Karlsruhe Institute of Technology

EUROfusion

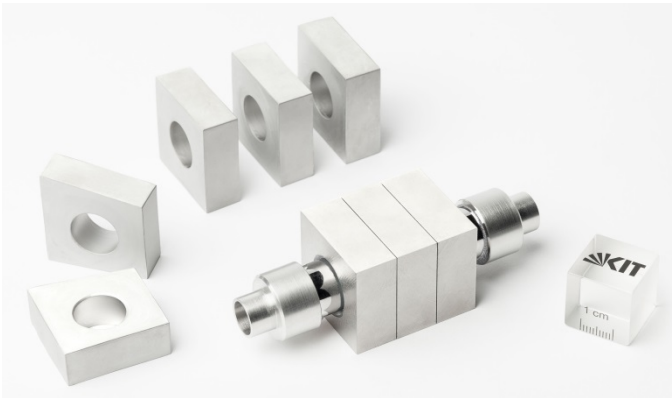
WPMAT

EFPW 2015, NOV 29TH – DEC 2ND, BLED, SLOVENIA

Progress in W alloy development and mass fabrication

Steffen Antusch*, Jan Hoffmann, Alexander Klein, Michael Rieth, Heinz Walter, Tobias Weingaertner

INSTITUTE FOR APPLIED MATERIALS



Outline

- **Powder Injection Molding @ KIT**
- **Mass fabrication of tungsten parts**
- **Development of new materials**
- **Summary**

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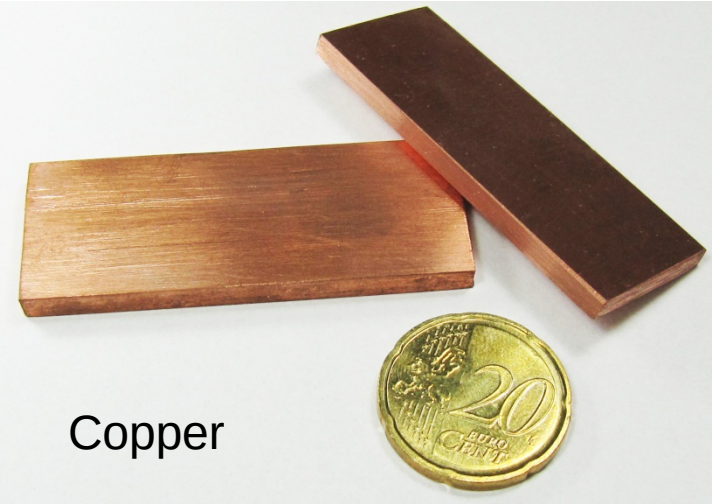
Powder Injection Molding @

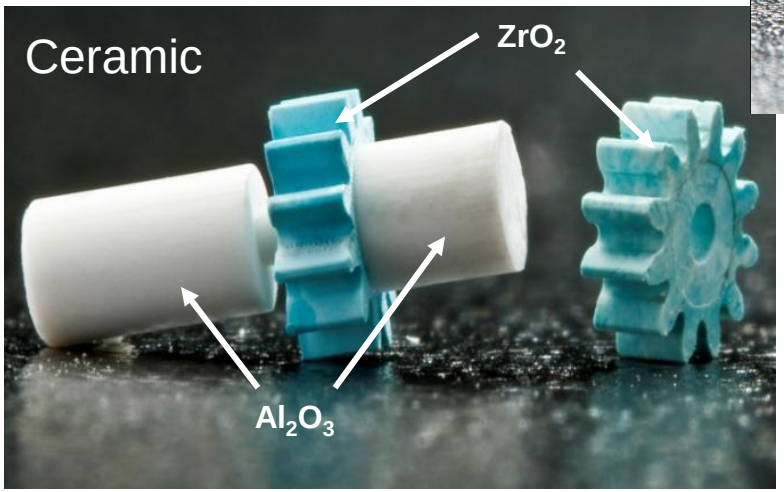
MANUFACTURING TECHNOLOGY

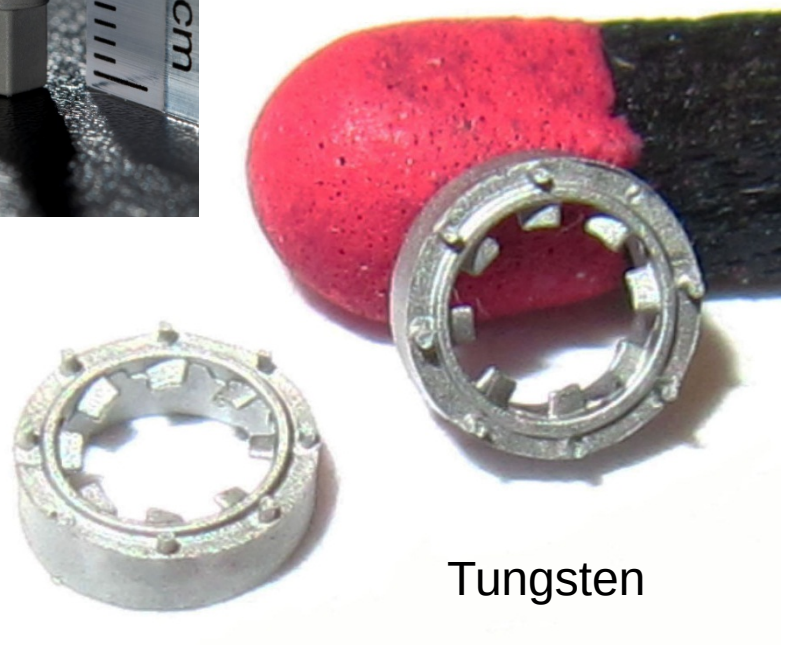
Metal Injection Molding (MIM)

Ceramic Injection Molding (CIM)

Powder Injection Molding @







Smallest ZrO_2 gear wheel of the world:
outer-∅ 275 µm

Tungsten Powder Injection Molding @

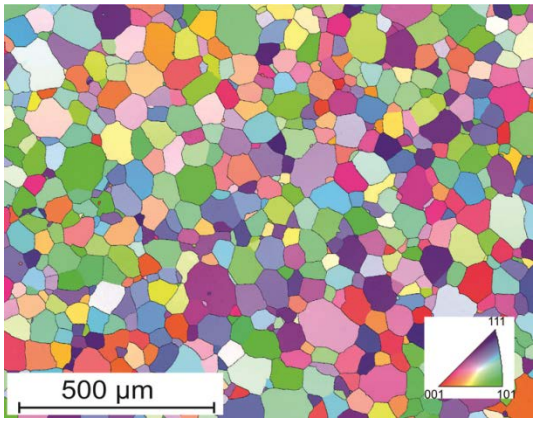
Karlsruhe Institute of Technology

Mass production of components

Time & cost effective
near-net-shape forming process

Shape complexity &
high final density

Material development



Tailoring new materials
&
Investigation of properties

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Mass fabrication of tungsten parts

…The PIM process for tungsten developed @

Karlsruhe Institute of Technology

Material development

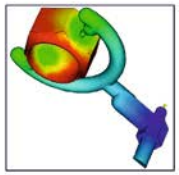
Powder

Binder

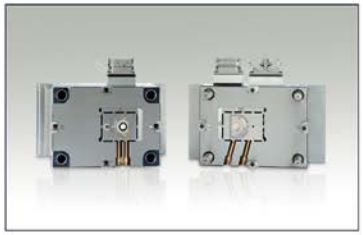
Mixing / Kneading / Extrusion

Feedstock

Design + engineering of a tool



Filling simulation



PIM-tool

Injection molding of green parts

Debinding / Heat-treatment

Green parts (dark), **finished parts** (brigth)

IAM Institute for Applied Materials

Mass fabrication of tungsten parts

…Tolerances…

Materials	min. lat. Dimension [µm]	min. Detail [µm]	Aspect Ratio [isolated walls]	Tolerance [%]	Roughness ** R_{max} / R_a [µm]	Materials tested
Plastics	10	≤0.08	>20 (200*)	± 0.05	0.05 / <0.05	Thermoplastics, TPE
Metals	50	10	>10	< ± 0.5	7 / 0.8	17-4PH, 316L, Cu, W, W-alloys
Ceramics	<10	<3	<15	(± 0.1) ± 0.3	2 / <0.3	ZrO_2, Al_20_3, ZTA, Al_2O_3/TiN, Si_3N_4

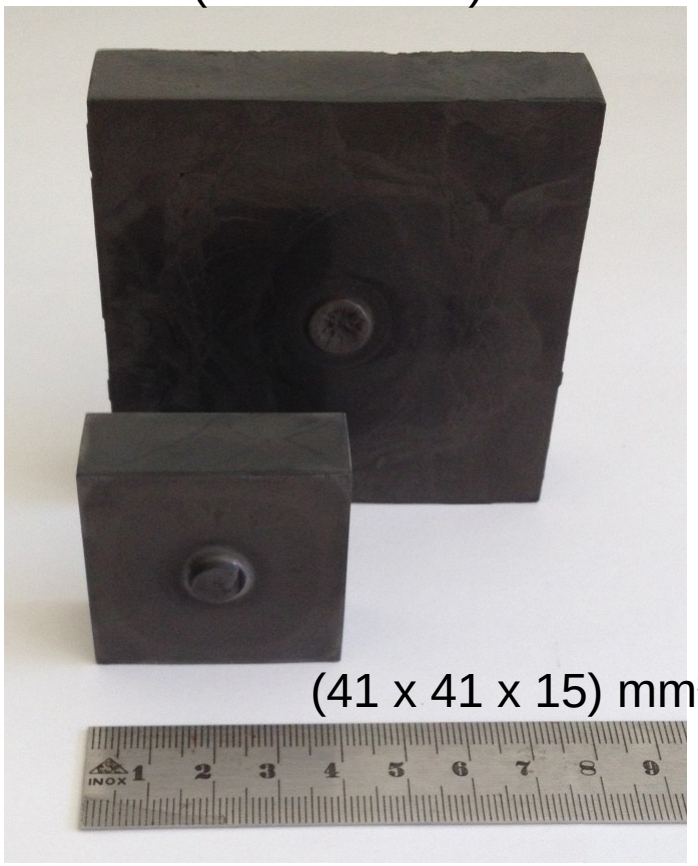
* flow length to wall thickness ratio

** depending on mold insert

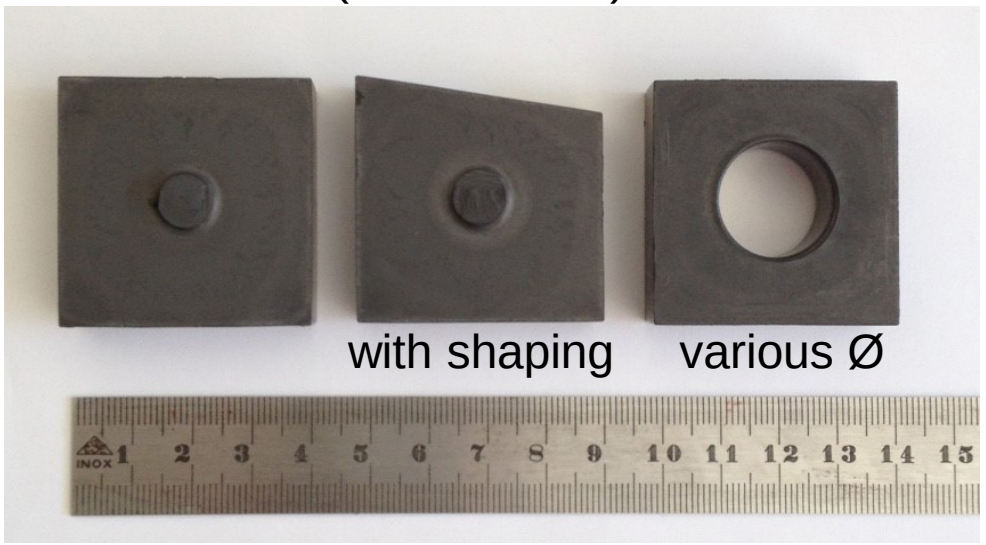
Mass fabrication of tungsten parts

…Dimension of **green-parts**…

(77 x 77 x 25) mm³



(41 x 41 x 15) mm³



Dimension & Quantity

(77 x 77 x 25) mm³	(~1.4 kg):	4 parts/hour
(41 x 41 x 15) mm³	(~0.25 kg):	15 parts/hour
(34 x 41 x 15) mm³	(~0.24 kg):	27 parts/hour

Mass fabrication of tungsten parts

…Dimension of **finished parts**…

(60 x 60 x 20) mm³

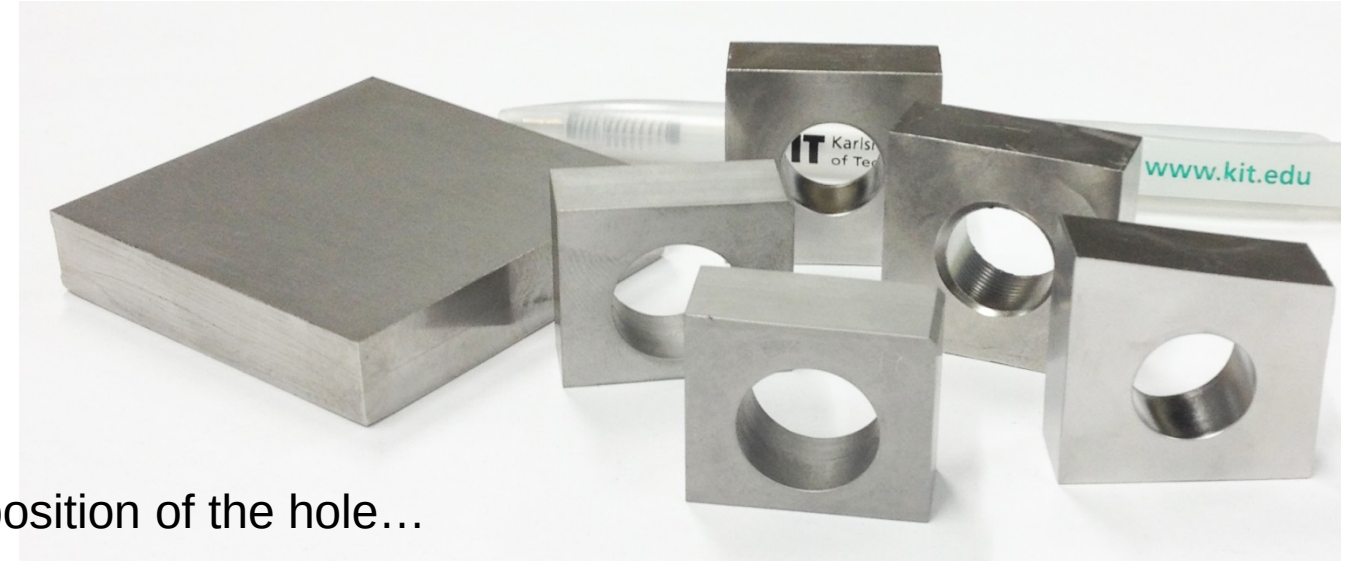
(32 x 32 x 12) mm³

(32 x 32 x 12) mm³ with shaping

(26 x 32 x 12) mm³

(26 x 26 x 12) mm³

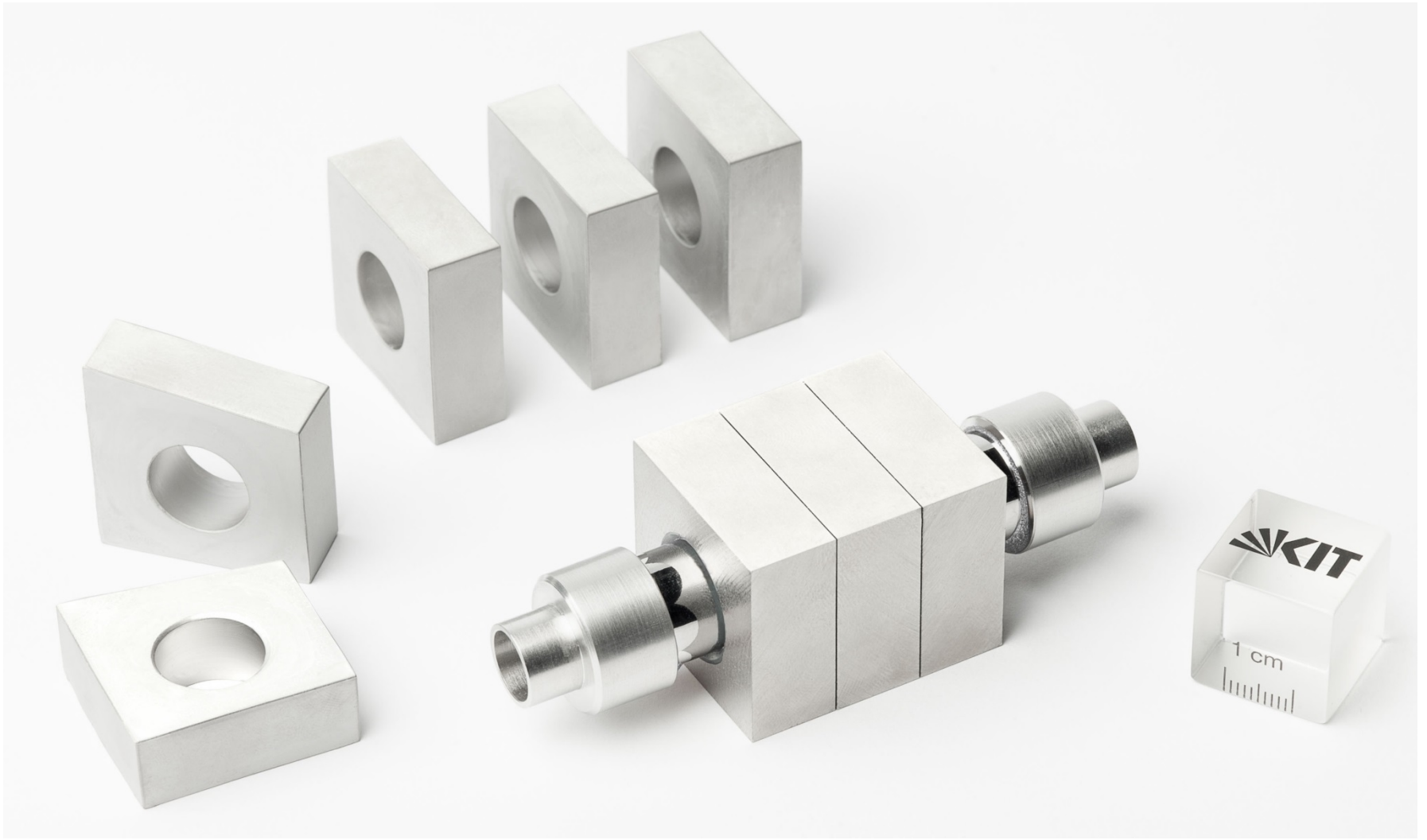
(24 x 22 x 4) mm³



...+ various Ø and position of the hole…

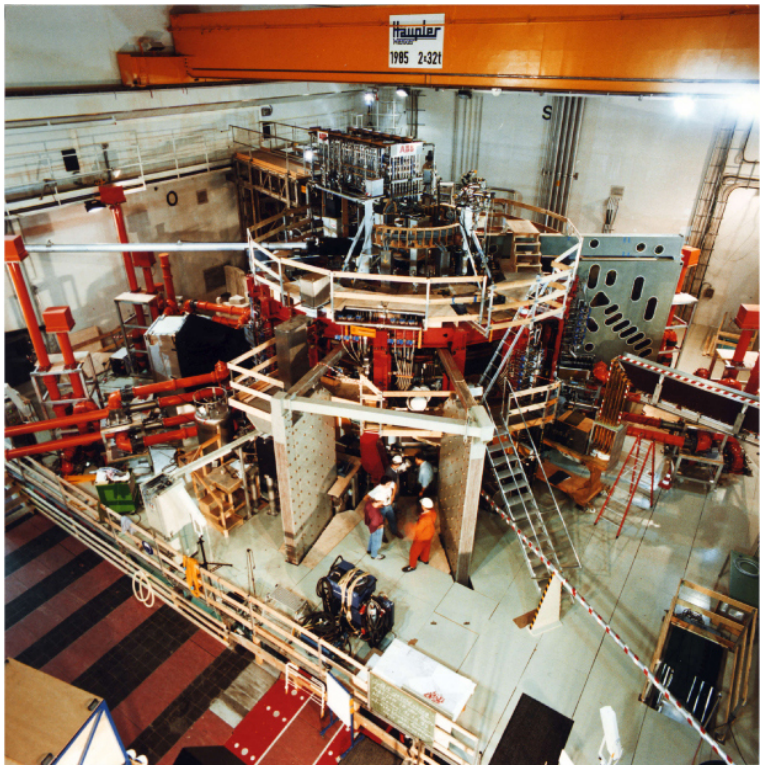
Mass fabrication of tungsten parts

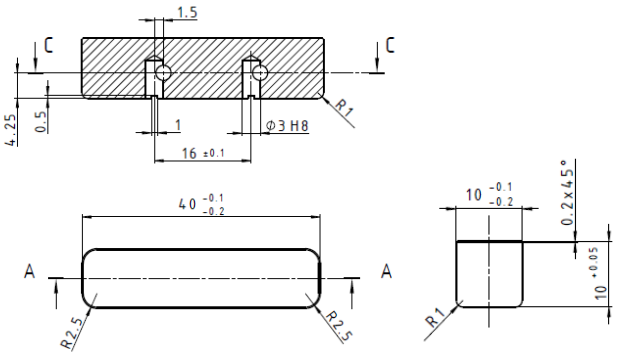
…W monoblocks - various size and shape - assembly to a component…



Mass fabrication of tungsten parts

…W PIM samples for ASDEX Upgrade…

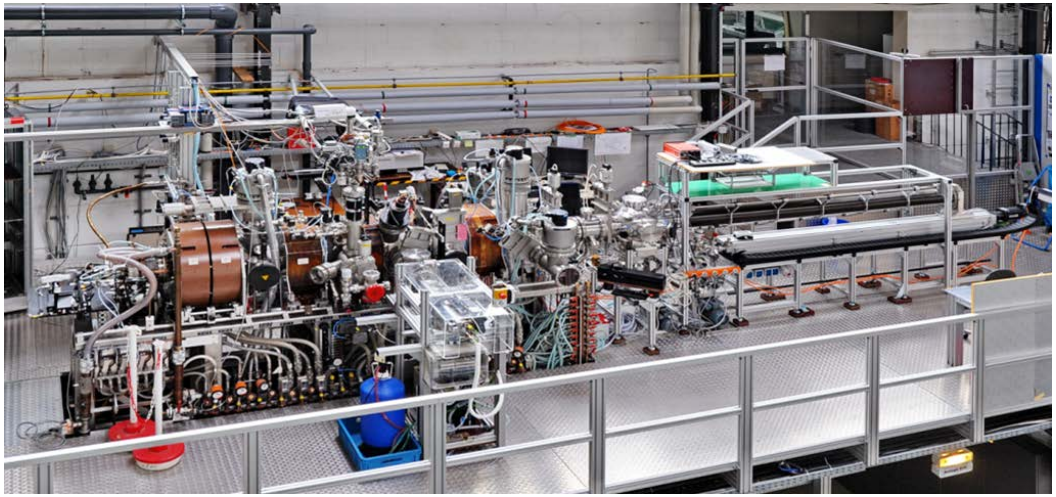




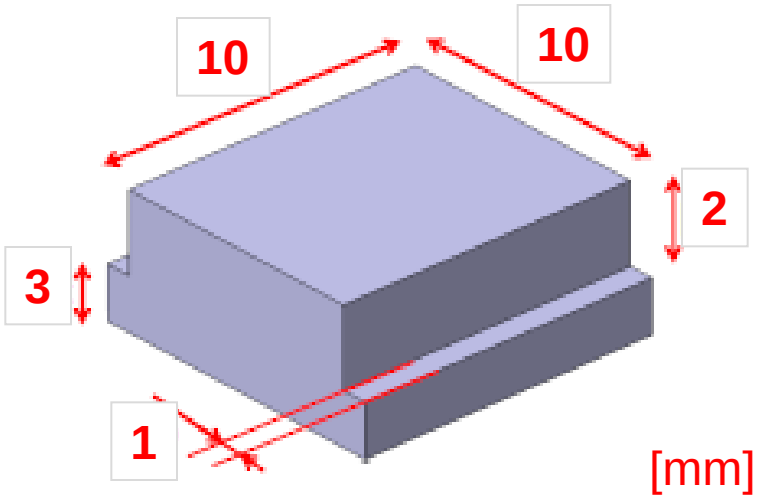
3 PIM (pure W) samples + 1 PLANSEE reference sample produced and delivered to IPP Garching by KIT in April 2015

Mass fabrication of tungsten parts

…W PIM samples for plasma-wall interaction…

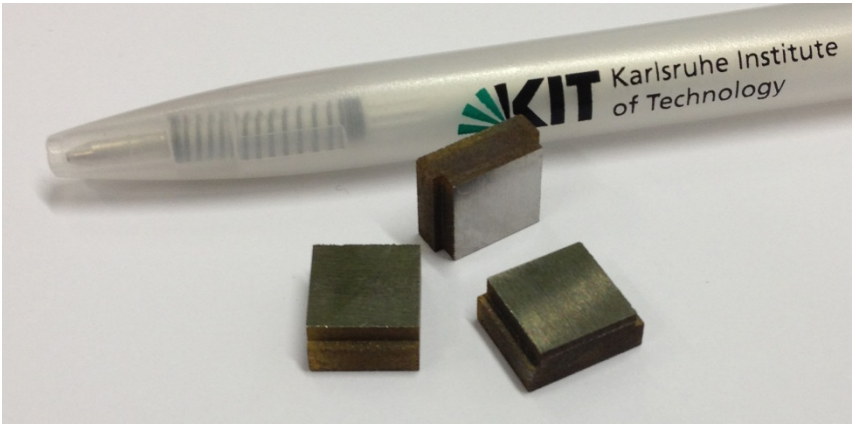


The PSI-2 linear plasma device at Juelich*



22 samples of pure W for PSI-2 produced and delivered to FZ Juelich by KIT begin of November 2015

→ See talk of Bernhard Unterberg



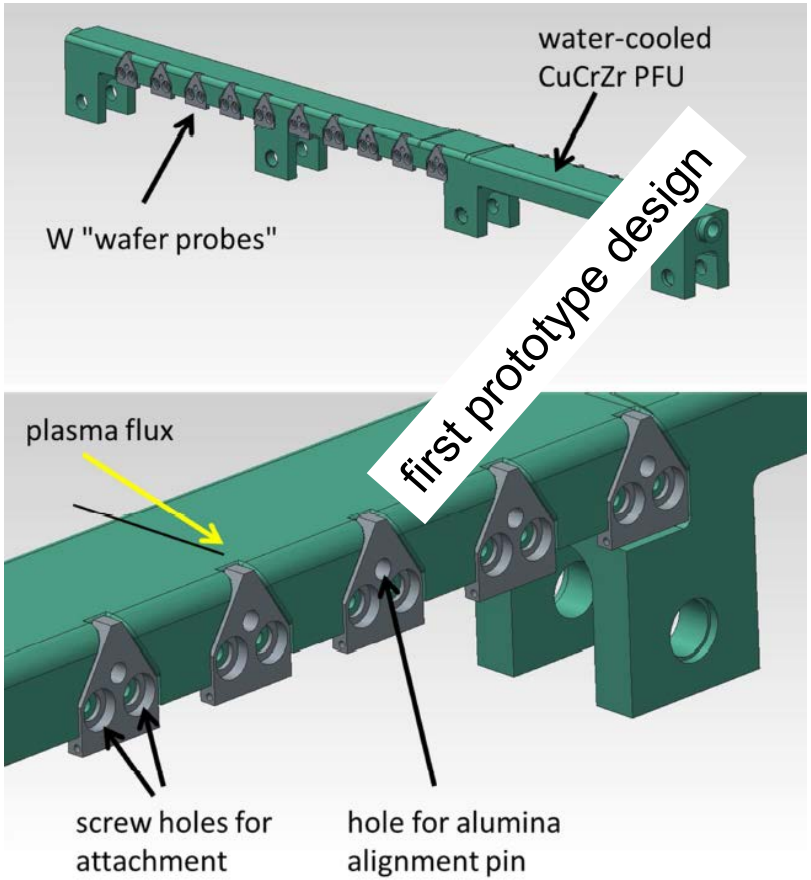
* http://www.fz-juelich.de/iek/iek-4/EN/Research/02_Linear_plasma_devices/artikel_2014.html?nn=668414

Mass fabrication of tungsten parts

…W PIM samples for WEST…

WEST: Langmuir probes (pure W)

Device to determine the electron temperature, electron density, and electric potential of a plasma.



2 prototype samples for HHF tests in GLADIS produced and delivered to CEA by KIT in September 2015

Production of a series of 60 Langmuir probes in progress

Outline

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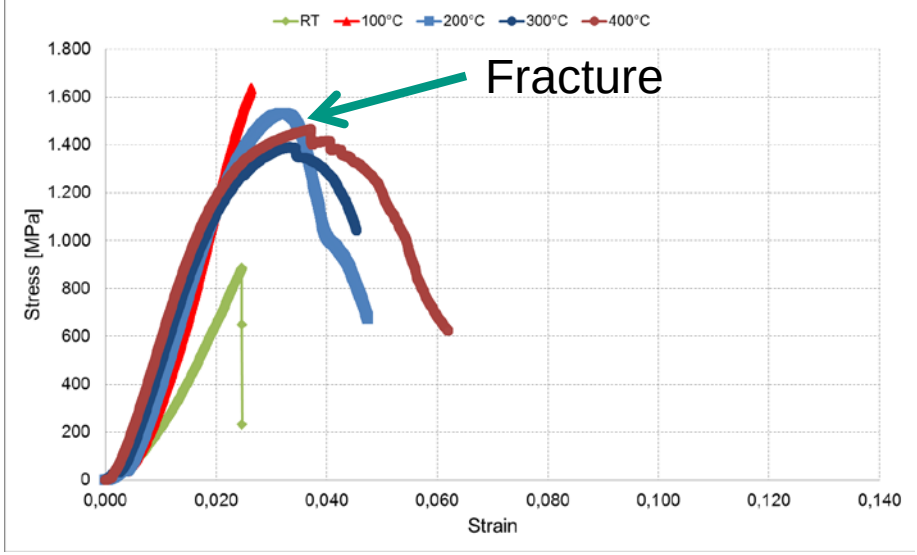
Development of new materials

…Mechanical testing via 4-PB tests from 20 °C to 400 °C…

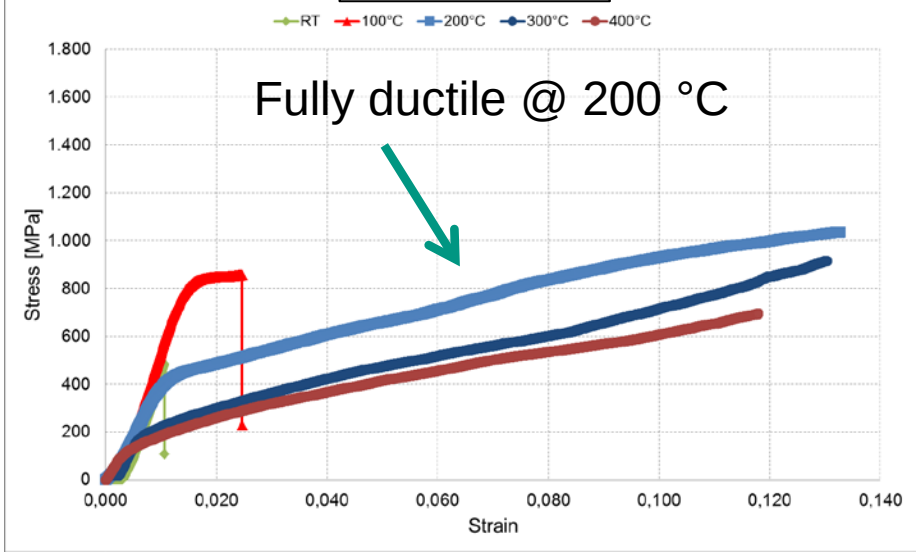
Sample geometry: (12 x 1 x 1) mm
Constant strain rate: 0.0330 mm/min

W PLANSEE (rolled)



High strength in rolling direction

W (PIM)



Same strength in all directions

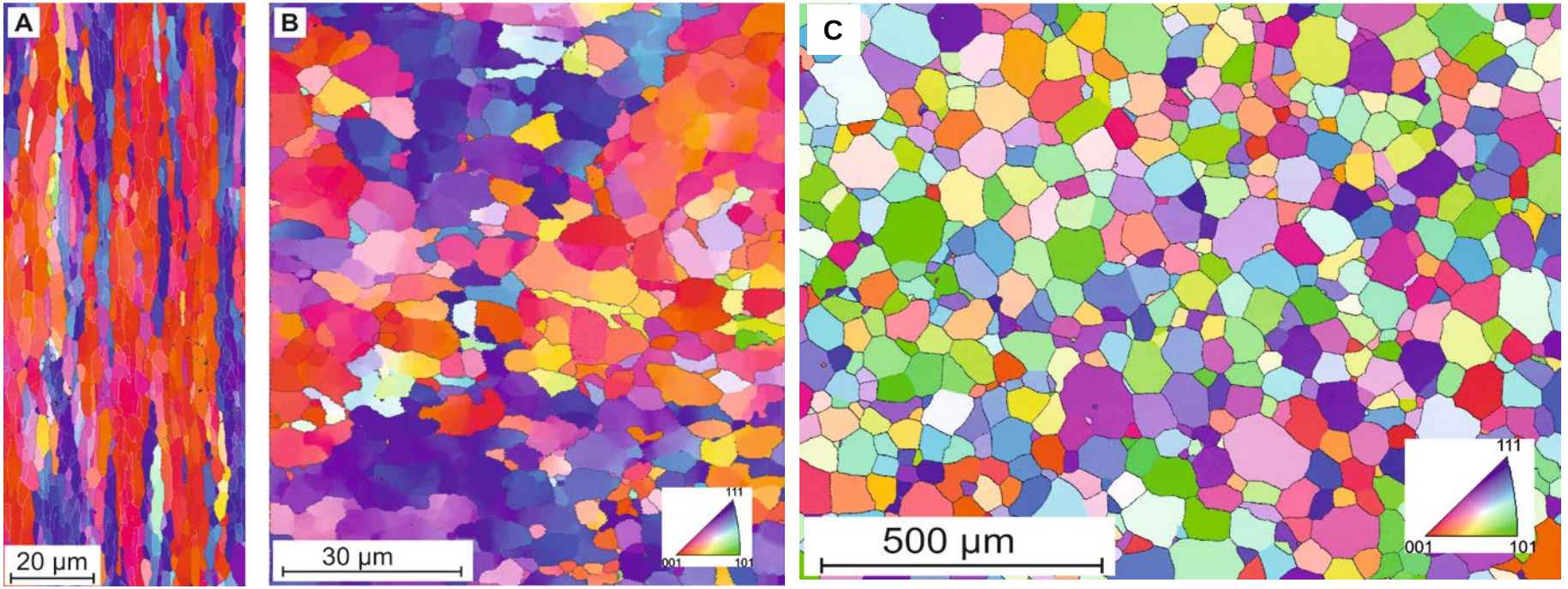
400 °C

Development of new materials

…Texture analysis via EBSD…

W-Plansee (rolled)

W-PIM



EBSD texture of rolled tungsten (Plansee): (A) in rolling direction; and (B) perpendicular to the rolling direction. The beneficial material properties - e.g. high strength, bending toughness - are only achieved in the rolling direction. EBSD texture of W PIM: (C), the material is fully anisotropic.

Development of new materials

…Thermal shock testing with e-beam in JUDITH-1…

JÜLICH FORSCHUNGSZENTRUM

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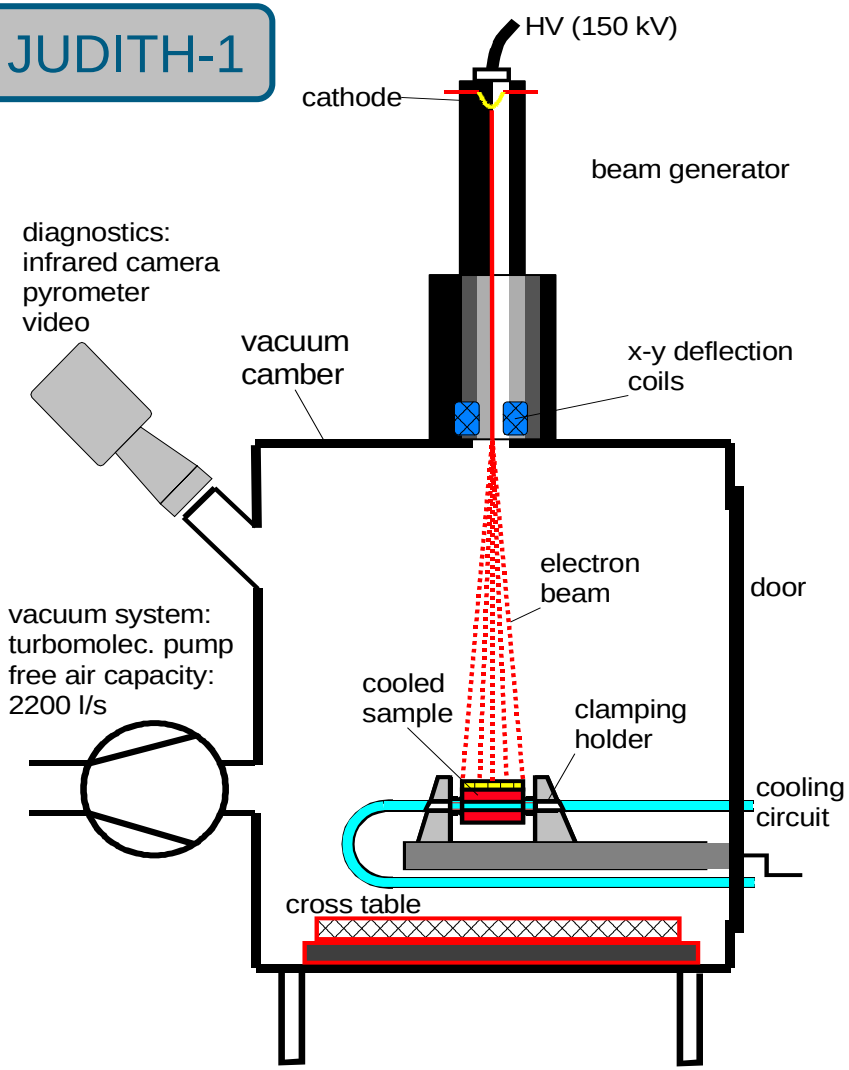
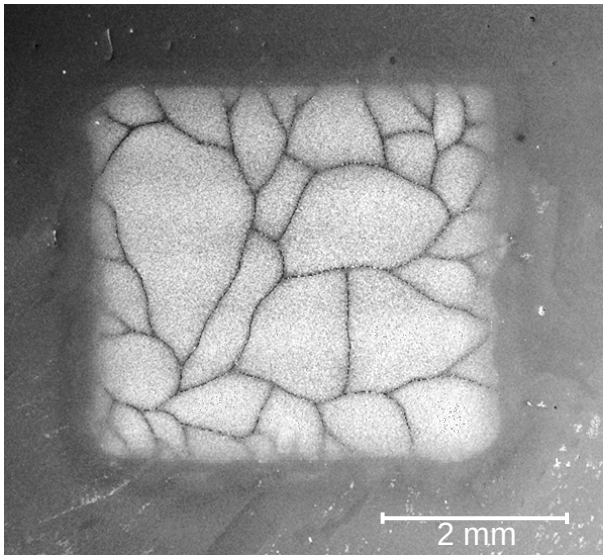
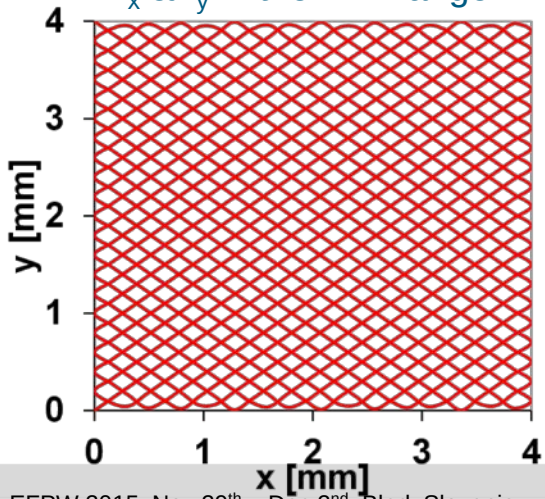
JUDITH-1

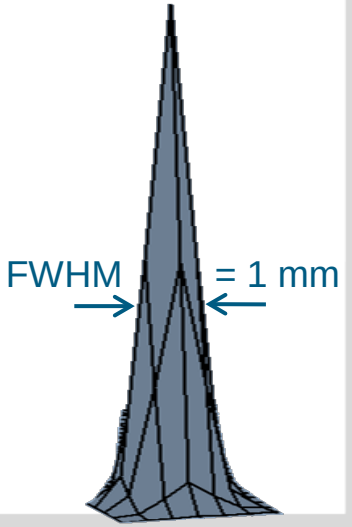


Courtesy of G. Pintsuk (FZJ)



f_x & f_y in the kHz range





Total power:	60 kW
Acceleration voltage:	120 kV

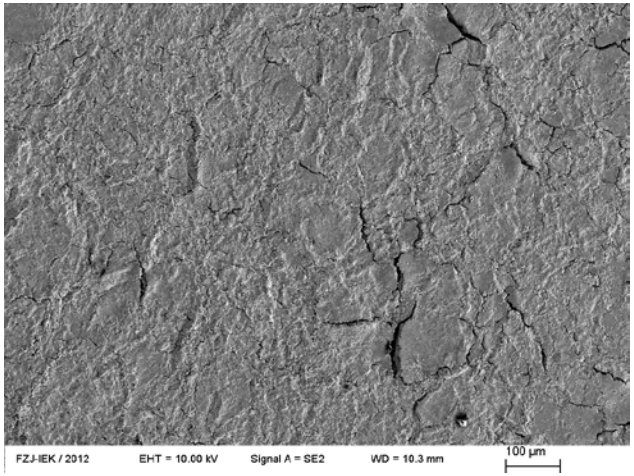
Development of new materials

…Thermal shock tests via e-beam @ JUDITH-1…

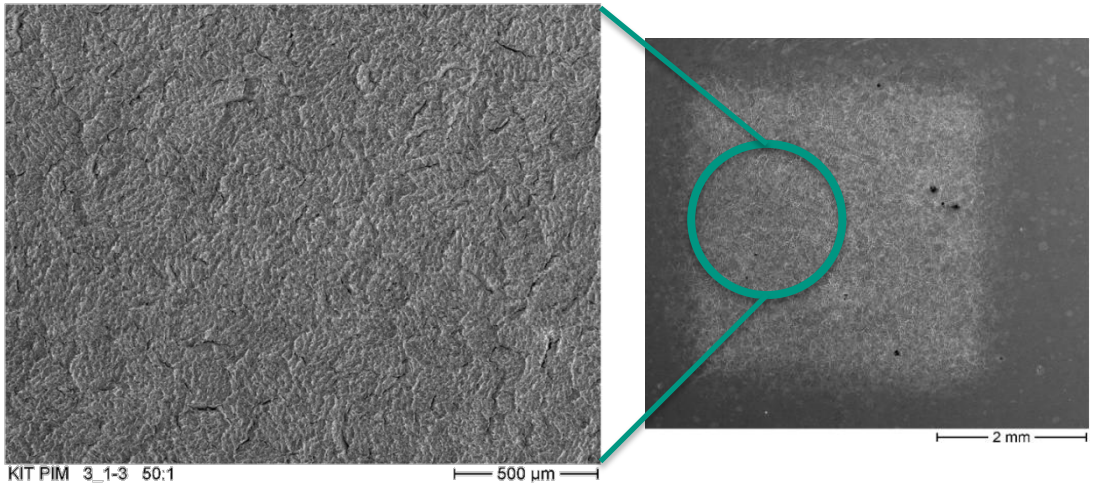
Courtesy of G. Pintsuk (FZJ)

#	T [°C]	P_{abs} [GW/m²]	Δt [ms]	E_{abs} [MJ/m²]	FHF [MW/m²*s$^{1/2}$]	# shots
C	1000	0.38	1	0.38	12	1000

W PLANSEE (single forged)



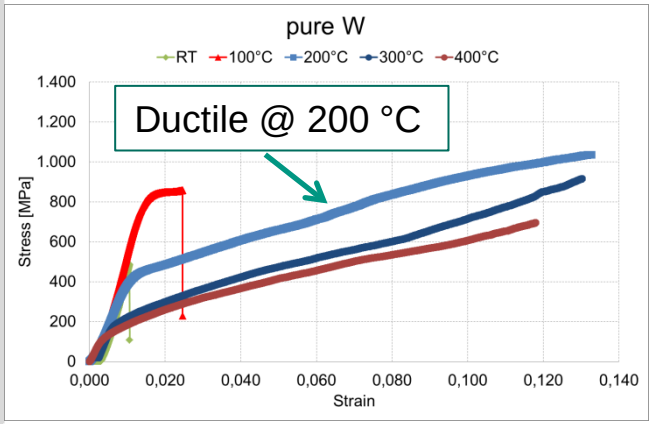
W (PIM)



Note the different scale markers !

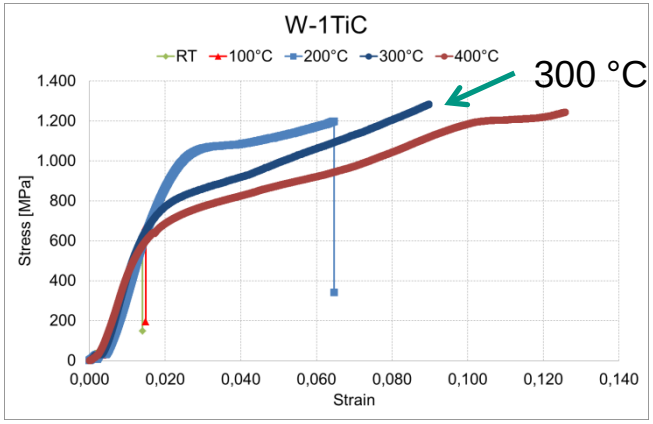
Development of new materials

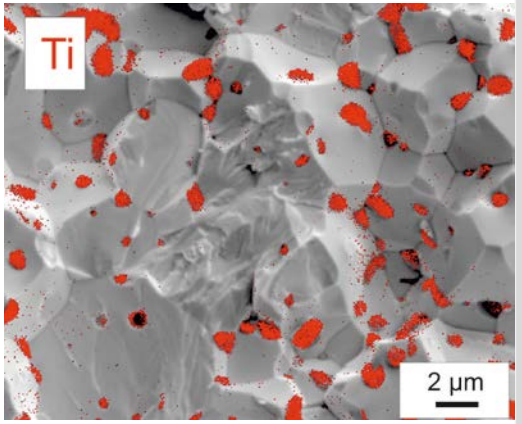
… Mechanical testing via 4-PB tests from 20 °C to 400 °C …



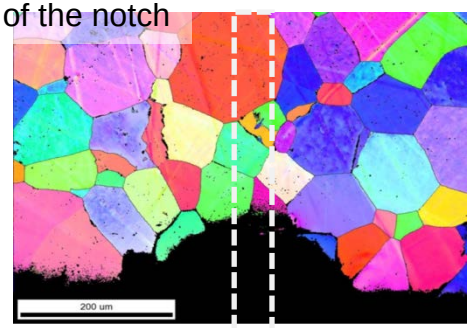
Sample geometry: (12 x 1 x 1) mm
Constant strain rate: 0.0330 mm/min

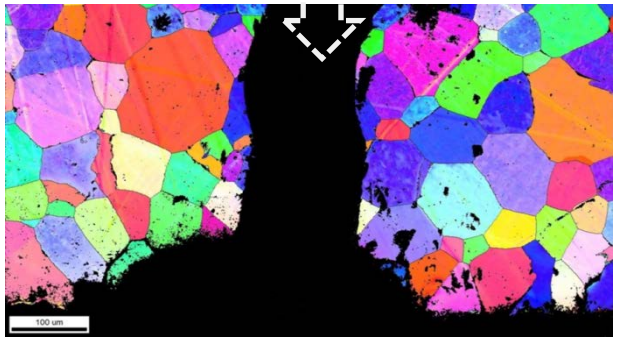
Grain size
Pure W: 50 – 100 µm
W-1TiC: 4 – 6 µm
W-2Y_2O_3: 4 – 8 µm



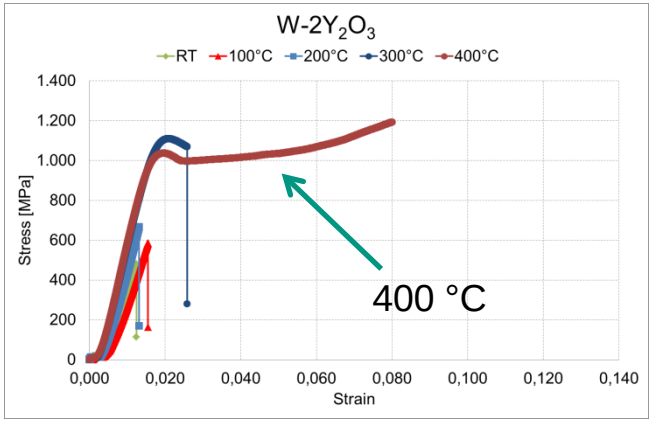


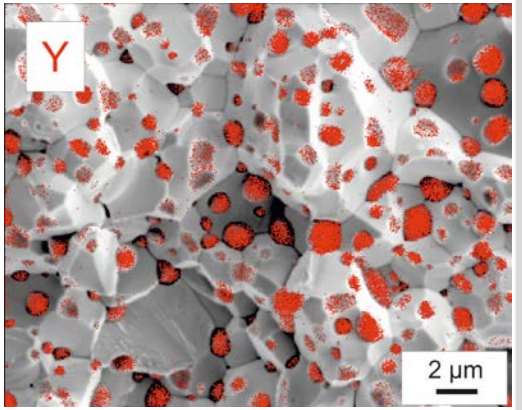
EBSD of the notch





Transgranular crack @ RT





AES: Microstructure & element allocation

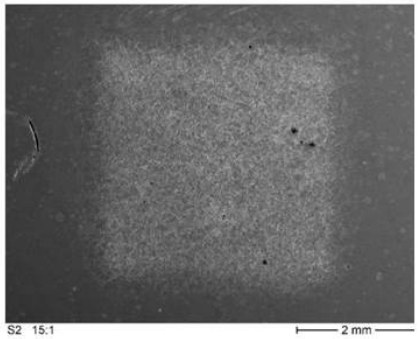
Development of new materials

… Thermal shock tests via e-beam @ JUDITH-1 …

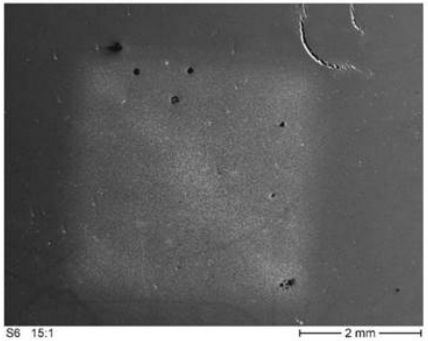
Courtesy of G. Pintsuk (FZJ)

T [°C]	P_{abs} [GW/m²]	Δt [ms]	E_{abs} [MJ/m²]	F_{HF} [MW/m²*s$^{1/2}$]	# shots
1000	0.38	1	0.38	12	1000

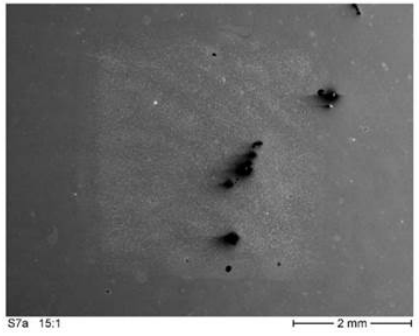
W

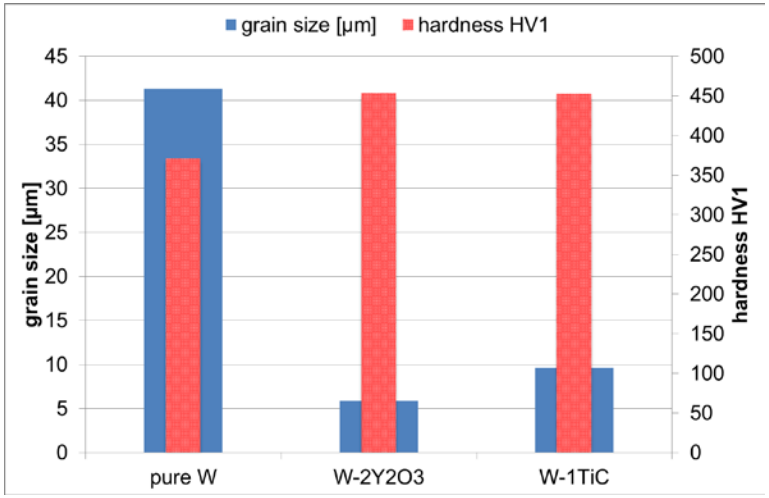


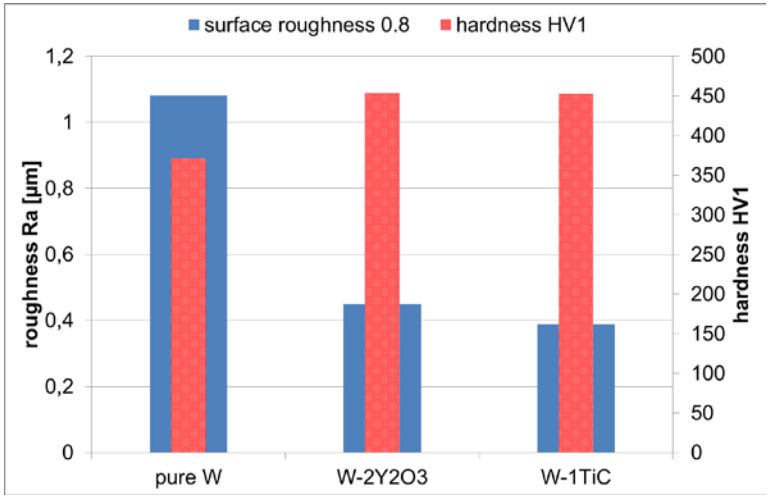
$W\text{-}2Y_2O_3$



W-1TiC







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Summary

→ ***Mass production*** of near-net-shape parts (~ **20 Monoblocks / hour**) via PIM @ KIT

→ Brittle to ductil transition for **pure PIM W** at **200 °C (low strain rates)**

→ No porosities or cracks, high density (better than 99 % T.D.)

→ No recrystallisation – possible grain growth at very high temperatures only

→ Fully anisotropic material properties

→ High thermal shock resistance

→ PIM is an ideal tool for rapid ***material development*** (oxide and carbide doped tungsten)

→ Further projects with FZJ and IPP Garching: W_f/W and self passivated W
→ See talk of Jan Coenen

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KIT Karlsruhe Institute of Technology

JÜLICH FORSCHUNGSZENTRUM

PLANSEE

IPP Max-Planck-Institut für Plasmaphysik

THANK YOU VERY MUCH!

PL FUSION

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