Demonstration of novel fiber-coupled phosphor thermometry in a laser powder bed fusion process

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Luminescence

"Some things,
though they are not in their nature fire, nor any species of fire,
yet seem to produce light"
~ Aristotle

Light emission distinct from incandescence / heat
Principle: electron excitation

Sorted by trigger:

- Bio-Luminescence
- Chemi-Luminescence
- …
- **Photo-Luminescence**

Source: Günter Hentschel (2019; flickr.com)

Phosphorescence

1. Excitation by external light source
2. Energy release, return to ground state

→ Radiative:

Fluorescence: < 10^ -8 s

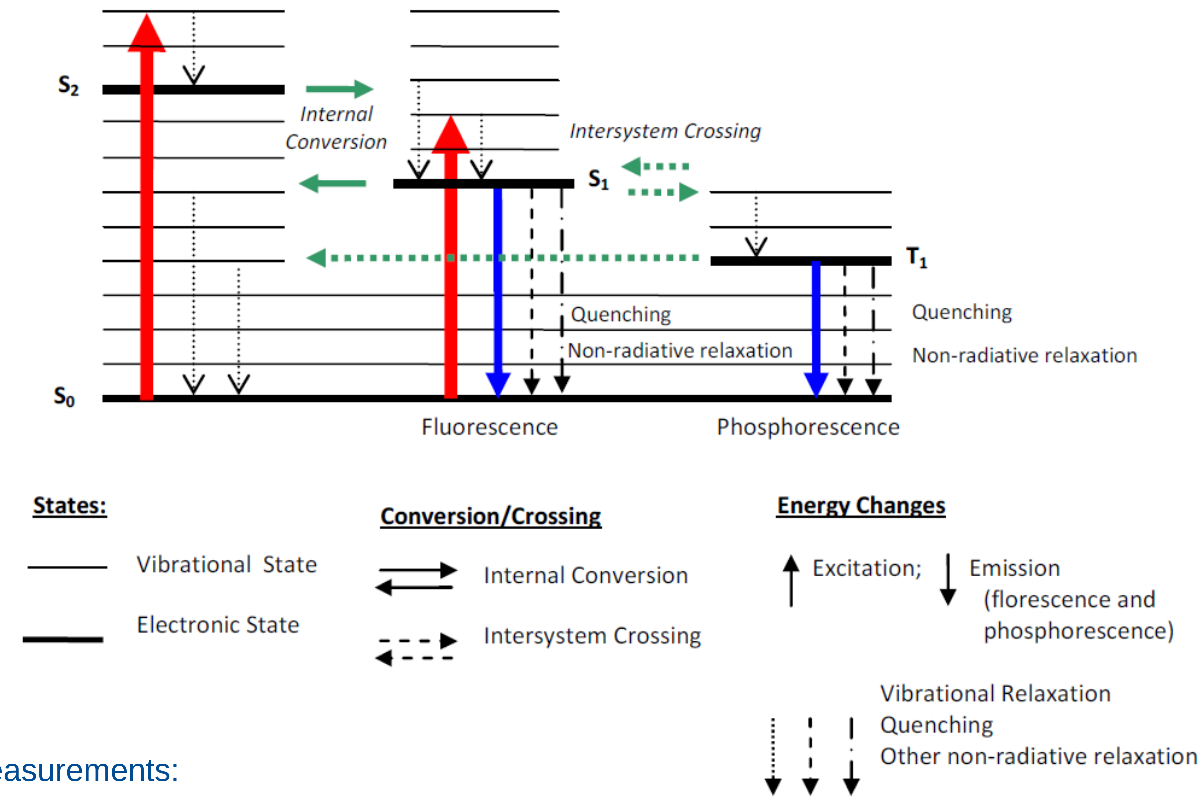
Phosphorescence: > 10^ -8 s

→ non-radiative:

vibrational

other

Jablonski energy-level diagram:



A. H. Khalid and K. Kontis, "Thermographic Phosphors for High Temperature Measurements: Principles, Current State of the Art and Recent Applications“ (2008)

Temperature Dependency

Excitation, then:

- Emission, radiant: photon emittance (C-D)
- Relaxation, non-radiant: vibration or other (B-C, E-D)

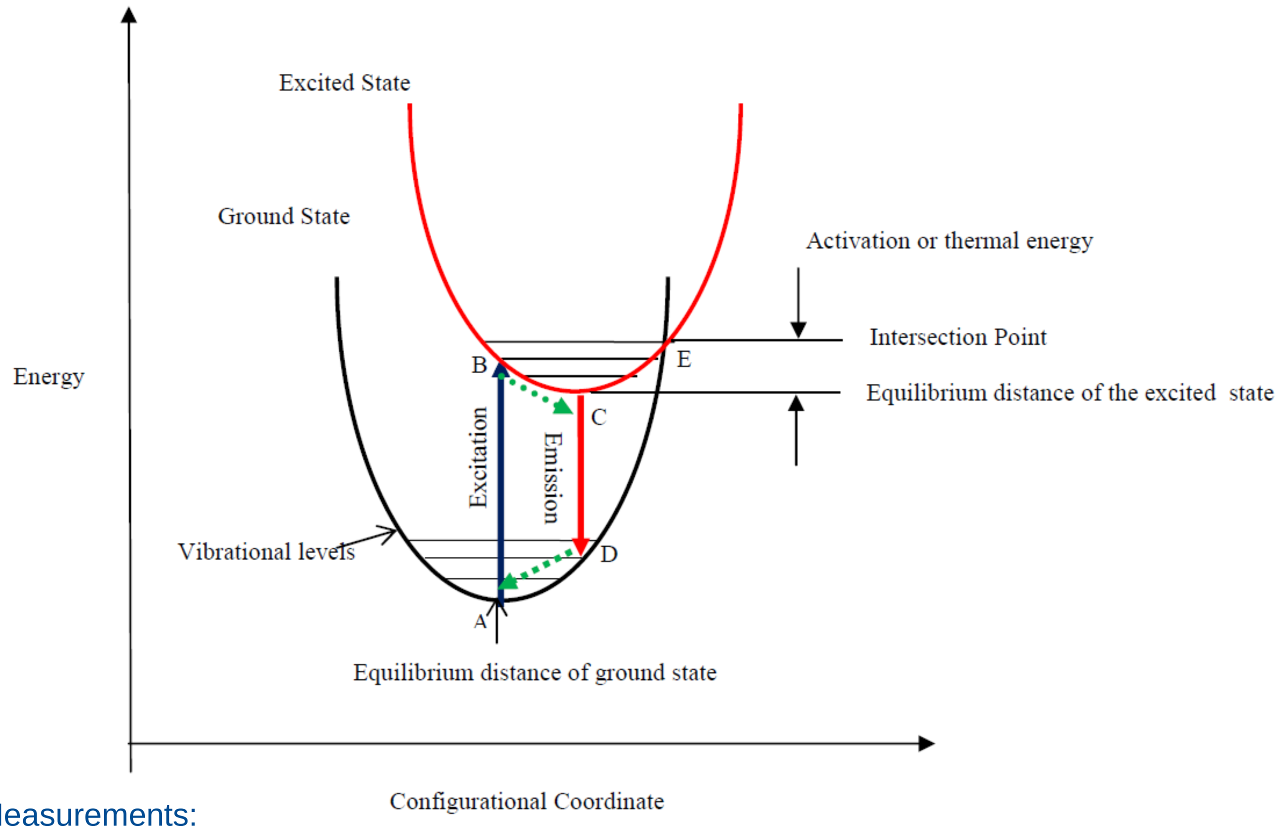
At higher temperature:

→ Increased intensity

→ higher probability for non-radiant return to ground state

→ decreased lifetime

Configuration co-ordinate diagram



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Phosphor Thermometry

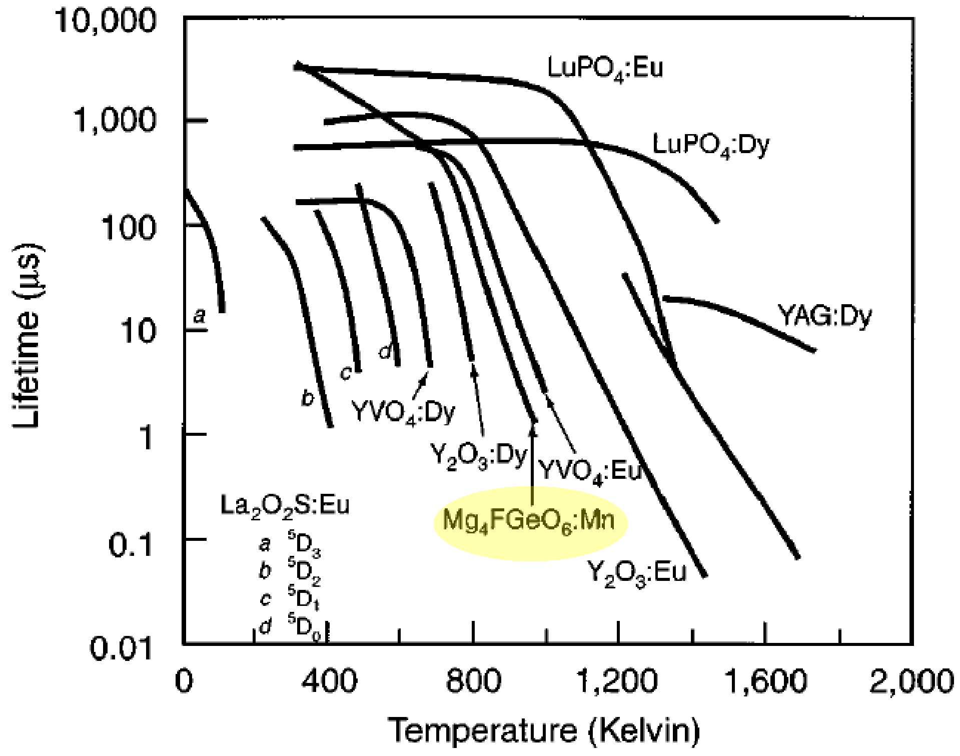
Lifetime - based

- Temperature recording possible after calibration

  Lifetime: $\tau = 1/\lambda$

  Decay: λ

- Thermographic phosphor: inorganic host doped with rare-earth elements or transition-metals



Current use cases: gas turbines, droplet and spray thermography

S.W. Allison; G.T. Gillies, "Remote thermometry with thermographic phosphors" (1997)

Proof of Principle: In-Situ Phosphor Thermometry

Thermometry in PBF needed:

- Cooling rates for manufacturing of bulk metallic glasses
- Temperature profiles for process monitoring
- Calibration of simulations

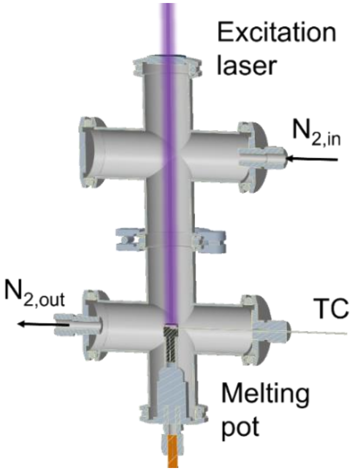
Current state of the

- Thermocouples - easy to apply, direct measurement, large range, discrete, intrusive
- Thermal paint
- Thermography - easy application, low resolution, intensity limited, emissivity varies
- Pyrometry - high resolution, limited Intensities at lower T, emissivity varies

- Phosphor Thermometry - ??
  → AlSi10Mg + MFG:Mn blend

Is it possible to detect the laser-induced temperature increase in PBF-LB/M by phosphor thermometry?

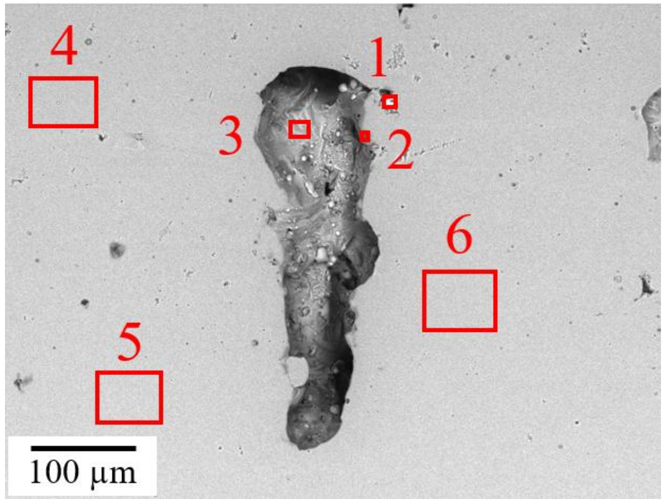
Ex-Situ Calibration



In-Situ Validation

[slm-solutions.com]

Ex-Situ Sample Analysis



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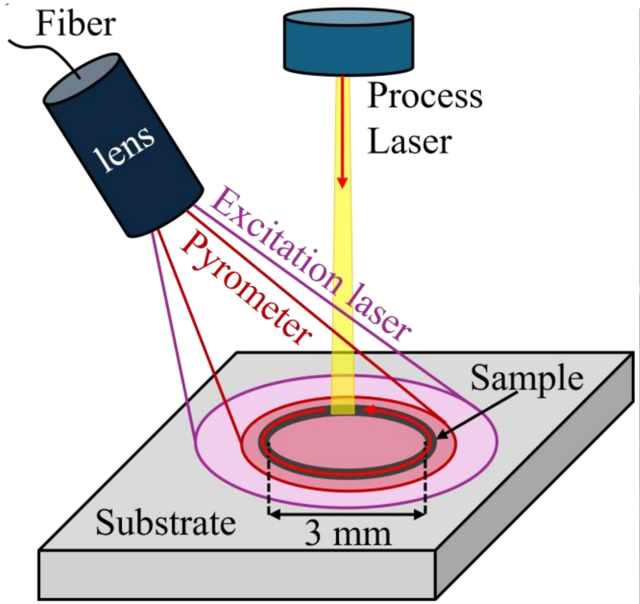
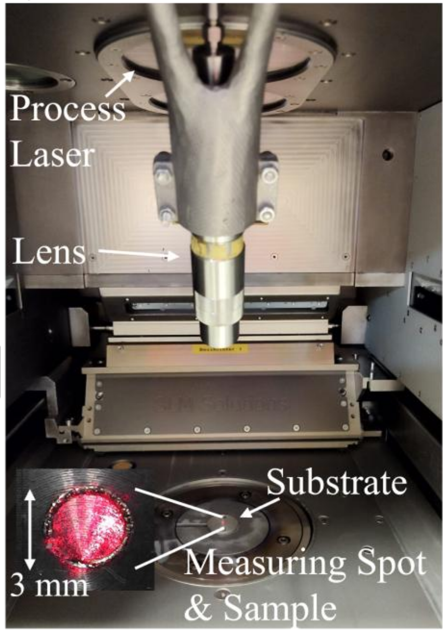
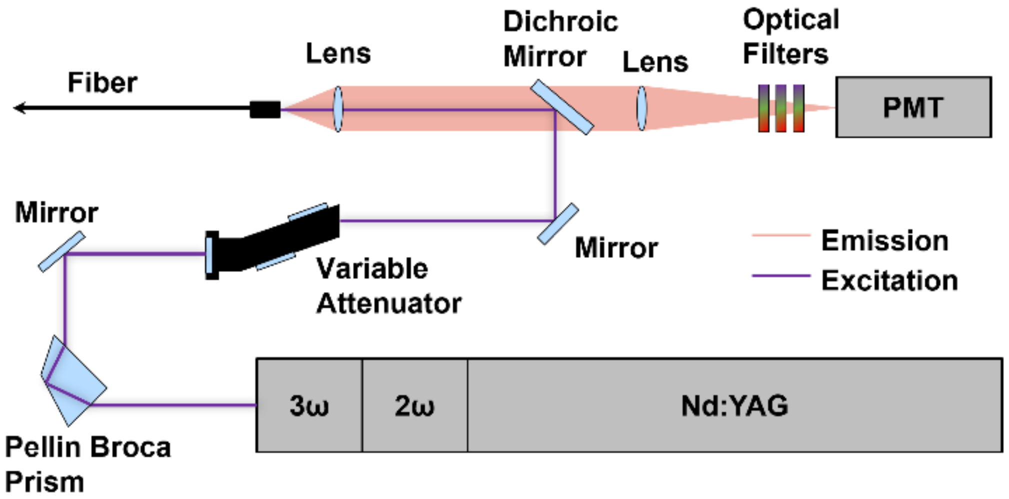
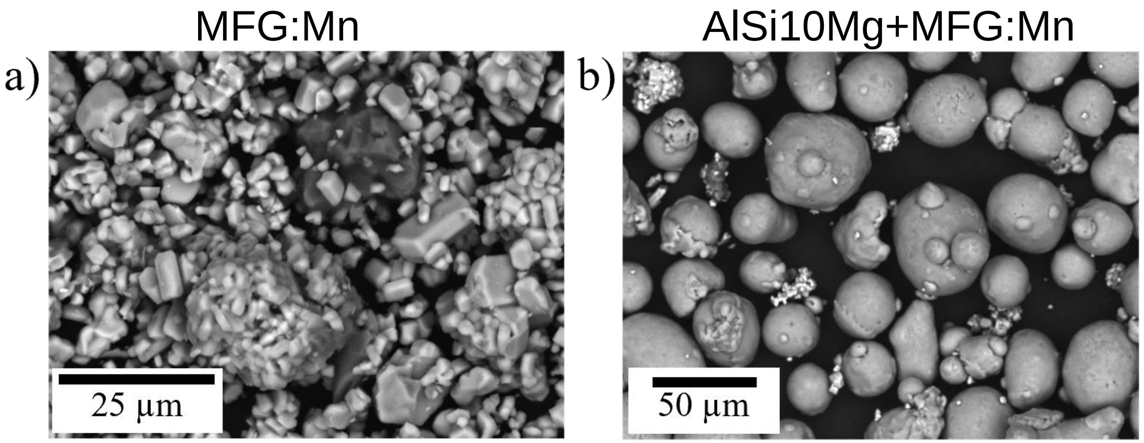
Phosphor Thermometry integrated into PBF-LB/M Machine



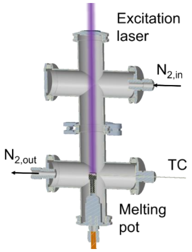


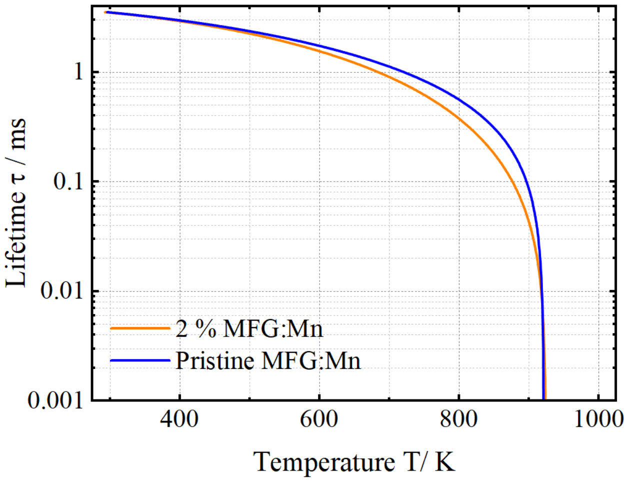


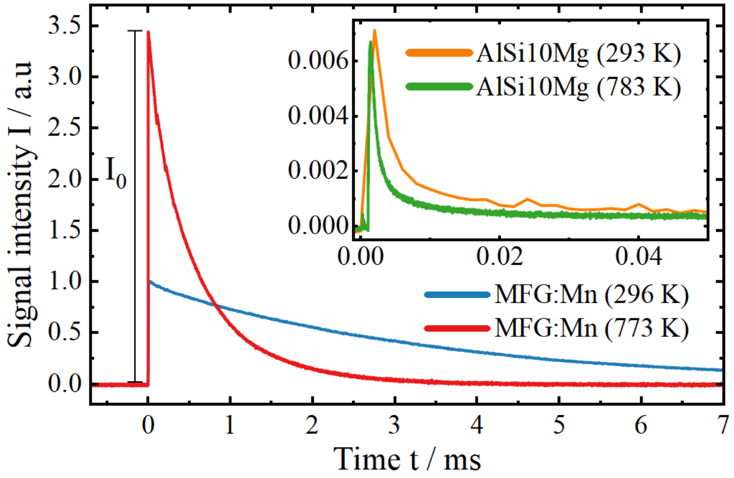
Calibration



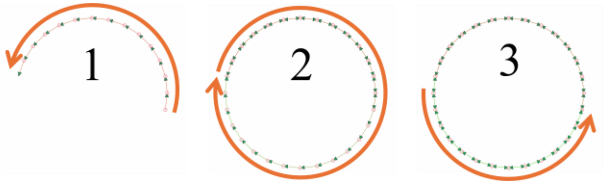
wt.%	Al	Si	Mg	F	Ge	Mn	O
Al [27]	89.7	10.0	0.4				
Al pwd	85.5	13.2	0.1				1.8
MFG:Mn, a)			47.2	6.8	30.0	0.2	25.6
Blend b)	83.9	9.35	1.1	0.2	1.6	0.1	3.75

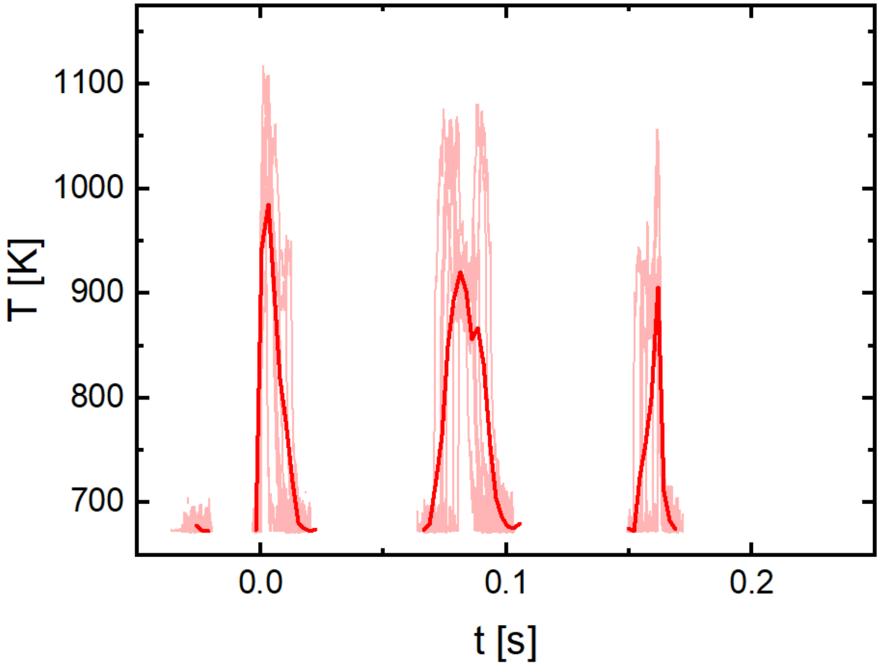






In-Situ reference pyrometry





- 10 layers, 25 kHz
- Emissivity acc to. T. Becker et al. (2024)
- Minimal spot size coverage (Rosenthal)

- Distinct peaks related to single laser vectors
- High temporal resolution
- Temperatures above 673 K registered

multiple peaks registered

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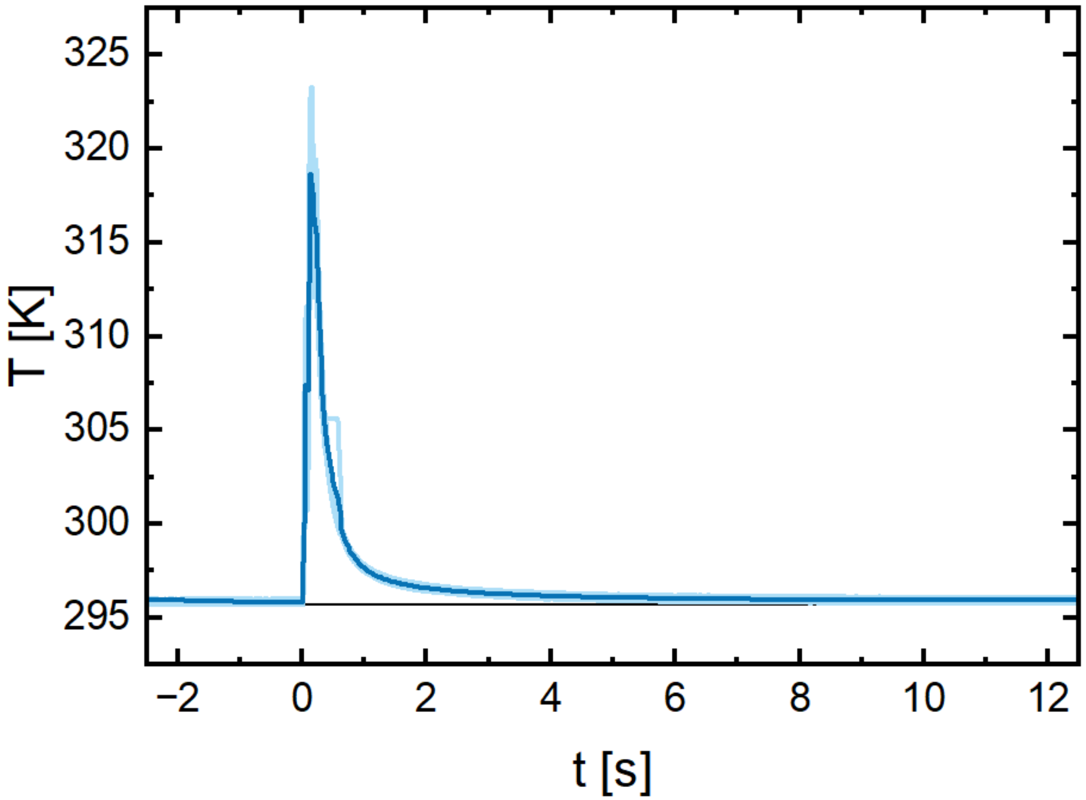
In-Situ reference thermocouple measurement



- TC welded to bottom of 2 mm thick substrate plate
- 10 layers

- Low resolution, max T registered at ~320 K (less than minimum of pyrometer)
- Decay of ~ 4 s

Temperature increase for ~4 s registered

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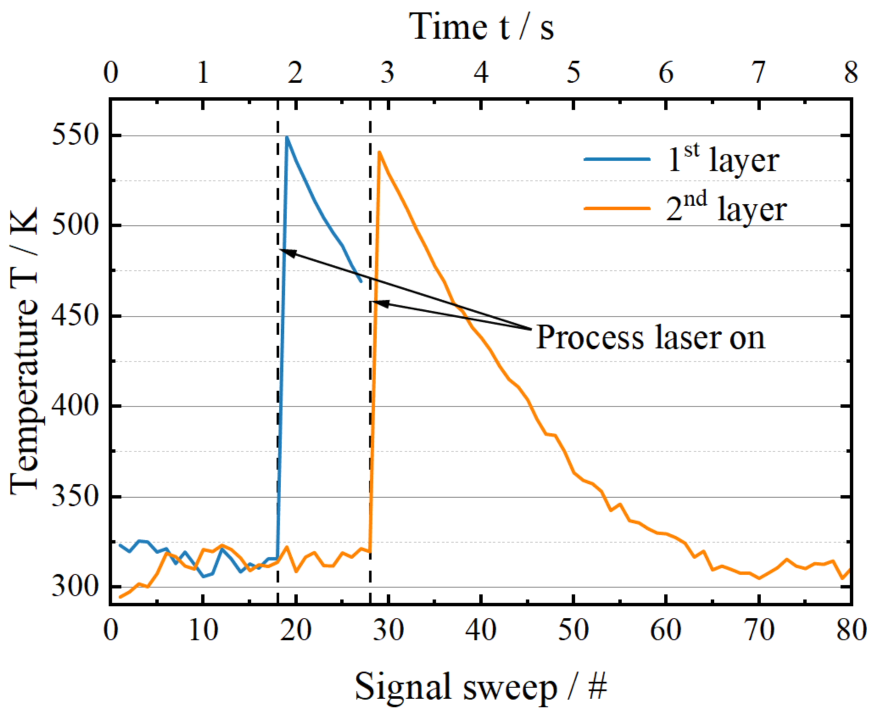
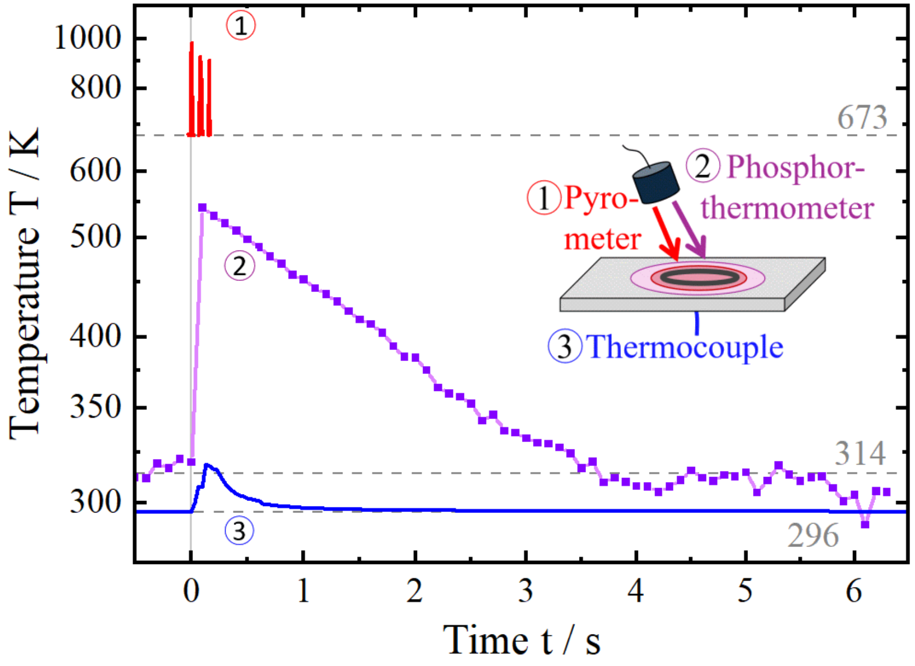
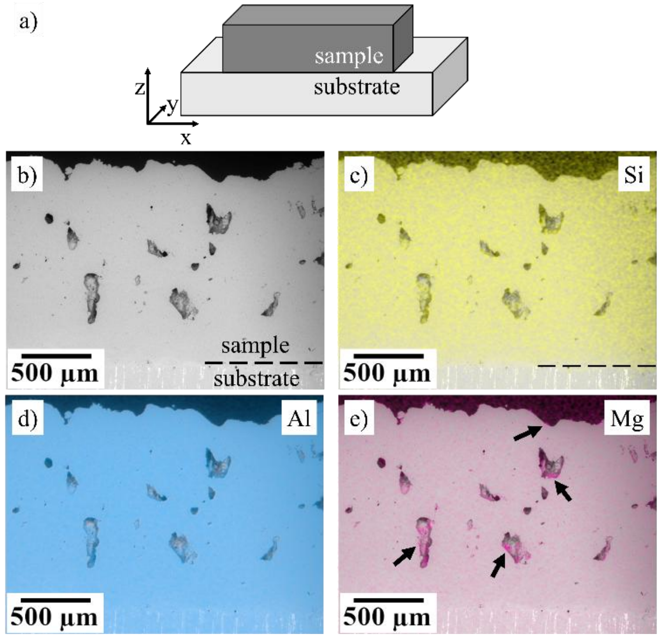
In-Situ Phosphor Thermometry

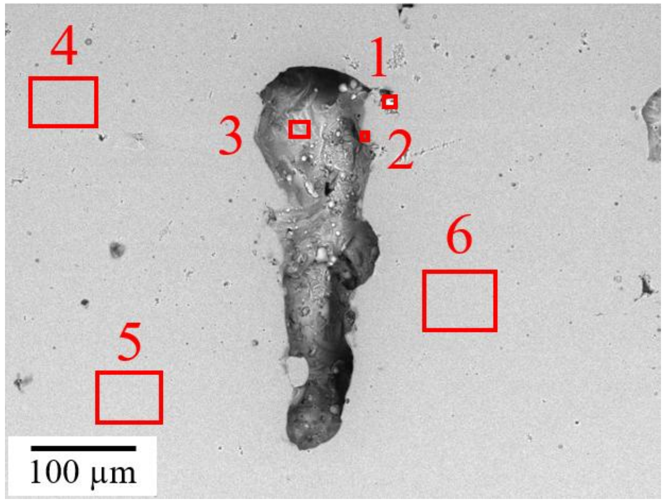




- 10 Hz, spot size excitation laser: 4 mm diameter
- Reducing diameter of ring-shaped sample, at 3 mm diameter: T- increase registered

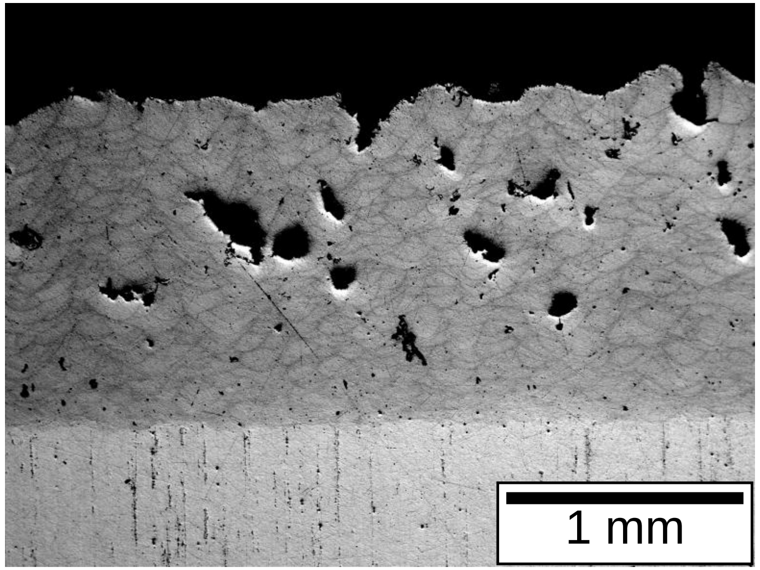
Ex-Situ Sample analysis





wt.%	O	F	Mg	Al	Si	Ge
1	16.4	2.5	12.5	54.0	2.9	11.7
2	19.9		22.0	55.2	3.0	
3	6.3	0.4	1.5	83.3	8.0	0.6
⌀ 4-6	1.0 ±0.1		0,5 ±0.0	89.6 ±0.2	8.8 ± 0.3	

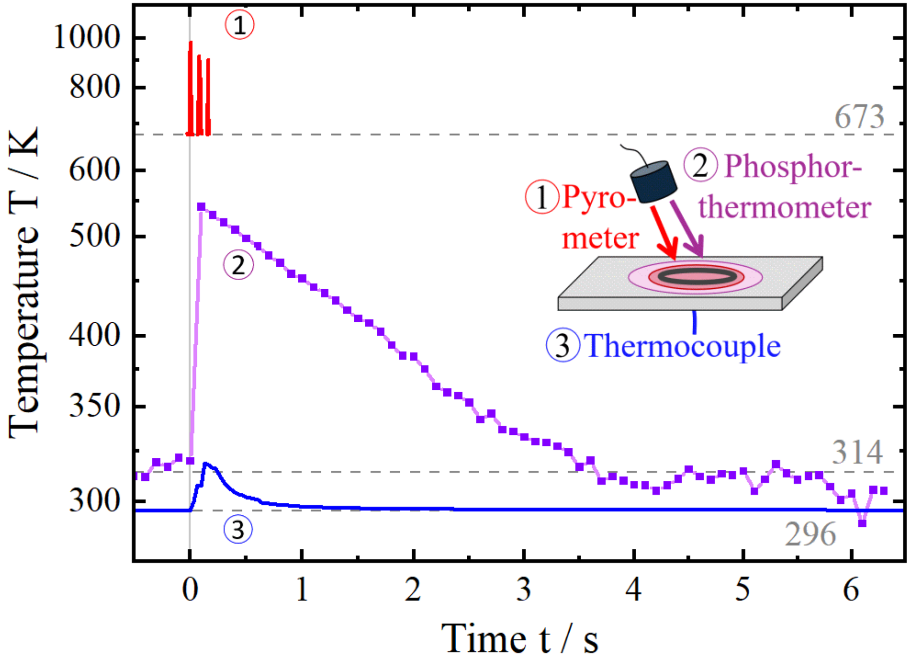
- Relative density: 95.66%
- Phosphorescence detected using PBF-LB/M-manufactured sample



Th. Phosphor found in pores

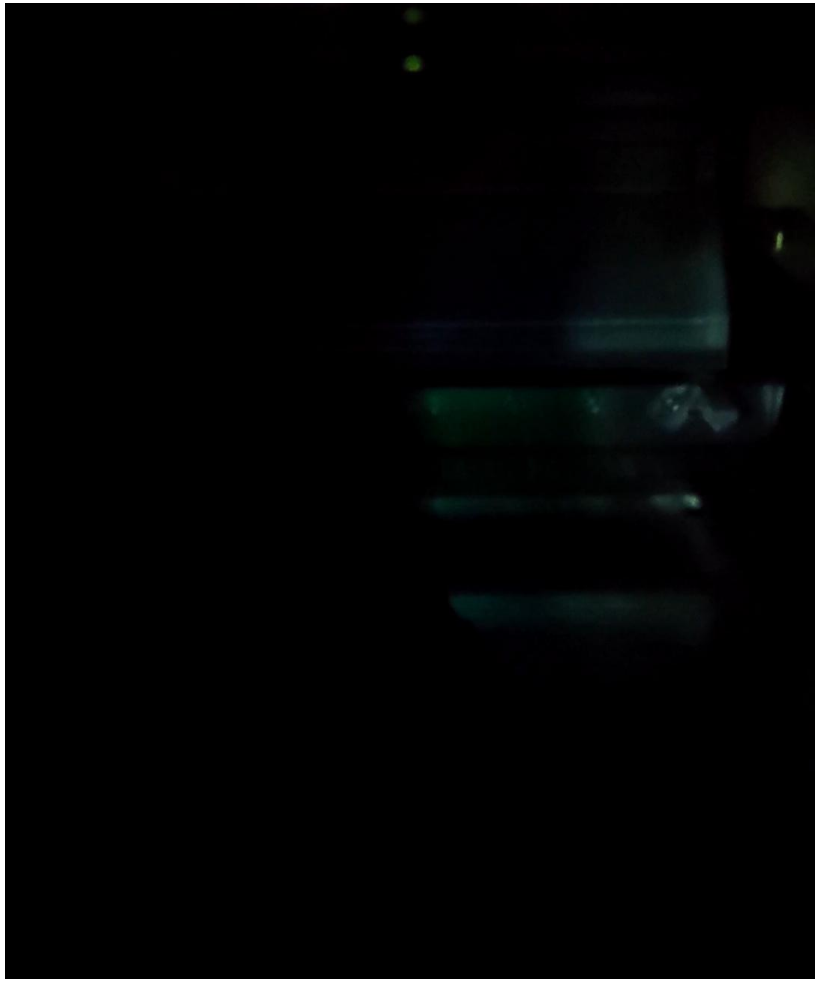
Summary

- Ex-Situ Calibration of Phosphor and matrix material
  - Matrix material contributes <0.6% to signal
- Reference measurements done by:
  - Pyrometry
  - Thermocouples
- In-Situ Phosphor Thermometry
  - Implementation
  - Successful measurement at low resolution



Outlook & Challenges

- Resolution
  - Spatial and temporal
- Porosity
  - Combination of matrix material & th. phosphor
- Calibration
  - Measurement spot coverage
  - Distribution of phosphorescent particles
- Online measurement
- Manufacturing of marker parts
  - Ex situ thermal monitoring during use



Science corner:
Demonstration experiment of bulk metallic glasses

Thank you for your attention!

Hanna Schönrath

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