Deuterium Retention in Silicon Carbide Materials

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Introduction

- Silicon Carbide (SiC) can be used in high temperature, corrosive environments due to its high melting point and chemical stability
- SiC as a "low-Z" material can be tolerate in higher concentrations as fusion plasma impurity than e.g. metallic impurities
- Disadvantages are the low mechanical shock tolerance and the poor manufacturability of 3D structures $\longrightarrow$ Ceramic Matrix Composite (CMC) of SiC could overcome these issues
- Concepts to use SiC composites as a structural material for the ARIES-AT power core [1]
- Erosion yield, and codeposition properties of SiC well researched, however little data on deuterium retention especially for composite materials
- The objective of this work thus is to characterise and compare the deuterium retention properties in bulk SiC, SiC_f/SiC, C_f/C-SiC and SiC coated graphite

Experimental Methods

Table 1: Origin and properties of the tested materials

Material type	Manufacturing process	Manufacturer	Density [g/cm^3]	Porosity [%]
SiC	Sintering	Ortech Ceramics		~ 0
SiC_f/SiC[a]	Polymer infiltration and pyrolysis	DLR Stuttgart	2.18	< 8 (7.21)
C_f/C-SiC	Liquid silicon infiltration	DLR Stuttgart	1.87	< 2 (1.39)
SiC coated C	Chemical vapour deposition	General Atomics	3.21[b]	-
C (HPG99)	Pyrolysis	Union Carbon	2.2	-

[a] Alternative name SiC/SiCN due to nitrogen remnants from silane precursor
[b] SiC deposition layer, density of graphite substrate ~ 1.76 g/cm^3

- All specimen (Tab. 1) except the SiC coated graphite were cut into 5 x 7 x 0.5 mm^3 slices and mechanically polished to a mirror finish
- The implantation was performed using a D_3^+ ion beam by varying either the particle energy, the substrate temperature or the ion fluence
- Retained deuterium was measured using the Thermal Desorption Spectroscopy (TDS) method
- Specimen were heated on a carbon cradle at a heating rate of 1 K/s from 300 K to 1500 K while the temperature was monitored with a W-Re thermocouple mounted on a reference bulk SiC specimen
- Desorption of mass 2 (H_2), mass 3 (HD), mass 4 (D_2), mass 16 (CH_4) and mass 20 (CD_4, D_2O) were monitored with Extrel and Hiden Quadrupole Mass Spectrometers (QMS)
- Quantification of the signals could be achieved by using D_2, CD_4 and H_2 calibrated leak bottles
- TDS profiles were integrated over time to obtain the total amount of retained deuterium

Results and Discussion

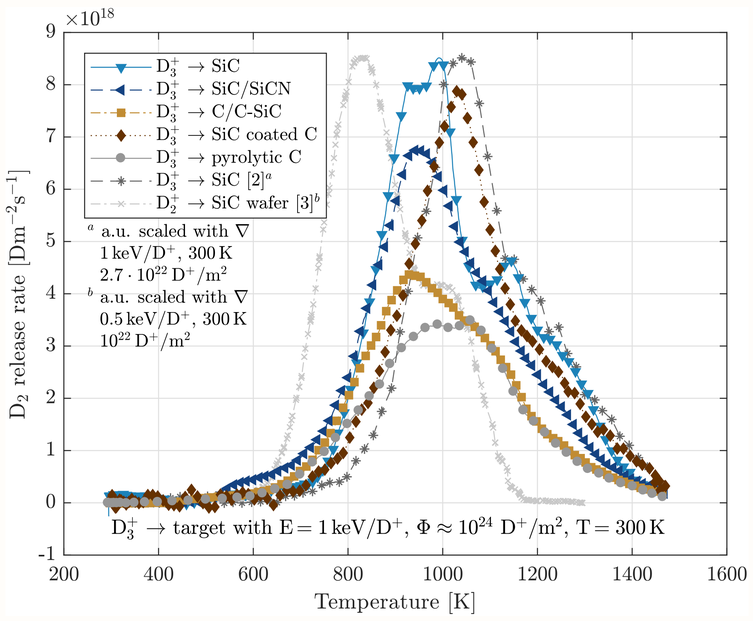

Figure 1: Thermal desorption spectroscopy profiles

- The shape of selected TDS curves is compared in Fig. 1 with curves from the literature [2, 3]
  - Variance in main peak position most likely result of different temperature measurement approaches
  - Overall shape with dominant major peak (Si-D) and minor or missing secondary peak (C-D) at higher temperatures
  - Shape and amount of retention in SiC_f/SiC and SiC coated graphite similar to bulk SiC, C_f/C-SiC rather to graphite

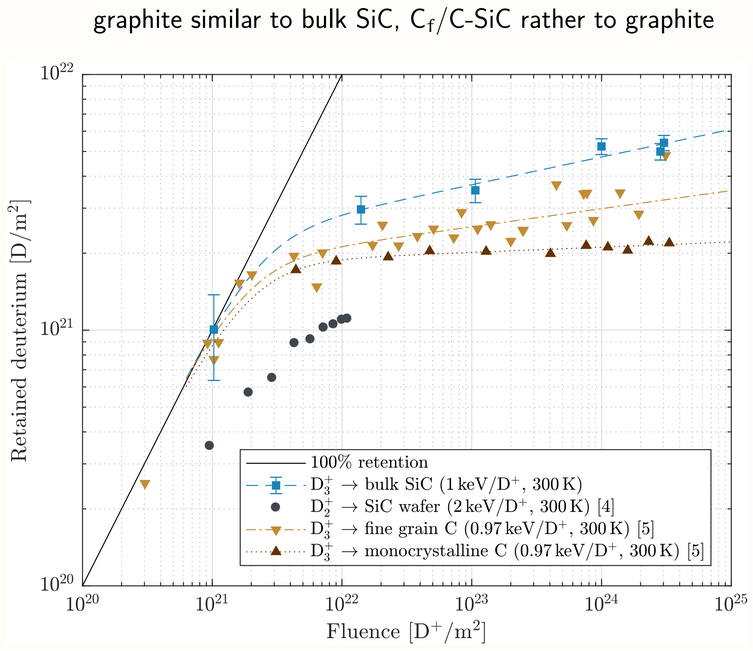

Figure 2: Fluence dependent deuterium retention

- Fig. 2 shows the fluence dependent retention of sintered SiC in comparison to literature data [4, 5]
  - Bulk SiC shows a steeper gradient than fine grade or monocrystalline graphite in the saturation region

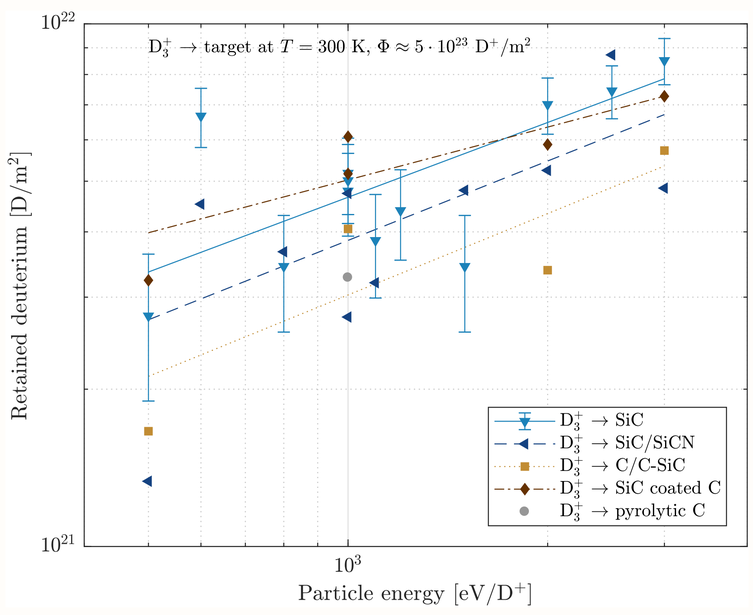

Figure 3: Energy dependent deuterium retention

- The particle energy versus the amount of retained deuterium is depicted in Fig. 3
  - Bulk SiC and SiC coated graphite retain similar amounts of deuterium, SiC/SiC_f and C_f/C-SiC slightly lower with C_f/C-SiC being more similar to graphite than to SiC
  - The increase in retention scales with $\sqrt{E}$ for SiC, SiC/SiC_f and C_f/C-SiC

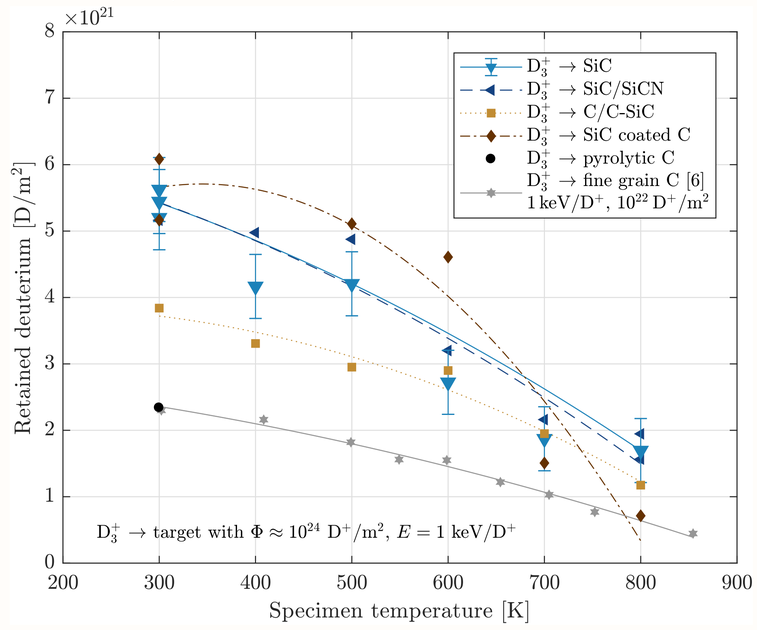

Figure 4: Substrate temperature dependent deuterium retention including literature pyrolytic graphite results

- Fig. 4 shows the temperature dependent deuterium retention properties of the tested materials in comparison with Haasz and Davis [6] pyrolytic graphite results
  - The trend lines reveal an almost linear decrease in the magnitude of retained deuterium with increasing temperatures
  - Bulk SiC and SiC_f/SiC show quite similar retention curves
  - The C_f/C-SiC curve lies in-between the graphite curve and the higher bulk SiC and SiC_f/SiC curves
  - The last two data points of the SiC coated specimen are rather low in magnitude. The quite non-linear decrease might be flawed and should be verified by further experiments.

Conclusion

- The total amount of retained deuterium is similar for all investigated materials with a significant silicon content at the surface (bulk SiC, SiC_f/SiCN, SiC coated graphite) whereas C_f/C-SiC shows results in-between SiC and pyrolytic graphite
- Neither the fibres nor the porosities seem to foster retention
- The difference in the amount of deuterium retention between graphite and the tested SiC materials decreases with increasing specimen temperature indicating that thermonuclear devices operated at high wall temperatures will only face moderate increases in retention if the walls are changed from graphite to SiC materials
- If a small increase in the hydrogenic retention can be tolerated, SiC CMC materials could be an alternative to graphite as a structural material in fusion devices to benefit from the superior mechanical properties

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