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Measurement of strain evolution in irradiated UO_2 using micro-beam X-ray diffraction

Nuclear Engineering Master students - Introduction at PSI – 17.05.2021

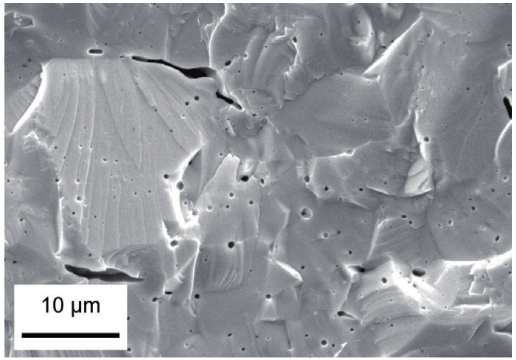
Motivation: Why fuel structure is studied?

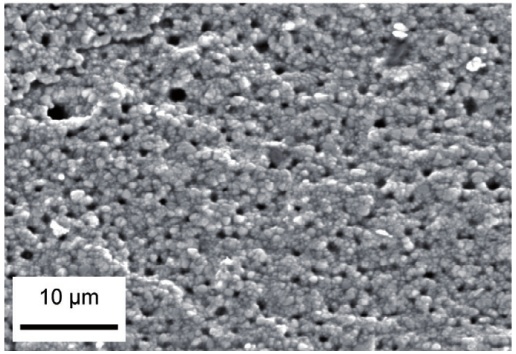
Development of high burn-up structures in UO_2 fuel:

- High concentration of intra- and inter-granular porosity
- High concentration of defects
- Grain sub-division or polygonization

The word **burn-up** is a measure of how much energy is extracted (or how much uranium is burned in the reactor).

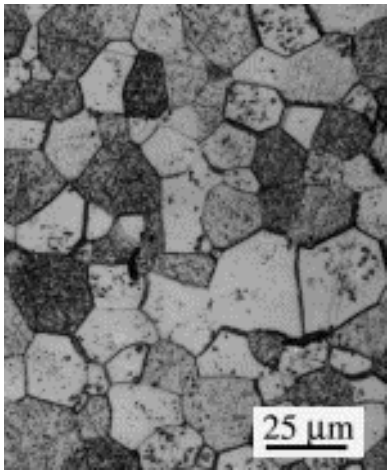
A conventional unit is **MWd/kgU**.





V. Rondinella, T. Wiss. Materials Today. 13 (2010) 24–32.

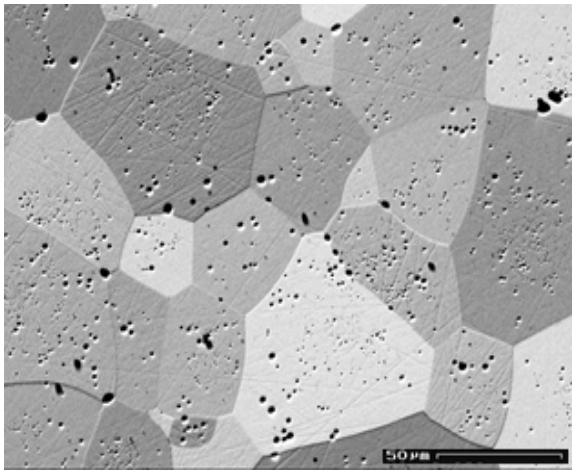
Motivation: Why chromia-doped fuels?



Standard UO_2

Avg. grain size: ~10 µm

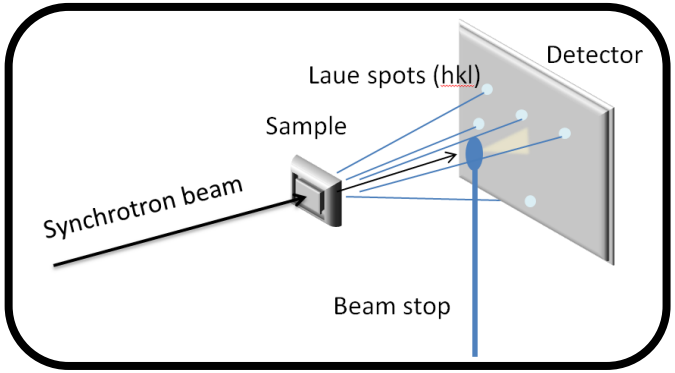
Doped fuels are fabricated to have enhanced performance at high burn-up due to softening of fuel pellet and better fission gas retention.

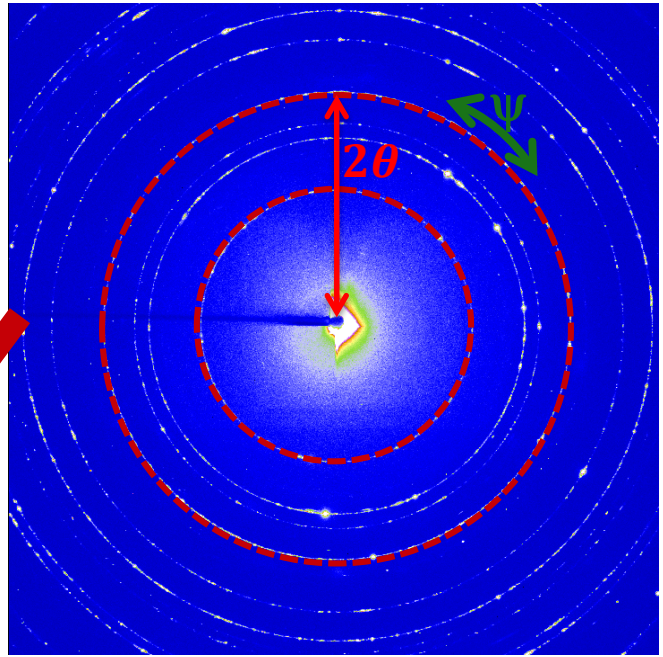


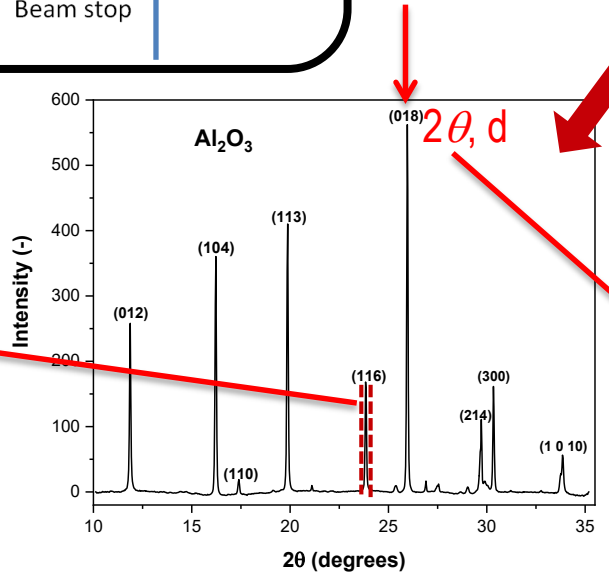
Chromia-doped UO_2

Avg. grain size: ~60 µm

Methodology and Principles of XRD







- Structural disorder
- Strain and stress investigations

Lattice parameter $\boldsymbol{a}$ determined from experimental $\boldsymbol{d_{hkl}}$ values

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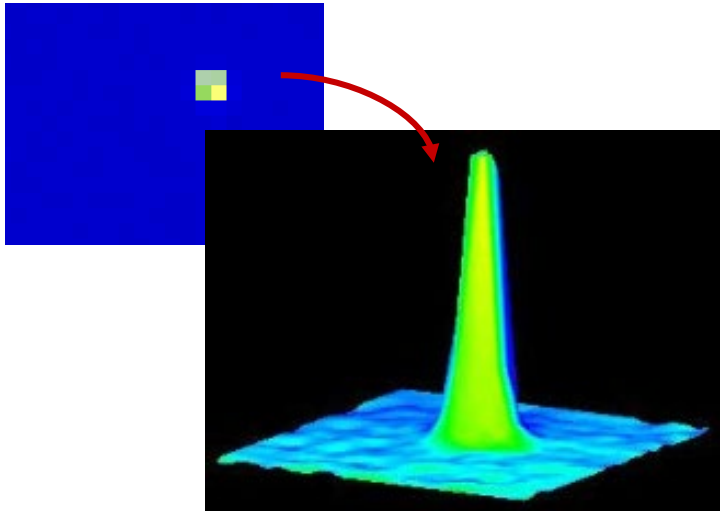
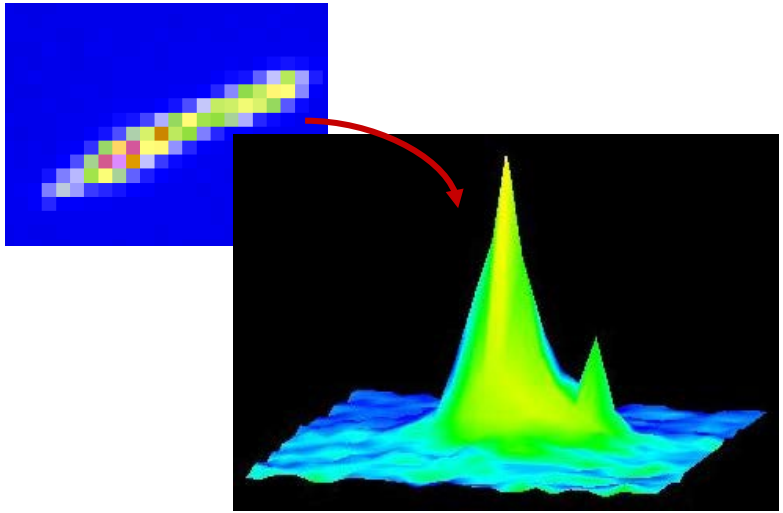
Radiation Damage: Results of Irradiated UO_2

Peak broadening, Streaking, Splitting



Non-irradiated sample



Irradiated sample

Peak shapes provide information on plastic deformation, and dislocation distribution in the diffracted volume

Estimation of dislocation density

Curvature of Laue spot streaking can be calculated theoretically as:

$$R = \delta/[2\sin(\psi/2)]$$

where, δ: beam spot size

ψ: asymmetric broadening of all indexed peaks in Laue image (in degrees)

GNDs are often related to bending of crystal lattice.

↓

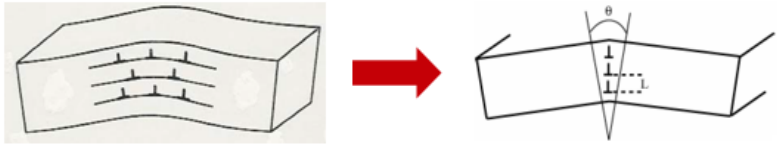
Geometrically necessary dislocation content calculated using **Cahn-Nye relationship**:

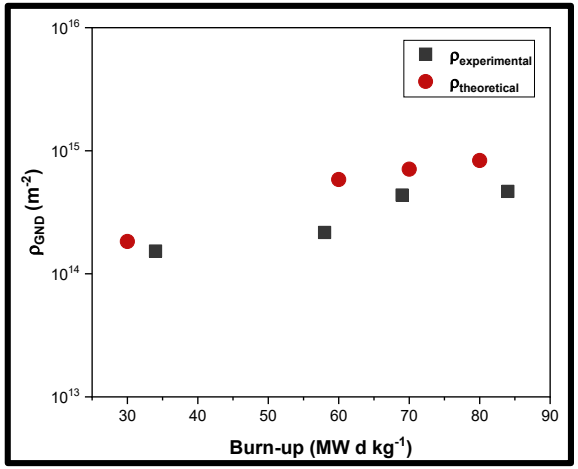
$$\rho_{GND} \approx 1/(Rb)$$

where, R: local radius of lattice curvature

b: Burger's vector

Apparent bending (R) of the crystal grain due to dislocation





Standard UO_2

Average BU (MW d kg^{-1})	$\rho_{experimental}$	$\rho_{theoretical}$
34	1.53×10^{14}	1.83×10^{14}
58	2.16×10^{14}	5.83×10^{14}
69	4.36×10^{14}	7.08×10^{14}
84	4.67×10^{14}	8.33×10^{14}

J. Rest. Journal of Nuclear Materials. 349 (2006). 150-159.

Project Outline- Semester Project

Title: Measurement of strain evolution in irradiated UO_2 using micro-beam X-ray diffraction

Workplan:

- Literature review and catching up with previous data on the sample;
- Learning of software- Fit2D, XRDua- and analysis of available XRD data;

Supervision: Shaileyee Bhattacharya, Ph.D. student (and LNM senior scientists)

Results:

- Information about strain distributions within irradiated UO_2 crystallites.
- Estimated strain energy density and UO_2 grains subdivision at high burnup.

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