The interaction mechanism between irradiation defects and helium in tungsten based alloys by positron annihilation spectroscopy

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Abstract: Tungsten-nickel-iron heavy alloy (W-Ni-Fe Heavy Alloy) is a primary candidate material for collimators, possessing excellent mechanical strength, ductility, and thermal conductivity. The collimator surfaces are bombarded by high-energy neutrons, helium plasma from fusion reactions, and inherent deuterium plasma from nuclear fuel, causing irradiation damage. These damages capture helium atoms, leading to material issues like irradiation swelling, hardening, and embrittlement, directly affecting the service life of collimators. Experiments using positron annihilation spectroscopy (PAS) were conducted to study the formation and evolution mechanisms of irradiation defects. Thermal desorption spectroscopy (TDS) was employed to investigate the migration mechanisms of helium within the material and its retention and desorption behavior. The results indicate that irradiation with 50 keV helium ions in pure W, 97W-2Ni-1Fe alloy, and 90W-7Ni-3Fe alloy generates numerous irradiation defects, increasing the S parameter in positron annihilation spectra. At an irradiation dose of 1×1017 ions/cm2, defects are predominantly vacancy-type, and helium bubbles were observed within the samples. At this dose, the helium desorption amount is roughly equal for both W-Ni-Fe alloys, about 6.5 times that of pure W. Isothermal annealing of the irradiated 97W-2Ni-1Fe alloy sample showed the emergence of numerous nano-protrusions on the surface at 800 ℃, which are the growth points of fuzz structures. As the irradiation dose increases, irradiation defects also increase, further elevating the S parameter of positron annihilation spectra. Excess helium atoms combine with vacancies to form HemVn and HemVn-NiFe complexes. When the dose increases to 5×1017 ions/cm2, bubbling phenomena can be observed on the sample surface. After thermal desorption, vacancy recovery occurs in the W-Ni-Fe alloy, reducing the S parameter, while the S parameter for pure W samples rises, indicating that helium bubble rupture causes greater damage to pure W samples. In conclusion, the addition of Ni and Fe elements can inhibit helium migration and aggregation to some extent. The helium retention rate in W-Ni-Fe alloys is lower than that in pure W, and their resistance to irradiation swelling is superior to that of pure W.