Microstructural stability of ODS Fe-14Cr(-2W-0.3Ti) steels after simultaneous triple irradiation

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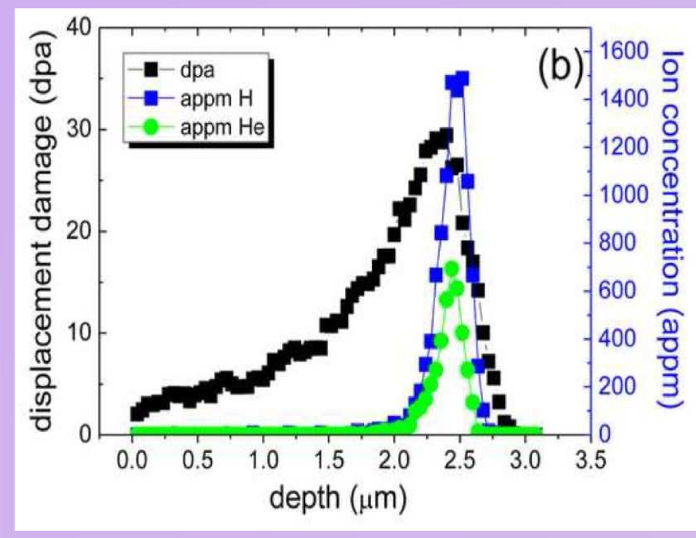
Abstract

Oxide dispersion strengthened (ODS) 14 wt.% ferritic steels are promising structural materials for future fusion reactors and generation IV fission reactors. The Y-rich nanodispersion present in these steels leads to higher mechanical resistance and creep strength, and is thought to provide a high concentration of sinks for irradiation-induced defects and transmutation gases, improving radiation resistance significantly as compared to their non-ODS counterparts.
In this work, two ODS Fe-14Cr alloys with were simultaneously triple-beam irradiated with Fe, He and H ions at 600°C to simulate the damage produced at DEMO per year. This irradiation was accomplished at the JANNUS-Saclay facility in France. The microstructural stability of these materials has been analyzed using TEM and PAS techniques

Materials used
$Fe\text{-}14Cr\text{-}0.3Y_2O_3$ (14YHT)
and
$Fe\text{-}14Cr\text{-}2W\text{-}0.3Ti\text{-}0.3Y_2O_3$ (14YWTi)

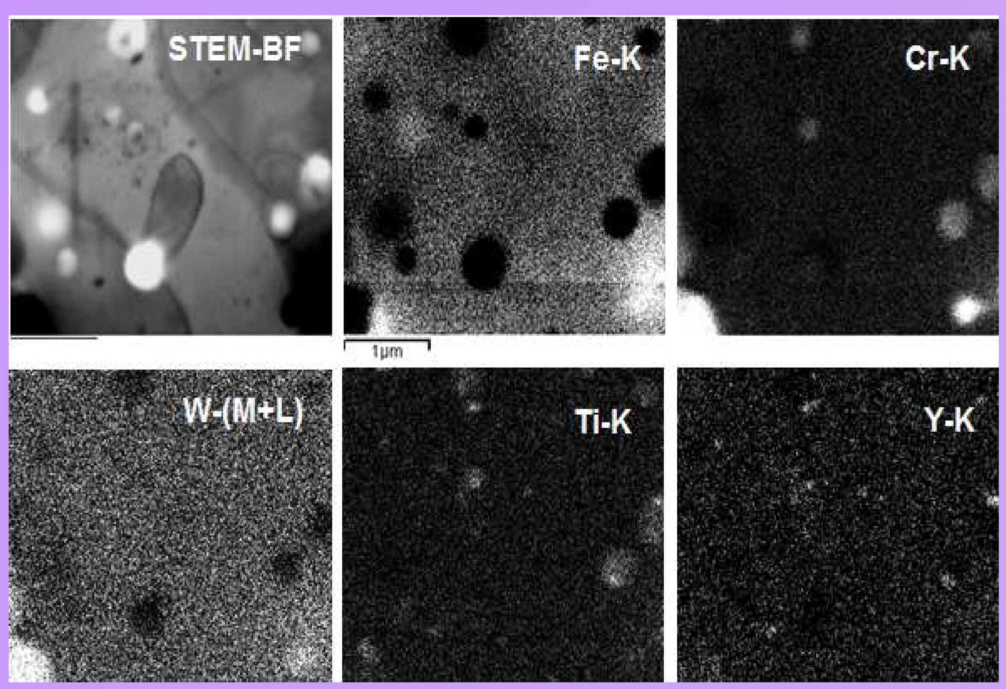
Ions	Energy	Temp (°C)	Maximum dose
Fe^{5+}	14 MeV	600	~30dpa
He^{+}	1.6 MeV		~600appm
H^{+}	500 keV		~1500appm



Transmission Electron Microscopy

14YWTi

pre irradiation

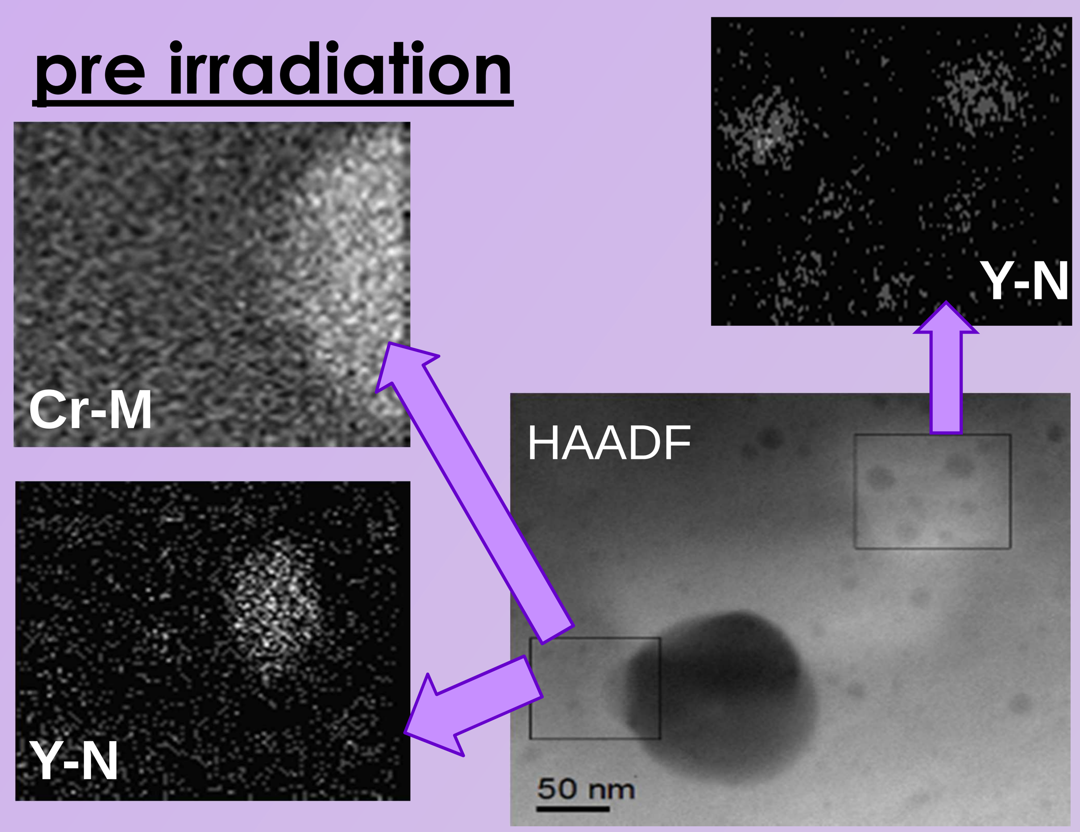


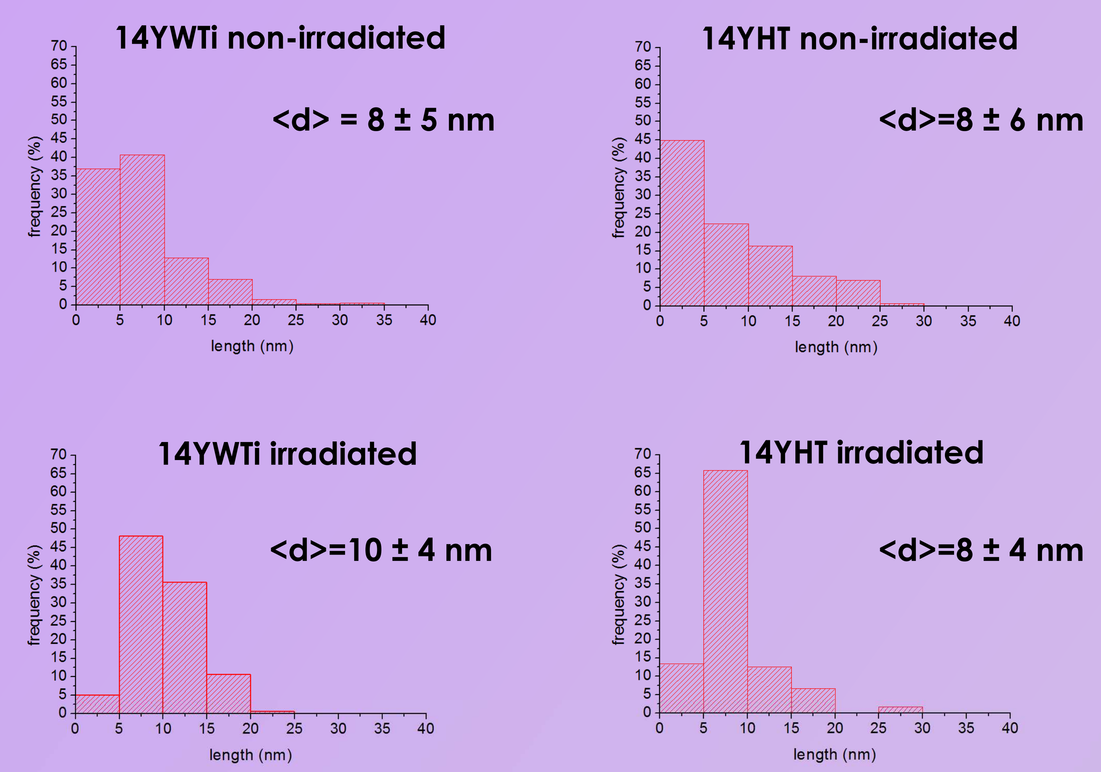
Bimodal grain distribution containing large recovered grains (up to 15 μm) and small unrecovered submicron grains (<800 nm). Nanoparticles (<40 nm) are Y and Ti-rich and have round morphologies.

14YHT

More uniform grain structure consisting of equiaxed grains with sizes in the range 0.5 – 3 μm. There are different types of secondary phases, with Cr-rich and Y-rich compositions. Nanoparticles (<30 nm) contain Y and are round.

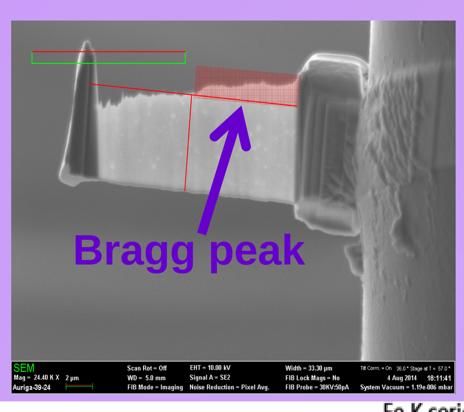
pre irradiation





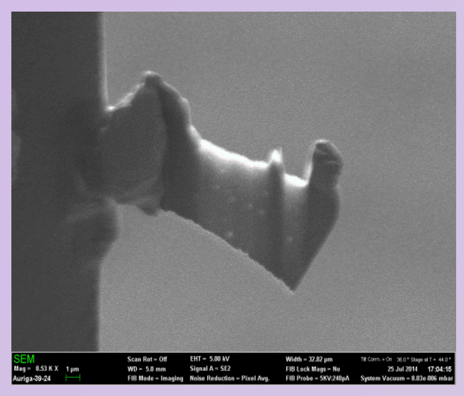
Distribution of nanoparticle sizes

post irradiation (14YWTi)

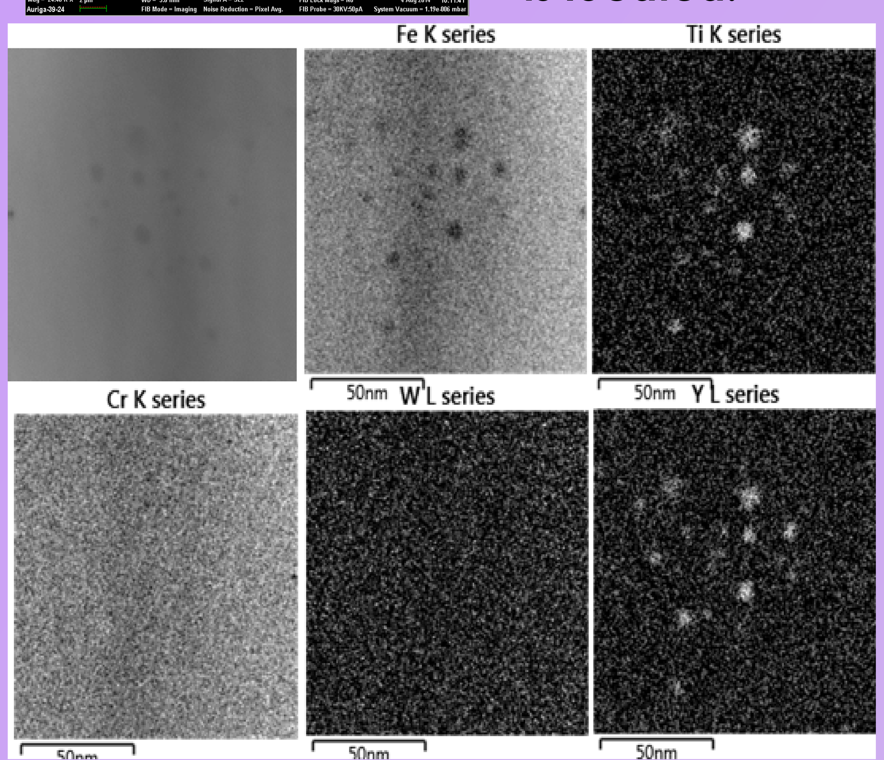


Cross-section of the sample cut by Focused Ion Beam. Analysis done near 2.4 μm, where Bragg peak is located.

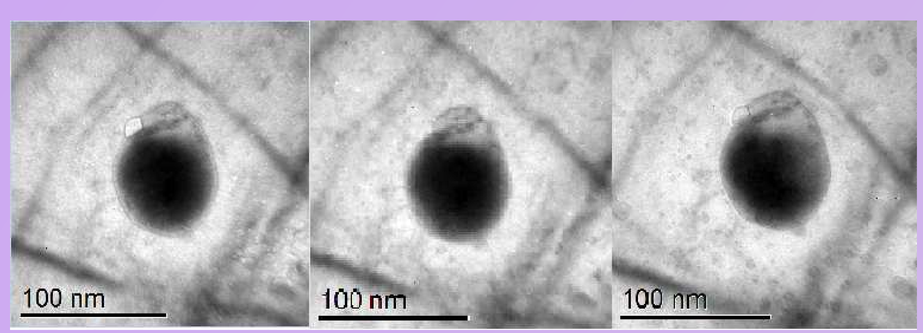
post irradiation (14YHT)



Cross-section of the sample cut by Focused Ion Beam. Analysis done near 2.4 μm, where Bragg peak is located.

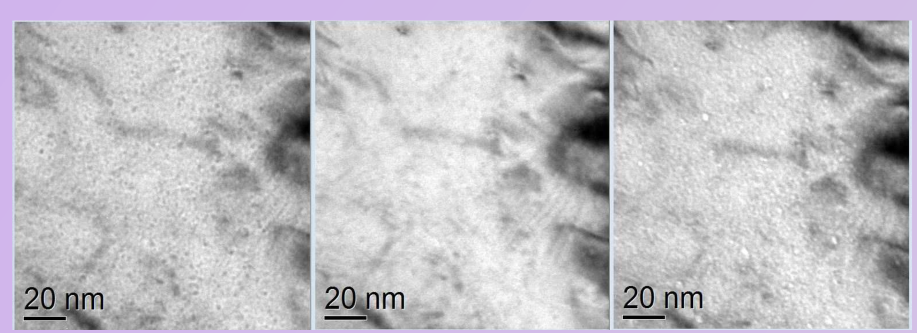


EDS maps show that there is no change in the composition of nanoparticles.



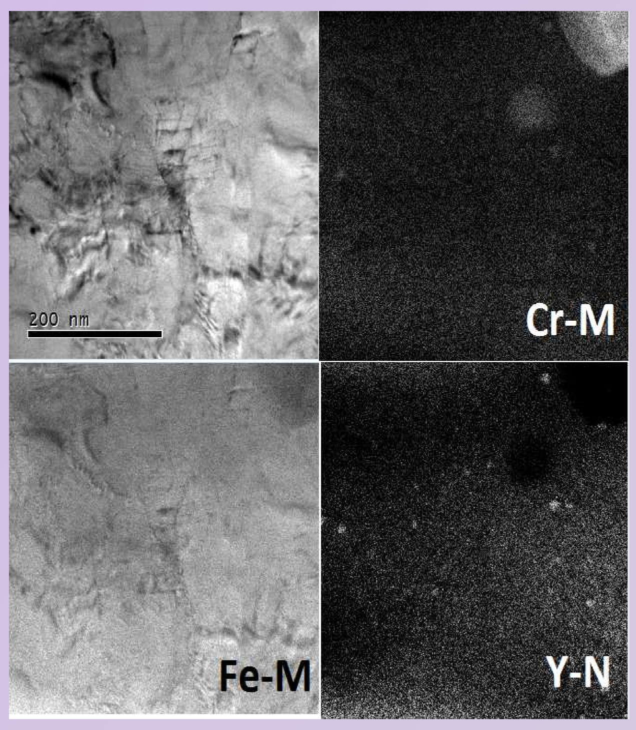
+ 1.5 μm In-focus - 1.5 μm

Very small (< 2 nm) irradiation induced bubbles are visible.



+ 1 μm In-focus - 1 μm

Very small (<4 nm) irradiation induced bubbles are visible.



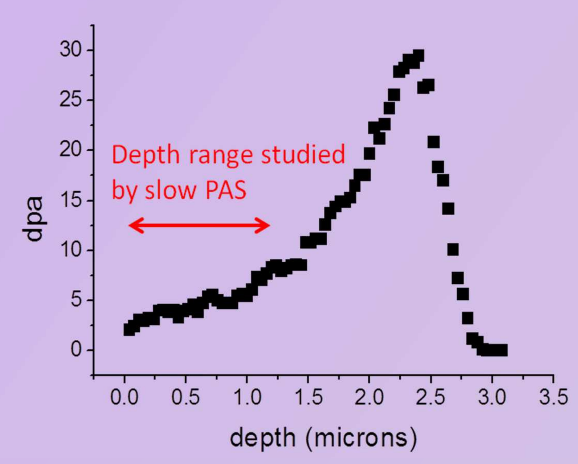
EFTEM maps show that there is no change in the composition of nanoparticles.

Results

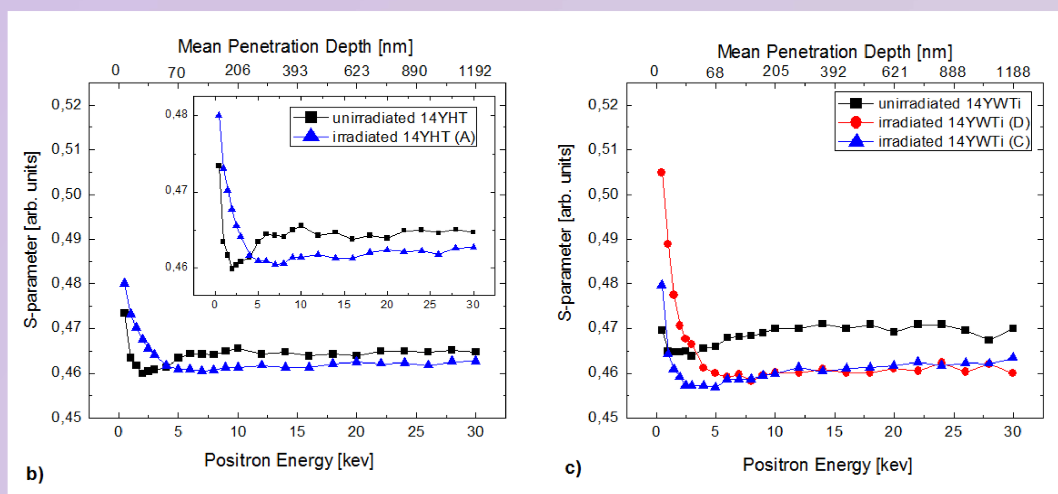
- General microstructure is stable – it does not change after irradiation.
- No significant irradiation induced changes in the average size, composition and morphology of nanoparticles.

Positron Annihilation Spectroscopy

PAS is a very effective technique to investigate open-volume defects in metals because they are strong traps for thermal positrons in the crystal lattice. It has been successfully applied to study radiation damage in the bulk of steels used in nuclear technology. Slow PAS allows obtaining the depth distribution of vacancy-type defects up to 1.2 μm from the surface (by varying the positron implantation energy ~ 1 - 30 keV)



Damage profile for 14 MeV Fe onto Fe-14Cr



S-parameter is constant in bulk for both non-irradiated and irradiated samples suggesting absence of irradiation-induced defects up to 1.2 μm.

Conclusions

For both samples, the nanoparticles have maintained their composition and morphology after triple irradiation, while their sizes appear to increase slightly. Small, irradiation induced, bubbles are visible. Positron Annihilation Spectroscopy results suggests that irradiation induced bubbles remain localized near the Bragg peak.

Future work

- Analysis of samples irradiated with beam degrader
- Analysis of other techniques used – nanoindentation, PALS, Atom Probe
- Irradiations under different conditions in CMAM and JANNUS

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