Thermal diffusivity of tungsten irradiated by protons in spallation environment up to 26.5 dpa

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Agenda

1 ESS target design

2 Importance of PIE on the target material

3 LFA measurement details

4 Data calibration

5 Data analysis for high dose samples

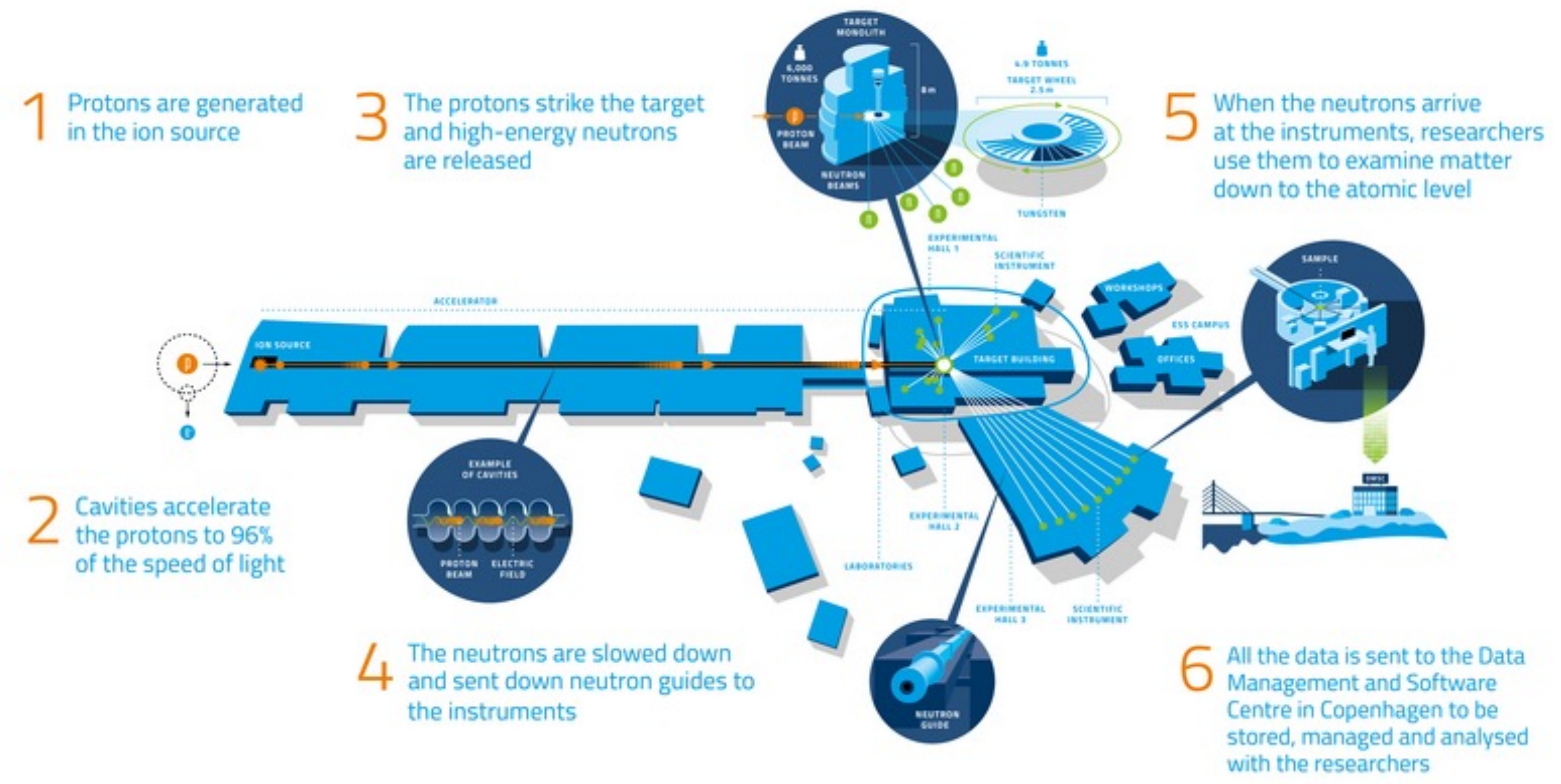
6 Effect of post irradiation annealing

European Spallation Source (ESS)

A partnership of 13 European countries - located in Lund, Sweden

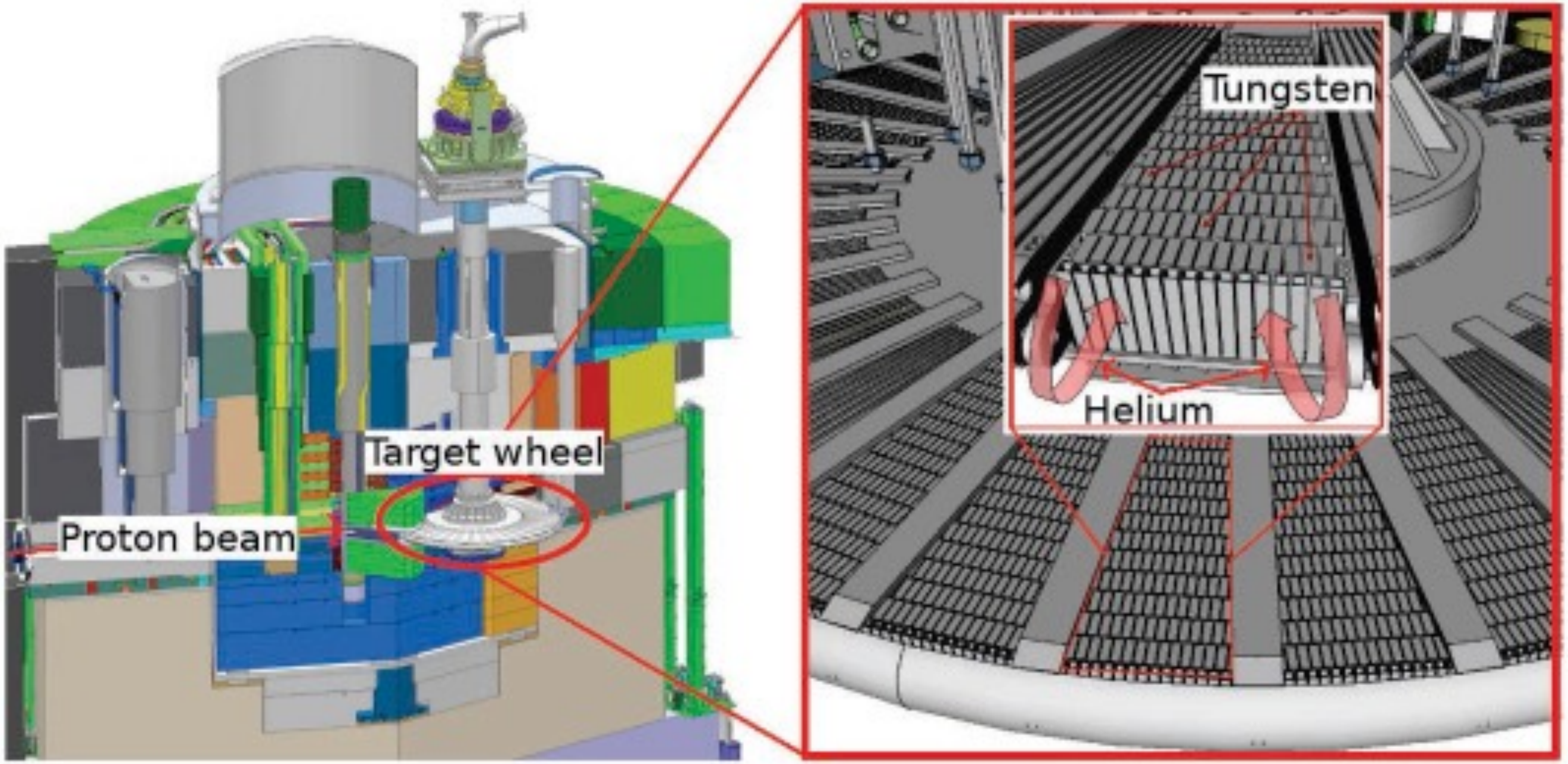
European Spallation Source (ESS)

An advanced, high-power neutron spallation source



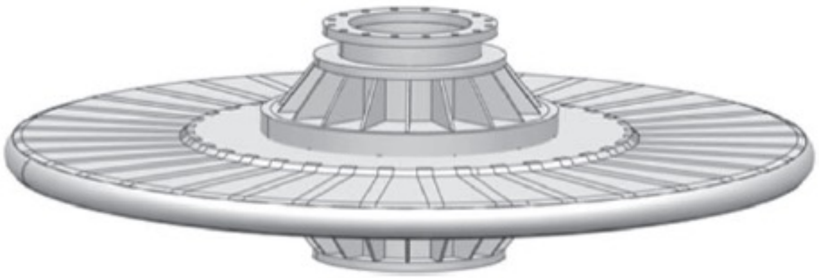
ESS Target Design

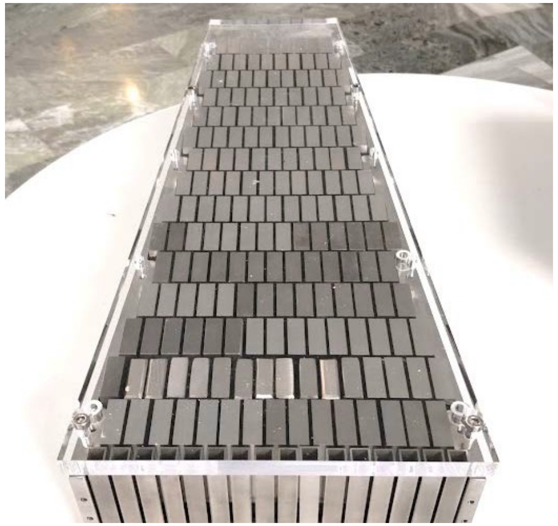
A helium cooled rotating target wheel



ESS Target Design

A target wheel consisting of Tungsten bricks





One of the 36 segments of the target wheel with W bricks

Table 45. Target wheel parameters.

Parameter	Units	Value
Wheel diameter	m	2.5
Number of sectors		36
Sector periphery	m	0.218
Rotational speed	rpm	23.3
Energy/Pulse	kJ	357
Temp. rise/Pulse	°C	100

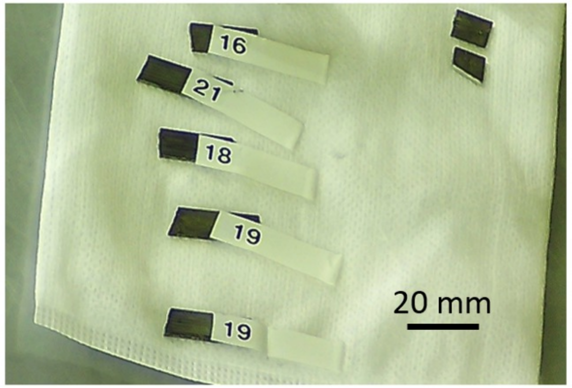
Thermal diffusivity is observed to decrease significantly in irradiated tungsten which results in larger thermal stresses in the material

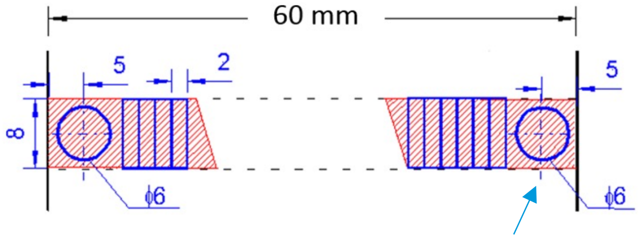
Knowledge of Radiation impact on thermal diffusivity of Tungsten is crucial to achieve a target with designed availability

PIE experiments

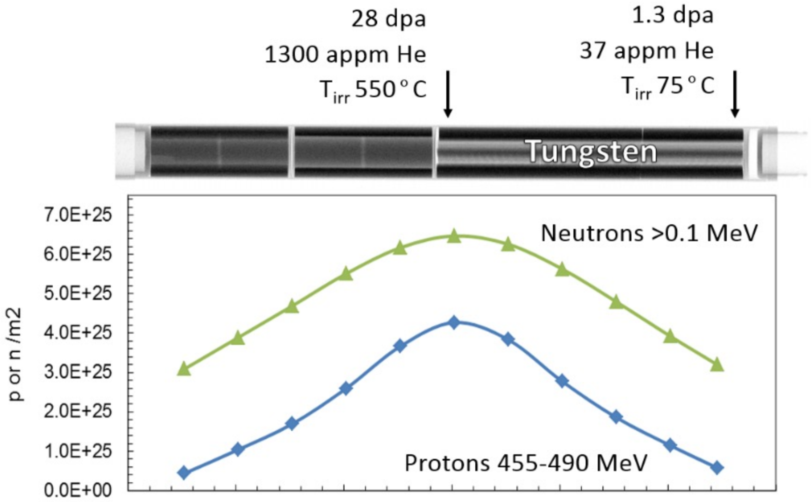
Irradiated samples preparation

As a part of STIP-V campaign, W plates (1×10×60 mm) were irradiated by high energy protons and secondary neutrons at Swiss Spallation Neutron Source (SINQ)-PSI





6 mm disc were cut by EDM



Fluence of protons and fast spallation neutrons as a function of distance to the Gaussian shaped beam center [6]

Samples with different doses were studied

Sample	Displacement per atom [dpa]	Irradiation temperature [°C]	He content [appm]	H content [appm]	Activity of Hf-178 [MBq]
19A-R5	4.4	121	180	1010	2.3
16-R5	6.9	172	305	1615	3.2
19B-R5	9.5	214	410	2375	4.0
18-R5	25.1	501	1150	6375	11.5
21-R5	26.5	534	1225	6845	12.5

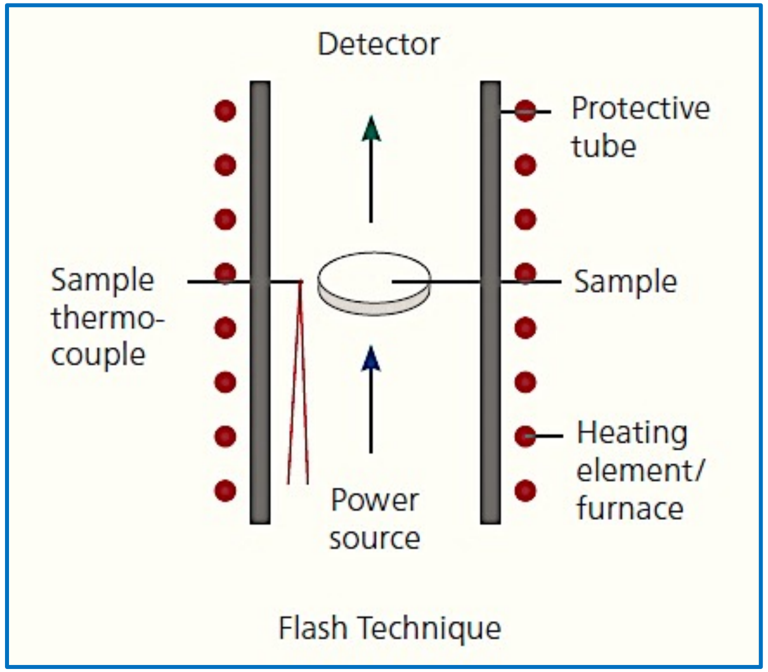
Measurement details

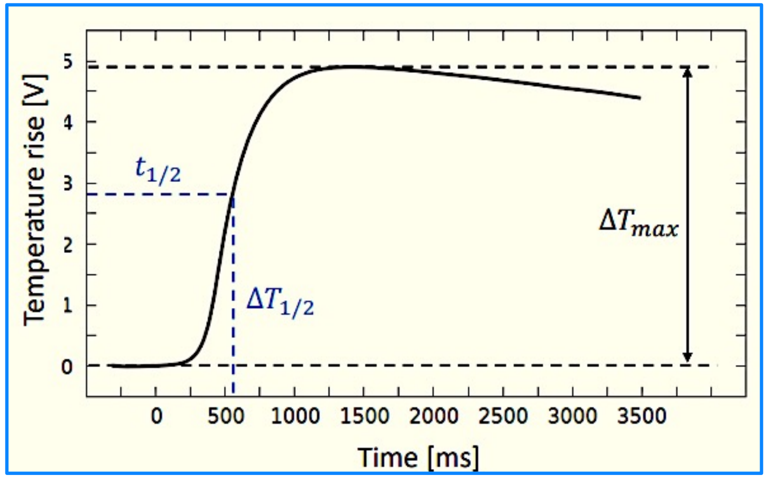
Laser Flash Analysis (LFA)

Sample	Displacement per atom [dpa]
19A-R5	4.4
16-R5	6.9
19B-R5	9.5
18-R5	25.1
21-R5	26.5

→ Low dose (previous study*): **with** surface polishing & coating

→ High dose (current study): **without** surface polishing & coating due to high dose (with EDM surface finish)

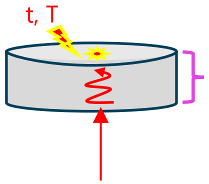




$t_0 \rightarrow T=T_0$

$t_1 \rightarrow T=T_{max}$

$t_{1/2} = (t_1 - t_0)/2$ (s)



d (mm)

Thermal diffusivity $\left(\frac{mm^2}{s}\right)$: $\alpha = 0.1388 \frac{d^2}{t_{1/2}}$

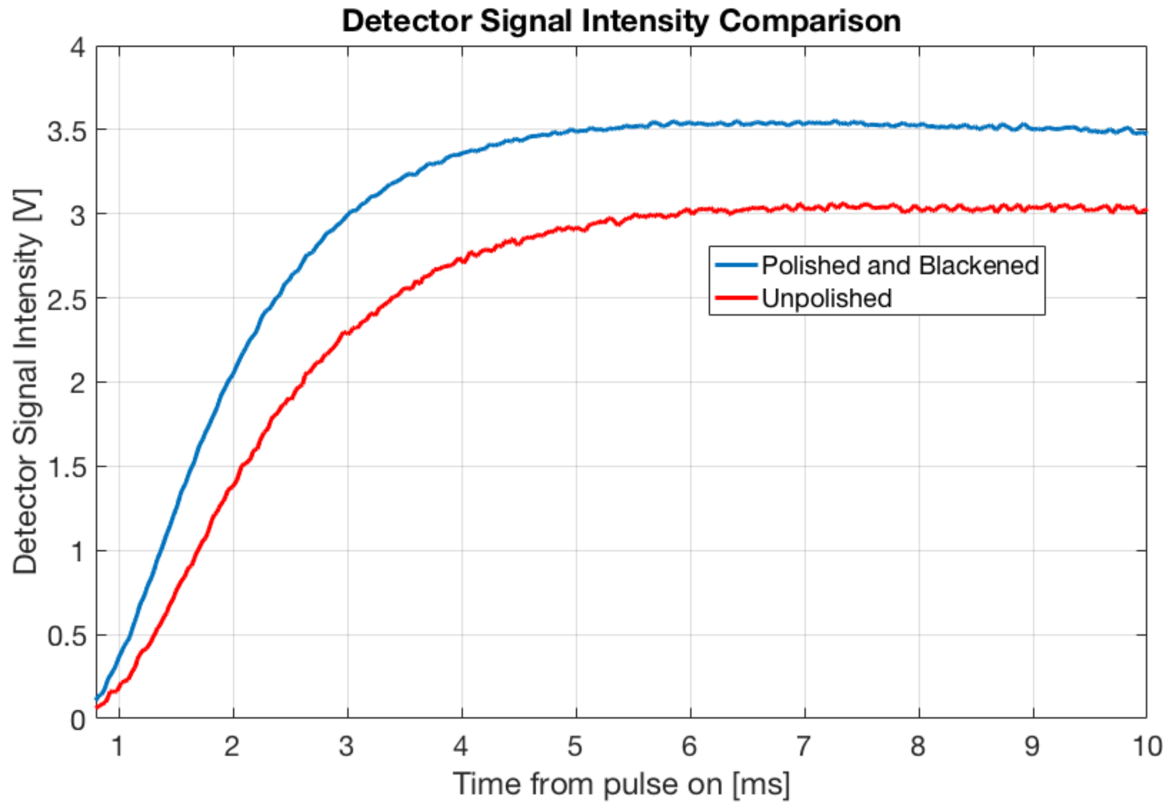
To measure the thickness **(d)** precisely, the sample surface is usually **polished** and then coated

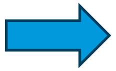
* J. Habainy, Y. Dai, Y. Lee, S. Iyengar, Thermal diffusivity of tungsten irradiated with protons up to 5.8 dpa, JNM. 509 (2018) 152–157.

Measurement details

Signal-to-noise ratio for the sample with unpolished surface

The detector signal was also compared for the polished-coated vs. unpolished-uncoated samples

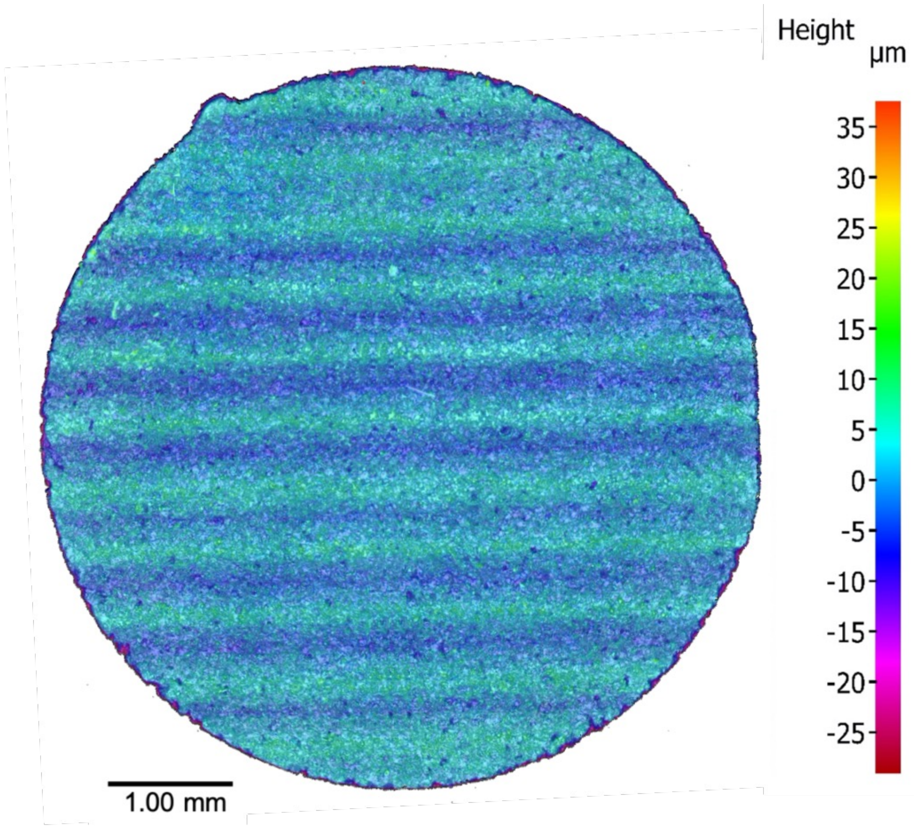




The detector signal intensities for the polished and un-polished samples were **comparable** with reasonable signal-to-noise ratios

Measurement details

Profilometry for the sample with unpolished surface



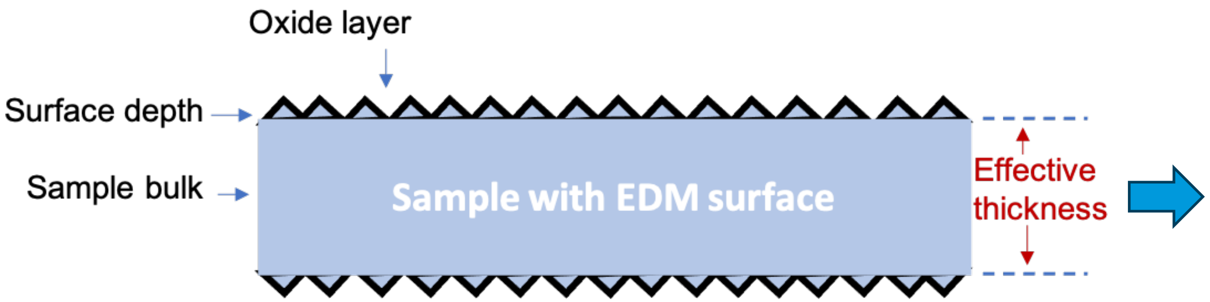
The alternating regions showed the average depth variation of 22.5 ± 5.6 µm

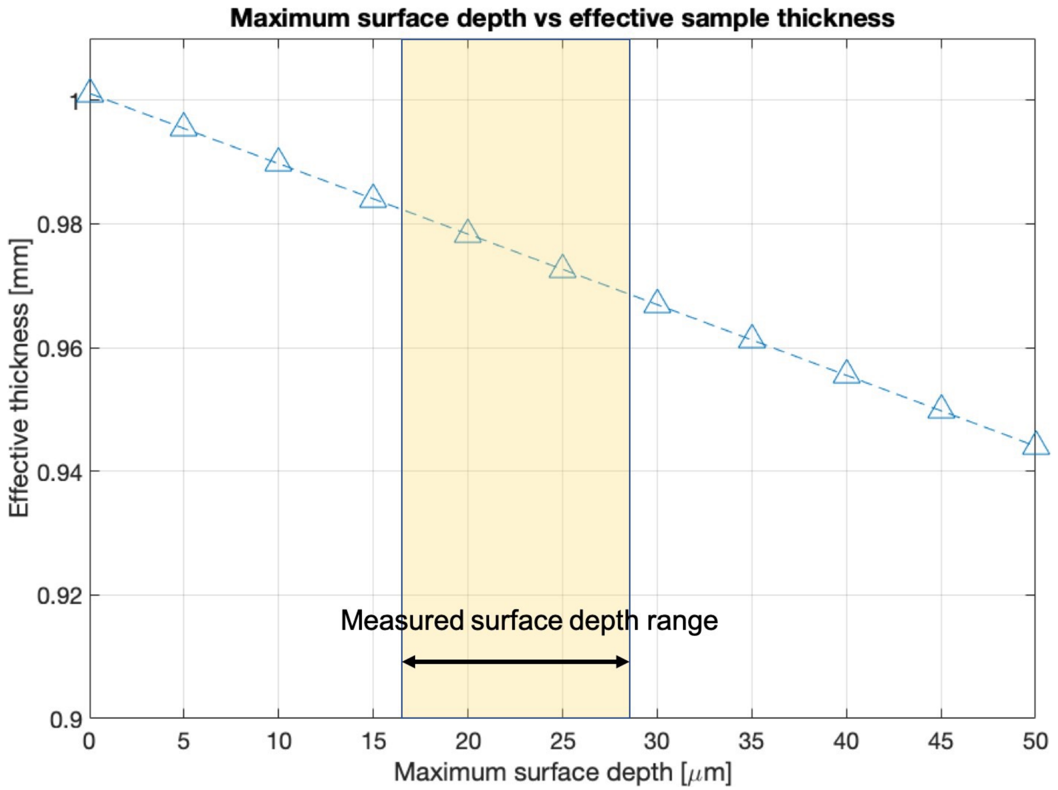
Profilometry of EDM surface with a wavy-like pattern

Measurement details

Data calibration for the samples with rough surfaces

To minimize the uncertainties due to the rough (EDM) surface for high dose samples, a calibration was made on an unirradiated EDM-cut sample (unpolished, uncoated)

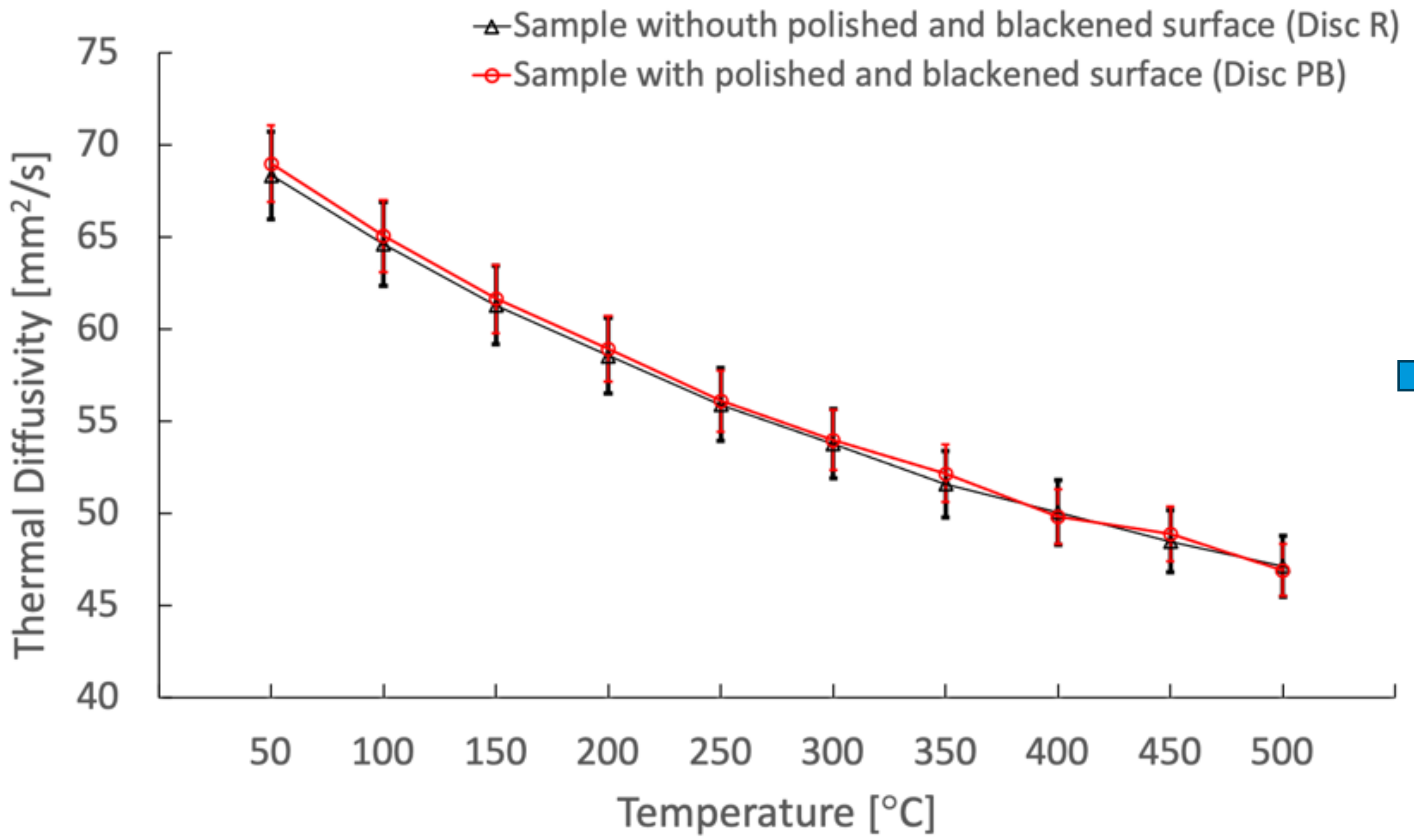




Correlation between the **roughness depth** and **effective thickness** (effect of oxide layer is assumed negligible)

Data analysis

LFA results for **unirradiated** samples after thickness calibration



Source of Uncertainty (error bars):

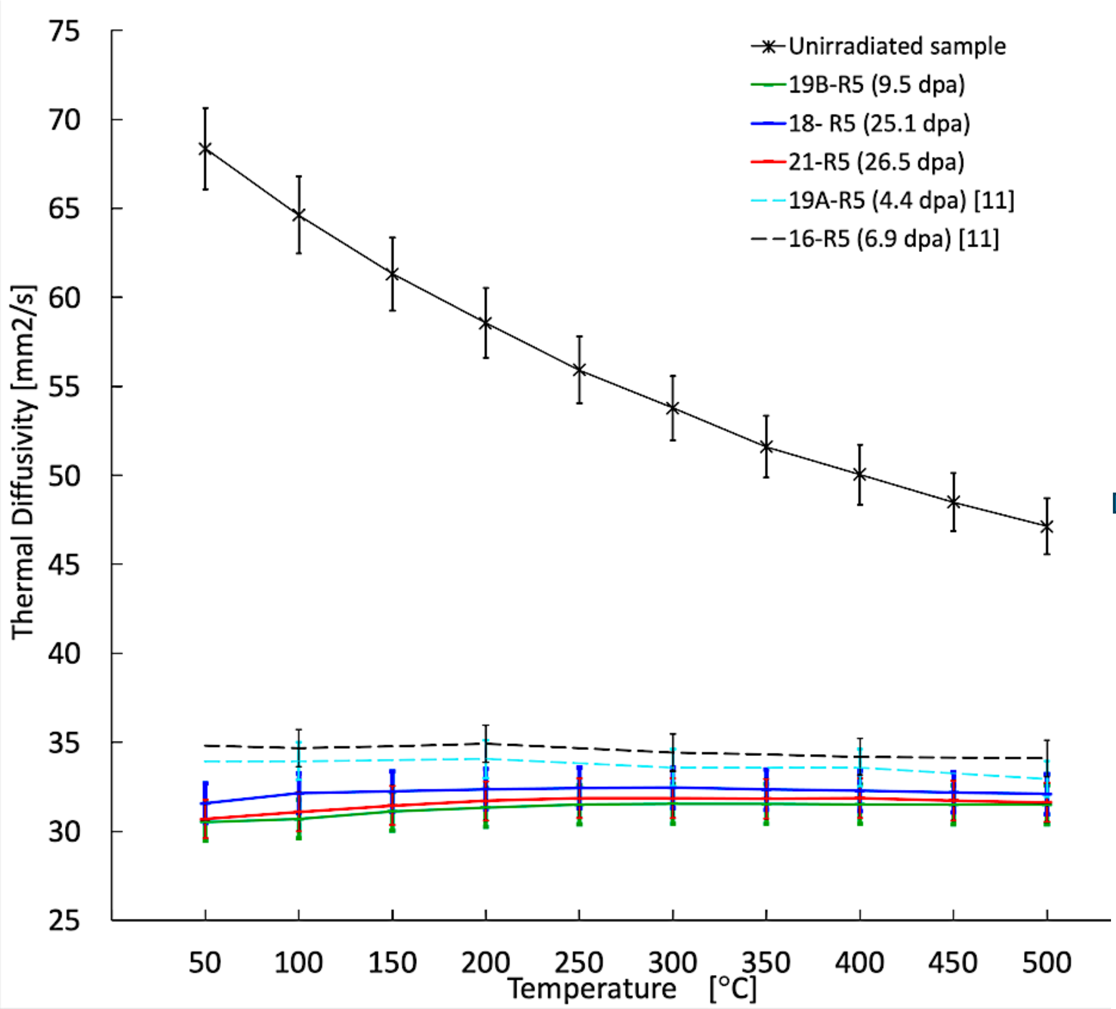
- Surface Roughness + LFA instrument
- LFA instrument

Both data sets **compare well** within the uncertainty ranges

Calibrated thermal diffusivity measurement data for the polished and un-polished (EDM surface) samples

Data analysis

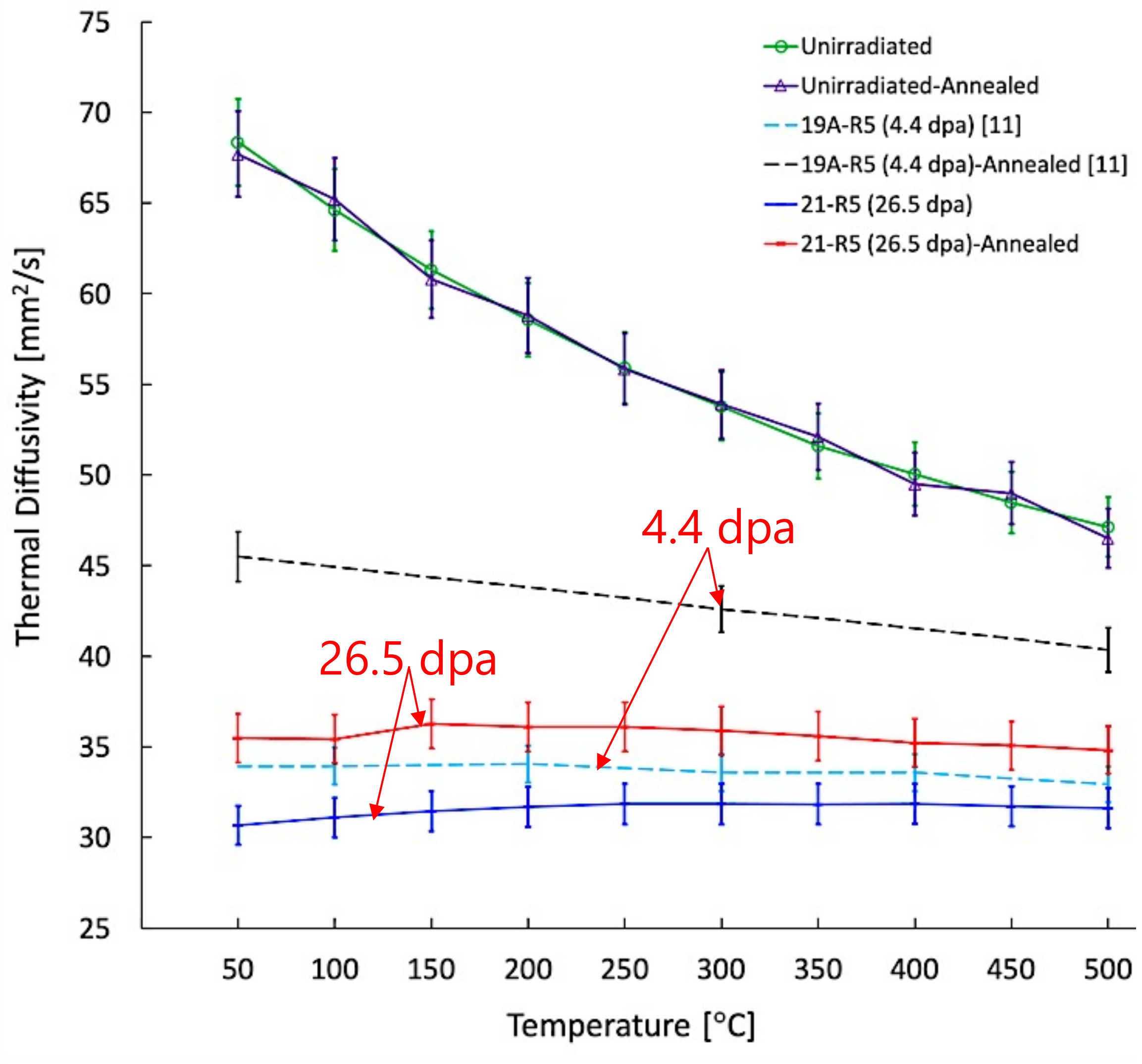
LFA results for **irradiated** samples after thickness calibration



- ✓ Drastic reduction of the thermal diffusivity as a result of irradiation
- ✓ Such a drop is attributed to Re formation and also displace damage
- ✓ Thermal diffusivities of three high dose samples are almost overlapping, independent of the damage dose and test temperature
- ✓ The threshold level for the high dose samples is marginally smaller than that for the low dose samples
- ✓ The uncertainty ranges overlap for the two data sets

Data analysis

LFA results for irradiated samples after post irradiation annealing



- ✓ 4.4 & 26.5 dpa samples were annealed at 1000 °C for one hour
- ✓ Thermal diffusivity was partially recovered by the annealing
- ✓ Such a recovery can be attributed to the reduced density of radiation induced lattice defects
- ✓ The recovery level was smaller for the high dose samples compared to that for the low dose samples
- ✓ This difference can be due to higher irradiation temperatures in the high dose samples.

Thank you for your attention!