Thick Tungsten and Rhenium coating by Chemical Vapor Deposition for fusion applications

Use of Tungsten coatings in fusion and X-ray applications

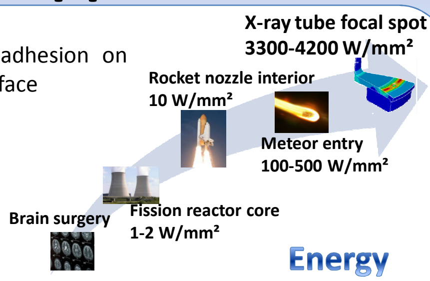
Constraints for Tungsten coating in fusion	CVD-W characteristics
High thermal load	High purity
Particles bombardment (abrasion)	High density
High operating temperature (until 1500°C)	High thermal conductivity
Need of high thermal conductivity	Fine control of deposited thickness (µm to mm)

Same constraints for fusion and X-ray applications

Acerde uses Chemical Vapor Deposition to deposit an X-ray-emitting tungsten layer on substrates in order to produce rotating X-ray anodes used in medical imaging devices.

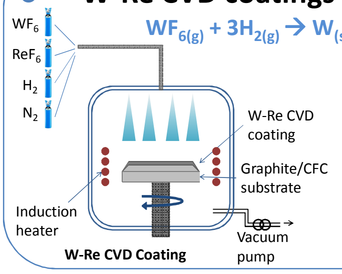
Problematics:

- Tungsten-layer adhesion on a carbon-rich surface
- Avoid cracking



W-Re CVD coatings

$WF_{6(g)} + 3H_{2(g)} \rightarrow W_{(s)} + 6HF_{(g)}$



W-Re CVD Coating


CVD reactor

CVD: 1 operation

1. Interface
   - Re barrier
   - Alternation of thin W and Re layers
2. W Coating
   - Alternation of thin Re interlayers and thick W layers

Experiments

CVD → Short annealing → TESTS 1200/1400 °C

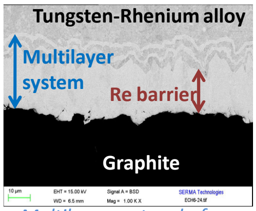
Results: Carburization and barrier (1)

Interface:

It is well-known [1,2,3] that a Rhenium-multilayer system can act as a barrier to prevent carbon migration.

This multilayer system is deposited between the graphite substrate and the tungsten layer and included:

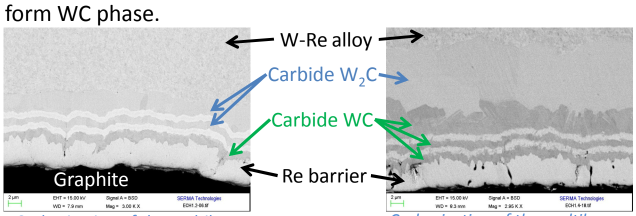
1. A thick Rhenium layer called barrier
2. An alternation of thin Tungsten-layers and Rhenium-layers.



Multilayer system before carburization

Carburization:

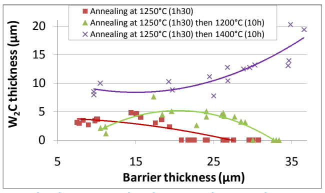
During high temperature exposure, carbon diffusion from the substrate to the W-layer leads to W_2C formation [4,5].
Then, carbon atoms from the substrate react with W_2C phase to form WC phase.



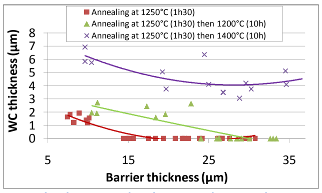
Carburization of the multilayer system after annealing at 1250°C – 1h30

Carburization of the multilayer system after annealing at 1250°C – 1h30 + 1400°C – 10h

→Acerde studied carburization progression depending on the Re-barrier thickness



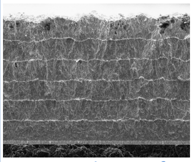
Carbide W_2C thickness depending on barrier thickness



Carbide WC thickness depending on barrier thickness

- Barrier thickness <20µm: after a short annealing at least at 1250°C, a controlled carbide layer is formed. This will reduce unwanted carburization during use at low temperature (1200°C) and high temperature (1400°C).
- Barrier thickness >25µm: only W_2C at 1200°C is formed but there is uncontrolled carburization at 1400°C

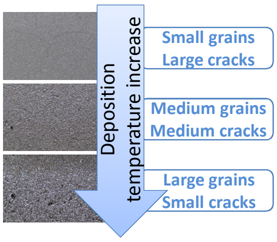
Results: Cracking resistance (2)


Sectional view of a coating made of several W-layers with Re-interlayers

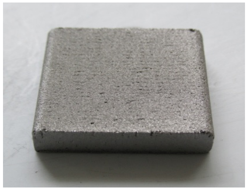
- The tungsten layer is deposited in several successive layers with rhenium interlayers. Between each W-layer, the system is cooled to release thermal stresses.

*→ Patents **FR2962591** and **FR1451695***

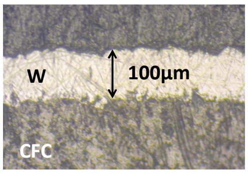
- More, the interface between each layer will interfere to the cracks propagation and avoid the complete cracking of the coating



Experiments for WEST:

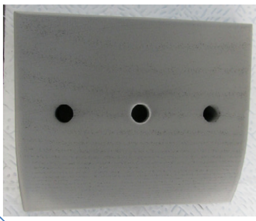

CFC tile with W-coating for divertor

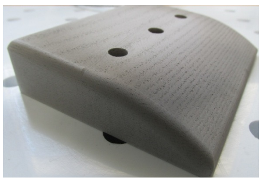
- ACERDE realized tungsten coatings on CFC tiles prototypes for divertor that are currently being tested by the *Design and Exploitation of Plasma Facing Components Group* (Cadarache)

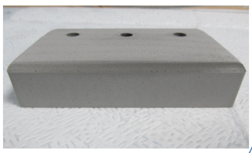


Cross sectional view of the W-coating on CFC tile

- ACERDE also realized W-deposition experiments on CFC bricks for Tokamak first wall







CFC brick with W-coating for first wall

Conclusion

Carburization:

- The best barrier thickness is between 20 and 25 µm ; this allow first controlled carbide layer formation which will prevent uncontrolled carbide formation during use at low temperature

Cracking resistance:

- Depositing several successive layers with intercooling allows to reduce thermal stresses and control cracking
- High temperature deposition leads to less critical crack appearance

- **Using HTCVD process developed by ACERDE, W-layers and Re-interlayers can be deposited in only one run**
- **Compared to requirements for fusion applications, HTCVD W-coating is a good alternative**

(1) Liu et al. (2004) "High heat flux properties of pure tungsten and plasma sprayed tungsten coatings"; (2) Hirai et al. (2009) "Failure Modes of Vacuum Plasma Spray Tungsten Coatings Created on Carbon Fibre Composites under Thermal Load"; (3) Tamura et al. (2004) " High-temperature properties of joint interface of VPS-tungsten coated CFC"; (4) Schmid et al. (2002) "Concentration dependent diffusion of carbon in tungsten"; (5) Luthin et al. (2000) "Carbon films and carbide formation on tungsten"

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