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Quantifying C profiles in heavy ion irradiated Fe(50nm)/SiO_2(300nm)/Si stacks by ion beam analysis techniques*

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Accelerator-based ion irradiation is widely employed to investigate radiation effects in solids. In fusion materials research, it is particularly valuable as a surrogate approach for studying neutron-induced damage. For ion irradiation to serve as a reliable tool for radiation damage studies, extrinsic effects such as impurity incorporation during the irradiation process must be minimized.

Ion beam-induced carbon uptake is a notable concern, particularly in studies of Fe-based ferritic/martensitic steels, which are considered candidate structural materials for future fusion power plants. Carbon can influence microstructural evolution and irradiation response through its strong interaction with irradiation-induced point defects. Since the extent of carbon contamination depends on the specific experimental conditions, it is important for ion irradiation studies on steels to verify whether carbon uptake has occurred and, where possible, to quantify it.

In the present study, carbon depth profiles of irradiated pure Fe films were acquired by combined Rutherford Backscattering Spectrometry (RBS) and Nuclear Reaction Analysis (NRA). The 50 nm Fe films were deposited by DC magnetron sputtering onto Si substrates capped with a 300 nm thermally grown SiO_2 layer. The thickness and structure of the films were confirmed by X-ray reflectivity and grazing incidence X-ray diffraction. Specimens were irradiated with 4 MeV O^{2+} ions to a damage dose of 0.25 displacements per atom (dpa) and with 5 MeV Cu^{3+} ions to 1 dpa. The RBS/NRA measurements were performed using a 1.4 MeV deuterium beam and a surface barrier detector positioned at a scattering angle of 170°. Spectra were acquired from irradiated specimens, unirradiated reference samples, and the pristine Si/SiO_2 substrate. All irradiations were conducted at the 5.5 MV Tandem accelerator of NCSR "Demokritos". Carbon was detected via the $^{12}C(d,p_0)^{13}C$ reaction. The carbon signal comprised a high-energy peak, attributed to a surface layer typically formed under high-vacuum conditions by hydrocarbon deposition, and a low-energy tail, associated with carbon distributed throughout the sample volume. Carbon profiles were quantified by simulating the RBS/NRA spectra with the SIMNRA code. For the given experimental conditions, the detection limit for the carbon volume concentration was $\sim 2 \cdot 10^{19}$ at./cm^3. Carbon was identified in all specimens, exhibiting a characteristic near-surface enrichment and extending to a depth of approximately 4 μm. The irradiated specimens showed substantially higher carbon concentrations than the reference sample, consistent with ion-beam-induced carbon uptake. Quantitatively, the near-surface carbon concentration increased by $1.2(2) \cdot 10^{20}$ at./cm^3 and $2.4(2) \cdot 10^{20}$ at./cm^3 for the 0.25 dpa and 1 dpa specimens, respectively, demonstrating a dose-dependent enhancement of carbon incorporation.