An updated modelling of Be and BeD spectroscopy at JET ILW, W spectroscopy at PSI-2 and ADAS-relevant data

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Spectroscopy at inner-wall Be limiter

1. JET-ILW Be/W ITER-like Wall completed - 8th May 2011

- Graph showing sputtering yield (atoms/ion) vs. ion energy (eV)
  - Data points for IPP (RT), IPP (600-650°C), PISCES in situ Be (37±5°C), PISCES poly-c Be (27-477°C)
  - Lines indicating Eckstein 2007, ERO Max, ERO Min

- Image of JET tokamak with tiles 6-8 in octant 7X highlighted

- Toroidal direction indicated: ~23cm
ERO code – gyromotion and PFC shape

ERO is the PSI and 3D local impurity transport code (MC)
Incl. sheath E-field

ERO simulates:
1) Erosion, deposition, surface content (2D)
2) 3D spectroscopy

“Universal geometry” (S. Bozhenkov, D. Matveev)
Massive parallelization is necessary – ERO2.0

Relevant for ITER blanket modules and other large and shaped PFCs
Be limiter surface shadowing

PFCFLUX simulations
by M.Firdaouss
Local Be transport and light emission

Bel, physically eroded Be

Emiss. int. [Ph/(sr*s*cm²)] of Bel 457nm.

Bell, physically eroded Be

Emiss. int. [Ph/(sr*s*cm²)] of Bell 527nm

BeD band, chemically eroded Be (BeD)

Emiss. int. [Ph/(sr*s*cm²)] of BeD

Bell, chemically eroded Be (BeD)

Emiss. int. [Ph/(sr*s*cm²)] of Bell 527nm

Bell intensity and fraction coming to the observation chord depends on the erosion mechanism
Plasma parameters fitting

+ Ne scaled so that \( Ne^*Te = \text{const} \)

\( D\gamma /D\beta \) ratio, embedded probes indicate that \( T_e \) is overestimated . . .
Embedded probe measurements

\[ T_e \text{ (separatrix)} \approx 15 \text{eV} \]

#82826, 52s

\[
\begin{align*}
L22: & \quad \rho=1.013 \quad T_e=16.82\text{eV} \quad N_e=7.30\times10^{18}\text{m}^{-3} \\
L26: & \quad \rho=1.004 \quad T_e=4.57\text{eV} \quad N_e=1.66\times10^{18}\text{m}^{-3} \\
L27: & \quad \rho=1.003 \quad T_e=14.05\text{eV} \quad N_e=5.51\times10^{18}\text{m}^{-3} \\
L28: & \quad \rho=1.007 \quad T_e=4.06\text{eV} \quad N_e=1.41\times10^{18}\text{m}^{-3} \\
L30: & \quad \rho=1.021 \quad T_e=3.14\text{eV} \quad N_e=1.75\times10^{17}\text{m}^{-3}
\end{align*}
\]
D spectroscopy and recycling flux

Parameters at Be limiter surface (inside the observation 'spot')

- $\text{Exp, } D_\gamma^{1/2}$
- $\text{Exp, } D_\beta^{1/2}$
- $\text{ERO, } \frac{D_{-}\text{-flux}}{S/XB(D_\gamma)}/4\pi^{*1.5}$
- $\text{ERO, } \frac{D_{-}\text{-flux}}{S/XB(D_\beta)}/4\pi^{*1.5}$

Map 1 (81261)
Map 2 (80836)
Map 3 (80835)
Map 4 (81015)
**T\textsubscript{surf} scan: spectroscopic observations:**

Spectroscopic observation under otherwise constant plasma conditions:
- Reduction of BeI, BeII and BeD photon flux with increase of surface temperature
- Increase of D\textsubscript{2} photon flux with increase of surface temperature
- D\textsubscript{γ} - reflecting recycling flux – remains constant

- Comparison of BeD A-X band, BeI and BeII provides information on dissociation path
- Dominant path BeD + e -> Be + D + e (75%) over BeD + e -> BeD\textsuperscript{+} + 2e (25%)
BeD release – $T_{\text{surf}}$ scan

Evident in the JET ILW surface density scan, the $I$ ($10^{13}$ Ph/(s*sr*cm$^2$)) decreases with increasing $T_{\text{surf}}$ [°C].

**BeD/Be released**

Clear drop at $E=75\text{eV}=2T_i+3kT_e$

**ERF simulations ongoing**

**A. Lasa et al**, recent cumulative simulations (normal incidence, 1500 impacts . . .)
Treating angular part in sputtering yield

\[ Y(E_{in}, \alpha_{in}) = Y(E_{in}, 0) \cdot A(E_{in}, \alpha_{in}) \]

**Preliminary ERO runs . . .**

“Integration” produces effective sputter yields:

Very recent: analytic solution by I. Borodkina (MEPhI, RF)

**ERO pre-calculation**

B=4.8T

\[ \alpha (\text{angle of incidence}) \]

\[ \eta (\text{“B-angle”}) \]

Injection of D\(^+\) or Be\(^+\) with Maxwell energy around \( T_i \) and uniform initial angle distribution

\[ T_e = 20\text{eV} \]
Numeric simulation of the distributions on impact

Series of ERO “Pre-simulations”
To get distributions of energies and angles on impact as a factor of surface angle to B-field and plasma $T_e$...

$$\{E_{imp}, \alpha_{imp}\}$$

(normal to surface $n$

B=4.1T
(like at Be limiter surface)
Analytical approach

1) Sheath potential approximation

The expression benchmarked with another analytics and simulations

2) Formula for velocity at the part of trajectory just before the impact

- Energy distribution on impact quite similar to the numeric one.
- Angular distribution in ERO pre-runs seems to be too peaked:

- Analytic result is in a good agreement with various of PIC simulations give

I. Borodkina et al., PET-2015, submitted to CPP
S/XB approach – ERO and experiment

Corrections:

+10% for ‘ERO-min’

+30% for ‘ERO-max’
It was shown that the variation of the Be line intensities up to factor 3 due to the ICRH antenna can be explained by an additional biasing.

Reading of Edge2D data for the plasma BG was provided with proper interpolation and extrapolation to far SOL.

Ch. Klepper et. al., PFMC-2015, accepted to Phys. Scripta.
Eroded W spectroscopy at PSI-2

Series of experiments on W sputtering:
- Plasma: Ar
- Target: W
- Target bias voltages: $U_b = 50 – 150$ V
- Target: $100 \times 80$ mm, a line of mass loss samples

Measurements:
- Line intensity profiles (4009 A):
  1. Along z (device axis)
  2. Perpendicularly to z (installation) axis at several z-positions
2D patterns based on multiple profiles taken

\[ I_{\text{max, ERO}} \approx 4.5 \times 10^{15} \text{ ph/(m}^2\text{s)} \]
\[ I_{\text{max, experiment}} \approx 2.4 \times 10^{15} \text{ ph/(m}^2\text{s)} \]

2 more independent measurements:
1) weight loss (with space resolution) and 2) QMB as a witness plate.
Experimental and ERO simulated dependence of neutral W radiation intensity on the distance from the target surface. ERO simulation doesn’t give us maximum from the experiment.

Assumed parameters:
- Angular distribution – from ERO
- $V_{10} = V_{10} \approx 1 \times 10^4$ s$^{-1}$ (electron impact (de)excitation coefficient)
- PEC $\approx 2 \times 10^5$ s$^{-1}$
- $S_{\text{ion}} \approx 3 \times 10^4$ s$^{-1}$ (electron impact ionization coefficient)
ADAS data needed for PSI studies

**W – JET divertor**
PEC and ionization for WI and WII. UV spectroscopy for WIII is also expected. For many experimental applications S/XB can suffice as a first approach.

**W – PSI-2 experiments.**
Basic needs are same as for JET. However, the simple geometry and continues operation allow us to go into more detail. We can observe MS effects and need resolved adf11 (‘scd’, ‘acd’, ‘qcd’) data. Some effort from FZJ side is considerable.

**Be – JET ILW, PISCES**
we find it quite good covered for now by the ‘96’ package. Only checking and additional questions are to consider. E.g.: do we need to track MS in Bell?

**Ar, N and Ne – important as seeding impurities.**
Ar is used to increase sputter efficiency in PSI-2, experiments with N and Ne are under discussion. We need ionization data and PECs for neutrals and +1 and +2 ions. Purpose: BG plasma, impurity concentration control etc.

**Al and Mg as a proxy for Be**
Some experiments are already done for Al. Mg is complicated because of the vapor pressure. We need any data for Al. MS resolved data for Mg can motivate related experiments.
Thanks for the attention!
1) Same density scan as for Be sputtering – surface temperature $T_{surf}$ varying with “memory effect”. IR camera data not yet interpreted.

2) $T_{surf}$ variation (S.Brezinsek) at constant plasma $T_e=15\text{ev}, \text{LAD3}=2.2e19\text{m}^{-3}$