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Erosion Suppression of Carbon by Beryllium Plasma Impurities

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Tritium retention and accumulation in plasma confinement devices is an issue that could curtail the operating time of burning plasma experiments and can impact issues related to licensing and construction. In the proposed ITER device, the first wall plasma facing surface will be constructed using beryllium tiles. The divertor region will be constructed of tungsten, but with the high heat flux divertor strike points fabricated from carbon. Material eroded from the first wall is expected to be ionized in the scrape-off layer and flow into the divertor. Experiments have found that when deuterium plasma is seeded with 0.2% beryllium impurities, the erosion of carbon targets is reduced by 90% as a result of formation of beryllium rich layers on the surface of the targets. Developing an understanding of the interaction of this beryllium containing hydrogenic plasma with both tungsten and carbon surfaces is crucial to accurately predicting the tritium accumulation rate within the ITER vacuum vessel.

The PISCES-B linear plasma simulator has been equipped with a beryllium atom beam source, allowing seeding of the deuterium plasma column with controllable amounts of beryllium impurity ions [1]. The collimated Be atom beam is orthogonal to the plasma column such that Be atoms ionized by the plasma electrons are then entrained in the flow of plasma toward the target (much like the plasma scrape-off layer in a diverted tokamak). There is no Be atom flux incident on the target itself. In addition, a temperature controlled witness plate manipulator has been installed to allow collection of redeposited material in a region shielded from the primary plasma flux. The collected witness plate can then be analyzed ex-situ to determine its elemental composition and hydrogenic species content.

In ITER, the beryllium impurity concentration in the divertor plasma is expected to be in the 1-10% range. We find that even a very small beryllium impurity concentration (as low as 0.2%) is sufficient to dramatically reduce the graphite target chemical and physical erosion rates. Figure 1a shows the spectroscopic signature of chemical erosion (CD band emission) from a sample exposed at 200°C while Figure 1b shows the physical sputtering signature (CI line radiation) from a sample exposed at 700°C to deuterium plasma. Data is

presented for cases with and without beryllium seeding of the plasma. Weight loss measurements confirm the spectroscopic signature data and indicate a reduction of the total erosion from the graphite samples by more than an order of magnitude when the beryllium concentration in the plasma is as low as 0.2% [2].

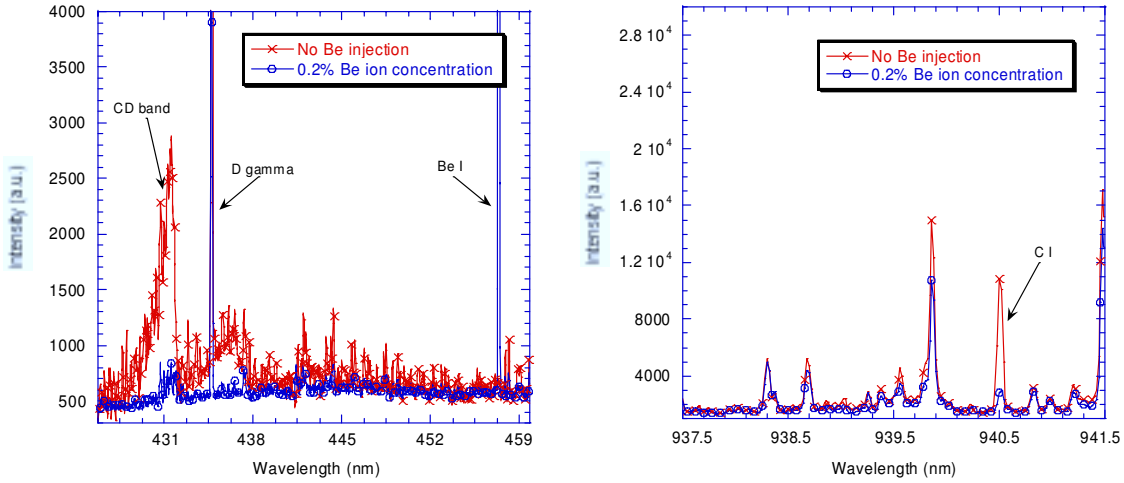

Figure 1 – Beryllium impurity seeding of the incident deuterium plasma reduces both a) chemical erosion and b) physical sputtering of graphite target plates.

The cause of the reduction becomes apparent during post-exposure surface analysis of the graphite targets. Auger Electron Spectroscopy (AES) of sample surfaces exposed to beryllium containing plasmas reveals essentially complete (>90%) coverage of the graphite sample by a thin beryllium layer so long as the Be seeding concentration exceeds 0.1%. Similar effects are observed during exposure of graphite samples up to 1000°C, although a slightly higher Be seeding rate (>0.3%) is needed to achieve high values of Be surface coverage. This is due to the larger rate of diffusion of Be into the bulk at the higher temperature, as well as an increase in the Be erosion rate at higher temperature [3]. Figure 2 shows the resultant elemental surface composition measured using AES of the targets as the beryllium impurity concentration in the incident plasma is varied. Each target is typically exposed for 5000-10000 seconds to ensure that the measured surface composition has achieved an equilibrium value.

The modification of the eroding surface also becomes apparent when inspecting the witness plate samples that collect material from the eroding sample during the plasma exposure. Figure 3 shows a depth profile of the elemental composition of a witness plate that

collected material during a 700°C exposure of a graphite sample to deuterium plasma containing approximately 0.2% Be impurities. The material collected on the Ta substrate consists almost entirely of Be, with only small amounts of residual oxygen and carbon contamination. The deposited surface again confirms the idea that the Be coatings that form on the exposed graphite surfaces acts to shield the underlying carbon from erosion. The Be coating and subsequent incident Be interact with the incident plasma, tending to sputter and deposit on surfaces with line-of-sight views of the target.

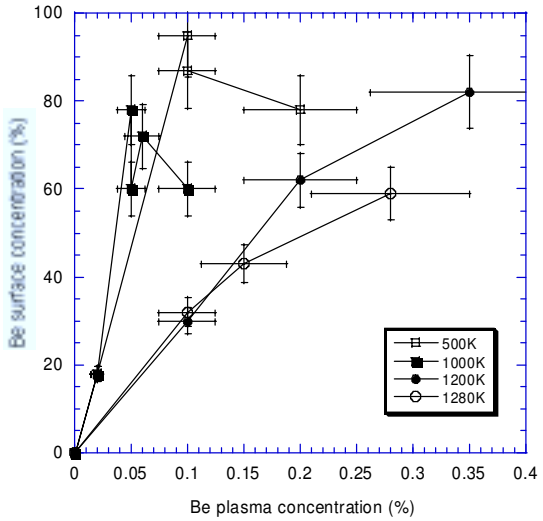

Figure 2 – Resulting equilibrium surface composition of graphite samples exposed to Be containing deuterium plasma.

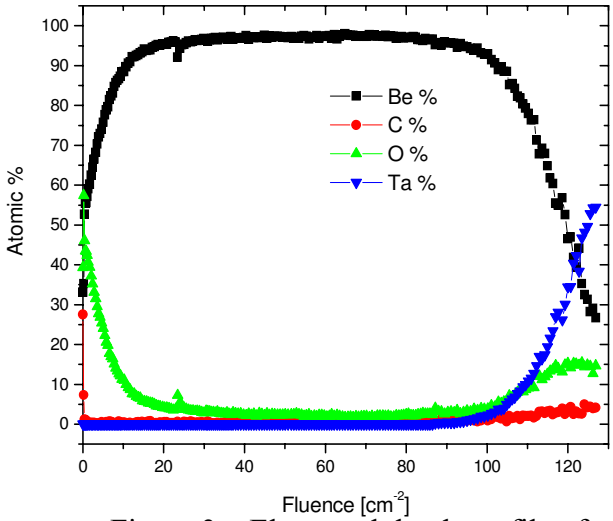

Figure 3 – Elemental depth profile of redeposited material collected during high-temperature exposure of a graphite sample to a beryllium containing deuterium plasma.

The lack of impurities in the collected eroded material may influence the amount of deuterium contained within the deposited layers. Two series of exposures were performed to measure the deuterium content of witness plate samples collected during exposure of graphite samples to Be seeded deuterium plasma at 300°C and 700°C. The temperature of the collecting witness plate surface was varied between room temperature and 300°C. The deuterium content of the samples was measured both by thermal desorption spectroscopy (TDS) and nuclear reaction analysis (NRA). The results from the two techniques were found to be in good agreement. The TDS results for the D/Be and O/Be ratios in the collected films [4] are shown in Figure 4. Also shown in the figure are comparisons to previous

measurements of the deuterium retained in 'clean' and 'dirty' redeposited Be surfaces [5, 6]. As seen previously, the D/Be ratio decreases quickly with increasing collection temperature. The present PISCES data systematically has the lowest D/Be concentration of all the measurements in the literature, even though the oxygen content of the films collected at higher temperature is larger than in previous measurements. It is clear from this data that the role of temperature dominates over the role of oxygen impurities in determining the deuterium content of deposited beryllium surfaces.

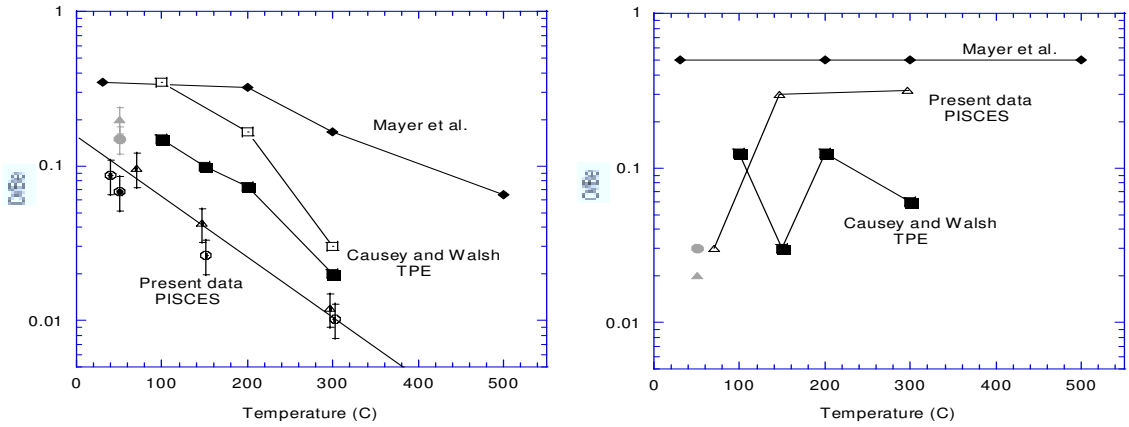

Figure 4 – D/Be and O/Be ratios for redeposited material collected on Ta (grey), Mo (dotted), and W (white) witness plate coupons as a function of collection temperature. Target temperatures are indictaed by triangular (300°C) and circles (600°C).

These experiments show that the first wall material will likely dominate the plasma-surface interactions in ITER. The implications of this result for ITER are twofold. The first is that triuitum accumulation within the ITER vessel will most likely be dominated by retention in Be rich redeposited layers. The second is that, since the sticking coefficient of beryllium on most materials is high, most redeposited material will occur in line of sight locations from the point of erosion. Both of these results should make the issues of accumulation and subsequent removal of tritium from the ITER vessel more tractable.

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