Energy and atomic level distribution of sputtered tungsten determined by high-resolution optical spectroscopy

S. Ertmer, O. Marchuk, S. Dickheuer, S. Brezinsek, Ph. Mertens, M. Rasinski, and A. Kreter

Forschungszentrum Jülich GmbH - Institut für Energie- und Klimaforschung - Plasmaphysik, Partner of the Trilateral Euregio Cluster (TEC), 52425 Jülich, Germany

Tungsten (W) is proposed as plasma-facing material (PFM) in the divertor and main chamber of future fusion devices. The net erosion of W mainly caused by impinging impurities and fast charge exchange neutrals determines largely the lifetime of PFM. Passive optical spectroscopy is a powerful and reliable diagnostic tool to monitor the W gross erosion, which is converted into W net erosion either via combined spectroscopy on W and W^+ or modelling considering prompt re-deposition processes [1]. The initial energy level population distribution of the released W atoms remains one of the uncertainties related to the physical sputtering of W. A second critical issue is the discrepancy between the modelled and experimentally observed energy and angular distribution of sputtered W [2,3]. This work addressed both topics using passive spectroscopy with high spatial and spectral resolution in the linear plasma device PSI-2 operated in low electron temperature (T_e) argon (Ar) plasmas with low ionisation degree, and thus minimised impact of ionisation processes.

For measurements of the population distribution of sputtered W atoms within the ground state ($^5D_0$) and the first excited levels, e.g. the quintet ^5D_J (J=1,..4) and the metastable level $^7S_3$, a mirror-finished W target was exposed to an Ar plasma ($T_e \approx 2$ eV; electron density $n_e \approx 1 \cdot 10^{18}$ m^{-3}). The ions were accelerated to mono-energetic kinetic energies E_i of 100 to 200 eV applying biasing to the target. The intensities of neutral tungsten lines (WI) emitting in front of the W target were recorded by a Czerny-Turner imaging spectrometer (resolving power $\lambda/\Delta\lambda \approx 3 \cdot 10^4$) with a high spatial resolution of 50 µm/px in axial direction of the plasma [4]. The spatial evolution of WI line emission in front of the target was compared versus the lifetime of WI levels populated by electron impact excitation. Under the experimental plasma conditions and with a target at room temperature, W is sputtered from the W target predominantly in the ground state $^5D_0$, whereas the other levels $^5D_{J>0}$ and $^7S_3$ get populated deeper in the linear plasma by multi-step processes.

The energy distribution function of sputtered W atoms is obtained from the Doppler shift of the WI line ($^5D_0$-$^7F_1$) detected perpendicularly to the target surface by a high resolution Echelle spectrometer ($\lambda/\Delta\lambda \approx 7 \cdot 10^5$). The model of the Doppler-shifted emission at the surface used in [5] was extended in order to take into account the Zeeman splitting in the PSI-2 plasma operating at about 0.1T and instrumental broadening of spectral lines. The data for W is in a very good agreement with the Thompson energy distribution function featuring a rise in the high energy tail with increasing impact energy of the incident Ar^+ ions. Moreover, this method determines *in-situ* the target's optical reflectance, which impacts the measured net emission. For the first time high spectral resolution spectroscopy of sputtered atoms combined with polarisation measurements close to the pseudo-Brewster angels is proven to be suitable for surface morphology studies such as recrystallisation independently of other diagnostics.

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