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Evolution of the W cristalline structure under He irradiation: surfacic evolution and bubble formation experimental characterization

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Plasma-facing materials (PFM) for next generation fusion devices like ITER will be submitted to intense fluxes of He and H isotopes (H, D and radioactive T transmutating as He). This is particularly significant for the divertor components, for which tungsten (W) is the first-choice material thanks to its low sputtering yield, low HI retention and high melting point. Plasma-wall interactions could jeopardize conservation of these key properties throughout long-pulse operation, triggering concerns for the reactor efficiency and safety: notably, incident He particles can drastically affect the surface, with the formation of dislocation loops, bubbles or W-fuzz [1]. The W surface properties plays a major role on HI retention/permeation, a crucial process for reactor efficiency and safety; it is therefore of prime importance to characterize the structural modifications triggered by He and their driving parameters in order to assess their potential impact. We will present structure evolution of various W samples submitted to He exposure, with some first T inventory results, with the main objective to improve our modelling effort and thus achieve a better evaluation of the long term inventory in W PFC of ITER through our predictive rate equation codes.

The WHIrr project [2-3] tackles the study of He bubble formation in different grades of W after exposure either to in situ conditions or laboratory devices. We have observed that He bubbles form at all irradiation temperature studies (from 60℃ to 800℃), even at energies below the minimal displacement energy or low exposition fluences. Transmission Electron Microscopy (TEM) highlights a high concentration in the near surface area (0-10/25 nm deep depending on the He fluence). A strong increase in bubble average size along with a decrease in bubble density is observed as the irradiation temperature elevates over 500℃, which is the operational condition expected for the W divertor of ITER. In order to obtain insight on the kinetics of fundamental mechanisms of bubble growth in the near surface area, measurements were carried out for the first time using in situ nano science techniques: surface evolution was followed by Low Energy Electron Microscopy (LEEM), and bubble size, shape and distribution was monitored by Grazing Incidence Small Angle X-ray Scattering (GISAXS) during He irradiation at the ERSF. Size and shape evolution of He bubbles in W single crystals held at 1000℃ during continuous implantation of 2 keV He ions for W(110), W(100) and W(111) showed the growth of facetted He bubbles up to 20 nm wide and a large strain field in W crystals; bubble coalescence generates larger bubbles as temperature increases up to 1500℃, while the surface partially recovers its original crystallographic structure. Finally, IsGISAXS simulations are presented to complete the description of the early stages of He bubbles formation, and their evolutions regarding the temperature and the crystallographic orientation of the sample.

[1] Y. Ueda et al., Fusion Engineering and Design 89 (2014) 7-8, 901-906.
[2] E. Bernard et al., J. Nucl. Mater. 484 (2017) 24-29
[3] E. Bernard et al., Nucl. Mater. En. 19 (2019) 403-409

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