S-O5-2

PISCES Plasma-Beryllium Interactions Studies for ITER

Daisuke Nishijima[1], Russell P. Doerner[1], Matthew J. Baldwin[1], Timo Dittmar[1], Thomas Schwarz-Selinger[2] and Jonathan H. Yu[1]

[1]*Center for Energy Research, University of California at San Diego*
9500 Gilman Dr., La Jolla, CA 92093-0417, USA
[2]*Max-Planck-Institut für Plasmaphysik, Boltzmannstr. 2, D-85748, Garching, Germany*

Recent studies on plasma interactions with beryllium surfaces in the PISCES-B linear divertor plasma simulator for the support of ITER are briefly reviewed. The sputtering yield of Be by D has been measured, and surface morphology evolution is found to result in a reduction in the yield by a factor of ~2. Chemical sputtering of Be due to D plasma bombardment has been identified from the detection of BeD molecular band emission. Mixed materials of Be with C and W have been investigated to clarify (1) the formation conditions of beryllium carbide and tungsten beryllide layers, and (2) the behavior of mixed-material layers exposed to plasmas. Nitrogen effects on Be surfaces and D release from Be codeposits by laser flash heating have been also explored.

1. Introduction

In ITER, plasma-facing materials will be a mixture of beryllium (Be) on the first wall with the largest area, and tungsten (W) and carbon (C) on the divertor subjected to higher heat fluxes [1]. Edge plasmas will interact with Be surfaces, and eroded Be will migrate into divertor regions, where material mixing with W and C can occur and alter original material properties. Thus, for successful operations of ITER, it is critical to understand/control plasma interactions with Be. However, the database for plasma-Be interactions is limited, since Be is hazardous and the handling is accompanied by difficulties.

The linear divertor plasma simulator PISCES-B [2] is capable of safely handling Be and is suitable to simulate edge/divertor plasma interactions with Be surfaces. We will present recent Be-related work performed in PISCES-B.

2. PISCES-B

The PISCES-B device is contained in a safety enclosure with a negative pressure to prevent Be dusts from releasing into the general laboratory area. Steady state high flux plasmas (ion flux Γ_i ~10^{21}-10^{23} $m^{-2}s^{-1}$) are produced in the reflex-arc plasma source region with a negatively biased LaB_6 cathode and a grounded stainless steel anode. In the target region, the plasma is diagnosed with a reciprocating double probe system, uv-visible spectrometers, and a residual gas analyzer (RGA). The incident ion energy, E_i, to the sample surface is controlled with negative biasing with respect to the plasma potential. The sample temperature, T_s, during plasma exposure is measured with a thermocouple attached to the back side of the sample as well as a pyrometer and an IR spectrometer looking at the plasma-exposed surface. A plasma-exposed sample is analyzed in an in-situ AES (Auger electron spectroscopy)/XPS (X-ray photoelectron spectroscopy) system. A thermal desorption spectroscopy (TDS) system to investigate D retention properties of Be-contaminated materials is also located inside the enclosure.

A high-temperature effusion cell is used to seed Be impurities into the plasma column. Be atoms can be ionized, and then be transported to the target due to background plasma parallel flows. In this way, Be-involved material mixing, which is expected to occur in ITER, have been studied.

3. Sputtering Yield

The sputtering yield of Be by D determined from mass loss measurements in PISCES-B [3,4] is ~5-10 times lower than the TRIM.SP calculation [5]. The surface Be concentration was measured from AES to be > 90% just after D plasma exposure. In addition, spectroscopic measurements showed that the O I line emission intensity in front of a Be surface first increased and then disappeared early during the exposure, indicating that native BeO layer was removed. Thus, the lower sputtering yield cannot be due to the formation of a BeO layer.

It is found that the sputtering yield decreases by a factor of ~2 with an increase in the incident ion fluence, which is consistent with the time evolution of the Be I line emission intensity in front of the target. SEM observations reveal that surface morphology significantly changes to needle-like shapes. A similar morphology change and sputtering yield reduction have been reported from an ion beam experiment at a higher incident energy of 1 keV (H_2^+) [6]. Further, simulations show a reduction of the sputtering yield by a factor of ~2-3 due to an accumulation of implanted D in the near surface [7]. Therefore, the discrepancy in the sputtering yield between our experiments and

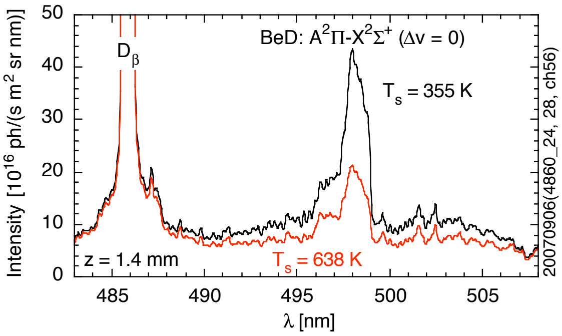

Fig. 1. $A^2\Pi$ - $X^2\Sigma^+$ (Δv = 0) band emission spectra of BeD molecules sputtered from a Be target due to D plasma exposure at T_s ~ 355 and 638 K [4]. The plasma parameters (n_e ~ 2.6x10^{18} m^{-3}, T_e ~ 8 eV, and E_i ~ 34 eV) are identical in the two cases.

TRIM simulation can be explained by morphology evolution and accumulated D.

4. Chemical Sputtering

It was experimentally found that Be surfaces were chemically sputtered as BeD by D plasma bombardment [8], which was then reproduced by molecular dynamics simulations [9]. As shown in Fig. 1, the $A^2\Pi$ - $X^2\Sigma^+$ (Δv = 0 sequence) band emission of BeD molecules is clearly observed in front of the Be target. The behavior of Be chemical sputtering was found to have similarities with C chemical sputtering. For instance, the chemical sputtering yield of both Be and C peaks at a certain surface temperature: for Be at ~440 K, being consistent with the onset temperature of the decomposition of BeD_2 [8], and for C at ~600-900 K [10]. Also, the chemical sputtering yield of both Be and C decreases with increasing Γ_i.

5. Mixed Materials

Be impurities in plasmas can mitigate both chemical and physical sputtering of C [11]. XPS reveals the formation of beryllium carbide (Be_2C) layer on the surface, as shown in Fig. 2 [12]. The characteristic time for sputtering mitigation depends on T_s, E_i, Γ_i, and Be^+ concentration in the plasma [13].

The formation of Be-W alloy can be a concern for ITER, since the melting temperature of tungsten beryllide is lower than that of pure W. PISCES-B experiments at T_s > 1000 K, simulating strike point regions, showed evidence of the formation of a Be-W alloy surface layer [14]. It should be, however, noted that the Be-W alloy formation is limited by Be availability on the surface.

6. Summary

In PISCES-B, plasma-beryllium interactions have been extensively studied. In addition to the

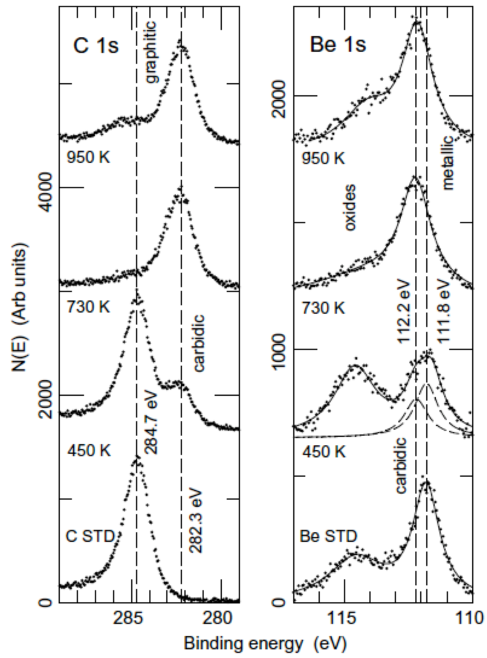

Fig. 2. C 1s and Be 1s XPS spectra taken on graphite targets exposed at 450, 730, and 950 K to Be-seeded D plasma [12].

topics mentioned above, other work, including nitrogen effects and flash heating of Be codeposits, will be also presented.

Acknowledgments

The authors are grateful to PISCES technical staff for their professional skill and dedication. This work is conducted under the US Department of Energy contract No. DE-FG02-07ER54912.

References

[1] A. Loarte et al.: Nucl. Fusion. **47** (2007) S203.

[2] R.P. Doerner et al.: Phys. Scr. **T111** (2004) 75.

[3] R.P. Doerner et al.: J. Nucl. Mater. **257** (1998) 51.

[4] D. Nishijima et al.: J. Nucl. Mater. **390-391** (2009) 132.

[5] W. Eckstein: IPP-Report 9/132, Garching, (2002).

[6] D.M. Mattox and D.J. Sharp: J. Nucl. Mater. **80** (1979) 115.

[7] C. Björkas: private communication (2011).

[8] D. Nishijima et al.: Plasma Phys. Control. Fusion **50** (2008) 125007.

[9] C. Björkas et al.: New J. Phys. **11** (2009) 123017.

[10] W. Jacob and J. Roth: Sputtering by Particle Bombardment (Springer, Berlin, 2007) p.329.

[11] M.J. Baldwin and R.P. Doerner: Nucl. Fusion **46** (2006) 444.

[12] M.J. Baldwin et al.: J. Nucl. Mater. **358** (2006) 96.

[13] D. Nishijima et al.: J. Nucl. Mater. **363-365** (2007) 1261.

[14] M.J. Baldwin et al.: J. Nucl. Mater. **390-391** (2009) 886.