STUDIES ON LOW ENERGY HELIUM PLASMA EXPOSURE BEHAVIOUR OF TUNGSTEN-BASED HIGH ENTROPY ALLOY

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Tungsten (W), the primary plasma facing material in the ITER tokamak has multiple superior properties like very high melting point, good thermal conductivity, less sputtering erosion and negligible retention of the hydrogen isotopes. However, it has limitations in terms of irradiation resistance, susceptibility to oxidation, and poor ductility. Therefore, for the upcoming modern tokamaks including DEMO, there is a constant search for new plasma facing materials, with better characteristics compared to W. W-based high entropy alloys (HEAs) are emerging as possible alternative plasma facing materials, as they are characterized with higher yield strength, greater radiation resistance, improved oxidation resistance, and increased hardness. El-Atwani *et al.* focused on the following composition of W-HEA: W-Ta-Cr-V, which he demonstrated had negligible irradiation hardening and no irradiation induced dislocation loops formation, even when exposed under MeV ions [1]. Shi *et al.* irradiated the same W-HEA under helium plasma (100 eV), up to an ion-fluence of 2.02×10^{25} m^{-2} at 673 K [2]. He showed that the sizes of the sub-surface helium bubbles formed in the exposed samples were smaller than that in pure W, and their depth distribution was also shallower, indicating that the evolution of the gas bubbles was inhibited in the matrix of the alloy.

In this paper, we study low energy helium plasma exposure behaviour of bulk W-Ta-Cr-V HEA, in the CIMPLE-PSI device, under large ion-fluence (2×10^{26} m^{-2}) and very high target temperature of 1250 K. The CIMPLE-PSI is a linear tokamak divertor simulator device, which can reproduce ITER divertor like extreme parameters in terms of the both ion-flux (~10^{24} $m^{-2}s^{-1}$) and heat-flux (~5.1 MWm^{-2}) parameters [3]. The plate type HEA samples were prepared by the technique of arc melting. The samples, before and after irradiation were characterized using XRD, optical microscopy, FESEM and EDX. Cross-sections of the exposed samples were prepared by the technique of focused ion-beam (FIB). The XRD pattern of the as-prepared sample is presented in Fig. 1(a), which confirms a single phase alloy is forming with bcc structure. The EDX measured the atomic concentration of the elements in the alloy as follows: W (32.3%), Ta (51.6%), Cr (1.6%) and V (14.5%), which were homogeneously distributed in the matrix (Fig. 1(b)).

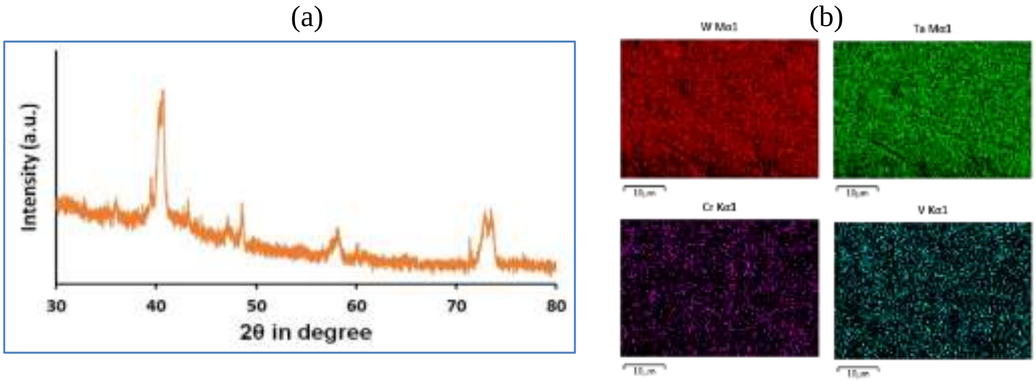

Fig. 1: (a) XRD pattern and (b) EDX elemental mapping of the as-prepared W-Ta-Cr-V high entropy alloy sample.

The optical and FESEM micrographs of the exposed sample are presented in the Fig. 2(a) and 2(b) respectively. There was no visible discoloration of the exposed sample and the surface was almost featureless under optical microscope (Fig. 2(a)). However, FESEM confirms surface modification at the nanometer level (Fig. 2(b)). Comparing this with our previous results with tungsten shows, the same exposure conditions would have led to serious surface modification of W, with copious growth of the so-called W-fuzz nano-tendrils [3]. So, we may conclude this particular HEA demonstrates larger irradiation resistance compared to pure W, even at very high He^+ flux, fluence and target temperature conditions.

The surface atomic concentration of the helium plasma exposed HEA sample was measured as W (57.2%), Ta (37.9%), Cr (0.46%) and V (4.47%), which clearly indicate the enrichment of the high-Z elements (W, Ta) on the surface. This must have happened due to the preferential sputtering of low-Z element (Cr and V), by the 45 eV helium ions.

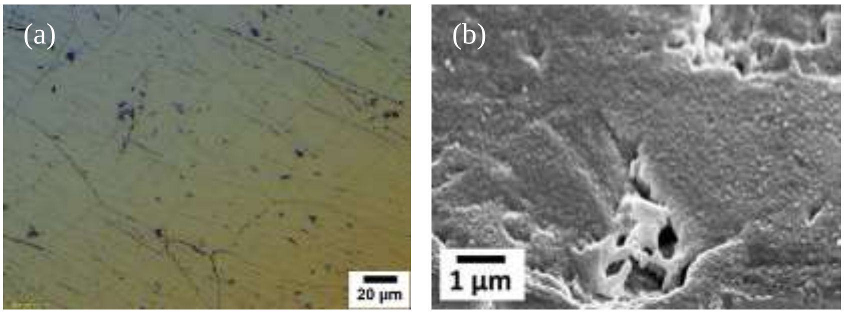

Fig. 2: (a) Optical microscopy image and (b) FESEM micrograph of the plasma exposed sample.

The FIB made cross-section of the exposed sample is presented in Fig. 3. He bubbles were identified down to a depth of about few hundreds of nanometer, with individual sizes ranging between 10-15 nm as shown in Fig. 3. They were distinctly smaller and closer to the surface compared to W irradiated in the same device, which may be considered a clear indication that the formation and evolution of the bubbles are inhibited in the matrix of the current alloy even under the intense irradiation conditions. The W-Ta-Cr-V HEA is produced also in the thin-film form by magnetron sputtering, whose low-energy helium plasma irradiation behavior is studied currently, results from which will be presented in the paper. In addition, we are also studying the high-energy ion irradiation behavior of the HEA, which will reflect response of the alloys under exposure of the fusion neutrons.

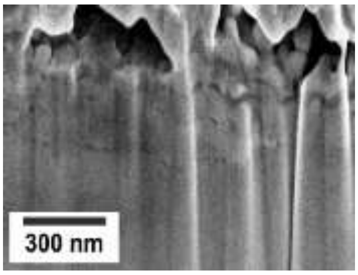

Fig. 3: FESEM micrograph of the FIB made cross-section of the plasma exposed sample.

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