O.V. OGORODNIKOVA[1], V. GANN[2], M. ZIBROV[1],
Yu. GASPARYAN[1], V. EFIMOV[1]
[1]*National Research Nuclear University MEPhI*
[2]*National Science Centre "Kharkov Institute of Physics and Technology", Kharkov, Ukraine*

COMPARISON OF DEUTERIUM RETENTION IN TUNGSTEN PRE-DAMAGED WITH ENERGETIC ELECTRONS, SELF-IONS AND NEUTRONS

Due to high melting temperature, low erosion yield and low retention of hydrogen isotopes, tungsten (W) is used as plasma-facing materials in present tokamaks as ASDEX Upgrade (AUG) [1] and JET [2] and selected to be used in future fusion devices as material facing to the plasma [3,4]. In previous works it was shown that pre-irradiation with self-ions [5-8] and with neutrons at high-flux isotope reactor (HFIR) [9,10] significantly increases the deuterium (D) retention in W. In the present work, we investigate the D retention in W in dependence on the pre-irradiation with different species. The objective of this work is to compare the deuterium retention in tungsten pre-damaged with electrons (e), ions and neutrons. Self-ion irradiation was performed at IPP (Garching) with 20 MeV W ions, e-beam irradiation at MEPhI (Moscow) with 3.5 MeV e^-, and neutron irradiation at Oak Ridge National Laboratory in high-flux isotope reactor (HFIR) [10]. After pre-damaging, specimens were exposed to deuterium plasma in well-defined laboratory conditions.

A comparison of the D concentration in self-ion- and n-irradiated W was done in [7] and is presented in Fig. 1.

From Fig. 1, the correlation coefficient between n- and self-ion irradiations was found to be 0.65 [7]. This means that 1 dpa neutrons corresponds to 0.65 ion-equivalent dpa in relation to the D retention. The conclusion was drawn in [7] that self-ions can be used as a surrogate for a simulation of the D retention in n-irradiated W at low irradiation doses.

Electron irradiation produces damage mainly with primary knock-on energy (PKA) around the displacement threshold energy and therefore creates Frenkel defects. Therefore, e-beam with energy of 3.5 MeV produces cascade-free collisions and isolated vacancies can be created at relatively low irradiation doses. In this case we can compare an increase in the D concentration due to trapping by vacancies with that due to trapping by vacancy clusters produced in collision cascades under self-ion irradiation.

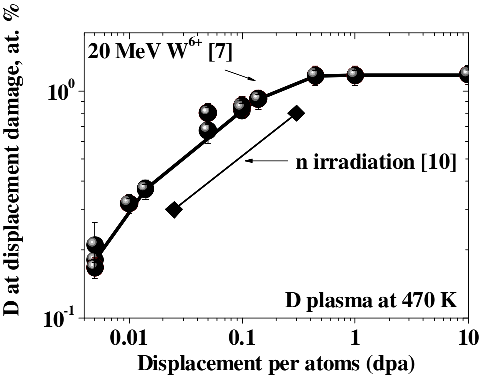

Fig. 1. Comparison of the deuterium concentration at radiation-induced defects in W created by neutron irradiation in the high-flux isotope reactor (HFIR) at Oak Ridge National Laboratory (ORNL) [10] and by irradiation with 20 MeV W^{6+} [7] and subsequently exposed to D plasma at sample temperature of 470 K. Reproducible with permission from [7]

Fig. 2 shows the damage functions for irradiation of W with self-ions, electrons and neutrons in HFIR. Obviously, the damage function of self-ions reproduces better the damage function of neutrons than that of electrons.

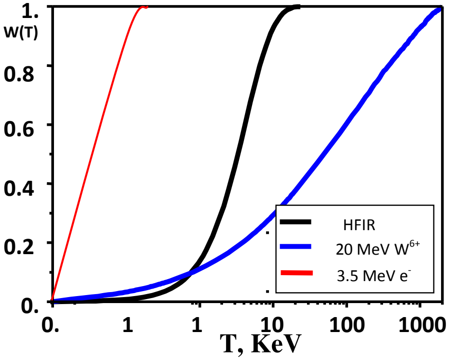

Fig. 2. Fraction of defects produced by PKA events of energies T for W irradiated with self-ions, electrons and neutrons in HFIR

Electron irradiation creates flat damage profile. While irradiation with 20 MeV W ions creates inhomogeneous damage profile up to ~2.5 μm with maximum at ~1.3 μm. The inhomogeneous damage profile complicates the interpretation of the D depth profile data and modelling. According to SRIM calculations, a four-step irradiation with W ions up to 0.45 dpa using energies of 20, 8, 4 and 2 MeV and fluences of 1.4×10^{18}, 3.06×10^{17}, 1.97×10^{17} and 1.38×10^{17} W/m^2, respectively, produces roughly rectangular damage profile. Fig. 3 shows the D depth profile in self-ion (0.45 dpa) and e-irradiated (10^{-5} dpa) W specimens after the plasma exposure at 370 K. No remarkable increase in the D concentration in W was found with electron pre-irradiated W at dose of 10^{-5} dpa. An increase of the D concentration by two orders of magnitude in damaged zone of self-ion pre-irradiated W up to 0.45 dpa was observed.

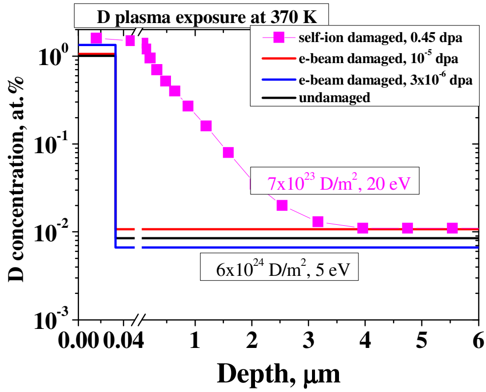

Fig. 3. A comparison of post-mortem depth profiles of deuterium in self-ion and electron pre-implanted W after exposure to deuterium plasma at 370 K. Electron irradiation was done at near room temperature with 3.5 MeV e^- up to a dose of 2.6×10^{22} e/m^2. Four step irradiation using four ion energies of 20, 8, 4 and 2 MeV up to an irradiation dose of $(1.4\text{-}1.6)\times10^{18}$ W/m^2 was applied in the case of self-ion irradiation to obtain flat damage profile

The e irradiation dose was not sufficient to produce remarkable damage in W. However, even at such small dose as 10^{-5} dpa, an increase of the D retention at vacancy-related TDS peak was observed. Future work is required to compare the D retention at radiation-induced defects produced in cascade-free and cascade-full conditions.

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