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Clustering and Radiation Induced Segregation in Neutron Irradiated Fe-(3-18)Cr Alloys

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High chromium ferritic-martensitic (F-M) steels are one of the promising structural material classes for future nuclear power plants. These steels are designed to combine corrosion resistance, conferred by chromium, with low swelling, high resistance to irradiation damage as well as to retain adequate toughness and elevated-temperature strength during service [1]. However, the long-term use of these steels in intense neutron irradiation environments requires reliable predictions of the evolution of their microstructures and mechanical properties. Binary Fe-Cr alloys constitute a model system for high Cr ferritic/martensitic steels and have therefore generated lot of interest by allowing the systematic study on irradiation induced microstructural changes.

In the present study, microstructural changes in neutron irradiated Fe-Cr binary alloys are investigated using atom probe tomography (APT). A series of six Fe-Cr alloys of nominal compositions 3, 6, 9, 12, 15, and 18 at.%Cr were irradiated at a neutron fluence (E>1 MeV) of 1.1 x 10^{21} n/cm^2 at 563 ± 15K and to a damage level of 1.82 displacements per atom (dpa). Solute distributions revealed α′ precipitation for alloys containing more than 9at.%Cr (Figure 1). Both the Cr concentration dependence of α′ precipitation and the measured matrix compositions are in agreement with the recently published Fe-Cr phase diagrams [2]. An irradiation-accelerated precipitation process is strongly suggested for α′ precipitation. Along with homogenously distributed Cr-enriched clusters of the α′ phase, few clusters involving Si, P, Ni, and Cr, are observed in the matrix [3].

For Fe-6, 9, 12 at.%Cr, Si and Cr are found segregated to dislocation loops and information pertaining to number density, size, and habit plane were analyzed for Fe-6at.%Cr alloy[4]. Grain boundary chemistry for Fe-Cr alloys are quantitatively compared between the as-received and the neutron irradiated alloys. Zones depleted of α′ clusters and Si are found at the interfaces of carbide and nitride precipitates and along grain boundaries in the vicinity of these precipitates.

To study stability of clusters and observed features in irradiated samples, annealing is carried out at high temperatures.

The results are discussed in the context of equilibrium segregation, radiation-enhanced diffusion, and/or radiation induced segregation.

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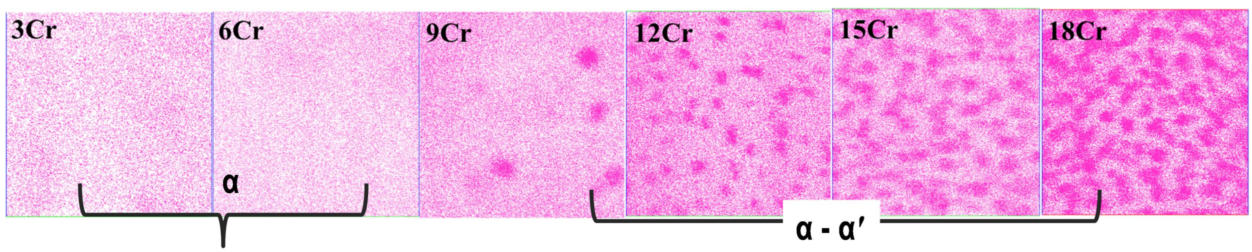

Figure 1**:** 20 nm thick slices showing the distribution of Cr atoms for each of the analyzed alloys: (a) Fe–3Cr, (b) Fe–6Cr, (c) Fe–9Cr, (d) Fe–12Cr, (e) Fe–15Cr, (f) Fe–18Cr

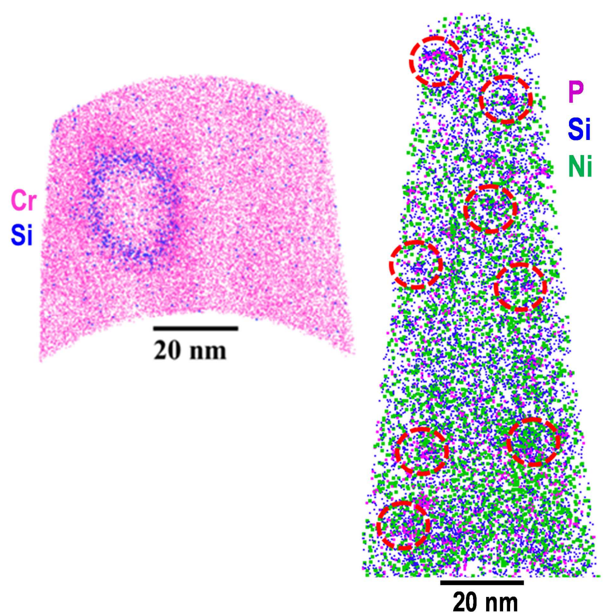

Figure 2: 3D reconstruction showing (a) dislocation loop decorated with Si and Cr in neutron irradiated Fe-6Cr alloy (b) segregation of impurities P, Si, Ni in the matrix of Fe-15Cr alloy

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