Max-Planck-Institut für Plasmaphysik, EURATOM Association

Phase formation of Erbia coatings on EUROFER 97, phase stability and deuterium permeability

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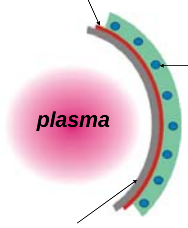
Motivation

Tritium permeation from plasma into and through structural materials of future fusion devices has to be avoided:

- radioactive tritium ends up in the coolant and may leave the reactor vessel with contamination of environment
- hydrogen and its isotope leads to embrittlement of material, especially of steel (structural material)
- loss of fuel due to hydrogen permeation



Application of a thin ceramic layer as permeation barrier between plasma facing material and structural material

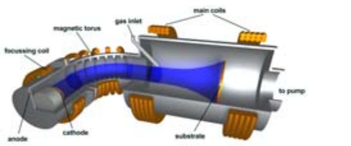
- high permeation reduction (10^2-10^3) with thin (≈1 µm) oxide coatings (α-Al_2O_3, Er_2O_3) [1-3]
- Er_2O_3 shows **phase transformation** under ion irradiation [4]: cubic C-phase ⇒ monoclinic B-phase
- Influence on permeation **barrier properties** ?

[1] Levchuk et al., Phys. Scr. T108 (2004) 119.
[2] Levchuk et al., J. Nucl. Mater. 367 (2007) 1033.
[3] Chikada et al., Fusion Eng. Des. 84 (2009) 590.
[4] Tang et al., J. Appl. Phys. 99 (2006) 063514.

Experimental

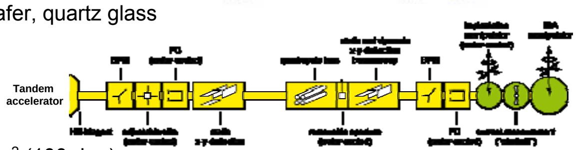
Er_2O_3 thin films by filtered cathodic arc

- pure Er cathode, 5×10^{-2} Pa oxygen
- ≈ 1 µm thickness (15 min deposition)
- RT – 700 °C, 0 – 450 V bias
- substrates: **Eurofer**, Si wafer, quartz glass



5.5 MeV Au^{++} irradiation

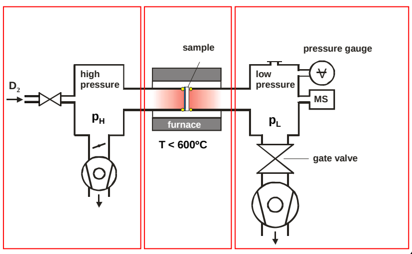
- RT (with water cooling)
- flux: ≈ 1-2×10^{12} $cm^{-2}s^{-1}$
- fluence: max. 2.2×10^{16} cm^{-2} (100 dpa)



HE: High energy **BPM**: Beam profile monitor **FC**: Faraday cup **IBA**: Ion beam analysis

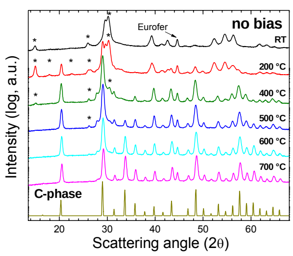
Permeation apparatus

- QMS sensitivity range: 10^{-7} to 10^{-2} mol/m²s (deuterium flux)
- liquid nitrogen trap for input gas
- temperatures range: up to 600°C
- hydrogen driving pressures range: 10^{-3} to 10^3 mbar

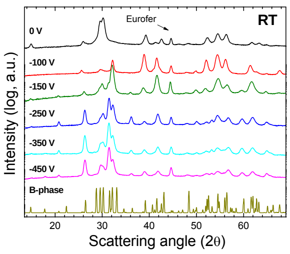


XRD

XRD diffractograms of Er_2O_3 thin films on Eurofer deposited at 0 V bias and varying temperature. Below 600 °C mono-clinic B-phase diffraction peaks occur (*)



XRD diffractograms of Er_2O_3 thin films on Eurofer deposited at RT and varying sample bias

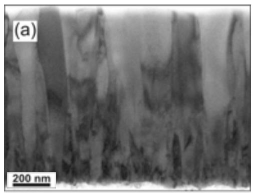


XRD at 3° incidence angle

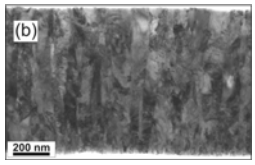
- pure **cubic C-phase** for T ≥600 °C / 0 V
- pure **monoclinic B-phase** for -150 – -450 V bias and T ≤400 °C
- strong B-phase **texture** Missing peaks can be detected by **tilting** the sample (θ-2θ scan)

C. Adelhelm et al., Scripta Materialia, 61 (2009) 789.
C. Adelhelm et al., ICFRM-14 proceedings

Microstructure (STEM)

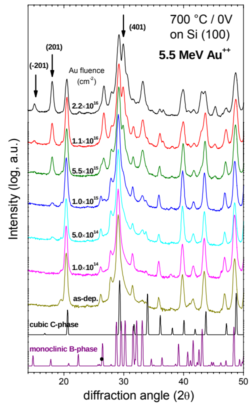


C-phase Er_2O_3 on Eurofer (600 °C / 0 V)



B-phase Er_2O_3 on Eurofer (400 °C / 250 V)

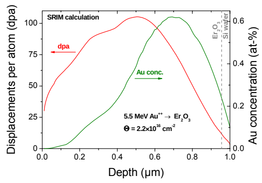
Irradiation Effects



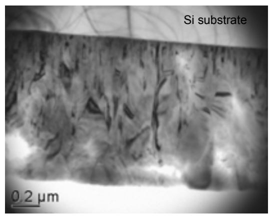
Irradiation of Er_2O_3 films on Si wafer with 5.5 MeV Au^{++} at RT

- starting with almost pure C-phase (700 ° / 0 V), transformation into B-phase starts at a fluence of 5×10^{14} Au^{++}/cm^2
- no influence of ion irradiation observed by XRD when starting with the B-phase

⇒ **B-phase is stable against further phase transformation!**

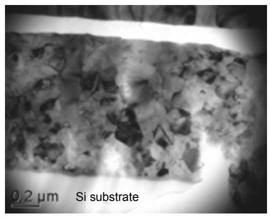


Microstructure (TEM)



C-phase Er_2O_3 thin film on Si

as-deposited



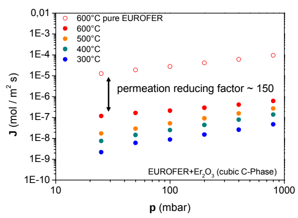
C-phase Er_2O_3 thin film on Si

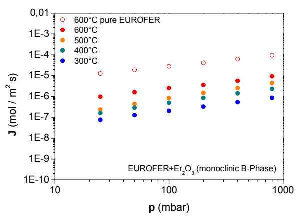
Irradiated (2.2×10^{16} cm^{-2})

Matt Chisolm, ORNL

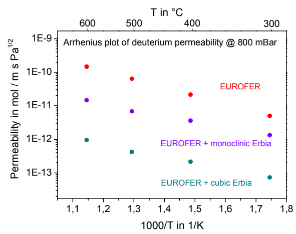
Permeation Results

Gas driven deuterium permeation through Eurofer and Er_2O_3 thin films on Eurofer substrate





Deuterium permeation flux J as a function of driving pressure



Gas driven deuterium permeation

- Eurofer → diffusion limited regime
- thin layer of Erbia leads to surface limited regime
- higher permeation reduction for the cubic phase
- permeation reducing factor ~ 150

Acknowledgement

Joachim Dorner and Michael Fußeder are acknowledged for performing the Au irradiation experiments.