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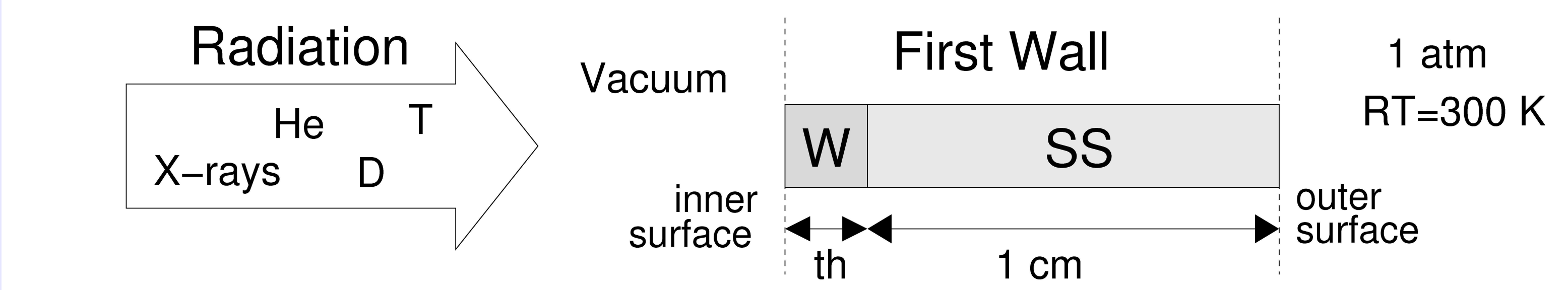
AN OVERVIEW ON ARMOUR RESEARCH FOR THE LASER FUSION PROJECT HIPER

ABSTRACT

During the current preparatory phase of the European laser fusion project HiPER, an intensive effort has being placed to identify an armour material able to protect the internal walls of the chamber against the high thermal loads and high fluxes of x-rays and ions produced during the fusion explosions. This poster addresses the different threats and limitations of a poly-crystalline Tungsten armour. The analysis is carried out under the conditions of an experimental chamber hypothetically constructed to demonstrate laser fusion in a repetitive mode, subjected to a few thousand 48MJ shock ignition shots during its entire lifetime. If compared to the literature, an extrapolation of the thermo-mechanical and atomistic effects obtained from the simulations of the experimental chamber to the conditions of a Demo reactor (working 24/7 at hundreds of MW) or a future power plant (producing GW) suggests that "standard" tungsten will not be a suitable armour. Thus, new materials based on nano-structured W and C are being investigated as possible candidates. The research programme launched by the HiPER material team is introduced.

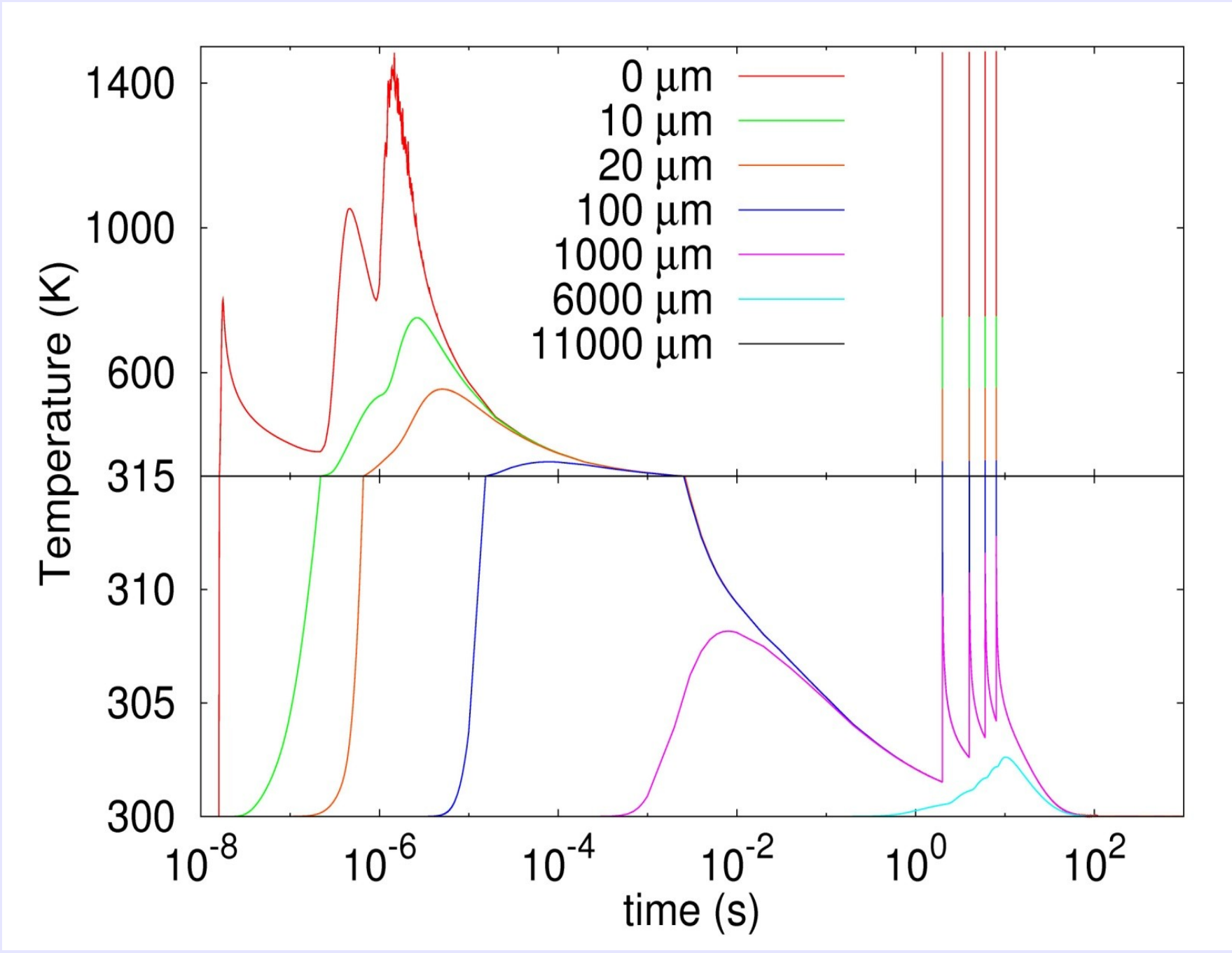
SIMULATION CONDITIONS FOR EXPERIMENTAL CHAMBER

- Spherical chamber of 5 m radius, with an inner Tungsten armour of 1 mm and a 1 cm structure of Stainless Steel at room temperature.
- Experimental campaigns of 5 shots of 48 MJ targets at 0.1 Hz.

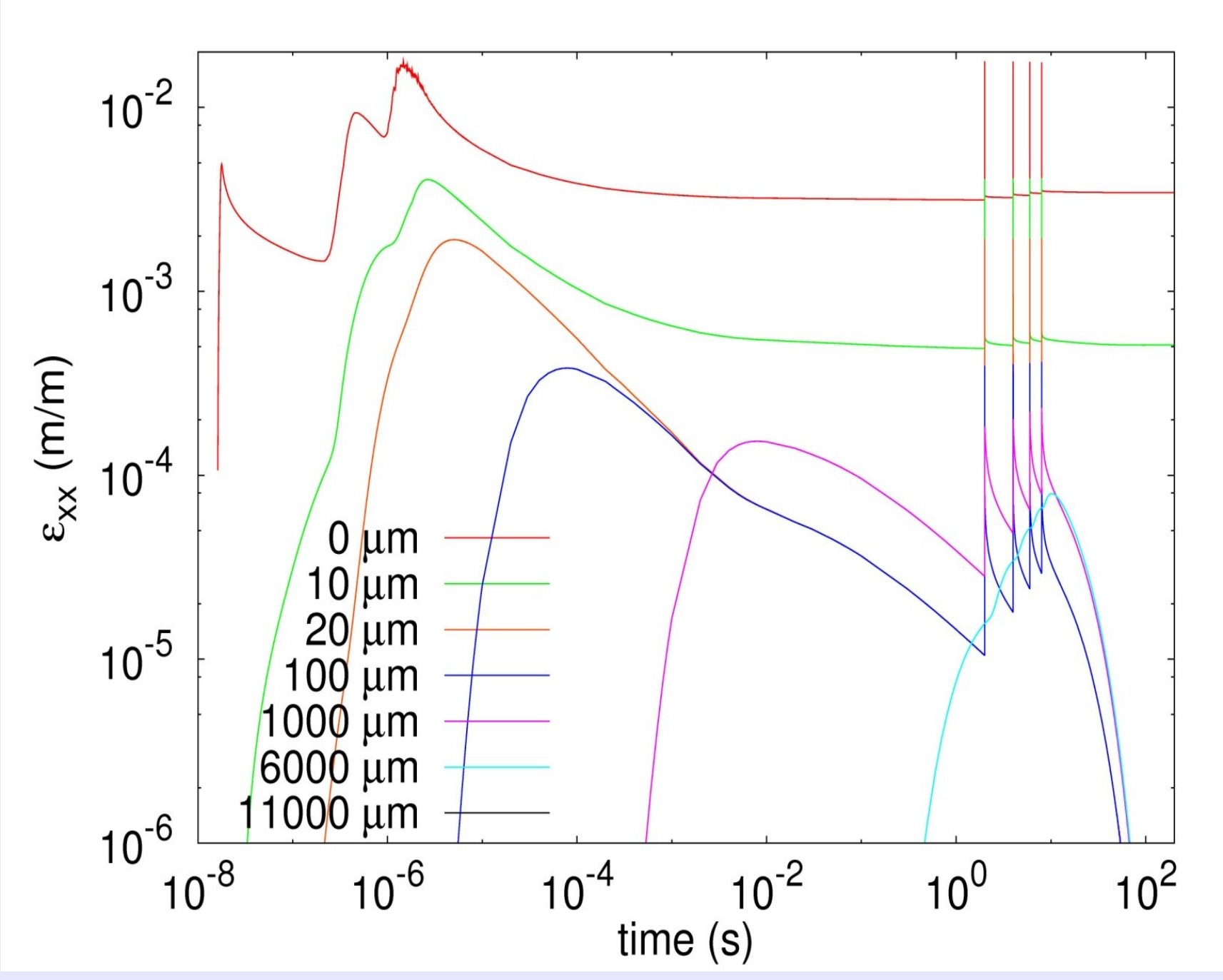


THERMO-MECHANICAL EFFECTS

Each 48MJ shock ignition explosion deposits around 35kJ/m^2 on the first wall in less than 3μs. In the case of W, that energy is deposited mostly in the first 3 μm.



Thermal response of W wall during 5 pulses. After that T decreases to room T in hundreds of seconds.



After the 5 shots, W depths<20μm deforms plastically ($\varepsilon_{xx} \neq 0$)

ATOMISTIC EFFECTS

Fusion products have very high energy and, when impacting with the first wall, they cause damage by: sputtering, atomic displacements (dpa), swelling and chemical changes. The following table gives rough numbers of implanted atoms, sputting yields and dpa per fusion shot. Last column shows the percentage of particles in the W, 24 h after the pulses (the diffusion study did not include trapping).

Shot	Fluence (at/m2)	Sput (at/m2)	Dpas	**Inventory 24 h after the 5 shots (%)**
D	$3{,}3\times10^{17}$	$4{,}3\times10^{14}$	2×10^{-3}	48%
T	$3{,}0\times10^{17}$	$3{,}9\times10^{14}$	3×10^{-4}	62%
He	$5{,}4\times10^{16}$	$1{,}5\times10^{14}$	7×10^{-4}	0.01%
C	$4{,}4\times10^{16}$	$8{,}8\times10^{14}$	$2{,}2\times10^{-2}$	Does not diffuse

As reference, W has an atomic density of $6{,}3\times10^{28}$at/m^3 and a surface density of $2{,}5\times10^{19}$at/m^2.

The atomistic effect of the X-rays (masive photo-electric effect and subsequent E-M pulse) has not been considered yet.

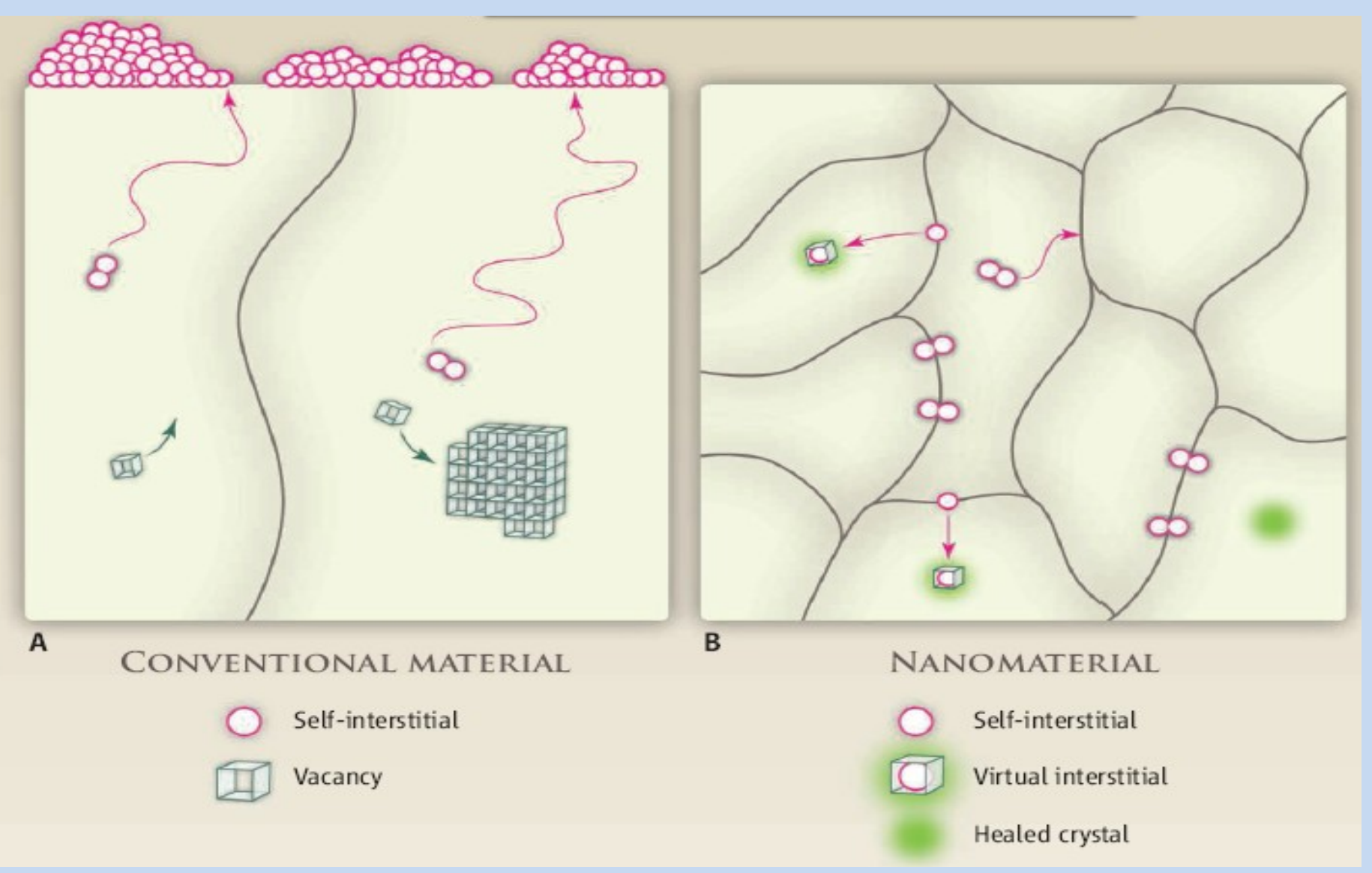
EXTRAPOLATION TO DEMO REACTOR

A demo reactor working 24/7 (3×10^8 shots/year) will most likely damage the W. The thermal expansion cycles and deformations will tend to produce cracking and material loss [1].

Sputtering and dpa will probably help to increase trapping of species which favours swelling and exfoliation of W[2].

RESEARCH ON NEW MATERIALS

Basics: Nanostructured Materials



G. Ackland, Science 327, 1587 (2010)

Nanostructured materials are very promising because:

+ increase self-healing properties
decrease species retentions

However, there are some caveats:

− thermal conductivity is reduced
grain instability with temperature

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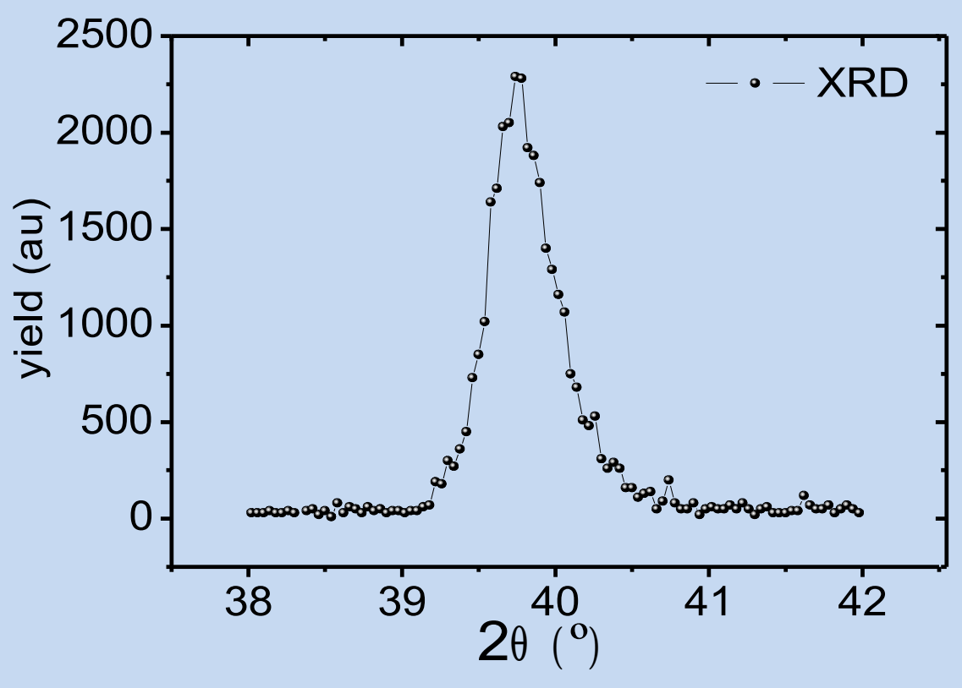
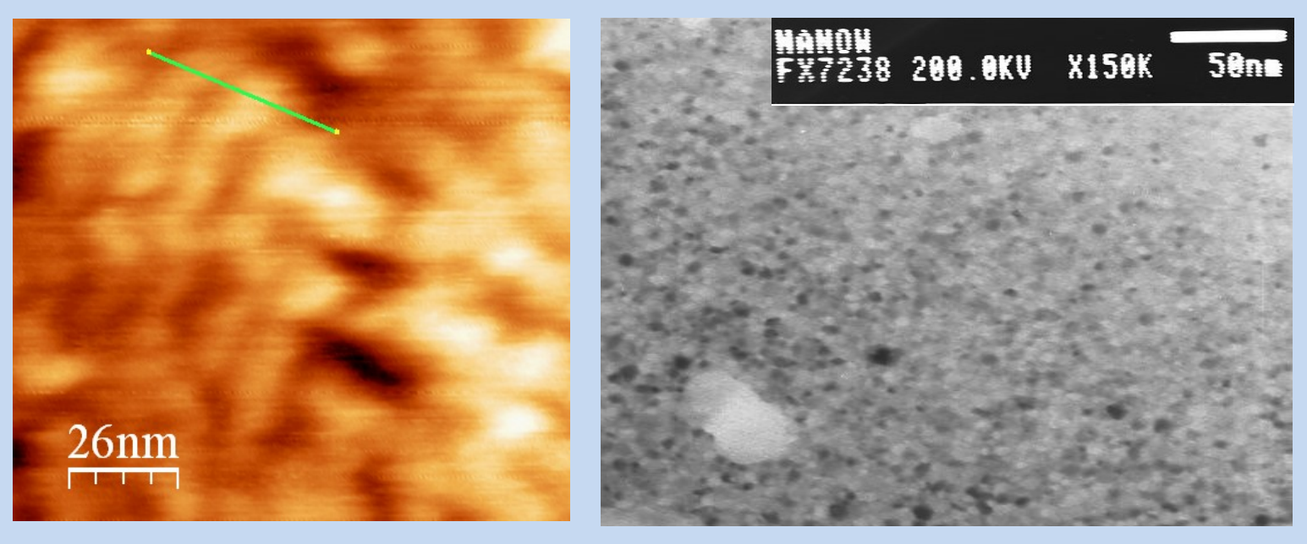
NANOSTRUCTURED TUNGSTEN

Samples were grown using DC sputtering at RT. Morphological and structural characterization of nanocrystalline W has already been performed. We are currently studying the thermal stability of grains prior to ion irradiation experiments.



Samples are preferentially oriented along the (110) direction



Films present very small grains with a size of ~ 5nm

This project is in collaboration with:
*Dr. I. Fernandez-Martinez and Prof. F. Briones (*IMM-CNM-CSIC*)*
Dr. J. del Rio Departamento de Física de Materiales, Facultad de CC. Físicas (UCM)
Dra. C. Gomez Departamento de Física de Materiales, Facultad de CC. Químicas (UCM)

NANO DIAMOND

The attractiveness of nanodiamond relies on its higher crystalline stability (reduced graphitization)[3], better radiation-resistance properties (self-healing properties)[4] and presumably reduced chemical erosion probably improved even further with appropriate doping[5]. Their higher radiation resistance in comparison with bulk isochemical and isostructural counterparts is explained by annihilation of radiation defects at abundant sinks such as grain boundaries.

Samples will be produced by Detonation ND: Detonation of high energy explosives in oxygen-poor atmosphere and subsequent chemical etching of residual non-diamond carbon.

This proyect is in collaboration with:
-Prof.Bogdan Pałosz, Institute of High Pressure Physics of the Polish Academy of Sciences (IHPP)
-Dr. A.A. Shiryaev Institute of Physical Chemistry (IPCE) and the General Physics Institute (GPI) of the Russian Academy of Sciences