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Microstructural evaluation of beryllium after neutron irradiation up to 6000 appm helium production

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Beryllium is planned to be used as a neutron multiplier material in the Helium-Cooled Pebble Bed (HCPB) European concept of a breeding blanket of DEMO. Long-term irradiation tests in high-neutron-flux nuclear research reactors yield information about microstructural evolution of beryllium pebbles under conditions relevant to fusion (temperature, damage dose, helium and tritium productions) excluding 14 MeV neutrons impact which is not present in the neutron spectra of fission reactors. The HIDOBE-02 irradiation campaign accomplished at the HFR, Petten, was started in June 2005 and was finished in August 2011 which corresponds to 1246.5 Full Power Days at a reactor power level of 45 MW. Beryllium pebbles were irradiated in the temperature range of 410-680 °C. The target preparation of transmission electron microscopy (TEM) specimens was performed using focused ion beam (FIB) which enables TEM investigation of defined areas such as secondary phases or grain boundaries.

Neutron irradiated beryllium pebbles show in the TEM analysis the formation of hexagonal flat gas bubbles in the grain volume. Usually the bubbles are located in the basal plane of beryllium having HCP lattice [1]. With increasing irradiation temperature, the diameters of the bubbles increase from a few nanometers at 410 °C to more than hundred nanometers at 680 °C. The density of bubbles decreases, correspondingly, by more than two orders of magnitude. Imaging of the lamellae in an oxygen EDX map reflects the topography of the beryllium surfaces which has been oxidized by contact with air. The formation of this thin oxide layer enables imaging of voids which got in contact with the foil surface during FIB preparation. The open voids got a surface decoration and are visible as narrow strips. The voids which do not have contact with a foil surface remain invisible in the oxygen map without any decoration of the void's surface with oxygen or other impurity elements.

Also the preferable formation of bubbles with sizes up to 1 µm along the grain boundary was observed. The edges of the voids correspond with crystallographic planes of the beryllium matrix, but because both halves of the bubble grow in two differently oriented grains, their shape is more irregular. The areas with high density of 30-70 nm large voids are located on the distance of 0.5-1.3 µm on both sides of the grain boundary. The areas of 0.5-1.5 µm thickness close to the grain boundary without any visible voids can be named as a denuded zone. These zones are formed because grain boundaries act as a sink for vacancies and interstitials that influence in the nearest area. On the other hand, this effect promotes also the formation of large voids direct on the grain boundary. The similar effect was already observed in polycrystalline neutron irradiated tungsten.

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