On the line shape of sputtered atoms in low-temperature magnetized plasmas

Marc Sackers, Oleksandr Marchuk, Sebastijan Brezinsek*, Arkadi Kreter

Forschungszentrum Jülich GmbH, Institute of Fusion Energy & Nuclear Waste Management - Plasma Physics
(*) HHU Düsseldorf, Faculty of Mathematics and Natural Sciences

The erosion of plasma-facing components in magnetically confined fusion limits the operating scenarios of the reactors. In particular, high-Z elements, such as the first wall and divertor material of tungsten in ITER, create excessive radiative cooling of the plasma. Therefore, it is essential to measure and simulate the tungsten influx. The latter depends to a great extent on our knowledge of the plasma-wall interaction (PWI).

In this case, some uncertainty lies in the near-threshold regime of physical sputtering by the seeding gas impurities and diagnostic gases, e.g. that is the sputtering yield of tungsten and the distribution function of tungsten atoms which define the boundary condition for kinetic plasma models. Linear plasma devices, such as PSI-2, cover this regime and enable erosion studies under well-definable conditions. The approach for evaluating the PWI in this contribution is to analyze the line shape of optical transitions by sputtered atoms.

More precisely, the physics of interest, which is the velocity and angular distribution function (VDF, ADF), is contained within the Doppler broadening of the tungsten spectral lines. The accurate interpretation of these line-of-sight integrated signals requires accounting for the geometry of the source and plasma. The other relevant line shape perturbing mechanisms (light reflection, hyperfine structure splitting or the Zeeman effect) are presented as well. Particularly interesting is that the external magnetic field at PSI-2 of 90 mT creates conditions, where the perturbing Hamiltonian with hyperfine and Zeeman terms must be evaluated.

Resolving the details of the hyperfine-Zeeman mixing ($\sim$ 2 GHz) is impossible using the emission spectra of tungsten measured at PSI-2 due to the similar size of the instrumental broadening ($\sim$ 3 GHz) and (unknown) Doppler broadening ($\sim$ 4 GHz). Benchmarking experiments using laser absorption from xenon effectively circumvents these issues: the instrumental broadening is negligible and the Doppler broadening is well-known (Maxwellian, 0.8 GHz).

This contribution presents new experimental data on the near-threshold erosion of tungsten by argon ions obtained at the linear plasma device PSI-2. The data illustrates the difference in line shape due the surface structure – e.g. the crystall orientation exposed to plasma, strongly reformed surfaces. The modeling reveals reasonable agreement with the angular distribution estimated using molecular dynamics simulations. As a result, line shape emission spectroscopy is suitable for operando measurements monitoring the surface structure of plasma-facing components during plasma operation.