Exploring Ce^{3+}:YAG glass ceramics by light sheet microscopy

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60th Ilmenau Scientific Colloquium: Living Glass Surfaces XII, 07. September 2023

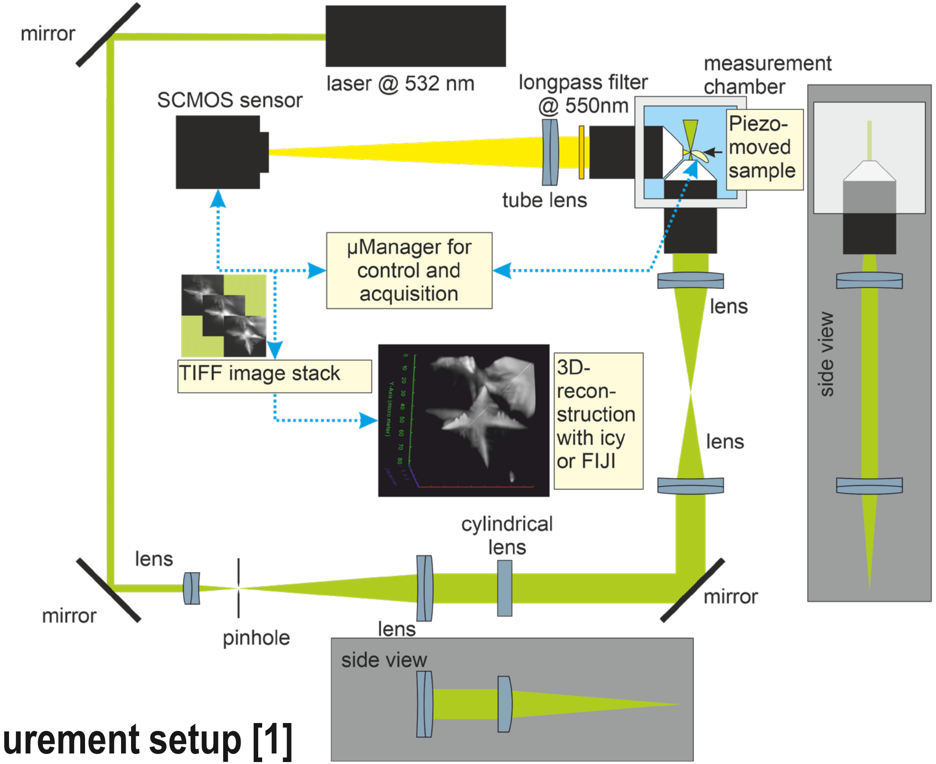
Motivation

- explore the crystall/glass interface by light-sheet fluorescence microscopy incl. fluorescence spectroscopy & fluorescence lifetime measurements
- sample: Ce:YAG glass ceramics as a model for material inhomogeneity
  ⇨ use the fluorescence of crystall and glass phases as structural probe
- work in progress:
  determine boundaries of the method / push it to its limits
  ⇨ probable future application in material characterization
  e.g. phase separated glasses
  photo-active glasses

Light-sheet microscopy

Light-sheet fluorescence microscope (LSFM):

- excitation: laser @ 532 nm, 25 mW
  (405 nm, 50 mW)
- laser beam formed into a „laser sheet“ by a cylindrical lens
  ⇨ only a thin slide of the sample is irradiated
- fluorescence light from the sheet is filtered and detected by SCMOS-sensor
  ⇨ fluorescence picture
  or by spectrometer
  ⇨ emission spectrum



measurement setup [1]

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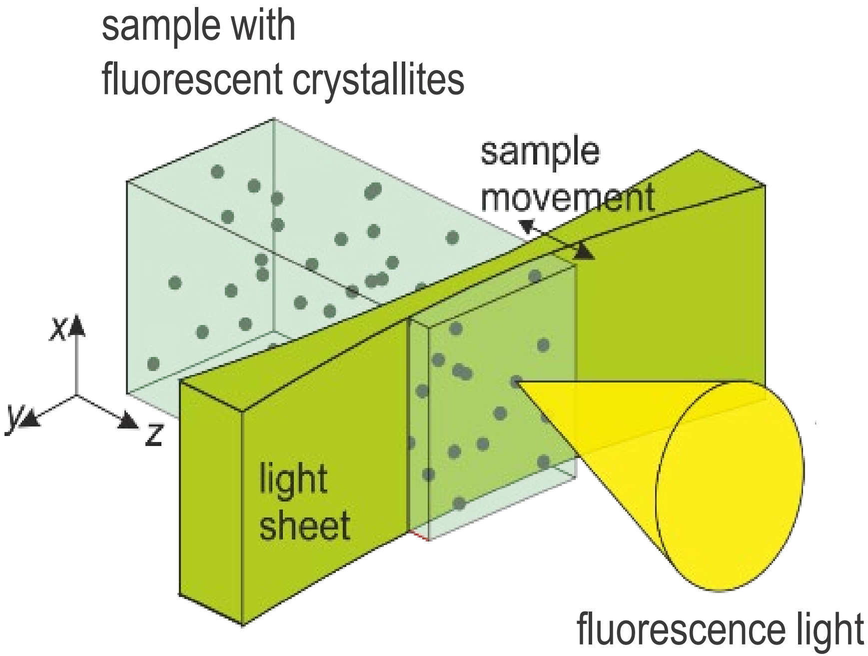
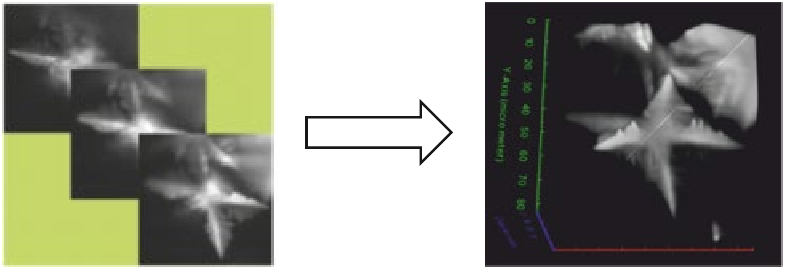
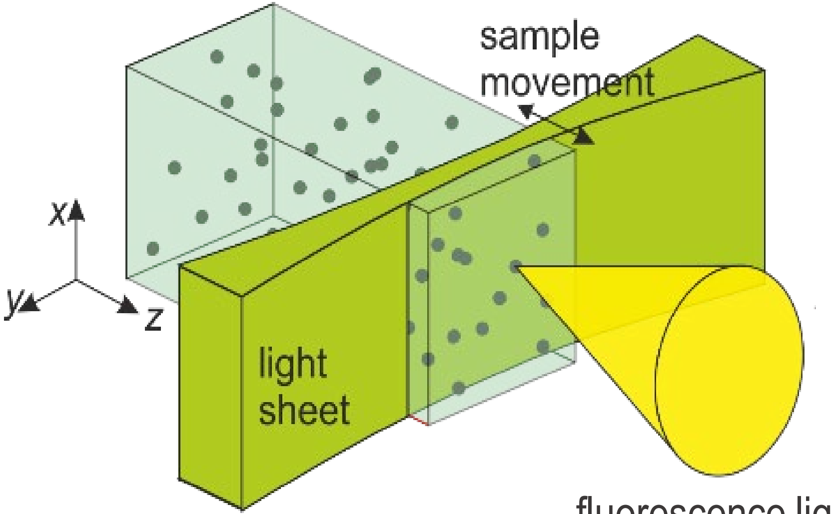


Light-sheet fluorescence microscope (LSFM):

- fluorescence light from the sheet is filtered and detected by SCMOS-sensor (or spectrometer)
- moving the sample: different light sheets/ stacks of light sheets
  ⇨ 3D picture of the sample

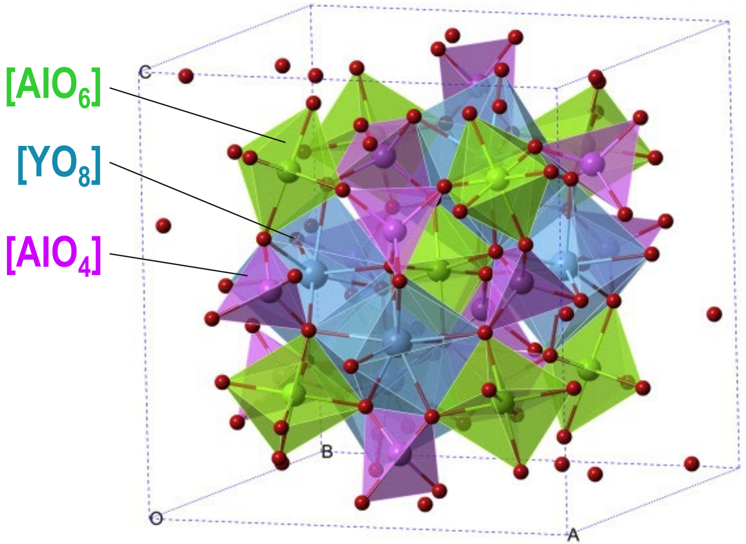




Ce:YAG glass ceramics

Yttrium Aluminum Garnet (YAG)

- $Y_3Al_5O_{12}$, cubic, colorless
- refractive index: 1.833
- melting temperature: 1950 °C
- chemically very stable
- very good solubility for rare earth ions
  ⇨ Ce^{3+} doping (yellow fluorescence)
- precipitation from a glass (previous project)
  ⇨ Ce:YAG glass ceramics [3]

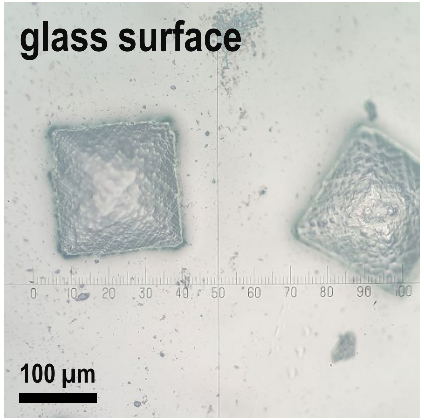


Structure of $Y_3Al_5O_{12}$ [2]

Ce:YAG glass ceramics

Ce:YAG glass ceramics

- taken from different project
- glass: yttrium alumino silicate
  doping: 1 mol% CeO_2
- YAG crystallization at only 1040 °C [3]
- some surface crystallization of YAG after casting
  ⇨ cubic crystals (‚pyramids' at surface)
  crystallite size 100-200 µm
  ⇨ dendritic growth in sample volume
  ⇨ crystals are Ce^{3+} doped (fluorescence)



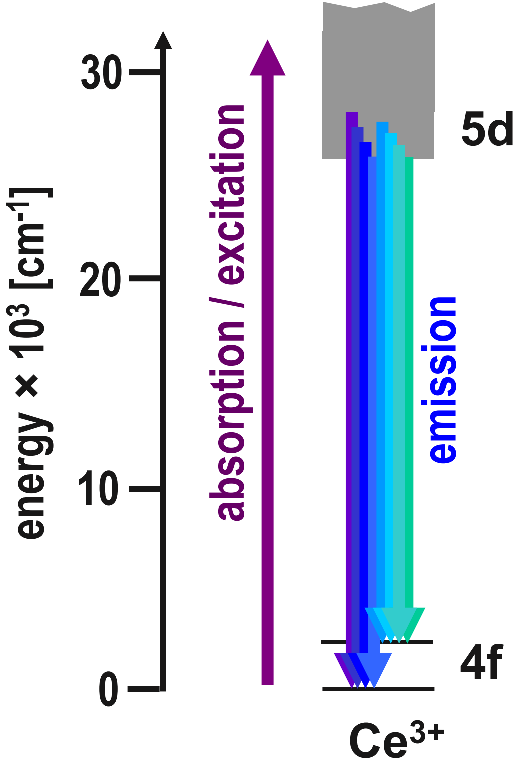
surface crystallization

Ce^{3+} fluorescence

$_{58}Ce$: electron configuration [Xe] $6s^2$ $4f^2$

- 5d orbital: five broad overlapping energy levels
  4f orbital: two narrow energy levels (‚shielding‘)
- 5d-4f transitions very broad and **sensitive to host material**
- excitation/emission in most glasses: UV-blue

Ce^{3+} doped glass under UV excitation



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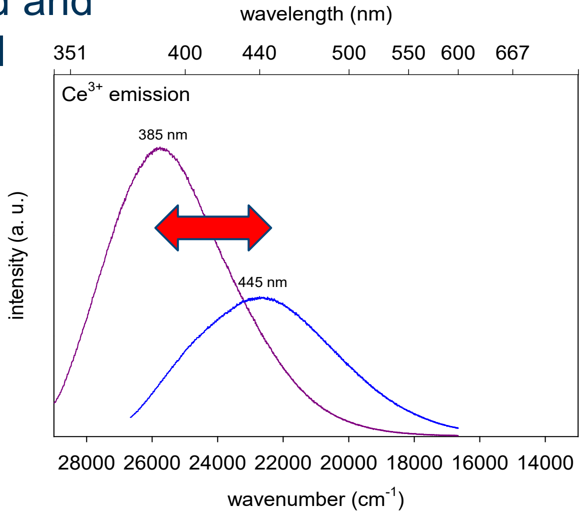
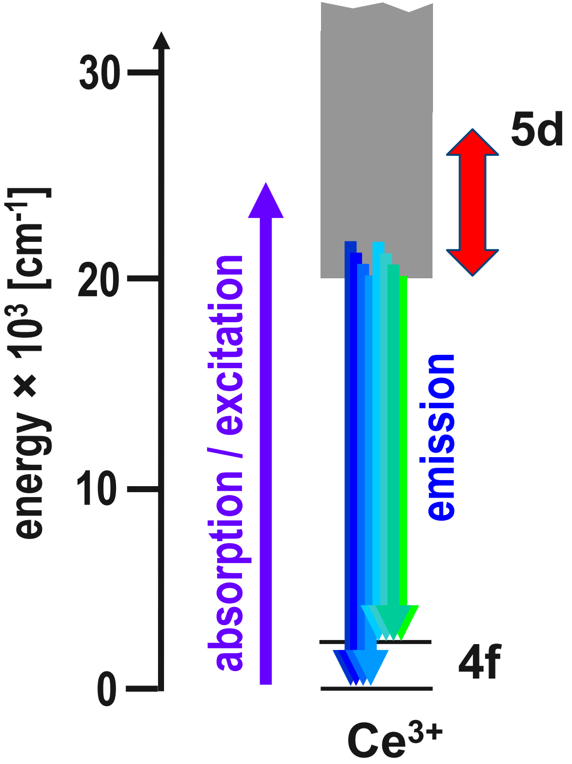
⇨ absorption and emission shift with host material [4]





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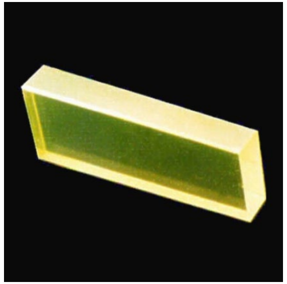

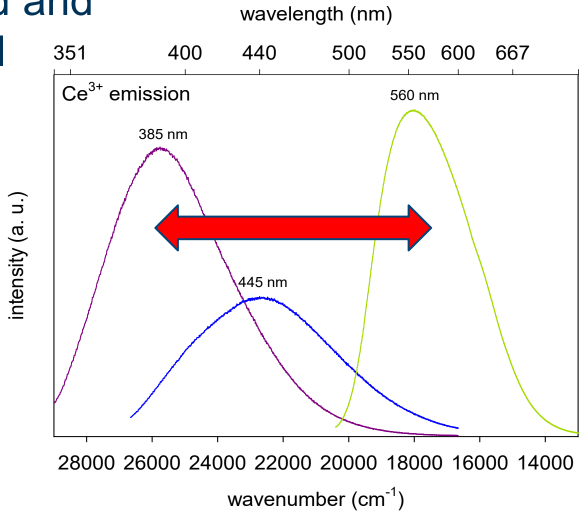

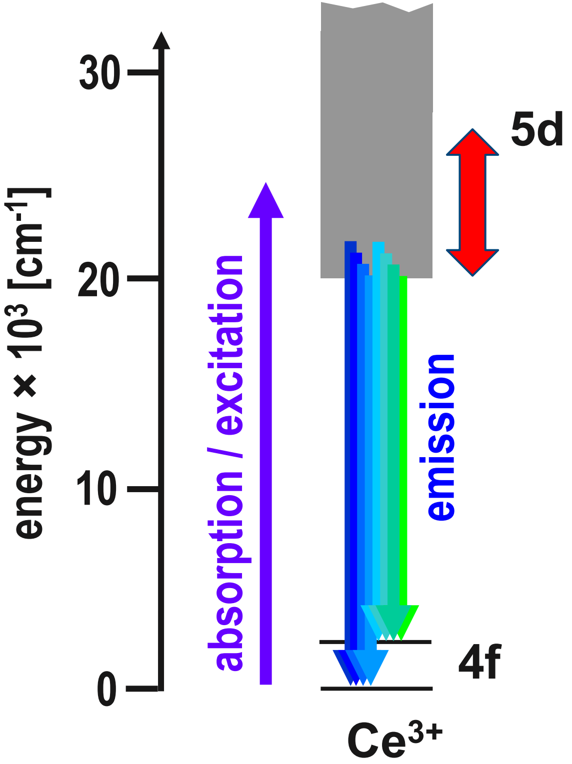

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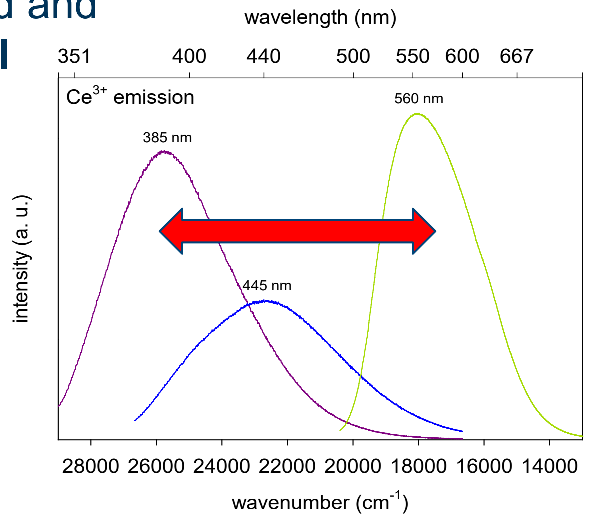
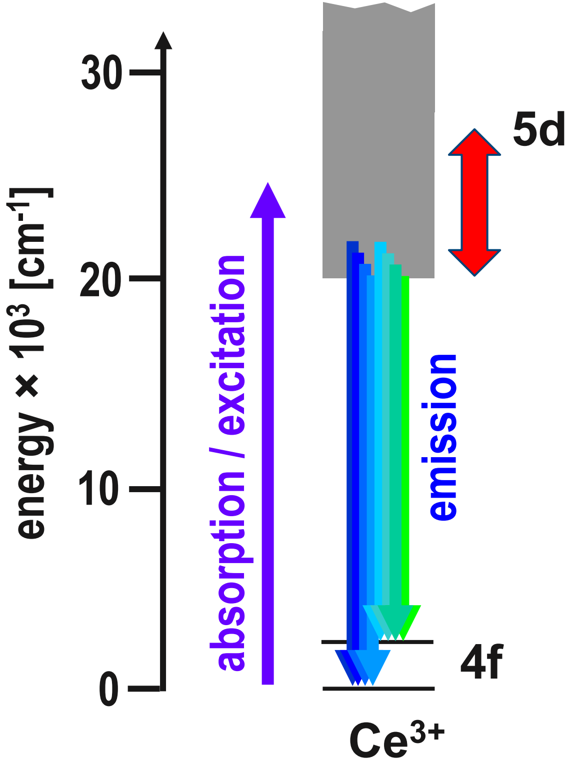
⇨ **changes in the emission spectra at the crystal/glass interface?**





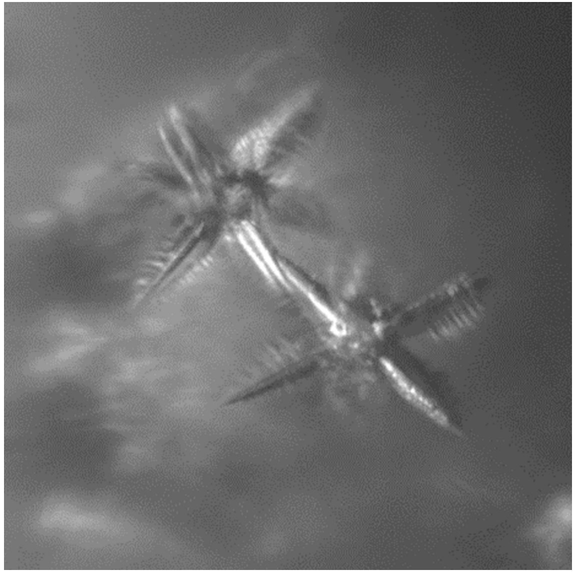
Results

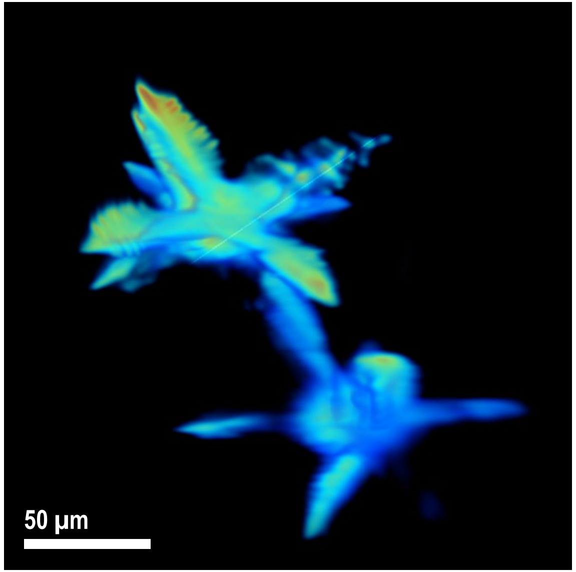
LSFM microscopic/fluorescence pictures

- preliminary results [5]: samples with volume crystallization

⇨ dendritic Ce:YAG crystals size ~100-200 µm

- excitation 532 nm: fluorescence well detectable ⇨ 3D pictures



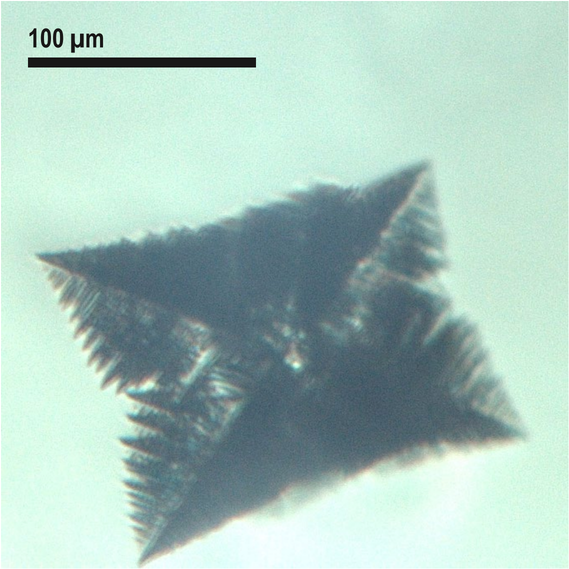


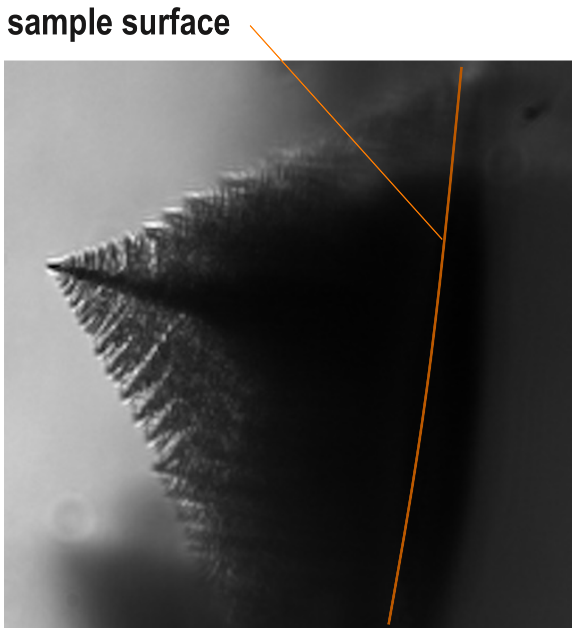
LSFM microscopic pictures

- new samples:
  mostly surface crystallization
  + some volume crystallization

⇨ dendritic Ce:YAG crystals
size ~100-200 µm

⇨ single dendrits visible





LSFM: spatial resolution
(luminescence picture, Ex.: 532 nm)

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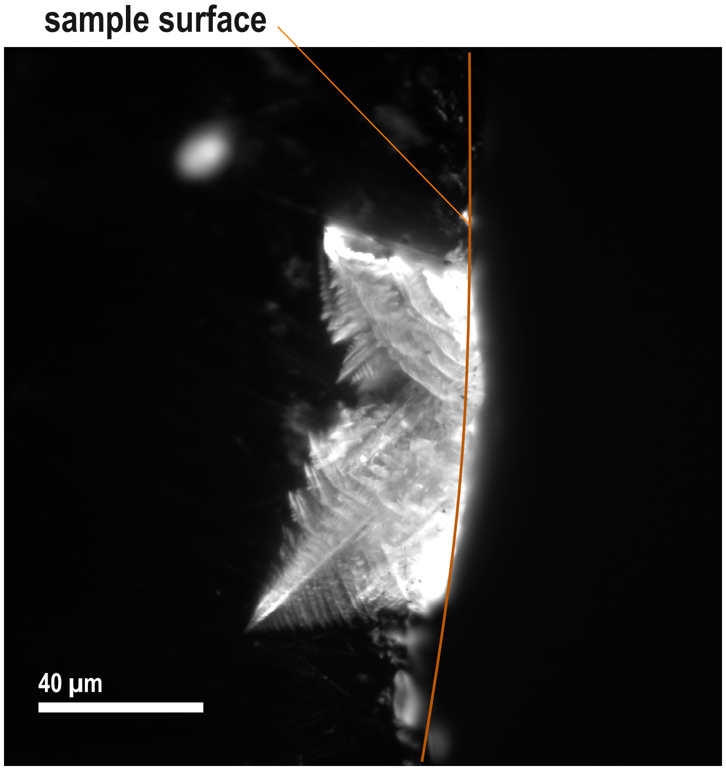

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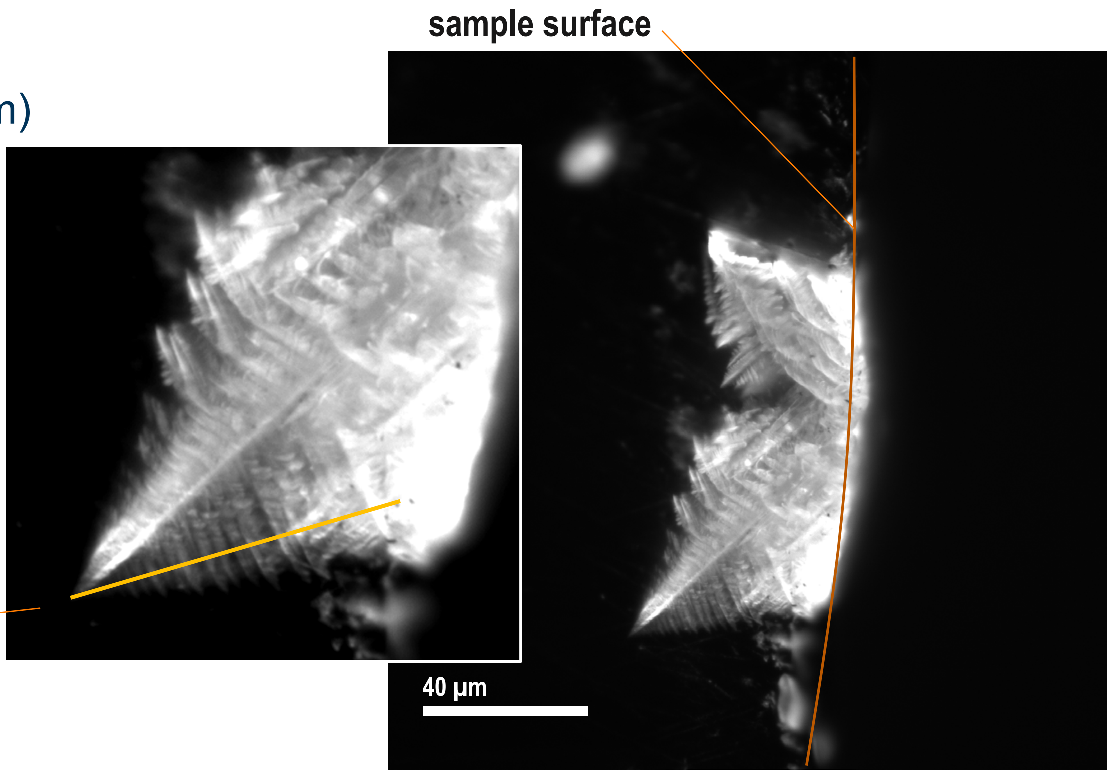
⇨ intensity profile



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LSFM: spatial resolution
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- new samples:
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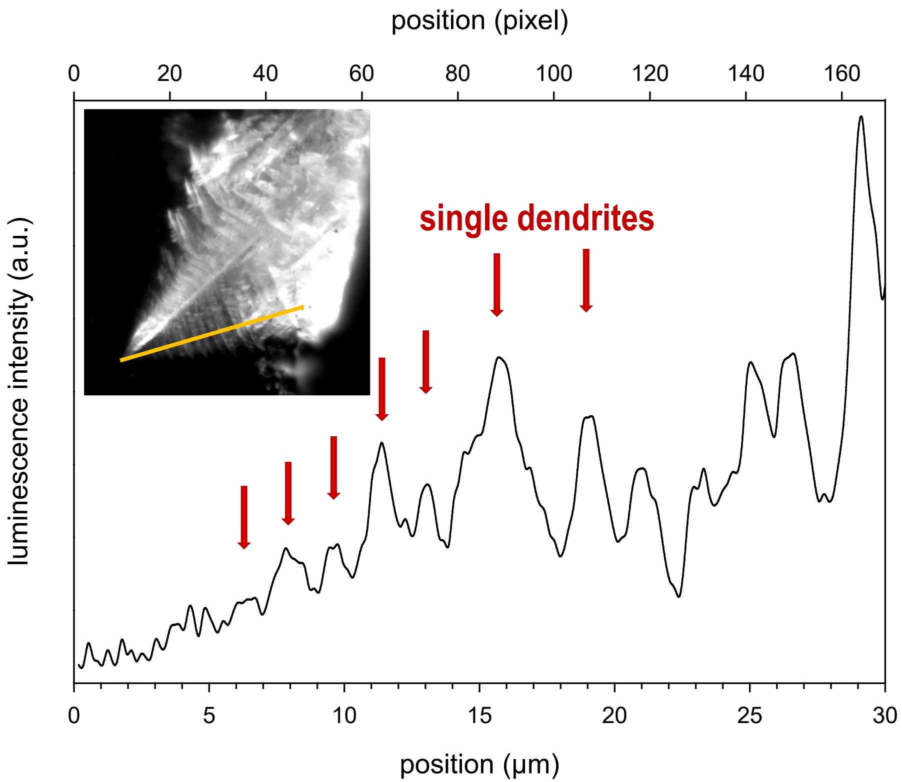
⇨ single dendrits visible

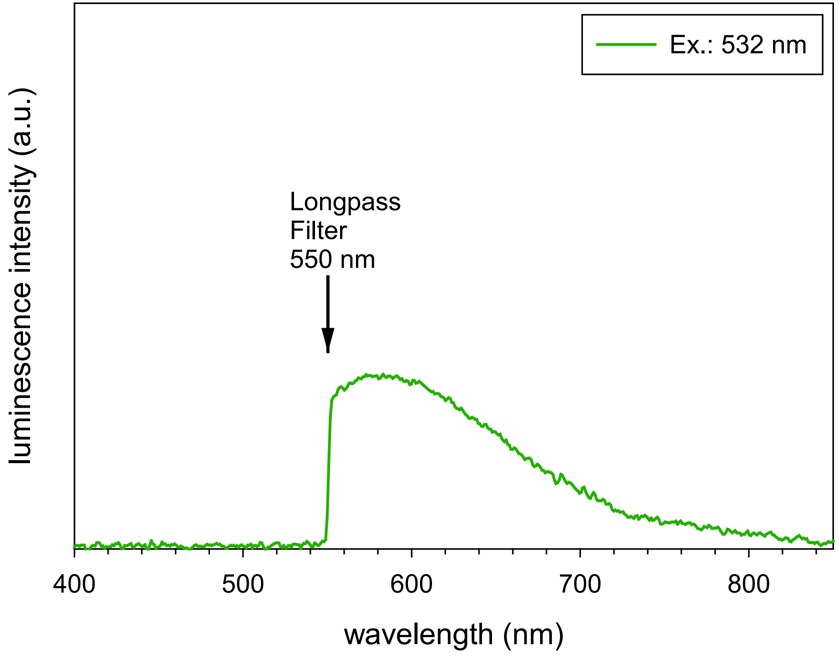
⇨ intensity profile
⇨ distance between dendrites ~ 1.5-2.0 µm



Results

LSFM emission spectra

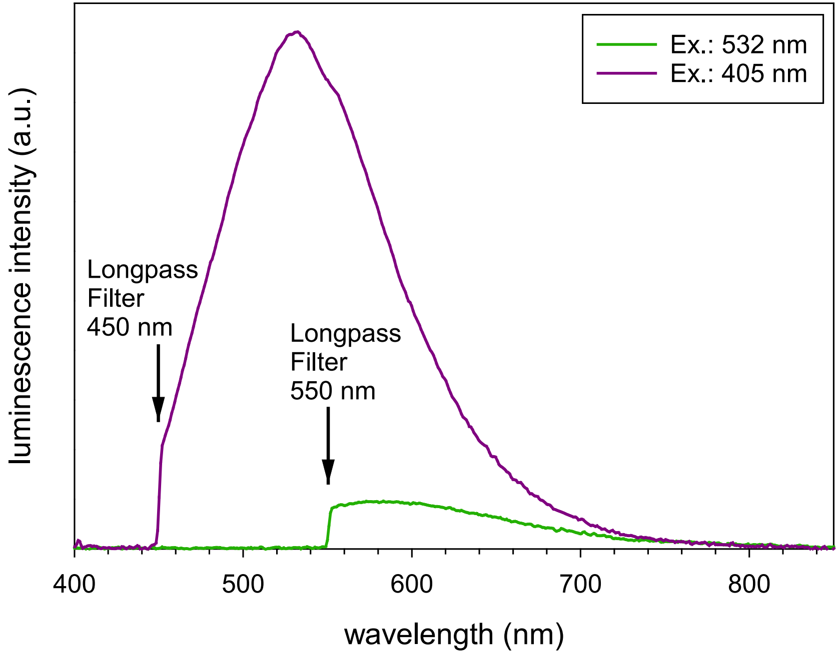
- 532 nm laser:
  low fluorescence intensity
  550 nm filter cuts peak maximum
  ⇨ not suitable to detect peak shift



Results

LSFM emission spectra

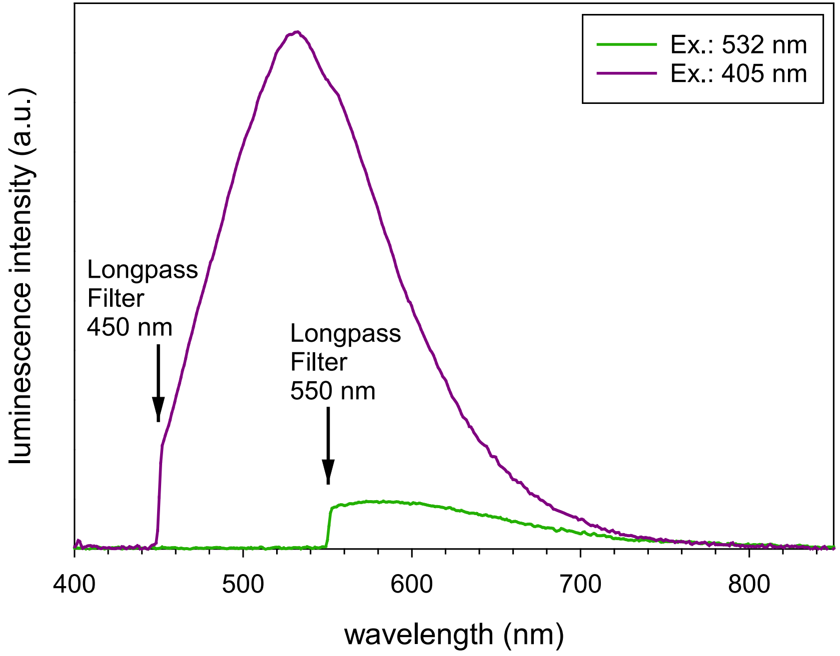
- 532 nm laser:
  low fluorescence intensity
  550 nm filter cuts peak maximum
  ⇨ not suitable to detect peak shift
- 405 nm laser:
  much higher fluorescence intensity
  good S/N ratio



Results

LSFM emission spectra

- 532 nm laser:
  low fluorescence intensity
  550 nm filter cuts peak maximum
  ⇨ not suitable to detect peak shift
- 405 nm laser:
  much higher fluorescence intensity
  good S/N ratio
- measurements at different crystal positions
  ⇨ but: peak position constant
  ⇨ no peak shift at crystal/glass interface detectable



Summary & Outlook

- LSFM can be used to create 3D pictures of the precipitated crystals
- spatial resolution ~ 1-2 µm
- fluorescence spectra could be measured with 532 and 405 nm excitation (532 nm not suitable, latter has much better S/N ratio)
- up to now no shift of the emisson spectra detected at the interface crystal/glass

Outlook:

- improvement of the spatial resolution (better fitting optics for 405 nm)
- scanning the samples at higher accuracy
- fluorescence lifetime measurements at different spots in the glass ceramics
- UV laser (fluorescence of glass and YAG phases detectable)

References

[1] P. Pitrone, J. Schindelin, L. Stuyvenberg et al.: OpenSPIM: an open-access light-sheet microscopy platform. Nature Methods 10 (2013) p. 598-599.

[2] Z. Yanchun, X. Huimin, F. Zhihai: Theoretical Investigation on Mechanical and Thermal Properties of a Promising Thermal Barrier Material: $Yb_3Al_5O_{12}$, Journal of Materials Science & Technology 30 (2014) p. 631.

[3] X. Xia: Optimization of a glass composition for synthesis of Ce^{3+}:YAG crystallites: MA thesis, TU Ilmenau, 2021.

[4] A. Herrmann, H. A. Othman, A. A. Assadi, M. Tiegel, S. Kuhn, C. Rüssel: Spectroscopic properties of cerium-doped aluminosilicate glasses, Optical Materials Express 5 (2015) p. 720.

[5] M. Hofmann, A. Herrmann, U. Brokmann: Light-sheet fluorescence microscopic probing of silicate materials, tm - Technisches Messen 89 (2022) p. 447-454.

Thank you for your attention!
Vielen Dank für Ihre Aufmerksamkeit!