Surface modification by deuterium and helium bombardments in RAFM

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Reduced Activation Ferritic/Martensitic (RAFM) steels, such as F82H and EUROFER, are candidate materials for fusion DEMO reactor. To understand bulk fuel retention and tritium inventories of plasma-facing materials in DEMO, analyses of specimens exposed to deuterium plasmas are essential. In this study, RAFM steel specimens are exposed to low energy deuterium and helium plasmas, and variations of surface modifications and compositions are elucidated.

RAFM steels, F82H (8Cr-2W) and EUROFER (9Cr-1W), are bombarded with steady-state deuterium plasmas under conditions relevant to the first wall environment using the PlaQ facility [1, 2]. The surface temperature of the specimens during plasma exposure was measured by thermocouples and an infrared camera. It was set at 450 K. Target steels were exposed to helium pre-irradiation applied a DC-bias voltage of 200V and deuterium plasma bombardment applied a DC-bias voltage of 100V. Applied deuterium and helium fluences are 1 x 10^{24} D/m^2 and of the order of 10^{24} He/m^2, respectively. After the plasma exposures, specimens were analyzed with nuclear reaction analysis (NRA), microbalance, Rutherford backscattering spectroscopy (RBS), scanning electron microscopy (SEM).

Deuterium retention in the steels was measured by NRA, which was using D (He^3, p) ^{4}He reaction at different energies, 690 keV, 1200 keV, 1800 keV, 2400 keV, 3200 keV and 4000 keV, respectively. Amounts of deuterium retention are of the order of 10^{18} to 10^{19} D/m^2 at the near top surface region using an energy of 690 keV. Target specimens with helium pre-irradiation show higher deuterium retentions to compare with without helium pre-irradiations. The difference between F82H and EUROFER is almost negligible.

Surface morphologies analyzed by SEM. After deuterium plasma bombardment, a smooth plane shown. From microbalance measurement, weight loss of 10 μg per 1 cm^2 was observed. But a surface on the target after helium pre-irradiation shows pin-holder like un-uniform structures. A weight loss after helium irradiation is about 60 μg per 1 cm^2 and then an erosion rate by helium irradiation is higher than that after deuterium irradiation.

From cross-section SEM observation after a focus ion beam (FIB) treatment, coral structures are observed on a plasma facing side. Each length of coral structure is less than 200 nm. In the cross-section image, the plasma facing side show tungsten enrichment during the thickness of 5 nm from the top surface, measured by an energy dispersive X-ray spectrometry.

[1] A. Manhard, et al., Plasma Sources Sci. Technol. (2011) 20 015010.
[2] N. Ashikawa, et al., Fusion Eng. and Design, 112(2016) 236.

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