Journal of Nuclear Materials 512 (2018) 25–30

Contents lists available at ScienceDirect

Journal of Nuclear Materials

journal homepage: www.elsevier.com/locate/jnucmat

The influence of helium on deuterium retention in beryllium co-deposits

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ARTICLE INFO

Article history:
Received 29 May 2018
Received in revised form
3 August 2018
Accepted 18 September 2018
Available online 23 September 2018

Keywords:
D retention
Be co-deposits
Helium

ABSTRACT

Tritium co-deposition with materials from the plasma-facing components is expected to be the main contributor to tritium retention in ITER. Since He will also be present in the plasma as fusion ash during the DT campaign, this study focuses on the effect of He on D retention in Be co-deposits. The PISCES-B linear plasma device was used to create co-deposited Be-D-He layers for various deposition temperatures (295 K - 475 K) and He concentrations in $D-\alpha He$ plasma mixtures ($0 \leq \alpha \leq 0.1$). Thermal desorption spectroscopy and nuclear reaction analysis were used to determine the D concentration in co-deposits. For the lowest He concentration (1%) an increase of D retention was observed for the deposition at room temperature, whereas for higher He concentrations a declining trend of D retention was found. Including 10% of He in the plasma is found to reduce D retention at deposition temperatures below 425 K and have a negligible effect at higher deposition temperatures.

1. Introduction

Tungsten (W) and beryllium (Be) are the materials of choice for the ITER divertor and first wall, respectively. Due to the plasma-wall interaction the material will be eroded and re-deposited together with other species present in the vessel, such as deuterium (D), tritium (T) and helium (He). Experiments from the JET-ILW show that Be rich co-deposits formed mostly on the cold surfaces of the inner divertor, where the surface temperature reaches around 373 K [1]. Moreover, the WallDYN [2] code for impurity migration and wall composition dynamics was used to predict Be deposition patterns and the resulting co-deposition for ITER [3]. The calculation predicts significant Be deposition on inner and outer divertor baffles, where the predicted surface temperature is around 388 K [4], according to calculations performed with SOLPS 4.3 code package [5]. However, extrapolation from JET-ILW to ITER is not straigthforward and simulation results depend strongly on the assumptions of ITER design and operation conditions.

Co-deposition is expected to be the main mechanism contributing to the long-term retention of the fusion fuel [6]. Since fuel retention presents a safety issue due to the radioactive nature of T, a safety limit of in-vessel T has been set to 1 kg [7] and a number of T removal techniques has been proposed in the case of ITER. To address T retention and removal issues, many studies on D retention and/or release behavior from Be-D co-deposits [8–12] have been performed. However, there is a limited number of studies on the effect of He co-deposition on hydrogen isotope retention. A low concentration of He (up to 6% of He in ITER [13]) will be present in the vessel as an ash from the D-T fusion reaction and moreover, ITER will operate with He/H plasma mixture during the Pre-Fusion Power Operation (PFPO) phase [14]. It has been shown that inclusion of He in D plasma reduces D retention in bulk Be exposed to $D-He$ plasma mixture [15,16]. The aim of the current study is to investigate the influence of He on D retention in Be-D-He co-deposits.

2. Experiment

The PISCES-B linear plasma device [17] was used to produce ten co-deposited Be-D-He layers. Each layer was produced under

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https://doi.org/10.1016/j.jnucmat.2018.09.032
0022-3115/

different deposition conditions varying the substrate temperature between 300 and 475 K and He concentration in the $D-\alpha He$ plasma ($0 \leq \alpha \leq 0.1$). Helium concentration was not monitored by optical spectroscopy during the experiment, however it was controlled by setting the pressure of He gas according to [18], where He concentration in $D-\alpha He$ plasma mixture was calibrated by He I (447.1 nm) optical emission spectroscopy for different He gas pressures. Deuterium partial pressure was kept constant for all plasma mixtures.

A S-65 Be target (made by The Peregrine Falcon Corporation) with a diameter of 25 mm and a thickness of 1.5 mm was exposed to pure *D* or a mixture of *D* and *He* plasma. The plasma parameters were similar for all exposures and were measured by a Langmuir probe close to the target. The electron density and temperature were $(2-3)\times 10^{18}$ m^{-3} and $(4-5)$ eV, respectively. The ion flux was $(1.5-2.5)\times 10^{22}$ m^{-2}s^{-1} and the floating and the plasma potential were around -30 V and -20 V, respectively. The Be target was biased to -120 V to keep the energy of the impacting ions at $\approx$100 eV. The target temperature was measured at the rear by a thermocouple and varied between 300 K and 800 K. Since Be erosion yield is constant in this temperature range [19], the formation of co-deposits is not influenced by this variation of the temperature.

Co-deposits were collected on circular polished W substrates with a diameter of 20 mm and a thickness of 1 mm, cut in two identical halves. The average Be deposition rate was 0.07×10^{15} Be/cm^{2}s, resulting in the average layer thickness of 15 nm, which was calculated assuming the atom density of bulk Be. The substrates had a direct line of sight towards the Be target and were shielded from the direct interaction with the plasma. They were kept at a constant temperature during the deposition. The deposition probe, holding the substrates, is fully retractable into a vacuum interlock chamber [20]. This allowed substrates to be inserted into position for deposition only after stationary plasma conditions were achieved. The main contributions to co-deposited layers are believed to be D and He reflection from the target and sputter erosion of the Be target [9]. A scheme of experimental setup is shown in Fig. 1.

Every deposition procedure resulted in identical co-deposits on two halves of the W substrate. One was used for thermodesorption spectroscopy (TDS) and the other for nuclear reaction analysis (NRA). The TDS analysis was performed in a quartz tube attached to a stainless steel vacuum chamber with a background pressure in a range of 10^{-7} mbar [11]. Each sample was linearly heated by an infrared heat source up to 1273 K at a rate of 18 K/min. Partial pressures of desorbing species were recorded by two residual gas analyzers (RGA). The first is a wide range RGA used to follow species of a mass up to 46 m/q. The second is a high resolution 0–6 m/q RGA capable of distinguishing between *He* and D_2. It was used to follow the partial pressures of H_2, *HD*, *He* and D_2. Both RGAs were calibrated with D_2 and *He* leak standards, enabling the conversion of the RGA signal to atomic desorption flux. The sensitivity for D_2 and *HD* was assumed to be the same.

The total D and Be amounts were determined by NRA technique utilizing $D(^3He,p)^4He$ and $^9Be(^3He,p)^{11}$ nuclear reactions. A ^3He probing ion beam with the energy of 2.0 MeV and 0.8 MeV was used and the number of reaction protons with respect to their energy was measured. The measured proton yields were converted in areal densities by comparing the signals with those derived from calibration samples. For D a 274 nm thick, plasma-deposited amorphous, deuterated carbon thin film on silicon was used and for Be a 680 nm thick, magnetron sputtered film on silicon was used. After NRA analysis the samples were used for additional TDS analysis, since the effect of NRA on D and He amount in the sample is negligible.

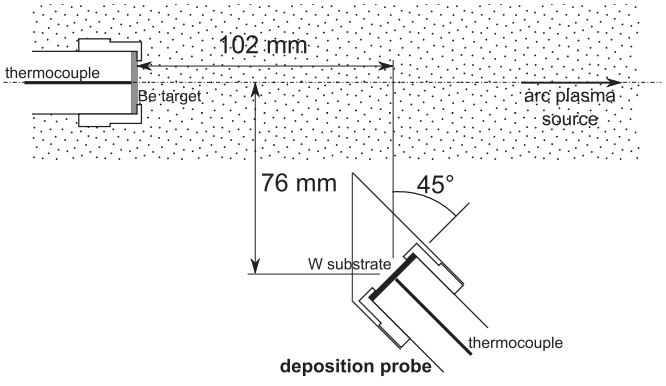

Fig. 1. A scheme of experimental setup.

3. Results

Fig. 2 shows D desorption fluxes from Be co-deposits exposed to pure *D* plasma and a mixture of $D-10\%He$ plasma for various deposition temperatures measured by high resolution RGA. The desorption spectra were obtained by adding together the mass 4 (D_2) and a half of the mass 3 (HD) spectra and dividing by the area of the co-deposit and areal density of Be atoms established from NRA analysis, enabling us to compare co-deposited layers with small variations of the layer thickness. A sharp desorption peak with a long high temperature tail arises around 500–530 K for the samples deposited at room temperature. For higher deposition temperatures the desorption moves to higher temperature. In the case of the highest deposition temperature, 475 K, the sharp peak is absent and only the 'tail' is visible.

Comparison between Fig. 2 (a) and 2(b) reveals much lower D desorption in the case of $D-0.1He$ plasma compared to pure *D* plasma. In the case of deposition at room temperature the peak height decreased by 57%. For higher deposition temperatures the difference in the peak height is reduced, the peaks decreased by 40% and 34% for 375 K and 425 K, respectively. In the case of 475 K the difference in the peak height is less than 1%.

For the deposition at room temperature the He concentration in $D-\alpha He$ plasma was also varied. Fig. 3 shows D desorption spectra

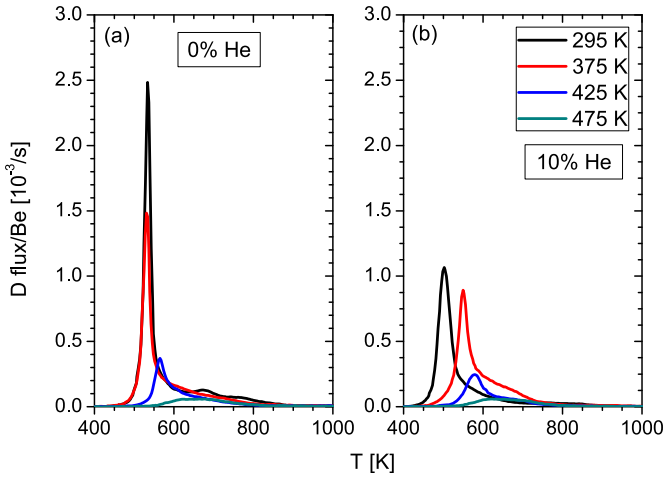

Fig. 2. Scaled deuterium desorption spectra of Be-D-He co-deposits for different deposition temperatures and (a) pure *D* and (b) $D-0.1He$ plasma.