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Angular distribution of eroded beryllium atoms from a beryllium target exposed to a deuterium plasma in PISCES-B

D. Nishijima[1], R.P. Doerner[1], M.J. Baldwin[1], R. Seraydarian[1], G.R. Tynan[1],
J.N. Brooks[2], J.P. Allain[2], M. Nieto[2]

[1] *University of California at San Diego, La Jolla, CA 92093-0417, USA*

[2] *Argonne National Laboratory, 9700 South Cass Avenue, Argonne, IL 60439, USA*

1. Introduction

The current design of ITER has beryllium (Be) as the first wall material [1]. Therefore, understanding the characteristics of Be as both a material and an impurity in plasmas is important for the successful operation of ITER. For instance, the angular distribution of eroded Be atoms from the first wall determines the penetration length of Be atoms into a plasma and affects the Be concentration in both the core and divertor plasmas. In this paper, the angular distribution of Be atoms eroded and transported from a Be target exposed to a deuterium plasma with a low incident ion energy, up to 140 eV, is investigated.

2. Experimental setup and derivation of Be atom density

The experiment was performed in the linear divertor simulator PISCES-B [2]. A schematic of the target region of PISCES-B is shown in figure 1. A Be target with a diameter of 21 mm was exposed to a steady-state deuterium plasma with electron density, $n_e \sim 1-3\times10^{18}$ m^{-3}, electron temperature, $T_e \sim 8$ eV and ion flux, $\Gamma_i \sim 1.5-3\times10^{22}$ m^{-2}s^{-1}. Radial profiles of these plasma parameters, measured with a scanning double probe system at an axial distance of $z = 152$ mm from the target, are nearly flat within the plasma diameter of around 50 mm. The incident angle of plasma ions is normal to the target. The incident ion energy E_i is controlled by biasing the target.

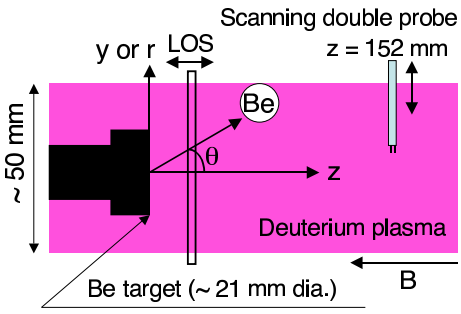

Figure 1: Schematic view of the target region in the linear divertor simulator PISCES-B.

The two-dimentional profile of eroded and transported Be atom density was determined spectroscopically. The light from the plasma is guided with a mirror and focused with a lens to the entrance slit of a 0.5 m Czerny-Turner type spectrometer equipped with a two-dimensional CCD

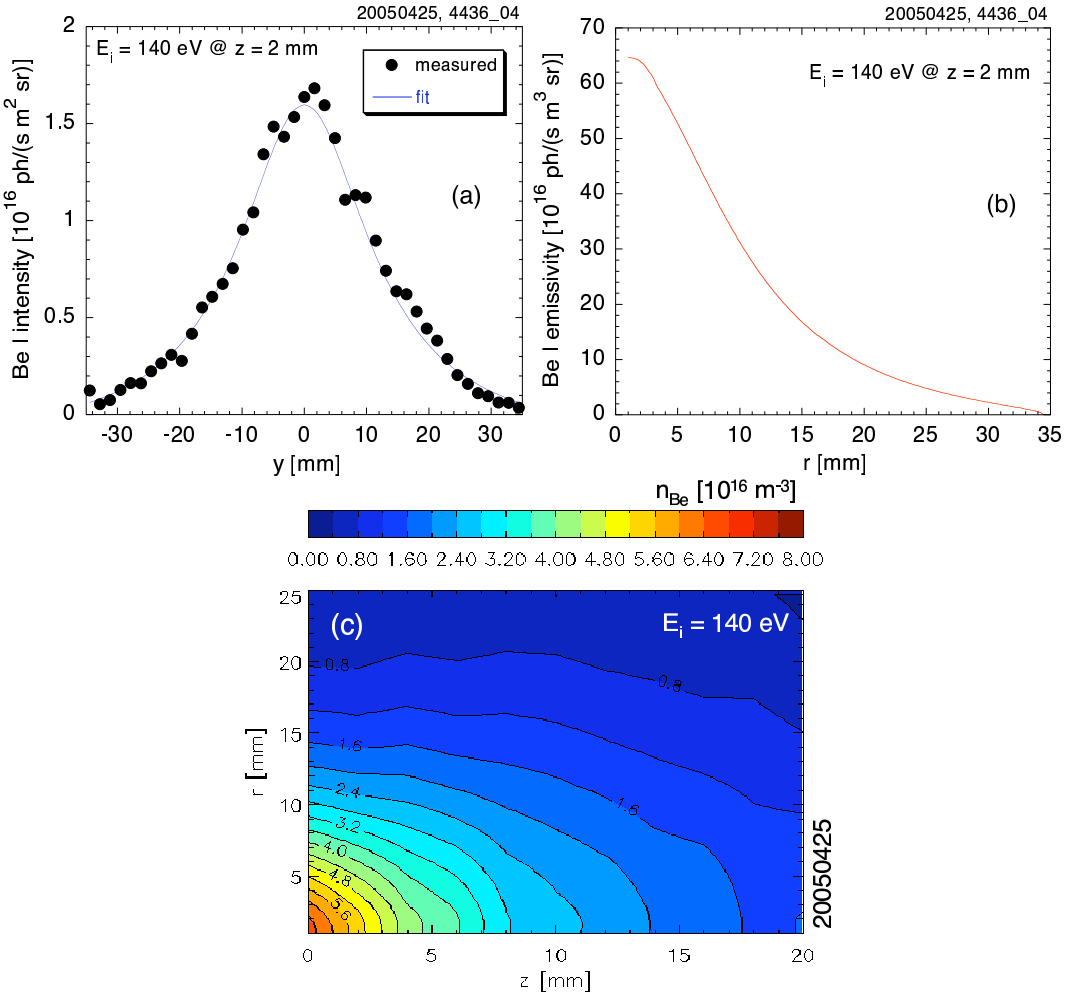

Figure 2: (a) Vertical profiles of the measured Be I line (457.3 nm) intensity and the fit taken at $z = 2$ mm. (b) Radial profile of the Be I (457.3 nm) local emissivity derived from (a) with Abel inversion. (c) Two-dimensional profile of the Be atom density in the plasma. $E_{\mathrm{i}} = 140$ eV.

camera. The whole optical system is absolutely calibrated with an integrating sphere. The spatial resolution in the axial (z) and vertical (y) directions is approximately 1.0 mm and 1.6 mm, respectively. Vertical profiles of Be I line (2s2p ^{1}P-2s3d ^{1}D: 457.3 nm) intensity from eroded Be atoms were recorded every 2 mm in the z direction. An example of the vertical profile of Be I line intensity is shown in figure 2 (a), where $E_{\mathrm{i}} = 140$ eV and $z = 2$ mm. From the vertical profile of the line-integrated intensity, I_{Be}, the radial profile of the local emissivity, $\varepsilon_{\mathrm{Be}}$, can be obtained by applying the Abel inversion:

$$\varepsilon_{\mathrm{Be}}(r) = -\frac{1}{\pi}\int_r^a \frac{dI_{\mathrm{Be}}(y)}{dy}\frac{dy}{\sqrt{y^2 - r^2}}. \qquad (1)$$

Figure 2 (b) is the radial profile of the local emissivity derived from the vertical profile of the line-integrated intensity in figure 2 (a). Finally, the local ground state Be atom density, n_{Be}, can

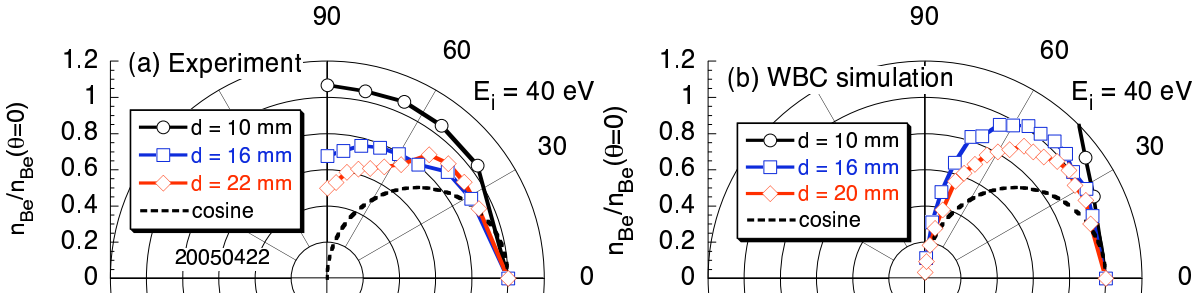

Figure 3: Angular distribution of eroded Be atoms in (a) experiment and (b) WBC simulation. The incident ion energy is 40 eV. d is the distance from the center of the target. The dashed curve shows the cosine distribution for a central point source of Be.

be obtained with the following formula:

$$n_{\mathrm{Be}} = \gamma_{\mathrm{loss}} \frac{4\pi\varepsilon_{\mathrm{Be}}}{\langle\sigma v\rangle_{457.3\mathrm{nm}} n_{\mathrm{e}}} [\mathrm{m}^{-3}], \tag{2}$$

where $\langle\sigma v\rangle_{457.3\mathrm{nm}}$ is the photon emission coefficient [ph m^3/s] of the Be I line at 457. 3 nm taken from the ADAS data base [3]. The geometrical loss factor γ_{loss} should be introduced since some fraction of eroded Be atoms can escape from the plasma before they are excited to the upper state of the transition and emit photons at 457. 3 nm. In the present experiment, γ_{loss} is around 20, which is derived from the mean free path of the emission $\lambda_{457.3\mathrm{nm}} \sim 500$ mm and the characteristic length of the plasma $l_{\mathrm{pl}} \sim 25$ mm. Figure 2 (c) shows a two-dimensional profile of the Be atom density near the Be target.

3. Angular distribution of eroded Be atoms

Figure 3 (a) shows the angular distributions of eroded Be atoms with $E_{\mathrm{i}} = 40$ eV at distances, d, of 10, 16 and 22 mm from the center of the target. The Be atom density is normalized to that at $\theta = 0$ degree. The angle $\theta = 0$ degree means normal to the target. As d increases, the measured distribution becomes closer to the cosine distribution for a central point source of Be. This can be intuitively understood because the target with the finite size approaches a point source with increasing d. However, we can not directly compare the measured and point source cosine distributions at $d \sim 20$ mm, since it is still close to the target size (21 mm in the diameter). The angular distribution from the WBC Monte Carlo code simulation [4] is shown in figure 3 (b), where the cosine distribution is employed. The angular distribution from the WBC code can be used as a reference of the cosine distribution of the target with the finite size. From a comparison between the experimental angular distribution and that from the WBC code, it is found that n_{Be} does not become small at large angle, $\theta > 60$ degree, in the experiment. This indicates a deviation from the cosine angular distribution.

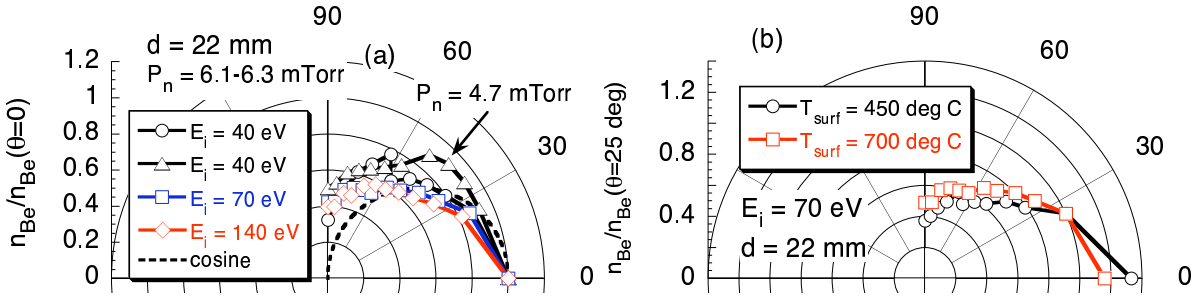

Figure 4: (a) Incident ion energy ($E_\mathrm{i} = 40 - 140$ eV) dependence of angular distribution of eroded Be atoms exposed to a deuterium plasma. (b) Surface temperature dependence of angular distribution. The incident ion energy is 70 eV.

The incident ion energy, E_i, to the target was scanned from 40 to 140 eV to investigate the incident ion energy dependence of the sputtered particle angular distribution. Figure 4 (a) shows the angular distributions as a function of E_i. The angular distribution is found to be insensitive to the incident ion energy between 40 and 140 eV. However, at lower neutral pressure of 4.7 mTorr, the angular distribution slightly deviates from others at $\theta \sim$ 30-60 deg. The effect of neutral pressure will be investigated in more detail in the future.

Figure 4 (b) shows the dependence of the angular distribution on the Be surface temperature. The Be atom density is normalized to that at $\theta = 25$ degree. At the lower surface temperature, the angular distribution seems to be more peaked. Experiments at both lower surface temperature, down to 50 °C, and higher surface temperature are planned.

4. Summary

The angular distribution of eroded Be atoms from a Be target exposed to a steady-state deuterium plasma with the low incident ion energy, from 40 to 140 eV, has been investigated with spectroscopic methods in the PISCES-B device. It is found, from a comparison between the experiment and the WBC Mote Carlo code, that the angular distribution deviates from the cosine distribution at large angle $\theta > 60$ degree. The angular distribution does not depend on the incident ion energy, and weakly depends on the Be surface temperature.

References

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