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We report the first experiment in a tokamak where post-exposure net erosion of molybdenum was measured for a sample exposed to well-controlled plasma conditions, and in-situ gross erosion was estimated as well. Net erosion rate of 0.40±0.04 nm/s was measured on a Mo-coated sample exposed in the DIII-D tokamak to the divertor plasma with n_e = 1.3–1.5x10^{19} m^{-3}, T_e = 25–30 eV using the Divertor Material Evaluation System (DiMES). Measurements of the Mo redeposited on the sample holder can only account for ~20% of the Mo eroded from the sample, suggesting the possibility of additional processes leading to a longer range migration. The gross erosion rate of Mo was estimated using a filtered camera, while the net erosion rate was determined from post-mortem ion beam analysis.

Net erosion of high-Z plasma-facing surfaces in a tokamak is expected to be reduced by local redeposition due to sputtered atom collisions with the impinging plasma [1]. In earlier experiments on ASDEX Upgrade [2] and DIII-D [3,4], samples of W, Mo and V were exposed to divertor plasma, and post-mortem analysis found redeposited material mostly within a few mm from the samples, supporting the local redeposition picture. Reduction of net compared to gross erosion has been demonstrated for W in ASDEX Upgrade [5]. However, in Alcator C-mod the measured campaign-integrated peak net erosion of Mo divertor tiles was found to be ~10X higher than that computed using the REDEP/WBC code, while the gross erosion predicted by the code was a reasonable match to MoI influx data [6]. The present experiment was aimed at measuring both net and gross erosion of Mo under stable well-diagnosed plasma conditions allowing more accurate comparison with the modeling.

A silicon disk 1 cm in diameter coated with a 24 nm thick film of Mo and mounted in a graphite DiMES holder [Fig. 1(a)] was inserted flush with the lower divertor tiles of DIII-D and exposed in a series of 7 reproducible lower single null L-mode deuterium plasma discharges. The exposure was performed near the attached outer strike point (OSP) for a total flattop time of ~28 s. The plasma density and temperature near the strike point were measured by the divertor Langmuir probes. The gross erosion rate of Mo, essentially completely due to a ~1% plasma carbon background, was measured spectroscopically, using an absolutely calibrated CCD camera with MoI filter centered around 390 nm and having a bandwidth of ~10 nm. A sample image from the camera is shown in Fig. 1(b). An upper bound estimate of an average gross erosion rate of 3.75 nm/s was inferred from the data. The 10 nm filter passed a number of lines other than MoI; the relative contribution of MoI light was estimated using high-resolution divertor spectrometer data. In order to improve accuracy, experiment is being repeated using a 1 nm filter.

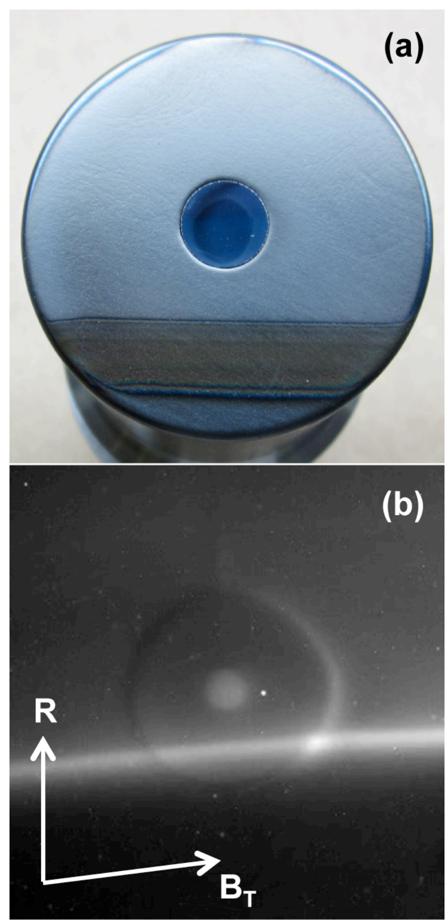

Fig. 1. Post-exposure photograph of the DiMES holder with Mo sample (a); image of the sample taken during the exposure by a CCD camera with MoI 390 nm filter (b).

Net erosion of Mo was measured by comparing the Mo layer thickness measured by Rutherford backscattering (RBS) before and after the exposure. Measured toroidal and poloidal profiles of the net Mo erosion across the sample are shown in Fig. 2(a). The reduction of Mo thickness was

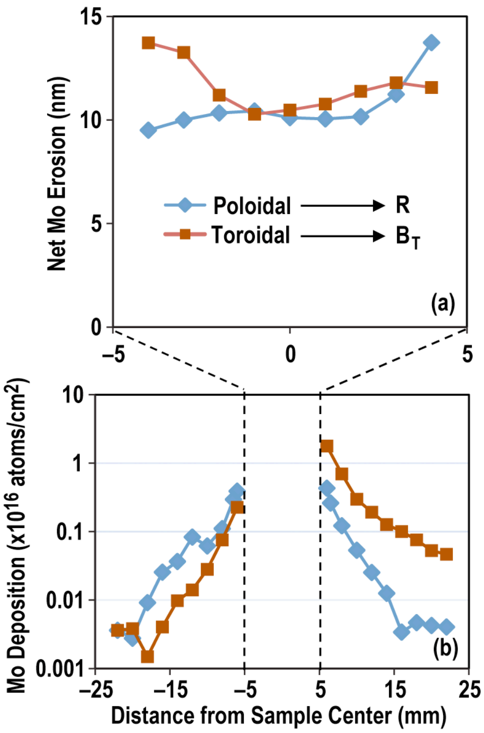

Fig. 2. RBS measurements of net erosion of Mo from the sample (a) and Mo deposition on the graphite holder (b).

11±1 nm on the average, corresponding to an average net erosion rate of 0.40±0.04 nm/s, i.e. significantly smaller than the gross erosion rate measured by the camera.

The distribution of Mo redeposited on the graphite holder was also measured by RBS [Fig. 2(b)]. As expected by our understanding of the dominant redeposition process, Mo deposits were concentrated near the Mo-coated sample edge, with an e-folding length of ~2 mm. Concentration of the deposited Mo was a factor of 8-10 larger on the downstream side of the sample compared to the upstream side. The total amount of Mo found on the holder was only ~20% of the net amount of Mo eroded from the sample, possibly due to high re-sputtering and further transport of deposited Mo from the graphite surface.

^{3}He nuclear reaction analysis was used to measure the coverage of carbon on the Mo/Si sample, which was low, and of deuterium on the sample and adjacent graphite. Deuterium coverage was low, consistent with net erosion, over most of the probe except for a narrow band just inside of the OSP [see Fig. 1(a)], where net deposition occurred at a rate of 1.8×10^{17} carbon atoms/cm^2/s with a relatively high deuterium content of D/C=0.8 atom ratio.

Mo erosion from DiMES is being modeled with the REDEP/WBC sputtering erosion/ redeposition code package, with plasma conditions supplied by the OEDGE code using Langmuir probe data input. REDEP simulations show a high Mo redeposition fraction (~50%) on the small Mo spot in good apparent agreement with the post-exposure RBS probe data, and essentially complete (~100%) redeposition on the divertor generally. Such high-Z sputtered material transport behavior has positive implications for the ITER tungsten divertor; tending to support predictions of very low net sputter erosion and core plasma contamination. This work was supported in part by the US Department of Energy under DE-FG02-07ER54917, DE-FC02-04ER54698, DE-AC04-94AL85000 and DE-AC52-07NA27344 and supported by Collaborative Research Opportunities Grant from the National Sciences and Engineering Research Council of Canada.

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