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[REGULAR POSTER TWIN] An overview of thick tungsten coatings prepared by chemical vapor deposition and manufacture of relevant mockups

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The versatility and practicability of a manufacturing route for the plasma-facing material and component (PFMC) are necessary for the final realization of fusion reactors. Currently, the powder metallurgy (PM) route followed by a suitable plastic deformation process (e.g. hot rolling) is the prevalent manufacturing technique for the preparation of tungsten (W) based PFM. However, this route is usually time-consuming, particularly, machining is unavoidable during the post-manufacture of the PFMC. An alternative route would be the coating technique, which exhibits repair potentiality for the PFM. According to the erosion rate of W under fusion-relevant conditions, the thickness of W armor in divertor area with a lifetime of 2 full-power-year in a future fusion reactor should be above 5 mm **1**. A W layer with a thickness of 2-3 mm has also been proposed in the designed concept of first-wall (FW) **2,3**. Therefore, regarding W coating for fusion application, the coating technique with high production efficiency is essential.
In the past several years, atmospheric pressure chemical vapor deposition (APCVD) with deposition rates in the range of 0.4-1.0 mm/h has been successfully developed at Southwestern Institute of Physics (SWIP, China) and Xiamen Tungsten Co., Ltd (XTC, China) **4,5**. W coating with a high purity of 99.999978% (exclude impurities, i.e. C, O, and N) **6** and thickness at millimeter level can be successfully achieved by this technique, which could fulfill the thickness requirement of the PFM.
Due to the ultra-high purity and highly oriented columnar structure, which is a benefit to heat transfer in the thickness direction, the prepared CVD-W has a comparable thermal conductivity with the theoretical value of pure W. The thermal stability of the prepared CVD-W under high-temperature annealing in the temperature range of 1000-1500 ℃ for 3 h was investigated. The result shows that there were no obvious Vickers hardness decrease and grain growth when the annealing temperature was lower than 1500 ℃, indicating is excellent thermal stability. This could be due to two factors: 1) compared to the rolled or forged W with plastic deformation, the stored energy in the CVD-W sample for thermal recovery is lower; 2) grain growth in the direction that perpendicular to the thickness could be effectively confined by the adjacent grains with columnar shapes.
Transient heat flux loadings including disruption-like and repetitive edge localized mode (ELM)-like thermal shock performance of the CVD-W at different base temperatures and absorbed power densities have been investigated at the electron beam device EMS-60 (60 kW Electron-beam Material-test Scenario) located at SWIP. Results **7** show that the power density related cracking threshold of the as-deposited CVD-W at room temperature was lower than 0.16 GW/m2, which was comparable to that of the rolled W **8**. However, a much higher cracking threshold of up to 0.33-0.44 GW/m2 was achieved for the polished CVD-W, which was higher than that of the rolled W **8** and forged W **9**.

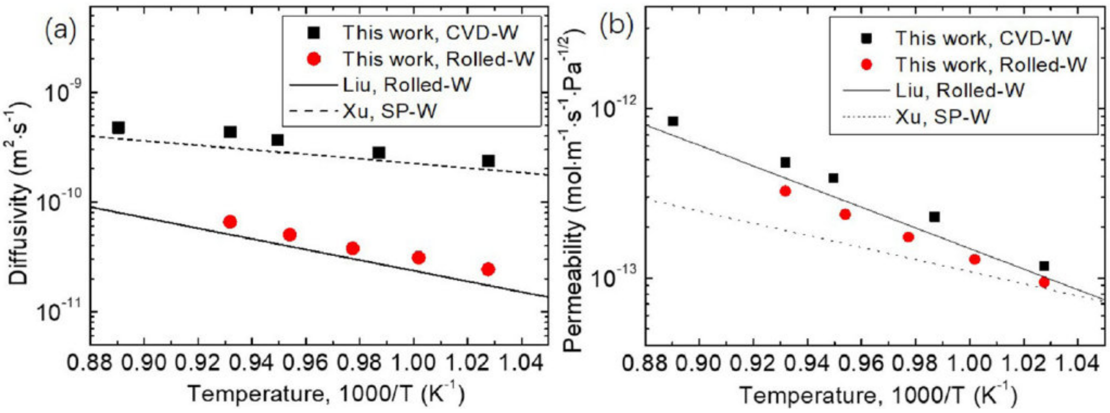

Figure 1: (a) D diffusivities and (b) permeabilities of the CVD-W and rolled W bulk.

The fusion fuel inventory in the PFM and permeation through the PFM into the coolant are also of particular concern during the long-term service of the PFM. Therefore, deuterium (D) diffusive transport parameters including diffusivity and permeability were investigated by gas-driven permeation (GDP) experiments. As shown in figure 1(a) and (b), in the temperature range of 973-1073 K, the CVD-W has a higher diffusivity and permeability than the rolled-W counterpart. Results of rolled W bulk (Liu et al. **10**) and sputter-deposited W film (Xu et al. **11**) are also plotted for comparison. The higher diffusivity and permeability could be because that grain boundary may act as fast transport channels for D by short-circuiting diffusion, leading to an enhanced diffusion rate in the CVD-W with columnar structure.

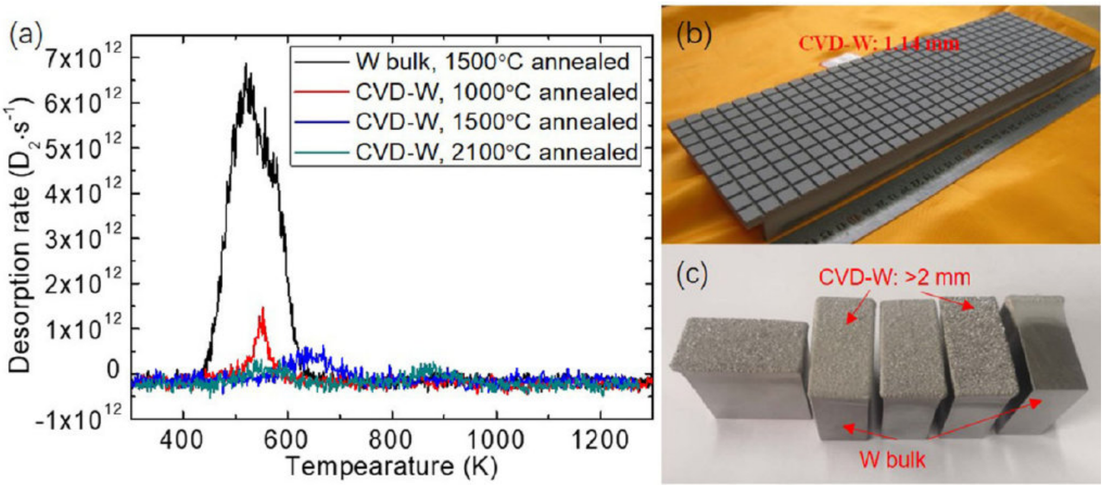

Figure 2: (a) TDS results of the pure W bulk and CVD-W samples after annealing at temperatures in the range of 1000-2100 ℃ for 1 h, (b) Large-scale deposition of CVD-W on the CuCrZr alloy, (c) W bulk samples with CVD-W coatings for the manufacture of water-cooled monoblocks.

A comparative study of the D plasma irradiation resistance of the CVD-W and pure W bulk was performed in the Magnum-PSI linear plasma generator. Samples with different heat treatments were exposed to D plasma with peak flux and fluence of ~3.5 × 1023 ions/m2·s and ~1.0× 1026 ions/m2, respectively. Results show that blistering behavior on the surface of the exposed CVD-W was much slighter than that of the W bulk, indicating its better plasma irradiation resistance. Additionally, as shown in figure 2(a), the D retention determined by thermal desorption spectroscopy (TDS) in the CVD-W was also lower than that in the W bulk, consistent with the nuclear reaction analysis (NRA) result derived from D(3He,p)α reaction. The slighter blistering behavior and lower retention could be due to its strong (100) texture **12** and large grain size with low defect (e.g. grain boundary) concentration, respectively.

The practicability of CVD-W as PFM for the first wall (FW) and divertor has also been investigated. For example, mockups of CVD-W coating on graphite with PVD-Si as an intermediate layer survived the thermal fatigue testing with an absorbed power density of 4.62 MW/m2 and 5 s pulse duration for 200 cycles **13**. Flat-type CVD-W/ functionally graded material (FGM)/CuCrZr mockup with a W layer of a thickness of 2.0 mm successfully survived heat flux loads of up to 11 MW/m2 for 1000 cycles **4**. A large-scale CVD-W/CuCrZr mockup has also been developed by the APCVD technique as shown in Figure 2(b). Preliminary research on the development of CVD-W/reduced activation Ferritic/Martensitic (RAFM) steel mockups for the FW has also been performed **3**.

In summary, inspiring results have been achieved during the R&D of thick CVD-W coating for fusion applications in the past several years. This work will give an overview of the preparation and characterization of the CVD-W. The practicability of CVD-W based water-cooled flat-type mockups has been demonstrated. Currently, CVD-W coatings on pure W bulk samples have been prepared as shown in figure 2(c), which will be used for the manufacture of the water-cooled monoblock with dimensions similar to the ITER divertor target design in the near future. The high heat flux fatigue loads of the monoblock at EMS-60 have been scheduled in July 2020.

Acknowledgments

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