Effect of Cr and C on dislocation loops in heavy ion irradiated ultra-high purity FeCr alloys

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One of the big challenges for fusion materials science and technology is to design structural materials able to operate over extended periods under extreme environments including high irradiation levels (150-200 dpa) as well as high temperatures (~350-550℃ for concepts utilizing steel structures). Fe-Cr based ferritic–martensitic steels are currently the most promising structural material candidates for the first wall and blanket structures of future fusion reactors. In these alloys, the Cr content needs to be optimized for a desired material response. It is now well-accepted that Cr addition to Fe matrix is highly beneficial in maintaining void swelling resistance of the alloy, but the key fundamental question of how Cr affects the microstructural evolution of defects like dislocation loops is not yet fully answered despite decades of research. In Fe and Fe-Cr alloys, a/2<111> and a<100> type loops are observed after ion, neutron, and electron irradiations, with a general evolution toward a<100> loops with increasing temperature. There is evidence that Cr addition favors nucleation of a/2<111> type loops and leads to higher loop densities. However, a clear trend of a/2<111> vs a<100> loops as a function of Cr content, dose rate and irradiation temperature is not available in the literature, which is a key to thoroughly understand the effect of Cr solute additions. Further, impurities like C, N, O etc. might also play a significant role in the development of the irradiation-induced microstructures, an effect that is usually largely ignored. In this context, we have performed multi-temperature (350-450°C) self-ion irradiation study using 8 MeV Fe ions (ion range of 2 μm) to midrange doses of ~0.35 and 3.5 dpa at dose rates of 10^{-5} and 10^{-4} dpa/s on a series of ultra-high purity Fe-Cr alloys with Cr content ranging from 3wt.% to 18wt.% and a 9%Cr with 780 ppm C. Using a combination of conventional diffraction contrast TEM imaging techniques and detailed Burgers vector analysis using the g·b method we reveal the effect of temperature, dose rate, dose, and Cr and C solute on the dislocation loop microstructures in these alloys. In addition, by combining diffraction contrast imaging with analytical scanning TEM (STEM)-high throughput energy dispersive X-ray spectroscopy (EDX) we will quantify Cr segregation behavior onto dislocation loops for Cr < 10wt.%.

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