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Plasma-material interaction research at the MAGPIE Facility

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Plasma-facing materials in fusion reactors must be capable of withstanding large heat loads (up to 10 MW/m2) due to energetically charged and neutral particle bombardment (eV to keV). Additional consideration should also be given to irradiation damage resulting from the high-energy neutron flux (14.1 MeV) created by the fusion reactions.

Tungsten has been chosen as the material for the ITER divertor and is a contender for the wall of DEMO, which will experience temperatures in excess of 1000 K. The interaction between high-flux helium plasmas with tungsten can lead to plasma-induced surface modifications. In particular helium retention in tungsten is problematic, since helium is known to form nano-scale bubbles beneath the surface, and is thought to be responsible for the formation of nano-fuzz and surface pitting [1, 2].

The consequence of helium-induced nanostructure changes in tungsten remains an important question for the operation of ITER's divertor. In particular, helium exposure can significantly reduce thermal conductivity [3] and increase the hardness [4] of tungsten, which is likely a consequence of the nano-scale bubbles that form beneath the material surface. Exposure to neutron irradiation during burning plasma operation is likely to complicate this matter further by introducing additional defect structures within the material, which in turn may change helium behaviour and tungsten's mechanical properties.

In this work the role of nanoscale modification on changing the mechanical properties of tungsten is investigated. Tungsten samples were exposed to both pure helium and mixed deuterium/helium plasmas using the MAGPIE linear plasma device [5]. In addition, some samples were exposed to a combination of high-energy heavy-ion implantation and plasma irradiation to study possible effects of neutron induced damage. Nano-bubble formation is quantified using Grazing Incidence Small Angle X-ray Scattering (GISAXS), while helium and deuterium retention is determined by Elastic Recoil Detection Analysis (ERDA). Nano-indentation is used to determine changes in the materials mechanical properties.

Results show an increase in hardness after exposure to both heavy-ion implantation and helium plasma. Recent advancements in GISAXS analysis methodology allow nanoscale bubble populations to be studied in unprecedented detail (Figure 1). A relationship between nanoscale bubble formation and tungsten hardness, for both heavy-ion implanted and non-implanted samples, and for mixed deuterium/helium plasma will also be presented.

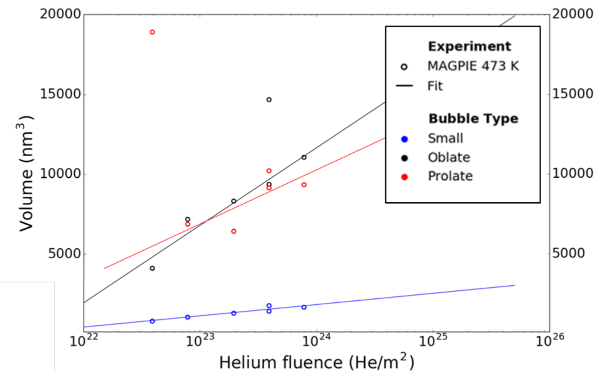

Figure 1. GISAXS measurement of median bubble volume of nano-bubbles exposed to mixed He/D plasma at 473 K. Several distinct sub-populations were classified based on their size and shape, which likely form via different mechanisms. D fluence (not shown) had no significant effect on nano-bubble behavior.

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