Comparing Environmental Barrier Surface Temperature Mapping with Either a Y_2SiO_5:Er or Sc_2SiO_5:Er Temperature Sensing Layer

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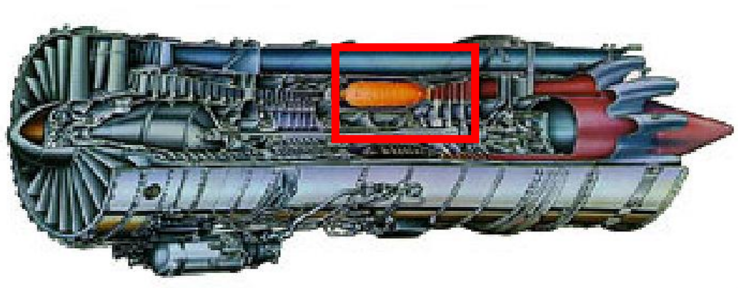
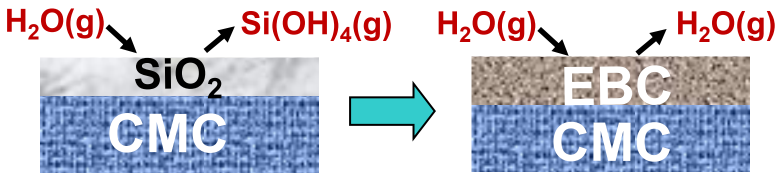
Background

Environmental Barrier Coatings (EBCs) Protect Ceramic Matrix Composite (CMC) Gas Turbine Engine Components

- Thermal barrier coatings (TBCs) provide thermal protection for metal engine components.
- EBCs protect SiC-based CMCs by reducing CMC recession (loss of material) due to volatilization of silica scales by water vapor.



EBC environmental protection



Unacceptable CMC recession occurs.

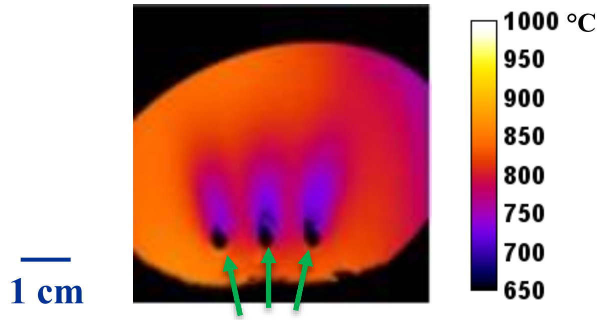
EBC prevents CMC recession.

EBC-coated airfoil

Objectives

- Meet challenges to develop phosphor thermometry temperature mapping capability from 1300 to >1500 °C range for evaluation of EBC performance and cooling strategies.
  - These are much higher temperatures than are reached at TBC surfaces (<1200 °C).
  - Intense thermal radiation background can overwhelm luminescence emission.
  - Phosphor compatibility with EBC-coated SiC at high temperatures.

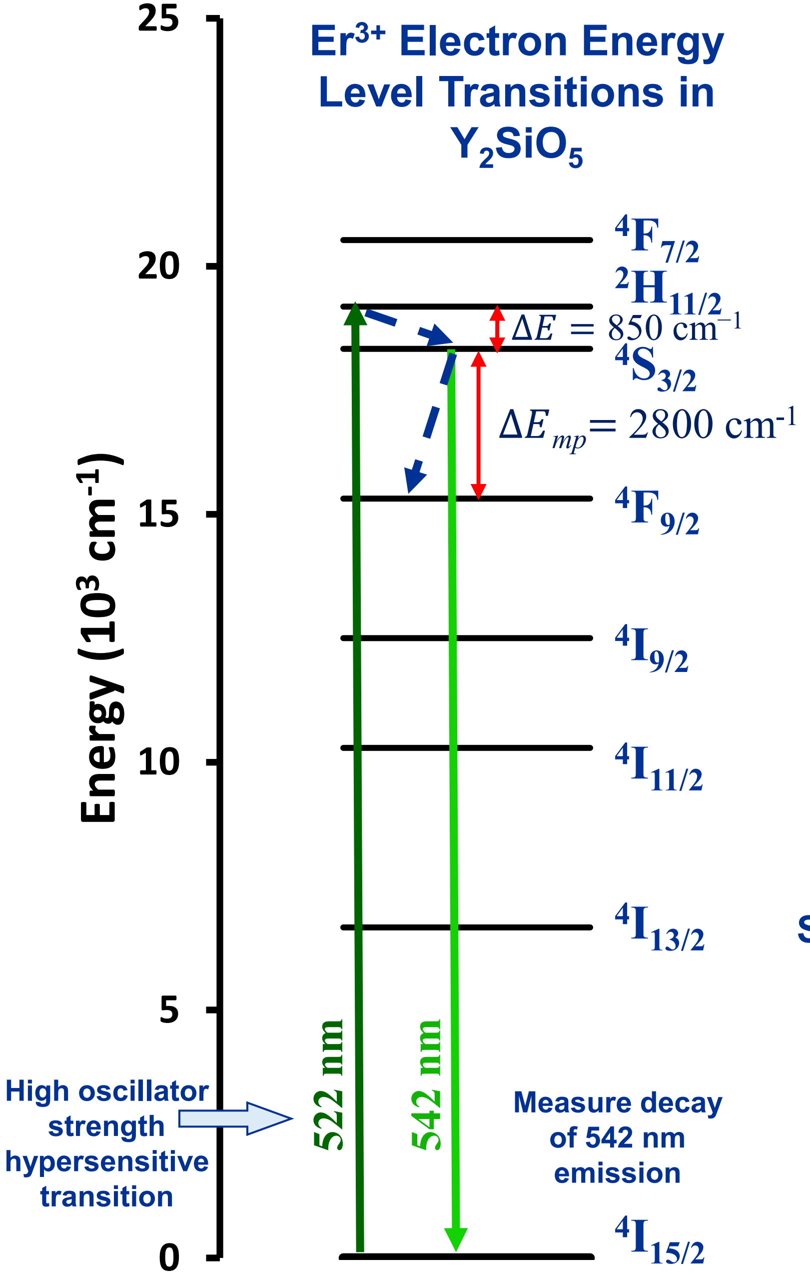
Air-jet cooling of TBC surface



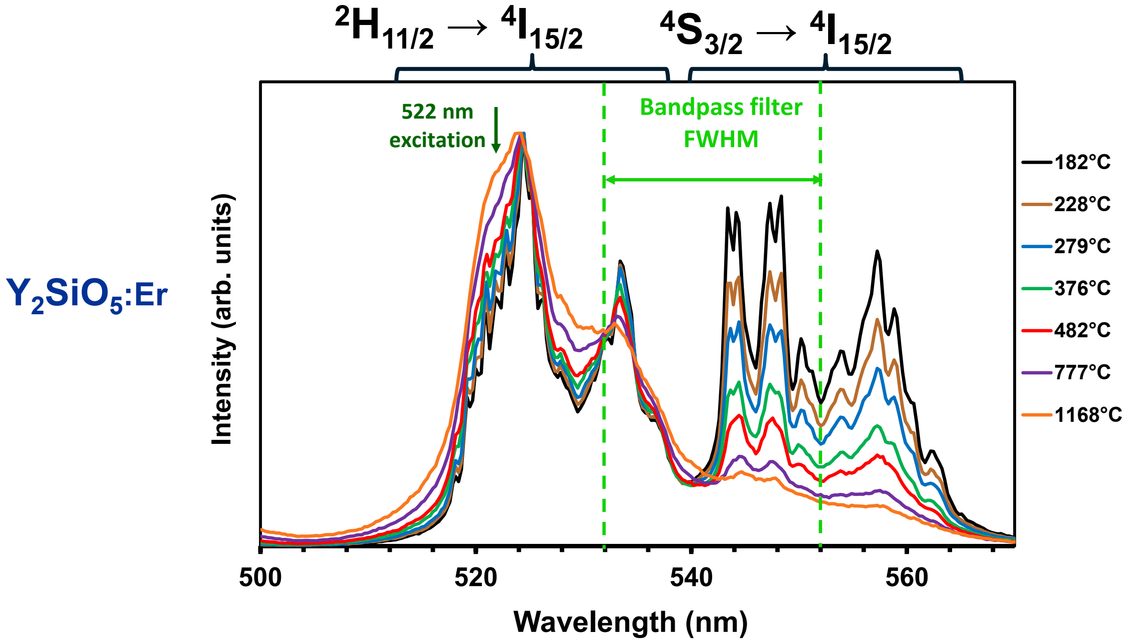
Approach

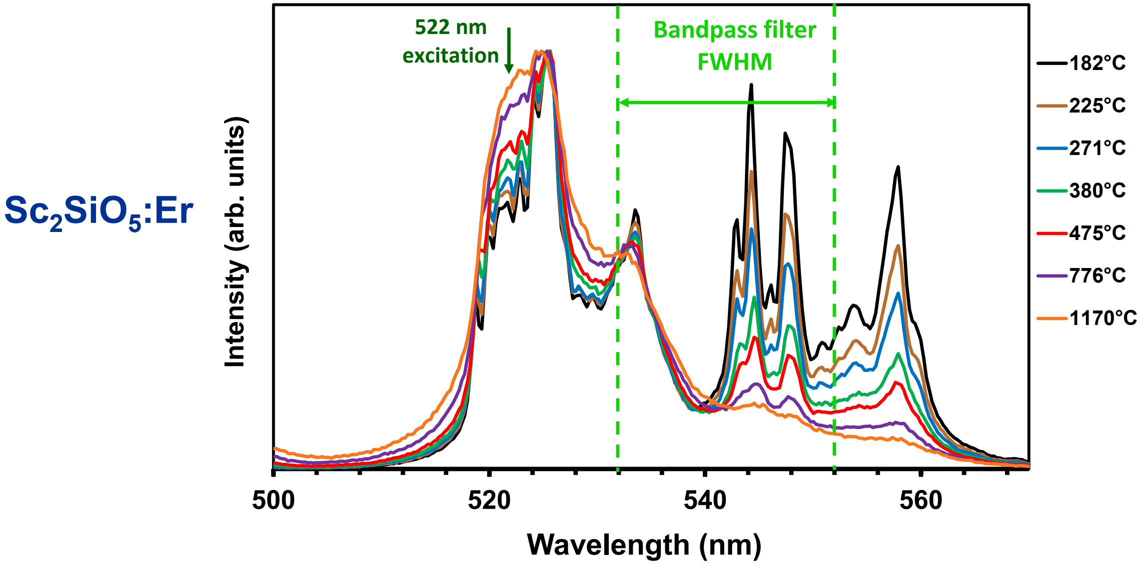
- Evaluate Y_2SiO_5:Er and Sc_2SiO_5:Er for surface temperature mapping of EBC-coated CMCs to beyond 1500 °C
  - Tradeoffs between temperature sensitivity and compatibility.

Luminescence Lifetime Temperature Dependence



Emission Spectra Temperature Dependence (380 nm excitation)



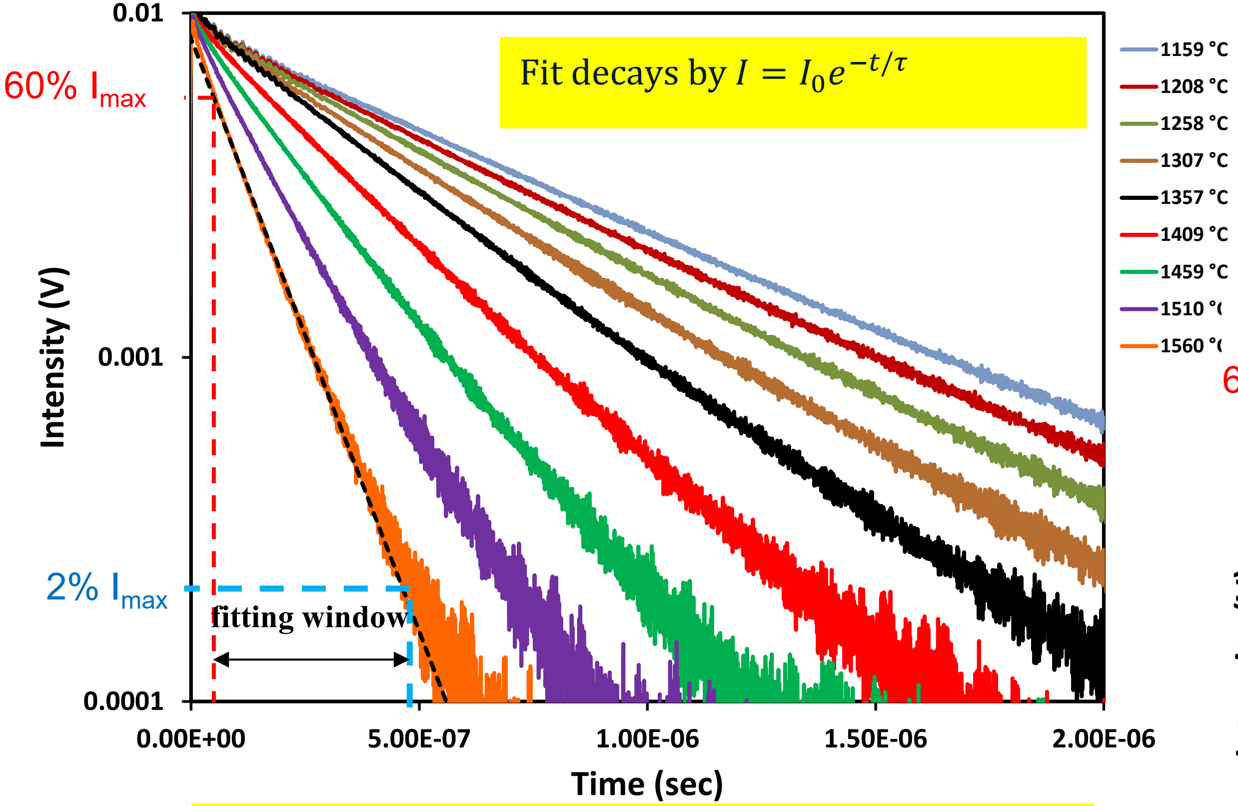


Decay detection captures part of thermally coupled $^2H_{11/2} \rightarrow {}^4I_{15/2}$ emission to substantially increase collected emission intensity at high temperatures.

Longer wavelength portions of $^4S_{3/2} \rightarrow {}^4I_{15/2}$ emission avoided to reduce thermal radiation background.

Luminescence Emission Decay Curves

Y_2SiO_5:Er disk

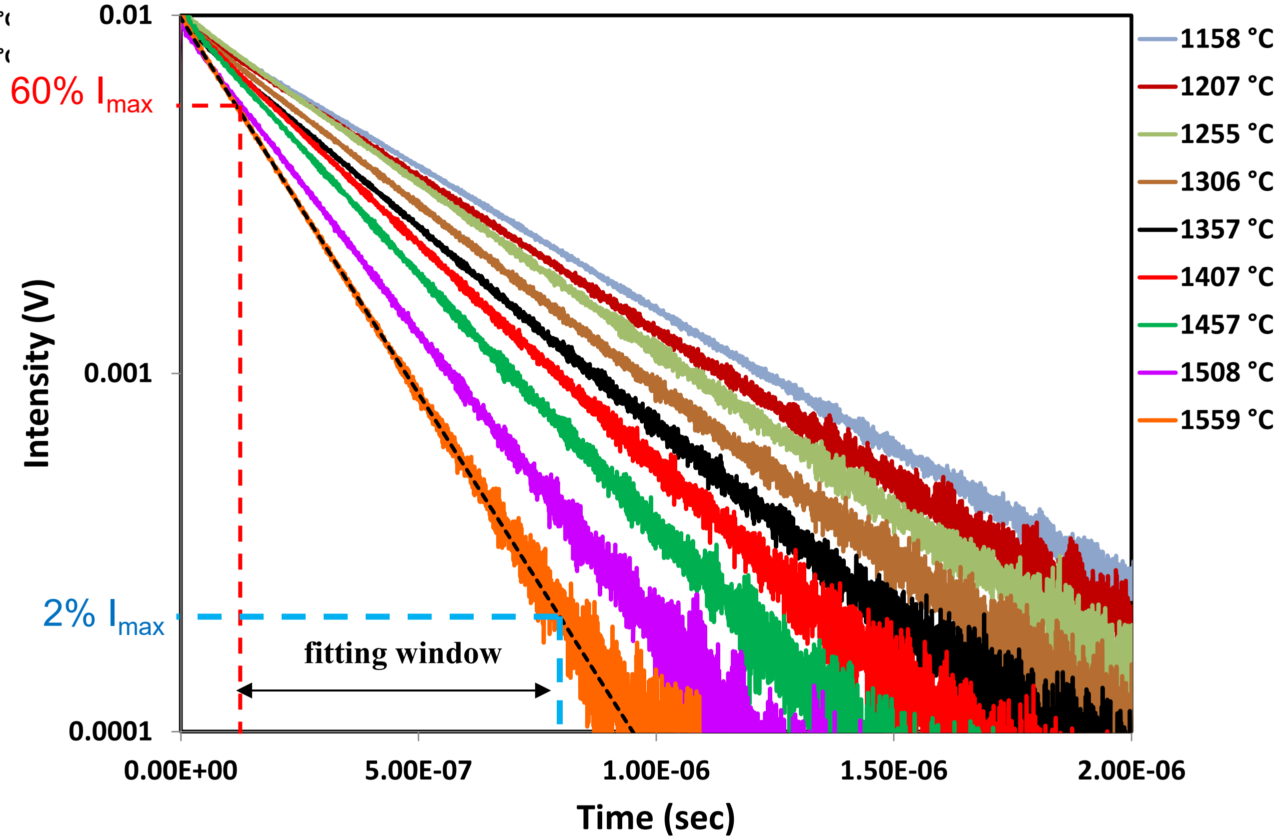


- More temperature sensitive

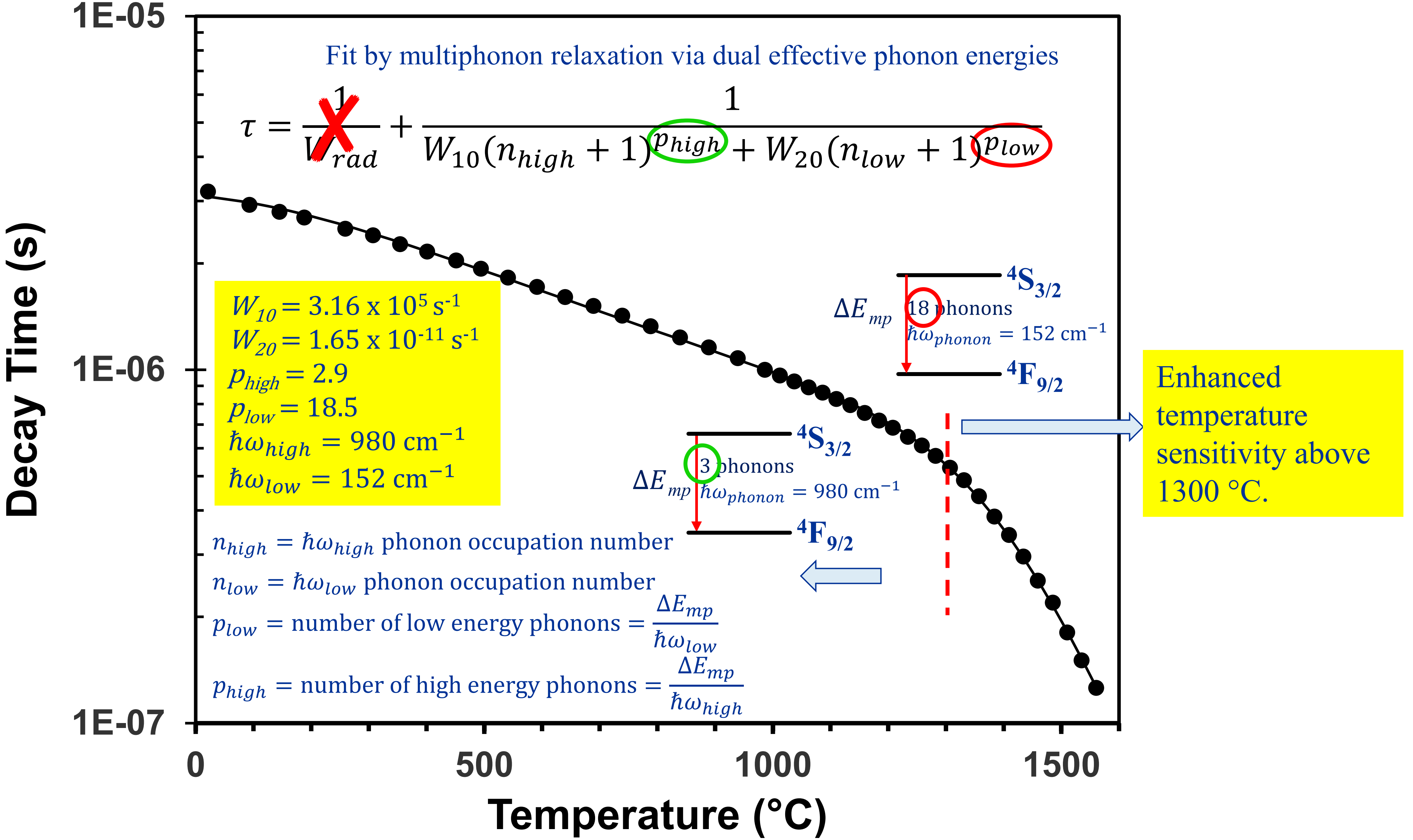
Monitor decay for real-time spot temperature measurements.

- Less temperature sensitive

Sc_2SiO_5:Er disk



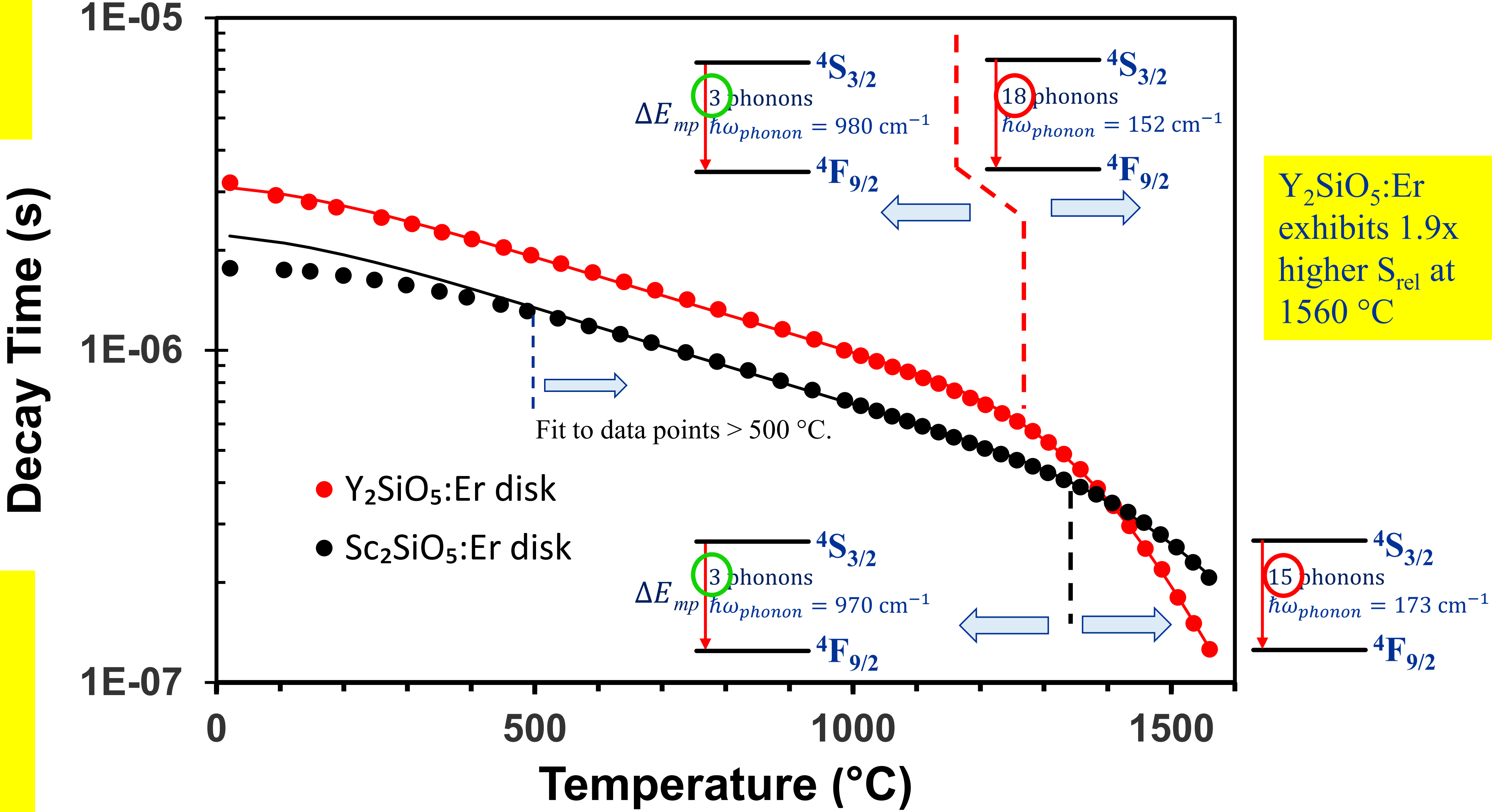
Y_2SiO_5:Er(0.8%) Decay Time Temperature Dependence



Y_2SiO_5:Er(0.8%) vs. Sc_2SiO_5:Er(0.8%)
Decay Time Temperature Dependence

Y_2SiO_5:Er

$W_{10} = 3.16 \times 10^{5}\ s^{-1}$
$W_{20} = 1.65 \times 10^{-11}\ s^{-1}$
$p_{high} = 2.9$
$p_{low} = 18.5$
$\hbar\omega_{high} = 980\ cm^{-1}$
$\hbar\omega_{low} = 152\ cm^{-1}$

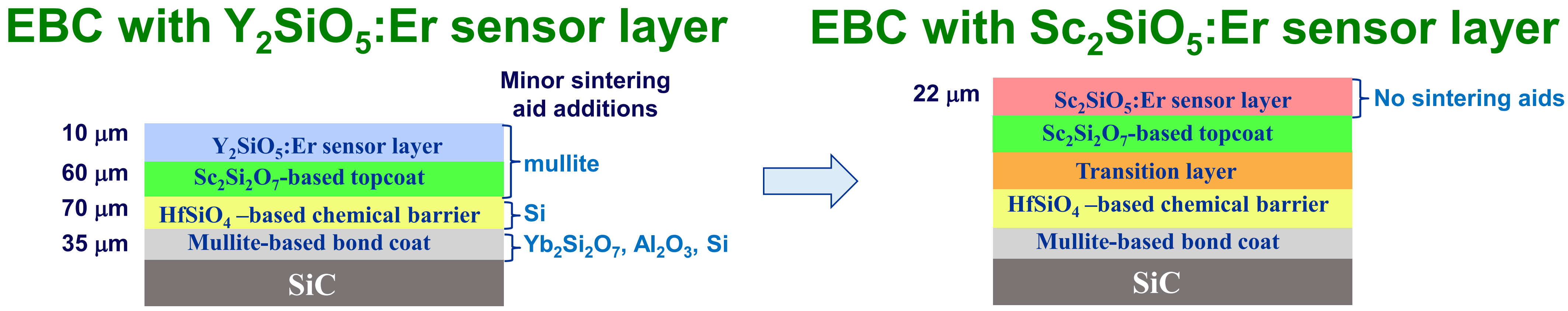


Y_2SiO_5:Er exhibits 1.9x higher S_{rel} at 1560 °C

Sc_2SiO_5:Er

$W_{10} = 4.42 \times 10^{5}\ s^{-1}$
$W_{20} = 4.82 \times 10^{-8}\ s^{-1}$
$p_{high} = 2.9$
$p_{low} = 15.5$
$\hbar\omega_{high} = 970\ cm^{-1}$
$\hbar\omega_{low} = 182\ cm^{-1}$

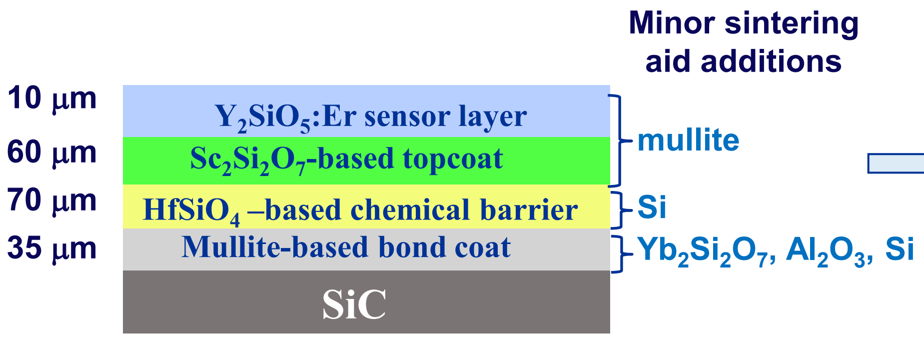
Sensor Layer/EBC Architectures

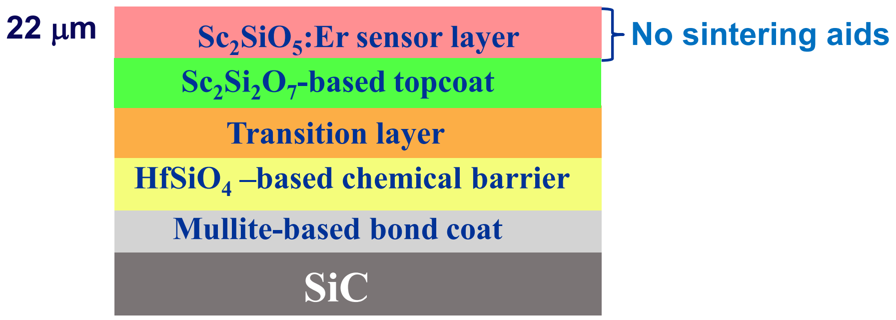


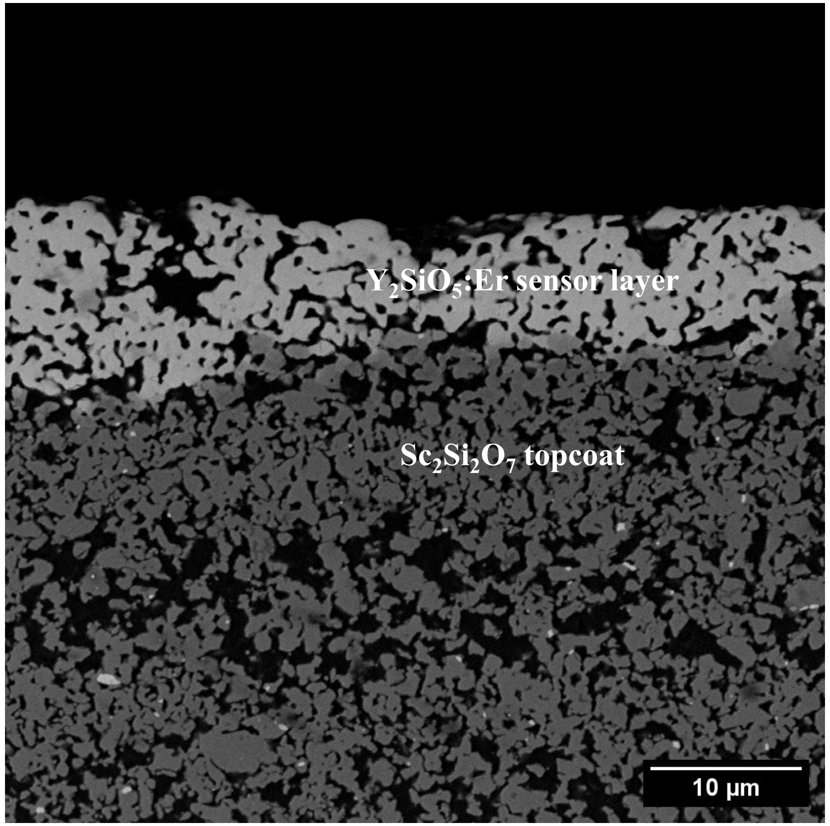
- Sensor coating + layered EBCs deposited using slurry process* via spin coating.
  - Sintering aids omitted in new Sc_2SiO_5:Er sensor layer.
    - Avoids reactions with sintering aids in sensor layer that could affect temperature sensing.
  - Monosilicates selected for sensor layer instead of disilicates for stability because surface disilicate can slowly convert to monosilicate.

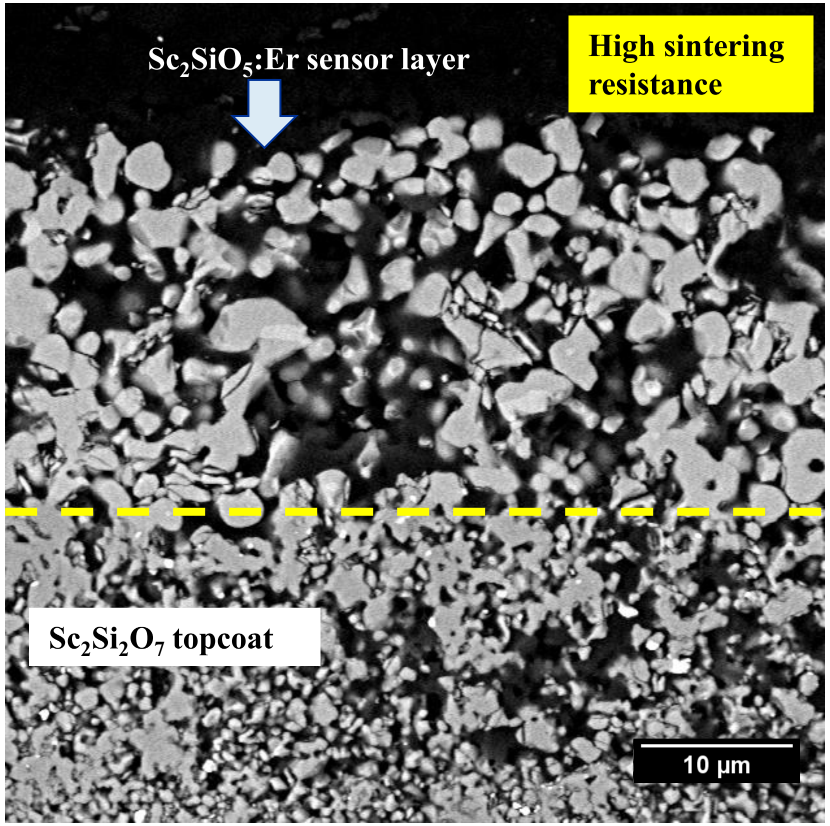
*K.N. Lee et al., J. Eur. Ceram. Soc., 41 (2021) 1639-1653.

Sensor Layer/EBC Architectures



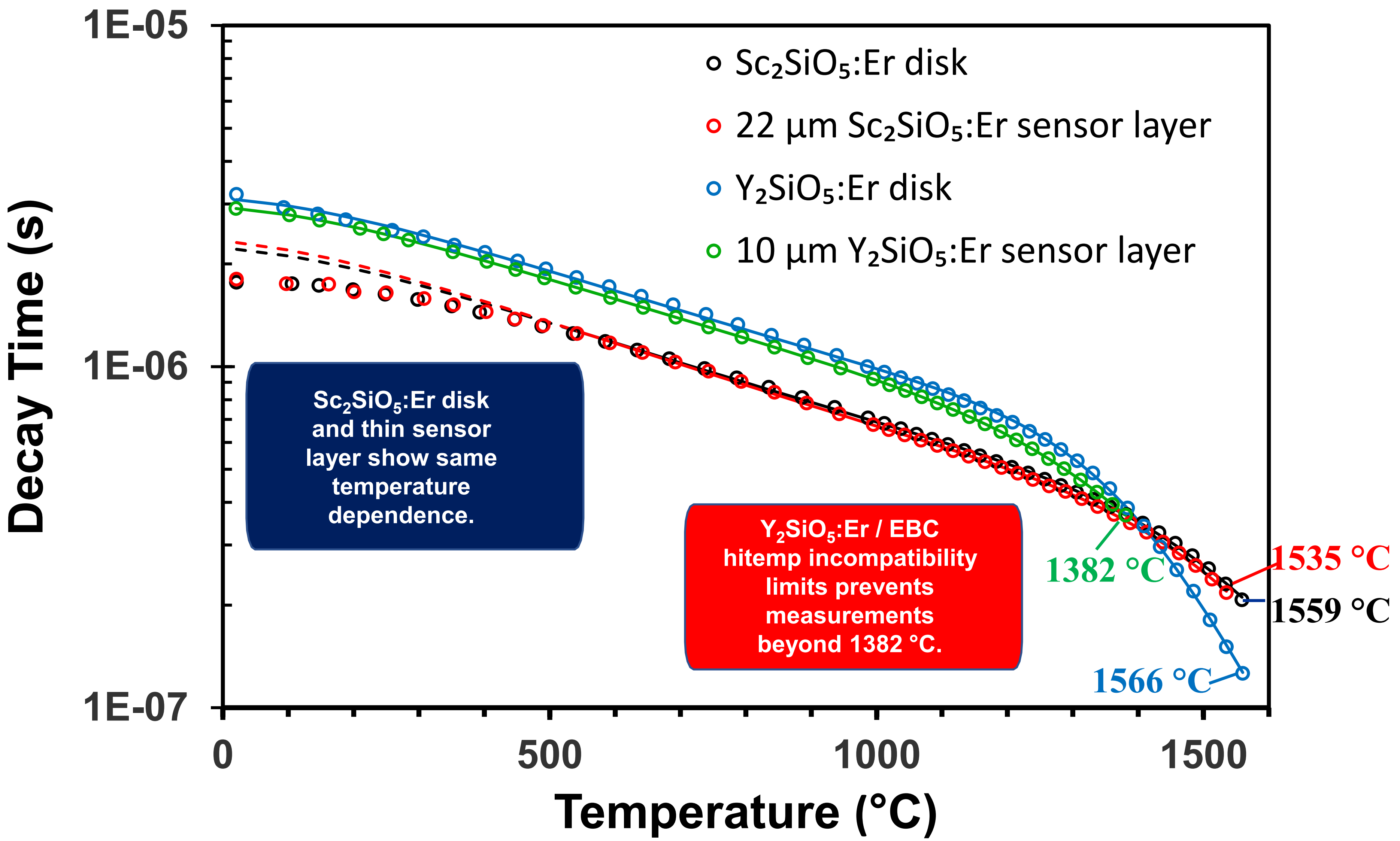






Performance of Sensor Layers vs. 2.4-mm Thick Disks

Decay Time Temperature Dependence



2D Temperature Maps from Luminescence Lifetime Imaging*

- Step 1: Acquire image stack of background-corrected exposures (restricted to steady state conditions).
- Step 2: Fit single exponential decay to luminescence decay curve at ***each pixel*** to produce decay time map.

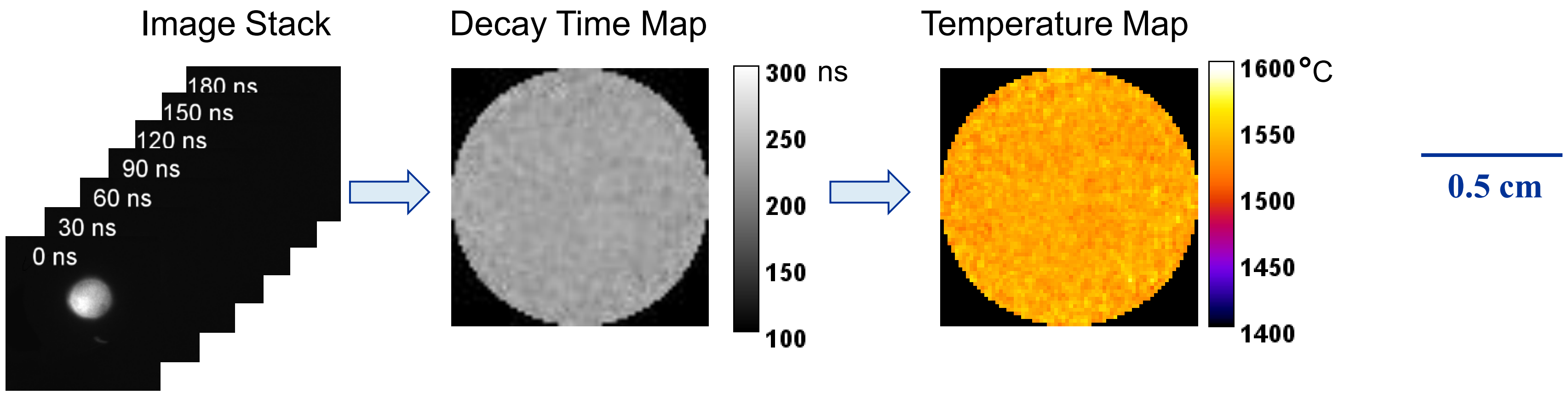
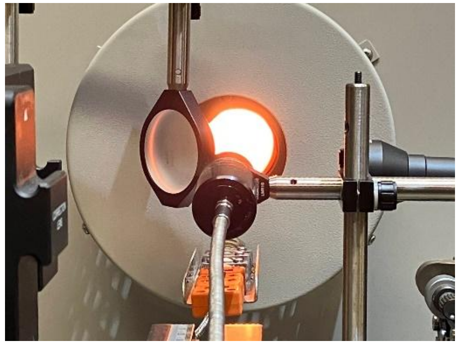


*Image processing developed by Adam Wroblewski at NASA GRC.

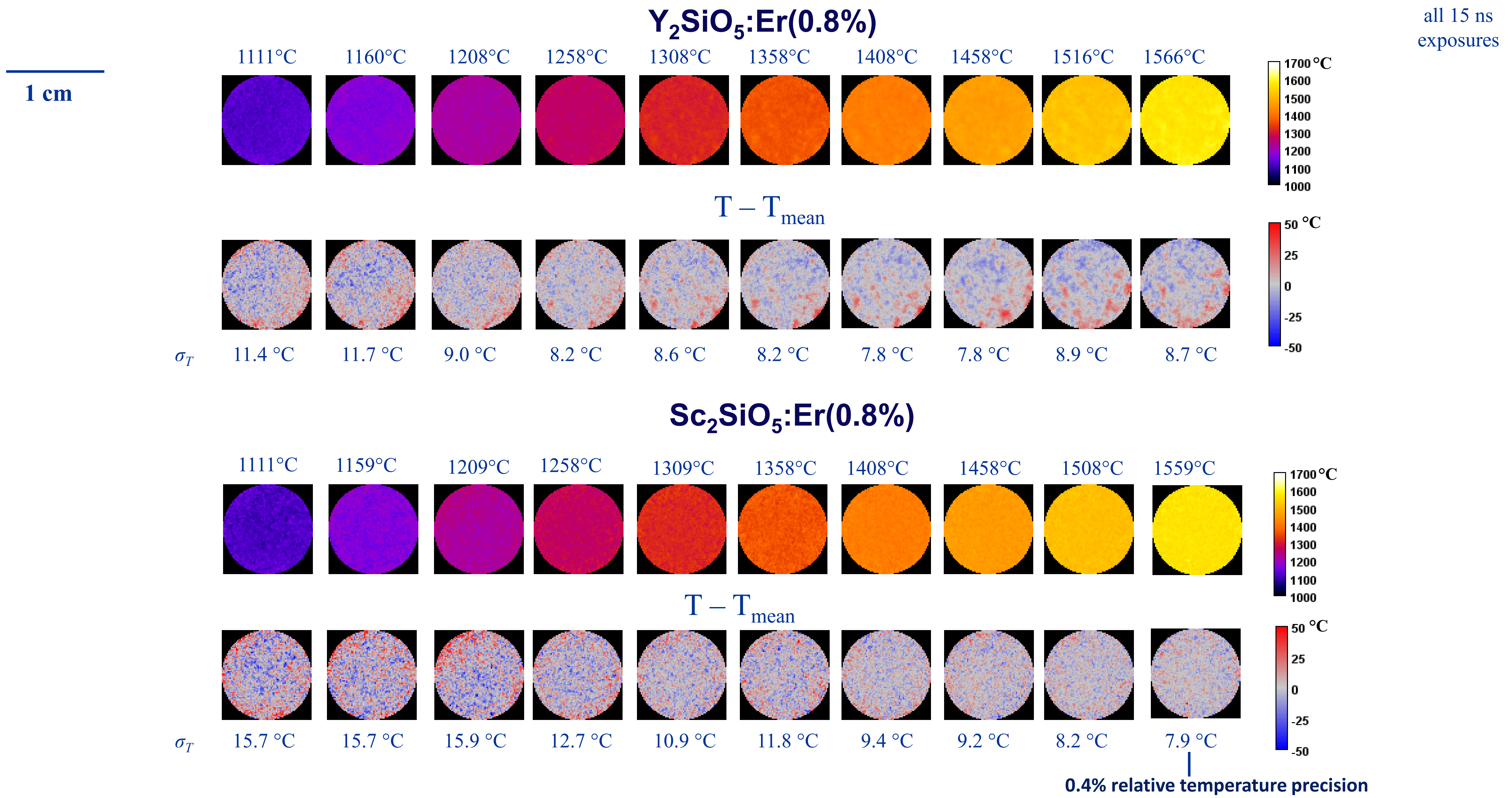
- Step 3: Use furnace calibration data to convert decay time map to temperature map.



$$\tau = [W_{10}(1 - e^{-\frac{\Delta E}{p_{high} kT}})^{-p_{high}} + W_{20}(1 - e^{-\frac{\Delta E}{p_{low} kT}})^{-p_{low}}]^{-1}$$

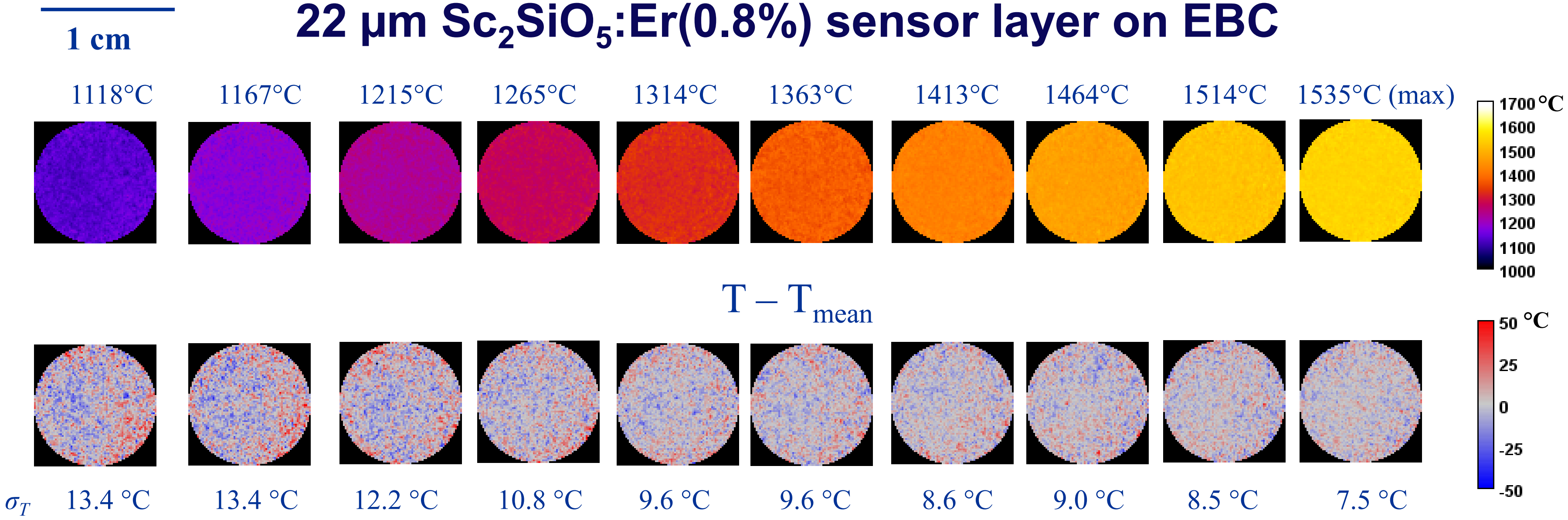
Dual effective phonon energy model

Luminescence Lifetime Temperature Maps
2.4-mmThick Standalone Disks



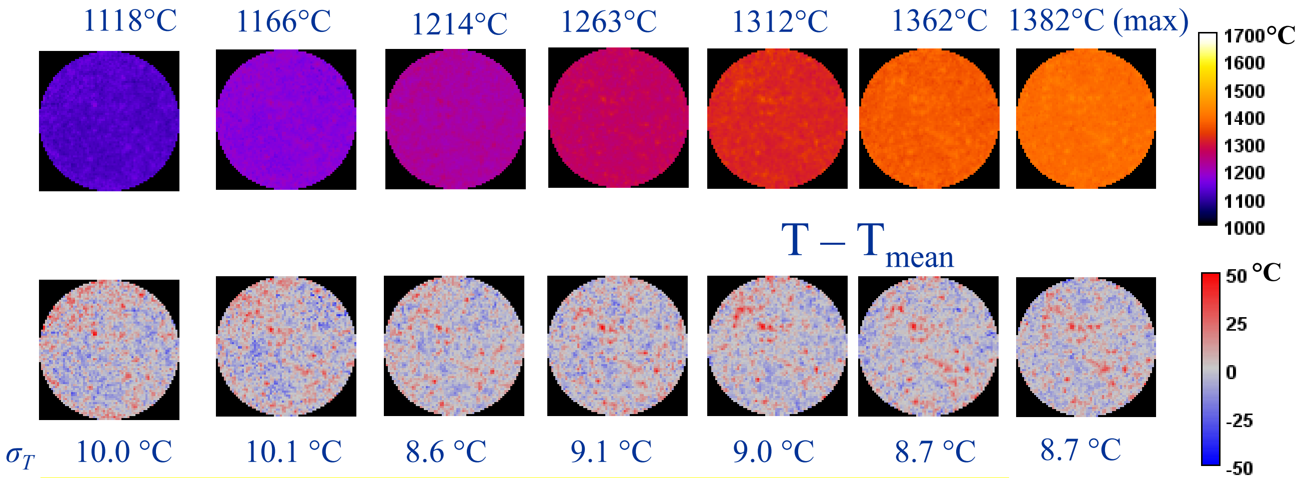
Luminescence Lifetime Temperature Maps

22 µm Sc_2SiO_5:Er(0.8%) sensor layer on EBC



0.4% relative temperature precision (same as disk!)

10 µm Y_2SiO_5:Er(0.8%) sensor layer on EBC



Y_2SiO_5:Er coating shows repeatable local variation.

Sc_2SiO_5:Er sensing layer provides surface temperature mapping max to 1535 °C without loss of temperature precision.

Conclusions

- Comparison of Y_2SiO_5:Er and Sc_2SiO_5:Er temperature sensing:
  - Y_2SiO_5:Er has higher (up to 1.9x) relative temperature sensitivity at high temperatures.
  - Better compatibility of Sc_2SiO_5:Er sensing layer with $Sc_2Si_2O_7$ EBC topcoat enables temperature mapping to 1535 °C vs. 1380 °C for Y_2SiO_5:Er. ✓
- No evidence of thin sensing layer chemical degradation or delamination.
- Good temperature sensing performance >1300 °C (despite low quantum efficiency) enabled by:
  - High oscillator strength of excitation transition
  - Transition from low to high phonon energy emission relaxation produces enhanced temperature sensitivity.
- Applications in progress
  - Temperature mapping to evaluate air film cooling at EBC surface.
  - Spot temperature measurements in hot combustion gas stream environment

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