Sputtering of EUROFER: The Role of Roughness

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The lifetime of a plasma-facing component is determined by sputtering due to the bombardment with energetic particles. At the first wall, the impinging particle flux is dominated by charge-exchange neutral hydrogen isotopes with energies below about 200 eV, but comprising also small fractions of high-energy species with energies up to several keV. RAFM steels contain small amounts of tungsten. Upon exposure to energetic hydrogen ions from the plasma, a W-enriched layer will be formed at the surface due to preferential sputtering. Such a W-enriched layer could lower the erosion rate to acceptable levels. We report on simulations and experiments aiming at quantifying the achievable reduction of erosion rates. In particular, we want to study the influence of surface roughening on sputtering.

The erosion of EUROFER steel by mono-energetic D ions was investigated in the IPP high current ion source SIESTA [1]. For EUROFER-97 a reduction of the sputter yield after high fluence bombardment with 200 eV D ions was found [2]. For higher ion energies the reduction is smaller. The existence of a W-enriched surface layer after D ion bombardment was proven by different ion beam analysis techniques. However, simulations with SDTrimSP (formerly known as TRIDYN) fail to reproduce the experimental observations quantitatively [2]. Surface morphology modifications found after ion exposures hint at a possible influence of surface roughening on the experimentally observed reduction in sputtering yields.

To allow for a modelling of surface roughness effects, the originally 1-dimensonal code SDTrimSP was extended into a 3-D version (SDTrimSP-3D) [3]. This new code was benchmarked in dedicated experiments in SIESTA [4] by comparing the sputtering-fluence-dependent changes of the surface morphology of specially prepared 3-D-structured samples with code predictions. The overall agreement between model and experimental results is excellent [4].

The sputtering of EUROFER with D at 200 eV was investigated up to a fluence of 1×10^{24} D m^{-2} at sample temperature of 320 K. The measured sputtering yields are in good agreement with published data [2].SEM imaging after exposure showed a strong, grain-dependent sputtering. Some grains exhibit an extremely structured surface with a relatively regular array of cone-like pillars, while other still look perfectly flat. The rough grains had experienced much more sputtering that the flat grains. In addition, the anticipated enrichment of tungsten was verified by XPS sputter depth profiling. For this series of experiments, a fluence- dependent decrease of the sputter yield by a factor between 3 and 4 was observed. A rough assessment of the contributions of tungsten enrichment and surface morphology development led us to the conclusion, that for the here applied experimental parameters, both effects contributed about equally to the observed decrease.

[1] R. Arredondo et al., “SIESTA: A high current ion source for erosion and retention studies”, Rev.

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[2] K. Sugiyama et al., "Erosion of EUROFER steel by mass-selected deuterium ion bombardment", Nucl. Mater. Energy **16** 114–122 (2018)
[3] Udo von Toussaint et al., unpublished
[4] R. Arredondo et al., unpublished