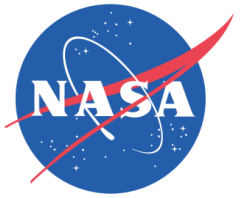

Environmental Barrier Coating Surface Temperature Mapping Using a Compatible Er-Doped Sc_2SiO_5 Temperature Sensing Layer

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Objectives

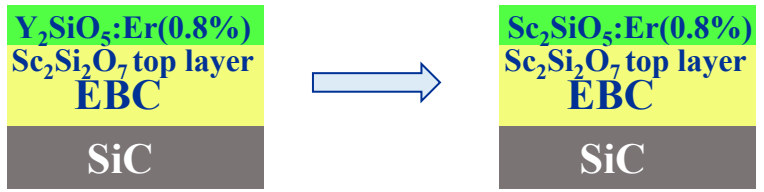
- Develop luminescence lifetime imaging-based temperature mapping for EBCs to > 1500 °C as a beneficial complement to thermal imaging/pyrometry.
  - \+ Emissivity independent.
  - \+ No interference from reflected radiation.
  - \+ Can avoid interference from hot gas stream chemiluminescence that can be intense in high-temperature/high-pressure environment.
  - \+ Can validate/calibrate selection of emissivity and reflected radiation + chemiluminescence corrections for thermal imaging.
  - \+ Spot temperature measurements acquisition rate only limited by excitation laser pulse rate.
  - – Temperature mapping by luminescence lifetime imaging limited to near steady-state conditions.

Challenges

- Intense thermal radiation background.
- Phosphor compatibility with EBC at high temperatures.
  - – Inadequate compatibility of previous Y_2SiO_5:Er temperature-sensing layer with $Sc_2Si_2O_7$ EBC top layer restricted temperature mapping to 1380 °C max.

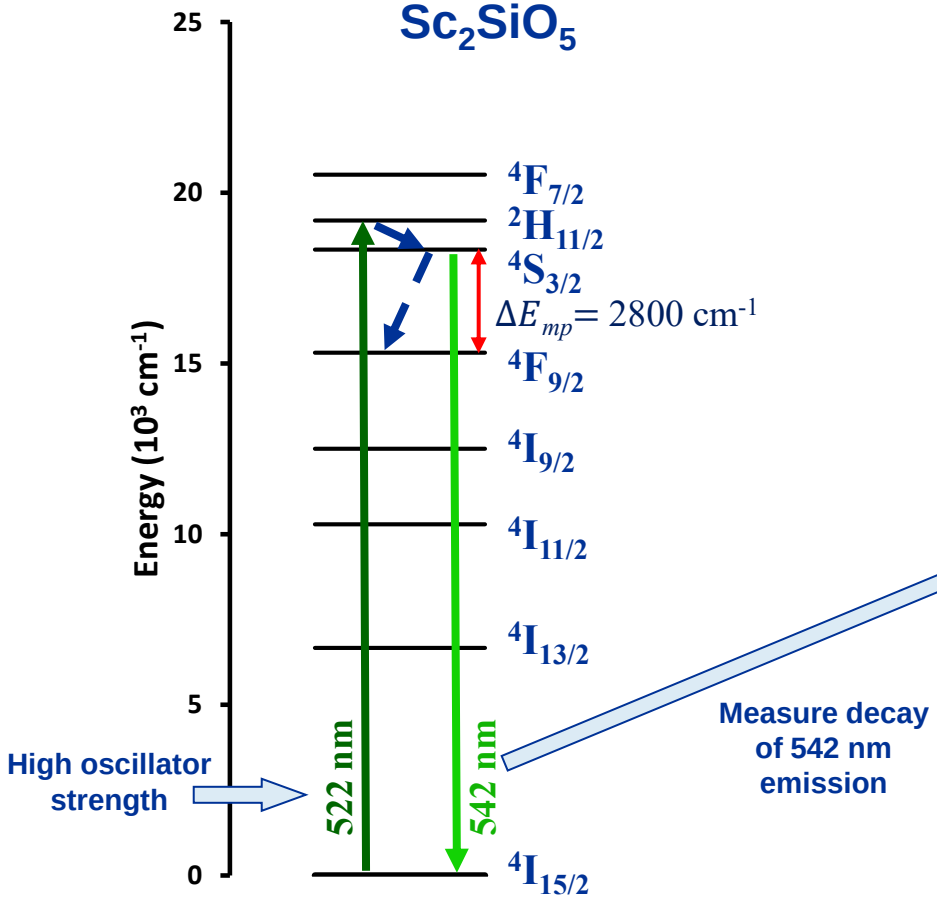
Approach

- Transition from Y_2SiO_5:Er to Sc_2SiO_5:Er temperature sensing layer.
- Evaluate temperature mapping performance and EBC compatibility of Sc_2SiO_5:Er temperature-sensing layer.



Temperature Dependence of Luminescence Decay

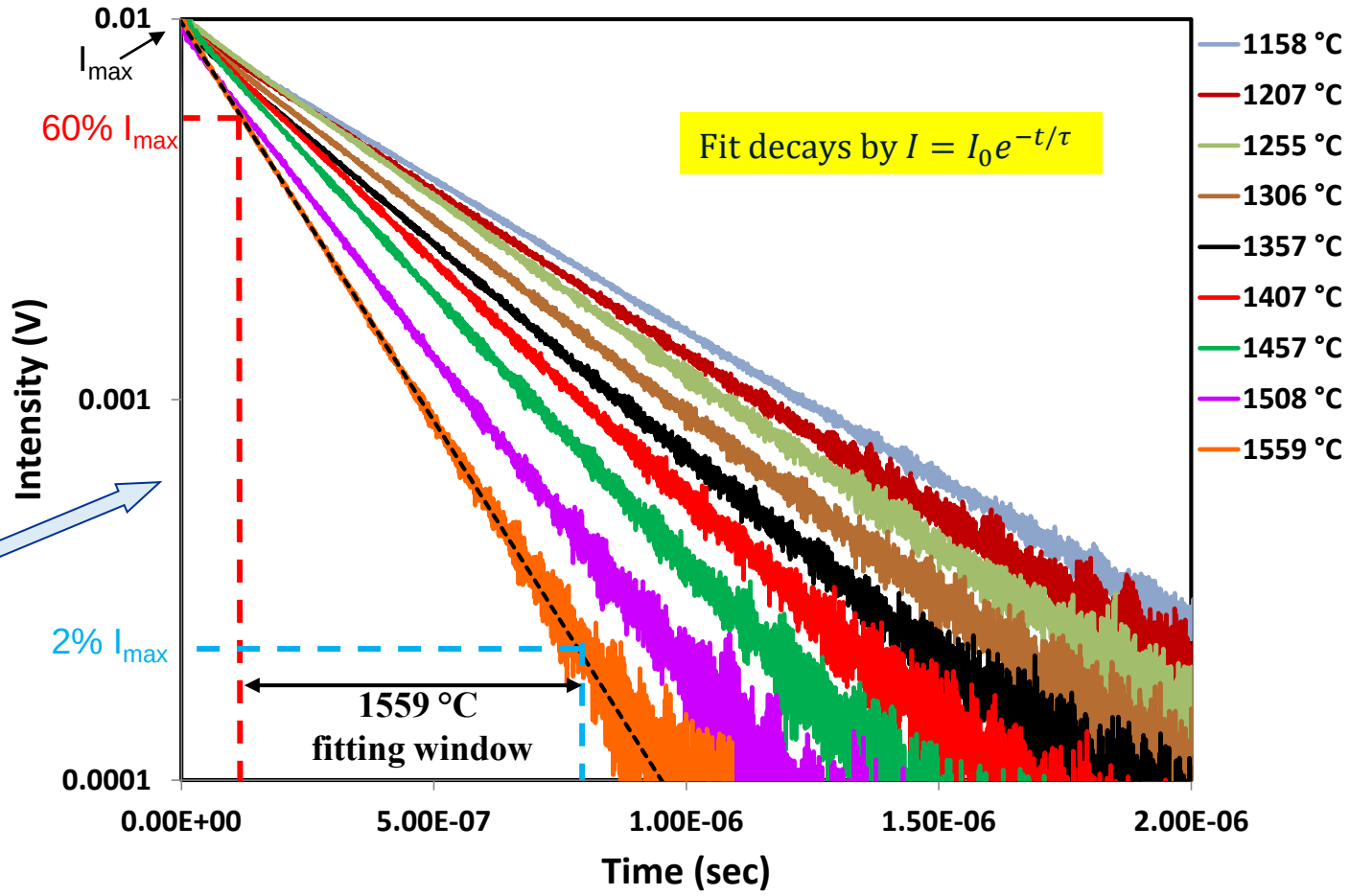
Er^{3+} Electron Energy Level Transitions in Sc_2SiO_5



Measure decay of 542 nm emission

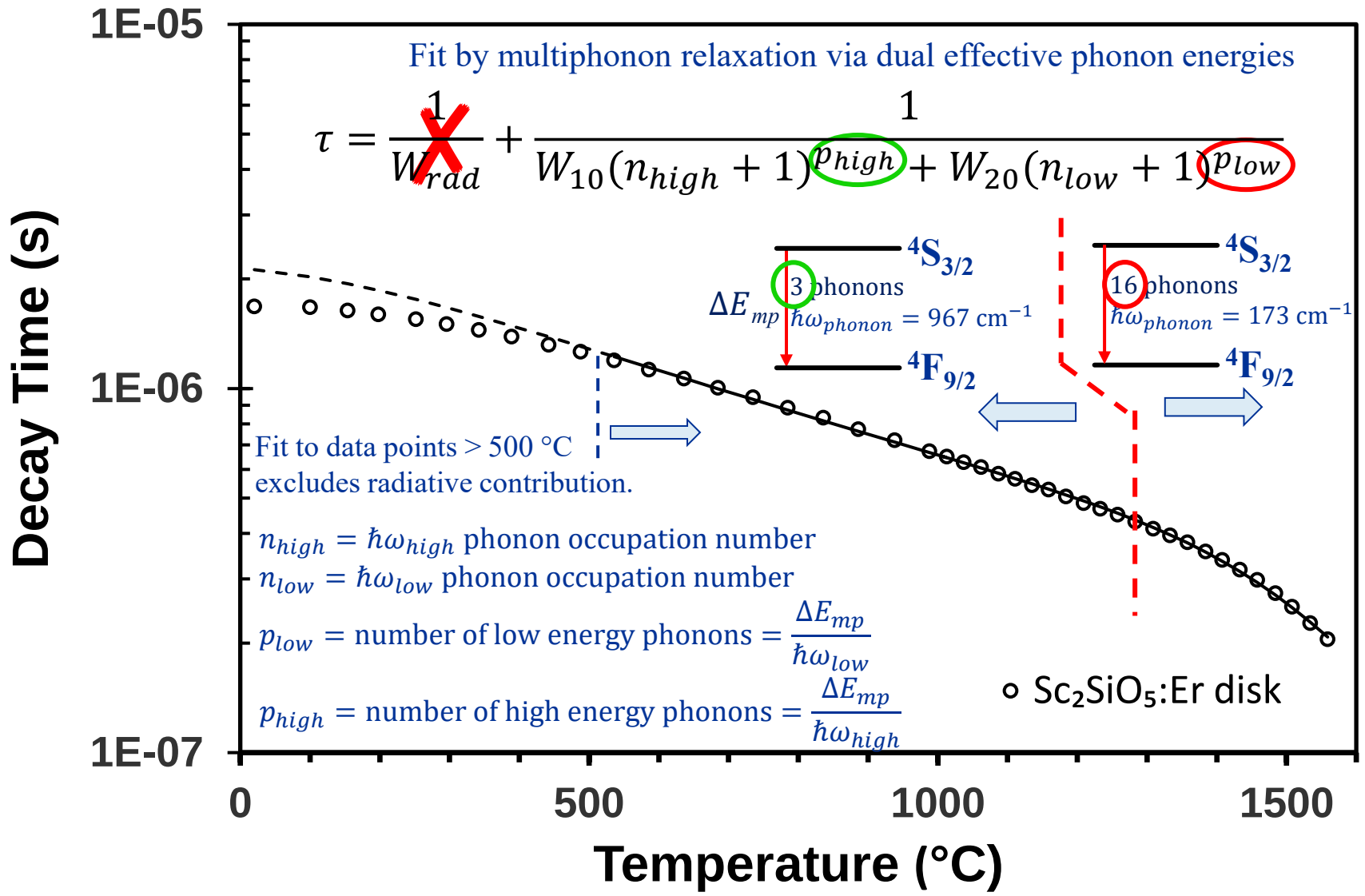
Luminescence Emission Decay Curves

Localized spot measurements using PMT

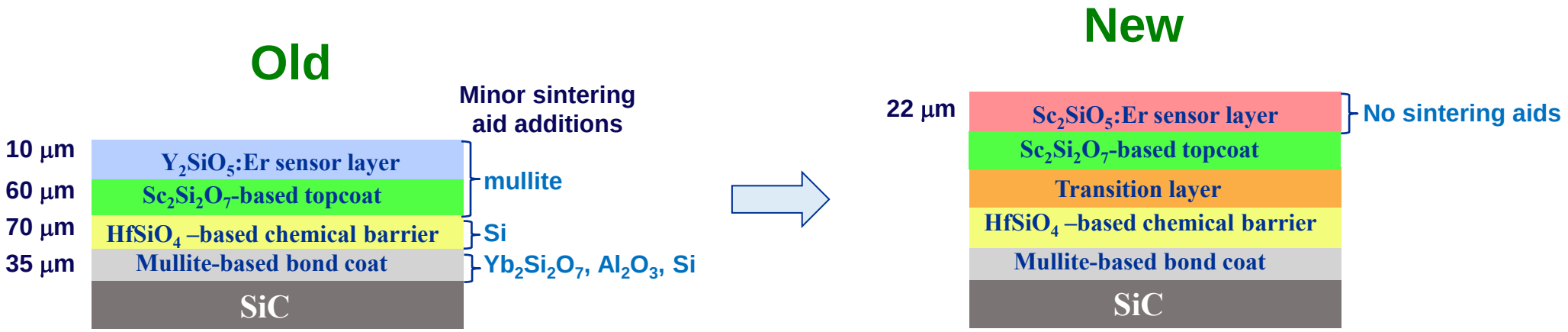


Excellent single exponential decay behavior

Sc_2SiO_5:Er(0.8%) Decay Time
Temperature Dependence



Sensor Layer/EBC Architectures

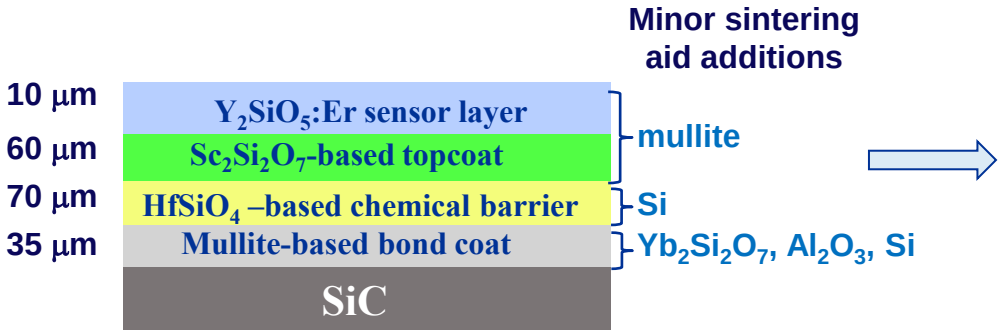


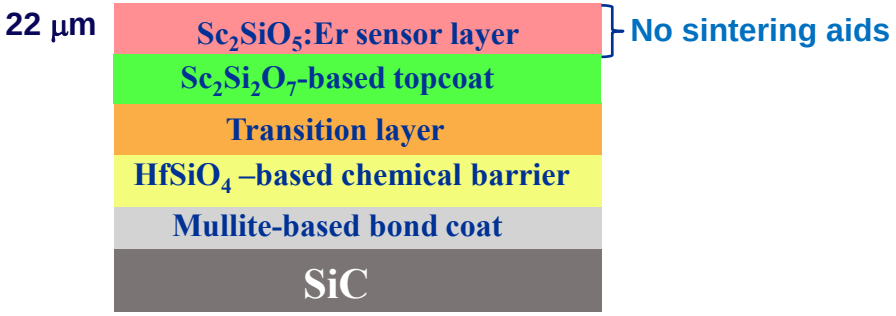
- Sensor coating + layered EBCs deposited using slurry process* via spin coating.
  - Replace Y_2SiO_5:Er with Sc_2SiO_5:Er sensor layer.
  - Sintering aids omitted in new Sc_2SiO_5:Er sensor layer.
    - Avoids reactions with sintering aids in sensor layer that could affect temperature sensing.
  - Monosilicates selected for sensor layer instead of disilicates for stability because surface disilicate can slowly convert to monosilicate.
  - New EBCs include a transition layer between $Sc_2Si_2O_7$ topcoat and $HfSiO_4$ based chemical barrier.

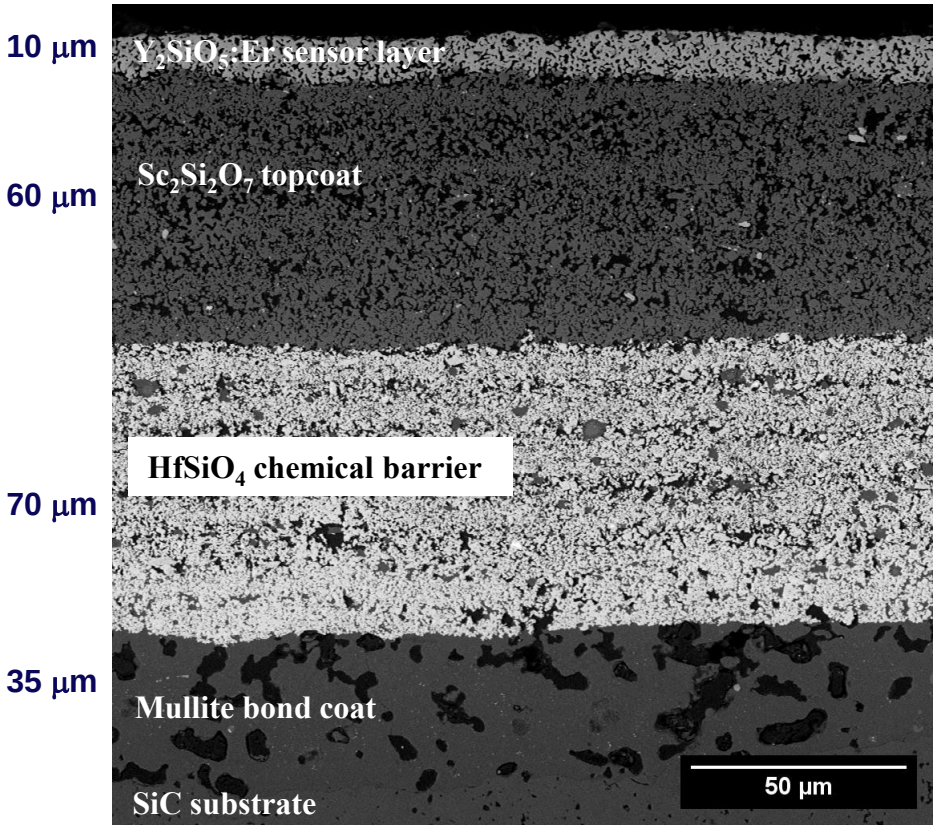
*K.N. Lee et al., J. Eur. Ceram. Soc., 41 (2021) 1639-1653.

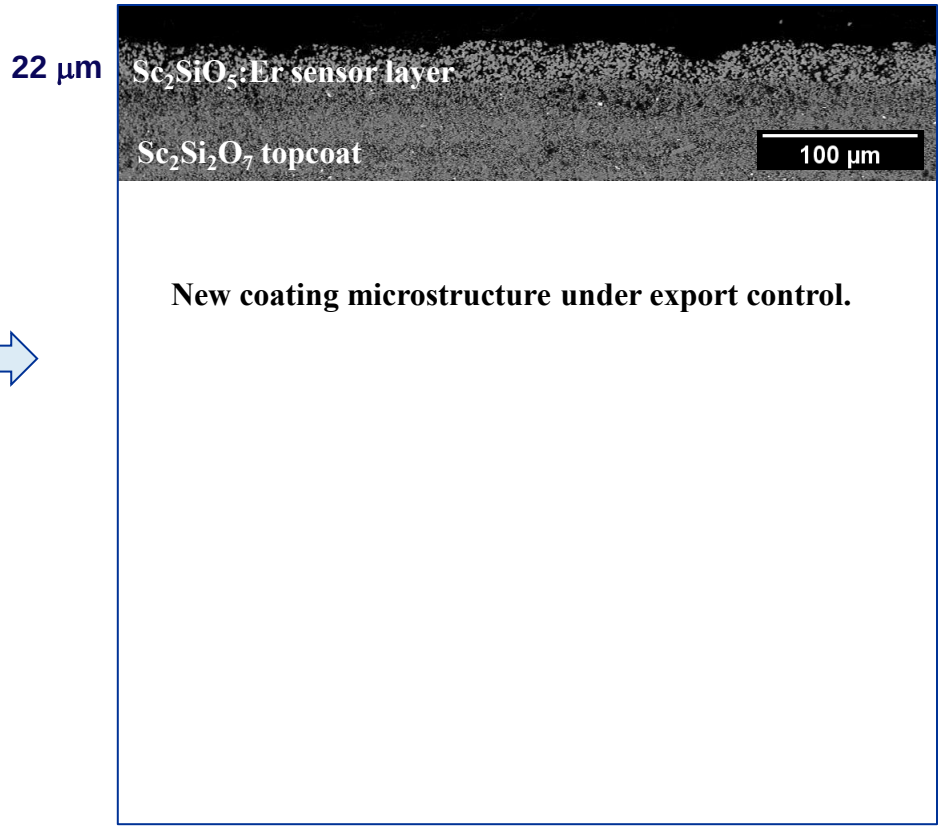
Sensor Layer/EBC Architectures

Sensor coating + layered EBC deposited using slurry process via spin coating.

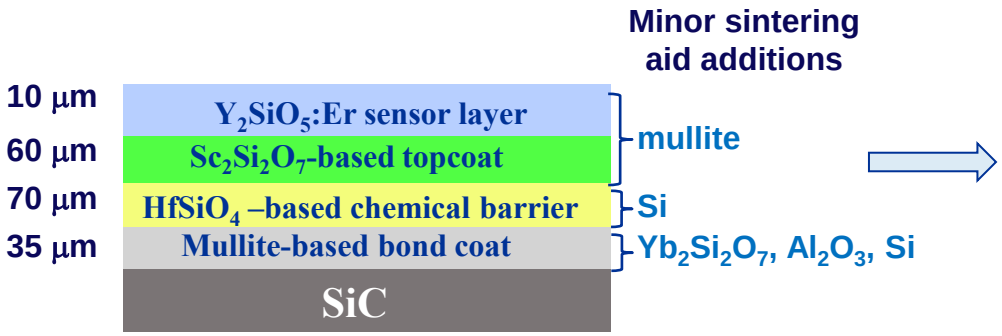


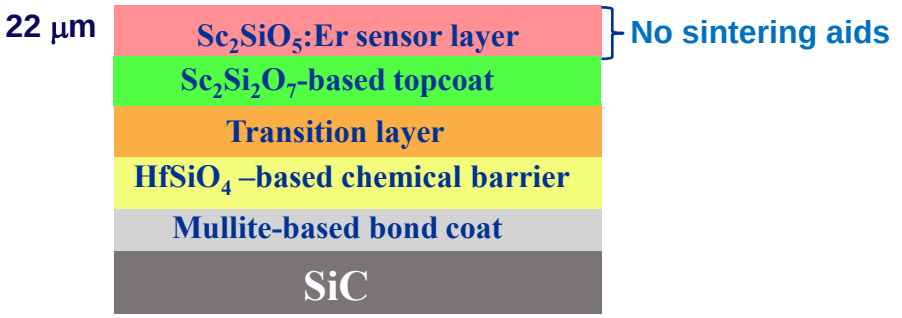


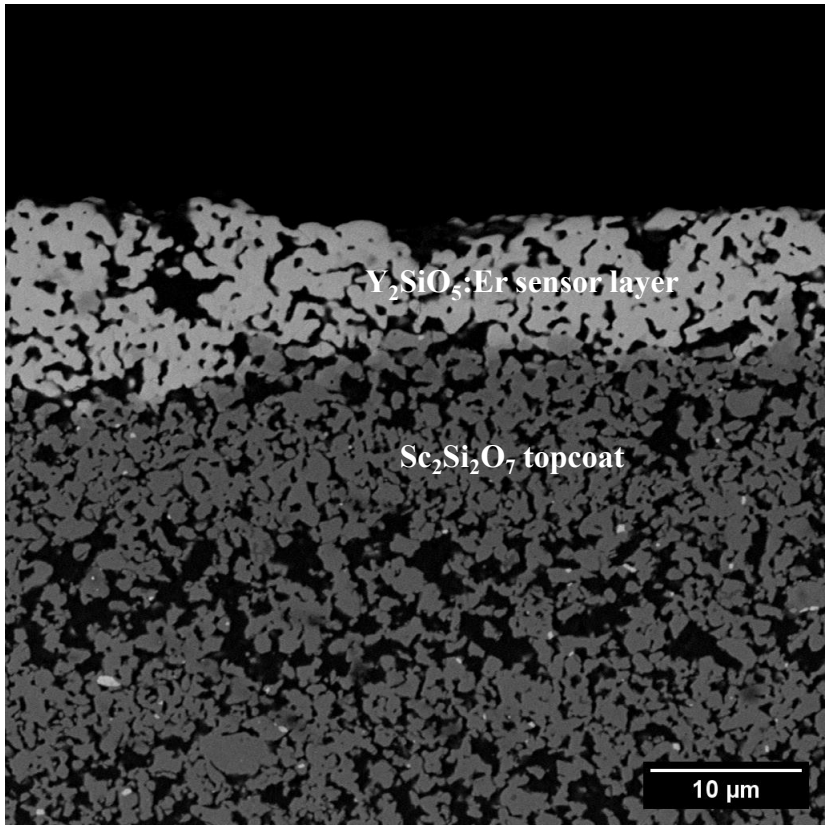


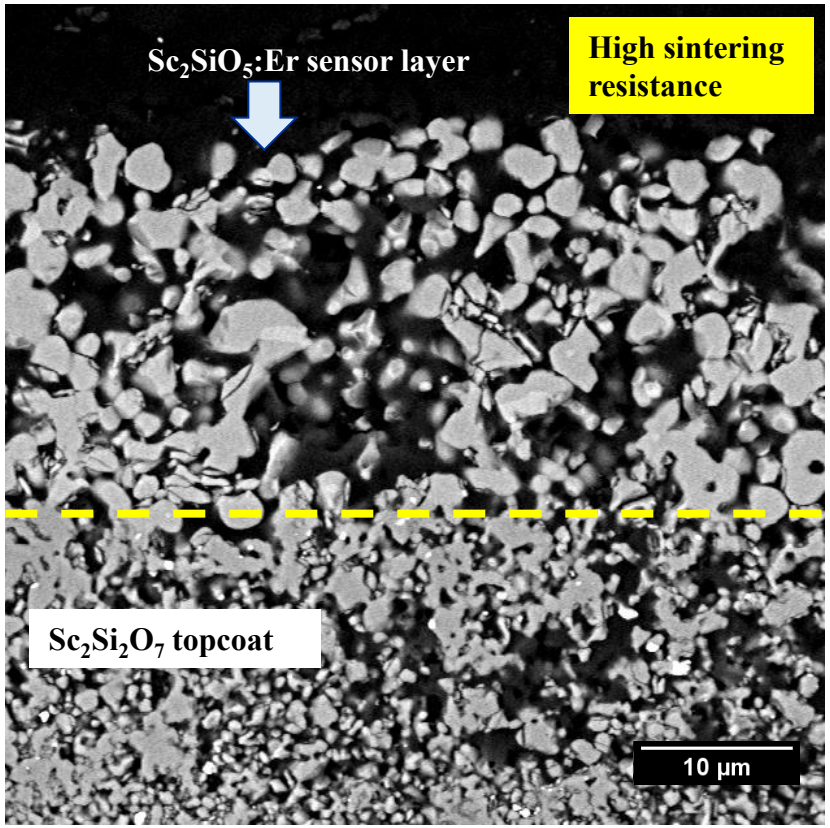


Sensor Layer/EBC Architectures



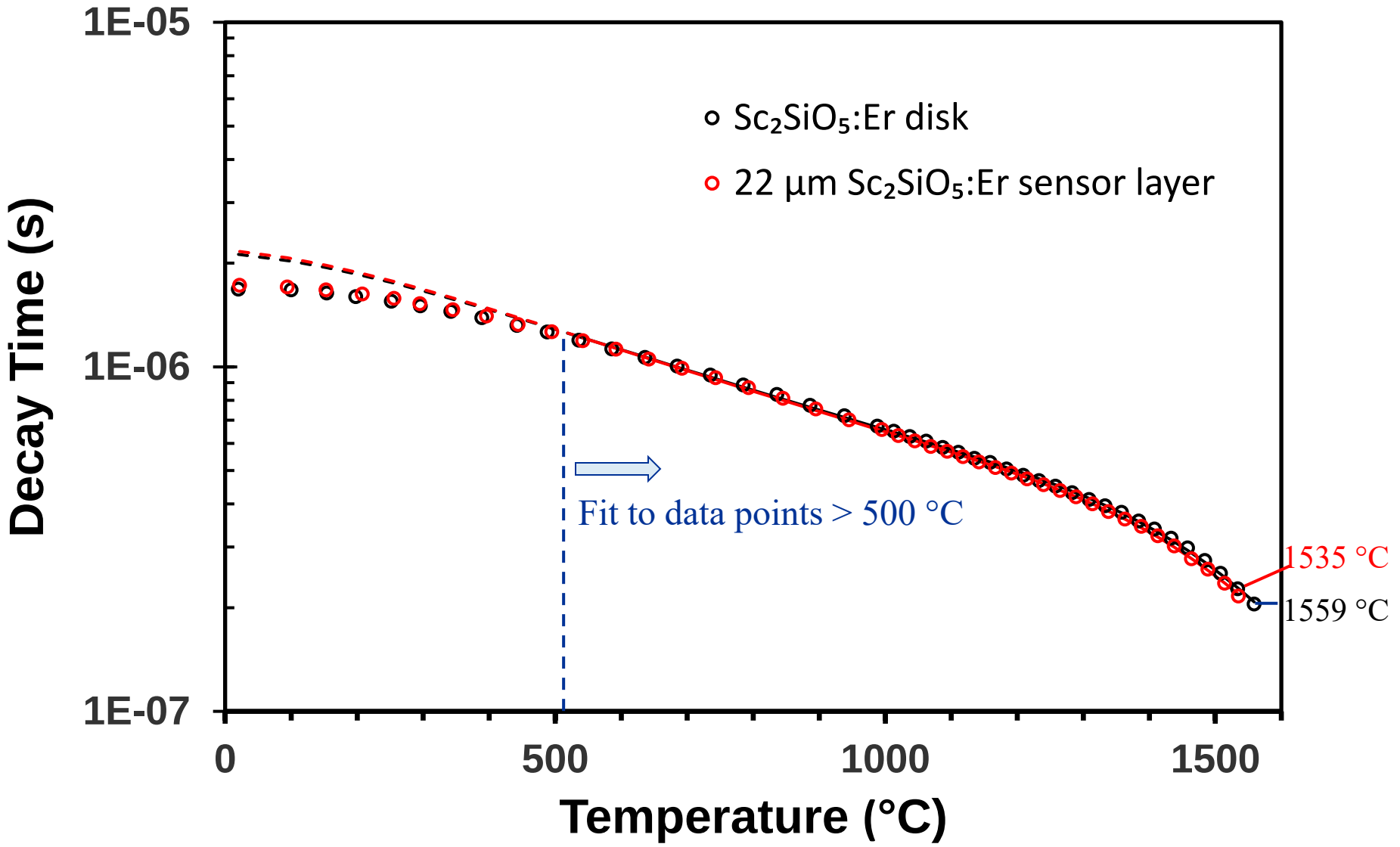






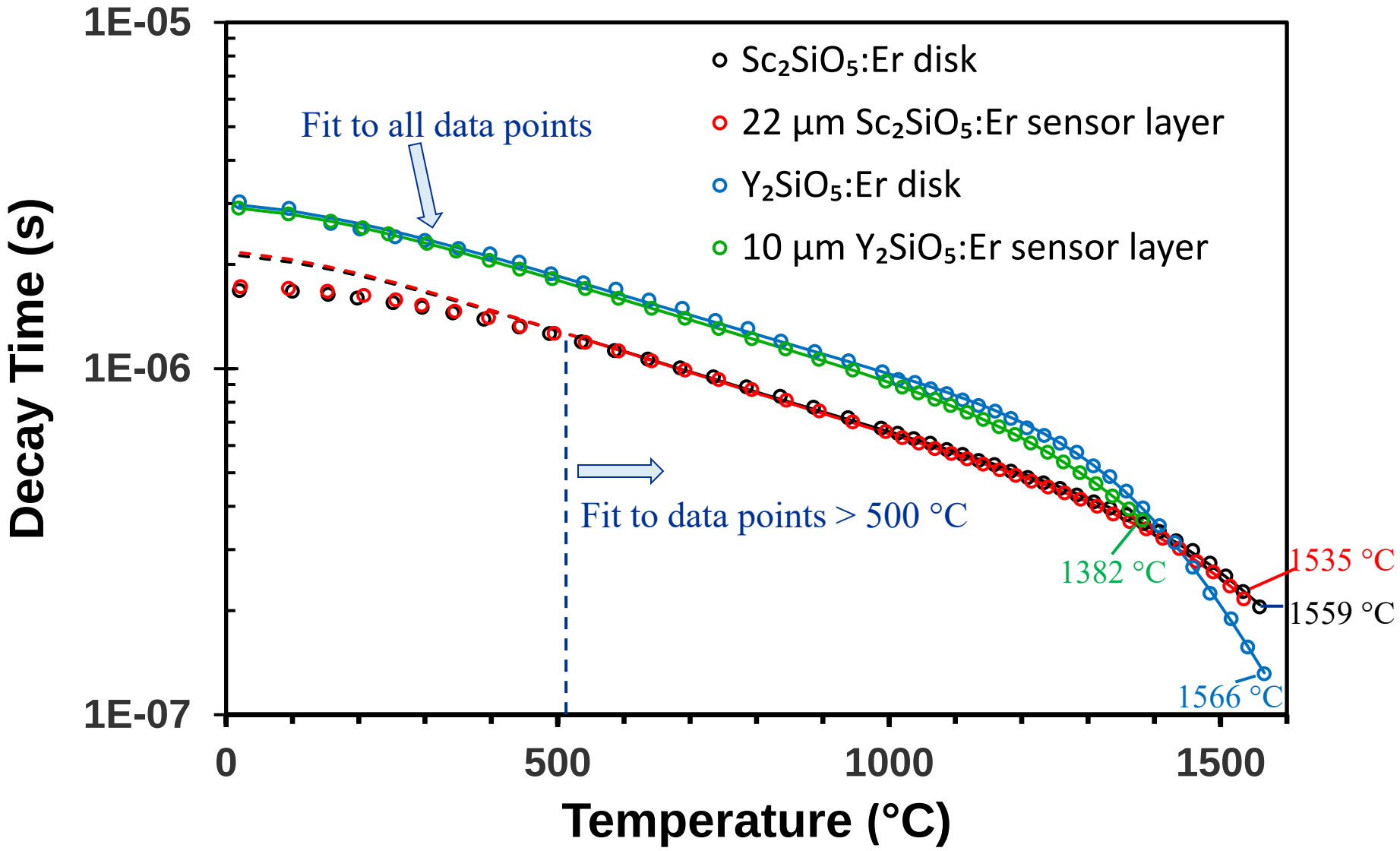
Sc_2SiO_5:Er(0.8%) Luminescence Lifetime Measurements

2.4-mm Thick Standalone Disk vs. Coating

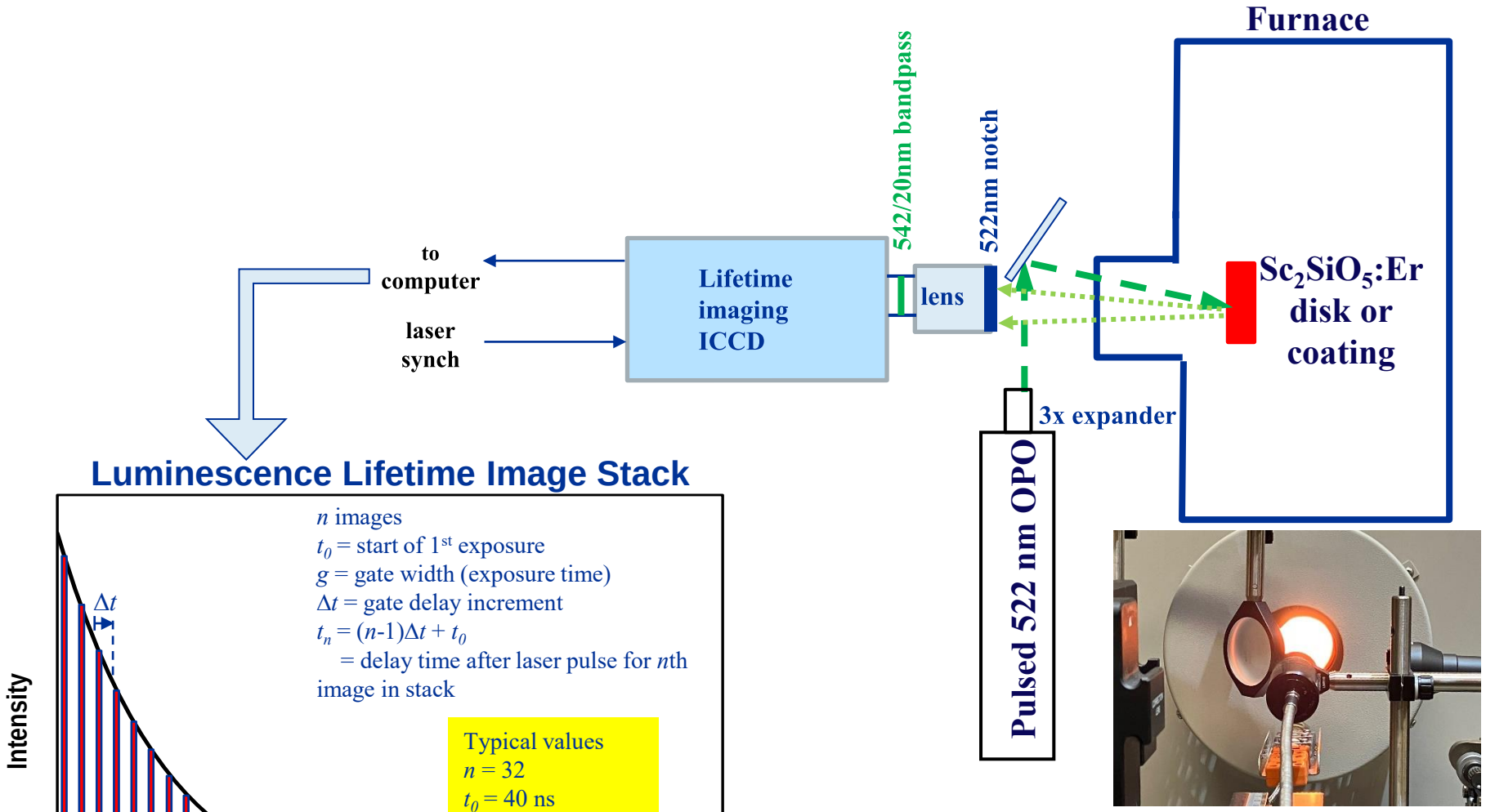


Sc_2SiO_5:Er(0.8%) Luminescence Lifetime Measurements

2.4-mm Thick Standalone Disk vs. Coating



Luminescence Lifetime Imaging



Low background using small lens aperture (f/22) and short frame exposure (15 ns)

2D Temperature Maps from Luminescence Lifetime Imaging*

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

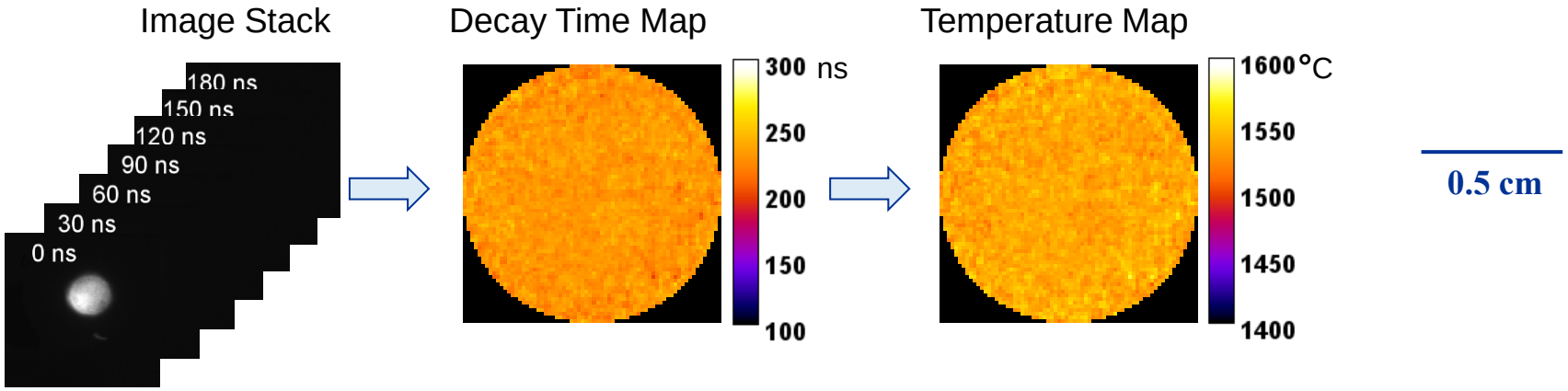


*Image processing developed by Adam Wroblewski at NASA GRC.

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

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

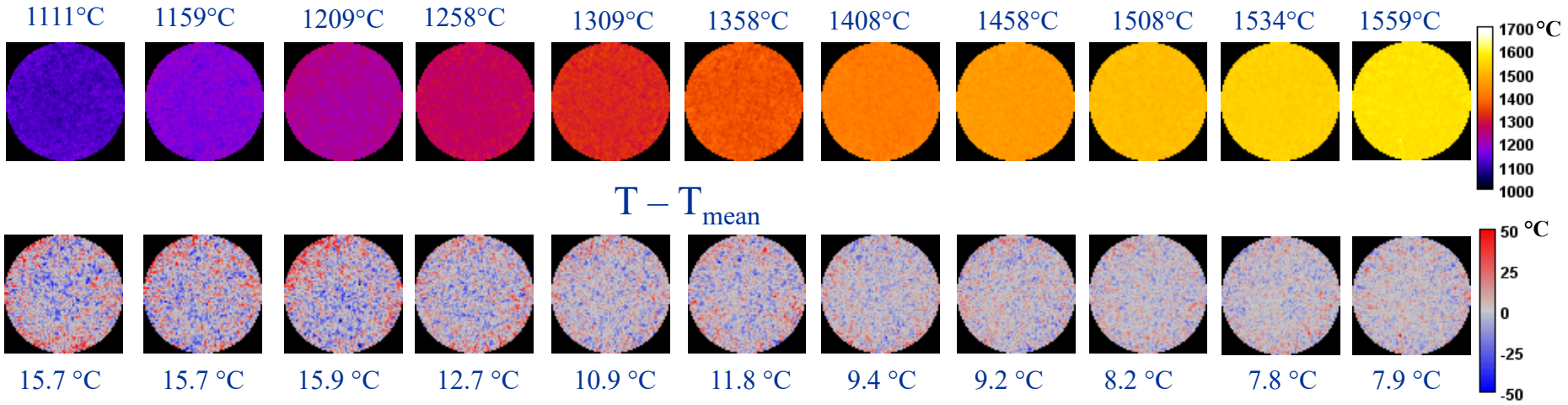
Dual effective phonon energy model

Sc_2SiO_5:Er(0.8%) Luminescence Lifetime Measurements

all 15 ns exposures

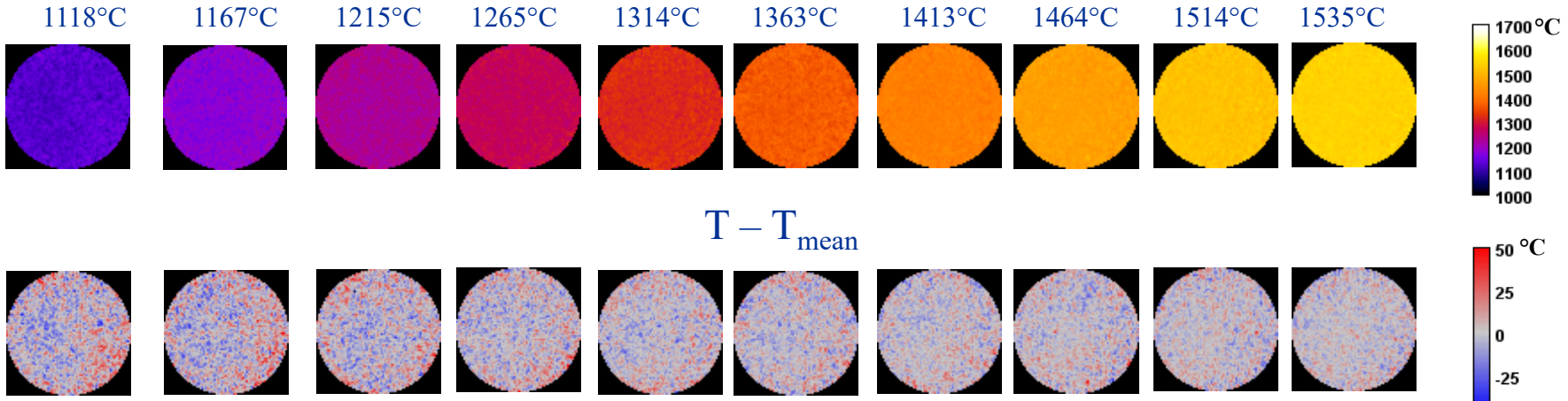
1 cm

Sc_2SiO_5:Er(0.8%) Standalone Disk



σ_T 15.7 °C | 15.7 °C | 15.9 °C | 12.7 °C | 10.9 °C | 11.8 °C | 9.4 °C | 9.2 °C | 8.2 °C | 7.8 °C | 7.9 °C

Sc_2SiO_5:Er(0.8%) coating on EBC

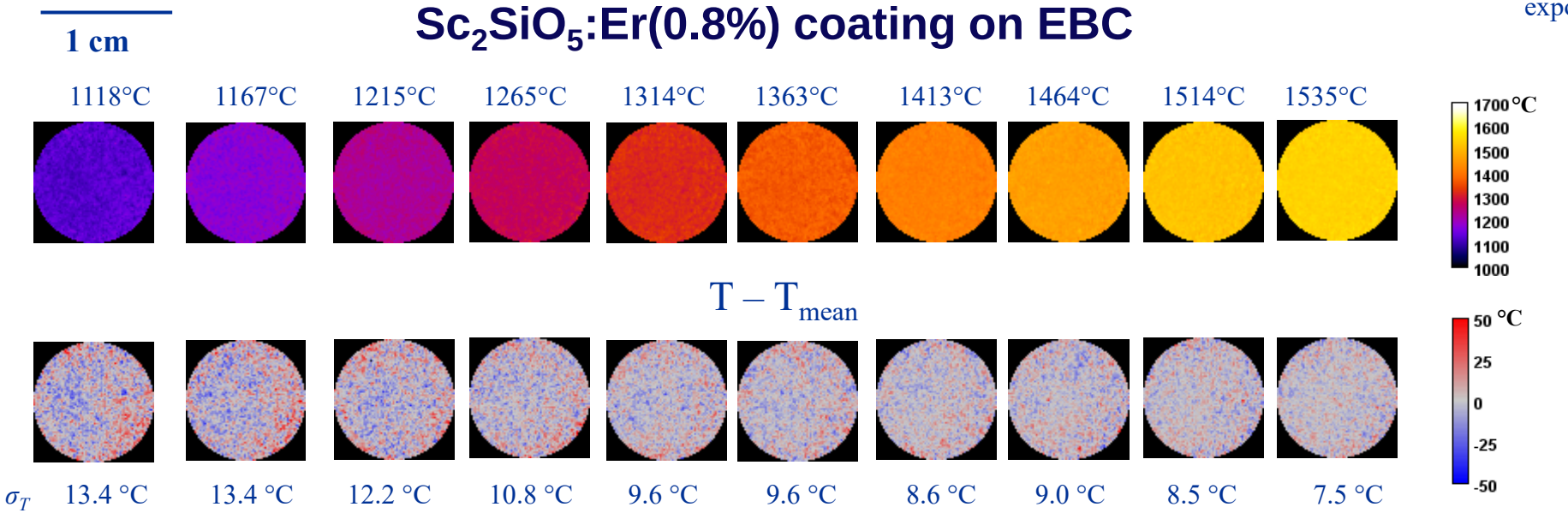


σ_T 13.4 °C | 13.4 °C | 12.2 °C | 10.8 °C | 9.6 °C | 9.6 °C | 8.6 °C | 9.0 °C | 8.5 °C | 7.5 °C

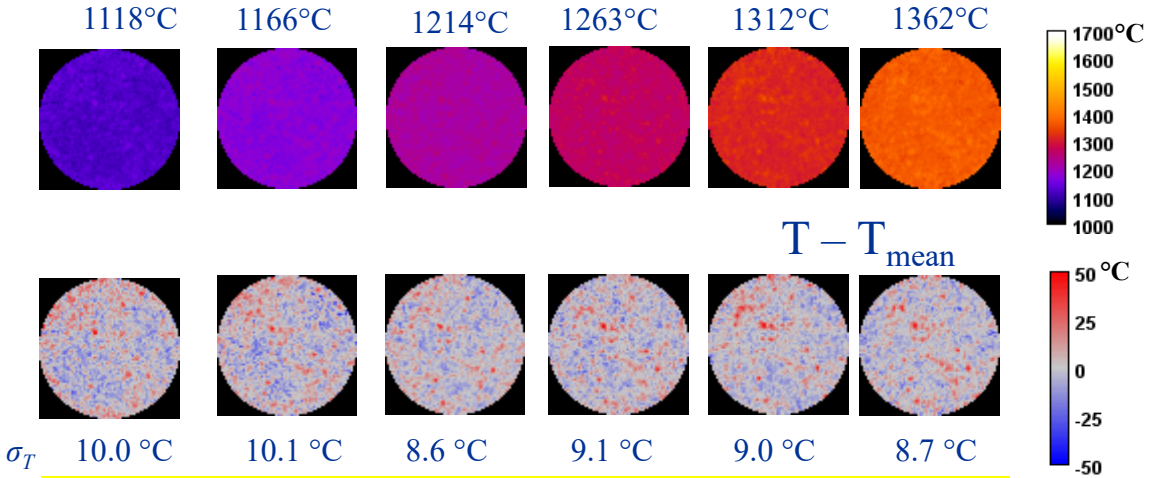
Sc_2SiO_5:Er(0.8%) Luminescence Lifetime Measurements

all 15 ns exposures

Sc_2SiO_5:Er(0.8%) coating on EBC



Y_2SiO_5:Er(0.8%) coating on EBC



all 50 ns exposures

Y_2SiO_5:Er coating shows repeatable local variation.

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

Conclusions

- Beneficial transition from Y_2SiO_5:Er to Sc_2SiO_5:Er EBC surface temperature sensing layer
  - Extends upper temperature measurement limit from 1380 to 1535 °C.
    - Higher eutectic melting temperatures in Sc_2SiO_5 than in Y_2SiO_5.
    - Absence of sintering aids in Sc_2SiO_5:Er sensor layer.
      - Reduces eutectic formation.
      - High sintering resistance results in high porosity (less protective but more compliant).
  - No evidence of sensing layer chemical degradation or delamination.
- Next Steps
  - Investigate long-term sensor layer durability.
  - Implementation
    - Temperature mapping to evaluate air film cooling at EBC surface.
    - Spot temperature measurements in hot combustion gas stream environment.

Funding from NASA Transformative Tools & Technologies (TTT) Project.