INSTITUTE OF PLASMA PHYSICS
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Plasma Sprayed Tungsten-based Coatings and their Usage in Edge Plasma Region of Tokamaks

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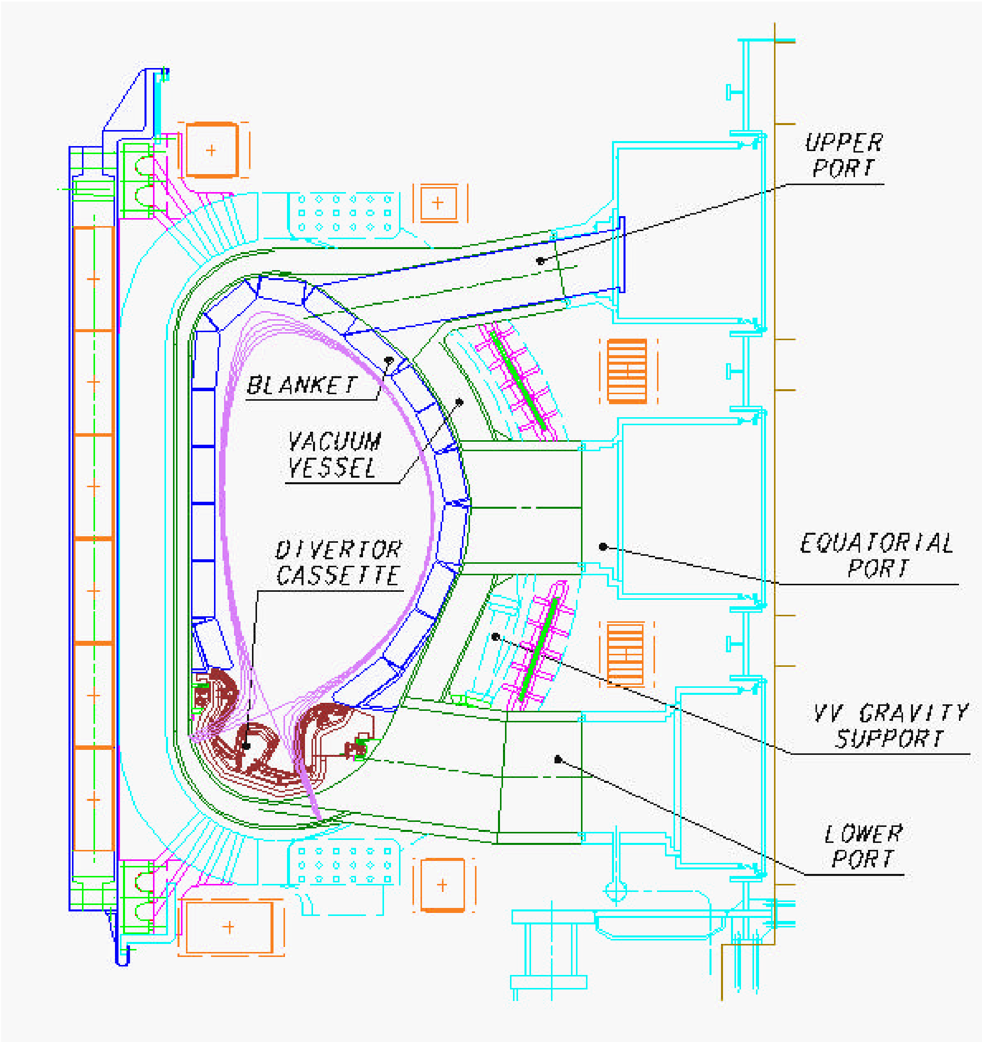
Outline

- **Introduction**
  - Plasma facing components for fusion reactors
  - Rationale for tungsten
- **Plasma spraying of tungsten**
  - Water- and hybrid-stabilized plasma torches
  - Coating properties and optimization
- **Testing in tokamak CASTOR**
  - With and without biasing
  - Effects on plasma discharge
  - Effects on the materials

Plasma facing components



ITER – vessel cross section

Plasma facing components:

- high heat and particle flux from the plasma

Material requirements:

- high melting point
- high erosion resistance
- high thermal conductivity
- thermal shock resistance
- compatibility with plasma and the cooling system

Advantages of PS:

- large area coatings
- non-planar surfaces
- graded layers

Plasma spraying of W

Tungsten:

- difficult to melt (T_m = 3410 C, ρ = 19.3 g/cm^3)
- in-flight oxidation and oxide evaporation

Spraying optimization:

- powder size selection
- reduced oxidation
- reduced porosity, increased thermal conductivity

Spraying techniques:

- water-stabilized plasma
- hybrid-stabilized plasma (water+argon)

- in air

Spraying development

Powder size selection:

criteria: deposition efficiency, porosity, Young’s modulus, oxide content, thermal conductivity

=> fine powder 63-80 µm selected

Reducing the oxidation:

Inert gas shrouding: only very small efefcts

Auto-shrouding: admixture of WC

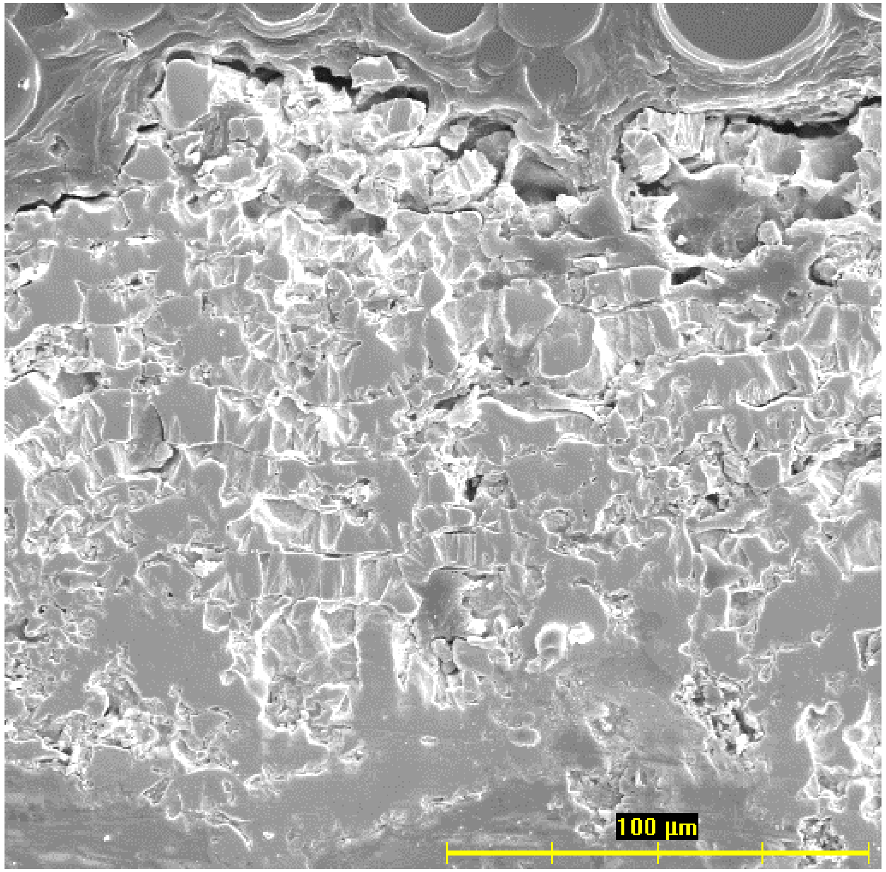
decarburization of WC -> W_2C -> W

C reacts with oxygen, forms carbon oxide

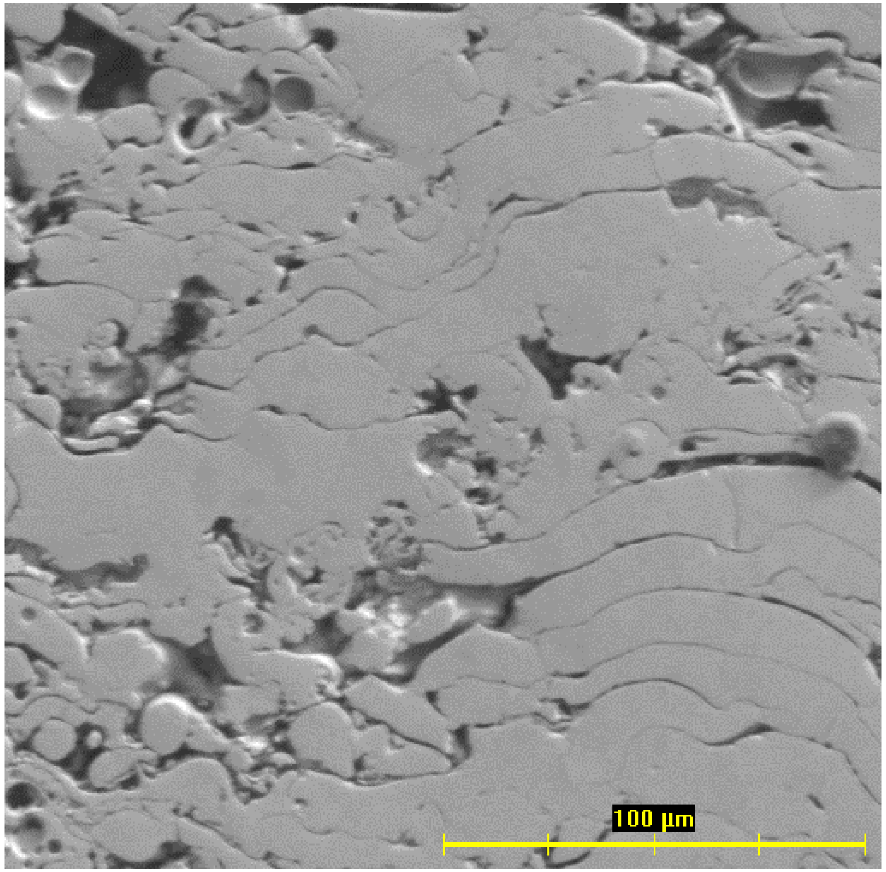
limits oxygen access to tungsten

Very little oxide in the coatings (~0.3-0.5% surface, 0.05% inside)

Reducing the in-flight oxidation



pure W

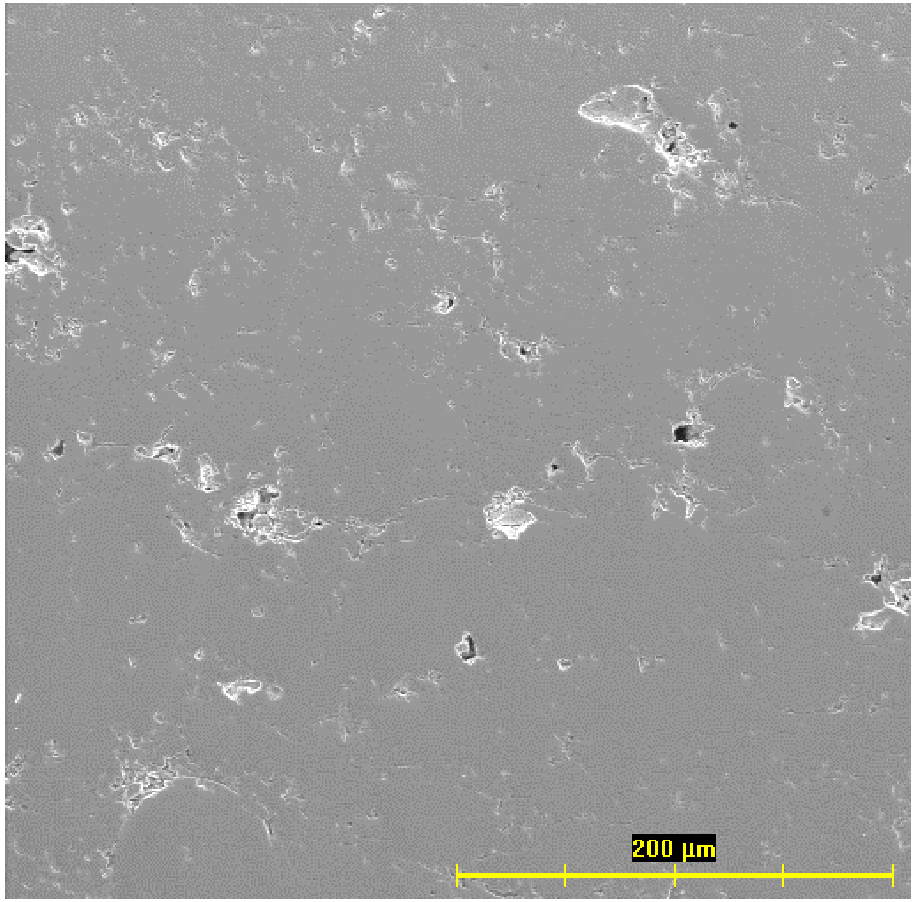


W+WC 5:1

Spraying by hybrid torch

- lower plasma temperatures
- Ar stabilizes and elongates the arc

- lower porosity
- fewer unbonded interfaces
- less oxide

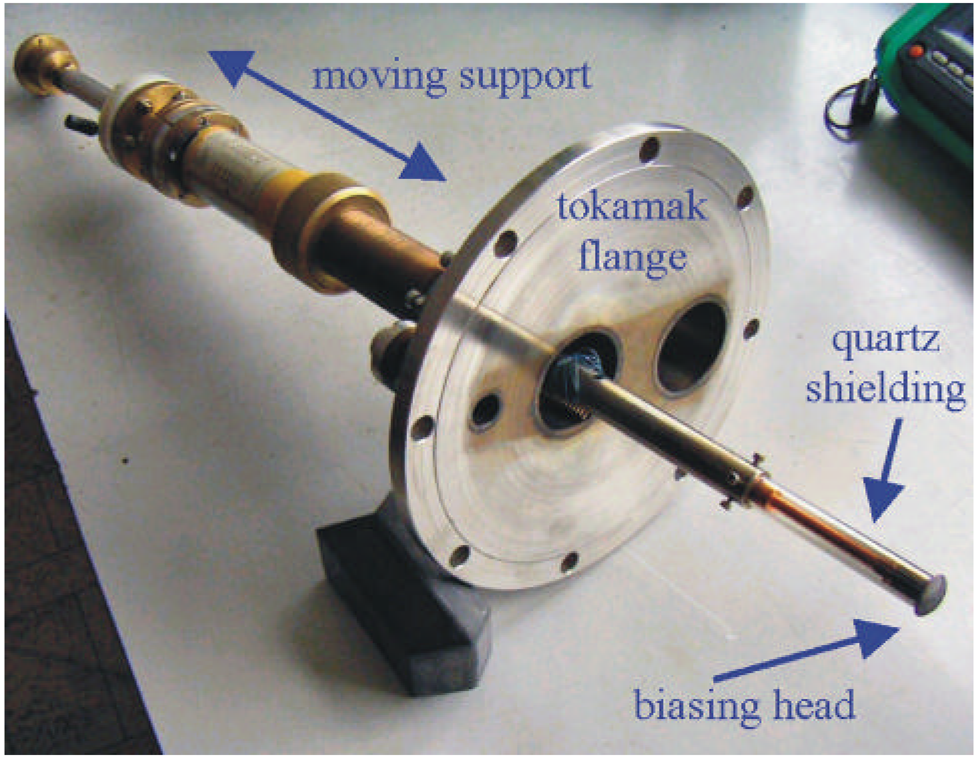


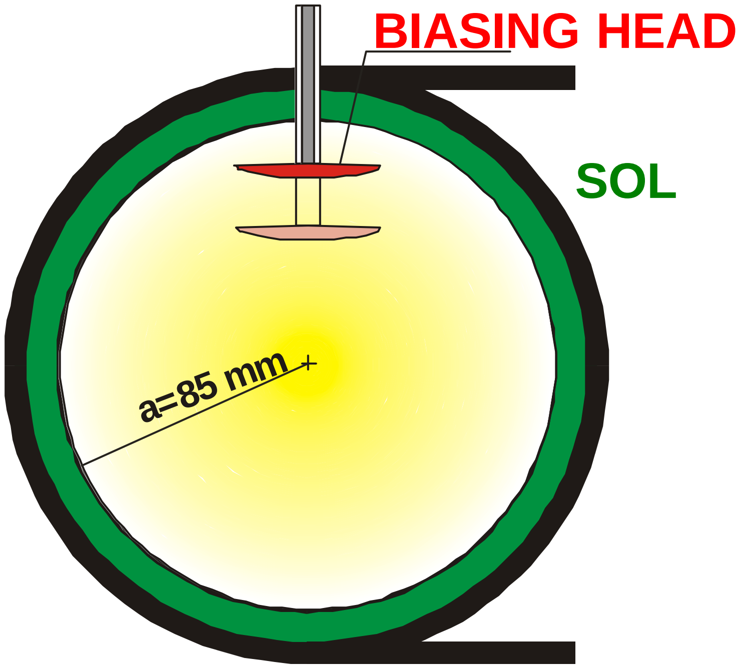
pure W

Testing at tokamak CASTOR

Experimental setup:

Biasing electrode with a changeable head





Testing at CASTOR (2)

Biasing head materials:

Plasma sprayed W

Plasma sprayed W+Cu (50:50 vol.)

Bulk W

Bulk Cu

Bulk graphite

Testing at CASTOR (3)

Plasma observations:

Biasing current measurements
Floating potential and plasma density measurements

Spectroscopic observations
- radiation of C III line (464.7 nm)
- radiation of W I line (400.9 nm)

Bolometric observations
- radiated power, radiation width and shift

Material observations:

Surface morphology
Surface composition (EMPA, RBS, ERDA)

Effects on plasma discharge

• $\lvert U_B - U_{fl} \rvert < 50\text{-}100$ V	- no change of discharge parameters
• $\lvert U_B - U_{fl} \rvert \sim 100\text{-}300$ V	- plasma density increase (improved confinement)
	- I_B in order of tens Amps
	- clear mainly for positive U_B
• $\lvert U_B \rvert > \sim 300$ V	- **arcing** from the biased electrode ($I_B > 50$ A)
	- minor electrode erosion
	- disruptions ($I_B > 150$ A)

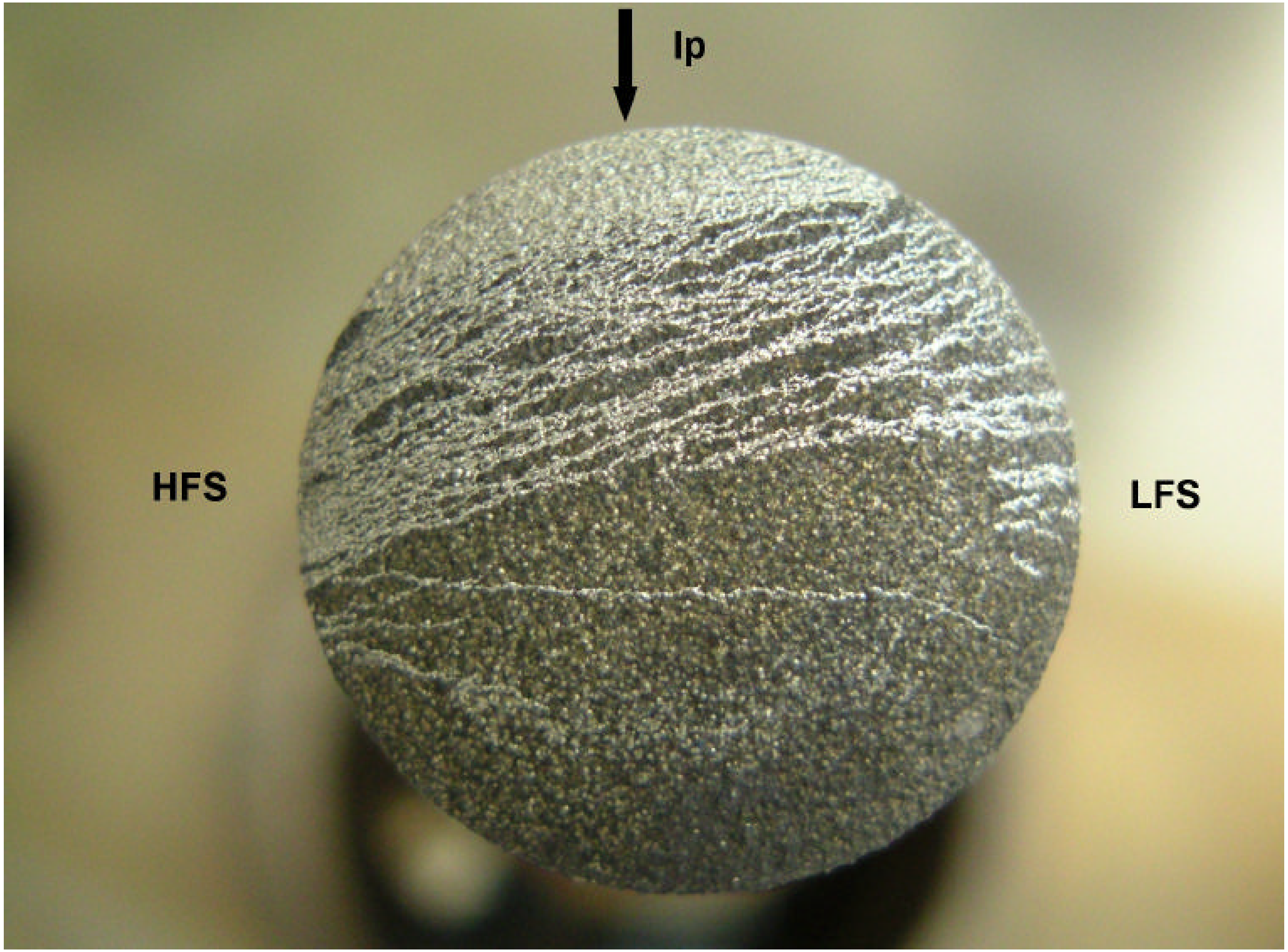
$\lvert I_B \rvert$ increases with $\lvert U_B \rvert$

• depends on the **electrode material** as well as the **electrode position**

C radiation mainly at positive bias

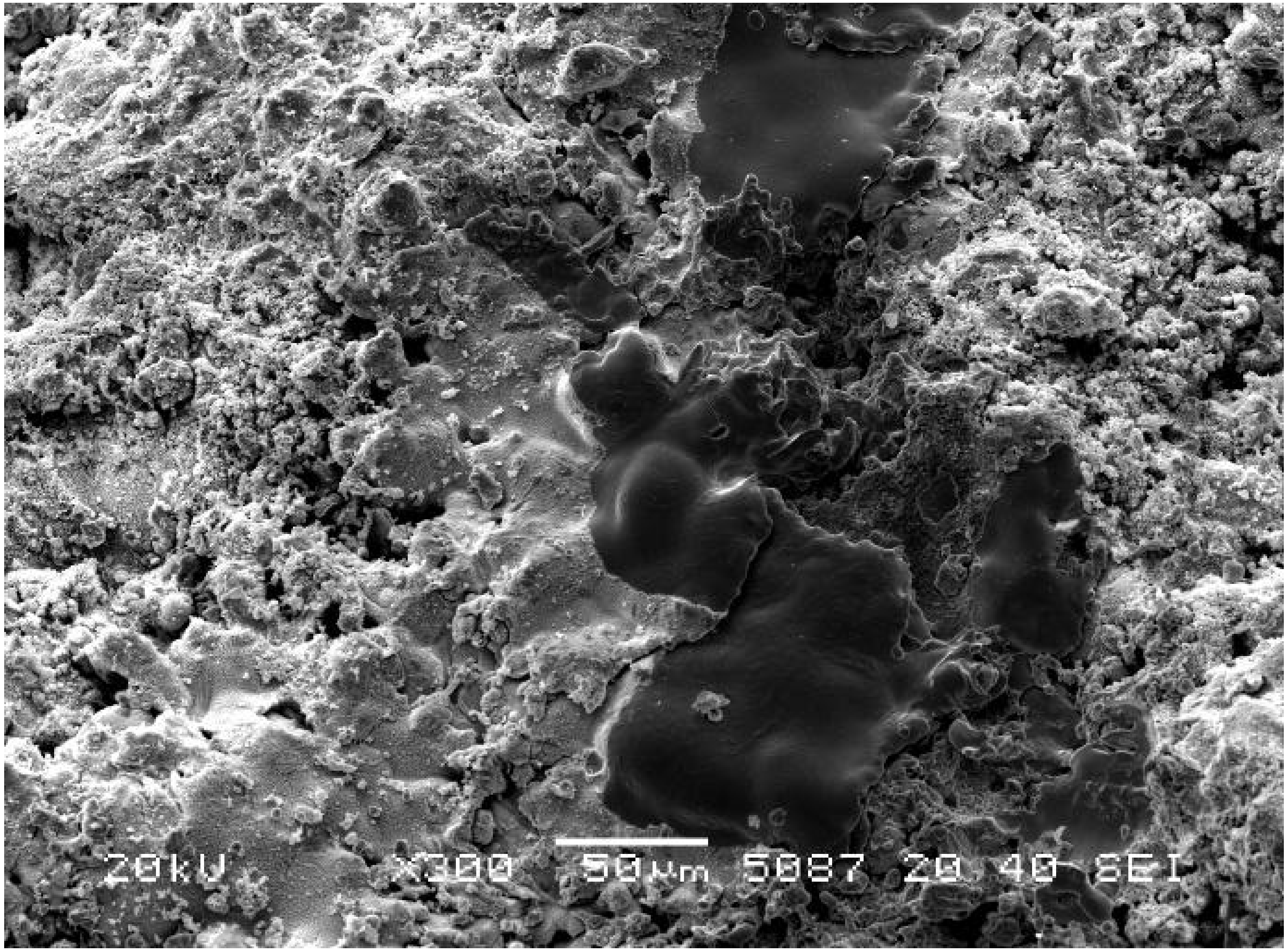
W radiation only when arcing occurred

Effects on the materials



Plasma sprayed W

Effects on the materials - morphology



Plasma sprayed W - detail

Effects on the materials - composition

Arc traces:

Removal of thin oxide layer
(oxygen: 0.15 wt% inside, 0.69% outside (EPMA)

Overall area (without biasing):

	W	W+Cu
Oxygen	↓	↓↑
Carbon	→	↑
Hydrogen	↑	→

(RBS+ERDA)

Conclusions

Conclusions & outlook:

- plasma spraying in air can be used for tungsten coating production
- significant in-flight oxidation occurs, but there is very little oxide in the coatings
- the lamellar structure limits thermal conductivity, but increases strain tolerance
- further optimization underway
- upon exposure in tokamak plasma, tungsten coatings show low surface erosion and negligible influence on the discharge parameters
- suitable for covering different edge plasma diagnostics

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