Yttria as a Tritium Permeation Barrier in Fusion Components

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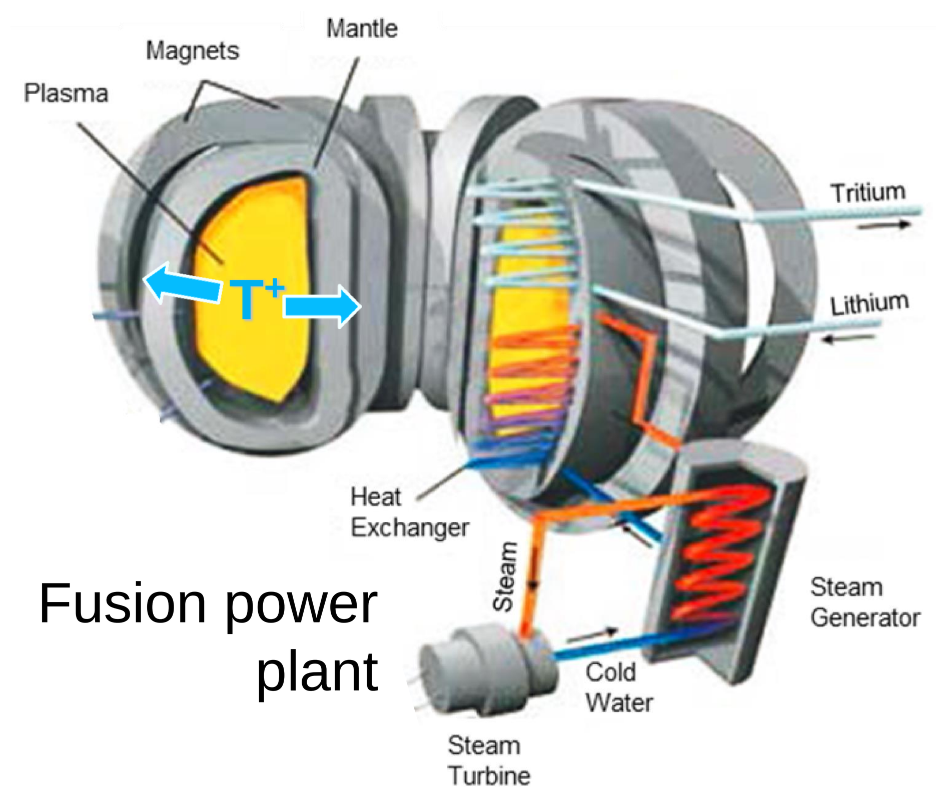
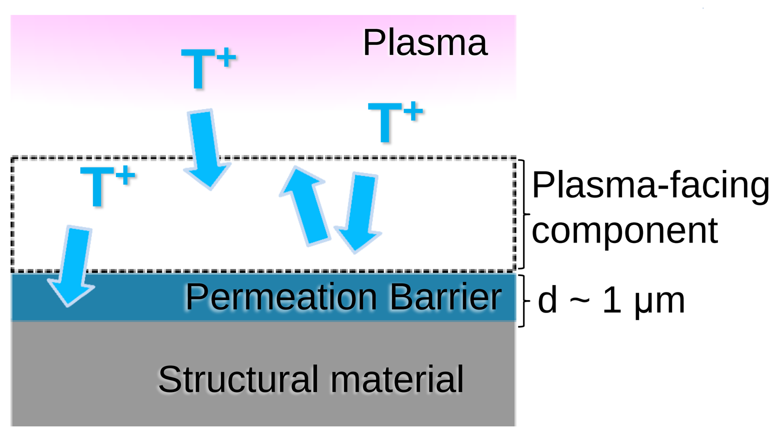
Motivation



Fusion power plant



First wall component

Problems of tritium permeation in fusion vessel:

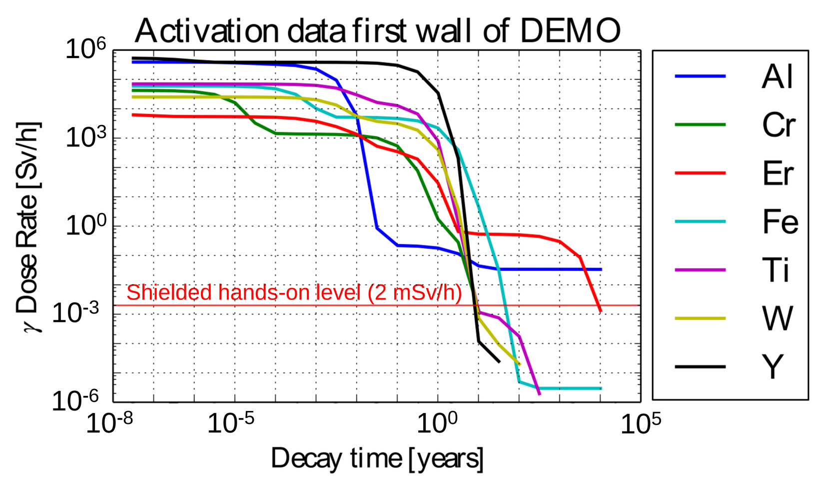
- Fuel loss
- Tritium accumulation: wall, cooling system, …
- Radiological hazards

→ **Prevention of permeation with tritium permeation barrier:**

→ Material research of thin film barrier layers (Y_2O_3): porosity, phase, heat load resistivity

→ Deuterium permeation studies of the barrier layers: Required permeation reduction factor is 50…100 for viable power plant – Does Y_2O_3 film fulfill this?

→ Advantage of Y_2O_3 compared to other candidates (e.g. Al_2O_3). Favorably low neutron activation behavior of Y:



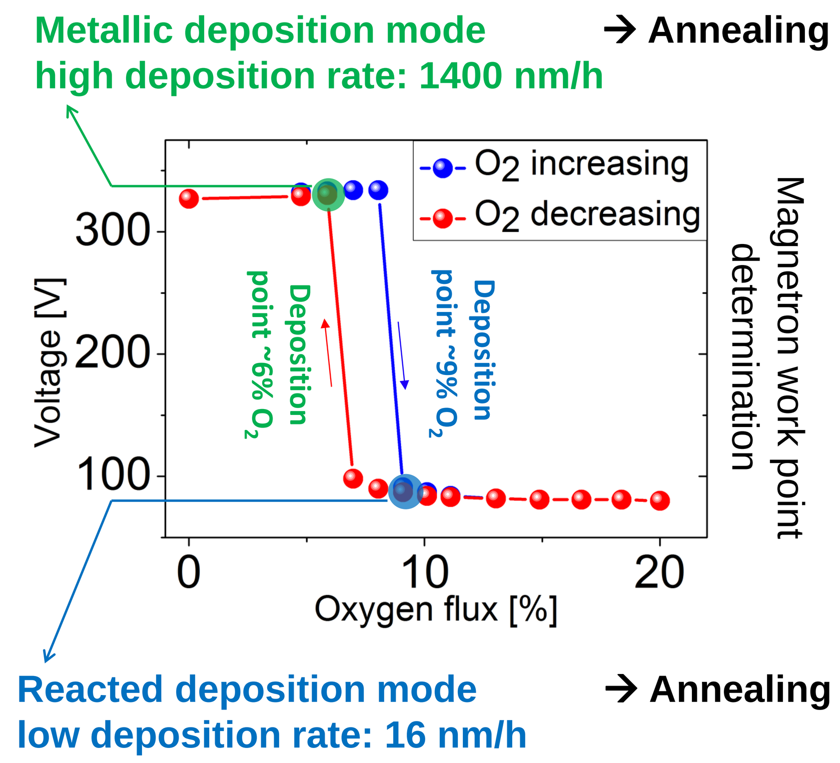
Barrier layers: Y_2O_3

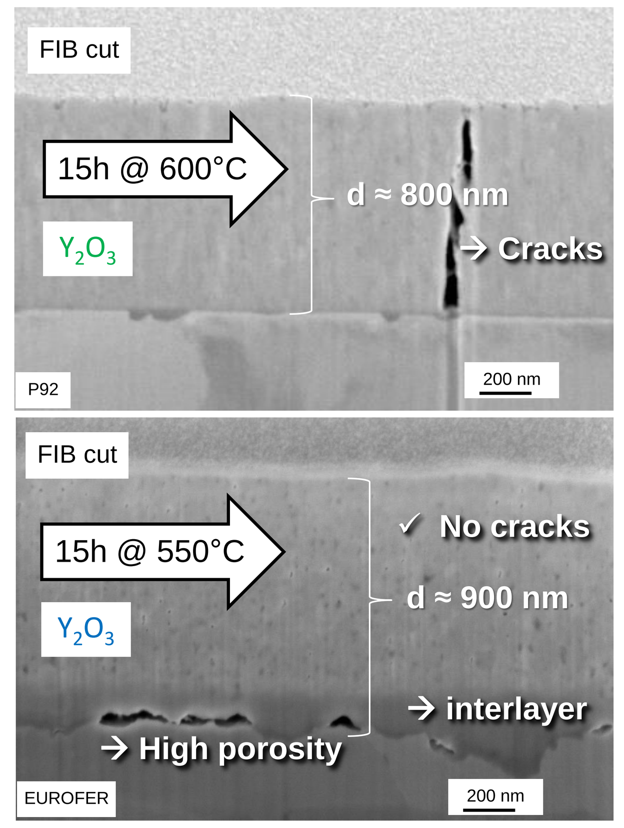
Y_2O_3 film:

- High thermal stability and corrosion resistivity
- Similar thermal expansion coefficients of:
  - Eurofer97 substrate: $12.7 \cdot 10^{-6}\ K^{-1}$
  - Y_2O_3 thin film: $8 \cdot 10^{-6}\ K^{-1}$

Layer deposition:

- Reactive magnetron sputtering: Ar/O_2 plasma, power-density: 2.9 W/l
- Change ratio of O_2 to Ar inlet flux:
  - < 6%: Metallic mode
  - > 9%: Reacted mode – Y target is oxidized:
  - → Deposition rate decreases by factor of ~100
  - → Porosity is formed





Phase analysis of Y_2O_3

XRD: Stable cubic phase after annealing

Lattice const.	Metallic	Reacted
Not annealed	10.747(5) Å	-
Annealed	10.629(5) Å	10.643(5) Å

✓ Lattice const. Y_2O_3: 10.6018 Å*

*H. Ishibashi, K. Shimomoto, K. Nakahigashi, J. of Physics and Chemistry of Solids (1994)

FIB-cut → SEM analysis of Y_2O_3 films:

- SEM of thin film cross-section:
- Metallic mode film: Cracks are formed, due to stress during annealing
- Reacted mode film: Porosity dissipates stress energy
  - → No cracks/damages in barrier layer after annealing
  - → Perform permeation measurement of this barrier (Possible influence on permeation of CrO_x interlayer, formed during annealing)

Background

Permeation Studies

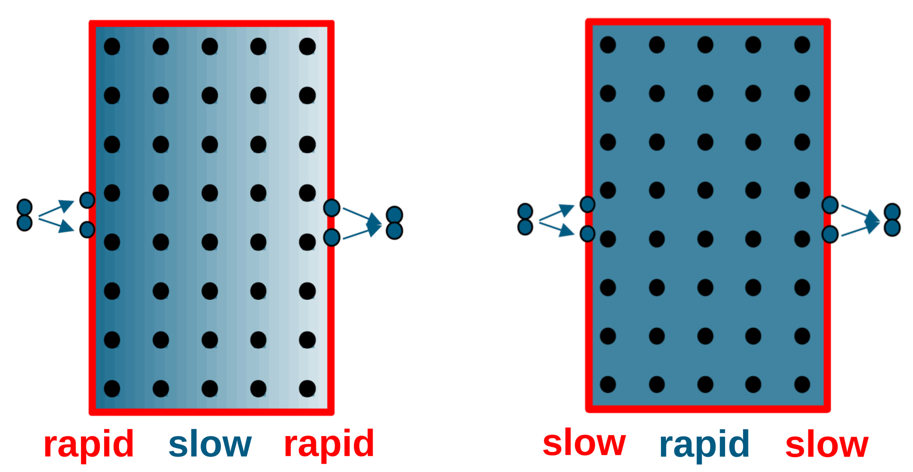
Pressure dependence (D_2 pressure (p): 25 - 800 mbar):

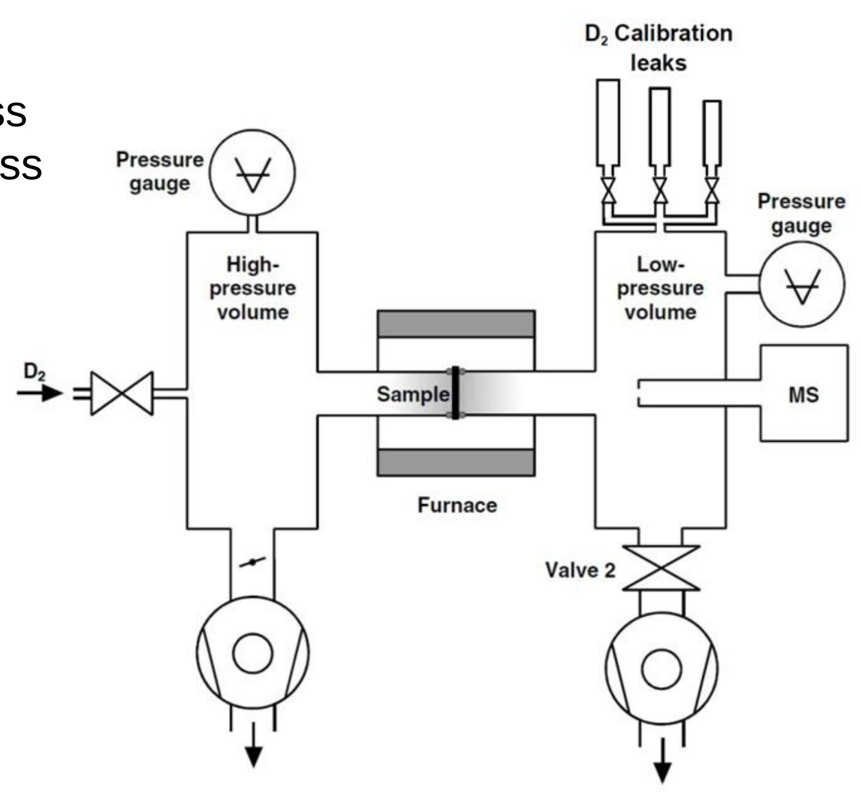
Permeation control mechanism (J: permeation flux):

- $J \sim p^{0.5}$: Diffusion limited regime, dependent on sample thickness
- $J \sim p^{1}$: Surface limited regime, independent on sample thickness

Temperature dependence (temperature: 300 - 550°C):

→ Provides activation energy for diffusion of D_2 in sample





Permeation setup

Substrate

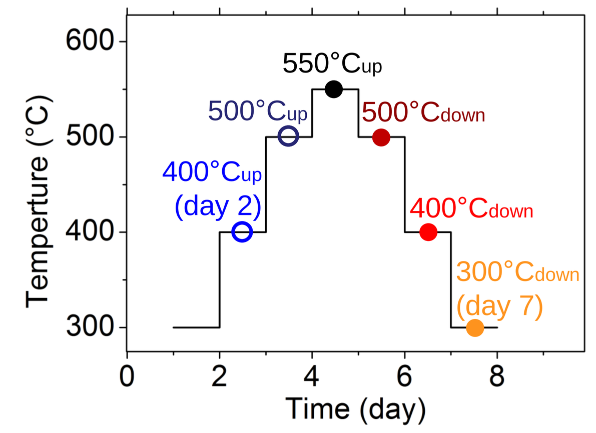
Eurofer97 - reduced activation ferritic martensitic (RAFM) steel:

- Low content of undesired elements: Nb, Mo, Ni, Cu…

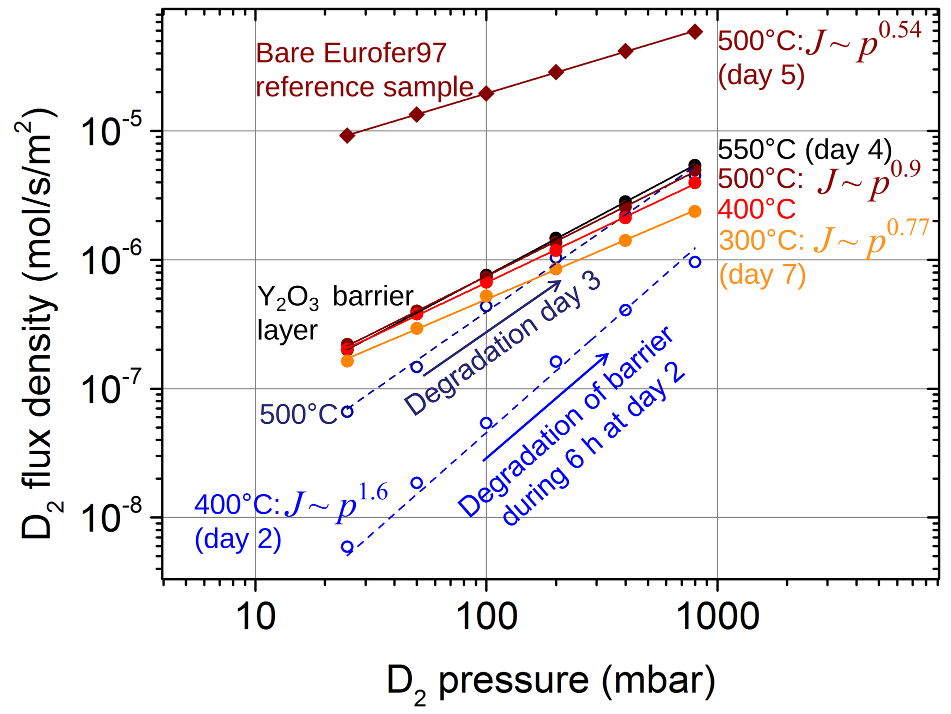
Sample preparation - wire-cut disks (0.3 mm thickness, 25 mm diameter):

- Annealing at 550°C: Removal of native hydrogen
- Mechanical polishing: Defines surface roughness

Permeation



Temperature progression during measurement



Comparison of Y_2O_3 film and substrate:

Pressure dependence: Slope of curve in the diagram equals exponent of D_2 pressure p

- Bare Eurofer97 reference sample: $J \sim p^{0.54}$ (500°C)
  - → Diffusion limited regime
- Reacted mode Y_2O_3 barrier layer: $J \sim p^{0.9}$ (500°C)
  - → Barrier performance degraded, probably because of change in Y_2O_3 grain structure
  - → Apparent change of exponent

Permeation reduction factor of oxide layer compared to substrate: ~30 (minimum factor after degradation)

Summary

Y_2O_3 barrier layer

- 1 µm layer by reacted mode magnetron deposition process
- Annealing for 15h @ 550°C

✓ **No crack formation** → Accurate permeation measurement possible

✓ **Cubic phase of the Y_2O_3 layer after annealing for metallic and reacted mode (XRD)**

✓ **Favorable neutron activation behavior of Y**

Preliminary result of D_2 permeation measurement

- Permeation reduction factor: ~ 30