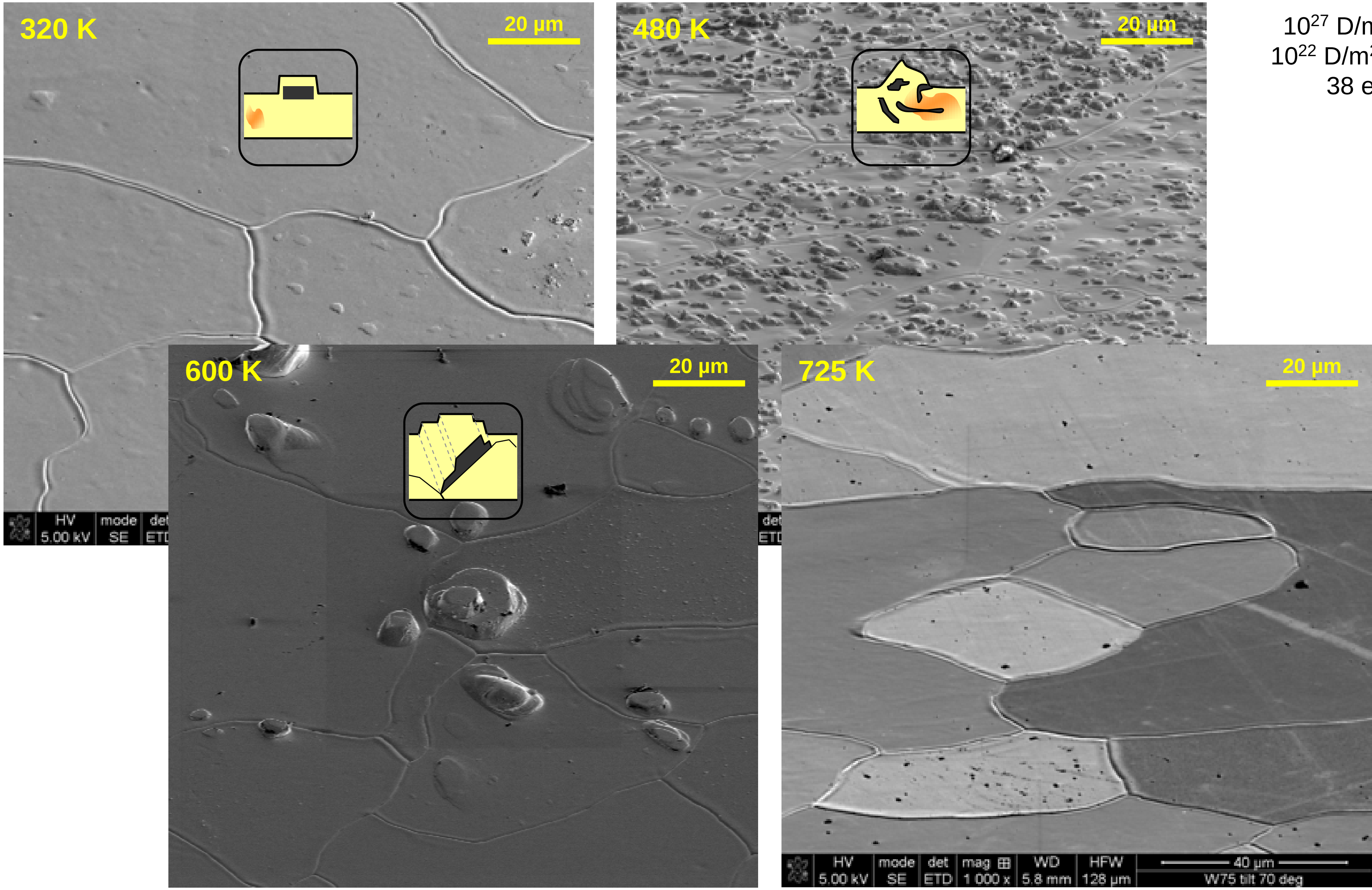
Martin Balden@ipp.mpg.de

Morphology investigations: Subsurface

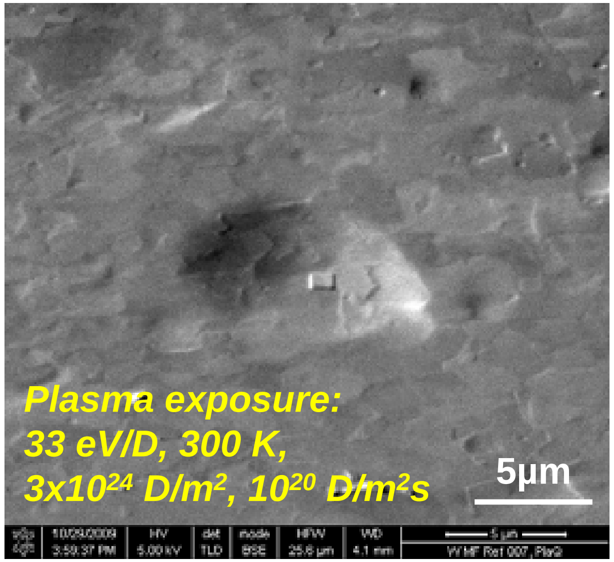


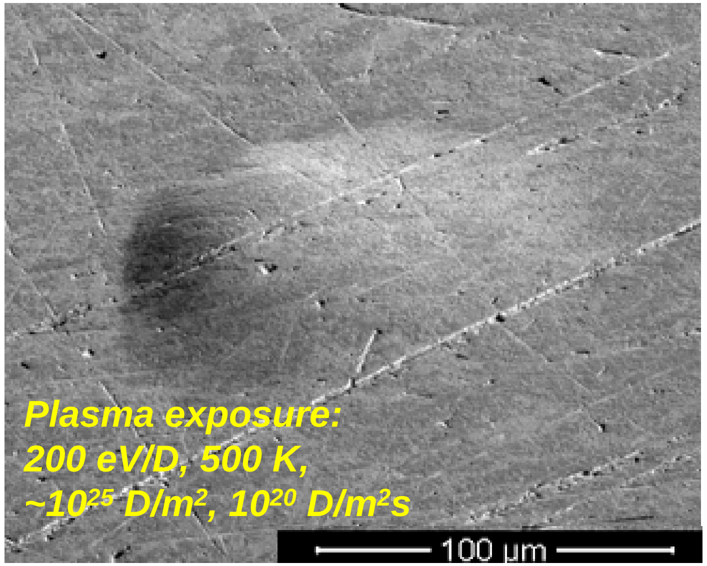
Temperature dependence on recrystallized W

10^{27} D/m^2
10^{22} D/m^{2}s
38 eV



Polycrystalline tungsten

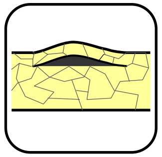


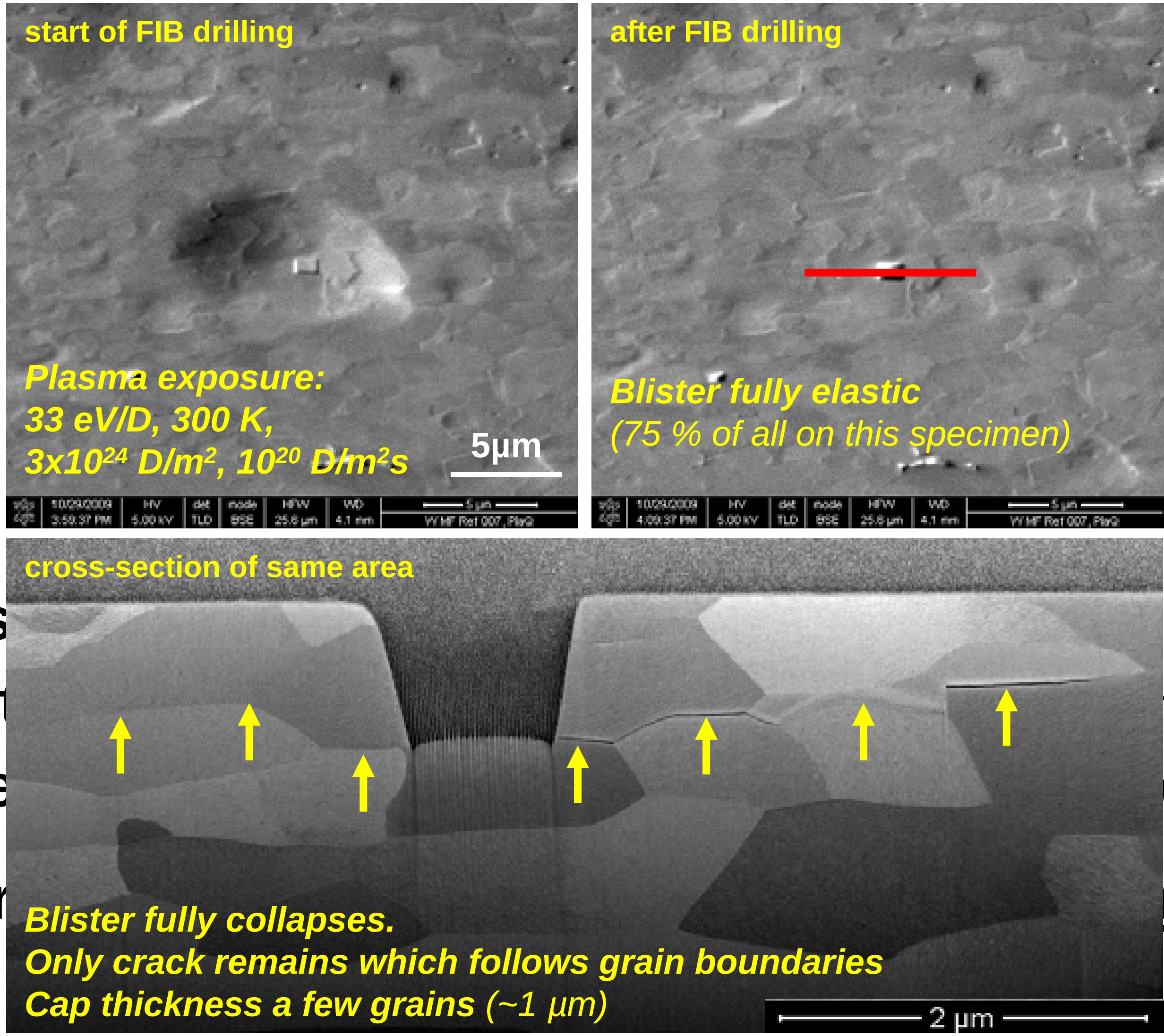


- **Blister size increase**
  - **with temperature** *(and vanish above 700 K as for recry. W)*
  - **weaker with energy** *(proposed, under investigation)*

⇨ **Morphology of blister strongly affected by <u>W grade</u>**
(e.g. polycrystalline vs. recrystallized)

Polycrystalline tungsten





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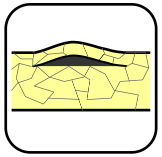
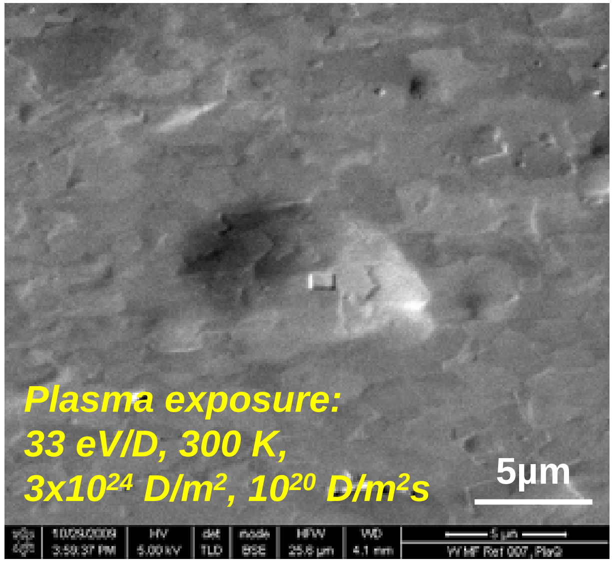
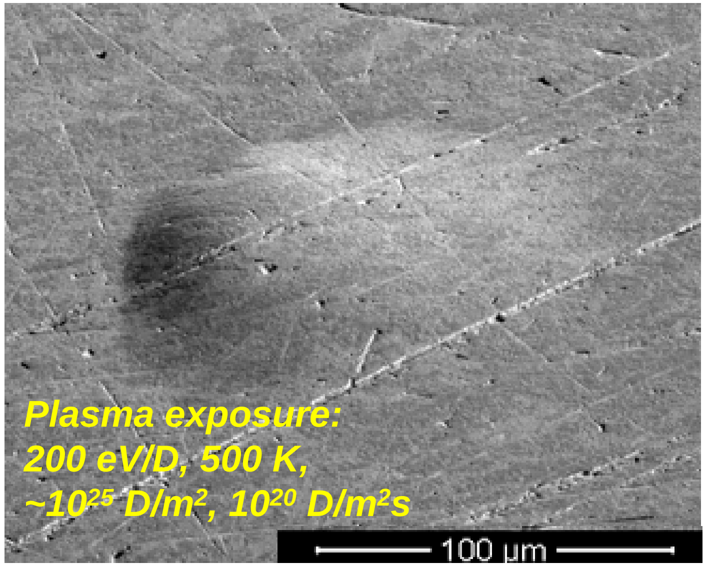
- **Blis**
  wi *ecry. W)*
  we *n)*

⇨ **Mor** **__V grade__**
(e.g.

Polycrystalline tungsten

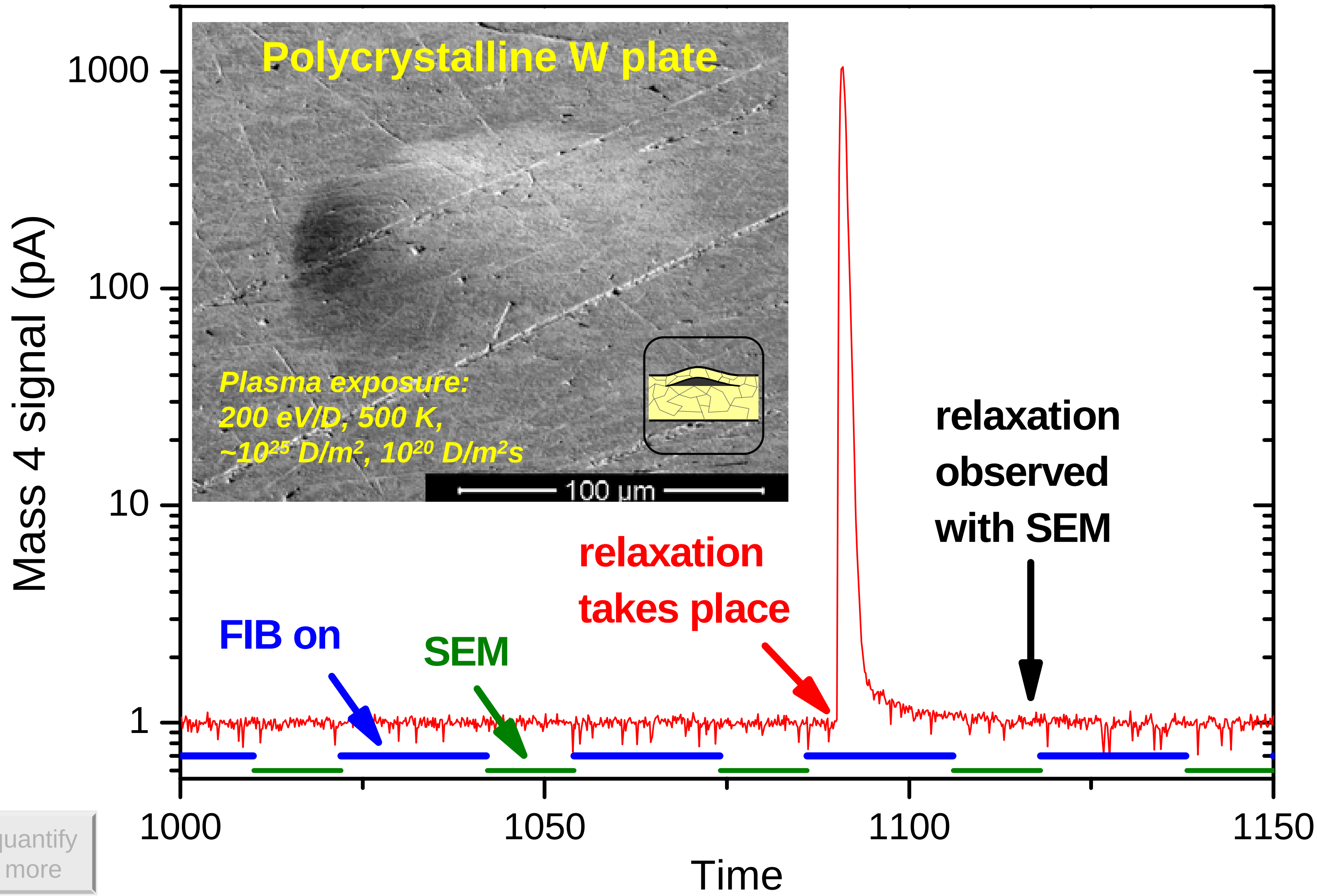






- **Blister size increase**
  - **with temperature** *(and vanish above 700 K as for recry. W)*
  - **weaker with energy** *(proposed)*
- **Partly elastic blister caps**
- **D_2 gas-filled blisters** *(FIB drilling + QMS)* ⇨ **quantify ?**

Polycrystalline tungsten



quantify more

Polycrystalline tungsten: Note

➢ Disappearance of blistering

- *surface finishing, e.g., strongly scratched* ***D. Nishijima et al., Nucl. Fusion 45 (2005)***
- ***He****-seeded D exposure* ***D. Nishijima et al., Nucl. Fusion 45 (2005); Alimov et al. Phys. Scr. T138 (2009)***
- ***Be****-seeded D exposure* ***R. Doerner et al., J. Nucl. Mater., PSI-2010***

➢ but not prevented by

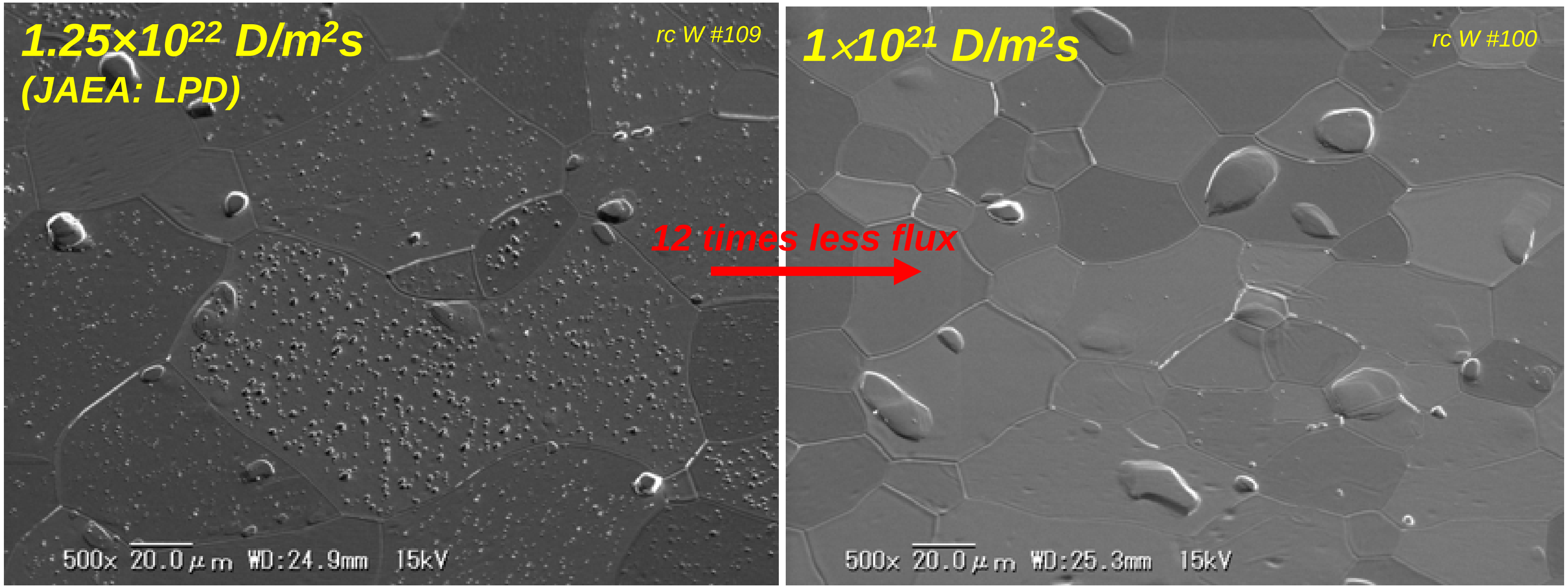
- ***C****-seeded D exposure* ***Y. Ueda et al., Nucl. Fusion 44 (2004)***
- ***N****-seeded D exposure* ***(unpublished results at PISCES and at IPP)***

⇨ "History" of W material is extremely important!

Martin Balden@ipp.mpg.de

Flux dependence on recrystallized W

Plasma exposure: 490 K, 38 eV/D, 10^{26} D/m^2 *(recrystallized at 2070 K, 1 h)*



- **High flux: Extrusions due to gliding and small features due to cracking and distortion inside individual grains**
- **Low flux: Only extrusions due to gliding remain; small features missing due to less dynamic D inventory**

Martin Balden@ipp.mpg.de

Conclusion & outlook

- **Various surface extrusions described**
  ⇨ *dependent on W grade, temperature, fluence, flux*
- **Some new facts about blister**
  fully elastic and D_2 gas filled blister ⇨ *quantified* ⇨ *mech. properties*
- **No direct prediction of D retention possible *yet***
- **Partly correlation between morphology of extrusions & formation mechanism proposed / determined** ⇨ *proceed* ⇨ *correlation to D retention*

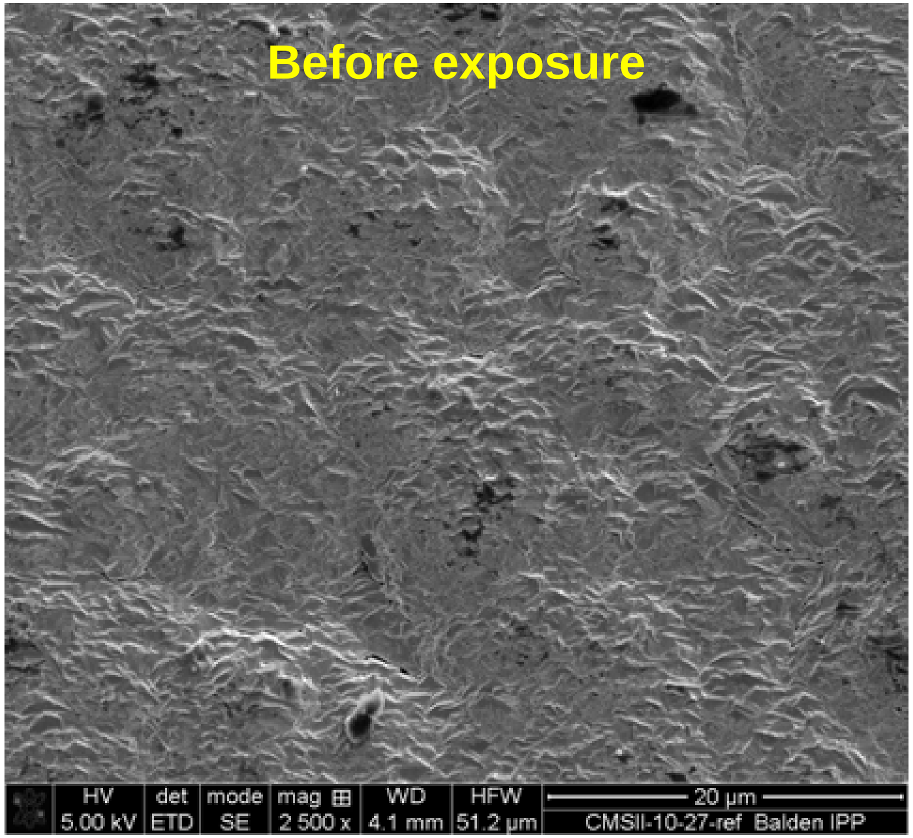
⇨ **Material degeneration:**
Cracking, overheating, grain loss, …

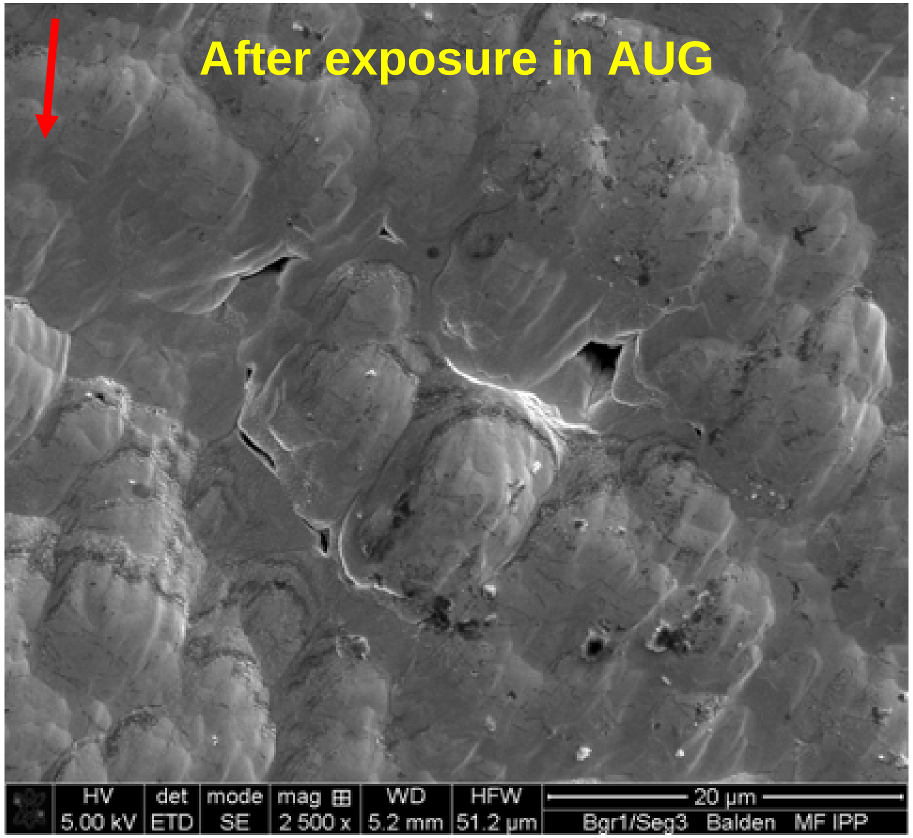
- **Final note** ⇨ *more global "history" of W tile*
  ↳ *AUG tile*

Martin Balden@ipp.mpg.de

Final notes

➢ W coating in AUG

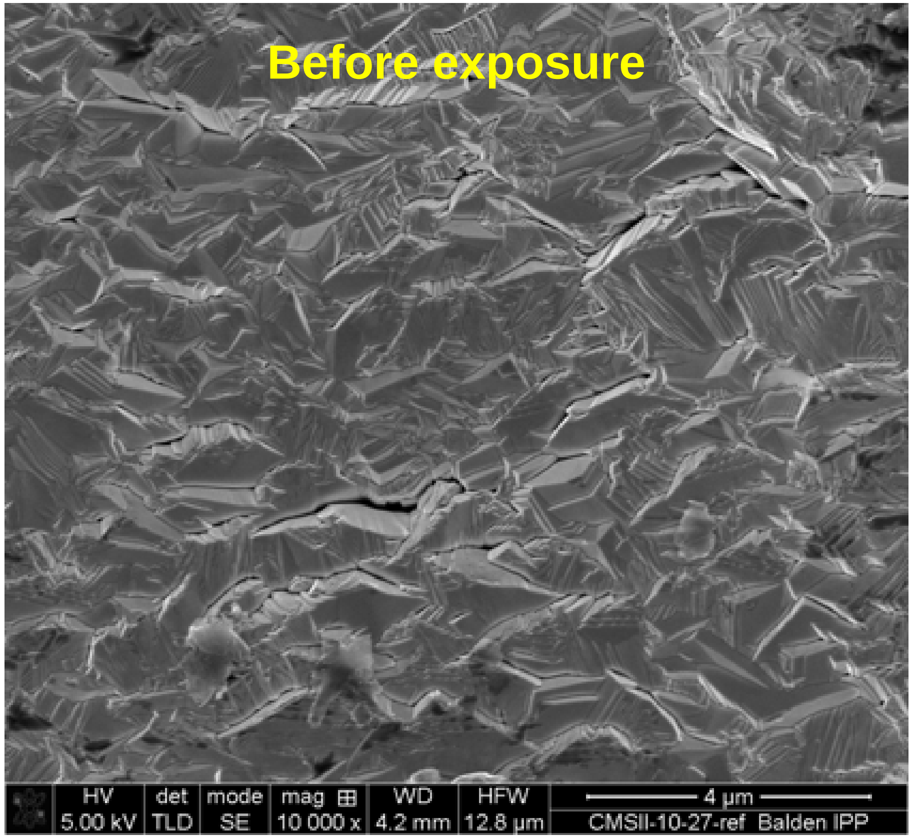


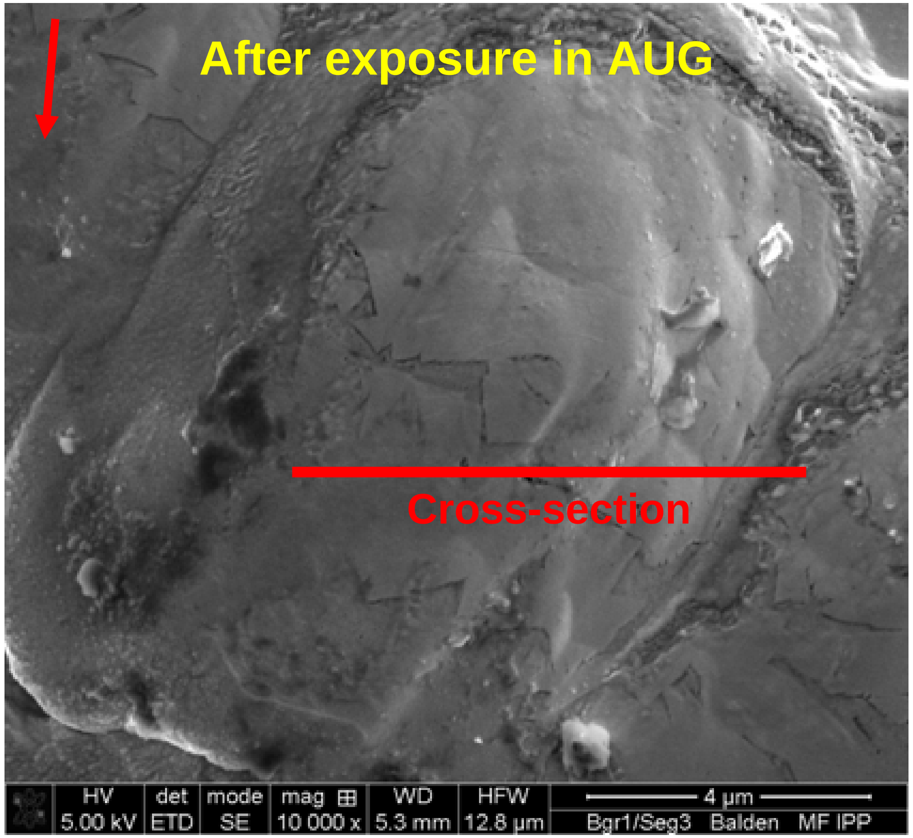


Martin Balden@ipp.mpg.de

Final notes

- **W coating in AUG**





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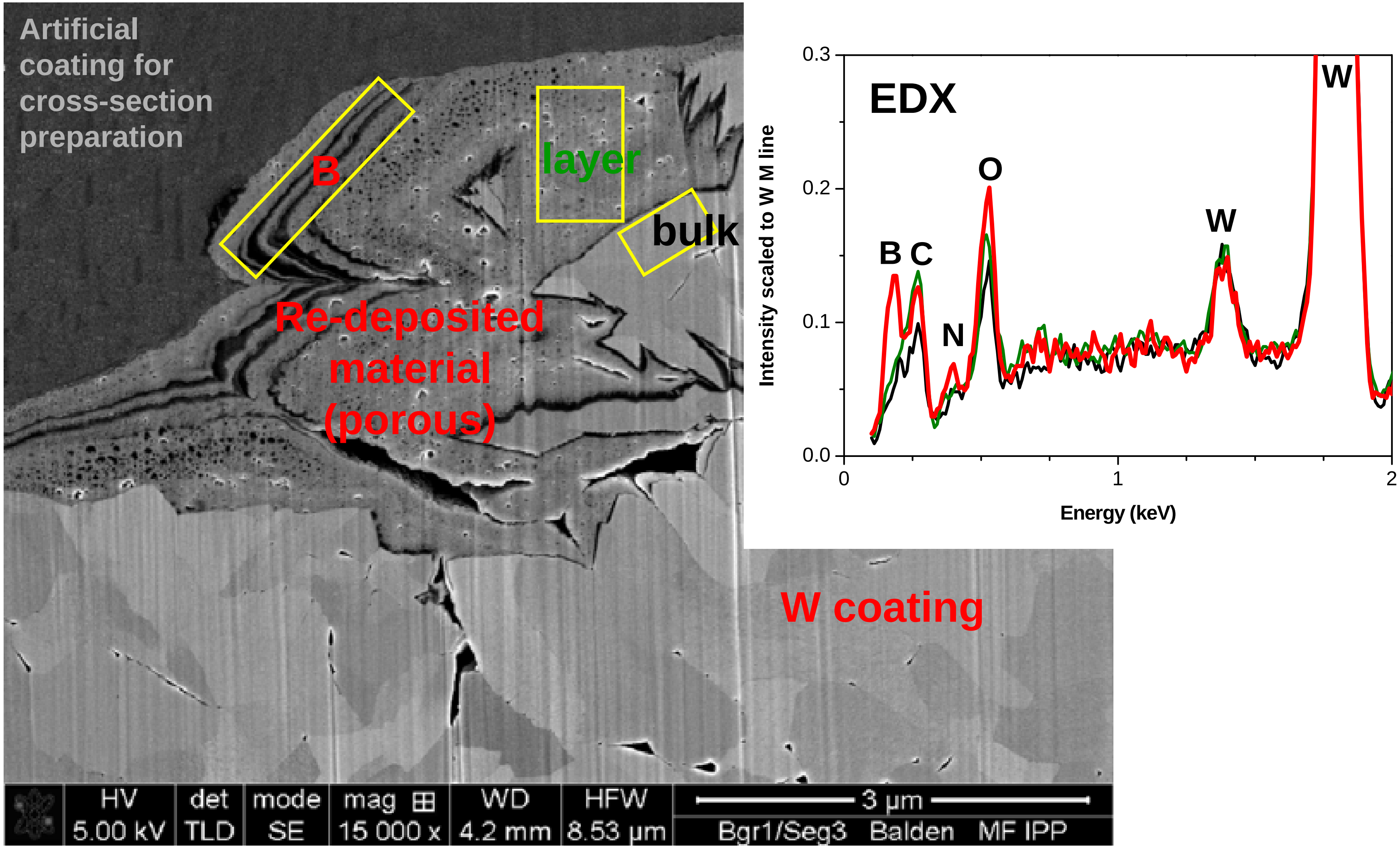
Final Note



Martin Balden@ipp.mpg.de

Discussion

- **Various surface extrusions described**
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- **Some new facts about blister**
  fully elastic and D_2 gas filled blister ⇨ quantified ⇨ mech. properties
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Thank you for your attention