Fusion Engineering and Design xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Fusion Engineering and Design

journal homepage: www.elsevier.com/locate/fusengdes

Deuterium retention in molten salt electrodeposition tungsten coatings

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HIGHLIGHTS

- We investigate D retention in electrodeposition W coatings.
- W coatings are exposed to D plasmas in the EAST tokamak.
- A cathodic current density dependence on D retention is found.
- Electrodeposition W exhibits lower D retention than VPS-W.

ARTICLE INFO

Article history:
Received 30 November 2015
Received in revised form 3 June 2016
Accepted 28 July 2016
Available online xxx

Keywords:
Hydrogen isotopes
Retention
Tungsten coating
Graphite
Molten salt electrodeposition
EAST tokamak

ABSTRACT

Molten salt electrodeposition is a promising technology to manufacture the first wall of a fusion reactor. Deuterium (D) retention behavior in molten salt electrodeposition tungsten (W) coatings has been investigated by D-plasma exposure in the EAST tokamak and D-ion implantation in an ion beam facility. Tokamak exposure experiments demonstrate that coatings prepared with lower current density exhibit less D retention and milder surface damage. Deuterium-ion implantation experiments indicate the D retention in the molten salt electrodeposition W is less than that in vacuum plasma spraying W and polycrystalline W.

1. Introduction

Tungsten (W) has been selected as the plasma-facing material (PFM) for ITER (International Thermonuclear Experimental Reactor) divertor [1] due to its outstanding material property. To understand the impacts of W-PFM on ITER plasma operation, extensive research activities are being organized in the fusion community. Recently, an ITER-like full W upper divertor has been successfully commissioned in EAST (Experimental Advanced Superconducting Tokamak) and a W first wall is proposed as well [2].

Although W plasma-facing components (PFC) can be fabricated by joining bulk W to the heat sink with existing technology, e.g. hot isostatic pressing (HIP) [3], the production of large size W-PFC is still challenging and costly, which may limit the prospect of using W as the PFM in fusion reactors. The typical of the first wall of fusion power reactors is as following: (1) the wall area will be as large as ~1000 m^2; (2) heat flux from plasma to the wall is significantly lower than that to the divertor target and (3) the armor

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http://dx.doi.org/10.1016/j.fusengdes.2016.07.023
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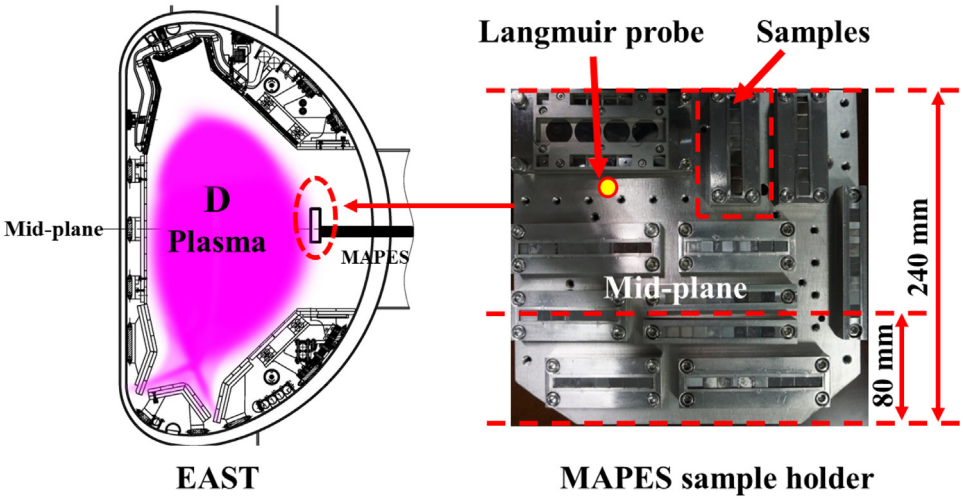

Fig. 1. Plasma exposure experiments using the MAPES system in the EAST tokamak.

layer must be thin to reduce thermal stress and to relieve neutron capture effect (i.e. to increase the tritium breeding ratio in the blankets) [4]. Taking all these into account, coating is considered to be a promising technology to manufacture the PFC (except divertor target) for fusion reactors.

Various W-coatings have been developed and tested for fusion purpose, e.g. vacuum plasma spraying W (VPS-W), physical vapor deposition W (PVD-W) and chemical vapor deposition W (CVD-W) [5–7]. Some coating materials exhibit relatively good compatibility with hydrogen isotopes plasmas (e.g. low retention) [5]. In several large- and medium-sized fusion confinement facilities, coating technology has already been utilized to prepare the first wall [7–9].

Molten salt electrodeposition is another attractive method to fabricate the W-PFCs because of its simple technics, capability to cover complex surfaces and relatively low cost. A high density (>97%) and thick (>1 mm) W coating has been successfully achieved with this technology by researchers from University of Science and Technology Beijing [10–12]. Our previous study indicated that higher electrodeposition current density will lead to larger grain size [11]. In the present work, deuterium (D) retention behavior in the coatings prepared with different current densities is investigated in the EAST tokamak using a material manipulator. To make a comparison between the coating and other W materials, D-ion implantation experiments are performed in a laboratory facility as well.

2. Experimental

2.1. Material preparation

Anhydrous Na_2WO_4 and WO_3 (Na_2WO_4:WO_3 = 3:1 by mole ratio) molten salts were mixed in the eutectic composition into an alumina crucible to make the W coating. The crucible was heated up to 1173 K with a ramping rate of 5 K/min. A 15 × 10 × 5 mm graphite (IG-430) substrate and a 15 × 10 × 5 mm W plate were used as the working electrode and the counter electrode, respectively. After the deposition process, samples were cooled in the air and then cleaned in ultrasonic bath to remove adherent molten salts. Further details of this material can be found in the reference [10]. In this work, W coating samples were prepared with four different cathodic current densities: 30, 40, 50 and 60 mA/cm^2. The substrates with coatings were cut into 10 × 10 × 1 mm pieces and the W surfaces were mechanically polished for the following plasma and ion irradiation experiments. The thickness of the coatings was measured to be 160–230 μm.

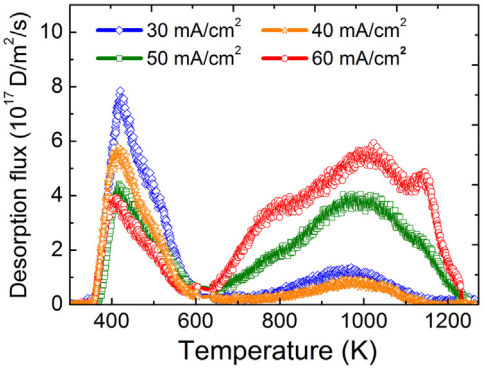

Fig. 2. Thermal desorption spectroscopy of D for the W coating samples after plasma exposure.

2.2. Plasma and ion exposure experiments

Deuterium-plasma exposure experiments were performed during the 2015 spring EAST campaign. Four W samples were fixed on the sample holder of the material and plasma evaluation system (MAPES) at the mid-plane of EAST [13] (Fig. 1). The sample surface was 5 mm behind the limiter and the local electron temperature and density were measured to be T_e = 5–10 eV and n_e = ~1 × 10^{18} m^{-3} by a Langmuir probe. The materials were irradiated by 367 shots and the total plasma exposure time was ~2000 s. Thermocouples were attached to the samples and the measured temperature varied from 323 to 623 K due to the heat from plasmas. Before and after the plasma experiments, surface morphology of the samples was examined by scanning electron microscope (SEM). Finally, D retention properties of the W coatings were analyzed using a thermal desorption spectroscopy (TDS) device which was calibrated with D_2 and H_2 standard leaks. The samples were heated up to 1273 K with a ramping rate of 10 K/min.

To make a direct comparison with other coating materials (e.g. VPS-W) and bulk W, D-ion exposure was also conducted using the triple ion implantation system at Shizuoka University in Japan [14]. For this case, the ion species is D_2^+ and the incident energy was 3 keV (i.e. the sample was irradiated with 1.5 keV D ions). The ion flux is 1 × 10^{18} D/m^{2}s and the fluence is 1 × 10^{22} D/m^2. The sample was kept at near room temperature during the experiment. After

Please cite this article in press as: H.-S. Zhou, et al., Deuterium retention in molten salt electrodeposition tungsten coatings, Fusion Eng. Des. (2016), http://dx.doi.org/10.1016/j.fusengdes.2016.07.023