Laboratory of Metrology and opto-thermal sensor technology at FHWS
Radiometry, Photometry and Thermal Metrology
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Aims

Improvement of thermal metrology in industry and science, with focus at high temperatures
• **Applied Research** in the field Metrology, opto-thermal Sensor technology and Thermo-Physics
• Support and set-up of metrological competence and infra-structure of SME in particular by **Technology Transfer**
• Joint **Research and Development projects** with industry (bilateral and within regional, national and EU programmes)
• **Standardisation** (VDI, DIN, CEN, ISO)
• Research, Development and application of optical methods for photometry, radiometry, temperature metrology and material investigation for industry and science
Facilities

- Spectrometer (UV-VIS-NIR)
- Thermal Imagers (-50 °C to 900 °C)
- Two color Pyrometer (350 °C to 1300 °C)
- High-precision Radiation thermometer (-50 °C up to 1500 °C)
- High temperature furnace
- Atomic force microscopes
High precision radiation thermometer

Heitronics TRT IV.82

- Measuring range -50 °C up to 1200 °C (1500 °C)
- Resolution <10 mK at room temperature
High-temperature furnace

Gero Typ HTRH 70-600/18

- Inner diameter of opening 70 mm
- Inner tube diameter 60 mm
- Heated length 600 mm
- Total length 890 mm
- Width 520 mm
- Height 620 mm
- $T_{\text{max}}$ 1800 °C
- Temperature ramp with tube <250 K/h
Atomic Force Microscope

50 Micron xyz Scanner

- Type: Modified tripod
- XY Linearity: < 1%
- XY Range: > 50 μ
- XY resolution: < 10 nm closed loop, < 1 nm open loop
- XY Actuator type: Piezo
- Sensor type: Strain Gauge
- Z Range: > 16 μ
- Z Linearity: < 5 %
- Z sensor noise: < 5 nm
- Z feedback noise: < 0.2 nm*
- Z Actuator Type: Piezo
- Z Sensor type: Strain Gauge
Atomic Force Microscope

Canteliver with probe
movable sample stage

quadrant photo diode
Laser diode

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Thermophysical Property Measurement

• Laser-Flash-set-up
Additive Manufacturing Facility

- Laser-Sintering Facility EOS M290
New Challenges in material science

Non-contact temperature and thermo-physical properties measurement, radiative transfer calculation and measurement in

- laser based, additive manufacturing and material processing
- High-temperature and composite materials for aerospace, power plants and turbines

Examples for application:

Keyhole Welding
Directed energy deposition (DED)
Powder bed fusion (PBF)

High-temperature systems

Steven Grantham National Institute of Standards and Technology (NIST) Gaithersburg, MD, USA
Measurement challenges during SLM process

Laser powder bed melting

Example: GEnx jet engine model (General Electric)

20 µm layer thickness, ~1 m/s Scan speed
200 W CW Laser
Laser-Flash Method (LFM)

- Well-established method for material investigation
- Based on (a pulse-like) laser heating and (optical) monitoring of the temperature distribution and evaluation for material properties measurement
- Similar situation as during SLM process
  → Combine Laser flash thermophysical measurement method and SLS process monitoring
Typical laser flash set-up

- Sample
- Front side laser heating
- Optical fibre
- Laser-System
- Amplifier
- Back side detection
- Furnace up to 2800 °C
- Furnace Control
- Software
- Computer and data acquisition
- Measurement
- T/°C

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Comparison of laser flash and SLM


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What is needed?

- **Material properties**: Emissivity, thermal conductivity, specific heat, density
  - can be obtained separately
- **Laser data, Wavelength, intensity, time evaluation**: already measured and monitored in commercial AM set-ups
- **Mechanical and thermal properties**: re-melting and layered structure, interface contact → results in contact resistance
  - requires detailed investigation
- **Process temperature measurement**: requires detailed evaluation of signals
Stargate:

Aircraft Gas Turbine

Stationary Gas Turbine


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Thermal Barrier Coating (TBC)

- Hot gas
- TBC
- Bond coat
- Ni-super alloy
- Cool air
Fatal Problem: Partial melting

www.dlr.de/dlr/en/desktopdefault.aspx/tabid-10258/368_read-11746/#/gallery/16676
STARGATE LWIR Radiation Thermometer

Details

Radiation from turbine blade

镜像 镜像
透镜
长矛：带有孔径的管子
透镜
长矛：带有孔径的管子
IR纤维
检测器
检测器与滤波器

氮气净化

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Measurement of Stationary Gas turbine at Siemens Berlin Test Facility (BTF)
Measurements at Siemens BTF

Measurements at Siemens BTF

Detected and analyzed temperature signal in arbitrary units

Hodge D., Hartmann J., Infrared Physics & Technology 80 120 - 130 (2017)
Measurements at Siemens BTF

Detected and analyzed temperature signal in arbitrary units

Opti-TBCs: Increasing Efficiency of Power Plants

\[ \eta_{\text{max}} = 1 - \frac{T_{\text{low}}}{T_{\text{high}}} \]

Coal power plants

Gas turbines

Non-contact temperature measurement
Challenge: Semi-Transparent TBCs and mechanical adhesion

Thermal barrier coatings (TBCs): Temperature Gradient

Cross section of turbine blade
Thermal Barrier Coating: TBC

Pre-Work OptiTBCs:
Thermal Barrier Coatings with Optimized Adhesion for Energy Efficient Stationary Turbine Engines

Method

- NIR-pyro
- LWIR-pyro

NIR (1 µm)
LWIR (10 µm)
1 mm

Sapphire with d = 1 mm

<table>
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<th>wavelenghth λ / µm</th>
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<th>opaque</th>
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</tbody>
</table>

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Pre-Work OptiTBCs: Thermal Barrier Coatings with Optimized Adhesion for Energy Efficient Stationary Turbine Engines

First Measurements

- NIR pyro
- LWIR pyro

- sapphire without gap
- sapphire with gap

LWIR pyrometry

Active heating

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ExdyMa: Experimental set-up for dynamic Material investigation

- Funded by BMBF FKZ: 03FH007IN6
- Partner: FHWS, ZAE, KE Technologie, TechnoTeam, Netzsch
- **Aim:** Optimization of high-temperature processes and Industry 4.0 manufacturing processes by in-situ measurement of optical and thermophysical material properties
- **Method:** Detection of the thermal heat spread to determine the opto-thermal layer characteristics, the thermal contact resistance and the mechanical adhesion via variable dynamical excitation (pulsed, modulated, step-like) and imaging detection at front and back side
- **Apply evaluation method to SLM** by using the available sensor signals
BMBF Project: Experimental set-up for dynamic Material investigation ExdyMa
Based on a conventional Laser flash set-up

Front side laser heating

Back side detection

Sample

Furnace up to 2800 °C

Amplifier

Software

Computer and data acquisition

Measurement

T/°C

© Netzsch
Idea:
Experimental set-up for dynamic Material investigation ExdyMa

Radiation thermometer, spectrometer or radiance camera

Laser diode

Amplifier

Furnace Control

Laser diode

Furnace up to 2800 °C

Computer and data acquisition

Software

Sample

Optical fibre

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First step: Implementation of the radiation thermometer for front side temperature measurement

Spectral range: 8 – 14 μm
Temperature range: 0 - 3000°C
Integration time: 5 ms
Front side temperature measurement

Measurement of the front side temperature of a poco graphite sample

Temperature on sample front side

Termination and restart of the measurement
Measurement of the front side temperature of a poco graphite sample.

- Temperature / °C
- Time / min

- Temperature on sample front side
- Laser pulse
- Heating
- Measuring time

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Laser induced front side temperature rise

Temperature evolution at front and back side of sample
Comparison of ExdyMa and SLM

Thank you!

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