Vacancies-solutes interactions and their role in the formation of oxide nanoparticles in ODS steels

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Oxide-dispersion strengthened (ODS) steels are good candidates for the structural materials of blanket/first-wall in fusion reactors as well as fuel cladding in advanced fission fast reactors. In these environments, ODS steels are submitted to hard conditions: high temperatures (500°C-1000°C) and high level of damage (200dpa). Their good properties are induced by the fine dispersion of low size oxide nanoparticles(Y,Ti,O). However, this nanoparticle distribution is often not controlled. It have been shown by theoretical models that the presence of vacancy during mechanical have to be considered as a key point for the control of the formation mechanism of these oxide particles and their composition.

In our experimental work, we have performed implantations with Y, Ti, O ions with several energies into high purity Fe samples (99,99%) in order to simulate the mechanical alloying step used for ODS steel fabrication. A slow positron beam coupled to a Doppler broadening spectrometer (SPBDB) was used to characterize the vacancy defects and vacancy-solute interactions. The solutes depth profiles were measured using secondary ion mass spectrometry (SIMS).

The effect of annealing temperature on the defects and solutes profiles was studied up to 550°C. The results show several evolution stages such as the disappearance of vacancy defects and precipitation of solutes. SIMS analysis showed that titanium and yttrium do not migrate during annealing experiments while oxygen show a complex behavior of migration and trapping that depends on the material microstructure. SPBDB results show that solute implantations produce vacancy clusters, dislocations and vacancy-solute complexes. Their proportion evolve as a function of depth and nature of the implantations. Vacancy clusters and dislocations are detected deeper than the implantation peak with a higher fraction for the dislocations indicating that the defects were able to migrate during implantations. Vacancy-solute complexes are detected in the ion stopping zone and it is in a good agreement with the theoretical binding energy calculations. The nature and the distribution of the defects evolve according to the annealing temperature. Vacancy clusters disappear between room temperature and 300°C while the dislocations are eliminated from 400°C. Oxide phases are detected for annealing at 500 and 550°C due to the oxygen contamination during these annealing.

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