Deuterium Retention in and Release from Beryllium Resulting from High Flux Plasma Exposure

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Motivation: T Removal in ITER

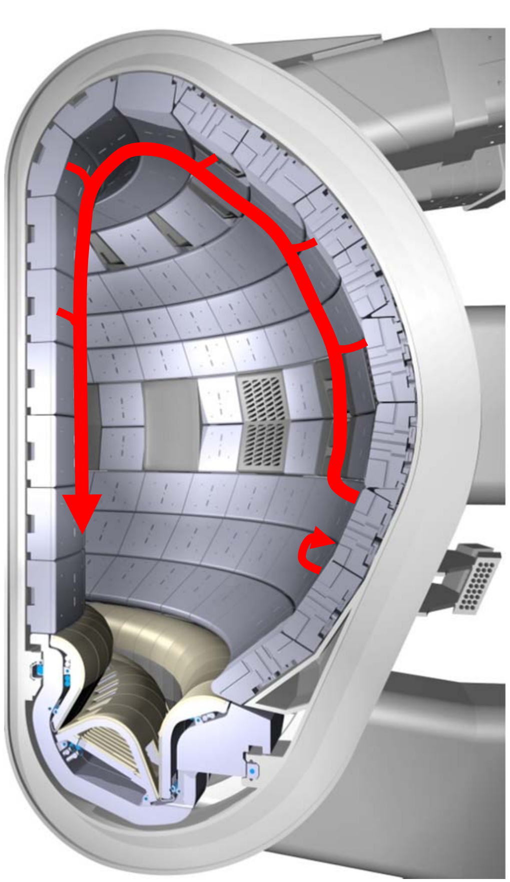
T Retention in pure Beryllium

- implantation: saturation at low levels ✓
- codeposition: unlimited

  main wall erosion dominated, but:

  - gaps are potential deposition zones!
  - resessed wall elements

⇒ assessing T removal by baking at 240°C / 350°C



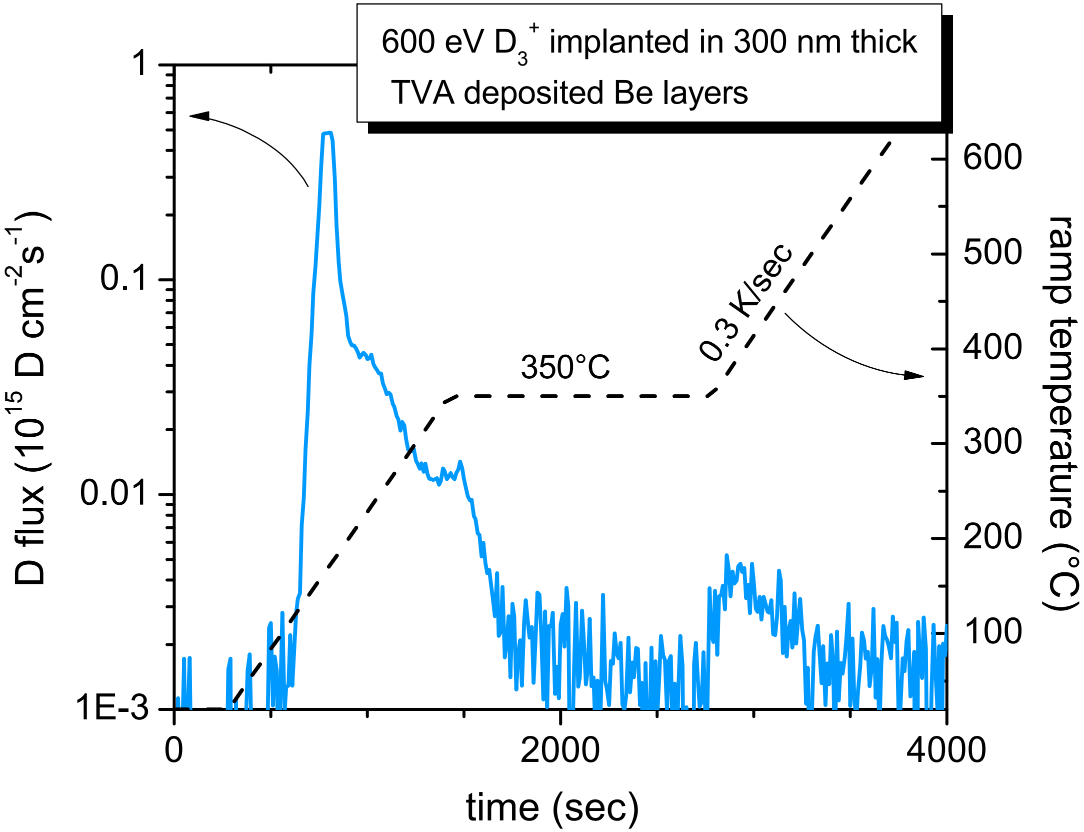
assessment of T removal in ITER by wall baking

- ITER baking temperatures

  240ºC (main wall)

  350ºC (divertor)

K. Sugiyama et al., PSI-19 (doi:10.1016/j.jnucmat.2010.09.043):



Here:

⇒ thick codeposits

⇒ is removal efficiency increased for longer hold times?
(is release determined by diffusion or by trap/bond energies)

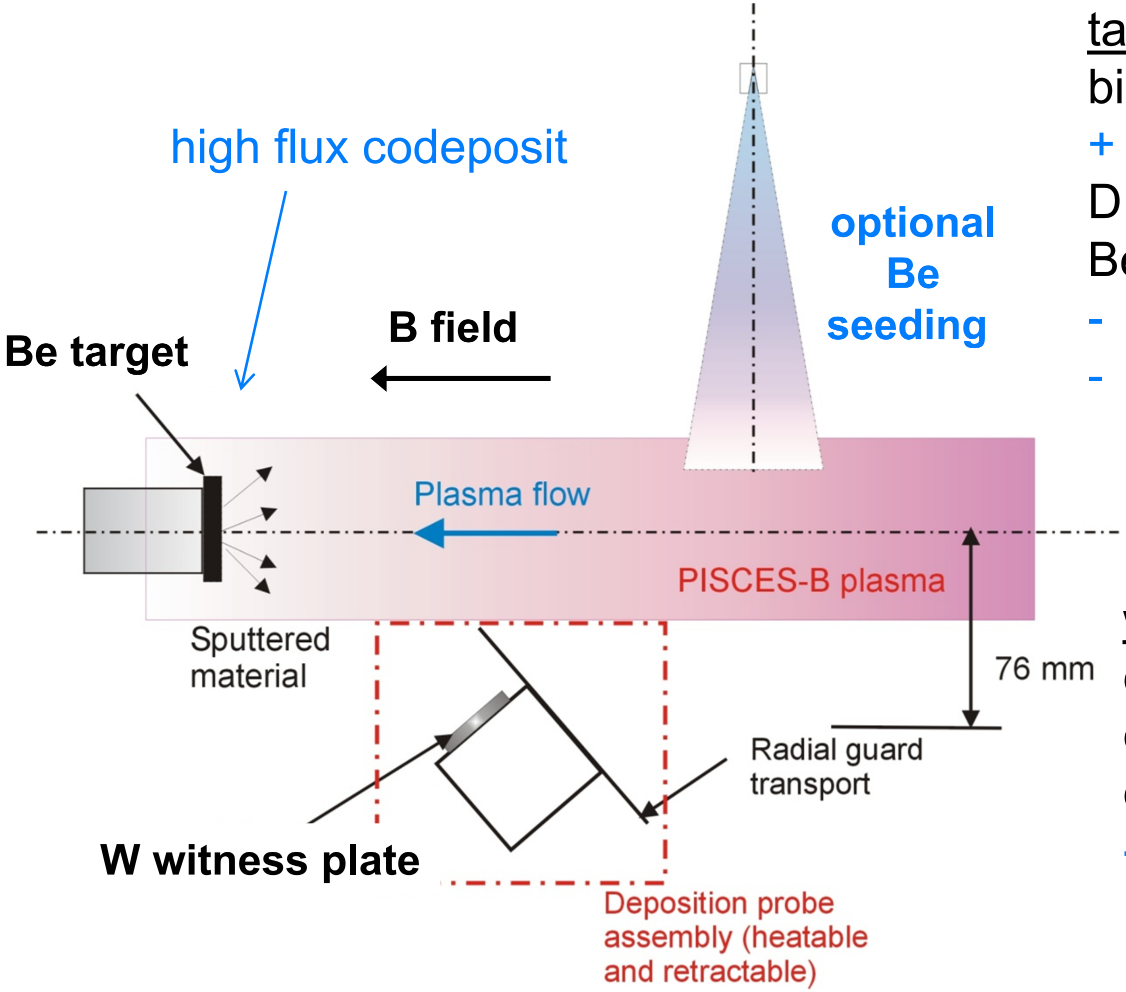
Deuterium Retention in and Release from Beryllium Resulting from High Flux Plasma Exposure

- **Comparing D release from**
  - **single / multilayer co-deposits**
  - **high flux codeposit**
  - **implanted Be**
  - **model system: magnetron sputtered D/Be**

- **D release from thick codeposits for long hold times at 240°C / 350°C**

PISCES-B

DC reflex-arc discharge within airtight Be enclosure

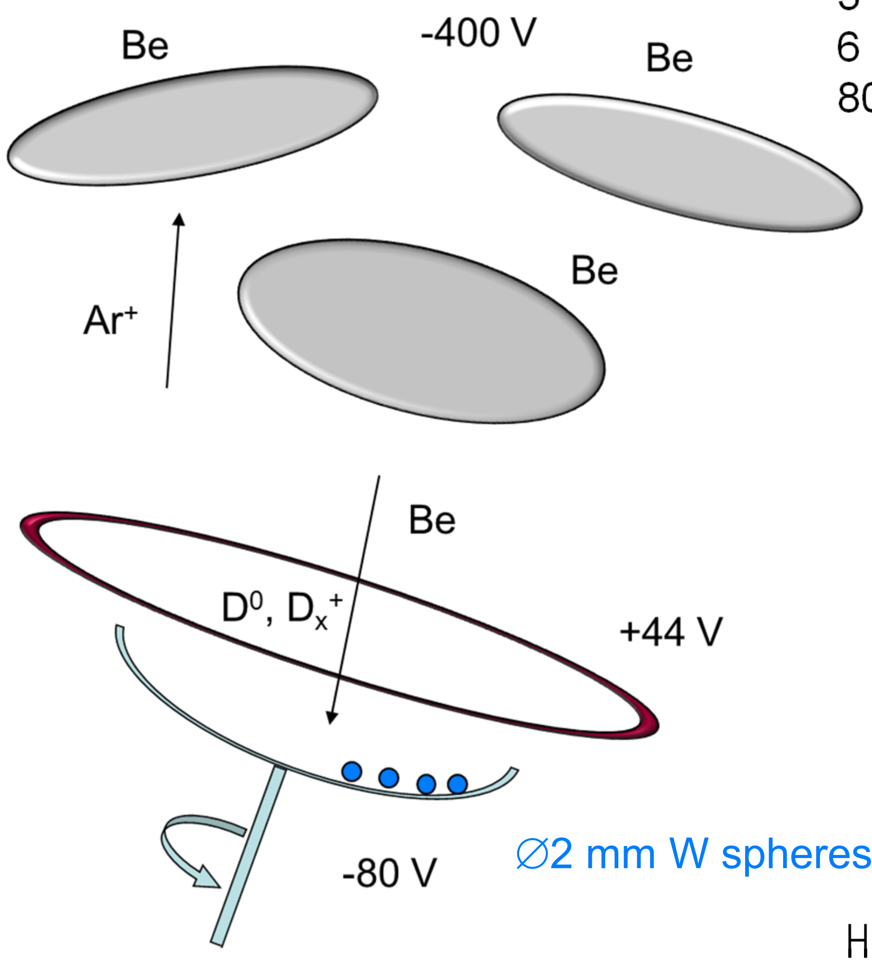


target:
bias: < -170V results in E < 150eV
+ high flux:
D ion flux: $< 5\cdot10^{18}$ cm^{-2}s^{-1}
Be seeding: $n_{Be}/n_D < 3\%$
- one sample at a time
- implantation profile

witness plate:
energy of sputtered Be: few eV
energy of reflected Be: < 10 eV
energy of reflected D: < 15-40 eV
- low fluxes:
Be flux: $<3\cdot10^{14}$ cm^{-2}s^{-1}
D flux: $<3\cdot10^{15}$ cm^{-2}s^{-1}
- radial inhomogeneity

model system: magnetron sputtered Be

+ up to 30 identical samples at a time



3 x 100Watt,
6 mTorr,
80% Ar, 20% D_2

energy of sputtered Be:	few eV
energy of reflected Ar:	few eV
energy of ionized Ar:	<120 eV
energy of D ions:	<120eV

Be flux: $2.5 \cdot 10^{15}$ $cm^{-2}s^{-1}$

∅2 mm W spheres

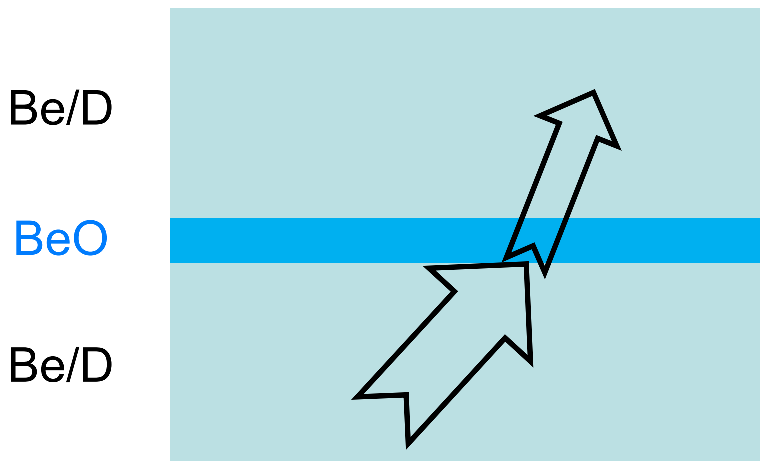
H.W. Xu et al., Fusion Sci. Technol. 51, 547-552 (2007)

D release from multilayer codeposits

D release from multilayer codeposits

Present predictions for T release in ITER are based on pure Be targets / codeposits.

Actual ITER codeposits will be multilayers with BeO interfaces in between.



Question: Do BeO layers influence the D release?

Diffusion barrier? Shift in release temperature?

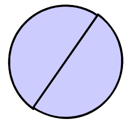
here: - collecting PISCES-B on W witness

- interrupted exposure for several hours / bring to air to allow an oxide layer to grow

D release from single layer codeposit

<u>experiment:</u> low flux codeposit

W

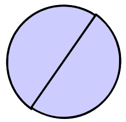


- single layer: Be target + cap, bias = -100V $\Rightarrow E_D$ = 22 eV
  $\Gamma = 1.2 \cdot 10^{14}$ Be/cm^{-2}s^{-1}, t = 10000 sec

D release from single layer codeposit

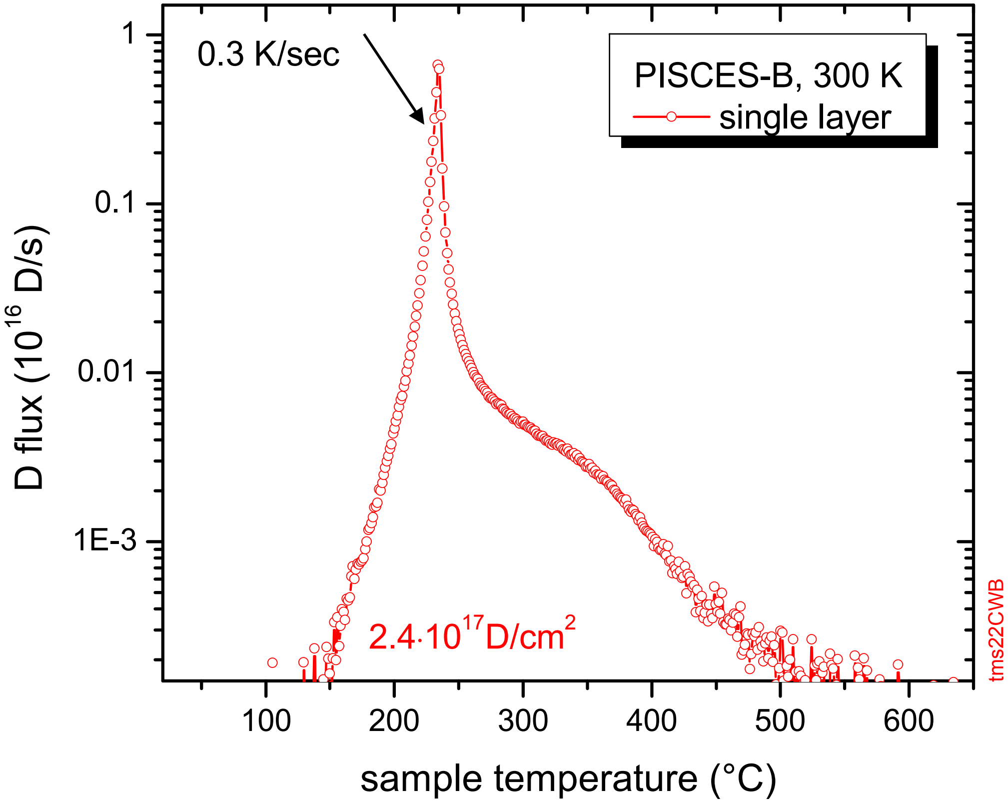
<u>experiment:</u> low flux codeposit

W



- single layer: Be target + cap, bias = -100V $\Rightarrow E_D$ = 22 eV
  $\Gamma = 1.2 \cdot 10^{14}$ Be/cm^{-2}s^{-1}, t = 10000 sec

TDS:

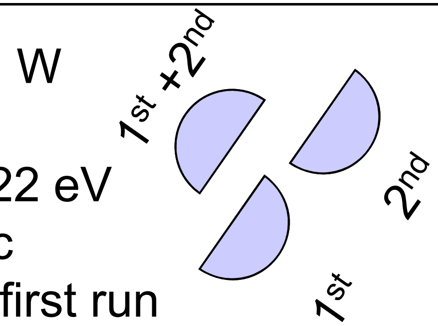


d = 100 nm
D/Be = 0.2

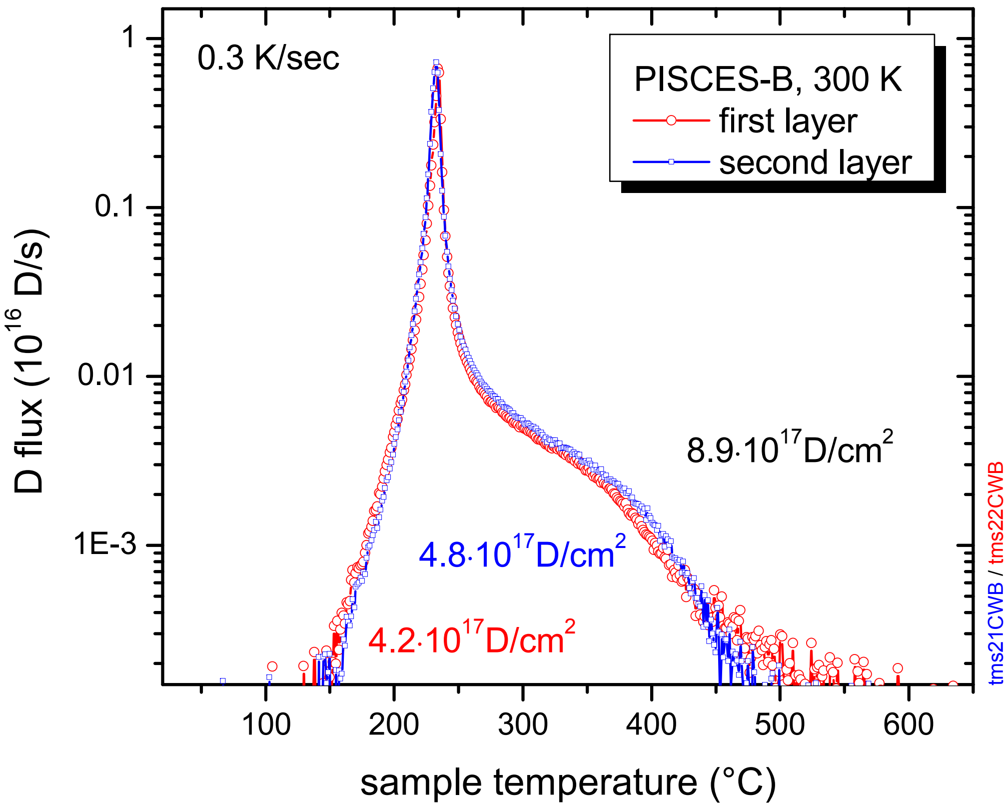
D release from multilayer codeposit

experiment

- 2 identical runs: Be target + cap, bias = -100V $\Rightarrow E_D = 22$ eV
  $\Gamma = 1.2 \cdot 10^{14}$ Be/cm^{-2}s^{-1}, t = 10000 sec
- replacing one half piece of circular W witness plate after first run



TDS:



d = 2 x 100 nm
D/Be = 0.2

BeO
expected 5-10 nm

D release from multilayer codeposit

experiment

- 2 identical runs: Be target + cap, bias = -100V $\Rightarrow E_D = 22$ eV
  $\Gamma = 1.2 \cdot 10^{14}$ Be/cm^{-2}s^{-1}, t = 10000 sec
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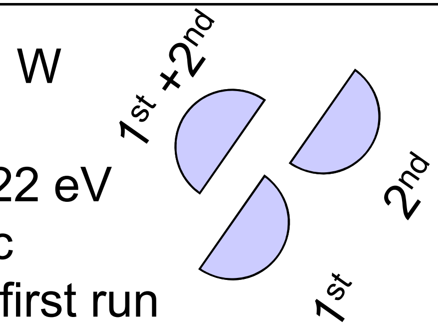
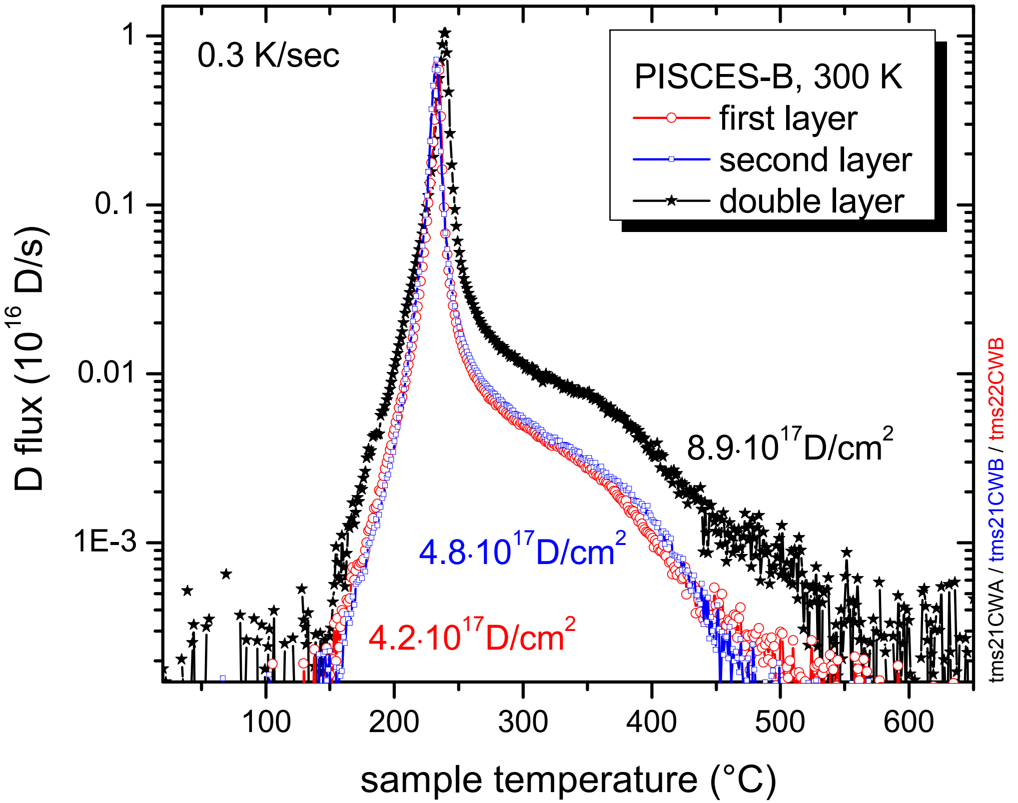


TDS:



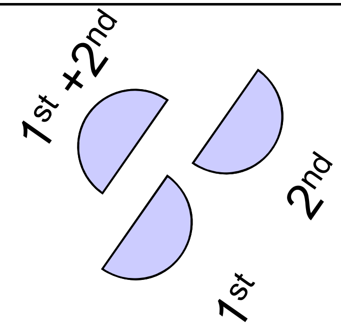
d = 2 x 100 nm
D/Be = 0.2

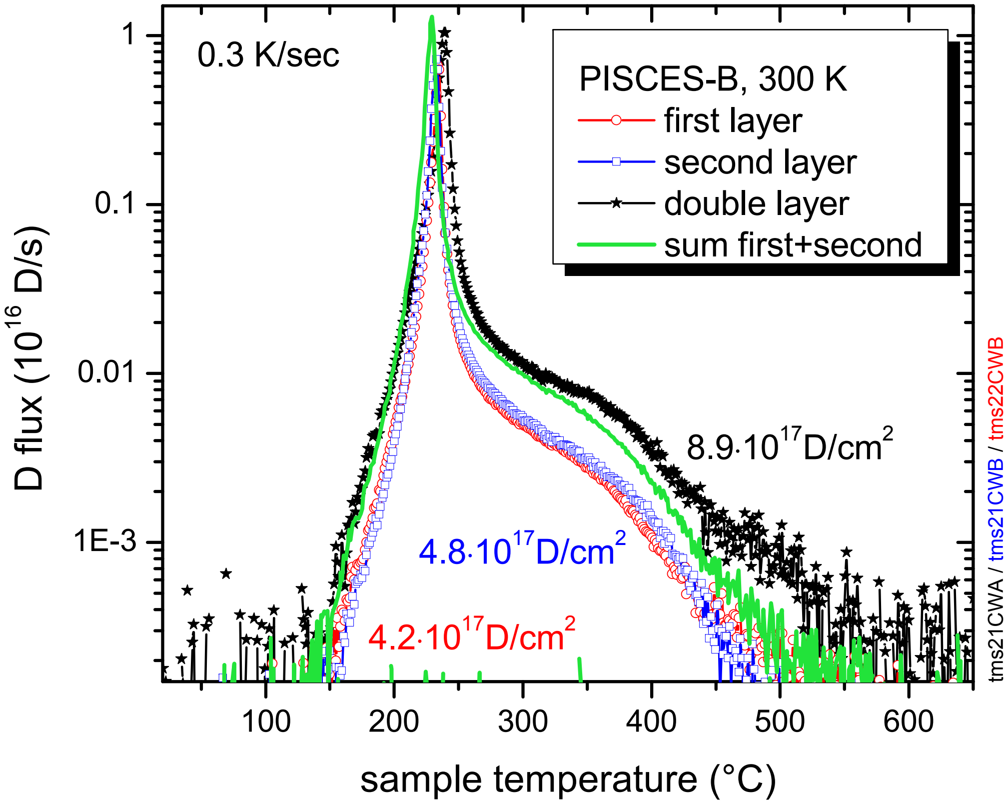
BeO
expected 5-10 nm

D release from multilayer codeposit

conclusion:

⇒ oxide interfaces (several nm thick) do not influence D release





d = 2 x 100 nm
D/Be = 0.2

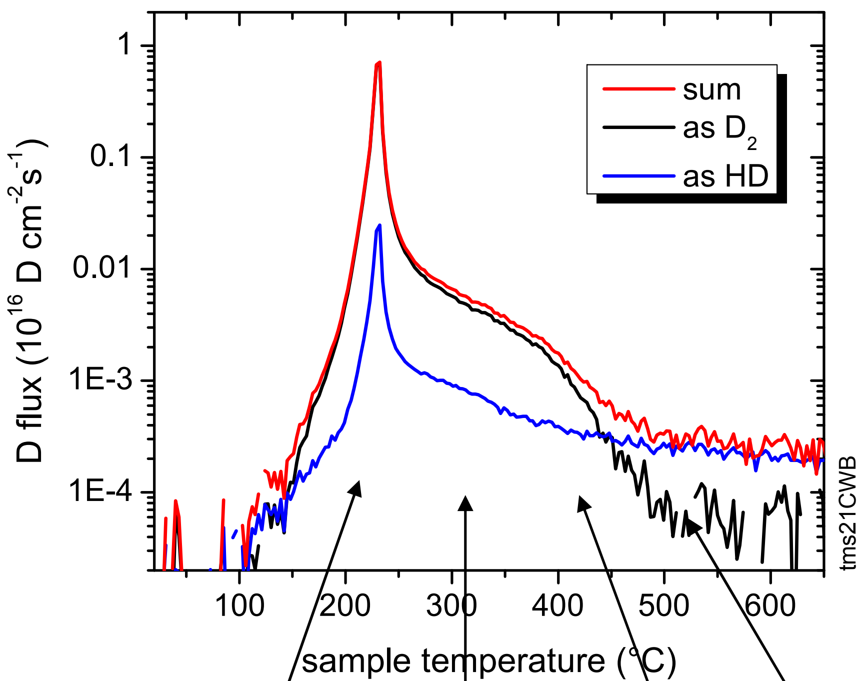
BeO
expected 5-10 nm

comparing different codeposits

PISCES-B low flux (witness plate) codeposit

collecting Be and D (on W) sputtered/reflected from a Be target:

thermal desorption:



Be-D_2 BeO

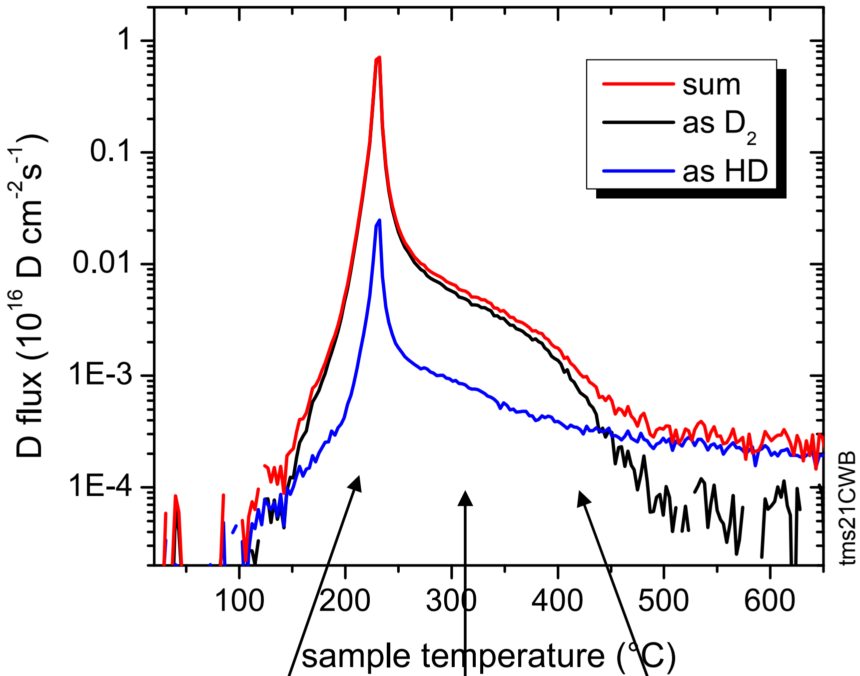
structurally modified, supersaturated (D_2 bubbles / a-Be-D)

defects by coll. cascade

PISCES-B low flux (witness plate) codeposit

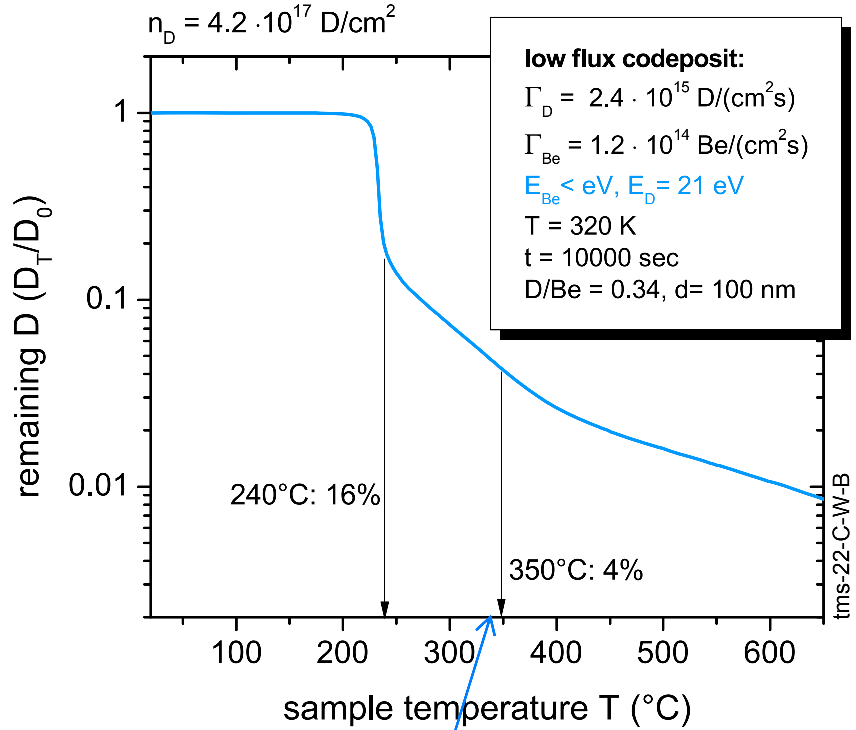
collecting Be and D (on W) sputtered/reflected from a Be target:

thermal desorption:



Be-D_2 BeO

structurally modified, supersaturated (D_2 bubbles / a-Be-D)

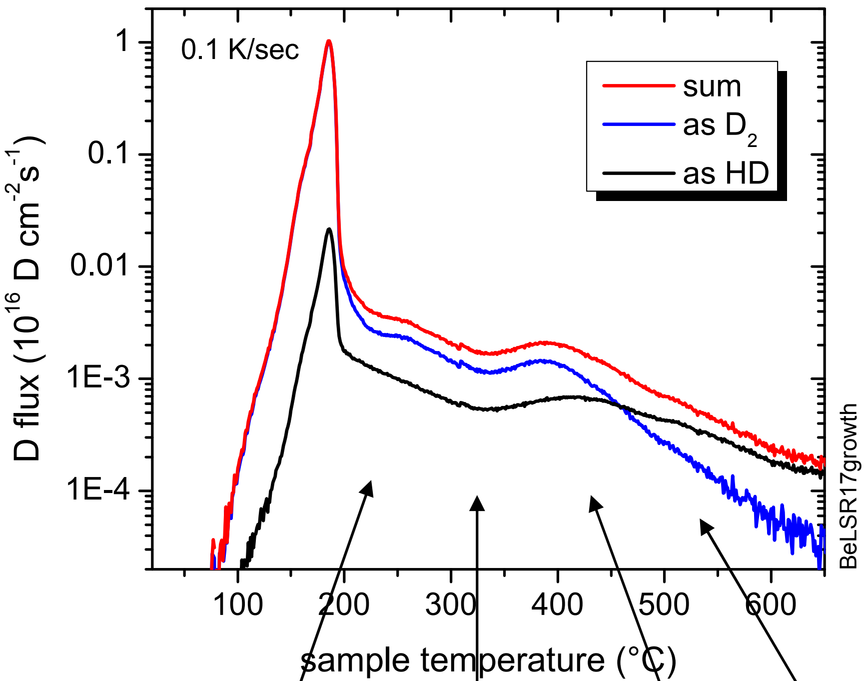


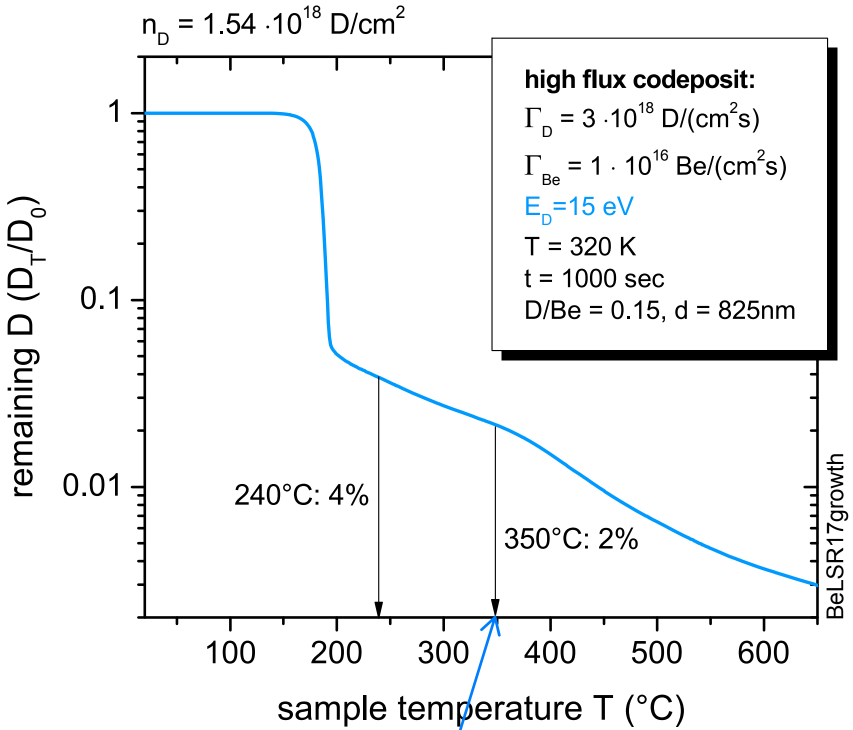
ρ = 1.8 ·10^{17} D cm^{-2} / µm
or: D/Be = 1.5%

PISCES-B high flux (target) codeposit

high flux codeposit: collecting Be and D at floating target in Be seeded D discharge

thermal desorption:





Be-D_2 BeO

structurally modified, supersaturated
(D_2 bubbles / a-Be-D)

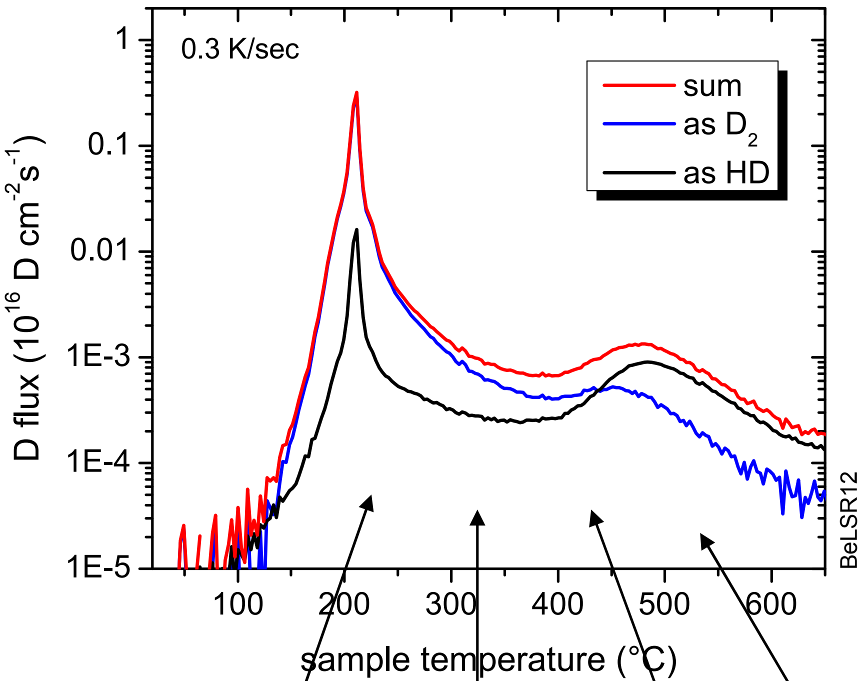
defects by
coll. cascade

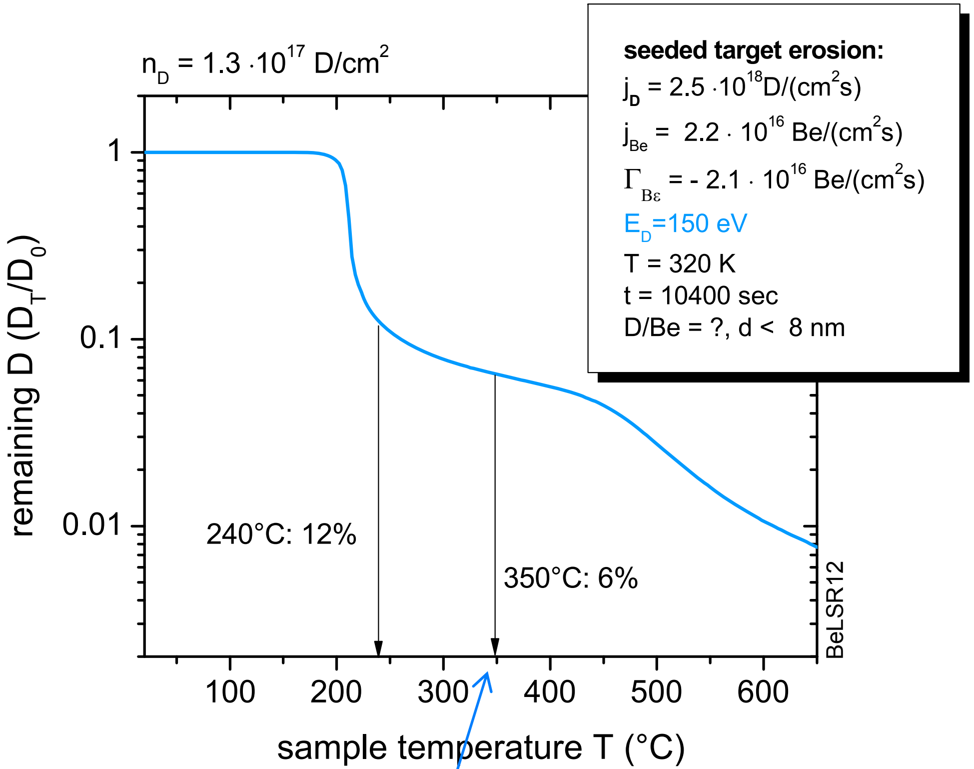
ρ = 5 ·10^{16} D cm^{-2} / µm
or: D/Be = 0.5 %

PISCES-B target

retention during net erosion:

thermal desorption:





Be-D_2 BeO

structurally modified, supersaturated
(D_2 bubbles / a-Be-D)

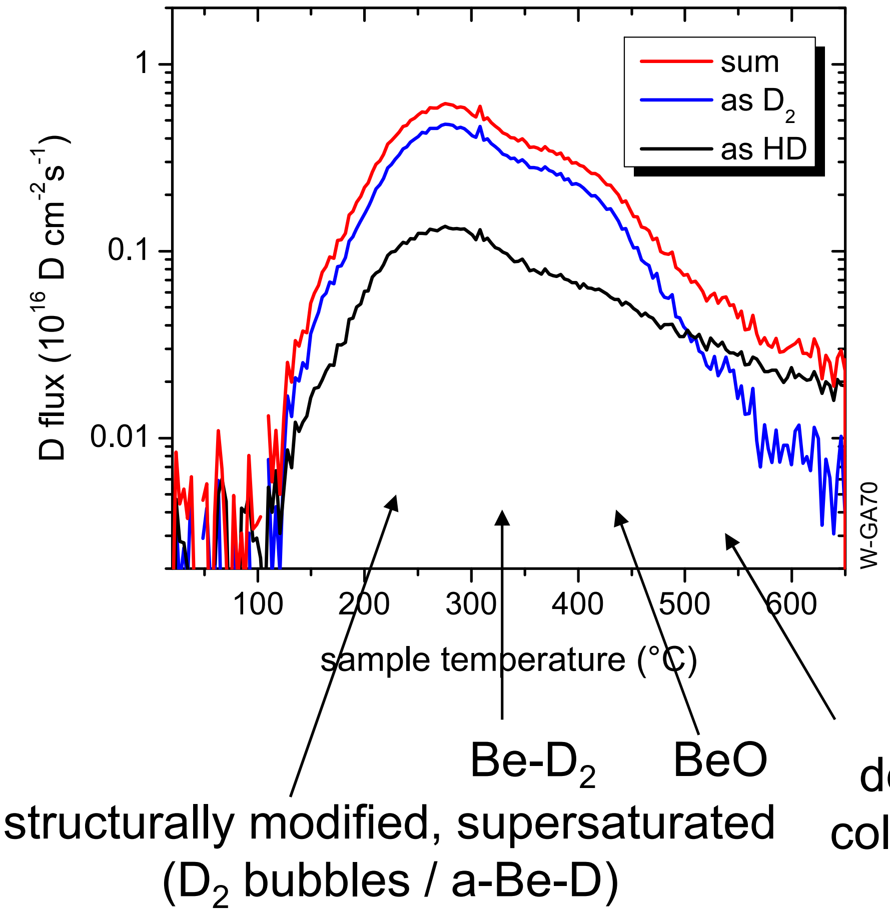
defects by
coll. cascade

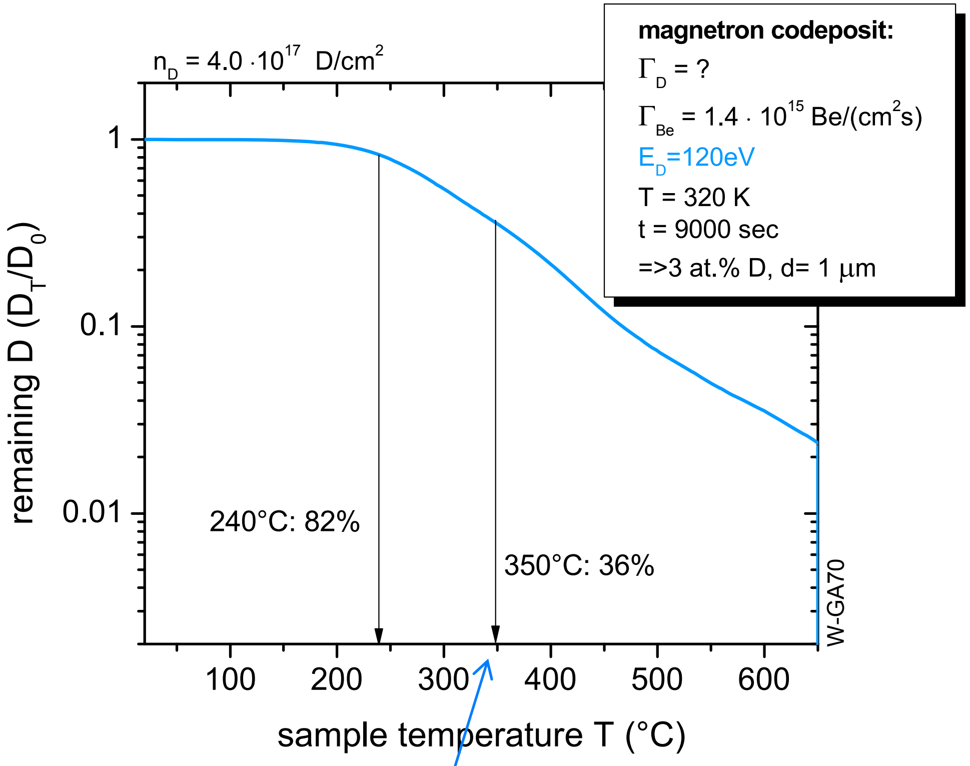
ρ = 1.5 $\cdot 10^{17}$ D cm^{-2} / μm
or: D/Be = 1%

magnetron sputtered films

collecting Be/D sputtered from a Be target in Ar/D_2 :

thermal desorption:





$\rho = 1.4 \cdot 10^{17}$ D cm^{-2} / µm
or: D/Be = 0.8%

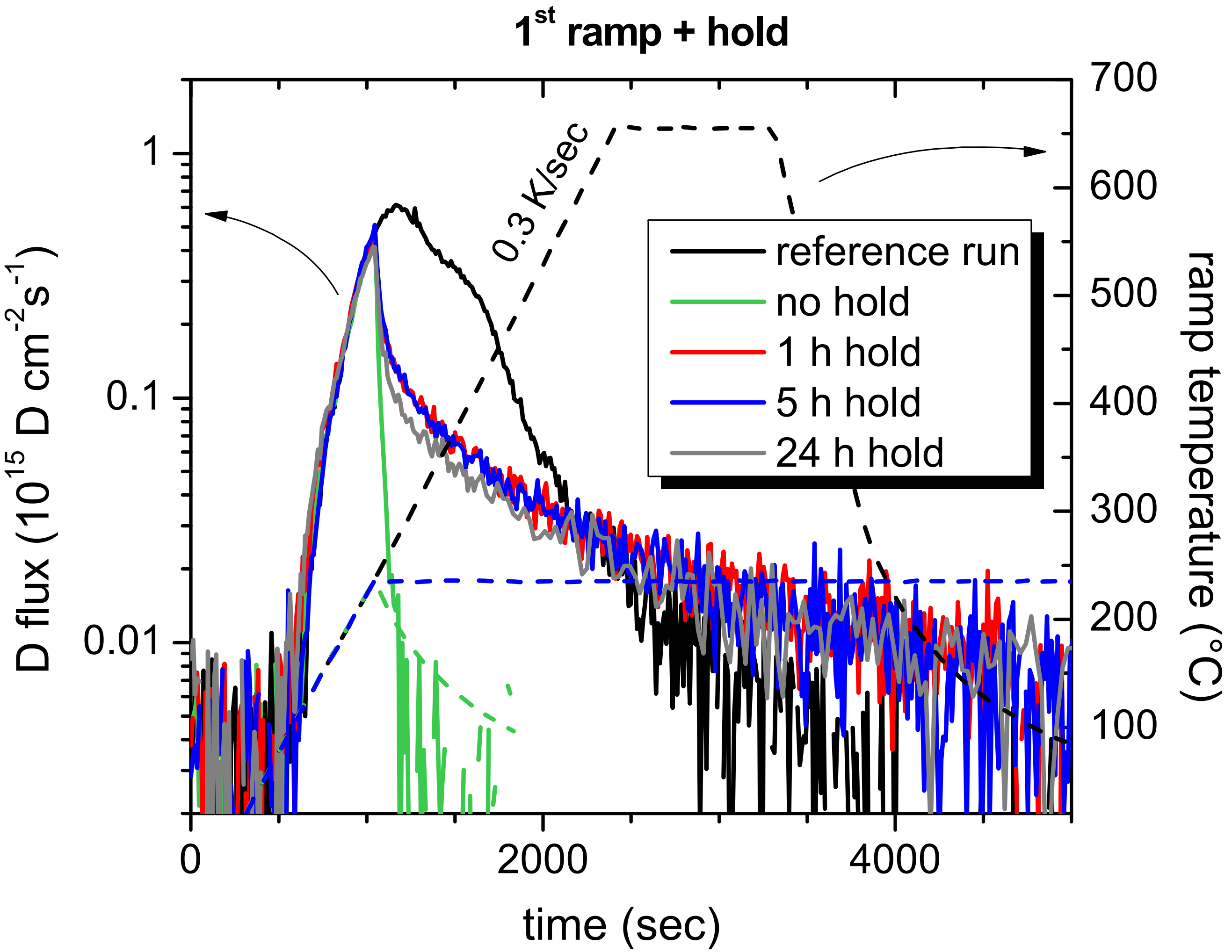
$\Rightarrow$ **the total amount of D retained above 350°C is the similar for all codeposits investigated:**

$$\rho \approx \cdot 10^{17}\ \mathrm{D\ cm^{-2}} / \mu\mathrm{m}$$

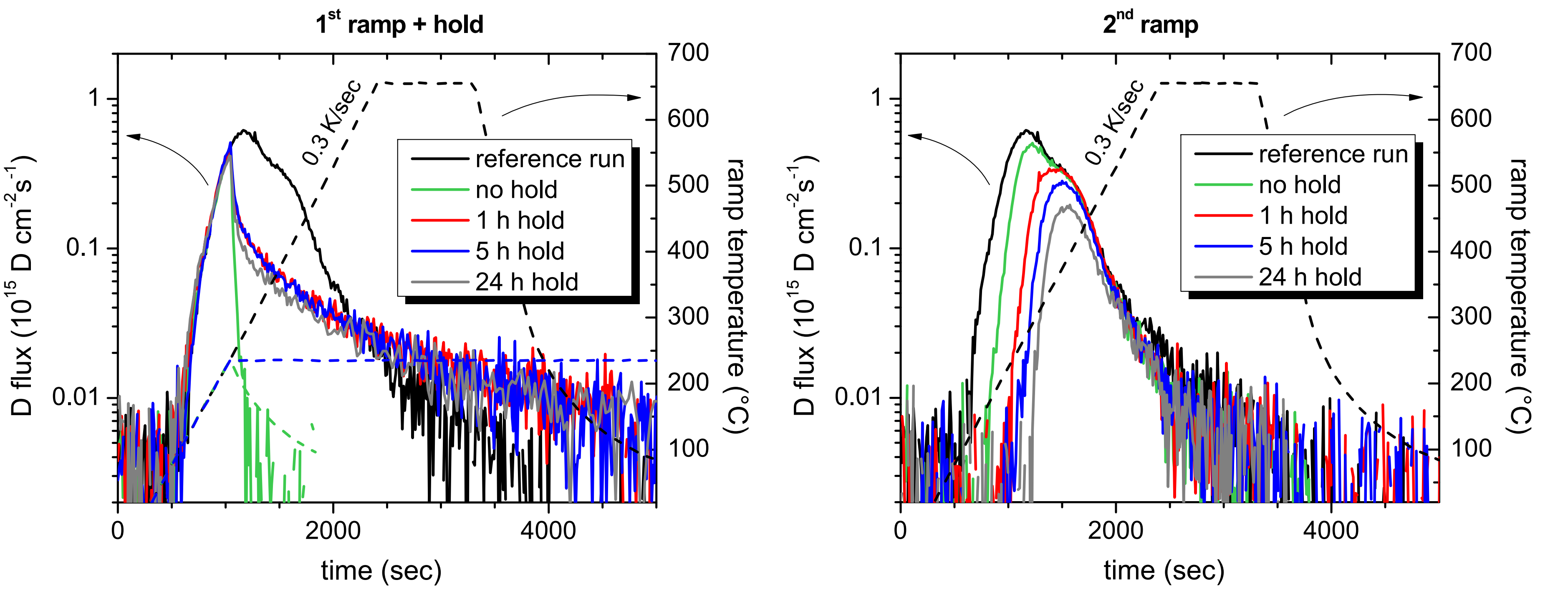
(D/Be ≈ 1%)

D release from thick codeposits during long holds @ 240°C (510K) and 350°C (620K)

D release from magnetron sputtered D/Be @ 240°C

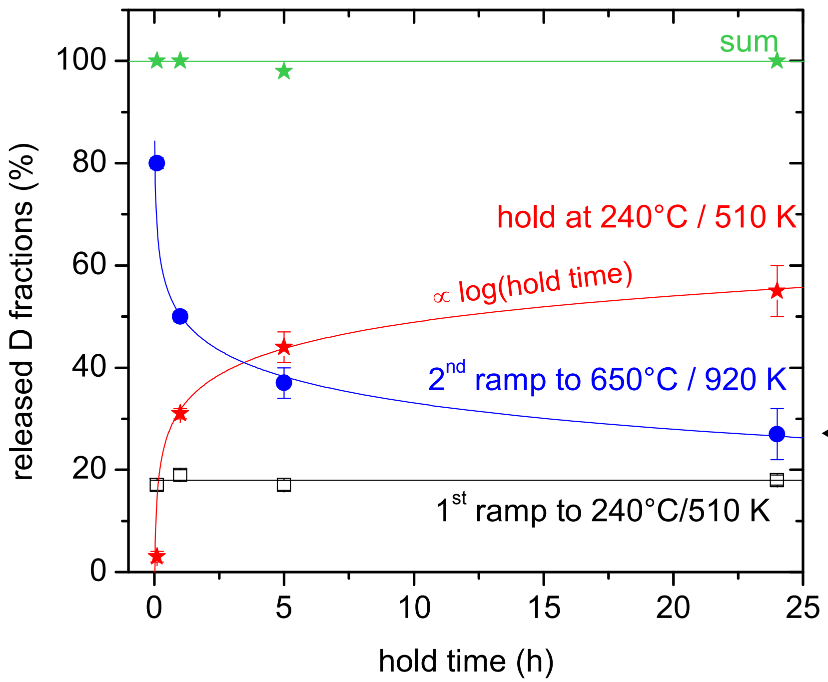


D release from magnetron sputtered D/Be @ 240°C



time constant of hours!

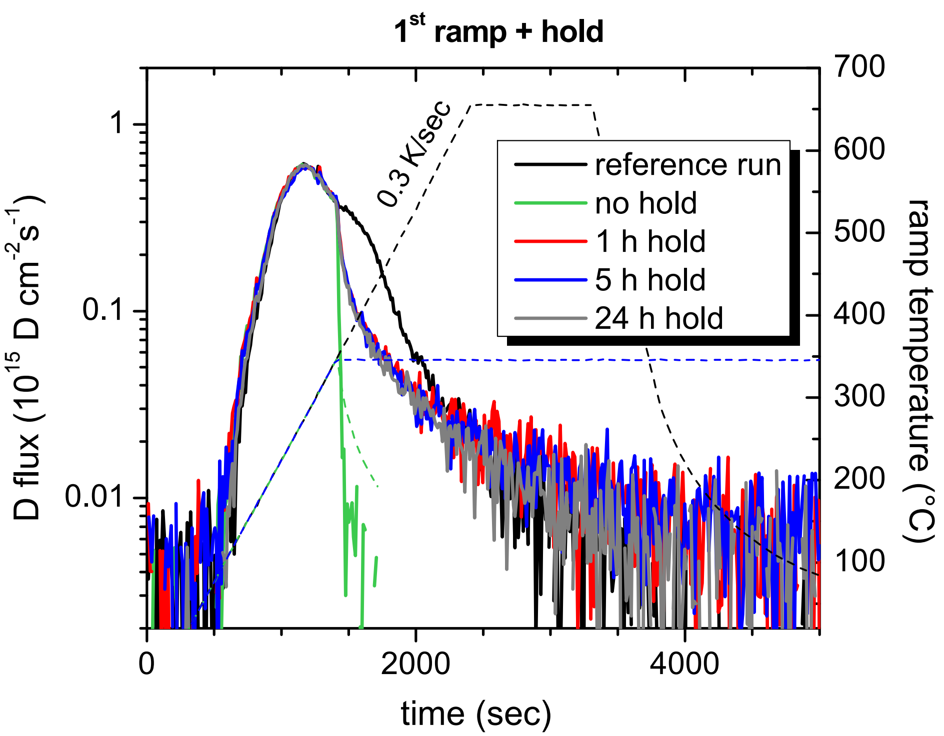
D release from magnetron sputtered D/Be @ 240°C

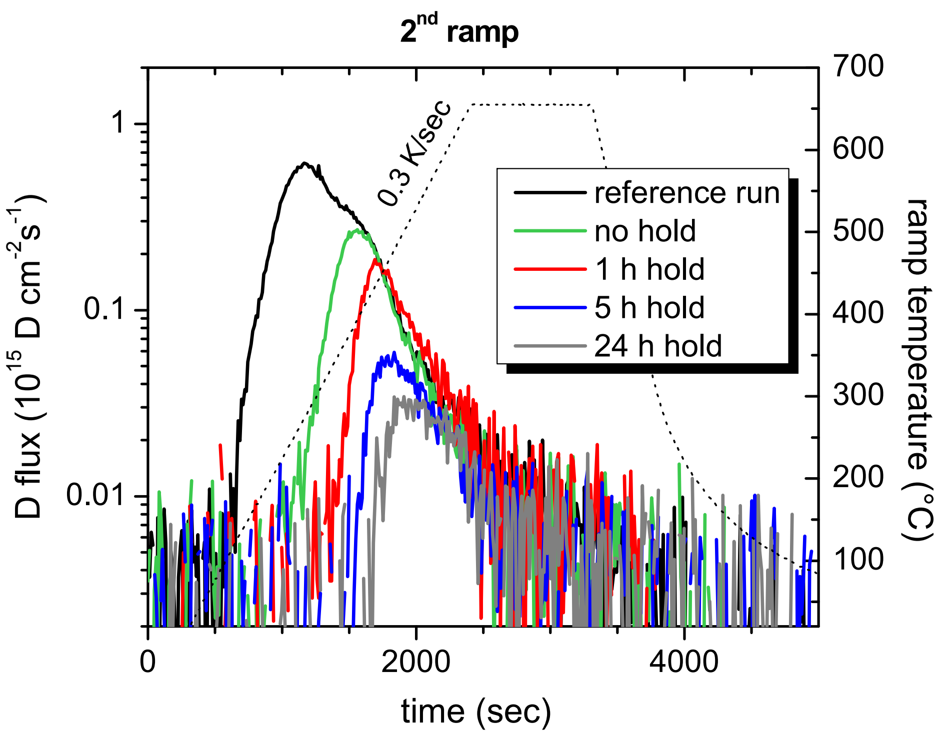


$1.0 \cdot 10^{17}$ D cm^{-2} remains after hold
or: D/Be = 0.8%

extrapolating to 690 m^2 ITER main wall: 9 g D per µm remains after 24h @ 240°C

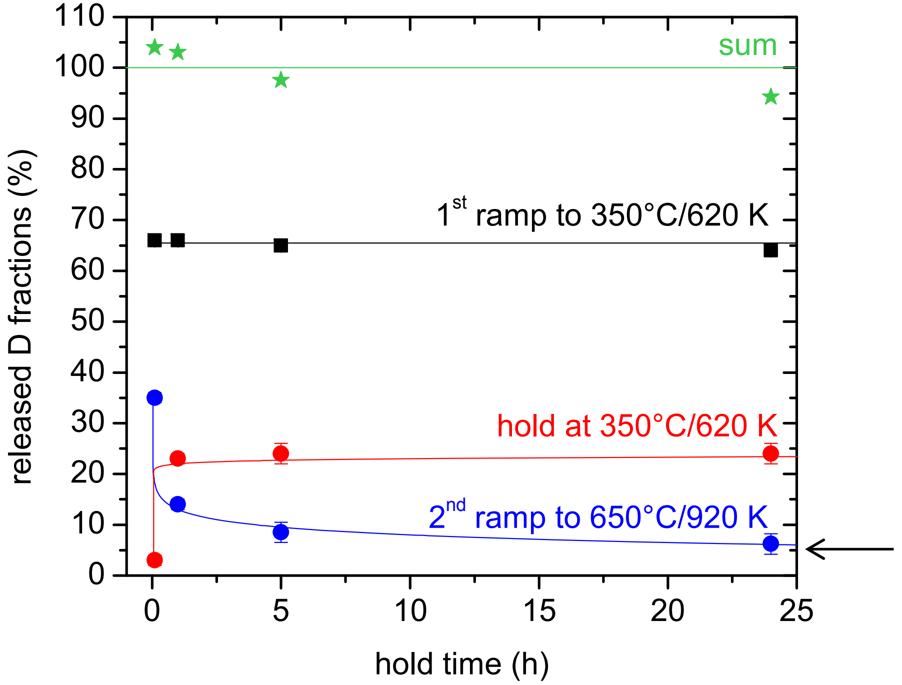
D release from magnetron sputtered D/Be @ 350°C





time constant of hours!

D release from magnetron sputtered D/Be @ 350°C



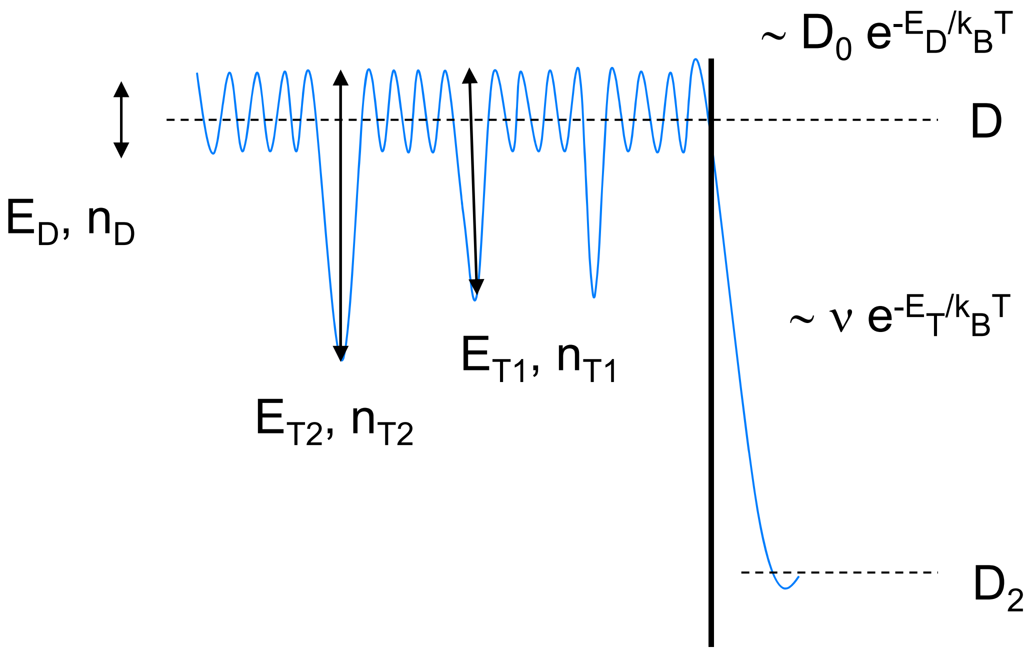
$2.5 \cdot 10^{16}$ D cm^{-2} remains after hold
or: D/Be = 0.2%

extrapolating to 690 m^2 ITER main wall: 2.5 g D per µm remains after 24h @ 350°C

modeling D release with diffusion and trapping

CRDS-code ("coupled reaction diffusion system" by Matthias Reinelt*)
= flexible code for simulation of such systems

Simple model: diffusion coupled with de-trapping (and re-trapping) from binding sites



<u>implemented mechanisms:</u>

- diffusion of D through BeD with
- trapping and de-trapping of D at 2 binding sites (one with, one without re-trapping)

modeling D release with diffusion and trapping

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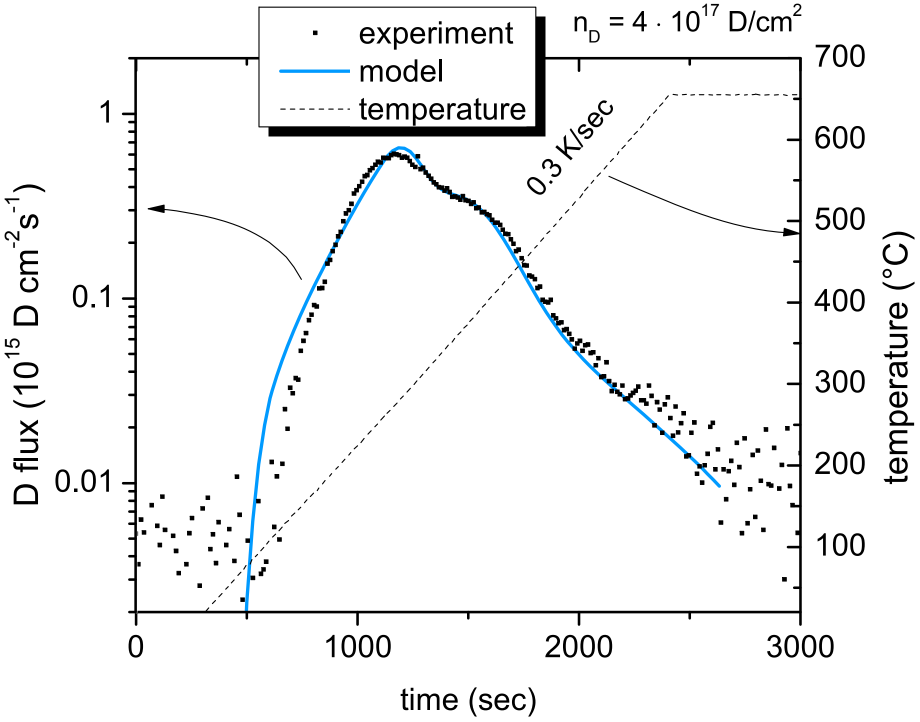
Simple model: diffusion coupled with de-trapping (and re-trapping) from binding sites



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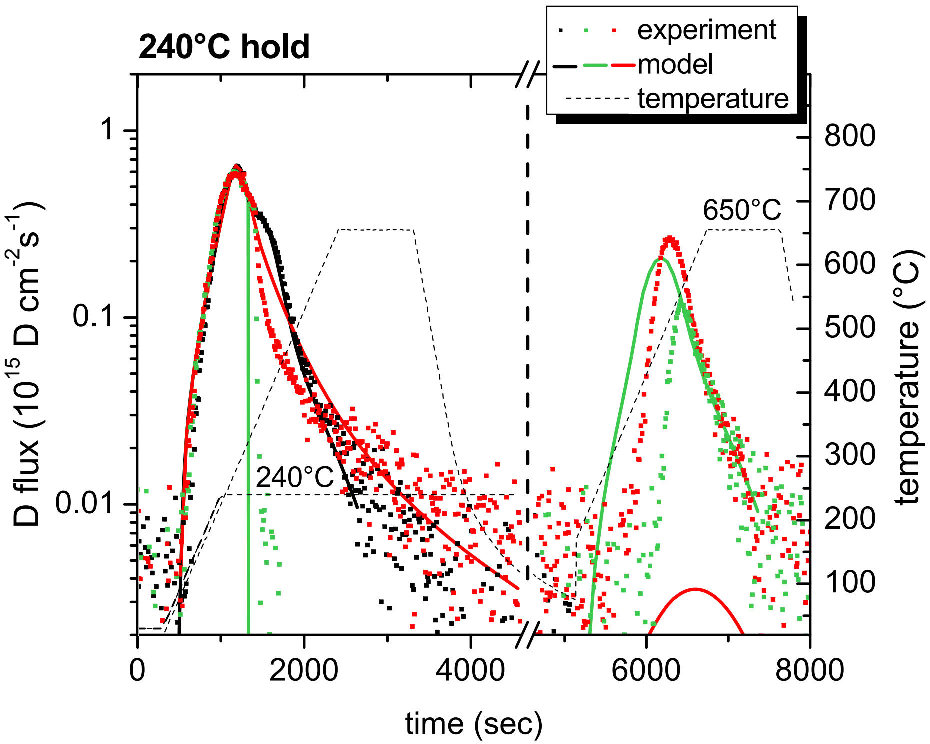
modeling D release with diffusion and trapping



discussion of the fit:

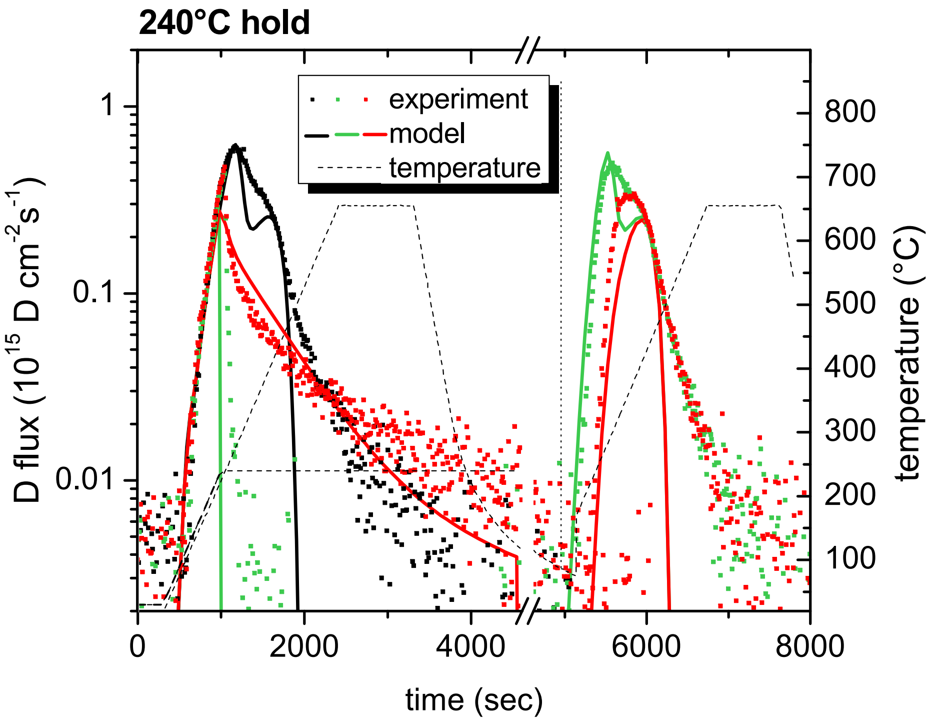
- although ramp better described

- hold @ 240°C: model incorrectly predicts too much desorption during the hold

⇒ analysis of independent measurements simultaneously

modeling D release with diffusion and trapping

present status:



- ramp and hold desorption behavior fairly well reproduced
- model shows sharper desorption peaks than observed in experiment
- outgassing above 450°C to fast in simulation

$\Rightarrow$ tool to interpolate

Next step: implementing decomposition

UCSD
University of California San Diego

summary

IPP

⇒ magnetron sputtered Be/D films are suited as a model system to study retention and release

⇒ release of D from Be at 240°C and 350°C has a very large time constant

⇒ even a several hours bake at 240°C or 350°C does not release all D
(a D/Be of 0.8% or 0.2% remains, respectively)
(deeper trap sites that cannot be drained)

⇒ codeposits grown in different ways (energies, growth rates) show similar release features

⇒ the total amount of D released above 350°C is the same for all codeposits investigated, equivalent to D/Be ≈ 1%

⇒ multilayer codeposits show the same release as single layer codeposits (BeO interface is no transport barrier)

Thanks to:

PISCES team:

Russ Doerner
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Ray Seraydarian
Leo Chousal
Rolando Hernandez