EUROMAT 2005 C32 (Sept.6, 2005)

Plasma Material Interaction Study on Low Activation Materials Used for Blanket and First Wall in Fusion Reactor

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1. Introduction

Major issues toward fusion demo. reactor

Plasma: high beta (>5%)& steady state operation

Fusion engineering: blanket development

Japanese plan: use of low activation materials

ferritic steel (F82H): solid breeder blanket (JAERI)

plasma suitability (JFT-2M, JT-60U)

V-4Cr-4Ti: ingot: 166kg(NIFS)

helical type reactor (FFHR)

SiC/SiC comp.: numerous test pieces (Kyoto Univ.)

SiC/SiC blanket – He gas cooling

Major study on low activation materials so far:

change of mechanical and thermal properties owing to neutron damage

Blanket:

Tritium breeding ratio has to be high, but decreases by armor.

It is better not to use armor.

Low activation material → first wall

Plasma material interaction → investigated

Present study

- **Ferritic steel(well oxidized) : erosion and hydrogen retention be changed, compared with SS ?**

  Deuterium retention and physical sputtering

Vanadium alloy: hydrogen embrittlement

Deuterium retention of vanadium alloy at different temperatures

- **SiC/SiC comp.(ceramics): He gas permeation**

  Helium gas permeability

2. Experiments

(1) Deuterium retention and erosio of ferritic steel

F82H ferritic steel (8Cr-2W)developed by JAERI

Cr~8wt%, W~2wt%, V~0.2wt%, Mn~0.1wt%(Ni, Mo, Nb <0.02wt%)

Deuterium ion irradiation experiment

1.7keV D, ~10^{19} D/cm^2, RT

- ****Deuterium retention/desorption behavior* by thermal desorption (TDS)**
- ****Physical sputtering yield* by weight loss**
- ****Compared with 316L SS***

(2) Deuterium retention of V-4Cr-4Ti alloy

Hydrogen embrittlement takes place when the hydrogen conc. exceeds ~40wt ppm (for oxidized V).

Deuterium ion irradiation at different temperatures

1.7keV D, ~10^{19} D/cm^2

Temp: 380, 573, 773K(blanket operation temperature)

Amount of retained deuterium by TDS

Deuterium concentration is lower or higher than the critical concentration?

(3) SiC/SiC composite

He gas leak into plasma – fuel dilution

He gas permeability be measured

SiC/SiC composites

(SiC fiber bundle layer filled by SiC matrix: 100μm)

nano powder of SiC

plus (SiC matrix layer: 100μm)

nano or macro powder of SiC

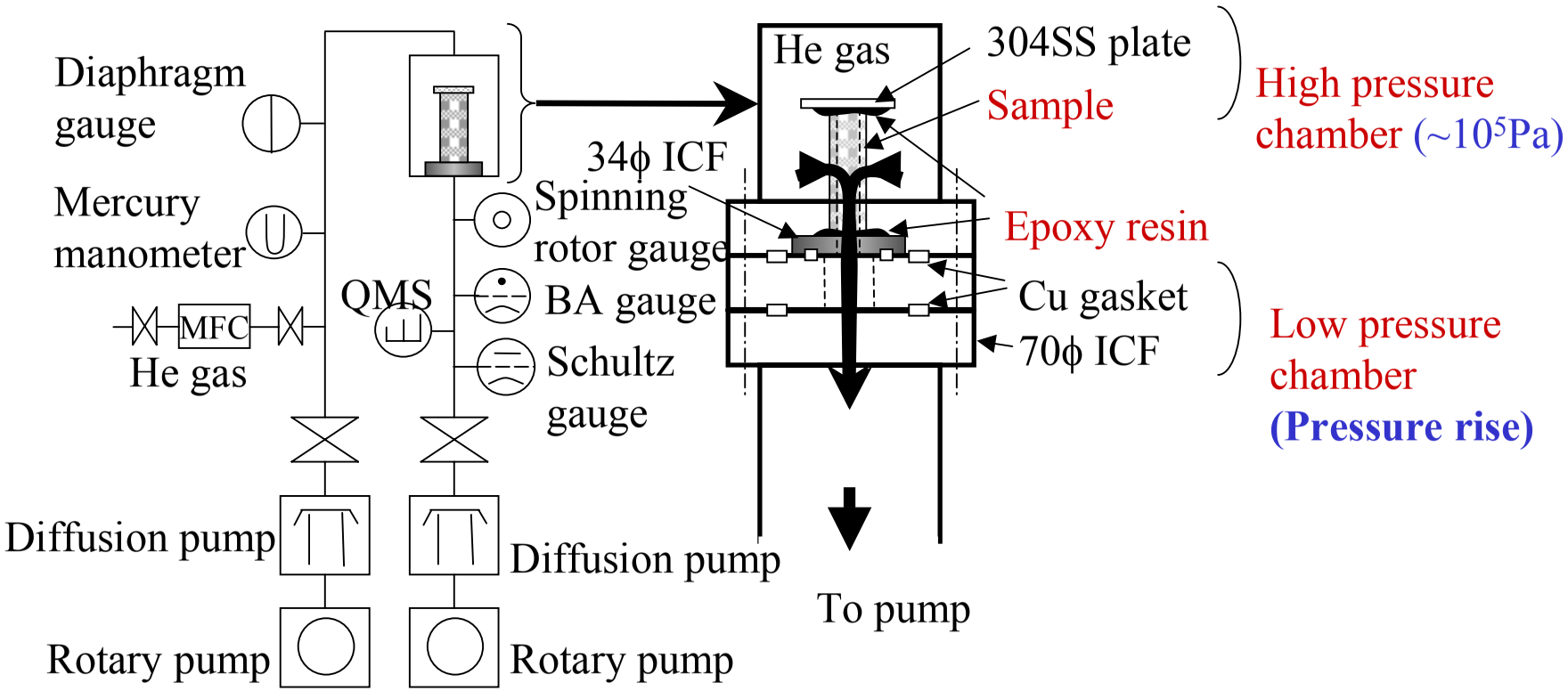
PIP: Polymer infiltration pyrolysis

HP: Hot pressing

MI: Melt infiltration pyrolysis

NITE: Nano-power infiltration and transient eutectoid

Vacuum device for measurement of He gas permeability

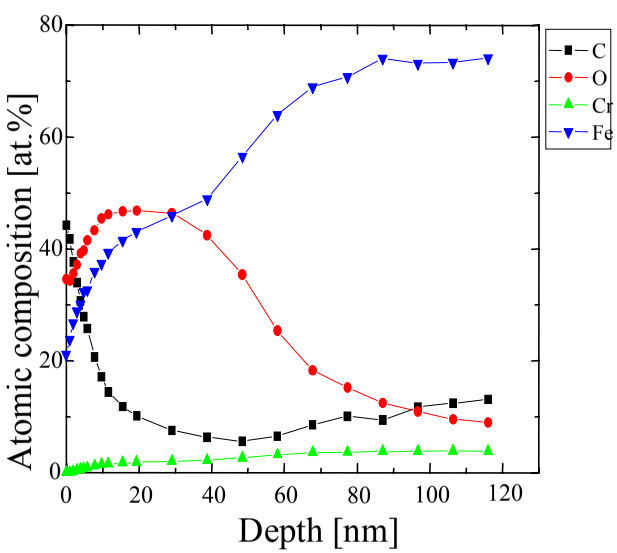


3. Results

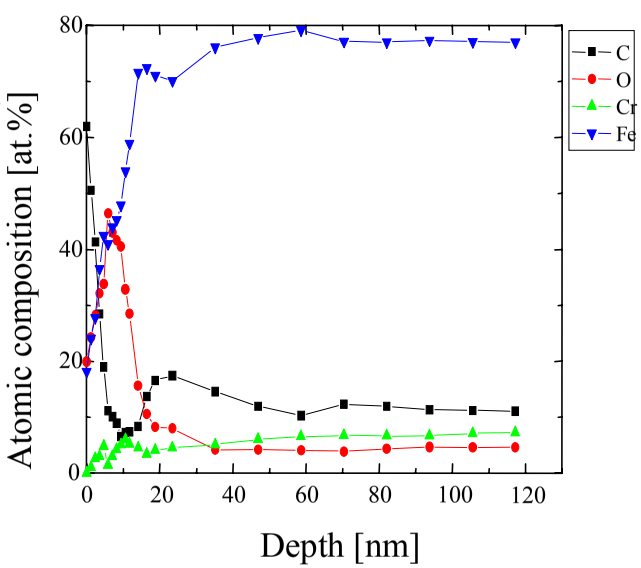
(1) Ferritic Steel

Depth profiles of atomic composition before and after mechanical polishing

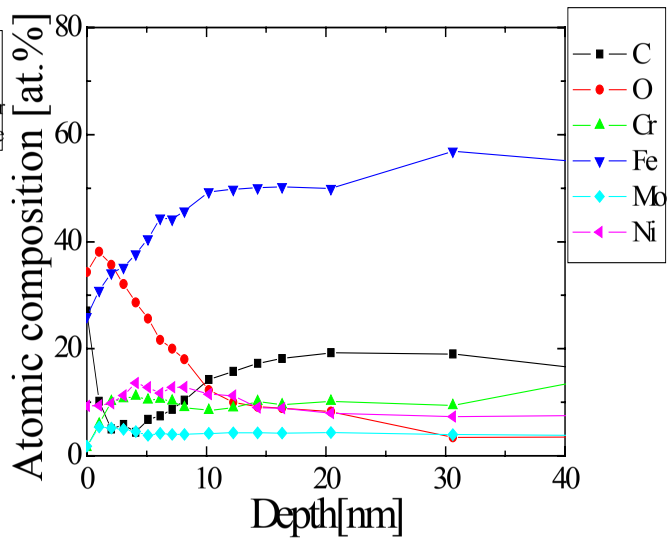
(a) F82H before



(b) F82H after



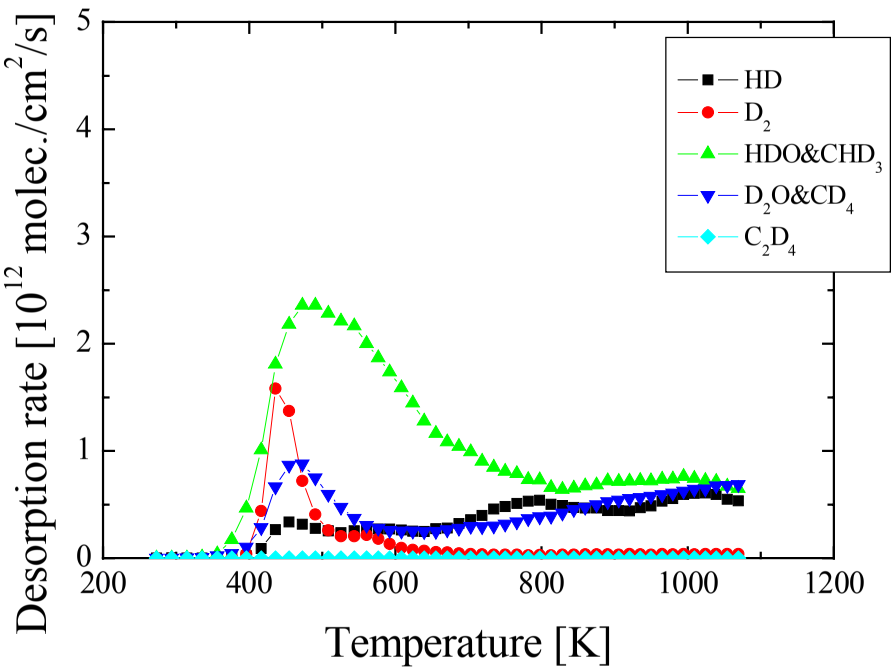
(c) 316L SS after



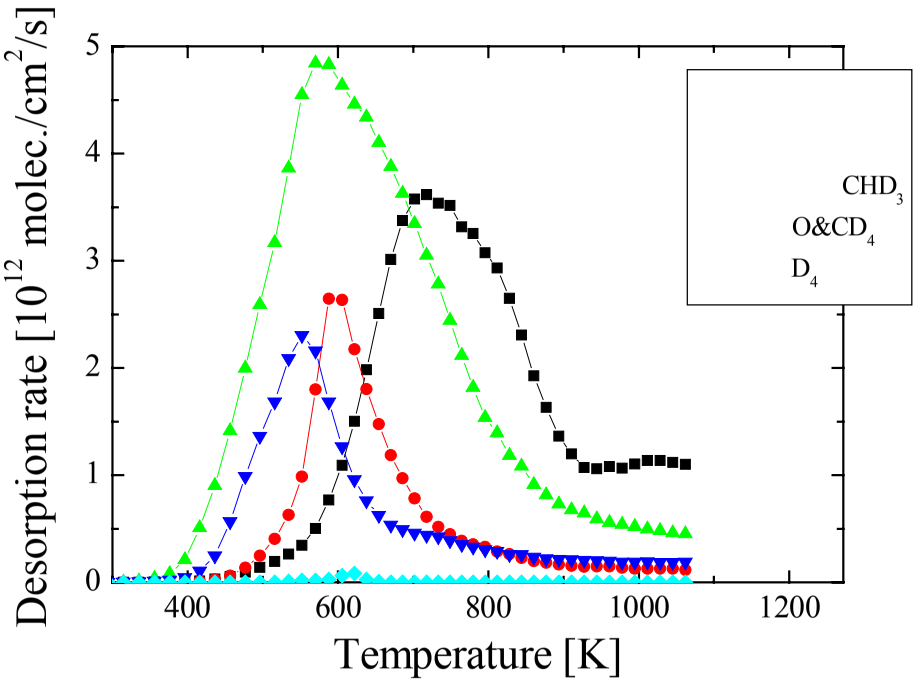
Deuterium desorption spectrum

5x10^{18} D/cm^2

(a) F82H



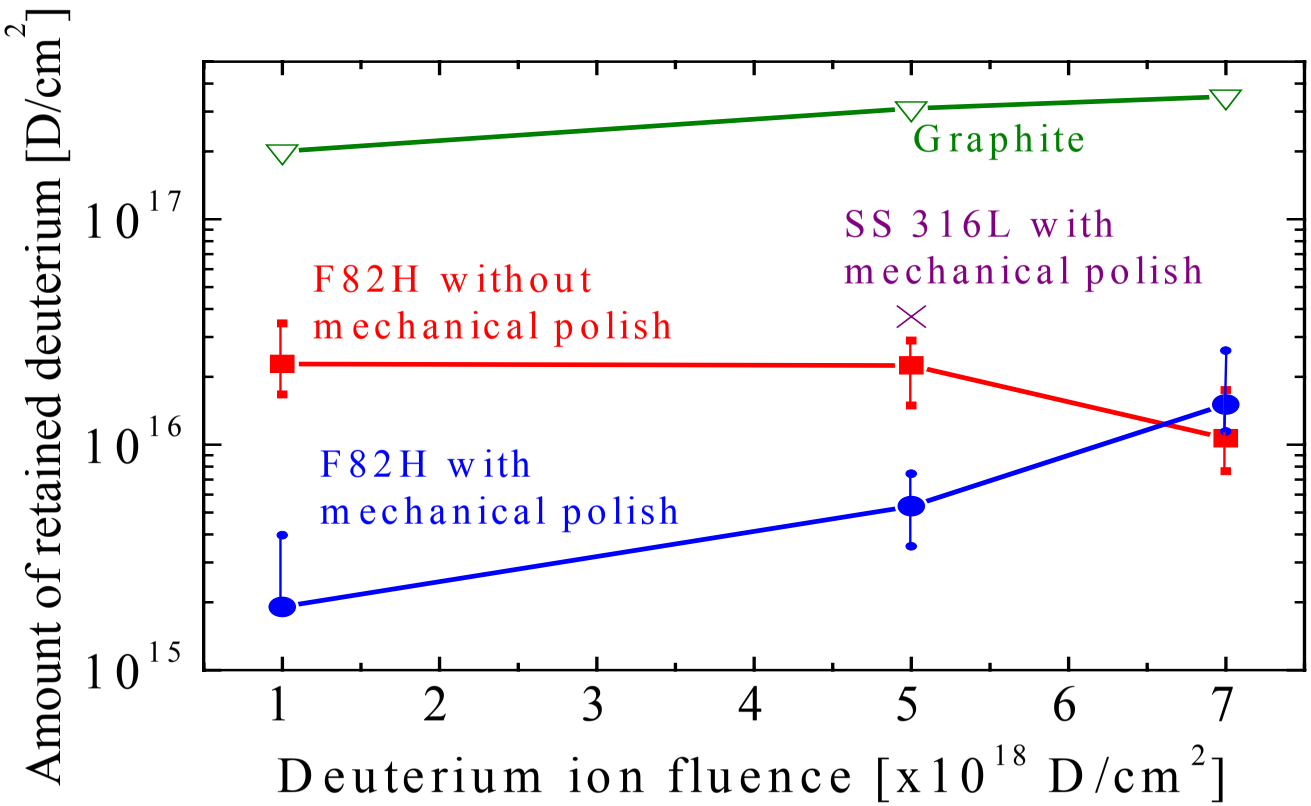
(b) 316L SS



Retention & desorption temp. : low

(Maybe thick oxide layer)

Fluence dependence of deuterium retention

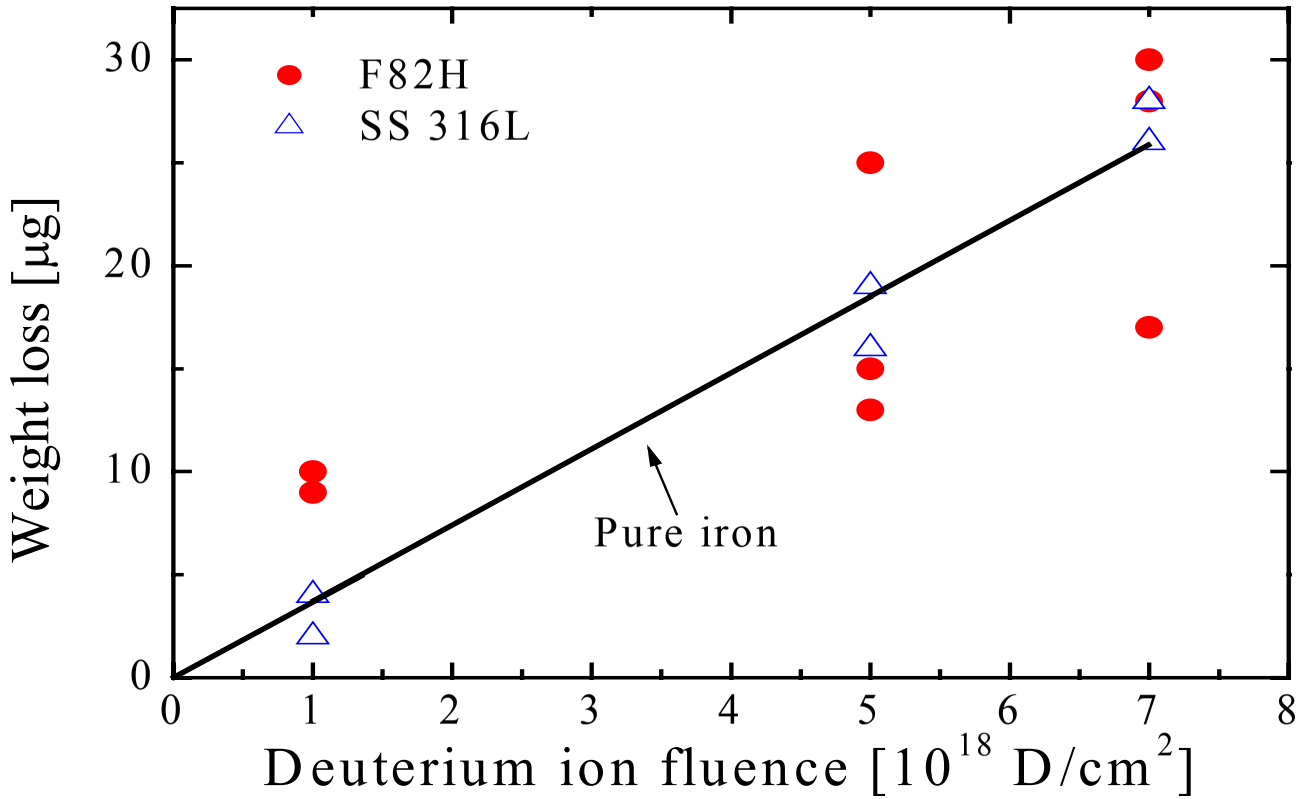


F82H oxidized has a large retention,

but F82H mechanically polished has a smaller retention.

Physical sputtering yield

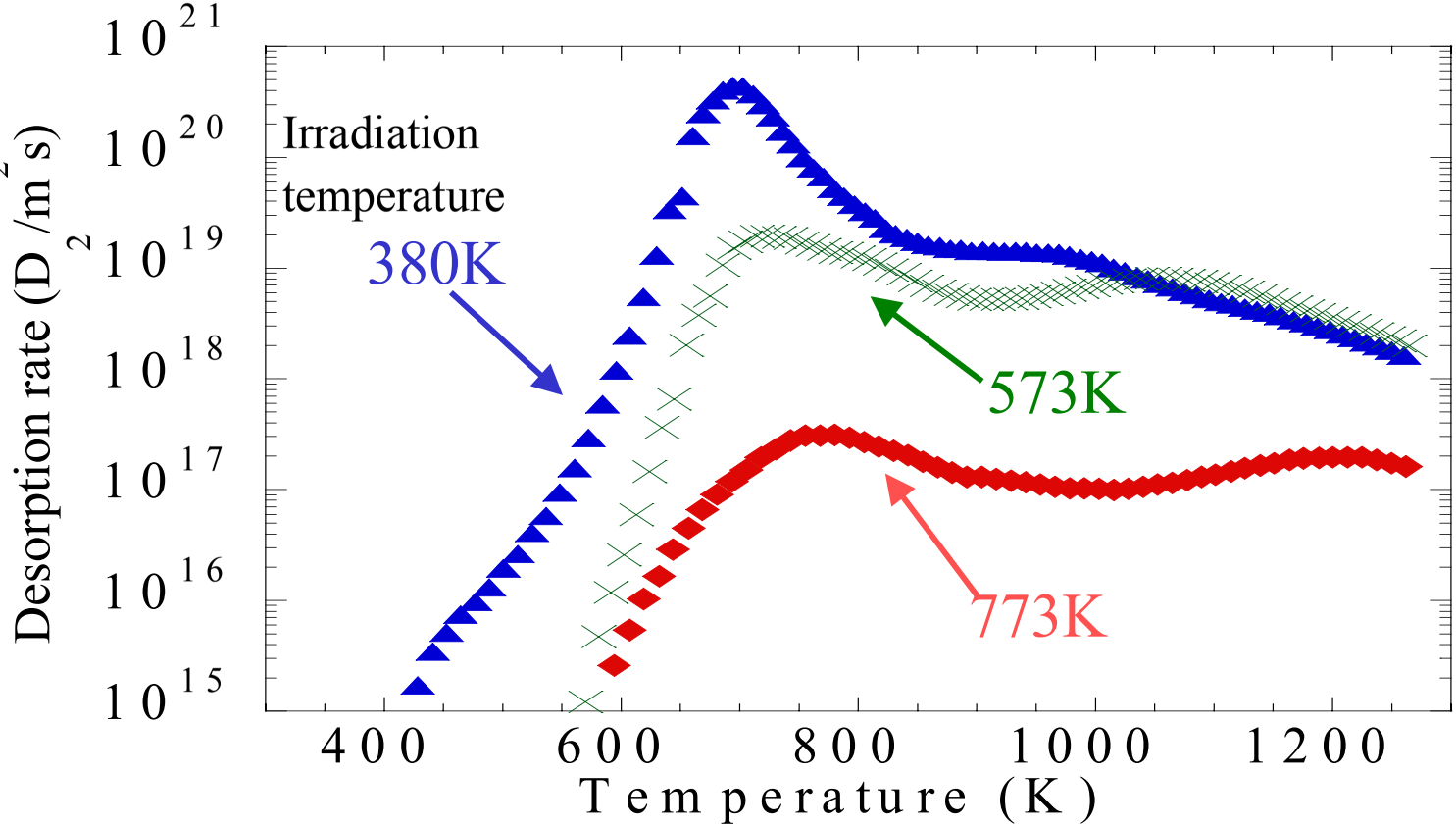
Weight loss



Sputtering yield ~ 0.04 (Comparable with pure iron and 316L SS)

(2) Vanadium alloy

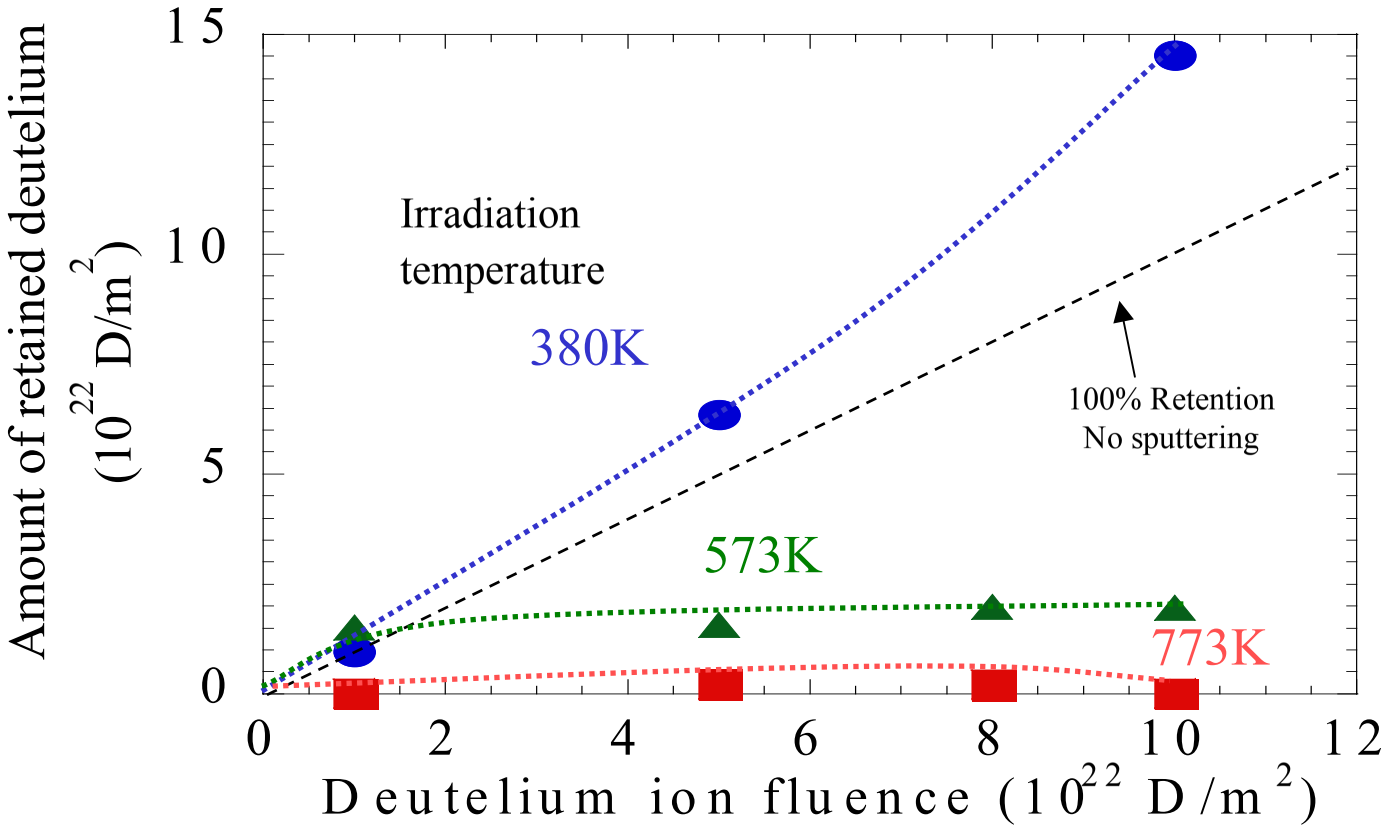
Thermal desorption spectra of D after D irradiation



Peak temp: 700-800K

Desorption rate decreases as increase of temp.

Fluence dependence of deuterium retention



At low temp., D conc. linearly increases.

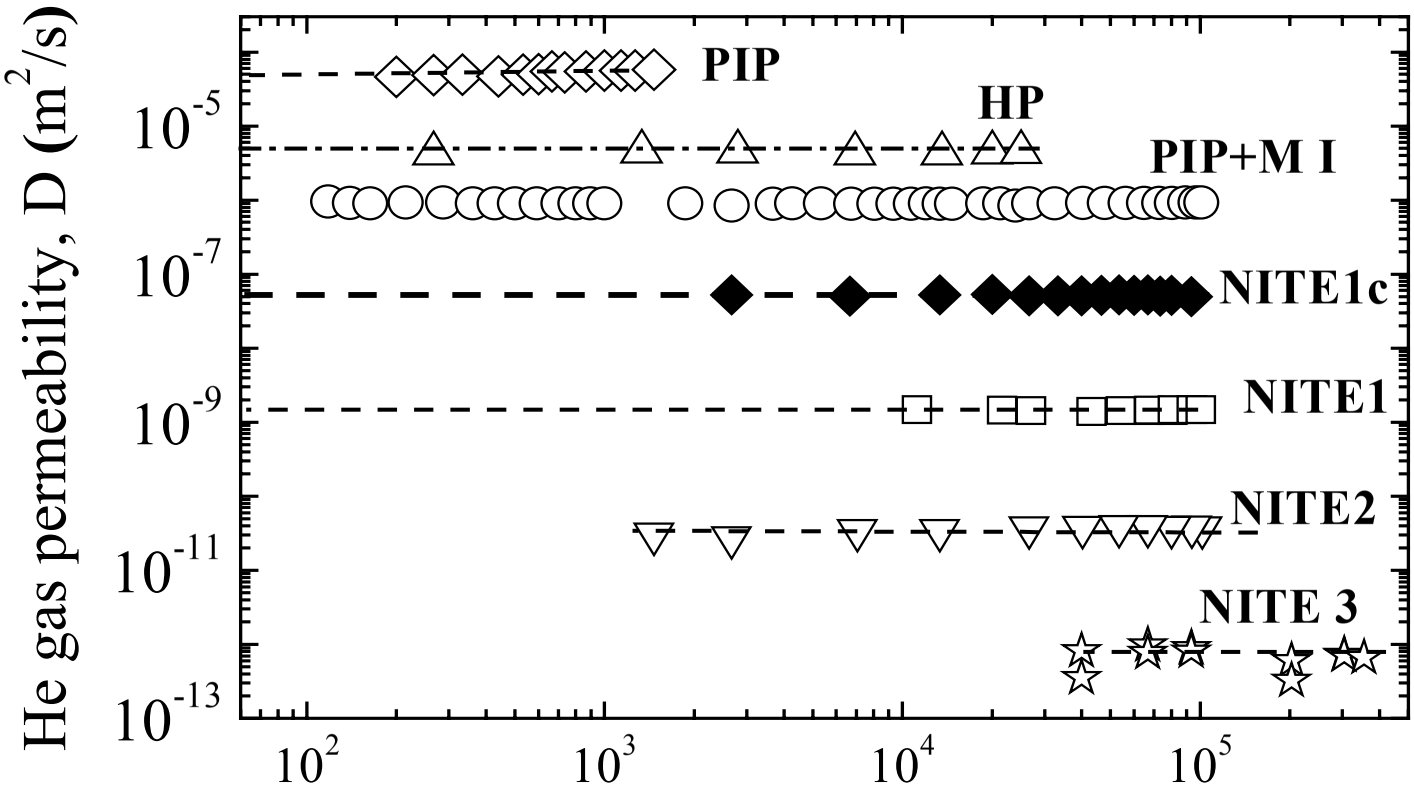
For temp. higher than 573K, D conc. saturates.

Saturation value: 0.5 wt ppm (No embrittlement)

D/V atomic ratio~ 10^{-5} (Hydrogen recycling ~ low)

(3) SiC/SiC composite

(1) He gas permeability before heat cycles

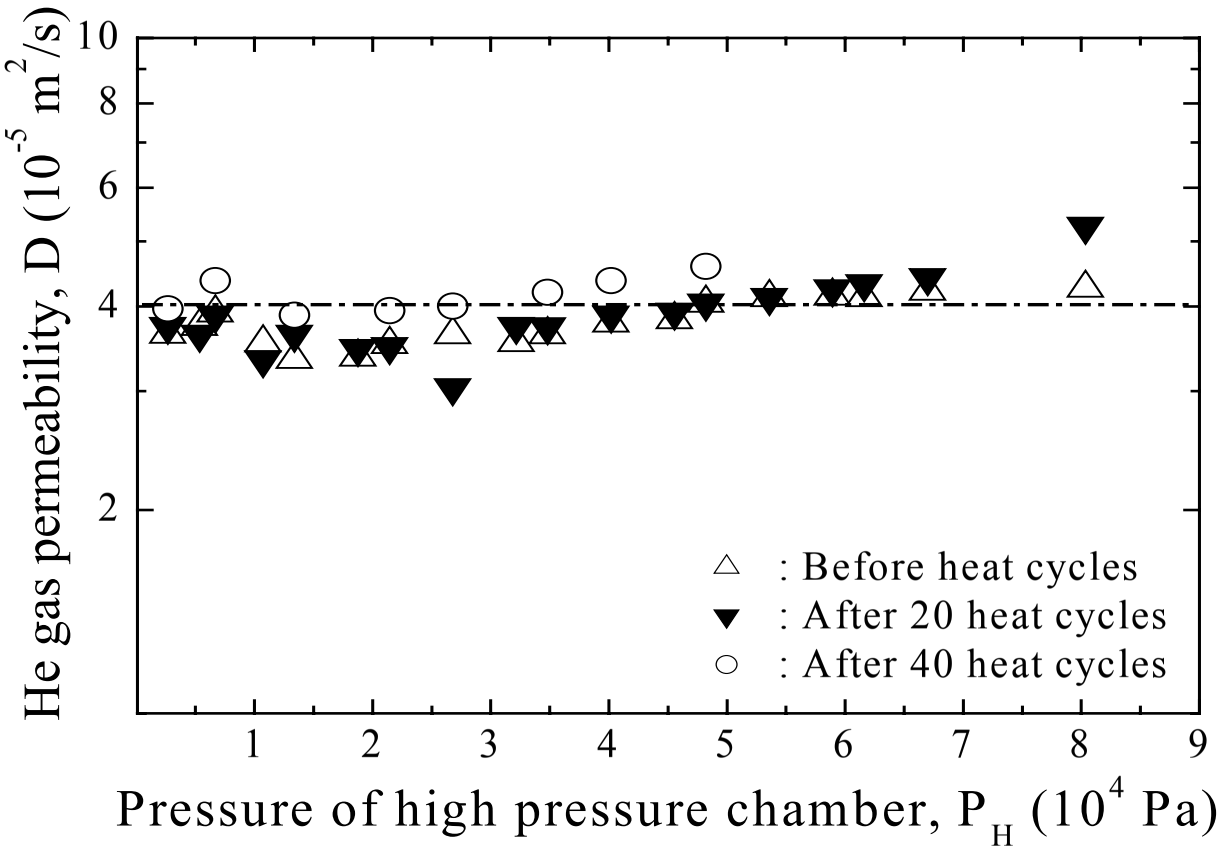


Very low permebility ~ 10^{-11} m^2/s

(2) He gas permeability after heat cycles

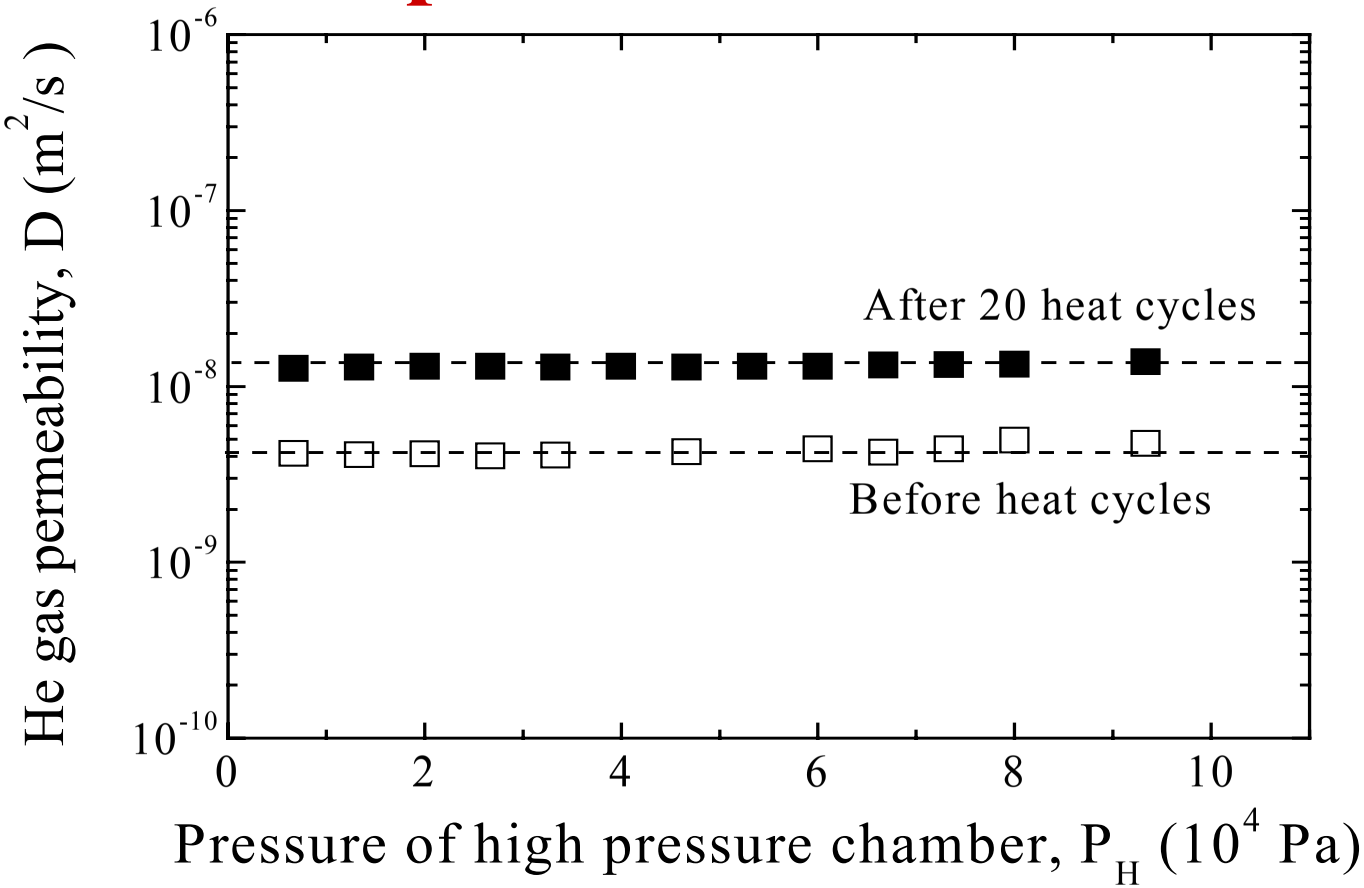
(1300K & 360K/min)

SiC/SiC composite (PIP)



No increase for PIP sample

NITE1 sample

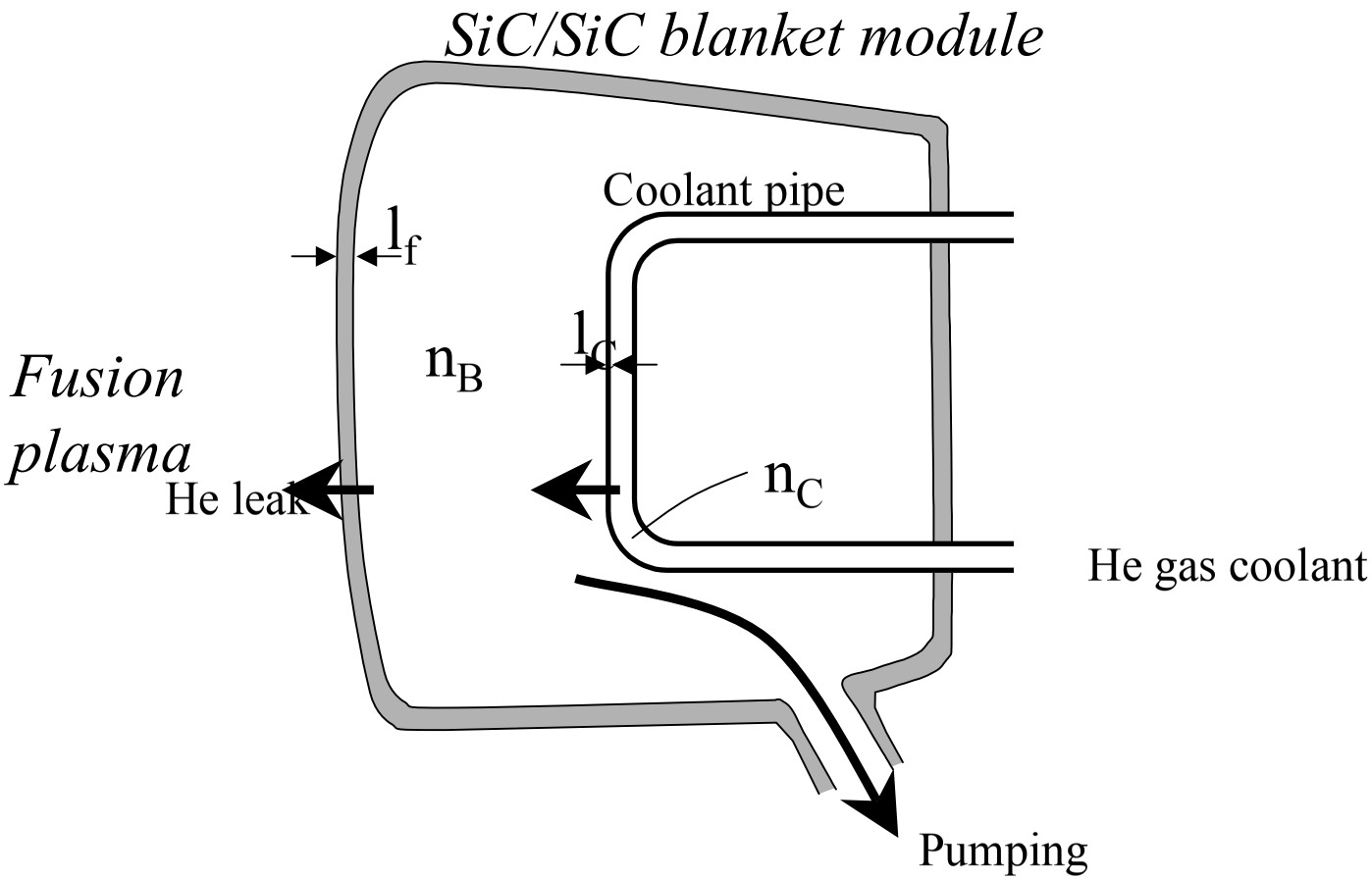


Increase ~ several times

No increase for more cycles

Permeability < ~10^{-8} m^2/s

SiC/SiC blanket



For leak flux to be lower than He production rate, additional pumping is required but the capability can be low, 100 l/s.

4. Summary

(1)Fuel hydrogen retention of ferritic steel becomes lower, compared with 316L SS.

(2)Hydrogen embrittlement does not occur if V alloy temperature is taken the operation temperature, ~900K.

(3)SiC/SiC composite has very low He gas permeability, and the increase of permeability due to heat cycles is only several times. Small pumping is required for SiC/SiC blanket.