Cold spray deposition of refractory metals for fusion plasma-facing components

M. Ialovega[1], M. X. Navarro-Gonzalez[1], T. Dabney[1], E. Willing[1], H. Yeom[2], A. Kreter[3], R. Bisson[4], T. Angot[4], C. Forest[5], J. Anderson[5], K. Sridharan[1] and O. Schmitz[1]
[1] Department of Engineering Physics, University of Wisconsin-Madison
[2] Division of Advanced Nuclear Engineering, Pohang University of Science and Technology
[3] Institute of Fusion Energy and Nuclear Waste Management (IFN), Forschungszentrum Julich GmbH
[4] Physics of the Interactions of Ions and Molecules, Aix Marseille University
[5] Department of Physics, University of Wisconsin-Madison
e-mail (speaker): ialovega@wisc.edu

New absorbing tantalum (Ta) coatings were developed using cold spray technology for advanced plasma-facing components (PFCs) for the Wisconsin HTS Axisymmetric Mirror (WHAM). WHAM is an experiment located at the University of Wisconsin, Madison that aims to demonstrate stability and confinement of hot, high-density plasma in a compact, high-field (17 T) simple magnetic mirror [1]. The absorbing first wall interface is intended to improve the performance of WHAM by the suppression of the number of charge exchange events in the plasma edge. Millimeter-thick Ta coatings were deposited on 316L stainless-steel coupons using commercially available cold spray (CS) technology (Figure 1 a). CS is a powerful technique which has been recently investigated by our group as an alternative method for high-Z materials deposition on the surfaces of PFCs. In the CS process, the velocity V_p and temperature T_p of the impacting powder particles have the most dominant effect of the coating microstructure properties, and adhesion. Computational fluid dynamics was used to simulate the flow behavior of the gas mixture and particle through the nozzle by considering parameters such as the mass, density, and cross-sectional area of the particle and the drag coefficient for a sphere, and the convective heat transfer between the carrier gas and the particle. For the set of CS parameters used in our research, these parameters were determined to be: V_p=673 m/s, T_p=590 K. Scanning electron microscopy cross-sectional examination revealed the coating to be dense but with fine-scale porosity, and a good adhesion to the substrate (Figure 1 b). The performance of the coatings in conditions relevant to fusion was investigated under high fluence (up to 3×10^{25} D/m^2) low energy (95 eV) deuterium (D) plasma irradiation experiments. Subsequent thermal annealing cycles associated with thermal desorption spectrometry (TDS) demonstrated superior structural stability of the coatings up to 1350 K. TDS experiments revealed an increased deuterium outgassing (as measure of its retention) for cold spray Ta coatings by a factor of 3.5 compared to bulk tantalum samples and by two orders of magnitude greater compared to the reference bulk polycrystalline tungsten W(B) samples [2]. A tendency for saturation of retention in the coatings and bulk tantalum was evidenced at a fluence above 1×10^{24} D/m^2. While deuterium retention gradually decreases with increasing surface temperature from 400 K up to 925 K in the case of bulk tungsten, it remains constant in the case of bulk tantalum. Retention significantly decreases in the case of cold spray tantalum when the surface temperature is above 750 K. It is suggested that the complex microstructure of the cold spray tantalum coatings containing inter-particle boundaries, subgrain structure, and even nano-scale porosity may play a significant role on deuterium trapping and release. Retention mechanisms in the materials can be described by the 1st order desorption kinetics in the case of tungsten and by the 2nd order desorption kinetics in the case of tantalum samples. The calculated activation energies for desorption are: 2.0 eV for bulk tungsten, 3.15 eV for bulk tantalum and 2.56 eV for cold spray tantalum coatings. The retention results for the materials have also been modelled using numerical code FESTIM [3] which confirms the estimated activation energies for the materials and allows for the prediction of hydrogen isotopes retention in the WHAM PFCs.

X-ray photoelectron spectroscopy revealed evolution of oxidation states upon deuterium irradiation and a partial recovery of the metallic signature of Ta after the thermal treatment. Results also suggest a formation of tantalum deuteride in the near-surface layer.

Finally, our work introduces strategies of the plasma-wall interaction studies on WHAM and advances the development of the refractory metal cold spray coatings and additive manufacturing solutions for the wider use in fusion technology.

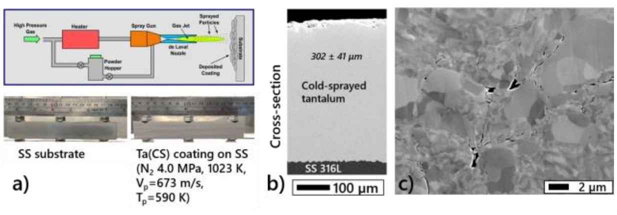

Figure 1. a) Schematic illustration of the cold spray system and images of stainless steel substrate before and after deposition of tantalum. b) and c) show cross-sectional SEM images of Ta(CS) at different magnifications.

References

[1] D. Endrizzi et al., J. of Plasma Physics, 89, 5, 975890501 (2023)
[2] M. Ialovega et al., Phys. Scr. 98, 115611 (2023)
[3] R. Delaporte-Mathurin et al, Nuclear Materials and Energy, 21, (2019)