Fe+ Irradiation Effects on Iron Films

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For fusion energy applications FeCr based steels are candidate structural materials. Understanding the neutron irradiation effects on Fe and FeCr steels is of paramount importance for the development of radiation resistance materials and the implementation of future fusion reactor.

The initial interaction of neutrons with lattice atoms can lead to the production of high energy recoils, known as Primary Knock-on Atoms (PKA). The energy of the incident fusion neutrons is 14 MeV. However, as the neutrons penetrate within the material they lose energy and thus the PKAs of Fe have a range of energies with a mean energy of 490 keV. Consequently, the main part of the damage arising from neutron or other ions irradiation is due to energetic Fe atoms which create the radiation damage cascades. This phenomenon can be studied by employing Fe ion irradiation of Fe or FeCr alloys. Since the penetration of 490keV energetic Fe ions is 400 nm, thin films need to be investigated. By the selection of the film thickness, radiation damage and implantation can be introduced in the film.

The aim of the current work is to investigate the effects of the two different mechanisms taking place as far as structural and magnetic properties are concerned. Simulations on the interaction of 490 keV Fe+ with Fe films were carried out. The simulations showed that in Fe film thickness of around 50 nm the Fe implantation is negligible whereas the radiation damage considerable, while for 300 nm thickness the implantation is accompanied by radiation damage effects in the film. With this reasoning films of 50 and 300 nm thickness were fabricated. The irradiations were carried out with 490 keV for different irradiation doses.

The structural and magnetic changes prior and after the irradiation were assessed by X-ray diffraction, X-ray reflectivity, magnetometry and polarized neutron reflectivity measurements. No amorphicity is observed even for the highest irradiation dose of 1.3×10^{17} ions/cm^2. The lattice constant and the grain size present exponential growth as the irradiation dose increases and follow a universal curve.

The irradiation has a drastic effect on the magnetic properties of iron films revealing the different contribution of the two mechanisms. For the case of radiation damage effects, the magnetic moment per atom increases with irradiation dose, changing from 2.1 μ_B/at in the non irradiated film to 2.45 μ_B/at in the film with the maximum irradiation dose of 3.8×10^{16} ions/cm^2 [1] . This increase is attributed to the creation of vacancy clusters as it is known that the neighbouring and next neighbours Fe atoms of the cluster have increased magnetic moments. When radiation damage and implantation effects occur, the magnetic moment varies with depth. For the depth up to which radiation damage is predominant the magnetic moment increases with dose, whereas deeper in the Fe film where the implantation phenomena become significant the magnetic moment decreases with the increase of the irradiation dose.

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References

[1] K. Mergia *et al.*, *"Polarized neutron reflectivity reveals enhanced moment on Fe^+ irradiated iron films",* LLB, CEA, 2013 Annual Report.