Mechanical, Erosion and Permeation Properties of Nanostructured W and W-Ta Coatings

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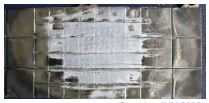
Abstract & Motivations

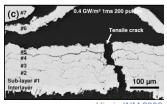
Tungsten is considered to be a promising first wall material thanks to its low sputtering yield and good thermal behaviour. The feature of W coatings are strongly influenced by their structure and morphology at nanometric scale.

The employment of tungsten films in tokamaks has already been exploited revealing several issues and concerns:

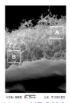
melting, cracks, peeling, delamination, brittle carbide and porous "fuzzy" structures formation.



Garuska, JNM 2009



Hirai, JNM 2009



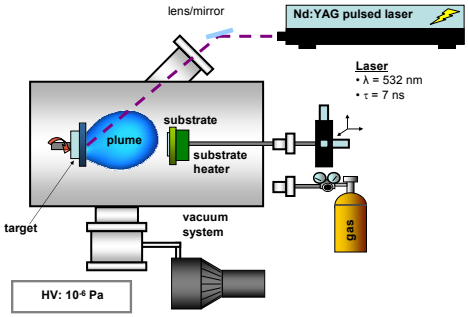
Baldwin, NF 2008

In addition, fuel diffusion and retention properties are crucial issues for all W. The properties of tungsten as hydrogen barrier layer are also under investigation.

In this work Pulsed Laser Deposition (PLD) is adopted for the production of W films on EUROFER. By varying the process parameters it is possible to tailor the nanocrystalline domain size of the films down to few nm, modifying their properties.

Films have been characterized by XRD, AFM and SEM. Mechanical properties and adhesion of the films have been tested with indentation and scratch tests, hydrogen permeation measurements are ongoing.

Pulsed Laser Deposition



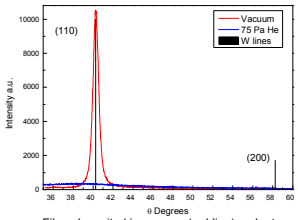
Deposition parameters
- He pressure P: 0-75 Pa
- Laser fluence F: 1-10 J/cm²
- Target-sub. dist. d_{t-s}: 6 cm

Target
- Metallic Tungsten
- Metallic Tantalum

Substrates
- Si(100)
- Molybdenum
- EUROFER

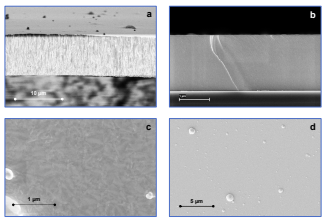
W films with different structures

XRD analysis



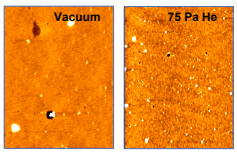
Films deposited in vacuum (red line) and at 75 Pa He (blue line)

SEM analysis



Films deposited in vacuum (a-c) and at 75 Pa He (b-d)

AFM analysis



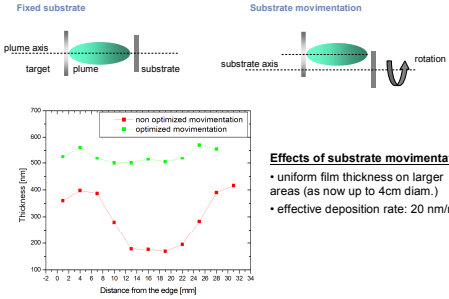
Films on Si with scan size of 10 µm

He pressure	Roughness RMS
vacuum	1.0425 mn
75 Pa	0.4784 nm

Roughness calculation by means of AFM analysis

Using a **background gas** during the deposition, it is possible to control either the film structure or the film morphology, moving from a **columnar crystalline film** to a **nanocrystalline amorphous – like** one, maintaining good surface parameters

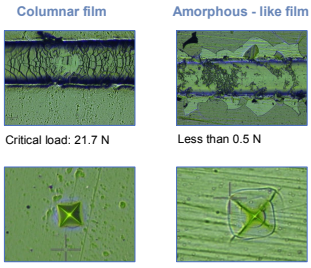
Increasing film area



Effects of substrate movimentation
- uniform film thickness on larger areas (as now up to 4cm diam.)
- effective deposition rate: 20 nm/min

W thick films mechanical properties

Mechanical properties on Molybdenum



Critical load: 21.7 N

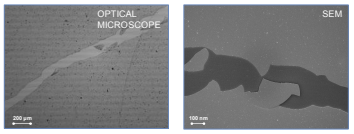
Less than 0.5 N

Indentation of the two films at 500 mN. Different fracture mechanisms are clearly visible

Film morphology	Hardness	Elastic Modulus (at 50 mN)
Columnar (0 Pa)	1158 HV	334 GPa
Amorphous-like (75 Pa)	1343 HV	246 GPa

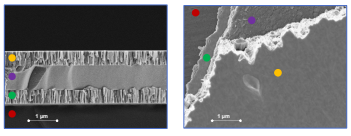
The columnar film exhibits strong substrate adhesion
The amorphous like film exhibits poor adhesion but strong cohesion

Optimization of the film on EUROFER



Examples of cracking in high thickness film due to internal stresses

Multilayer structure offers the possibility to combine the different film properties towards optimum:
- Columnar layer to maximize adhesion on the substrate
- Amorphous interlayer in order to relax the stresses
- The film grows indipendently with desidered mechanical behaviour on high thickness (up to 15 microns)

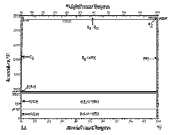


Substrate - EUROFER
Adhesion layer

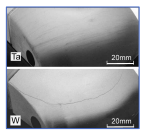
Mechanical interlayer
Micrometric thick film

W-Ta alloys

In order to improve mechanical properties **alloying pure tungsten in a binary system** can be a possible solution. Tantalum has a very high ductility and low thermal conductivity. Moreover W-Ta have unlimited solubility, potentially allowing the achievement of the desired combination.



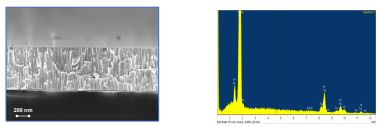
W-Ta phase diagram
Okamoto, JPE 2001



Ta and W limiters exposed to the plasma
Hirai et al., JNM 2003

First results

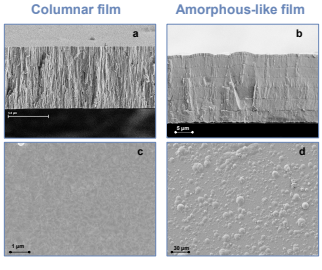
Simultaneous ablation of both materials allow the production of a W-Ta alloy. **The alloy composition can be varied by choosing the proportion of W and Ta in the target.**

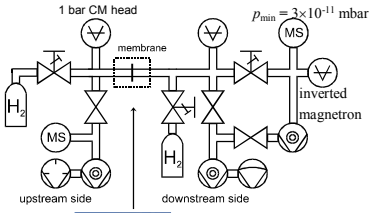


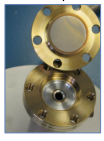
SEM cross section of a 1-µm film deposited in vacuum on Si and relative EDS spectrum. EDS **analysis revealed a composition 20%Ta-80% W**

Permeation measurements

10 µm uniform films have been deposited on 40 mm diam EUROFER disks with either columnar (a,c) or amorphous-like structure (b,d).







Hydrogen permeability of these W films will be tested at "Jožef Stefan" Institute, Ljubljana, Slovenia in order to understand structure role in permeation mechanisms and compare them with other W films*

* B. Zajec, JNM 2011

Conclusions

PLD has been successfully exploited in the production of nanostructured W and W-Ta films. In particular we obtained:

- very fine control of the film's structure, depositing both a columnar and an amorphous - like film
- micrometric films with good planarity over an extension of more than 16 cm²
- multilayer film is a possible solution for achieving desired thickness and optimized mechanical properties
- W-Ta alloys with desired composition can be produced by using a composite target
- by depositing on EUROFER we produced films suitable for permeation measurement (ongoing at Jozef Stefan Institute) to determine the effect of film structure on hydrogen retention