Study of heavy ion irradiation induced defects in nanocrystalline nickel by positron annihilation spectroscopy, nanohardness and TEM

Julie S[1,2*], R, Ramachandran[1,2], K. R. Sekhar[1,2], C. David[1], R. Ramaseshan[1,2], R. Rajaraman[1,2], M. Kamruddin[1,2]

[1]*Materials Science Group, Indira Gandhi Centre for Atomic Research*
[2]*Homi Bhabha National Institute, Kalpakkam, 603 102, India*
*email: julies@igcar.gov.in

Advanced austenitic steels and their variants are being deployed as structural materials in fast reactors. Among major limitations in increasing the residence time of fuel in fast reactors is the void swelling of structural materials. Recent reports on austenitic steels with ultra-fine grains have shown significant reduction in void density and void sizes as compared to their coarse-grained counterpart [1]. Hence there is considerable interest in studying steels with nanometer sized grains. Large volume fractions of grain boundaries in nanocrystalline materials provide increased sink strengths for point defect fluxes and thereby promote radiation resistance. In order to exclusively evaluate the role of grain boundaries as sinks and excluding interactions of minor elements with point defects, it is important to study model austenite systems like Ni. In this context, a host of studies dealing with the response of nanocrystalline Ni to various ion irradiation conditions has emerged. However, most of these studies have focussed on observation of radiation-induced defects of sizes which are discernible with TEM. As well known, the ability of positrons in detecting open volume defects starting from atomic size to large vacancy clusters renders Positron Annihilation Spectroscopy (PAS) as a powerful tool for investigating defects even in their nucleation stages. The study of ion irradiation response in nanocrystalline nickel (NC-Ni) using PAS, TEM and nanohardness is reported here.

Self-standing NC-Ni coatings of thickness 500 μm with an average grain size of 20 nm measured by TEM were synthesized using pulsed electrodeposition. Positron lifetime measurements of these coatings showed two prominent life-times: τ_1=162±1 ps, τ_2= 374±11 ps with intensities of 91% and 9%, respectively. These correspond to positrons trapped in vacancies/dislocations at grain boundaries and micro-voids at triple junctions. Further, the samples were subjected to 1.4 MeV Ni^+ ion irradiations up to a damage levels of 0.18 and 18 dpa. The temperature during irradiations is 313K which is below the stage III in Ni (350K). The depth profiles of irradiation induced defects were obtained using a variable low energy positron beam based Doppler broadening measurements. The S-parameter ratio of pristine sample NC-Ni to a well annealed coarse grain Ni is 1.10 which corresponds to positrons trapping at vacancies/dislocations and is in agreement with the lifetime measurements. The diffusion length of positrons obtained using VEPFIT analysis for the pristine samples is of the order of the grain size (20 nm).

As regards the irradiated samples, there is a decrease in S-parameter values for both damage levels to saturated values which might correspond to SFT ($S_{NC\text{-}Ni}/S_{Ni}$=1.08) [2]. Increase in grain size and formation of SFT at both damage levels is confirmed from TEM studies. Nanohardness measurements reveals decrease in hardness values for irradiated samples as compared to the pristine. The observed non-monotonic reduction in hardness with dpa level is due to collective effects of grain growth and production of interstitial loops as observed from TEM.

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