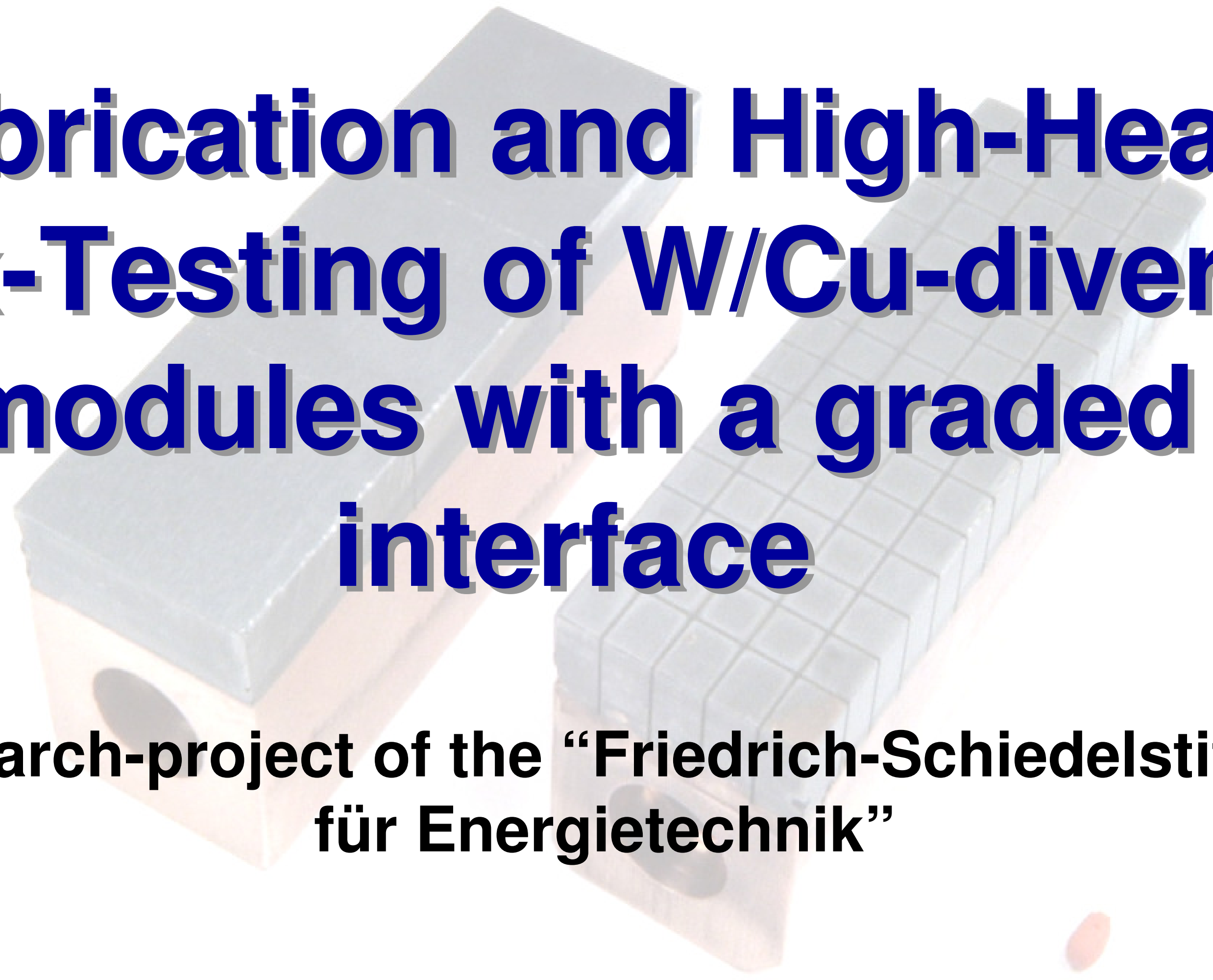


Fabrication and High-Heat-Flux-Testing of W/Cu-divertor modules with a graded interface

Research-project of the "Friedrich-Schiedelstiftung für Energietechnik"

Forschungszentrum Jülich
in der Helmholtz-Gemeinschaft

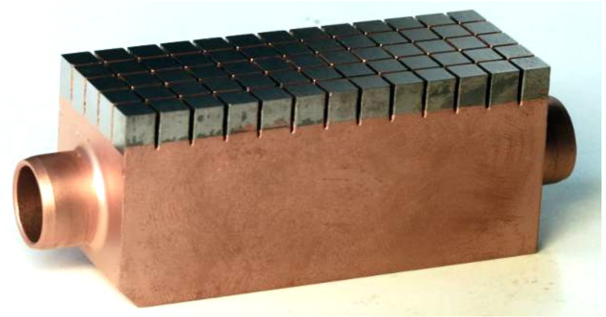
Actively cooled divertor test modules

W macrobrush mock-up

- coating of W-tiles with OFHC-Cu
- e-beam welding to CuCrZr heat sink

HHF test

1000 cycles @ **18** MWm^{-2}
without failure



PS-W mock-up

- vacuum plasma spraying of tungsten

HHF test

1000 cycles @ **5.5** MWm^{-2}
without failure

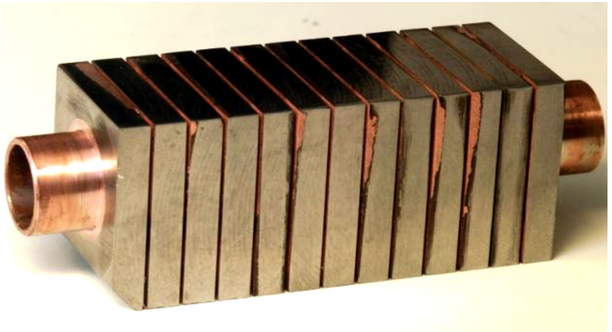
430 cycles @ 7.6 MWm^{-2}
increasing T_{surf}

W monoblock (monolytic type)

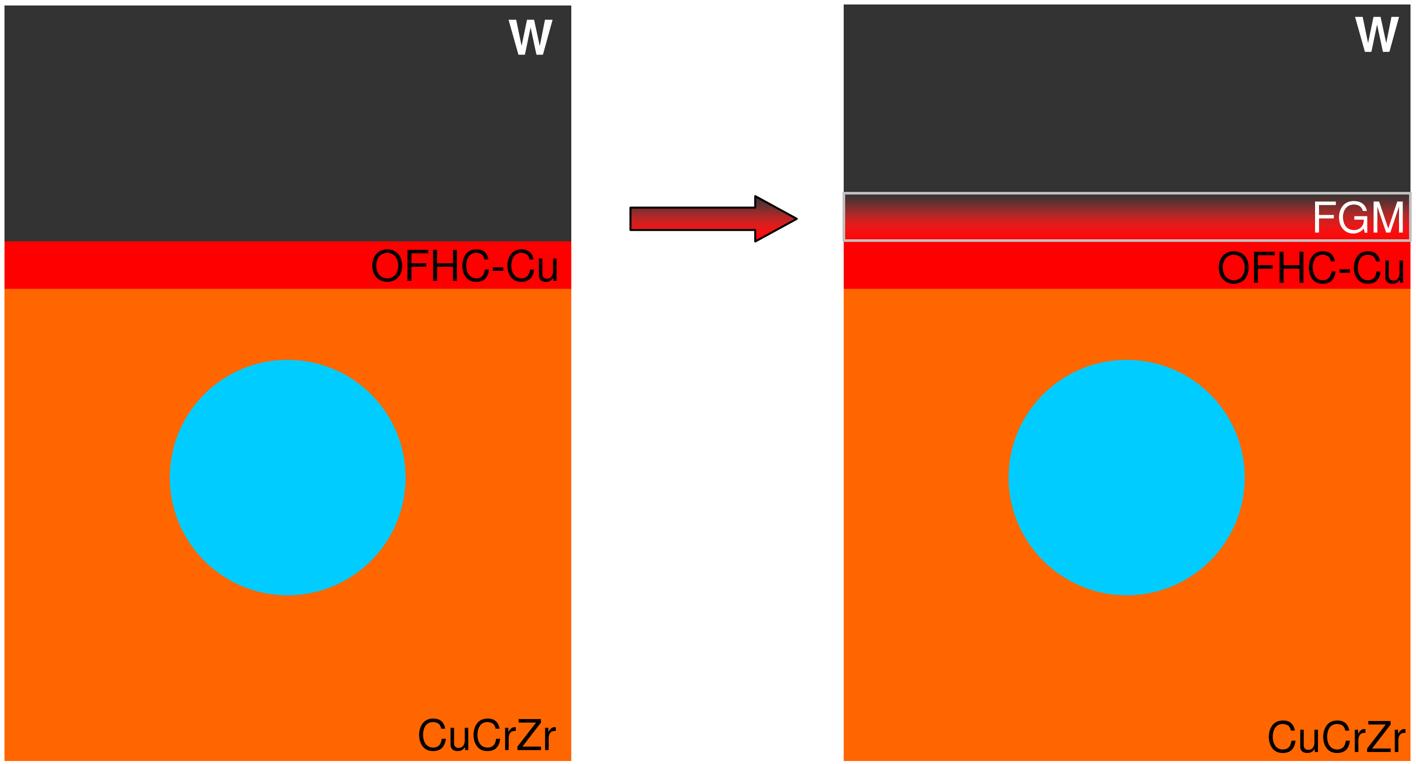
- drilling of $W\text{-}La_20_3$ monoliths (d = 4 mm)
- casting with OFHC-Cu
- HIPing (700°C, 3 hrs.)

HHF test

1000 cycles @ **18** MWm^{-2}
without failure



Flat Tile Concept with and w/o W/Cu-Gradient



AIM

Reduction of residual and thermal stresses at the interface ($\Delta\alpha_{W/Cu} \approx 12\times10^{6}$ K^{-1}) $\Rightarrow$ reduced delamination effects

$\Rightarrow$ **INCREASE OF LIFETIME**

Fabrication methods for W/Cu-FGMs

Investigated methods:

- **Vacuum Plasma Spraying**
- **Water Stabilized Plasma Spraying**
- **Direct Laser Deposition**

Other methods:

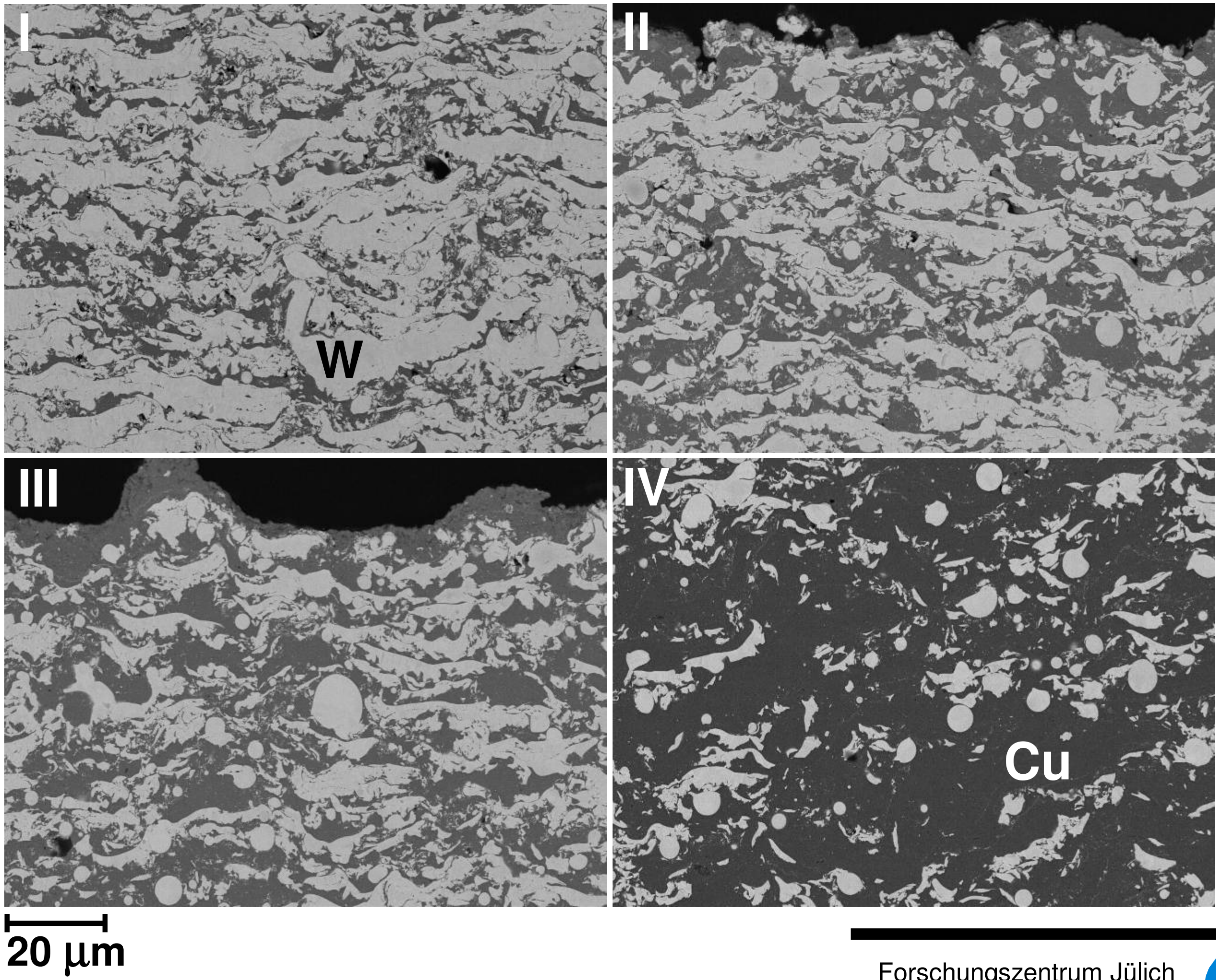
Electrochemical infiltration, Sintering, Spark Plasma Sintering,…

Vacuum Plasma Sprayed W/Cu-Composites

Parameters • 2 powder feeders • Transferred Arc Cleaning

Powder

W [< 10 µm] +
Cu [40 - 50 µm]



I) **W-Cu26**

II) **W-Cu43**

III) **W-Cu52**

IV) **W-Cu78**

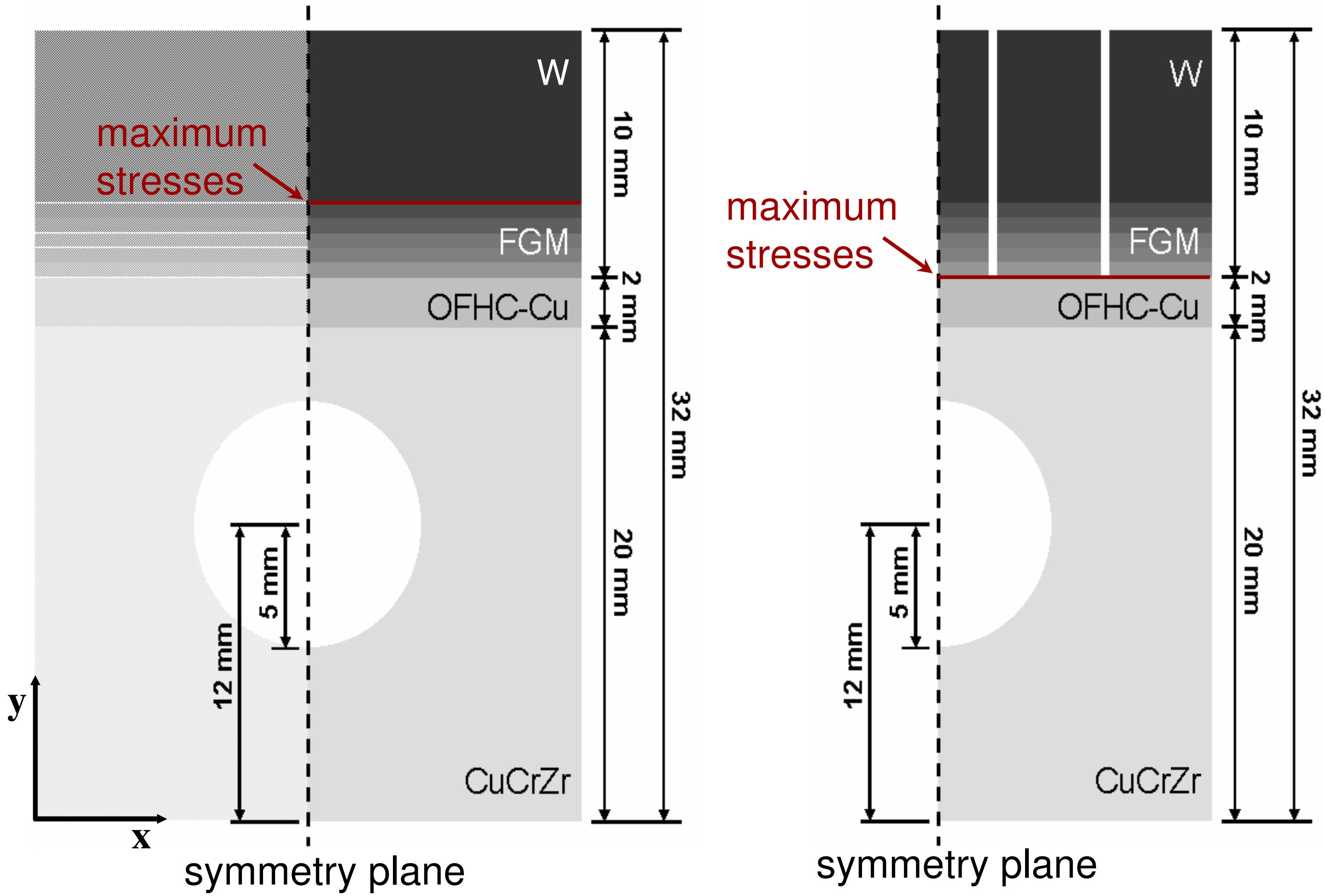
Finite Element Simulations

Parameters

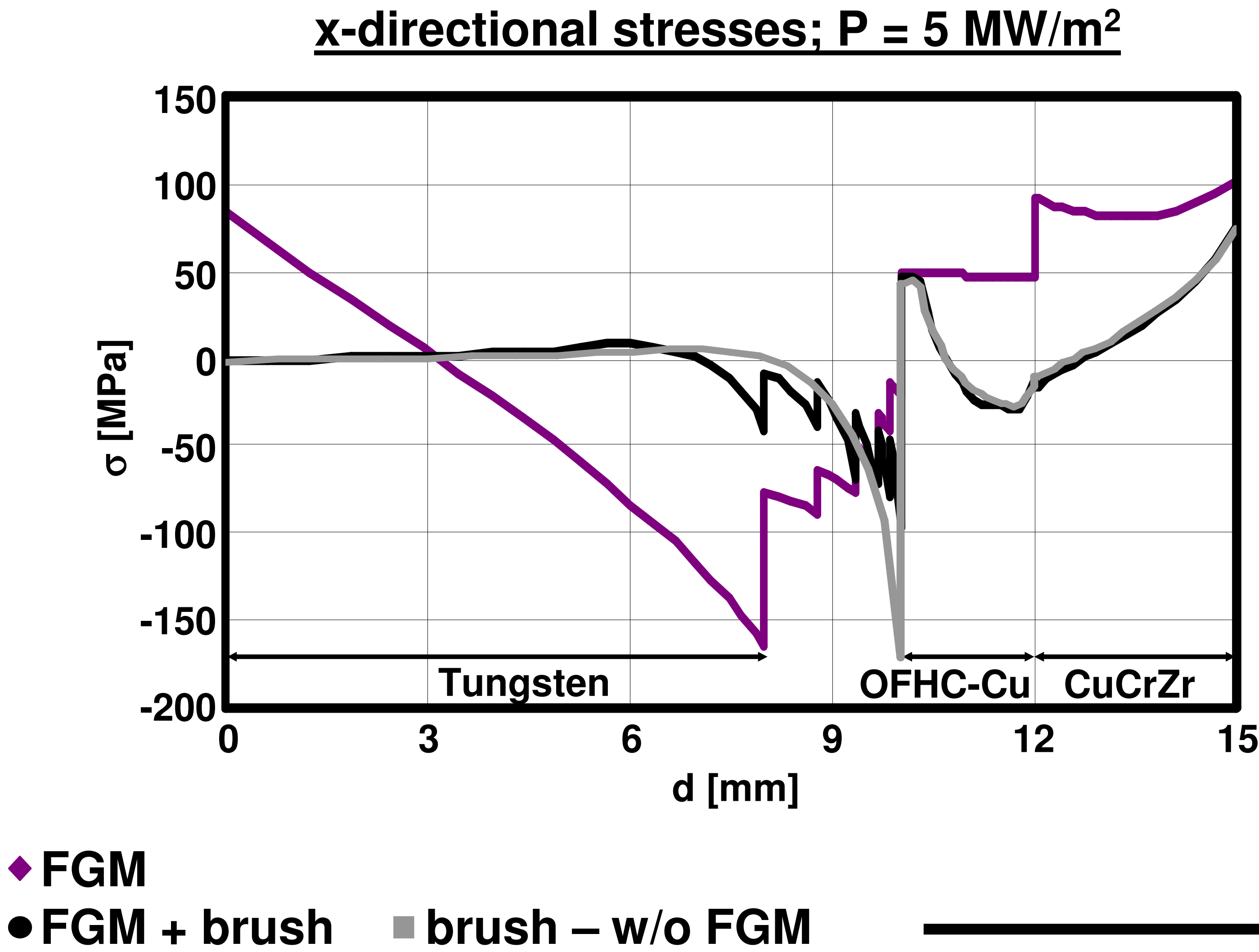
- optimal bonding at the interfaces
- stress-free state at 500 °C
- loading:

  5-20 MW/m²
- cooling:

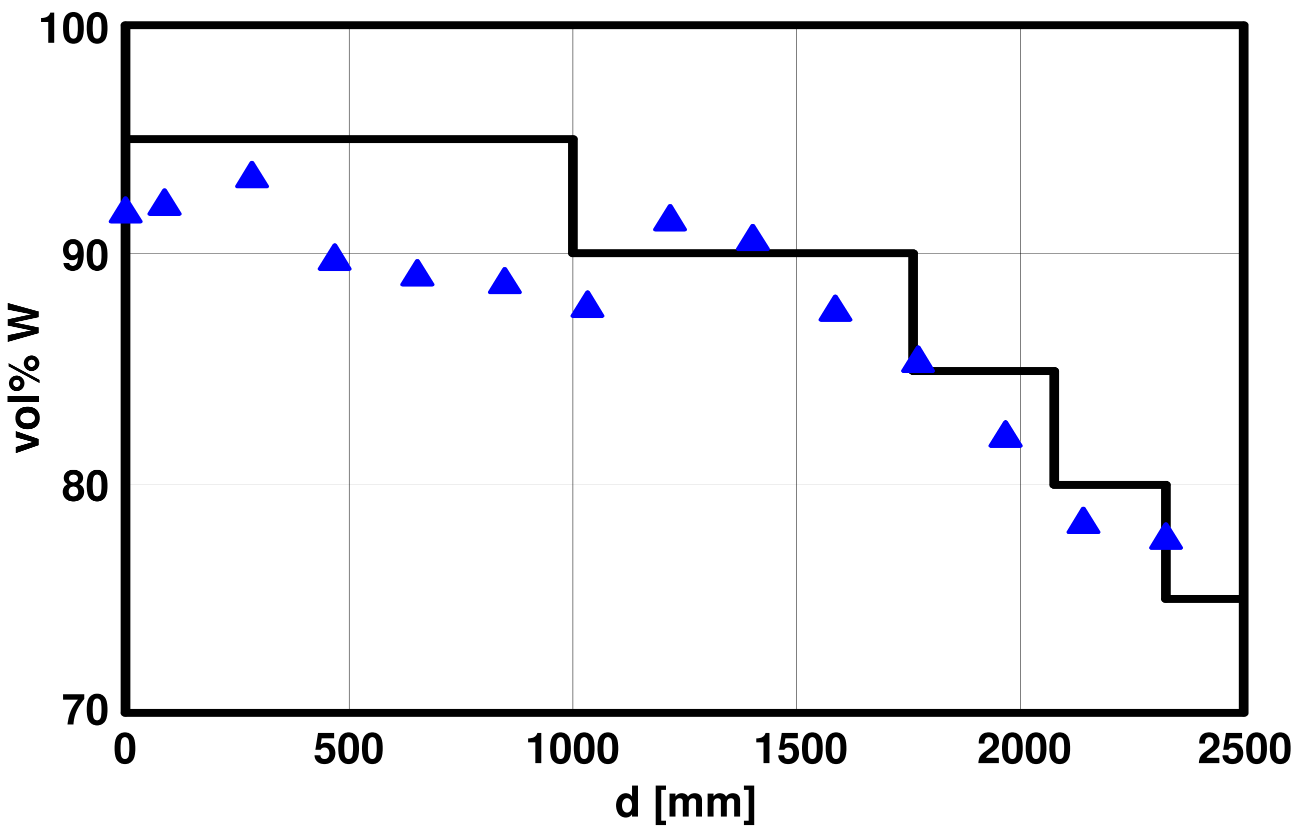
  T = 100 °C
  p = 4 MPa
  twisted tape



Finite Element Simulations - Stresses



Vacuum Plasma Sprayed W/Cu-Gradient



◆ theoretical

▲ measured

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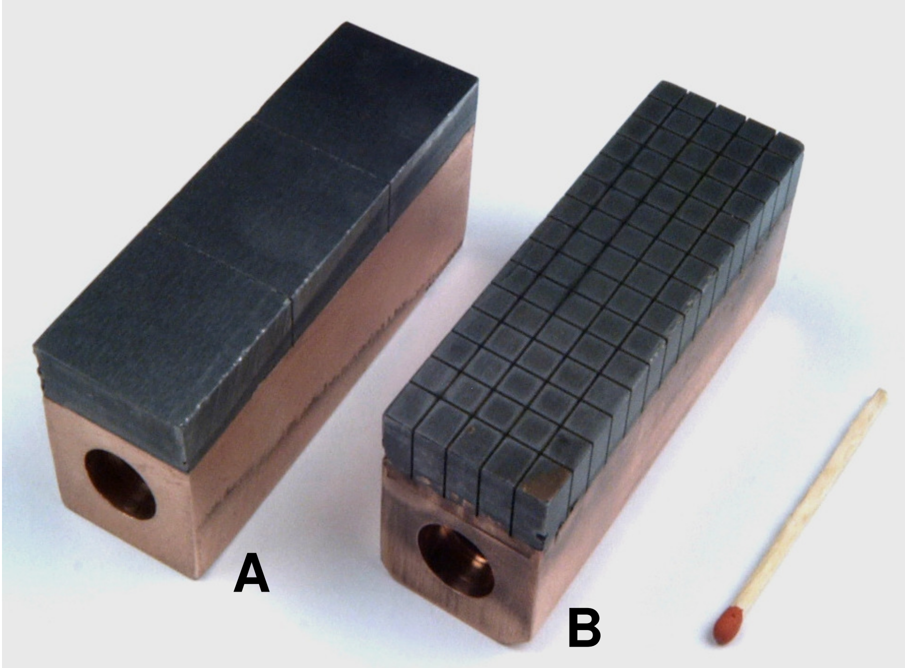
Fabrication of Actively Cooled Components

I. Cu-coating on the FGM
II. Ni-coating on OFHC-Cu (both sides)
III. Mounting of CuCrZr, OFHC-Cu and W+FGM in a Cu-can (vacuum)
IV. HIP cycle: 3h, T = 550℃
1h, T = 450℃

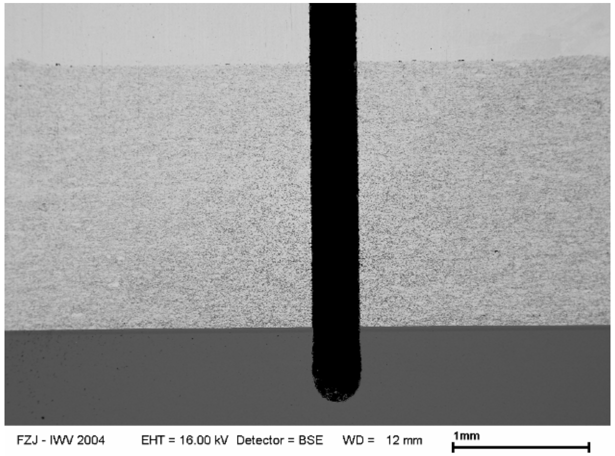


Castellation

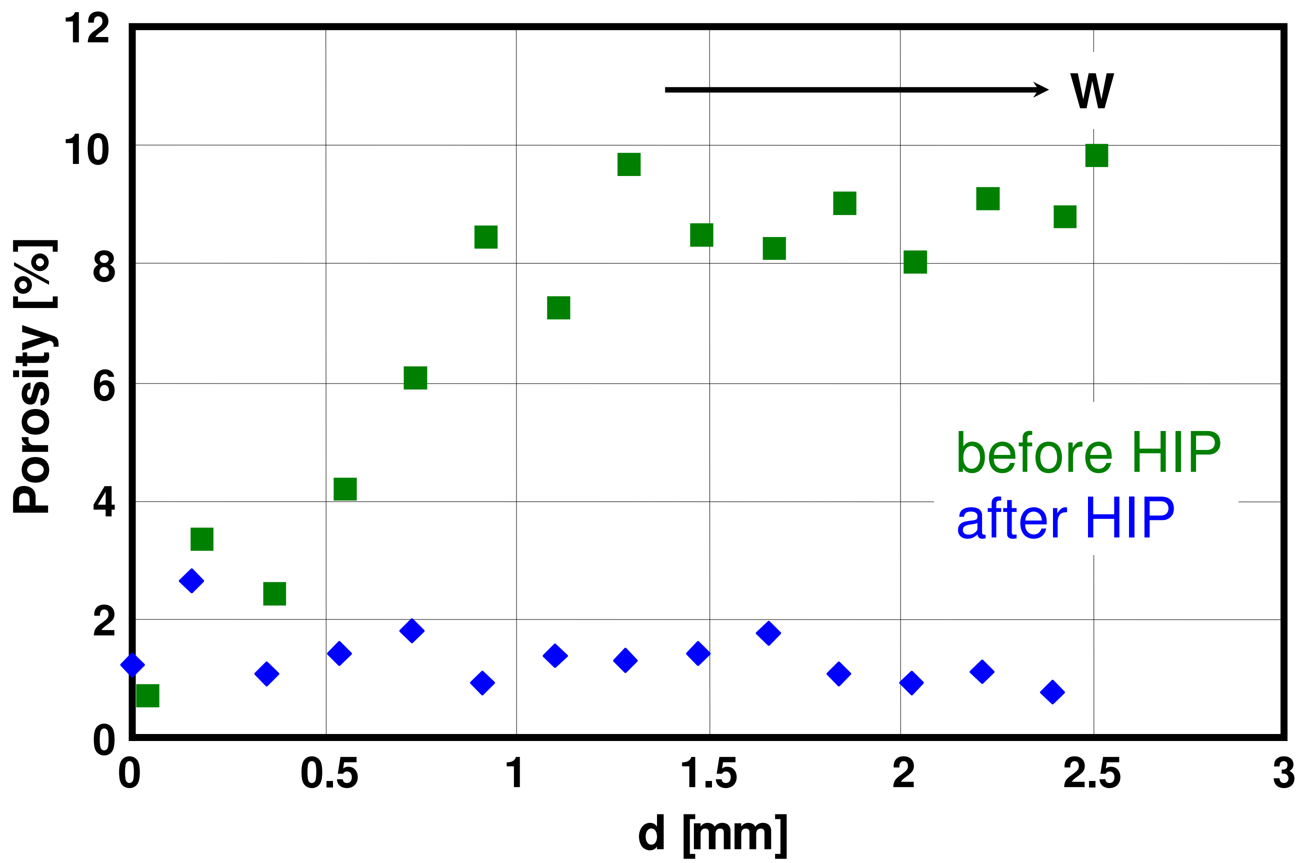
module A: **24 x 24 mm²**

module B: **4.5 x 4.5 mm²**

cutting width: **~0.35 mm**



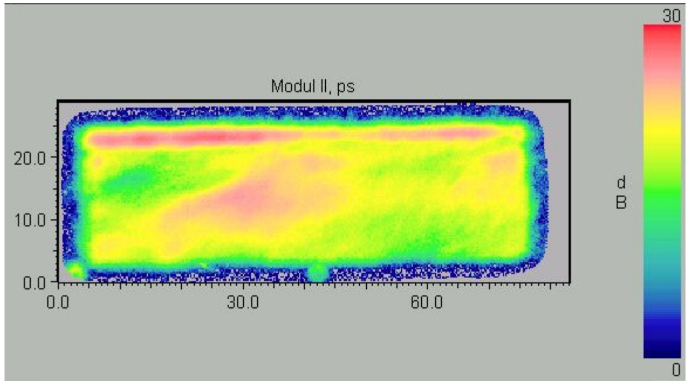
Porosity in the Gradient

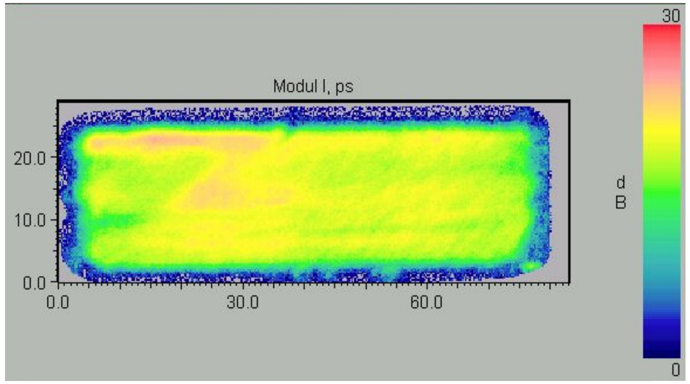


Interface Ultrasonic Inspection

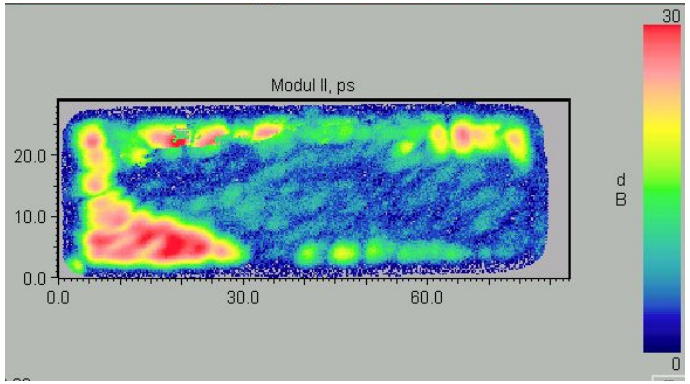
Module A | Module B

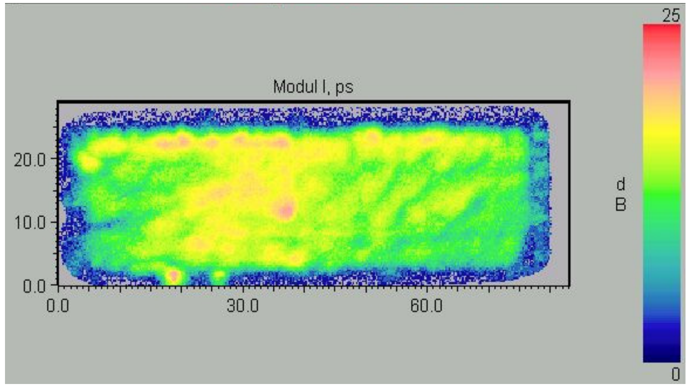
CuCrZr-OFHC-Cu interface





OFHC-Cu-FGM interface

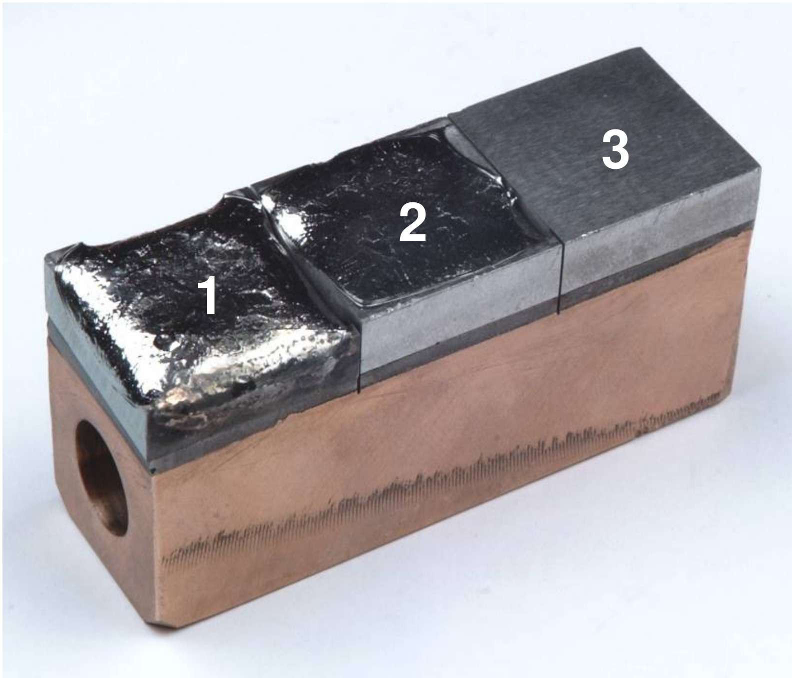


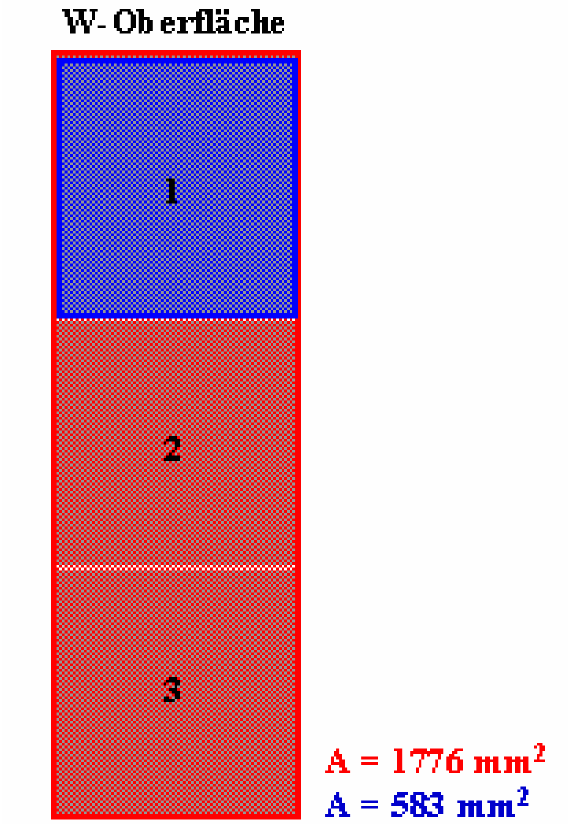


Screening Tests (1)

Electron beam loading: JUDITH (FZJ)

8 MW/m²: failure: brick 3
19.2 MW/m²: failure: brick 1

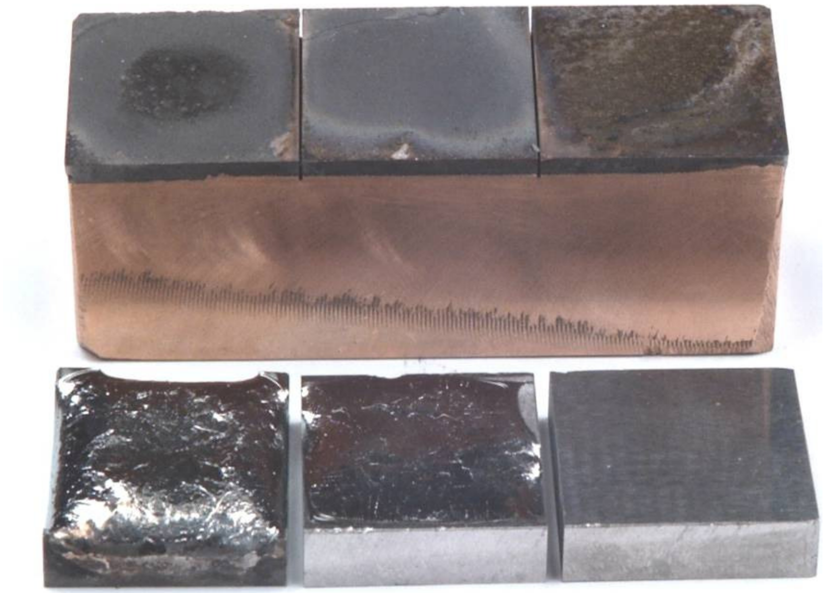


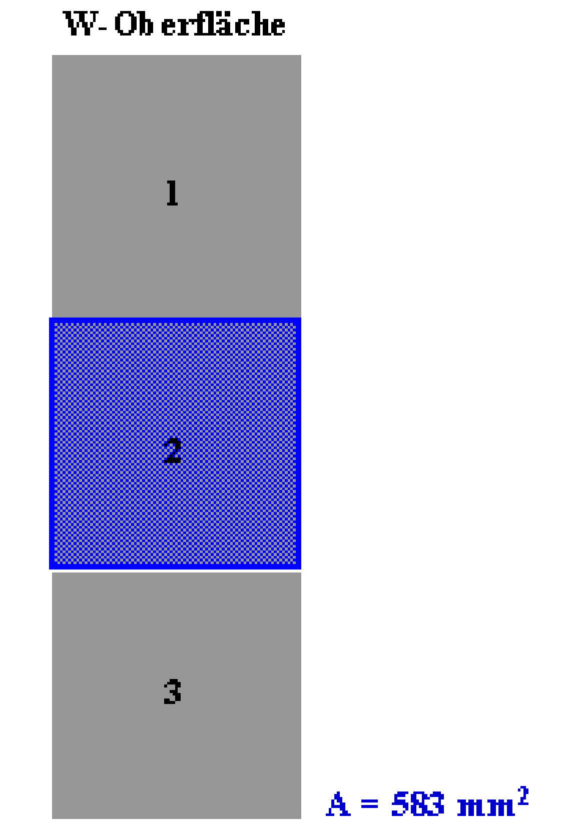


Thermal Fatigue Tests (1)

Electron beam loading: JUDITH (FZJ)

14.8 MW/m^2: 1 cycle, failure: brick 2

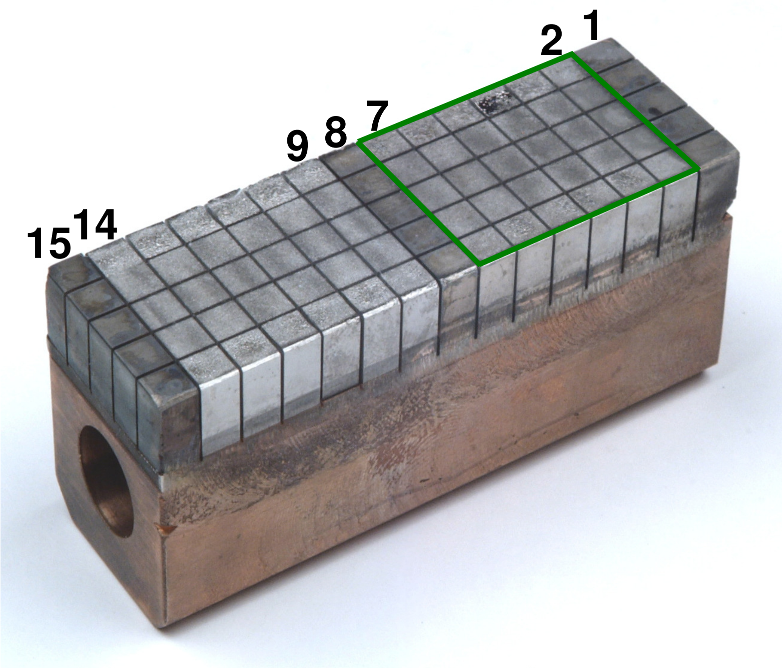


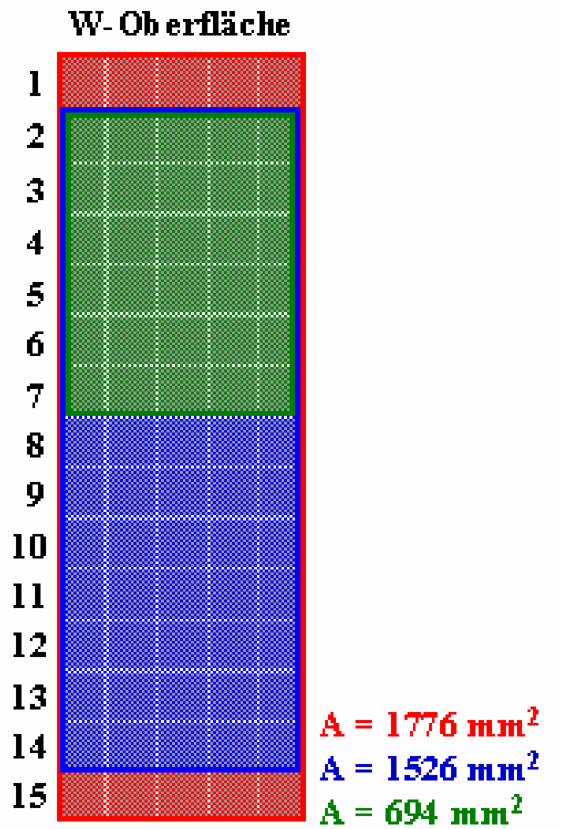


Screening Tests (2)

Electron beam loading: JUDITH (FZJ)

23.8 MW/m^2: no degradation

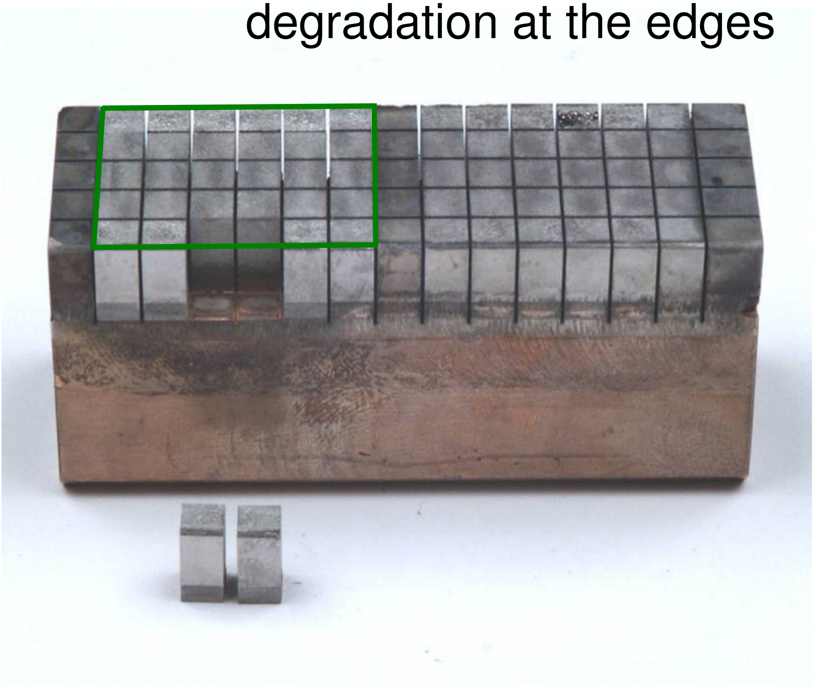


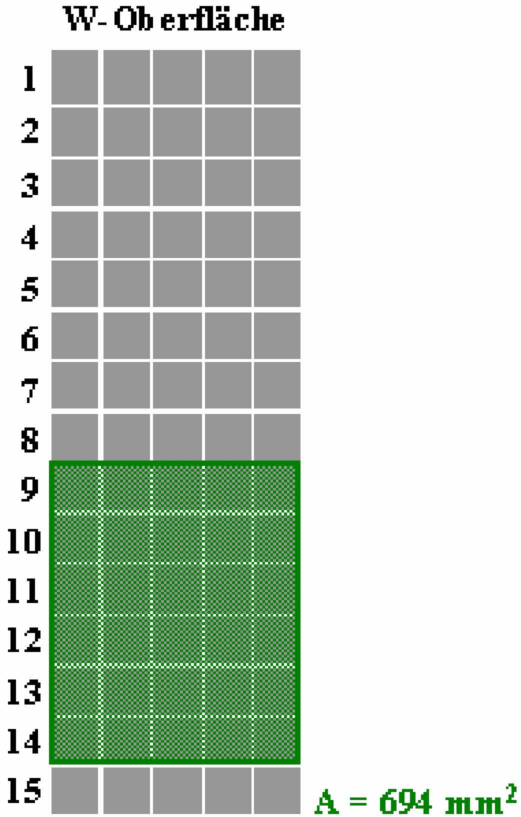


Thermal Fatigue Tests (2)

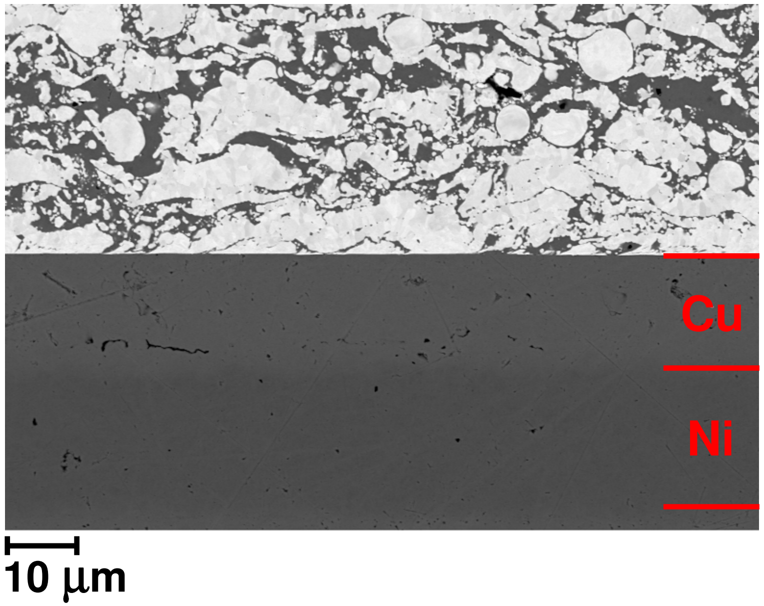
Electron beam loading: JUDITH (FZJ)

20 MW/m²: 100 cycles + 50 cycles
10 s loading, 20 s cooling
degradation at the edges



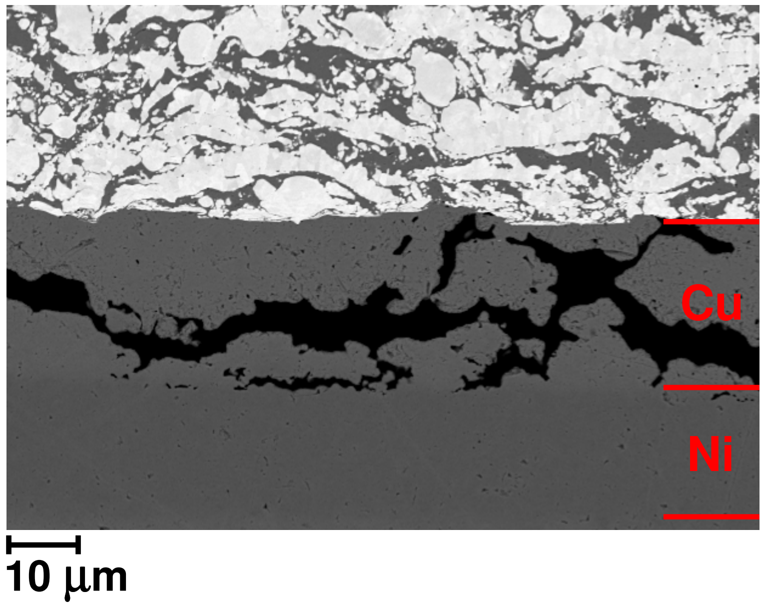


Failure Analysis

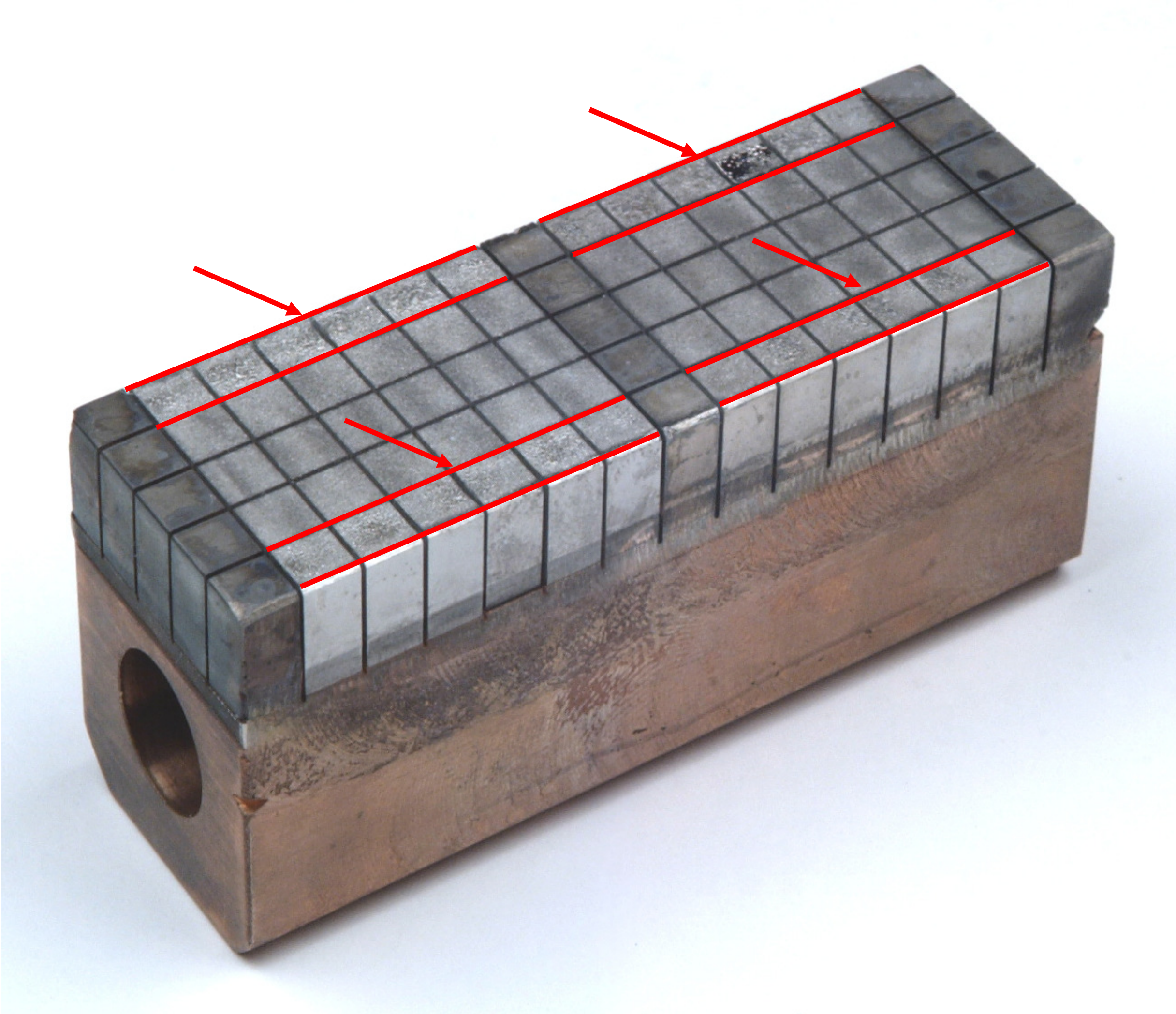


After Screening Test

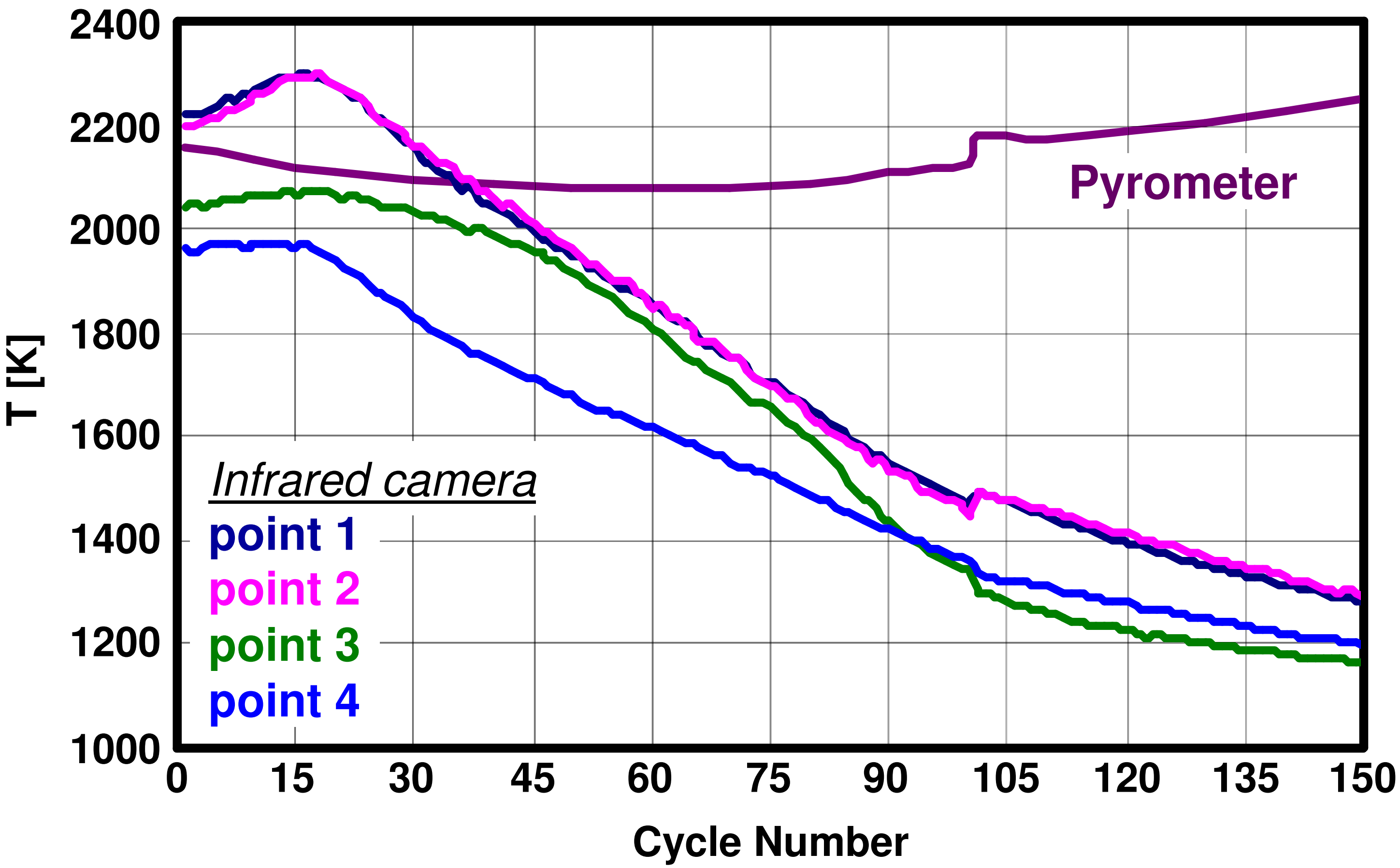
After Thermal Fatigue Test



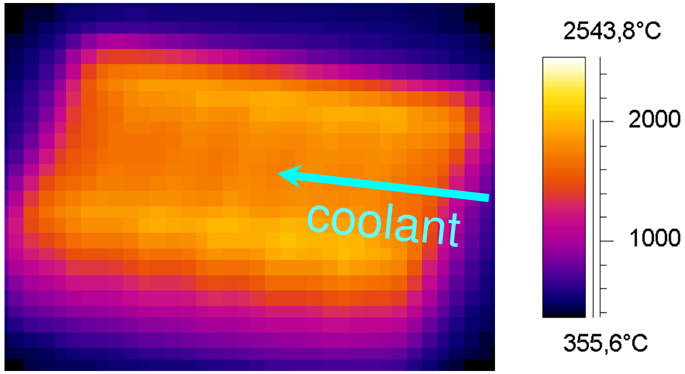
Surface Modification



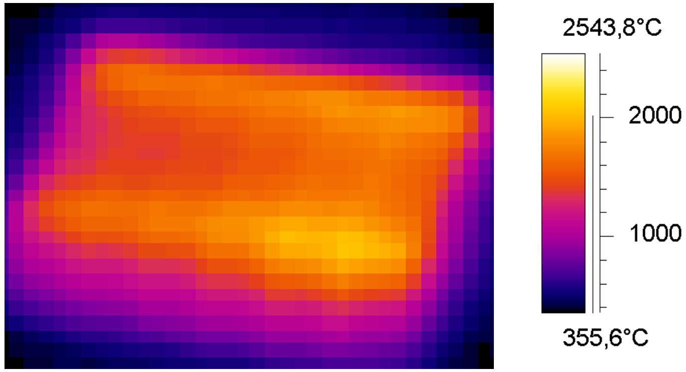
Temperature monitoring



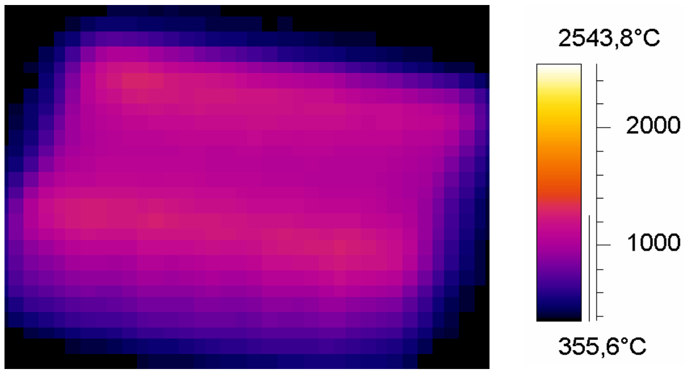
Thermal Fatigue Test – Infrared Pictures



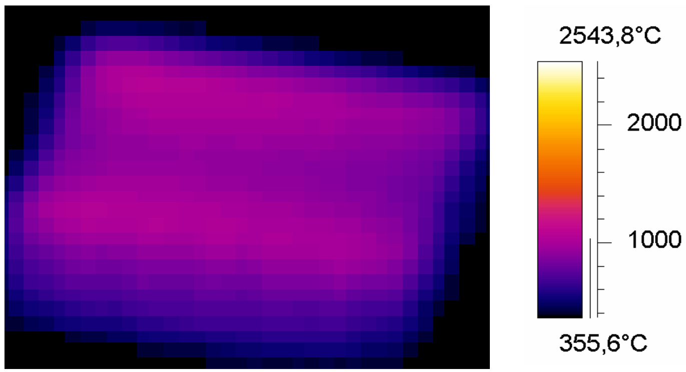
1. cycle



50. cycle

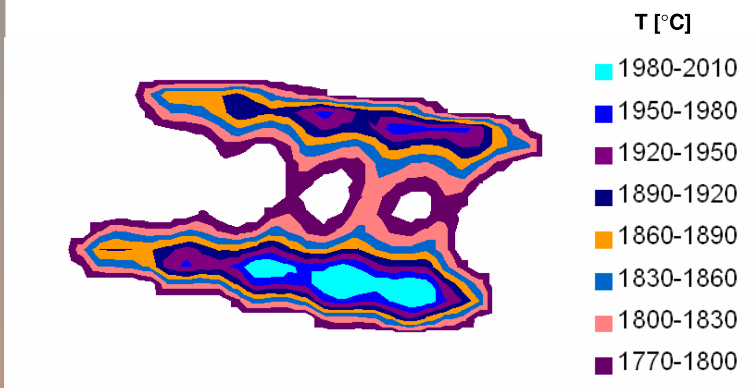


100. cycle

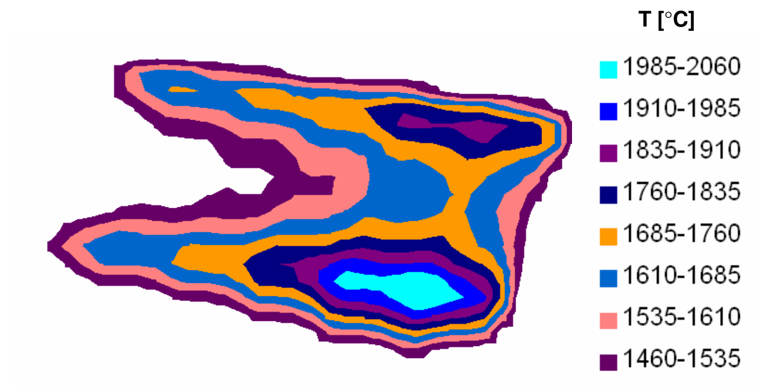


150. cycle

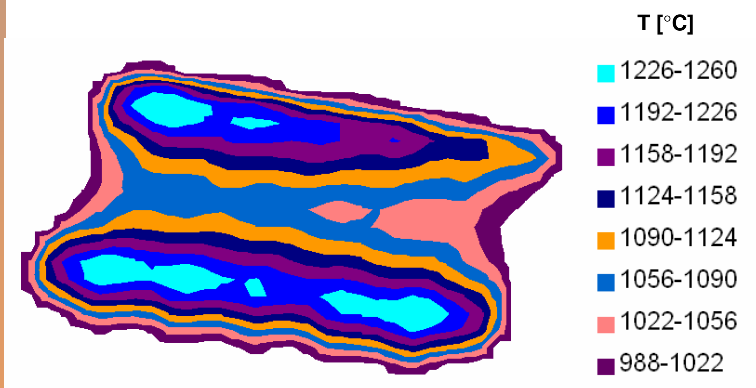
Thermal Fatigue Test – Temperature Graphs



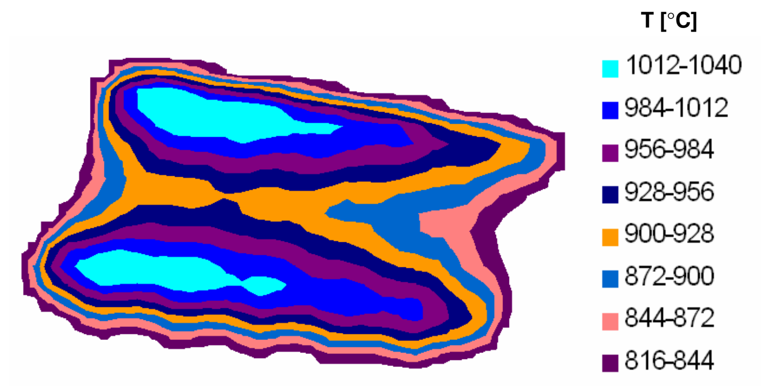
1. cycle



50. cycle



100. cycle



150. cycle

Conclusion

Vacuum plasma sprayed W/Cu-gradient: *W-content > 75vol%*

Castellation of the plasma facing material still *necessary*

High performance of test component: *150 cycles at 20 MW/m^2*

Full potential not yet reached

Problem

Castellated structure: *critical joint between gradient and OFHC-Cu → not yet optimized*

THE END!!!