大阪大学
OSAKA UNIVERSITY

Influence of surface melting or impurities (Ne, Ar) on deuterium permeation in tungsten

タングステン表面溶融及び不純物(Ne、Ar)が水素同位体の透過へ与える影響

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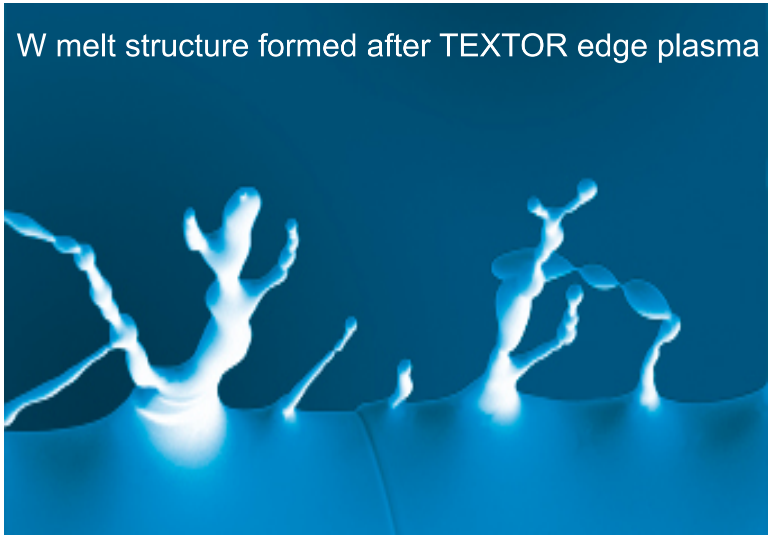
Motivation

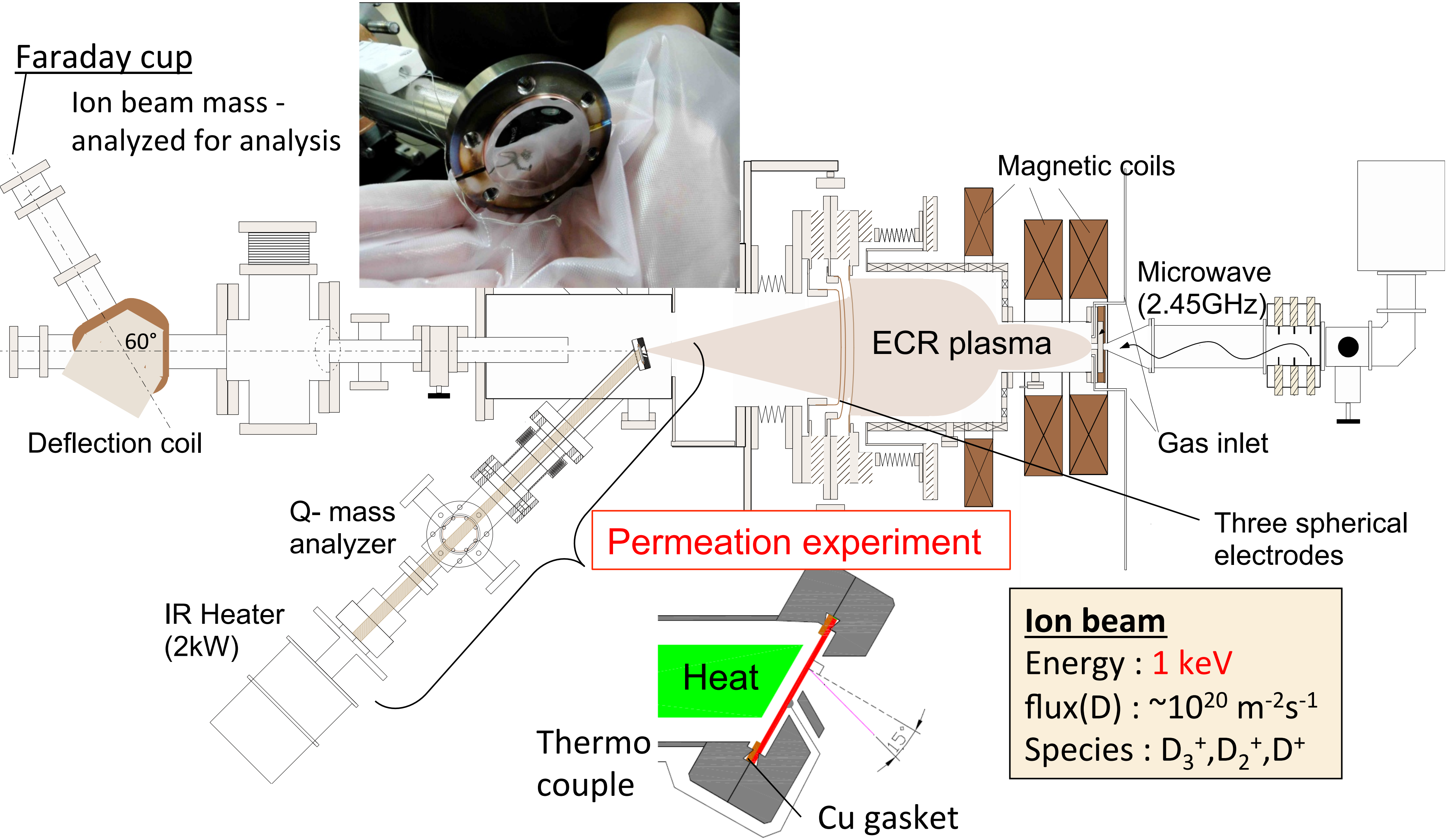
- Worldwide fusion program is now focused on Tungsten (W) as plasma facing material in divertor. (JET-ILW, ITER, DEMO)
- Probability of some W melting and surface morphological changes due to power loads.
- N, Ne, or Ar are considered as extrinsic impurities to reduce the local power load.
- Hydrogen transport under such changes in surface condition has not been investigated.
- May impact tritium retention and safety.



(i.e. change in boundary condition for hydrogen diffusion)

Research purpose:
1. To determine how hydrogen transport / retention affected by surface melting and N, Ne, or Ar impurities.
2. To evaluate the magnitude of such changes on Tritium retention estimates.

Ion driven permeation apparatus



Ion beam

Energy : 1 keV

flux(D) : ~10^{20} $m^{-2}s^{-1}$

Species : D_3^+, D_2^+, D^+

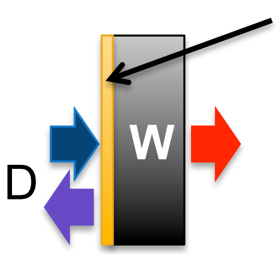
Influence of surface melting on deuterium permeation in tungsten

Experimental

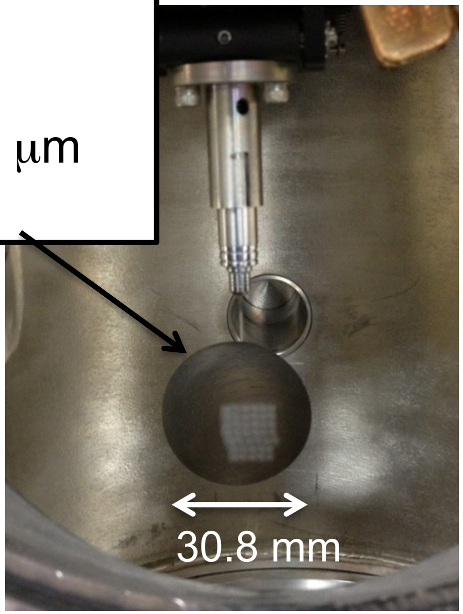
1. **Prepare surface melt layer on W**
   - Nano second laser irradiation.

2. **Characterization of surface melt and morphology**
   - SEM (surface/cross section).
   - Laser microscope (topological information).

3. **D-only ion driven permeation experiments**
   - HiFIT device.
   - Temp: 500 ~ 1000 K

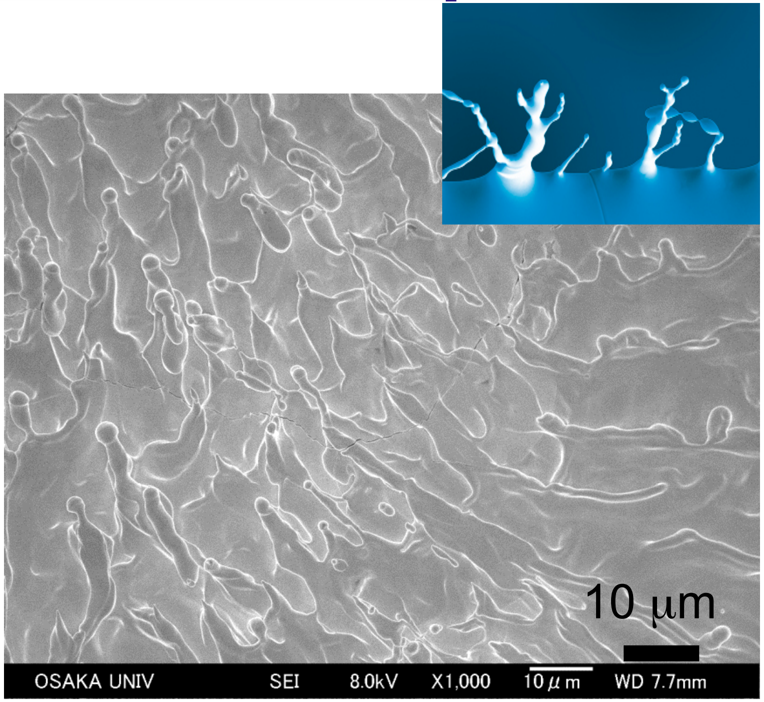


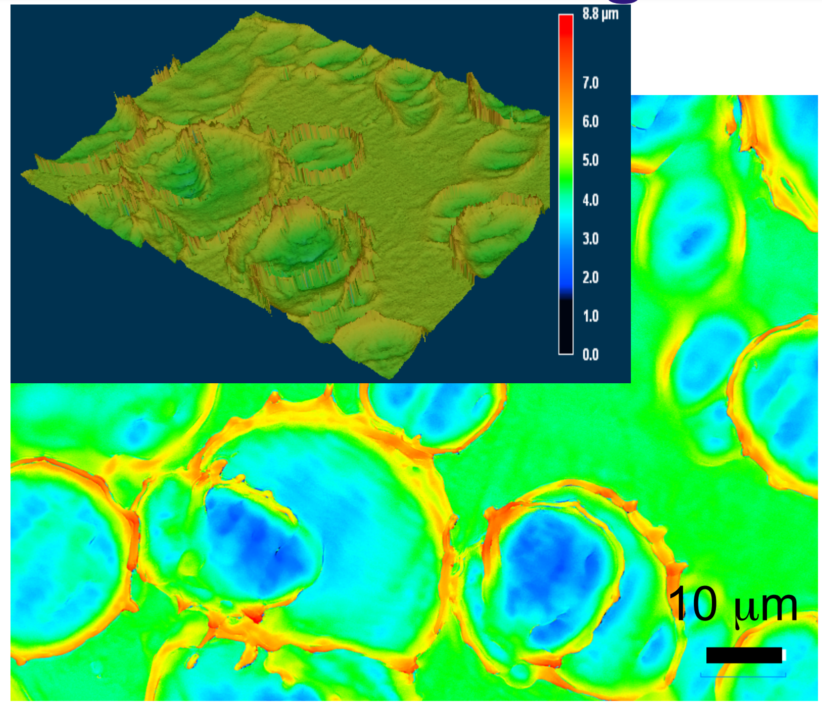
Sample
W disc
thickness = 71 μm
ϕ = 30.8 mm

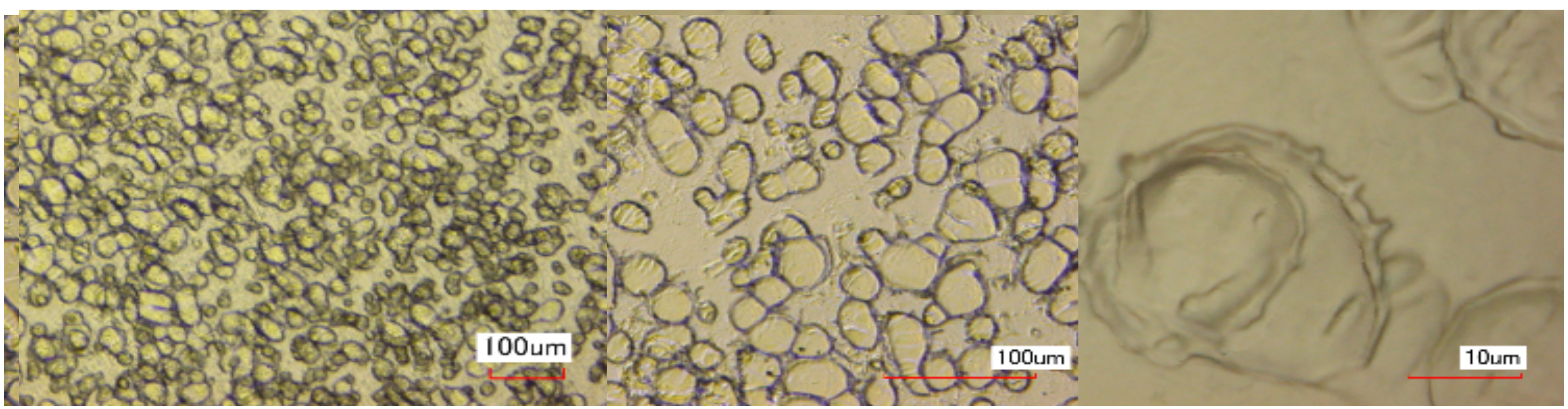


Laser parameters
Wavelength : 1064 nm
Pulse width (FWHM) : 7 ns
Beam spot: ϕ ~ 4 mm
Intensity: ~600 mJ
Laser power density:
7×10^{12} W/m^2

Fine filamentary features and crater-like dimples due to surface melting

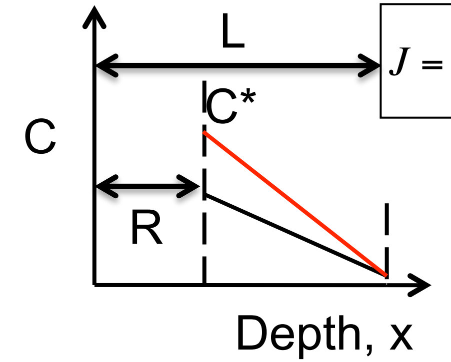






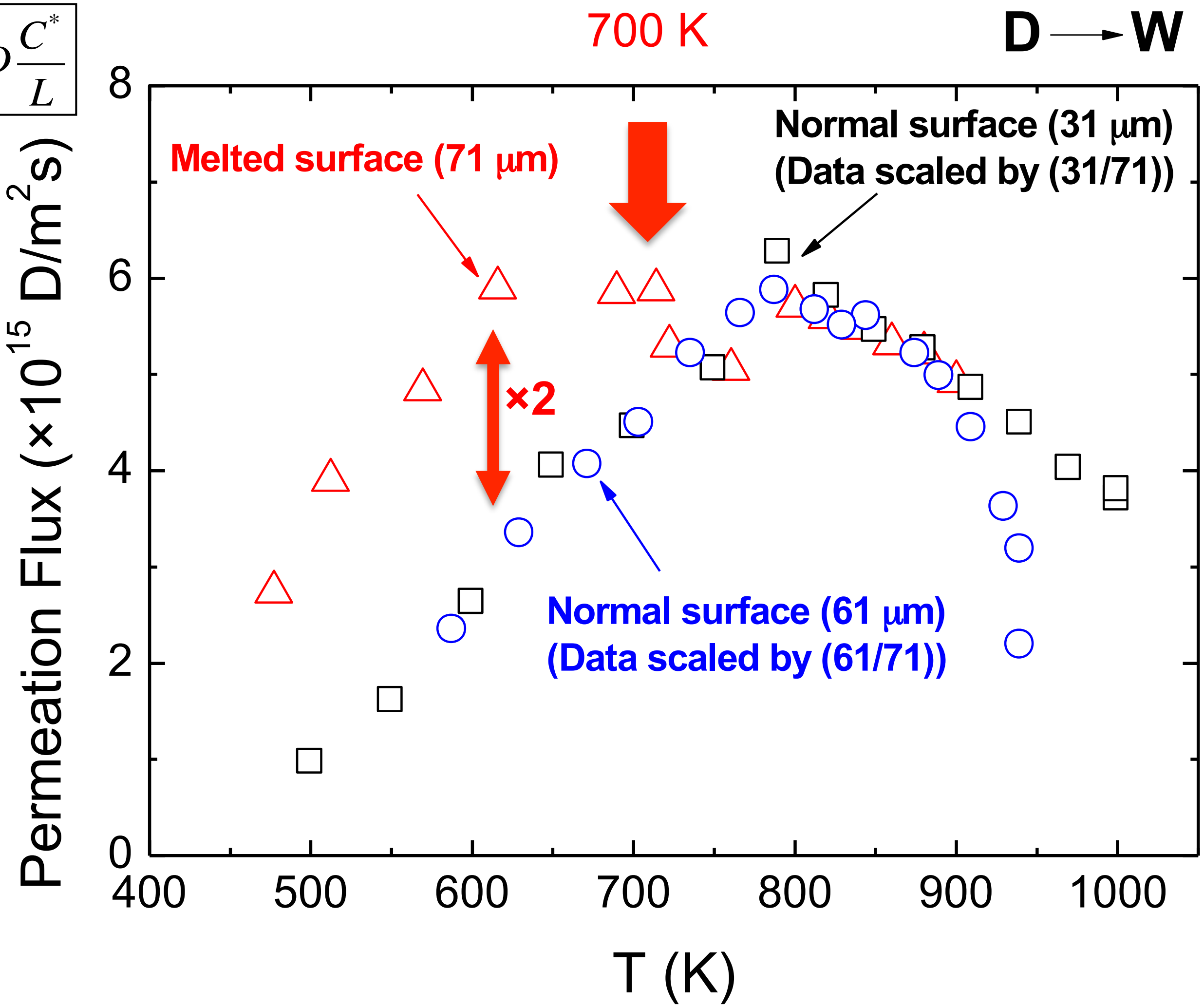
Increase in steady state permeation at T≤ 700 K

Steady State condition:

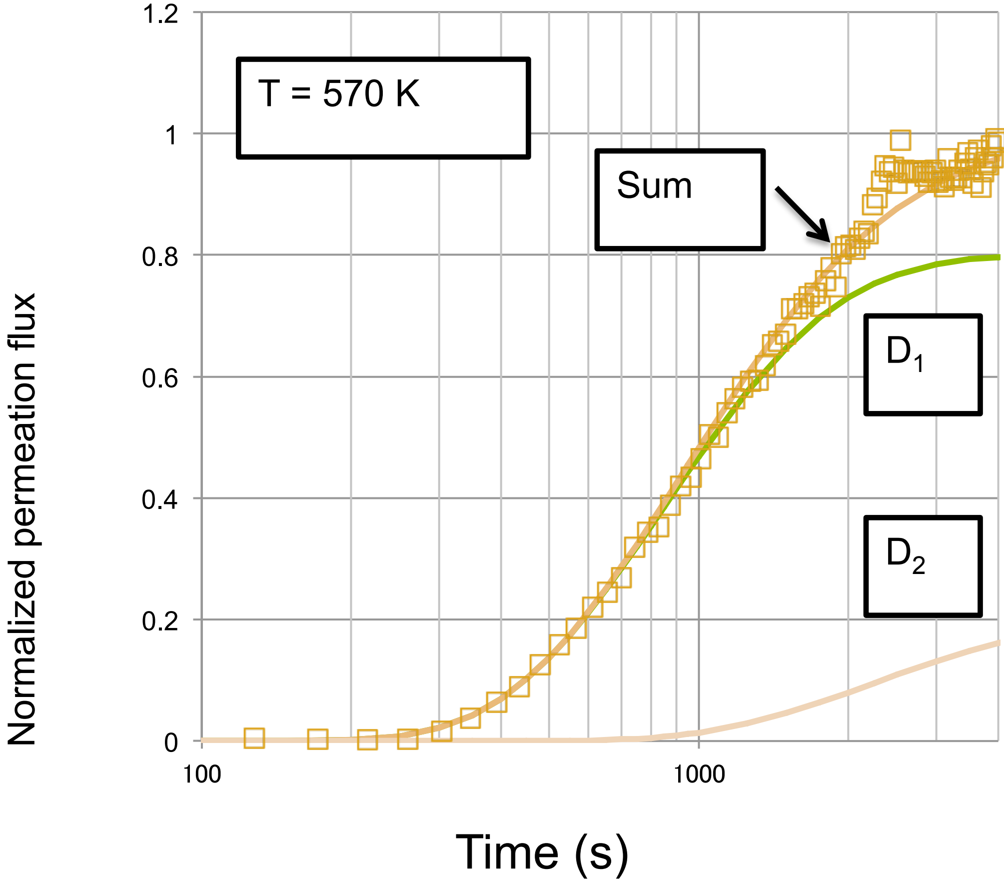


$$J = -D\frac{\partial C}{\partial x} \cong D\frac{C^*}{L}$$

- From inverse thickness dependence we confirm diffusion limited transport.
- Indicates R << L. (i.e. the controlling C is close to the surface < 1μm)
- T ≥ 700 K, an increase in steady state flux for melted surface (×2). (i.e an increase in solute C)

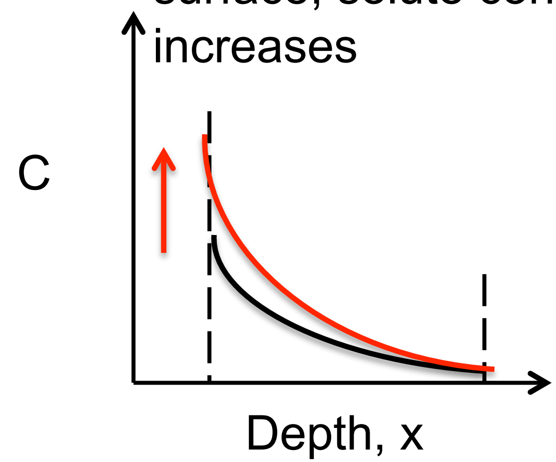


Transient permeation spectra



$$\Gamma_p = \frac{D n_{s0}}{d}\left[1+2\sum_{n=1}^{\infty}\left\{(-1)^n \cdot exp\left(-D\left(\frac{n\pi}{d}\right)^2 t\right)\right\}\right]$$

Once traps filled at near surface, solute concentration increases

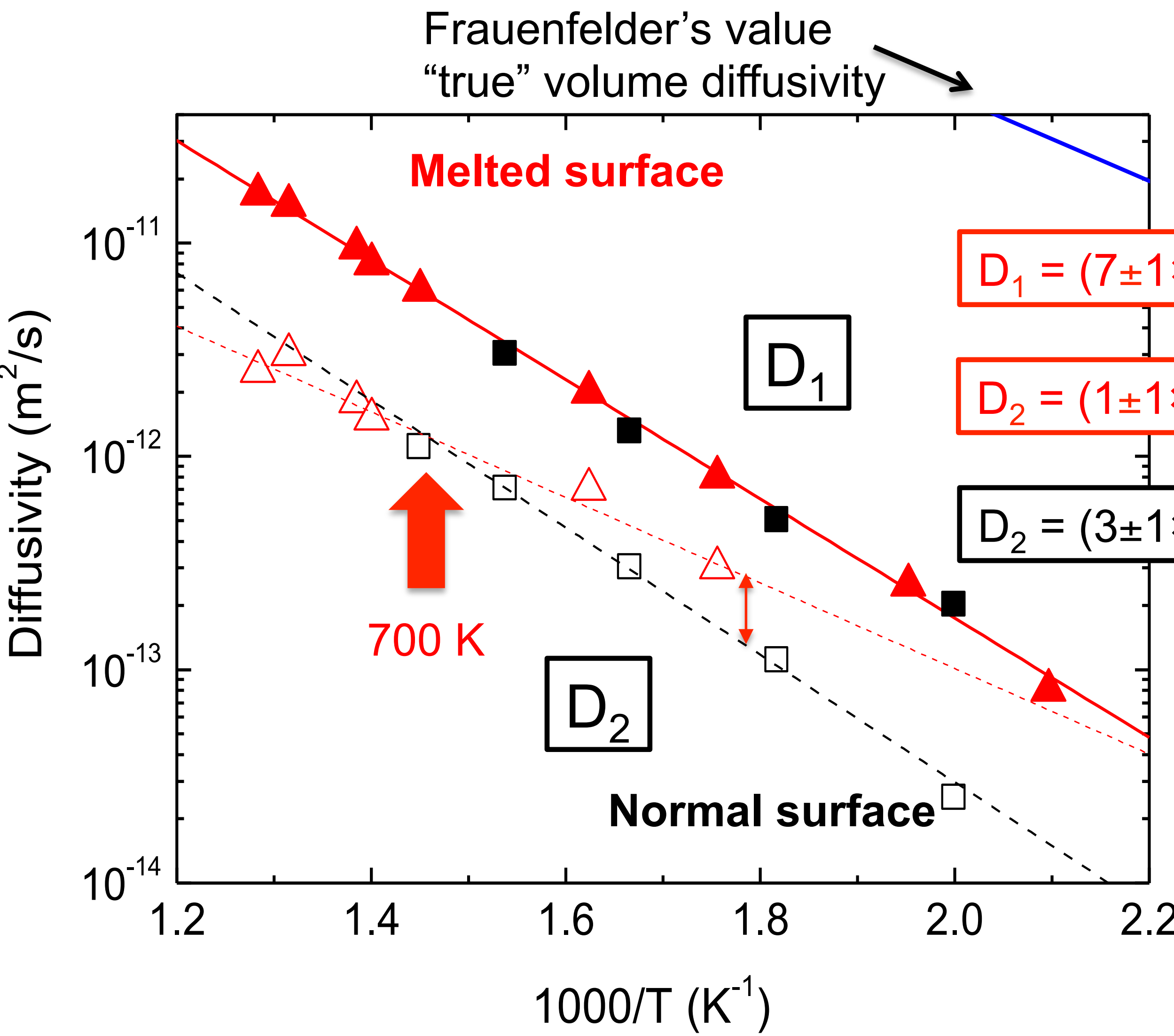


- At T = 570 K, good fit requires sum of two independent permeation curves with two different diffusivities.

- The two diffusivities interpreted to be:

Effective diffusivities reflecting trapping effects.

Difference only in the second diffusivity D_2 between melted and normal specimen



$D_1 = (7\pm1\times10^{-8}) \exp(-0.55\pm0.02\ eV/kT)$

$D_2 = (1\pm1\times10^{-9}) \exp(-0.40\pm0.05\ eV/kT)$

$D_2 = (3\pm1\times10^{-8}) \exp(-0.59\pm0.03\ eV/kT)$

- The higher D_2 for melted sample due to higher trap filling ratio due to higher solute D concentration.

Summary of surface melt experiments

- Surface melted layer on W permeation specimen and D-only irradiation experiments performed.

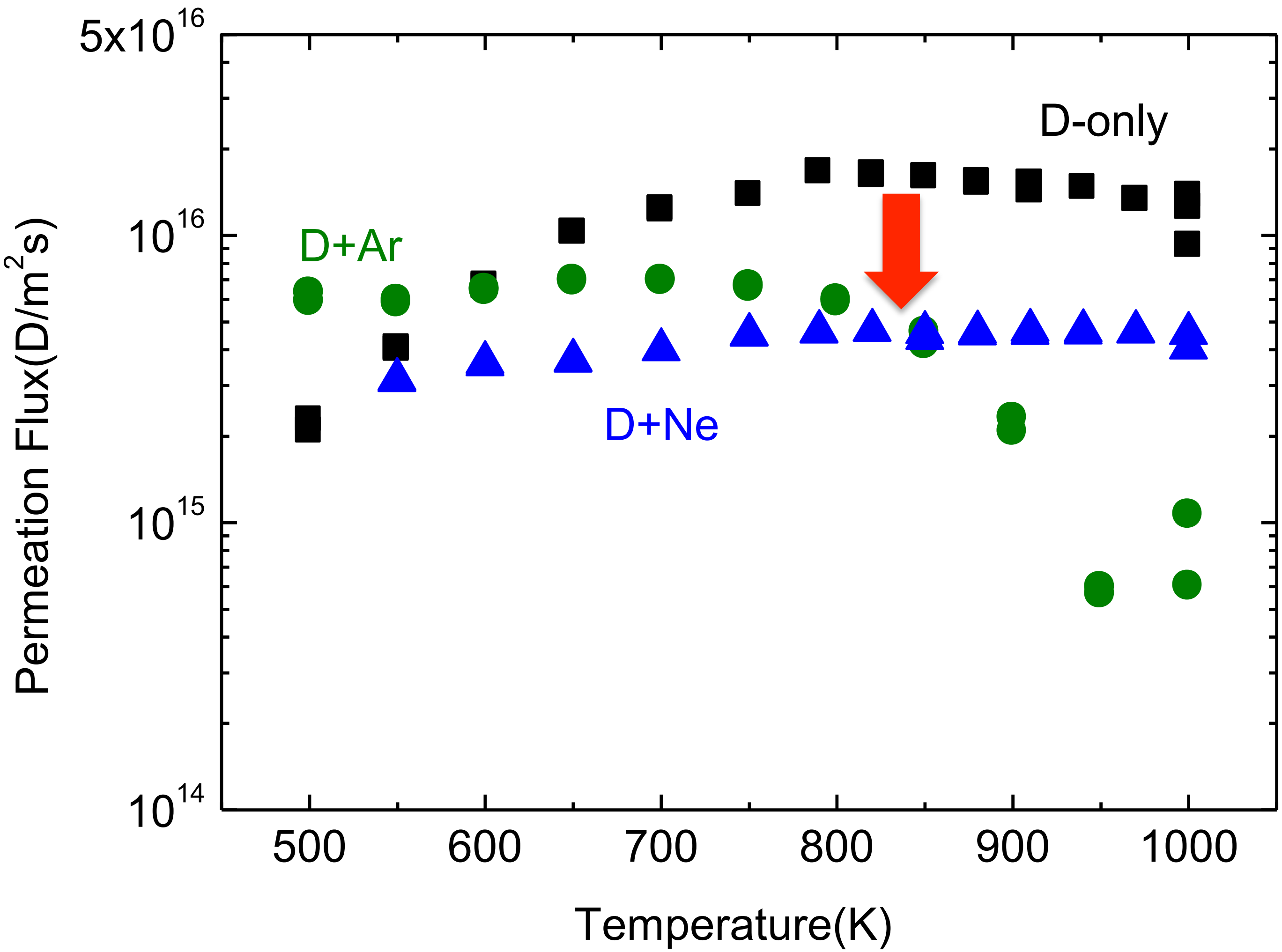
- T ≥ 700 K, an increase in steady state flux for melted surface (×2). This indicates increase in solute concentration due to surface melting.

- Two diffusivities provide good fit to transient permeation spectra. The higher solute concentration results in faster diffusion through the bulk (since traps are saturable).

> - The experiments clearly indicate that surface melting and morphology changes due to heat loads does change the D transport but its impact is modest (×2).
>
> - Effect of mixed irradiation (D+X (X = He, N, Ne, Ar)) unknown for melted layer.

重水素･Ne/Ar同時照射が透過挙動に与える影響

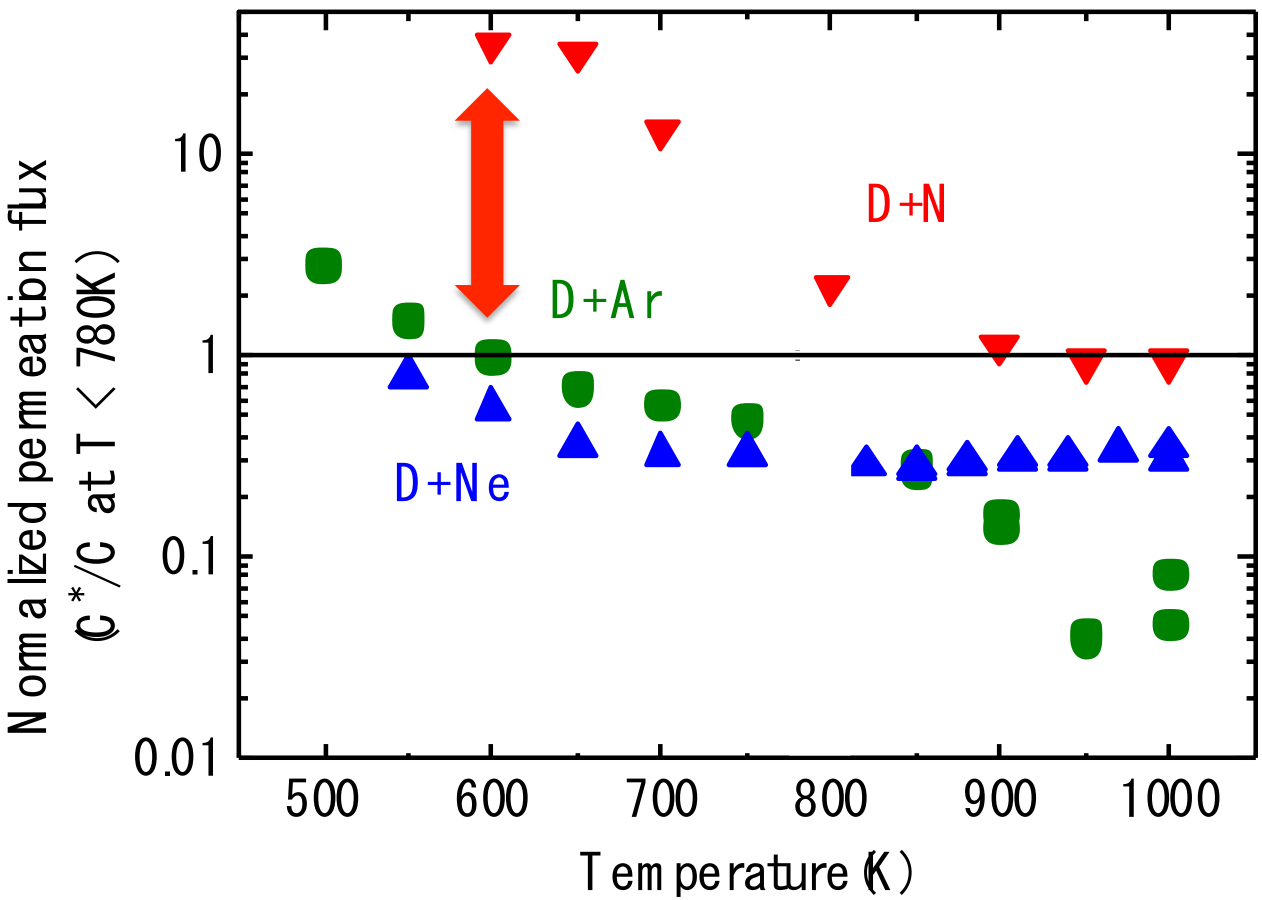
Ne/Ar同時照射による重水素定常透過フラックスへの影響

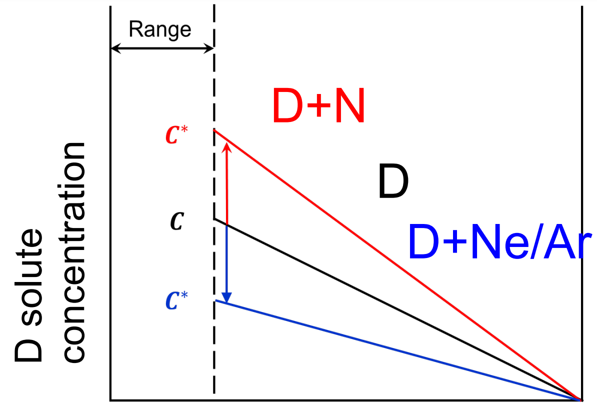


- D+Ne照射：550K以上の温度領域で透過フラックス減少
- D+Ar照射：600K以上の温度領域で透過フラックス減少

➢ NeやArと同時照射することで透過フラックスが減少する傾向が見られた

重水素のみの照射との比較





- 窒素によって透過フラックスは増加

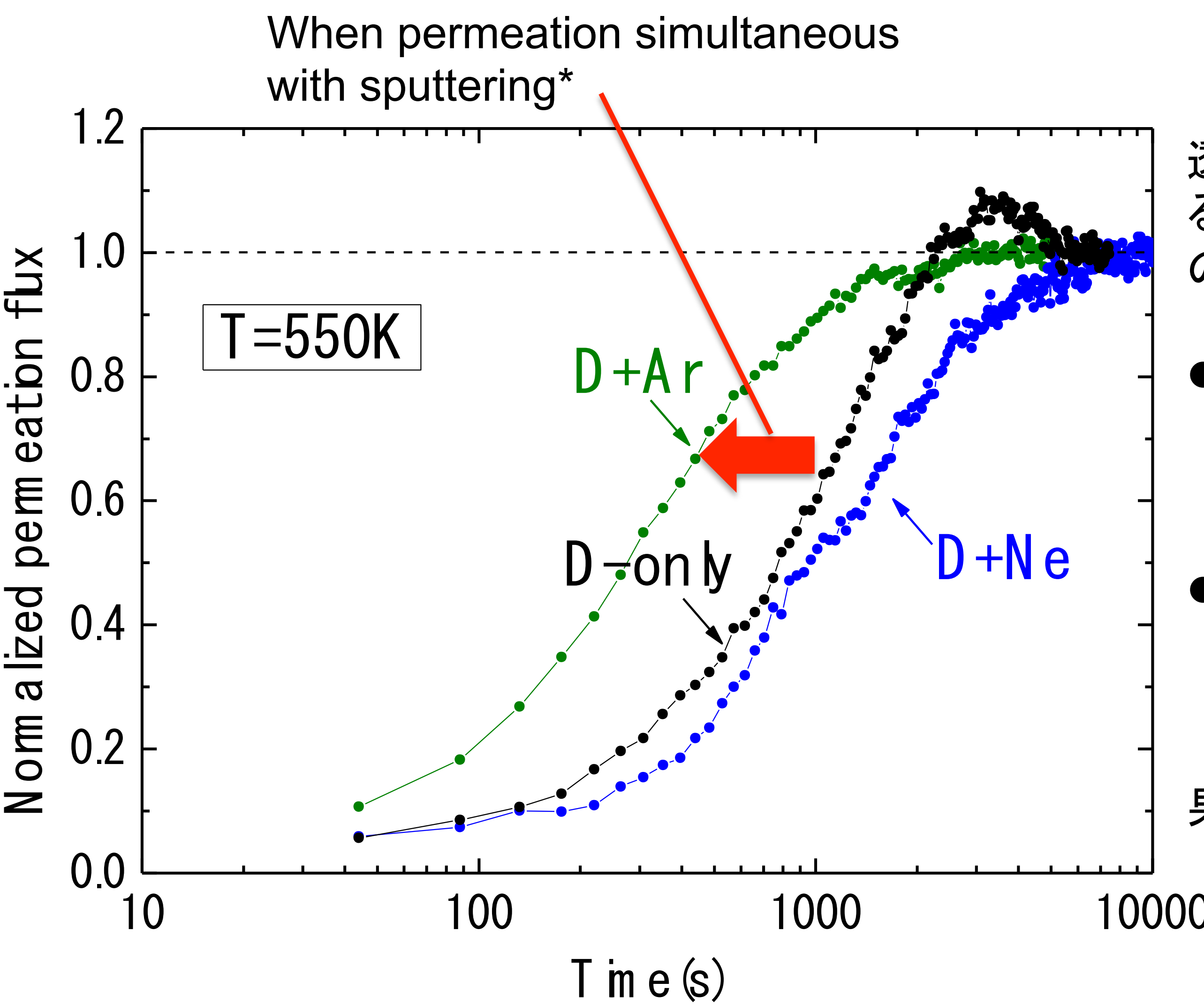
→表面にタングステンと窒素の混合層が形成、表面内部の重水素濃度が増加

- Ne/Arとによって透過フラックスは減少

→表面状態が変化し、表面内部の重水素濃度が減少

各照射におけるラグタイムの比較

*G. Federici, D. Holland, and R. Matera, *J. Nucl. Mater.* 233-237 (1996) 741-746.



透過フラックスが定常状態になるまでにかかる時間を重水素のみ照射の場合と比較

- D+Ar同時照射：重水素のみの照射より定常状態に早く達した
- D+Ne同時照射：重水素のみの照射より定常状態に達するまで時間を要した

→同じ希ガスの照射だが結果に違いが現れた

D+Ne/Ar　透過実験のまとめ

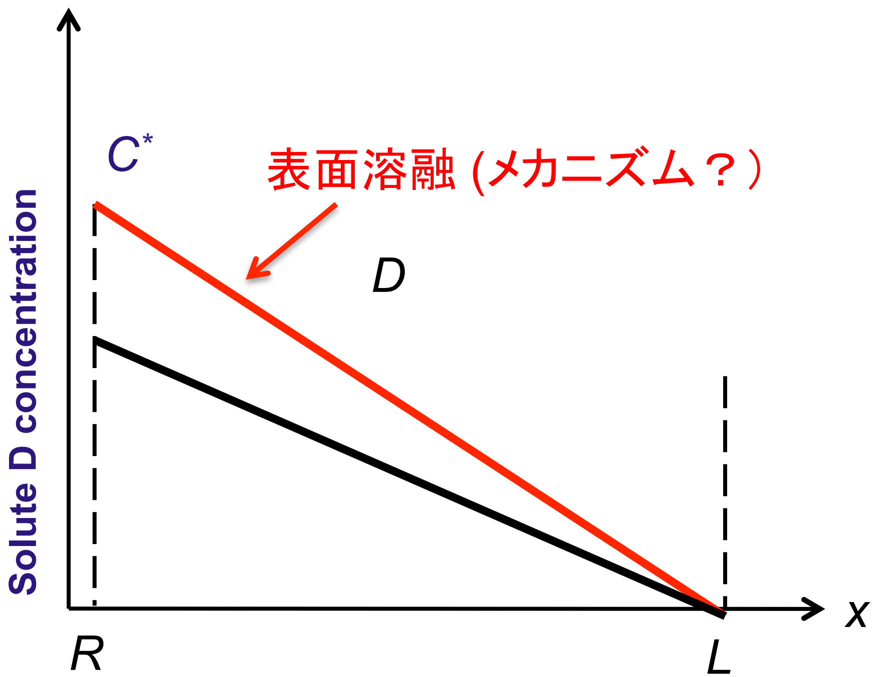
- D+Ne、D+Ar照射を行い、Ne/Arが重水素の透過に与える影響を調べた。

- Ne/Arとの同時照射で、大部分の温度領域で透過フラックスが減少する結果となった。これは、Wの表面内部の重水素濃度が減少したことによると考えられる。

- 透過フラックスが定常状態になるまでにかかる時間は、D+Ar照射では重水素のみの照射より短かったが、D+Neではより長い時間がかかった。Neの照射によってスパッタリング以外に拡散に影響をおよぼす現象がある可能性が考えられる。

まとめ

A) 表面溶融



B) Ne/Ar同時照射