Max-Planck-Institut für Plasmaphysik, EURATOM Association

Carbon erosion and deuterium retention of tungsten-doped amorphous carbon films exposure to deuterium plasma

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Motivation

- Tritium retention in redeposited carbon is one of the most crucial issues in nuclear fusion
- Use of carbon together with metallic plasma-facing materials will lead to cycles of erosion of the PFMs by hydrogen and subsequent deposition of mixed carbon-metal layers
- Carbon-metal mixed layers will be subjected to further erosion
- D retention in such film unknown

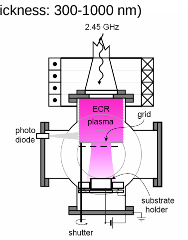
Experiments

Samples

- Preparation: Dual magnetron sputter deposition (Graphite: rf power, Tungsten: DC power)
- Film composition and thickness (*a*-C:W on silicon wafer, 0-7 at.% W, Thickness: 300-1000 nm)

Deuterium plasma exposure

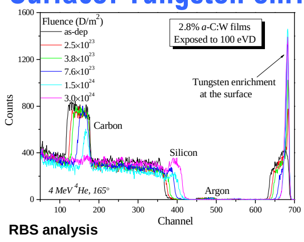
- ECR plasma ion source with freely expanding plasma beam (PlaQ)
- Ion energy: 30 eV/D, **100 eV/D**
- Ion flux: 8.8×10^{19} D/m^2, **1.05×10^{20} D/m^2**
- Fluence: from 1×10^{23} up to 7×10^{25} D/m^2
- Sample temperature: **300 K**

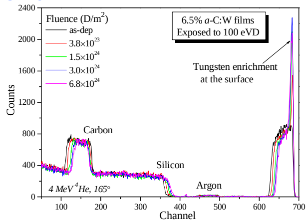


Characterization

- Nuclear reaction analysis: Deuterium retention, 700 keV, $^3He^+$ beam
- Rutherford backscattering spectrometry: Composition and thickness changes, 4000 keV, $^4He^+$ beam
- Atomic force microscopy/X-ray photoelectron spectroscopy: Surface morphology and chemical bonding

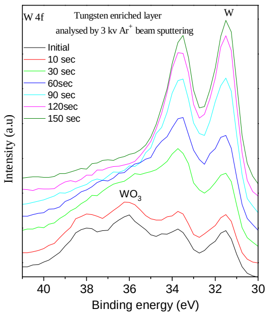
Surface: Tungsten enrichment

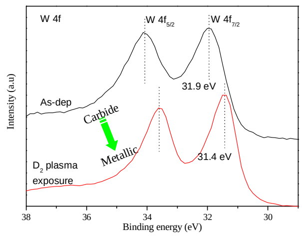




RBS analysis

- W-rich layer develops at the surface – a result of preferential erosion of carbon
- W enrichment increases with fluence, no W sputtering at 30 eV
- W enrichment accompanied by a slight W sputtering due to D^+ ions at 100 eV

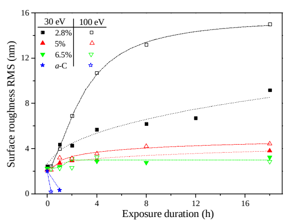


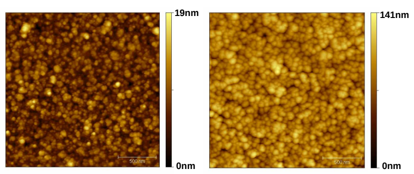


XPS analysis

- Tungsten carbide bonding in as-deposited film
- Tungsten metallic bonding after D plasma exposure

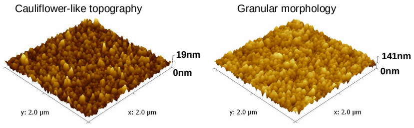
Surface: Morphology





Cauliflower-like topography

Granular morphology



AFM analysis

Initial surface

Fluence: 6×10^{24} D/m^2

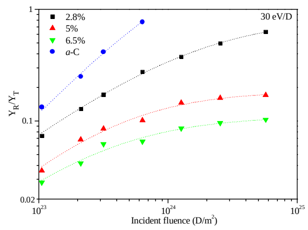
- Initial surface of *a*-C and *a*-C:W have comparable roughness
- Exposure of pure *a*-C film to deuterium plasma leads to an extremely smooth surface
- All tungsten-doped carbon films become even rougher after deuterium plasma exposure

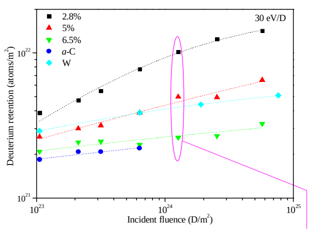
Summary

Exposure of W-doped amorphous carbon films to deuterium plasma

- Carbon removal rate of W-doped amorphous carbon films is clearly lower than the rate of pure amorphous carbon and decreases strongly with increasing W concentration. Carbon removal rates for *a*-C:W films decrease with increasing deuterium fluence due to a tungsten enriched-layer at the surface
- D retention in *a*-C:W films increases monotonically with increasing fluence, no obvious saturation detected in the investigated region.
- Deuterium penetrates surface tungsten-enriched layer and diffuses into the bulk *a*-C:W films, the diffusion depth is limited below to about 200 nm at 30 eV and increases to about 300 nm at 100 eV

Carbon erosion & deuterium retention





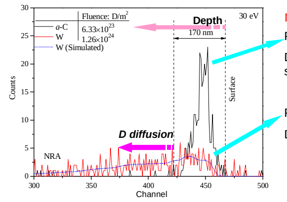
RBS analysis (Y_R: removed carbon amount, Y_T: total (initial) carbon amount)

W-doping reduces erosion rate by factors from 2 to 7 depending on the W concentration, carbon removal tends to saturate after fluence of 10^{24} D/m^2 in 5% and 6.5% a-C:W films

NRA analysis

D retention in a-C:W films increases monotonically with increasing fluence, no obvious saturation detected

Deuterium penetrates surface tungsten-enriched layer and diffuses into the bulk, the diffusion depth is limited to about 200 nm



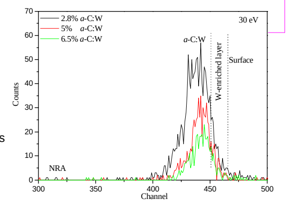
NRA alpha spectra

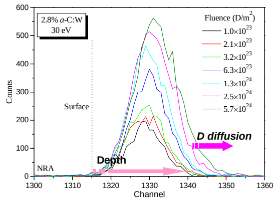
Pure *a*-C

D retained only at surface (< 200 nm)

Pure W

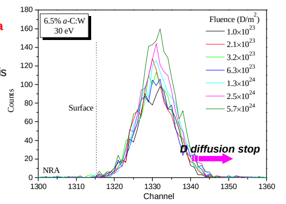
D diffusion dominates





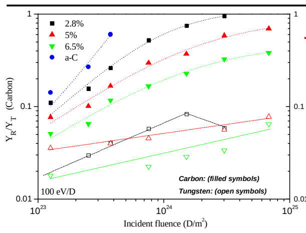
NRA proton spectra

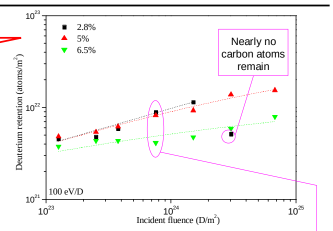
Deuterium retention is deeper and higher in lower concentration *a*-C:W film



30 eV

100 eV





RBS analysis (Y_R: removed carbon/tungsten amount, Y_T: total carbon/tungsten amount)

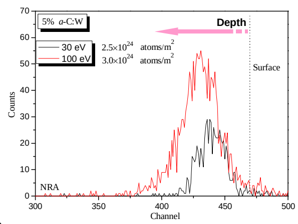
W-doping reduces erosion rate by factors from 2 to 5 depending on the W concentration, no carbon removal saturation for all investigated films

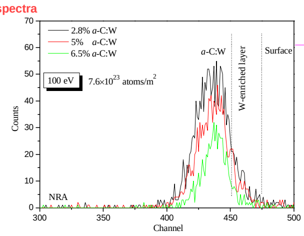
A slight tungsten sputtering can be detected at 100 eV due to D^+ ions

NRA analysis

The diffusion depth reaches to 300 nm at 100 eV, and the deuterium retention is deeper and higher compared to 30 eV

NRA alpha spectra





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