Helium Retention of Ion-irradiated and annealed Tungsten Foils

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In an inertial fusion energy (IFE) chamber, the tungsten armor on the first wall will be subjected to intense doses of ions. The most deleterious ions are helium in the energy range of 0.1-1 MeV. He ion irradiation damage creates vacancies within W that trap He and act as nucleation sites for He bubble growth. He trapping and bubble growth increases with dose and irradiation temperature due to increasing defect density and thermal mobility. At room temperature growth of He bubbles beneath the surface causes blistering at ~3 x $10^{21}/m^2$ and surface exfoliation at ~$10^{22}/m^2$. These critical doses increase with ion energy (in~1-2 MeV range), and are also dependent on annealing temperature as well as the annealing sequence. However, there is insufficient information on the effect due to MeV He ions and elevated temperature exposures and anneals. To understand the helium retention characteristics and helium bubble distribution of tungsten, a ^{3}He(d,p)^{4}He nuclear reaction analysis technique and transmission electron microscopy (TEM) have been performed for two forms of tungsten: single crystal and polycrystalline, implanted up to 1x10^{19} ^{3}He/m^2 and annealed to 2000°C.

Samples were implanted at 850°C, flash-heated at 2000°C, and analyzed by ^{3}He(d, p)^{4}He nuclear reaction with 780 keV deuterons. Surface blistering was observed for doses greater than 10^{21} He/m^2. Single crystal and polycrystalline tungsten samples implanted with 1 x 10^{19} He/m^2 at 850°C exhibited similar helium retention characteristics. A flash anneal at 2000°C had no effect on the retention of helium. This dose was low enough to avoid surface blistering, but high enough to result in strong helium trapping and bubble growth. Implantation and flash-heating in cycles indicated that retention strongly depends on the He dose per cycle and tungsten microstructure. When 10^{19} He/m^2 was implanted into single crystal tungsten in 1000 cycles (10^{16} He/m^2 per cycle), the observed helium yield dropped to ~5 % compared to ~30 % for polycrystalline tungsten. Considering the experimental results presented, the first wall of an IFE fusion reactor will potentially suffer from significant damage due to high fluences of helium ions and intense temperatures. Helium trapping and bubble formation just below the surface of the first wall material will result in surface blistering and exfoliation at critical helium doses. The data also suggest preference of single crystal over polycrystalline tungsten due to less retention compared to polycrystalline.