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RECOVERY BEHAVIOR OF HIGH-PURITY CUBIC SIC FOR FIRST-WALL APPLICATIONS IN FUSION REACTORS BY POST-IRRADIATION ANNEALING AFTER LOW-TEMPERATURE NEUTRON IRRADIATION

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ABSTRACT

- Examines the defect recovery behavior of two types of high-purity cubic silicon carbide (β-SiC) polycrystals, following low-temperature neutron irradiation in the BR2 reactor. (2.1×10^{24} n/m² (E > 0.1 MeV) at 340 K) then subjected to stepwise thermal annealing up to 1673 K.
- Measure macroscopic length recovery, and activation energies for defect recombination were extracted using first-order kinetic models.
- 70% of volume recovery occurred below 1223 K, attributed to the recombination of closely spaced Frenkel pairs.

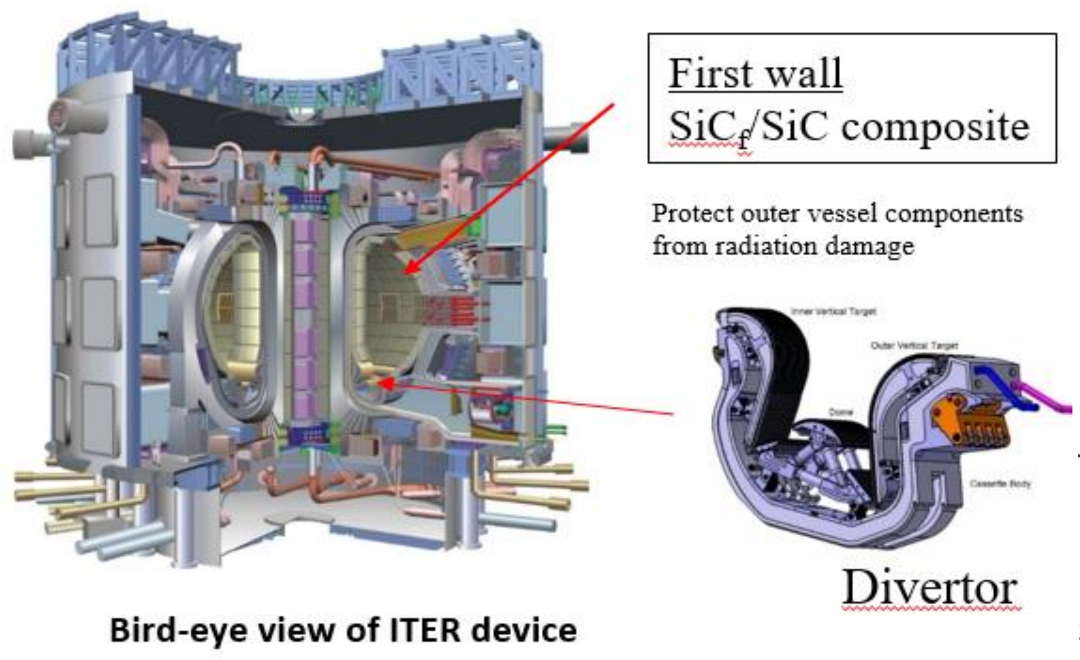
BACKGROUND

- Silicon carbide (SiC) is widely recognised for its superior thermal and mechanical properties, including high-temperature stability above 1273 K and strength exceeding 600 MPa.
- These qualities make it an attractive candidate for use in nuclear environments, particularly in TRISO fuel particles for high-temperature gas-cooled reactors.
- SiC also finds applications in high-stress industrial environments, such as combustion engines, magnetohydrodynamic generators, power semiconductors, and transport systems.

CHALLENGES & METHODS

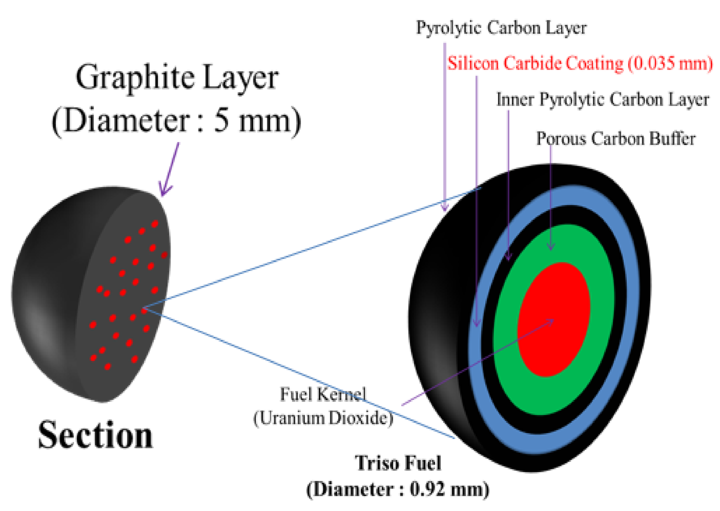
CHALLENGES

- The brittle nature of monolithic SiC remains a major drawback, limiting its structural reliability under mechanical loading.
- Fusion environments, especially near the first wall, expose materials to intense neutron flux, heat, and high-energy ions, which can cause severe displacement damage and material degradation.
- Studying the post-irradiation recovery behaviour of SiC is therefore essential to understanding the thermal and defect stability of these materials under reactor conditions



Bird-eye view of ITER device

International Thermonuclear Experimental Reactor (ITER)

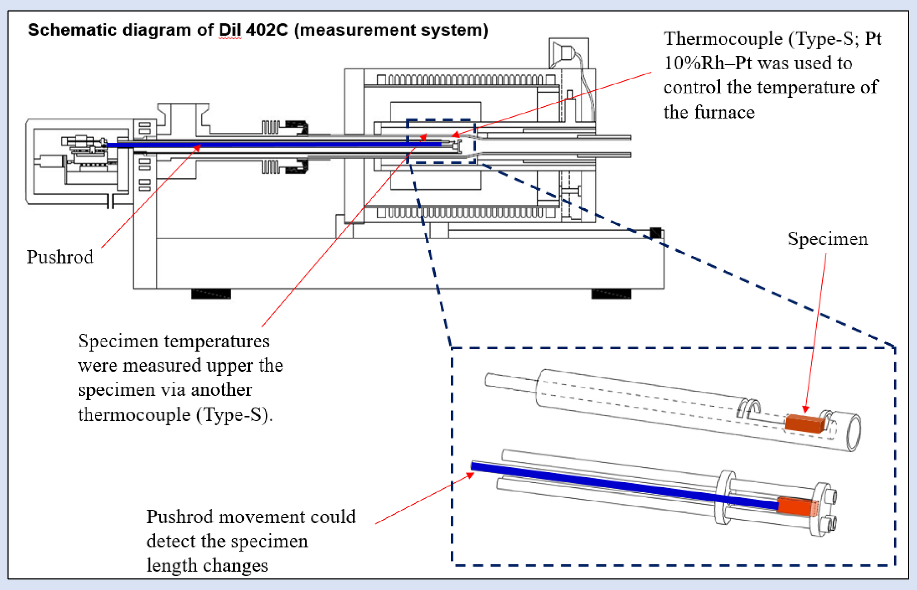


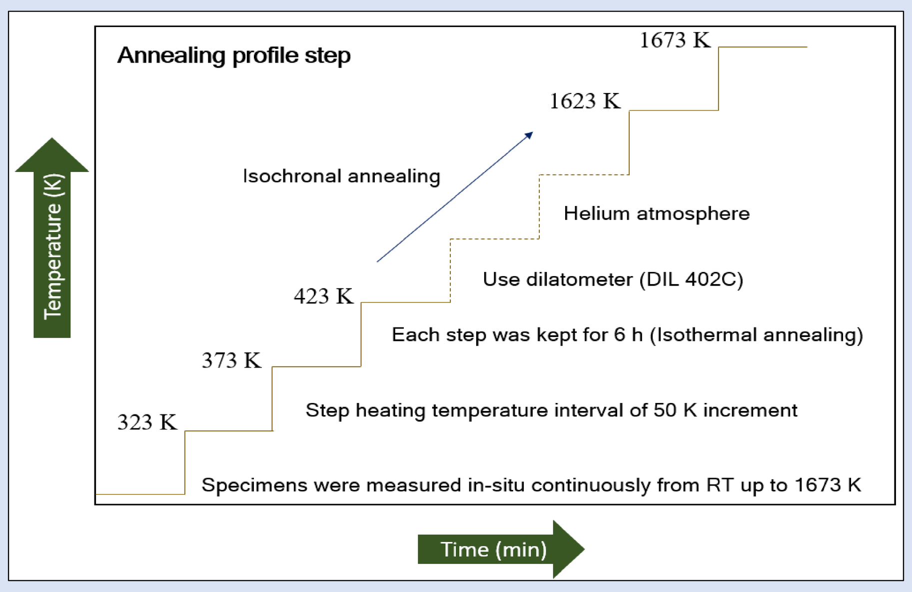
The SiC layer serves as the primary barrier against fission product release, providing exceptional mechanical strength, high-temperature stability, and resistance to radiation damage.

METHODS

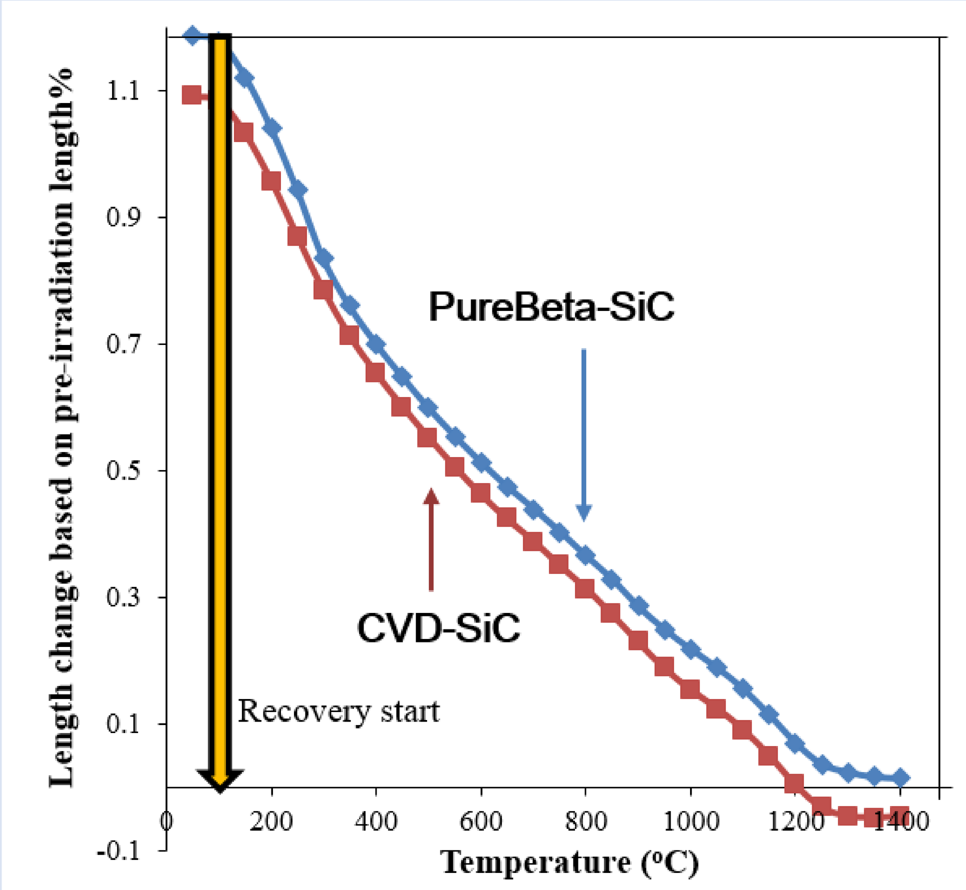
- Both SiC variants were simultaneously irradiated in the BR2 reactor (SCK CEN, Belgium) under identical conditions. The irradiation was performed at a nominal temperature of 340 ± 10 K for a duration of 60 days, achieving a fast neutron fluence of approximately 2.1×10^{24} n/m² (E > 0.1 MeV), equivalent to 0.21–0.25 displacements per atom (dpa).
- Post-irradiation, each bar was sectioned into smaller coupons for annealing measurements using a high-resolution dilatometer in a flowing helium environment.
- Isochronal annealing was performed from room temperature up to 1673 K in 50 K increments, with each temperature step maintained for 6 hours. After completing the thermal cycle, macroscopic length recovery was confirmed by micrometry, and crystallographic recovery was assessed via room-temperature X-ray diffraction (XRD).

IMPLEMENTATION





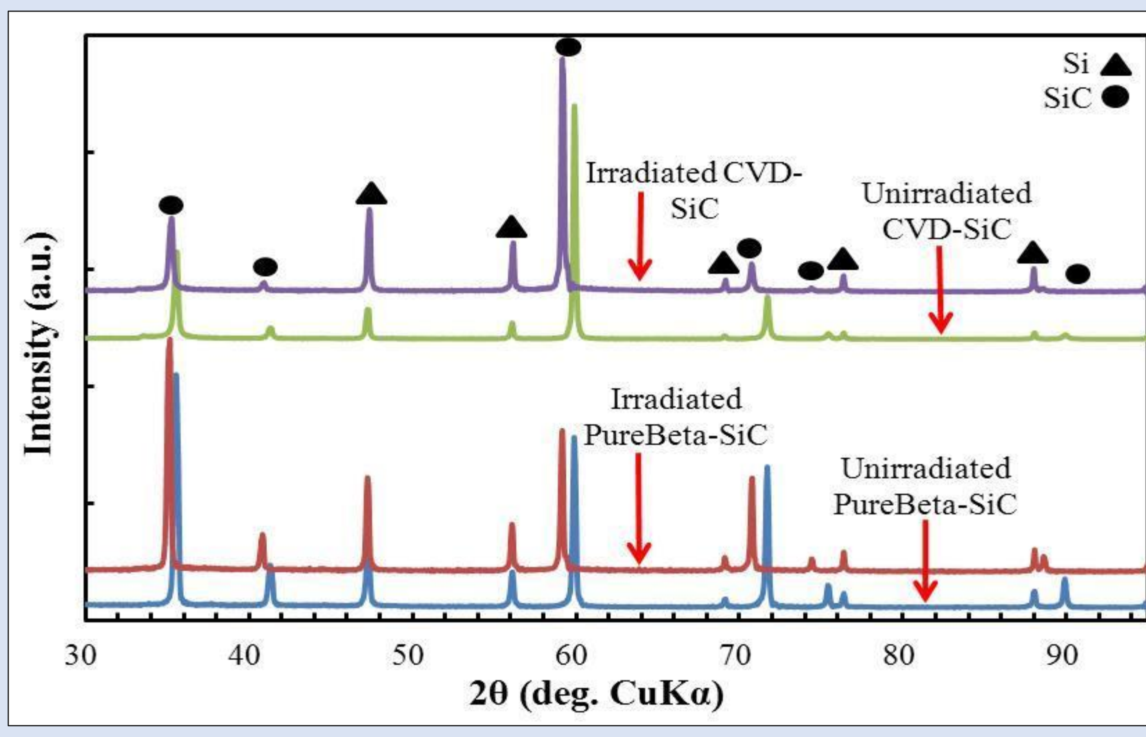
RESULTS AND DISCUSSION



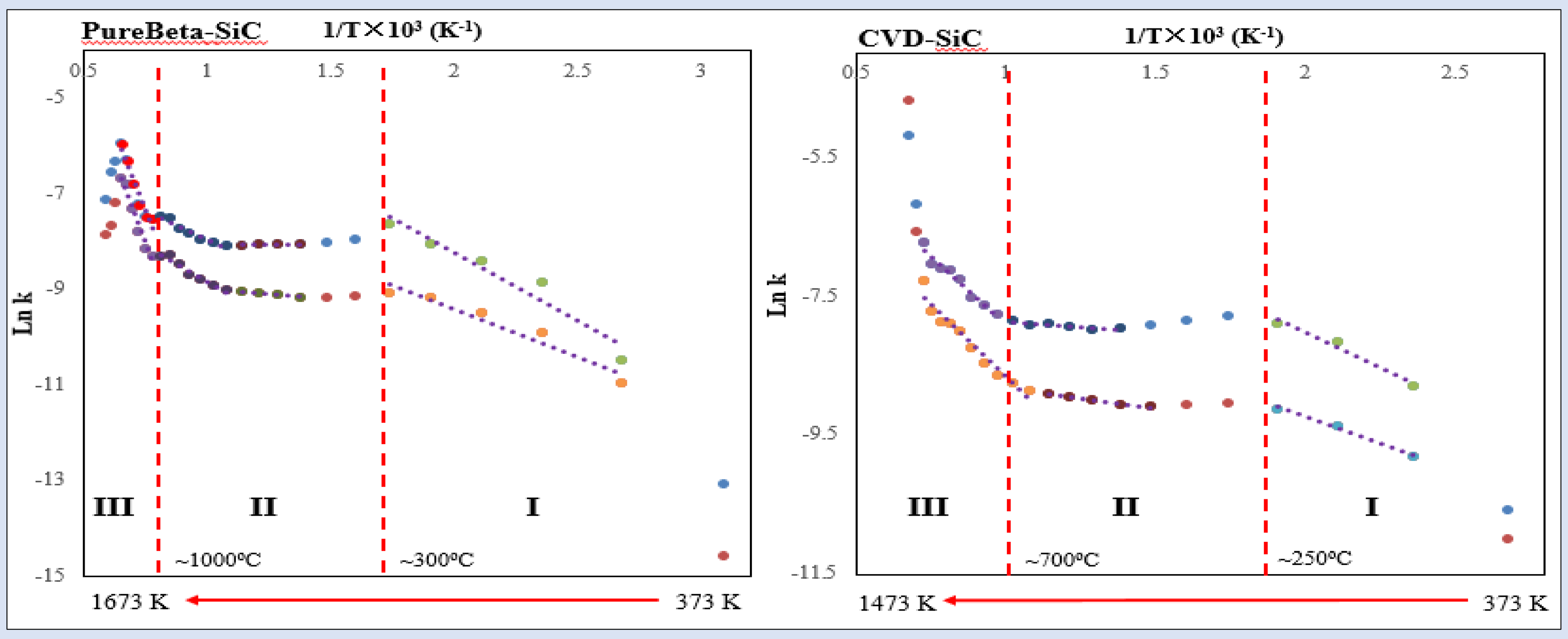
Recovery behavior by isochronal annealing from room temperature up to 1400 C

- Both materials exhibited comparable recovery patterns, initiating at approximately 70 C, close to the irradiation temperature and continuing with a marked increase up to 300 C.
- The majority of irradiation-induced defects were mobile at relatively low temperatures.
- Irradiation damage consisted of isolated point defects and small defect clusters, consistent with the low-temperature, moderate-fluence irradiation condition.

- XRD peaks showing restored peak positions corresponding to their unirradiated counterparts, indicating near-complete lattice recovery.
- β-SiC is more susceptible to low-temperature defect recombination



XRD profile peaks measured at room temperature after post-irradiation annealing



The Arrhenius plot of volume recovery of PureBeta-SiC and CVD-SiC according to k value which obtained by first order reaction with divided and fitted into two straight lines along isothermal annealing time

CONCLUSION

- Both β-SiC materials exhibited four distinct recovery stages, each characterised by different activation energies.
- A majority of recovery approximately 75% occurred below 950 C, likely due to recombination of closely spaced carbon and silicon Frenkel pairs, without requiring significant long-range migration

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