CORRELATION OF DEUTERIUM RETENTION WITH CRYSTALLINE STRUCTURE IN DENSE AND DISORDERED TUNGSTEN COATINGS

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Dense nano-structured tungsten (W) coatings are used as plasma-facing materials in current tokamaks and thick coatings are suggested to be used also for the future fusion devices, ITER and DEMO. In this study, deuterium (D) retention in various W coatings was investigated to understand dependences of the D retention on the crystalline structure of each W coating and on the substrate material.

Three W coatings with different crystalline structures: the disordered W coating produced by Pulsed Laser Deposition (PLD-W), the dense coating produced by Combined Magnetron Sputtering and Ion Implantation technology, CMSII-W, which is used in ASDEX Upgrade and JET, and the coating produced by standard vacuum magnetron-sputtering method (SMS-W) were deposited on different substrates: fine grain graphite (FGG), carbon fiber composite (CFC) and EUROFER steel. The prepared samples were exposed to the D plasma in well-defined laboratory conditions. The D depth profile was measured up to 6 μm by nuclear reaction analysis (NRA) and the total deuterium retention was measured by thermal desorption spectroscopy (TDS).

All types of coatings show higher D concentration compared to bulk polycrystalline W (PCW). PLD-W coating has the highest D concentration, whereas the lowest D concentration was found in SMS-W coating. No significant influence of the substrate on the D concentration in the coatings was found, nevertheless, the choice of substrate material can affect the total D retention measured by TDS. Fig. 1 shows TDS of D from CMSII-W coatings deposited on Eurofer, FGG, and CFC substrates in comparison with TDS of D from polycrystalline tungsten, WI (ITER grade), and from Eurofer. The D retention in coatings is much higher than the D retention in bulk WI and Eurofer. TDS of D from CMSII-W film on Eurofer has one very board peak with maximum of about 870 K. The broad shape of the TDS peak indicates the presence of a spectrum distribution of defects with similar binding energy for D.

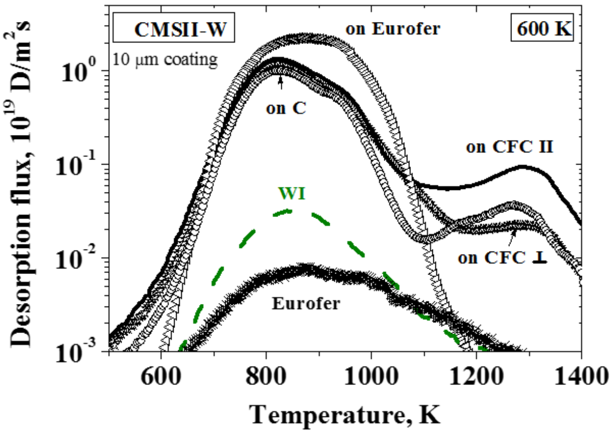

Fig. 1. TDS of D from CMSII-W coatings with 10 μm of the thickness deposited on Eurofer, FGG, and CFC substrates in comparison with TDS of D from polycrystalline tungsten, WI (ITER grade), and from Eurofer. The CMSII-W film was deposited on two kinds of CFC: with fibres oriented to be parallel (CFC II) and perpendicular (CFC ⊥) to the deposited surface. Deuterium was implanted in samples by ECR plasma source with ion energy of 20 eV per D atom up to a fluence of F=2.2x10^{25} D/m^2 at sample temperature of 600 K.

It is possible to resolve two main peaks of ~820 and ~930 K in TDS from coatings deposited on C-based substrate and additional third high-temperature peak of ~1270-1290 K with much smaller amplitude. The release of D at temperatures of ~1270-1290 K can be attributed to D trapped by carbon. TDS has a single broad peak with maximum of about 850 K in the case of WI. TDS has two peaks of ~870 and ~1000 K in the case of Eurofer. The absence of the high-temperature peak of ~1270-1290 K in the case of WI and in the case of the CMSII-W coating on Eurofer substrate confirms our suggestion that this peak is associated with D which was chemically bounded with carbon.

The D retention in a coating increases linearly with the coating thickness indicating the homogeneous distribution of intrinsic defects over entire coating thickness. Fig. 2 shows the D retention in CMSII-W coating with 10 μm of the thickness in comparison with that one in bulk W in a wide range of temperature. Obviously, the D retention is higher in coating than in a polycrystalline W. The mean grain size of CMSII-W coating is about 15 nm and the mean grain size of bulk W is 5-30 μm. The D concentration correlates with microstructure of W: the D concentration drastically increases with decreasing the grain size as shown in Fig. 3.

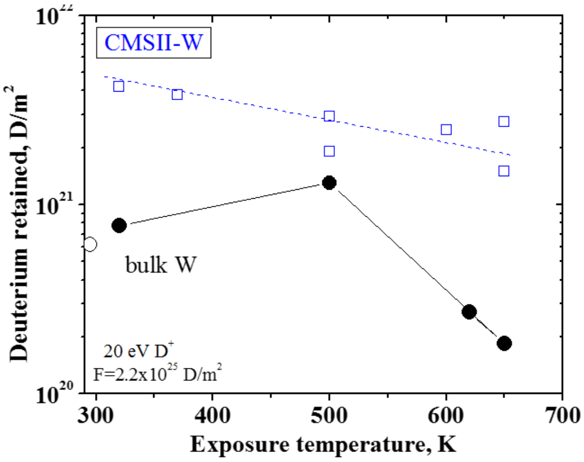

Fig. 2. Comparison of the temperature dependence of the D retention measured by TDS in CMSII-W coating with 10 μm of the thickness and in bulk W. Deuterium was implanted in samples by ECR plasma source with ion energy of 20 eV per D atom up to a fluence of F=2.2x10^{25} D/m^2.

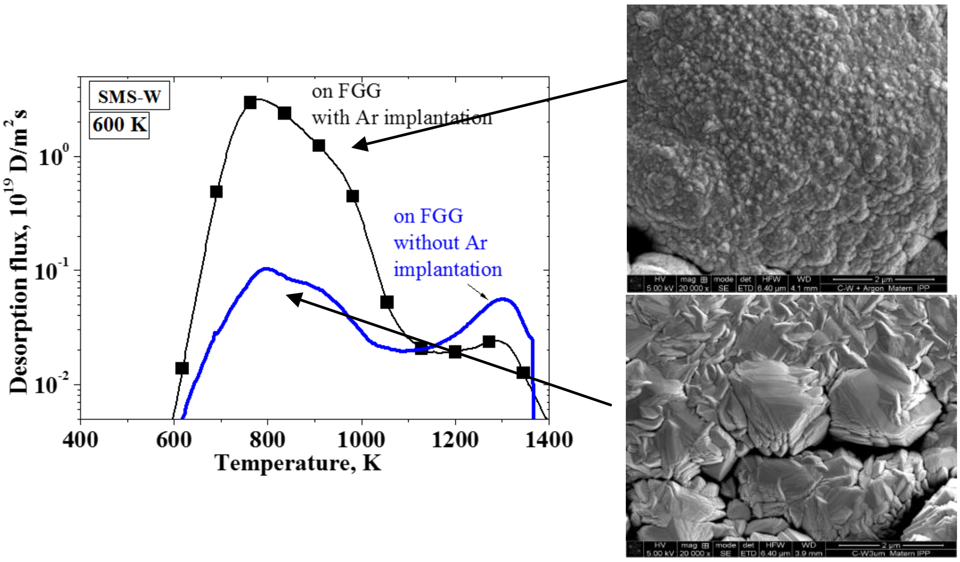

Fig. 3. TDS of D from SMS-W coatings with 3 μm of the thickness deposited on Eurofer and FGG substrates. The SMS-W coatings deposited with Ar implantation have smaller grain size compared to SMS-W coatings deposited without Ar implantation as confirmed by XRD. Deuterium was implanted in samples by ECR plasma source with ion energy of 20 eV per D atom up to a fluence of F=2.2x10^{25} D/m^2 at sample temperature of 600 K.

Consequently, from the viewpoint of the hydrogen isotope retention, coarse-grained crystals can be recommended for application of W-based materials in fusion devices. At the same time, coarse-grained crystals could be undesirable from the viewpoint of possibility of blister formation. We found that nano-crystalline structure of W coatings suppresses the blister formation. On the other hand, a disadvantage of thin coating is its erosion which prevents the use of the coating under the long operation time. The advantages and drawbacks as well as future development of tungsten coatings for application as plasma-facing material in fusion device are discussed.