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REDUCTION OF NET EROSION OF HIGH-Z PFC MATERIALS IN DIII-D DIVERTOR DUE TO LOW-Z COATING AND SHORT-SCALE RE-DEPOSITION

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GENERAL ATOMICS

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Reduction of Net Erosion of High-Z PFC Materials in DIII-D Divertor Due to Low-Z Coating and Short-scale Re-deposition EX-D

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We report suppressed erosion of molybdenum plasma facing component (PFC) surface due to a low-Z coating formed by a local gas injection in the lower divertor of the DIII-D tokamak. Local low-rate methane gas injection upstream of a 1 cm molybdenum-coated sample resulted in carbon deposition on the sample and reduction of the net erosion rate of Mo by more than a factor of 20 compared to a case with no gas puff. We also report a substantial reduction of net compared to gross erosion of a tungsten PFC, in good agreement with modeling. A net/gross erosion rate ratio of 0.29 was measured on a 1 cm diameter W sample exposed in the lower divertor of DIII-D to stable well-diagnosed L-mode plasmas. REDEP/WBC modeling of this experiment yielded a similar ratio of 0.33.

A sacrificial low-Z coating deposited in-situ on a high-Z PFC surface can protect the surface from erosion. Injection of a gas containing low-Z impurities such as B, C, Si, or Li through capillaries in a PFC surface can lead to local deposition of a low-Z coating on the surface due to a local decrease of T_e and increase of the low-Z impurity content. In experiments reported here, molybdenum-coated silicon samples 1 cm in diameter were exposed in the lower divertor of DIII-D using the Divertor Material Evaluation System (DiMES) under plasma conditions previously shown to cause significant net erosion of Mo [1]. Two exposures were performed, first in L-mode for ~14 s, second in H-mode for ~7 s. Both exposures were in lower single null discharges, with the samples located within 1–2 cm of the outer strike point (OSP). $^{13}CH_4$ gas was injected about 12 cm upstream of the samples at a low rate that did not cause measurable perturbation of the global discharge and divertor plasma parameters. Suppression of Mo erosion was evidenced in situ by the reduction of MoI line radiation at 386.3 and 390.2 nm once the gas injection was turned on. Figure 1 shows a time trace of the 386.3 nm MoI line in the first L-mode discharge with the lowest gas injection rate of 0.5 Torr*l/s. In subsequent discharges with injection rates of 1.5–2.8 Torr*l/s this line was fully suppressed. Post-mortem Rutherford backscattering (RBS) analysis found the net erosion of molybdenum near the center of the samples being below the measurement resolution of 0.3 nm, corresponding to a rate of 0.02 nm/s. Compared to the previously measured net erosion rates in L-mode of 0.4–0.7 nm/s [1] this constitutes a reduction of more than x20. Carbon deposition was measured on both samples, corresponding to a rate of ~20 nm/s in L-mode and ~4 nm/s in H-mode, assuming deposited C density of 2 g/cm^3. The ratio of $^{13}C/^{12}C$ carbon in the deposits was about 1.6 on both samples, indicating that the deposition was largely from the gas injection. The significant amount of intrinsic ^{12}C carbon

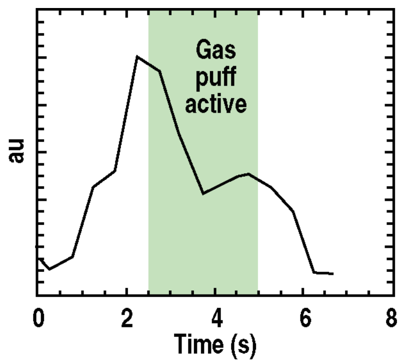

Fig. 1. MoI radiation at 386.3 nm measured by MDS spectrometer in a discharge with $^{13}CH_4$ gas injection in L-mode.

in the deposits is likely an indicator of the local T_e decrease due to the gas injection causing the carbon erosion/deposition balance to shift towards net deposition.

Net erosion of high-Z PFCs in a tokamak is expected to be reduced by short-scale re-deposition due to Lorentz forces and sputtered atom/ion collisions with the impinging plasma [2]. Reduction of net compared to gross erosion has been previously demonstrated for tungsten in ASDEX Upgrade [3] and for molybdenum in DIII-D [1]. Here we report measurements of both net and gross erosion of tungsten under stable well-diagnosed plasma conditions allowing comparison with modeling.

A sample featuring 1 mm and 1 cm diameter 15-24 nm thick W films deposited on a 23 mm diameter Si disc covered by a 300 nm thick carbon inter-layer [Fig. 2(a)] was exposed in the lower divertor of DIII-D using DiMES. The exposure was performed in lower single-null L-mode deuterium plasma discharges near the attached OSP for a total of ~16 s. The plasma density n_e = 1.2x10^{19} m^{-3} and electron temperature T_e = 32–35 eV near OSP were measured by the divertor Langmuir probes and divertor Thomson scattering. Net erosion was measured by comparing the W layer thickness measured by RBS on the 1 cm spot before and after the exposure. Measured pre- and post-exposure toroidal and radial profiles of the W areal density across the sample are shown in Fig. 2(b). The corresponding net erosion rate is 0.14 nm/s. Gross erosion was measured using a novel non-spectroscopic technique based on RBS analysis of the 1 mm coating, where net and gross erosion are expected to be about the same [1]. The measured gross erosion rate was 0.48 nm/s, corresponding to net/gross erosion rate ratio of 0.29. Toroidal and radial profiles of the redeposited W coverage over carbon coating are shown in Fig. 2(c). Comparing the amount of W deposited on the sample to the quantity lost from the original film, the fraction of eroded tungsten which has been re-deposited on the sample is 44%±5% with another 7% deposited at greater radii, assuming an exponential decrease with radius. This is a factor of 2.3 higher than found previously for Mo [1].

Sputtering and transport of tungsten were modeled with the REDEP/WBC erosion/ redeposition code package coupled to the ITMC-DYN mixed-material evolution/response code [4], with plasma conditions supplied by the OEDGE code. Calculated re-deposition fractions on the 1 cm and 1 mm spots were respectively 0.72 and 0.03, confirming that the net erosion on the smaller spot is approximately equal to gross erosion. The calculated ratio of net/gross erosion was 0.33, in good agreement with the experimental value of 0.29. For a toroidally continuous tungsten divertor surface the simulations predict essentially complete re-deposition in the divertor, which has positive implications for ITER.

A second experiment was recently conducted with a sample featuring similar W coatings deposited over a 20 nm Mo inter-layer in order to investigate a different set of mixed material effects. The sample was exposed for a total of 12 s in discharges with similar geometry and T_e at the OSP, but n_e at the OSP was about a factor of 3 higher. As expected, both net and gross erosion rates of W were higher, at 0.33 and 0.87 nm/s, respectively, yielding net/gross erosion ratio of 0.38. Modeling of the second experiment is in progress.

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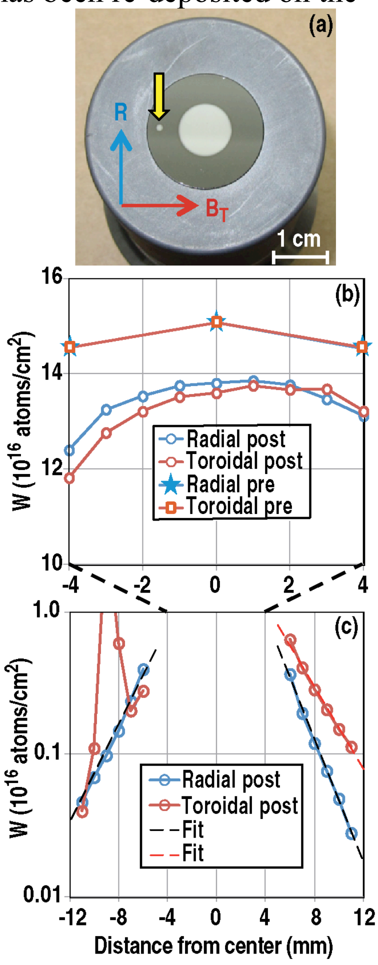

Fig. 2. Pre-exposure photograph (a); pre- and post-exposure RBS measurements of W coverage on the sample (b,c).

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