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Deuterium gas-driven permeation and retention in La_2O_3, Y_2O_3, and ZrO_2 dispersion-strengthened tungsten

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ABSTRACT

Oxide dispersion strengthened tungsten (ODS-W) materials were investigated as potential first-wall candidates for fusion applications. Three materials—W-La_2O_3, W-Y_2O_3, and W-ZrO_2—were examined using gas-driven permeation (GDP) and thermal desorption spectroscopy (TDS). W-La_2O_3 and W-Y_2O_3 show similar permeabilities, both slightly lower than W-ZrO_2. TDS results reveals distinct features: W-La_2O_3 exhibits a single high-temperature peak, W-Y_2O_3 displays double peaks, and W-ZrO_2 shows a single peak with a desorption flux over one order of magnitude higher. The results demonstrate that oxide type and microstructure strongly influence D transport and trapping behavior in ODS-W.

BACKGROUND

- Tungsten (W): excellent plasma-facing candidate but suffers from high DBTT, irradiation embrittlement, and recrystallization.
- Oxide dispersion strengthening (ODS): improves mechanical properties, DBTT and irradiation resistance.
- **Understanding D behavior is critical for plasma operation, fuel cycle efficiency, and radiation safety.**
- **Knowledge gap**: hydrogen isotope permeation and retention in ODS-W remain insufficiently studied.

MATERIALS AND METHODS

MATERIALS

- **ODS-W materials** (produced by AT&M Co. Ltd Inc., China):
  - WLaO (2.0 wt% La_2O_3)
  - WYO (2.0 wt% Y_2O_3)
  - WZrO (1.0 wt% ZrO_2)
- **Processing**: hot-rolled plates, specimens cut by EDM.
- **Samples**:
  - GDP: disks, Ø12.6 × 1 mm³
  - TDS: squares, 10 × 10 × 1 mm³
- **Preparation**: annealed at 1223 K (2 h), mirror-polished; TDS samples also polished on all sides.

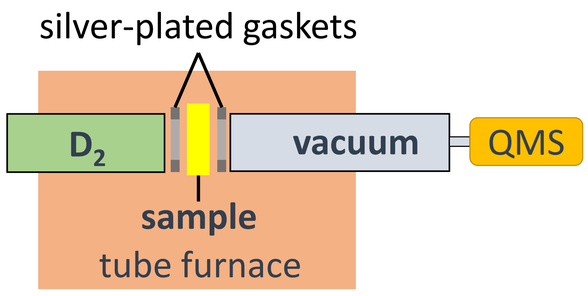
GB density and W-particle interface density of ODS-W

Materials	LAGBs ($\times10^6$ m^{-1})	HAGBs ($\times10^6$ m^{-1})	W-particle interface ($\times10^6$ m^{-1})
WLaO	0.53	0.18	0.15
WYO	1.32	1.08	0.11
WZrO	1.29	1.07	0.17

METHODS

GDP

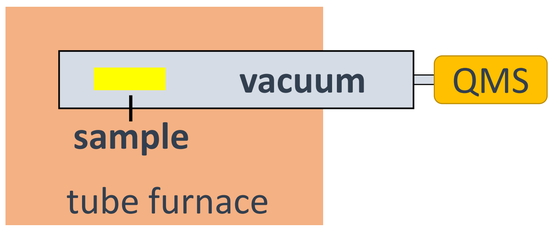
Gas-Driven Permeation



Temperature: 973 - 1123 K
Pressure: 5 × 10^4 - 1 × 10^5 Pa

TDS

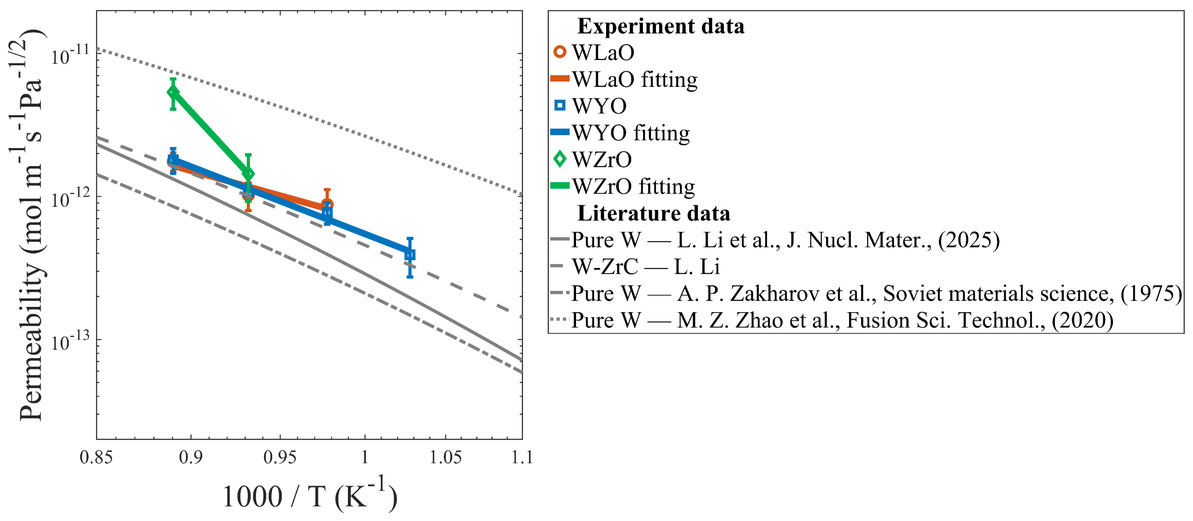
Thermal Desorption Spectroscopy



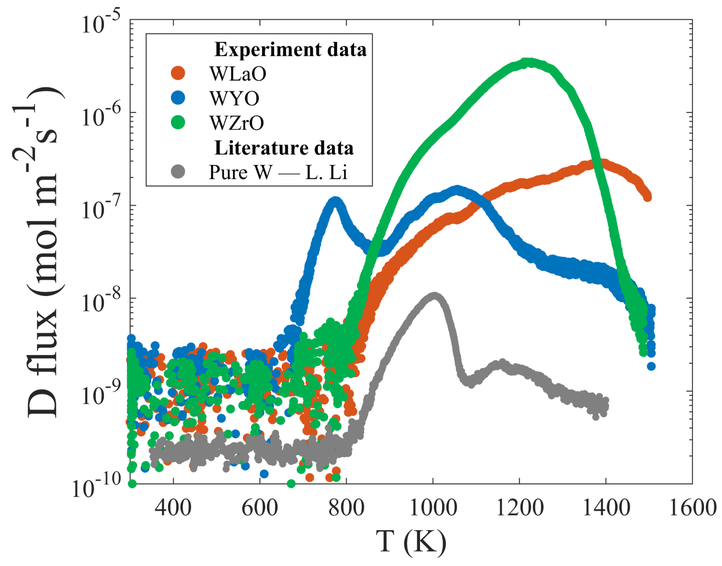
Temperature: RT - 1453 K
Heating rate: 0.5 K/s

OUTCOME

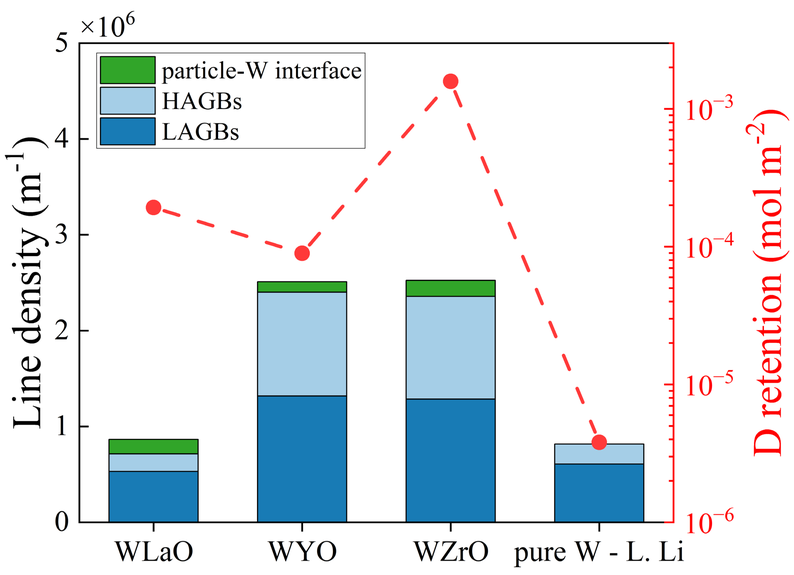
- **Comparable permeability:**
  WLaO and WYO exhibit similar D permeation rates, both slightly lower than WZrO. All three ODS-W show permeabilities comparable to pure W and W-ZrC, within the same order of magnitude.



- **Distinct desorption features:**
  TDS results show one high-temperature peak (1386.8 K) for WLaO, double peaks (773.7 and 1056.6 K) for WYO, and a single strong peak for WZrO (1228.4 K) with one order of magnitude higher desorption flux.



- **Microstructure-retention correlation:**
  D retention in ODS-W is dominated by oxide particles. WLaO shows higher retention from particle-W matrix interfaces, while WZrO traps more D than WYO, implying stronger trapping by ZrO_2.



CONCLUSION

- WLaO and WYO show similar permeabilities slightly below WZrO, while retention behaviors vary greatly, highlighting the influence of particle and microstructural interfaces.
- **Key challenge:** controlling retention peaks and flux to optimize D management in fusion first-wall components.
- **Discussion topic:** how to exploit particle size and interface density to balance D behavior and mechanical integrity under reactor conditions.