Embedded Optical Sensors for Thermal Barrier Coatings

Molly M. Gentlemen and David R. Clarke
Materials Department, College of Engineering
University of California, Santa Barbara

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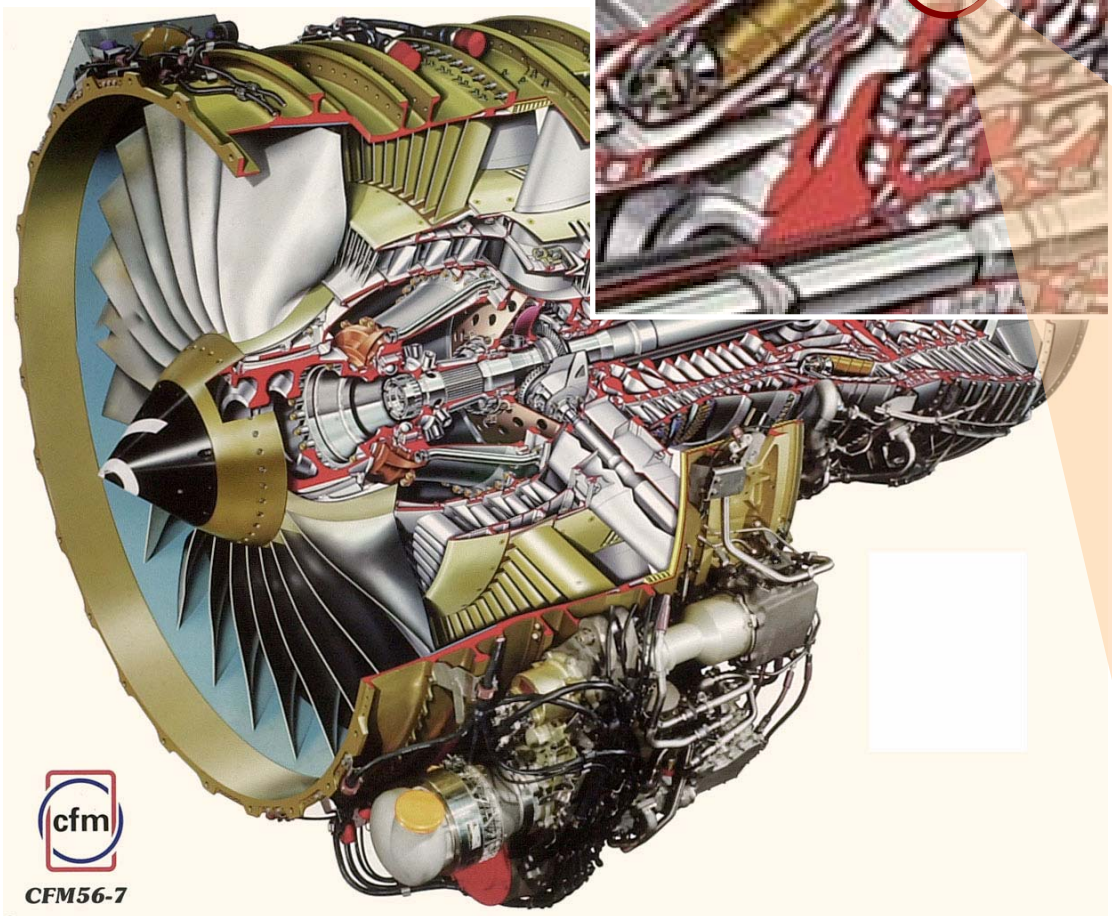
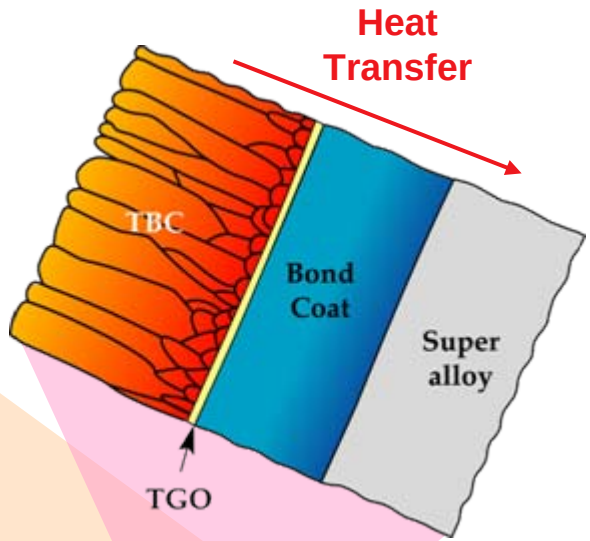
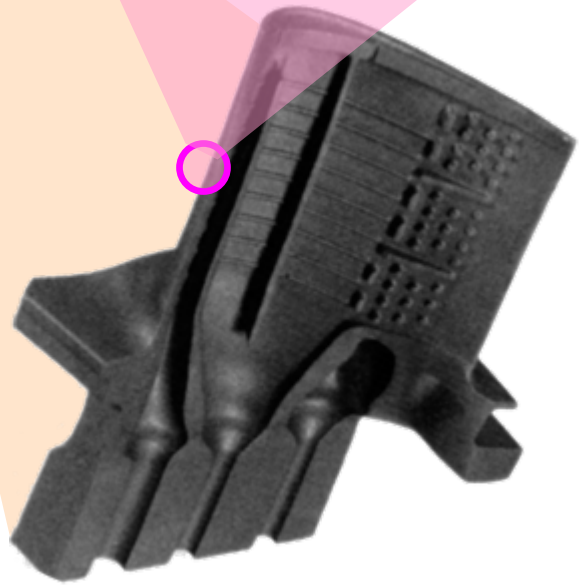
Overall Program Objective

The overall objective is to develop a class of prototype optical sensing systems for monitoring thermal barrier coatings based on the luminescence properties of dopants incorporated into the crystal structure of the coatings themselves. Concepts for different types of TBC sensors, for assessing damage, wear and temperature, will be tested. Integral to the overall objective is the demonstration of a combined optical and electronic system incorporating the embedded sensors.

TBC's in Gas Turbines





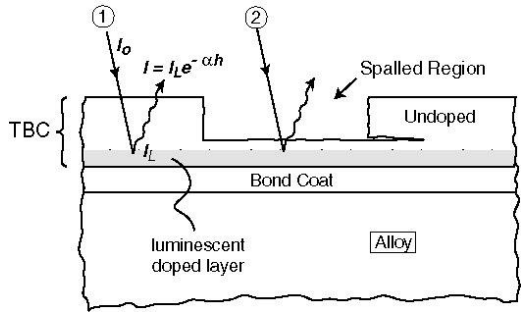


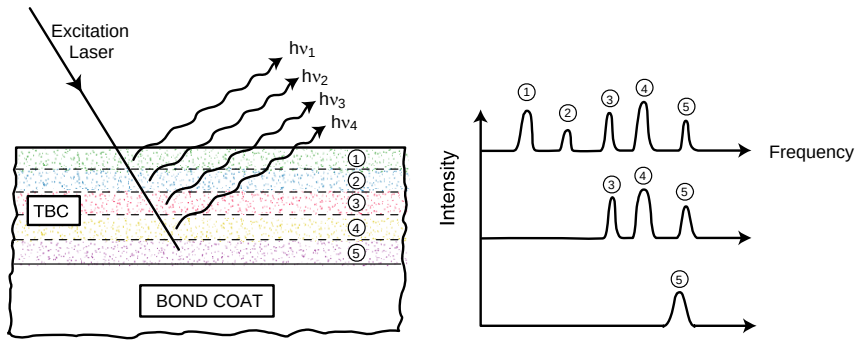
Luminescence Sensor Concepts

Underlying concept:

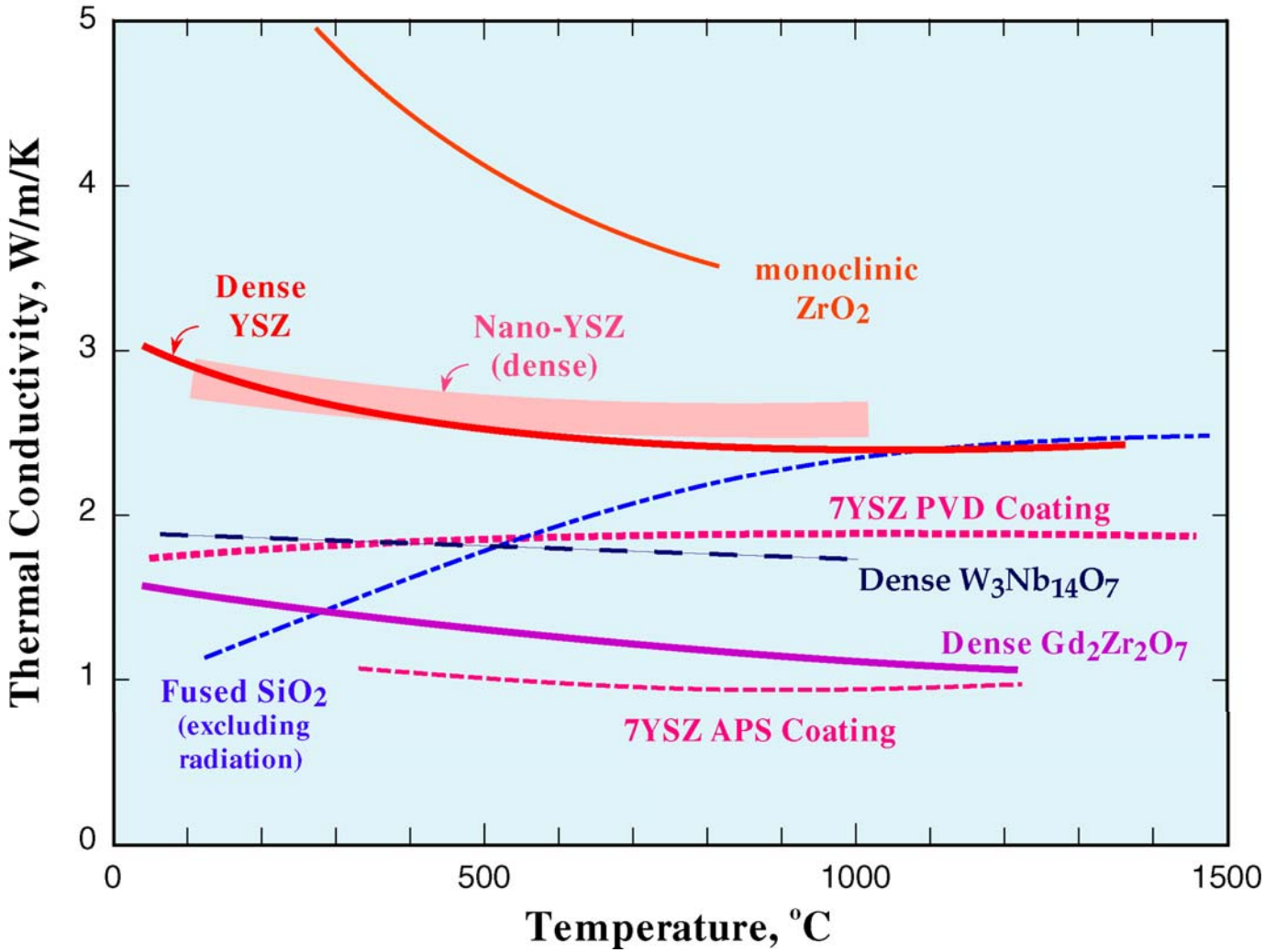
Incorporate luminescent ions (chromophores) into crystal structure of thermal barrier coating materials and sense "health" of coating from photoluminescence characteristics.

- "Red-line" Sensor
  - for sensing when coating has eroded / spalled close to TGO
  - TGO temperature sensor
- "Rainbow" Sensor
  - for monitoring wear of TBC
- Temperature Sensor
  - for monitoring outer temperature
  - for monitoring alloy surface tempertaure

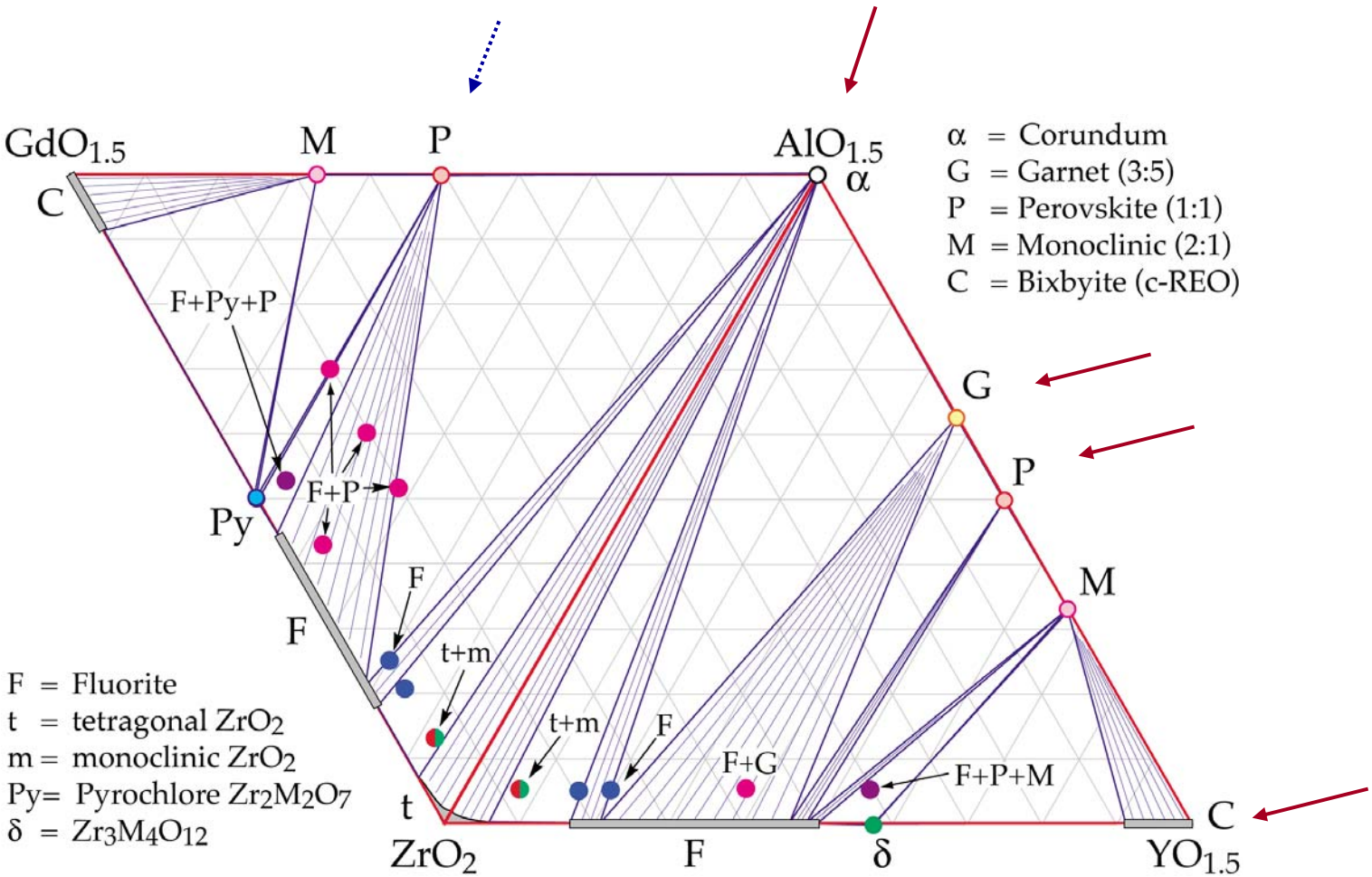




Materials Selection Based on Thermal Conductivity



Phase Compatibility Dictates Possible Luminescing Sensing Materials



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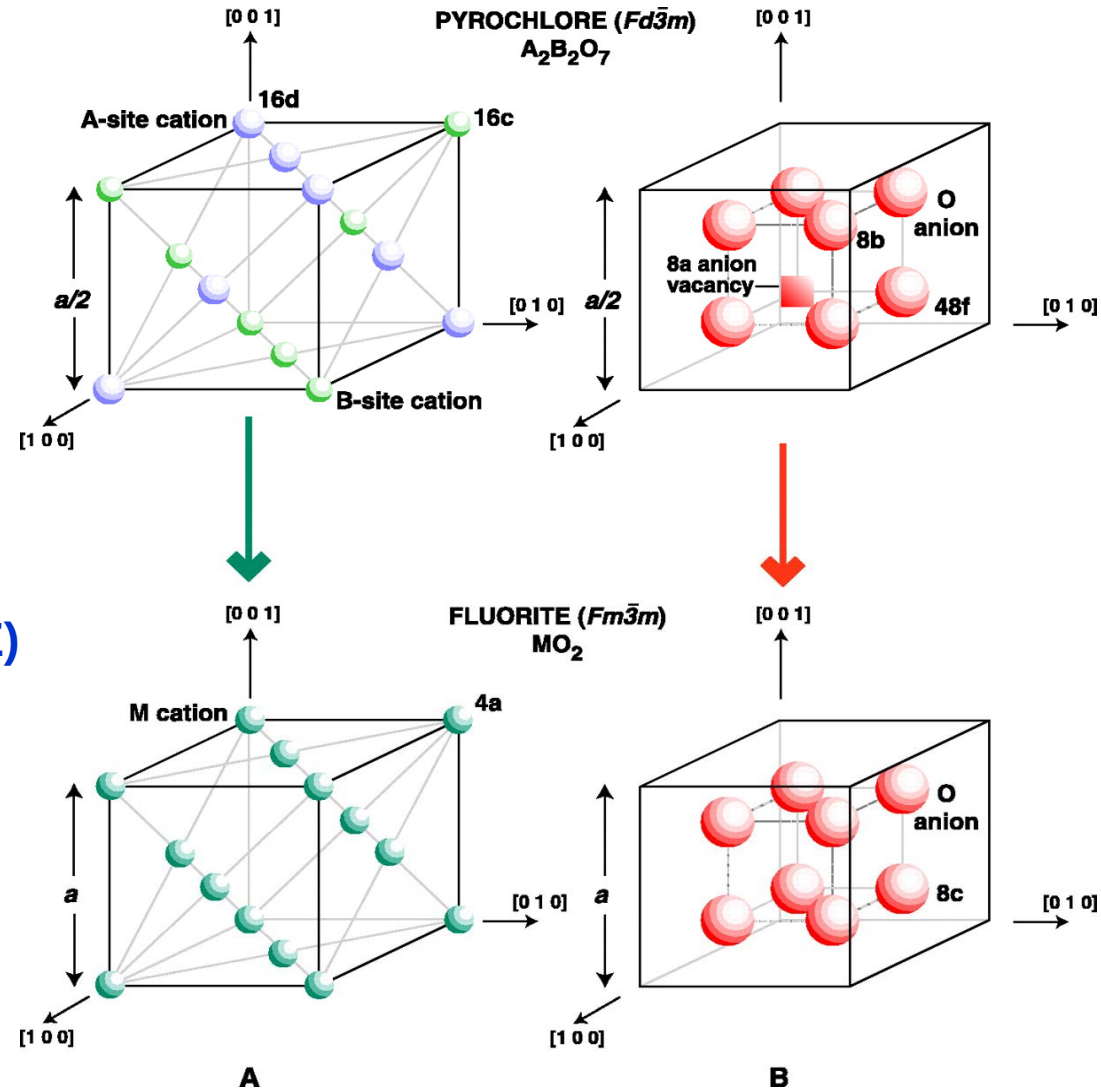
Trivalent Rare-Earth (RE) Chromophore Doping

Zirconate Pyrochlore (GZO)

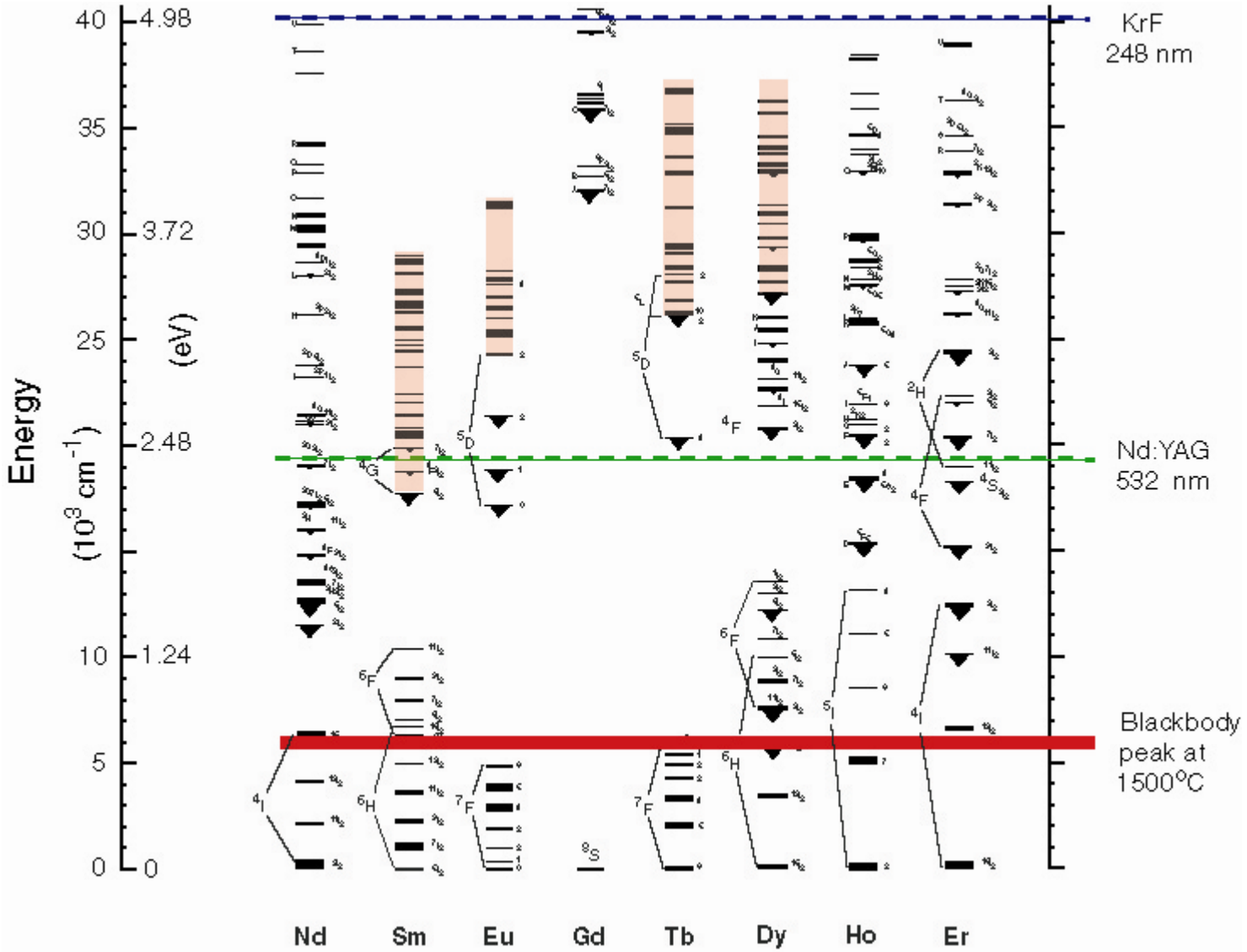
$$Gd_{2(1-x)}\ RE_{2x}\ Zr_2\ O_7$$



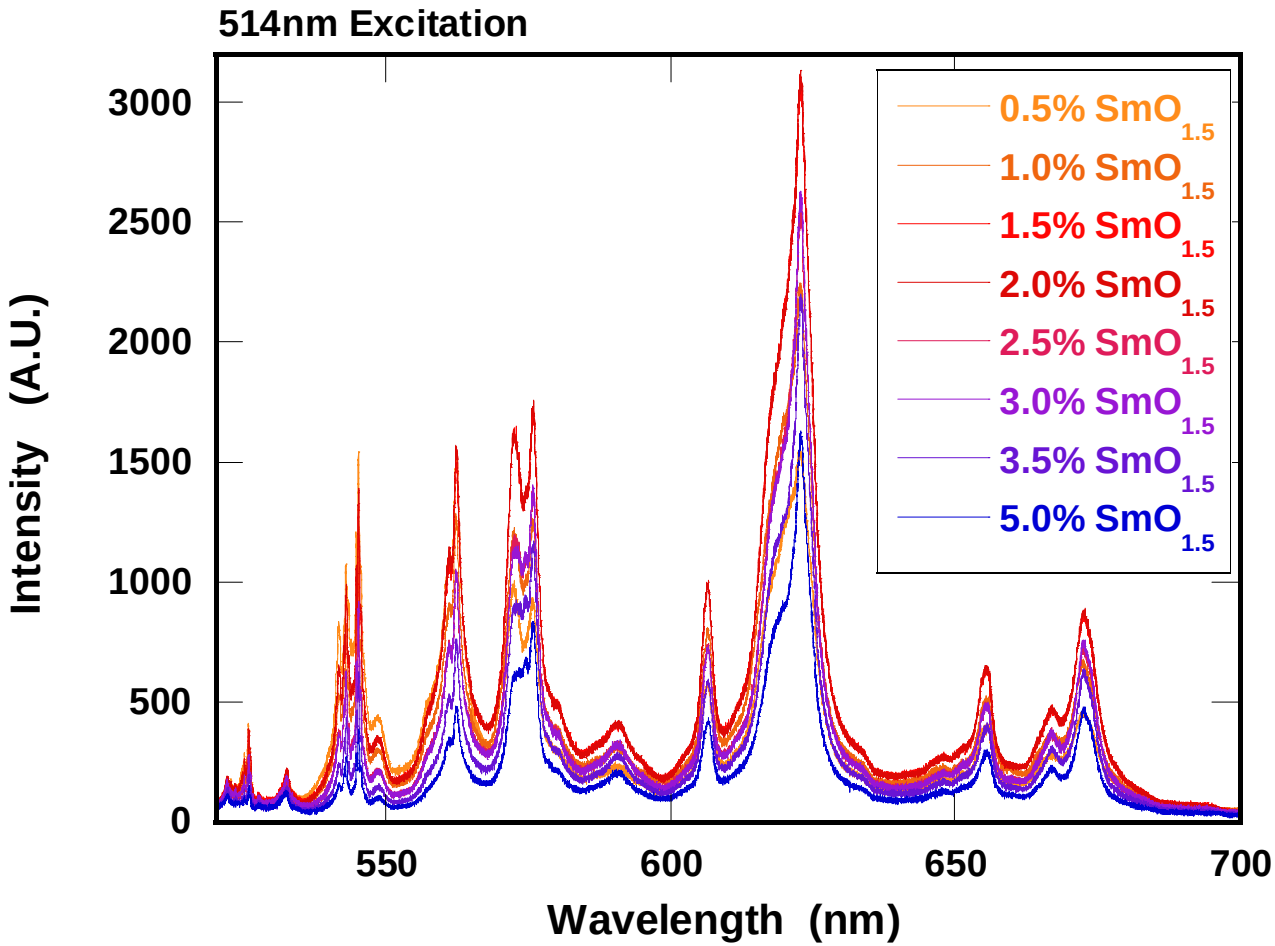
Yttrium Stabilized Zirconia (YSZ)

$$Zr^{4+}_{1-x-y}\ Y^{3+}_{x}\ RE^{3+}_{y}\ O^{2-}_{2-x-y}\ V_{x+y}$$

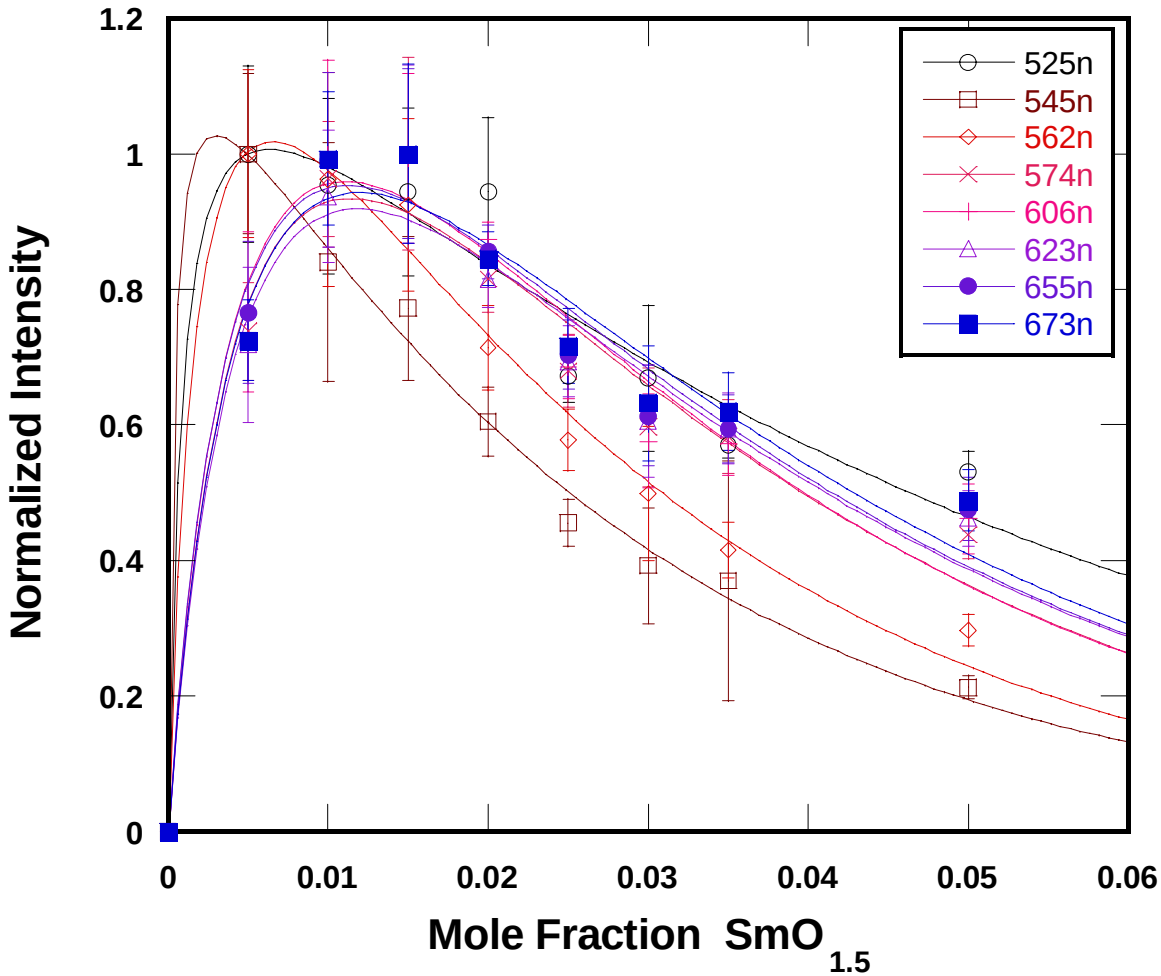
Luminescence From Trivalent Rare-Earth Chromophore Dopants



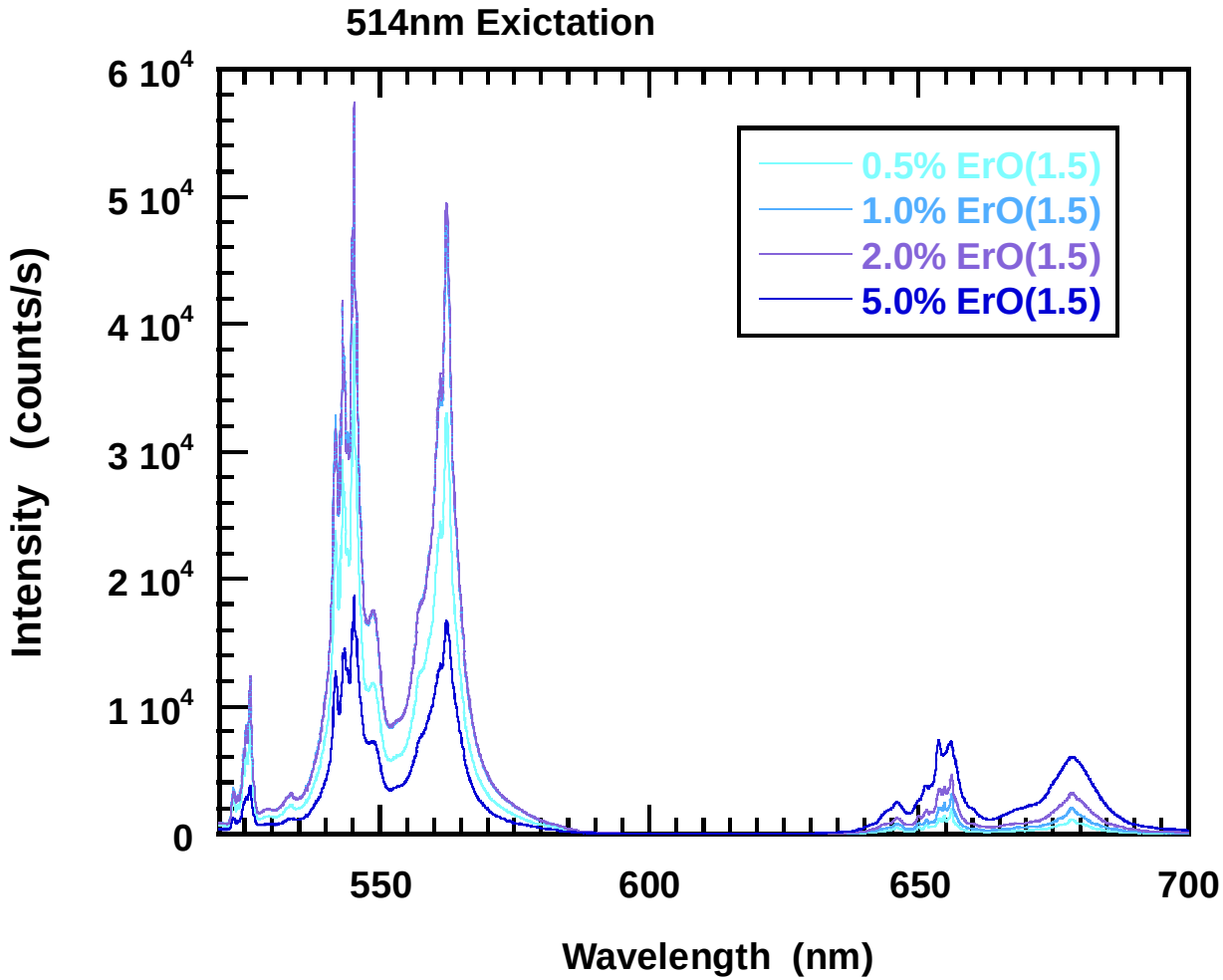
Sm-doped YSZ Luminescence



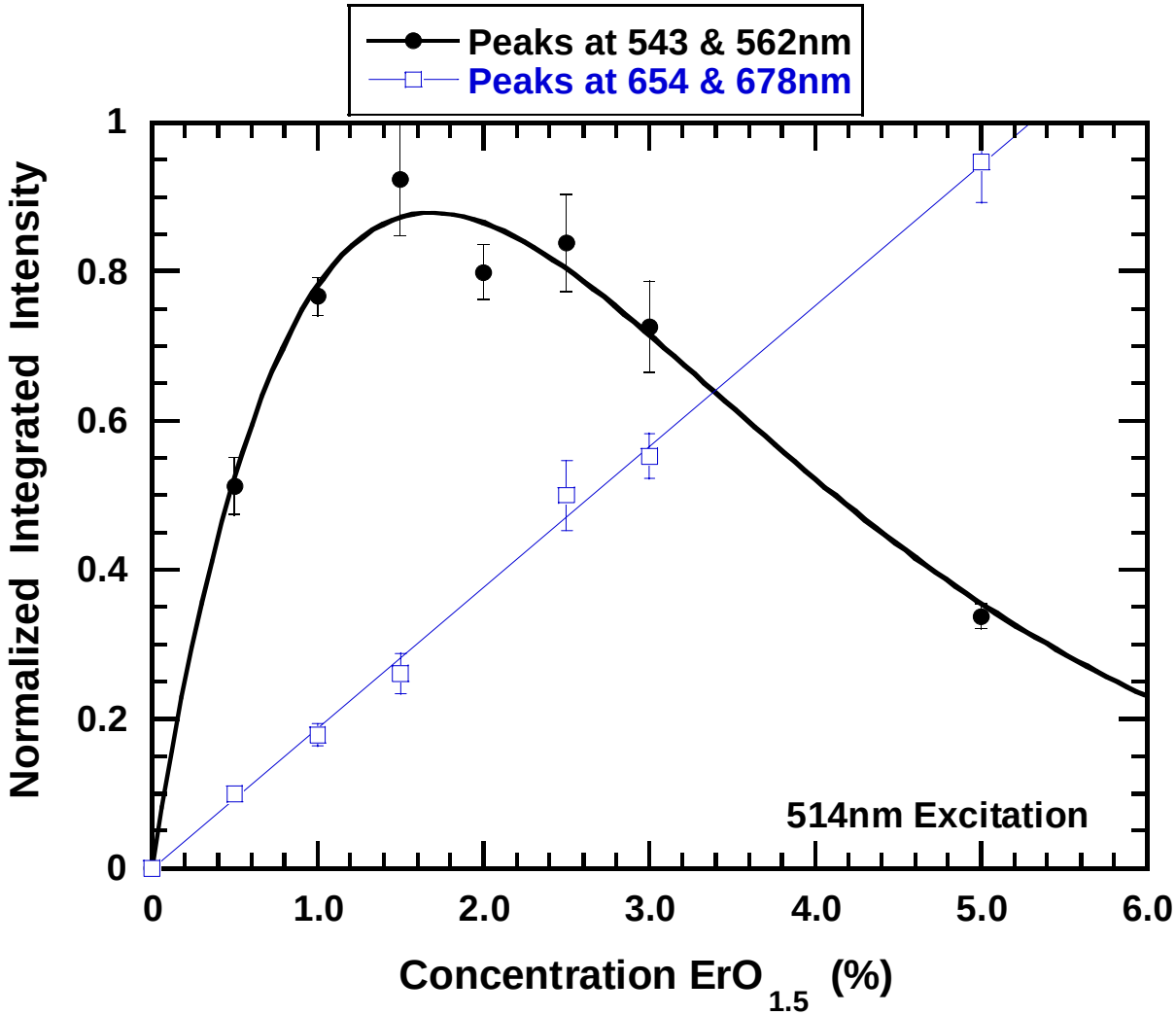
Luminescence Dependence on Concentration Sm-doped YSZ



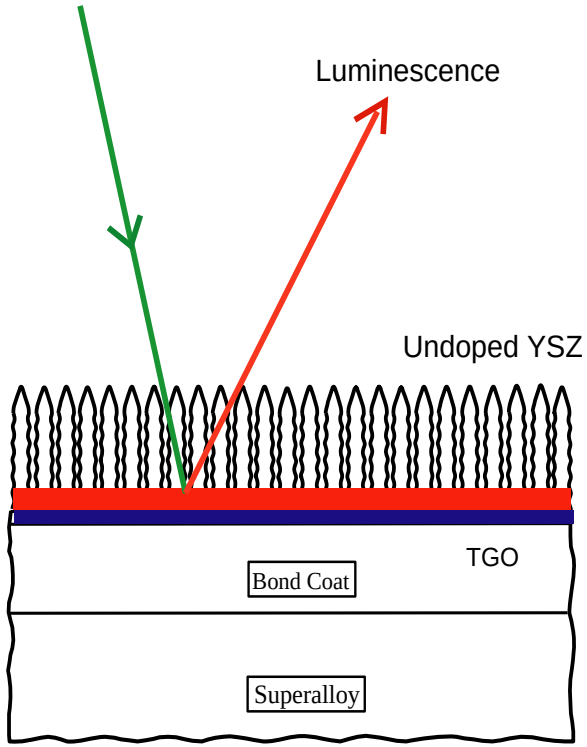
Er-doped YSZ Luminescence

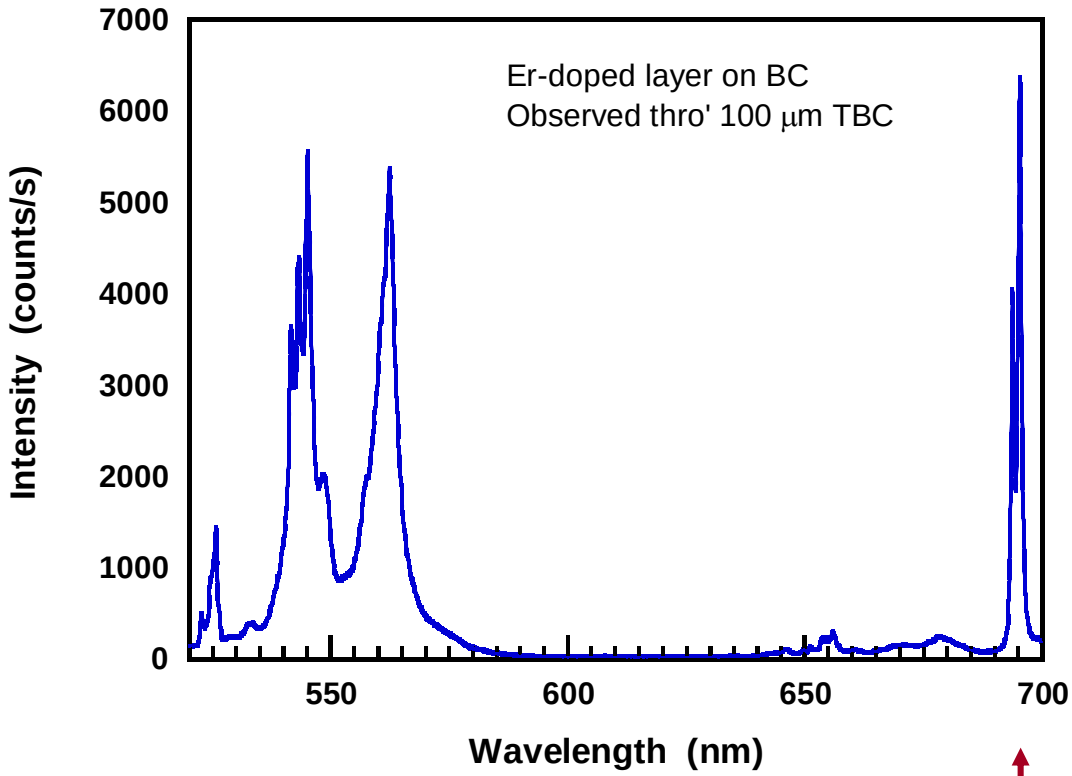


Luminescence Dependence on Concentration Er-doped YSZ



Luminescence From Er-YSZ Layer Next To Bond Coat

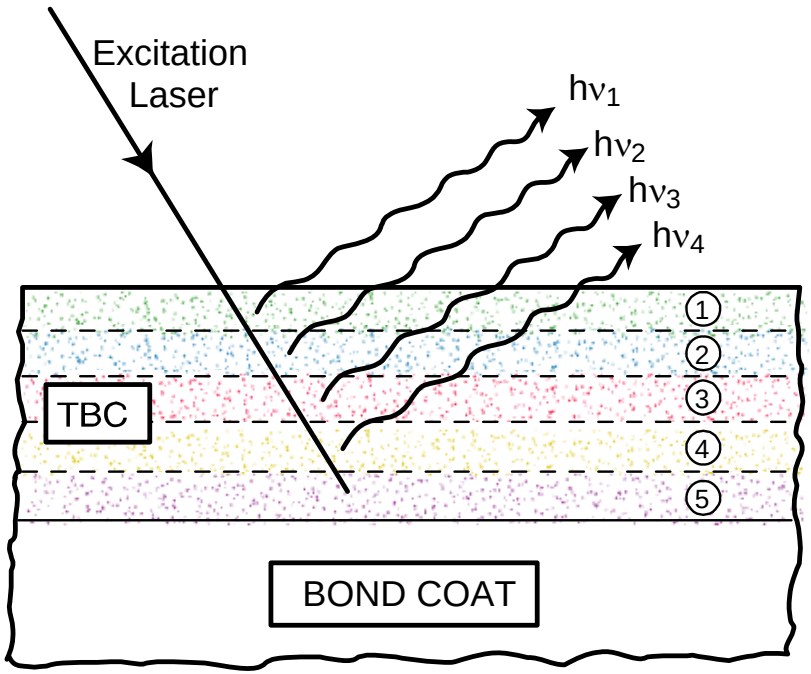


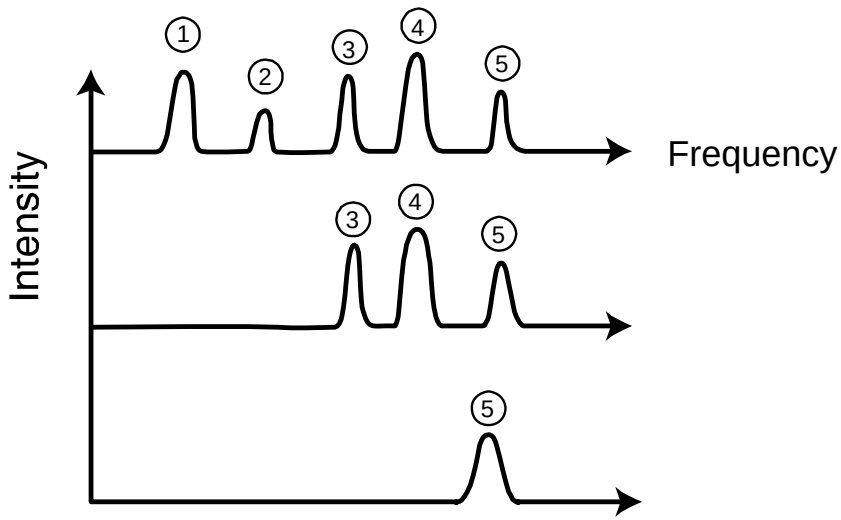


R-line luminescence from TGO

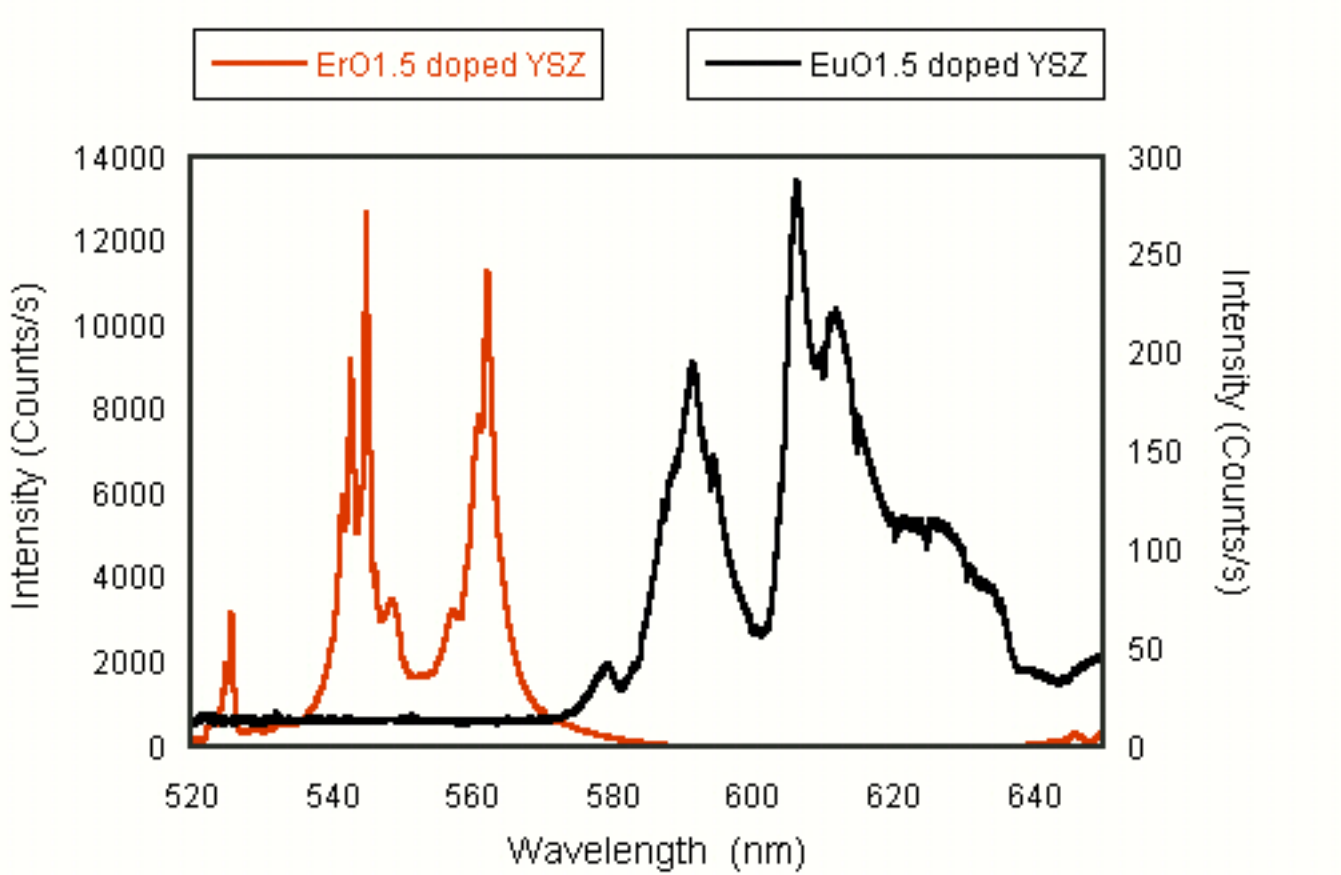
with C. Levi

“Rainbow” TBC Sensor





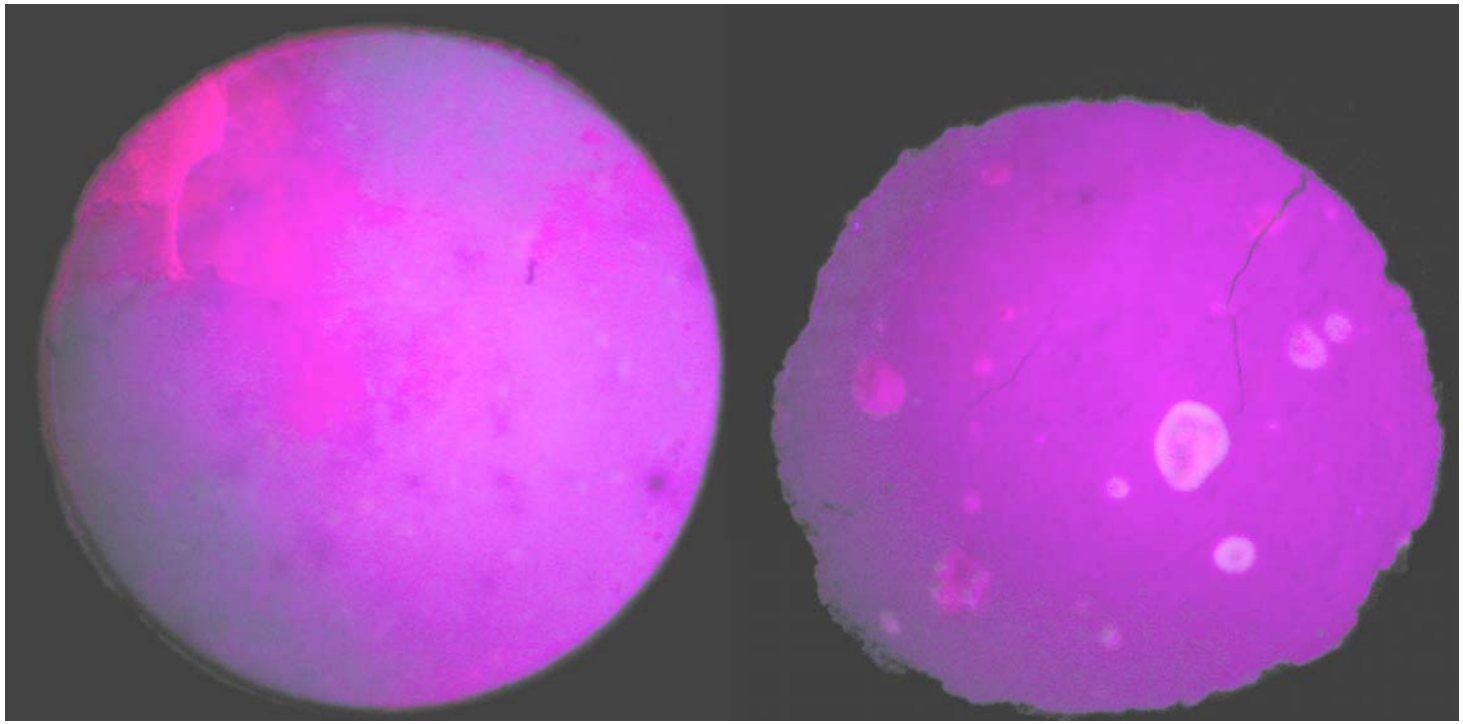
Photoluminescence from Doped YSZ



Luminescence from Multi-layers

Tri-layer YSZ

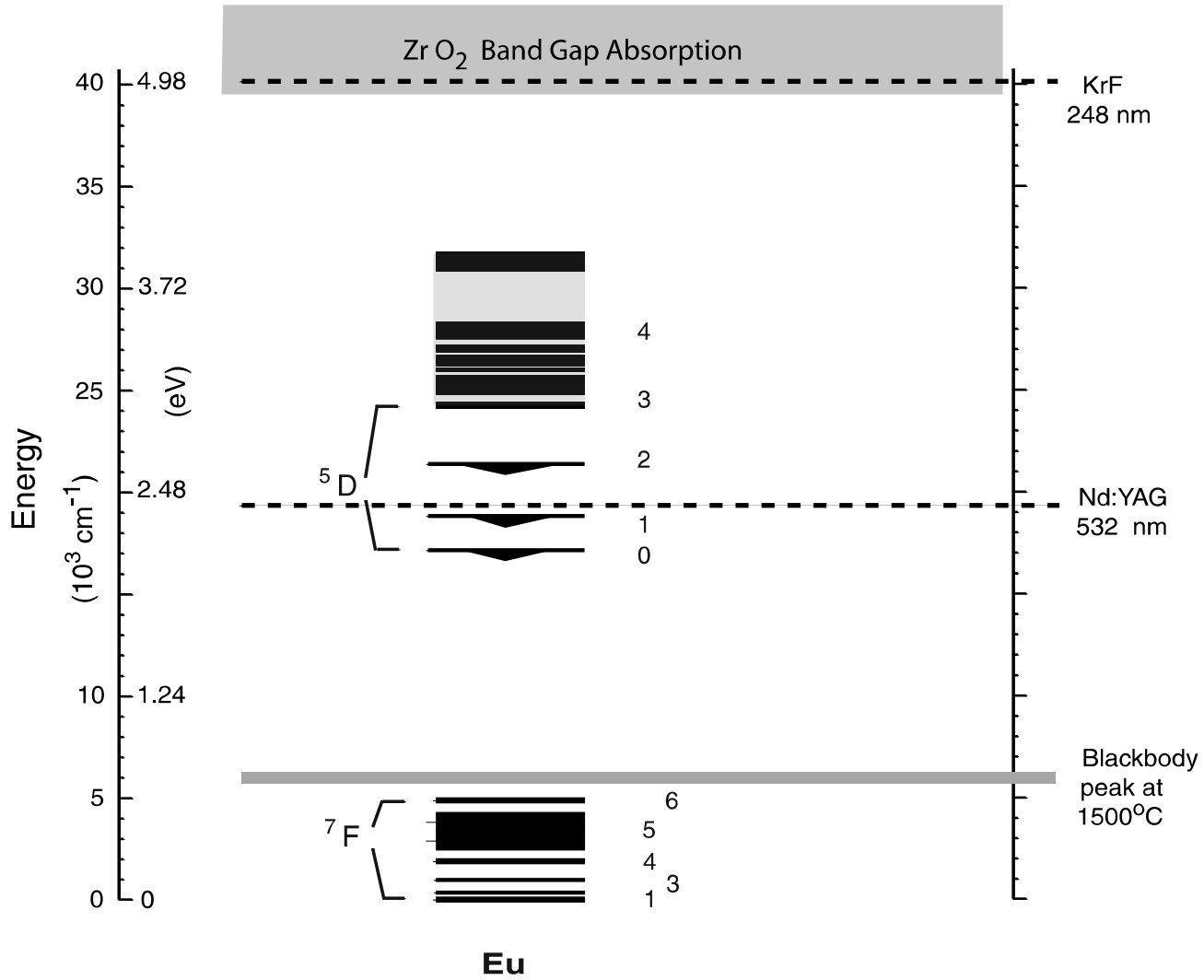
Bi-layer $Gd_2Zr_2O_7$



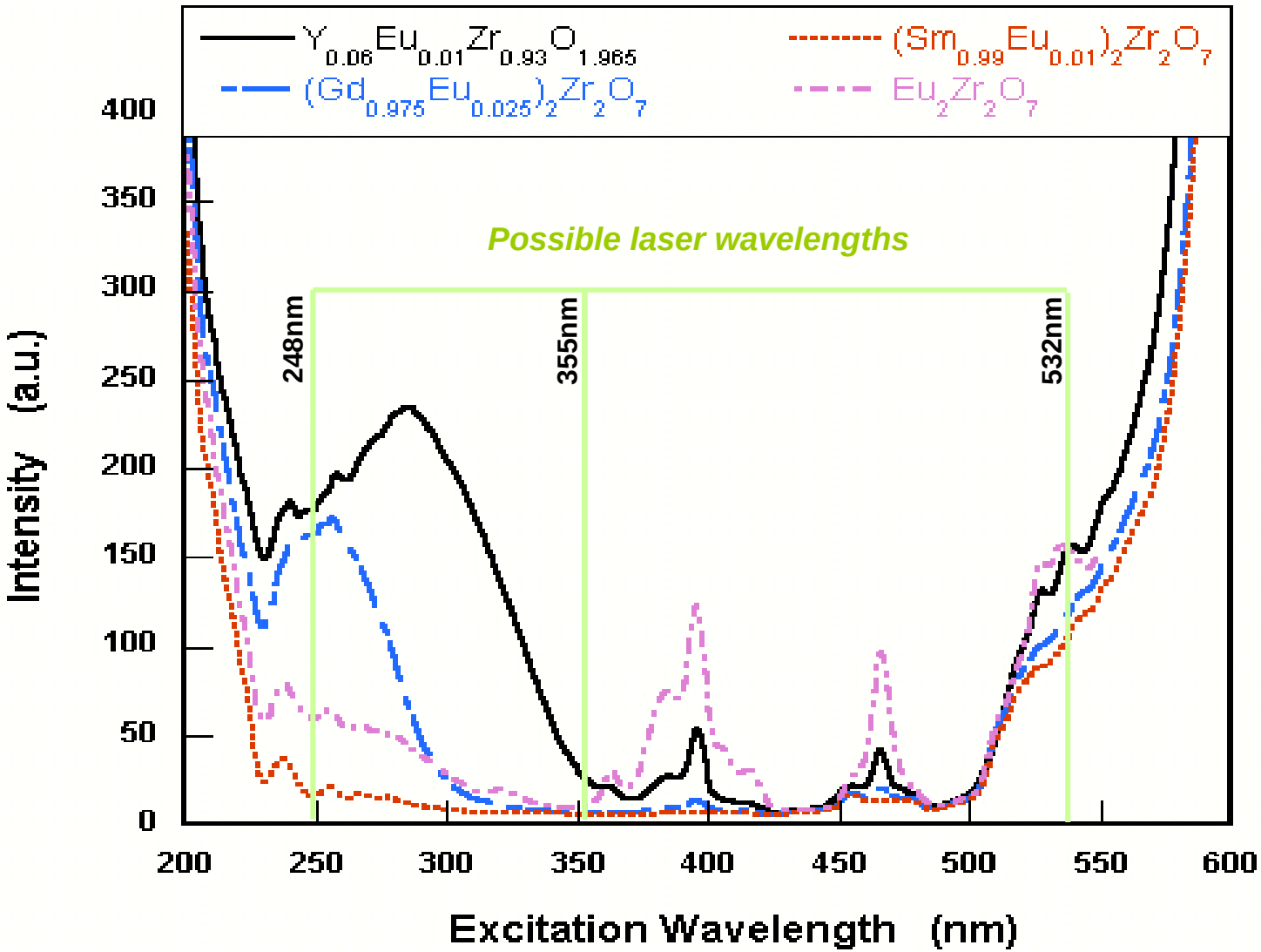
Eu (top), Dy (middle), Er (bottom)
Er appears red where top layers eroded away

Eu (top), Dy (bottom)
Brighter where top layer eroded away

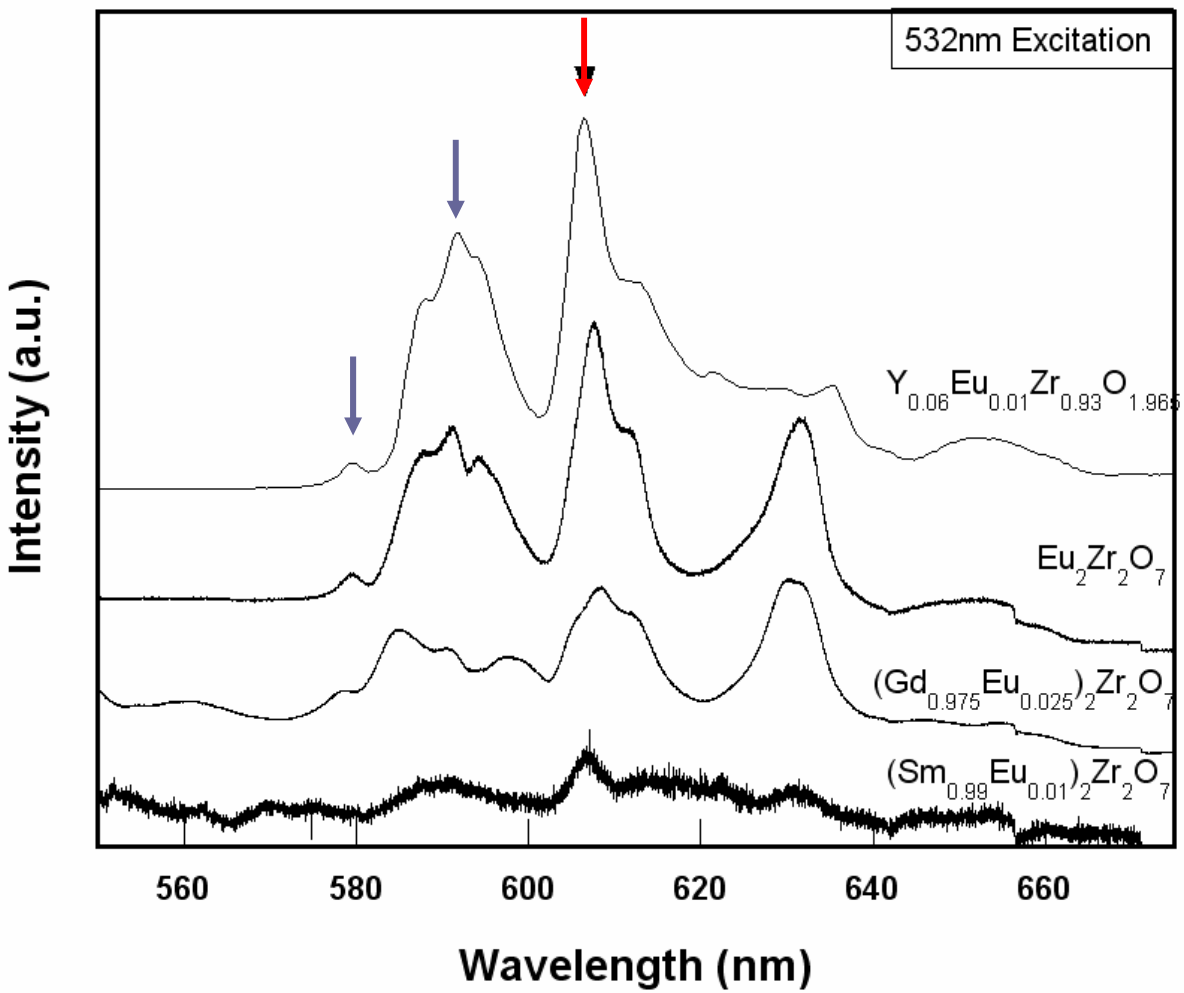
Europium Energy Levels

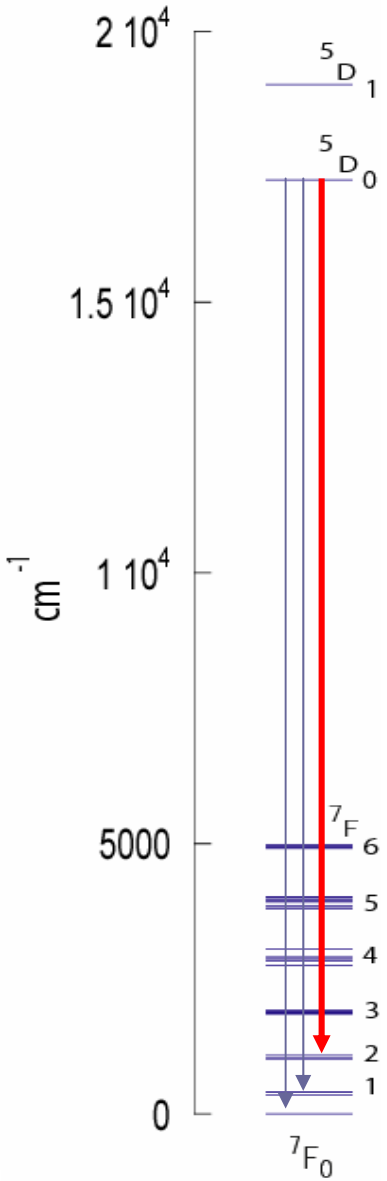


Selecting Optimum Laser Excitation

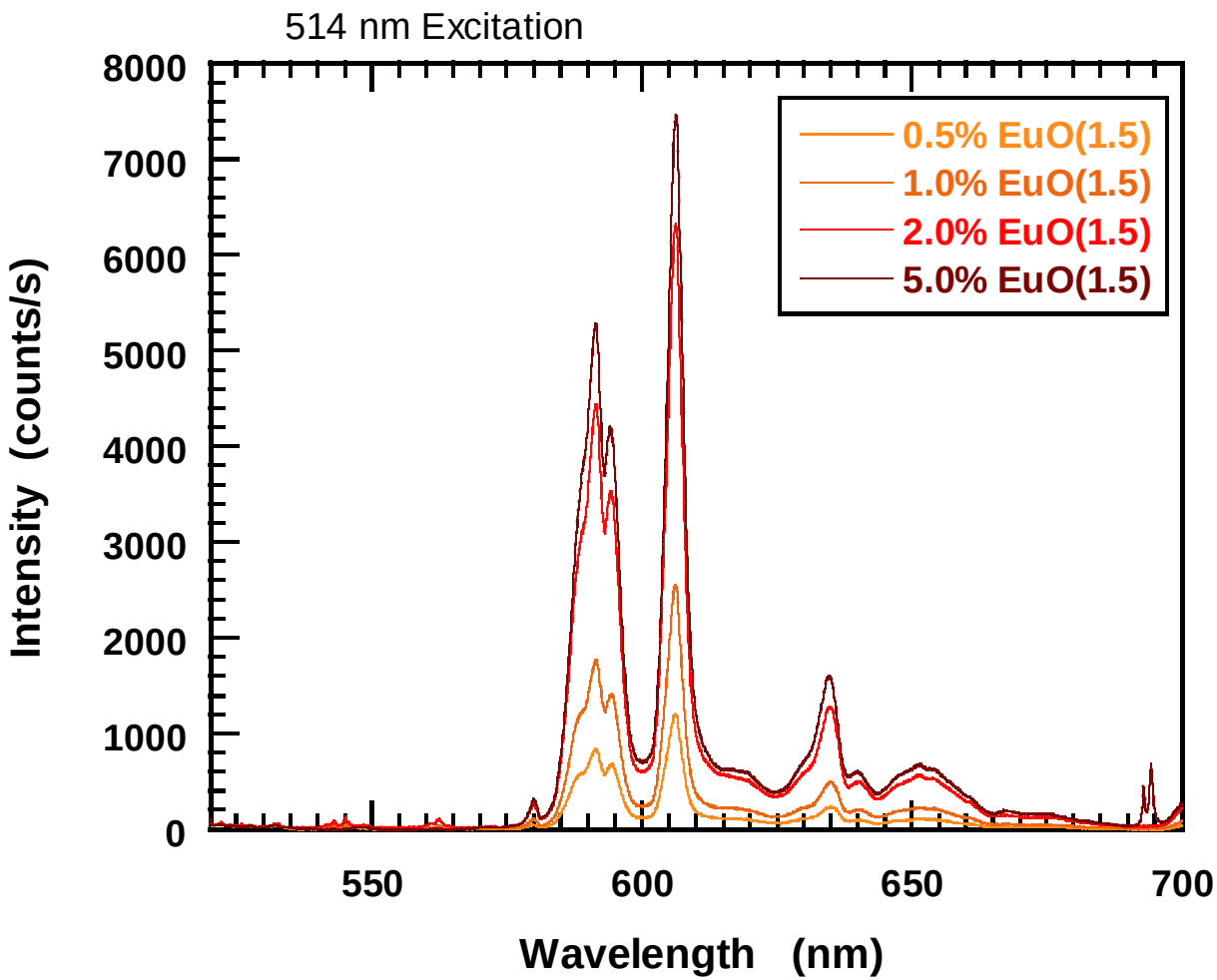


Luminescence Spectra From Selected Coatings Materials

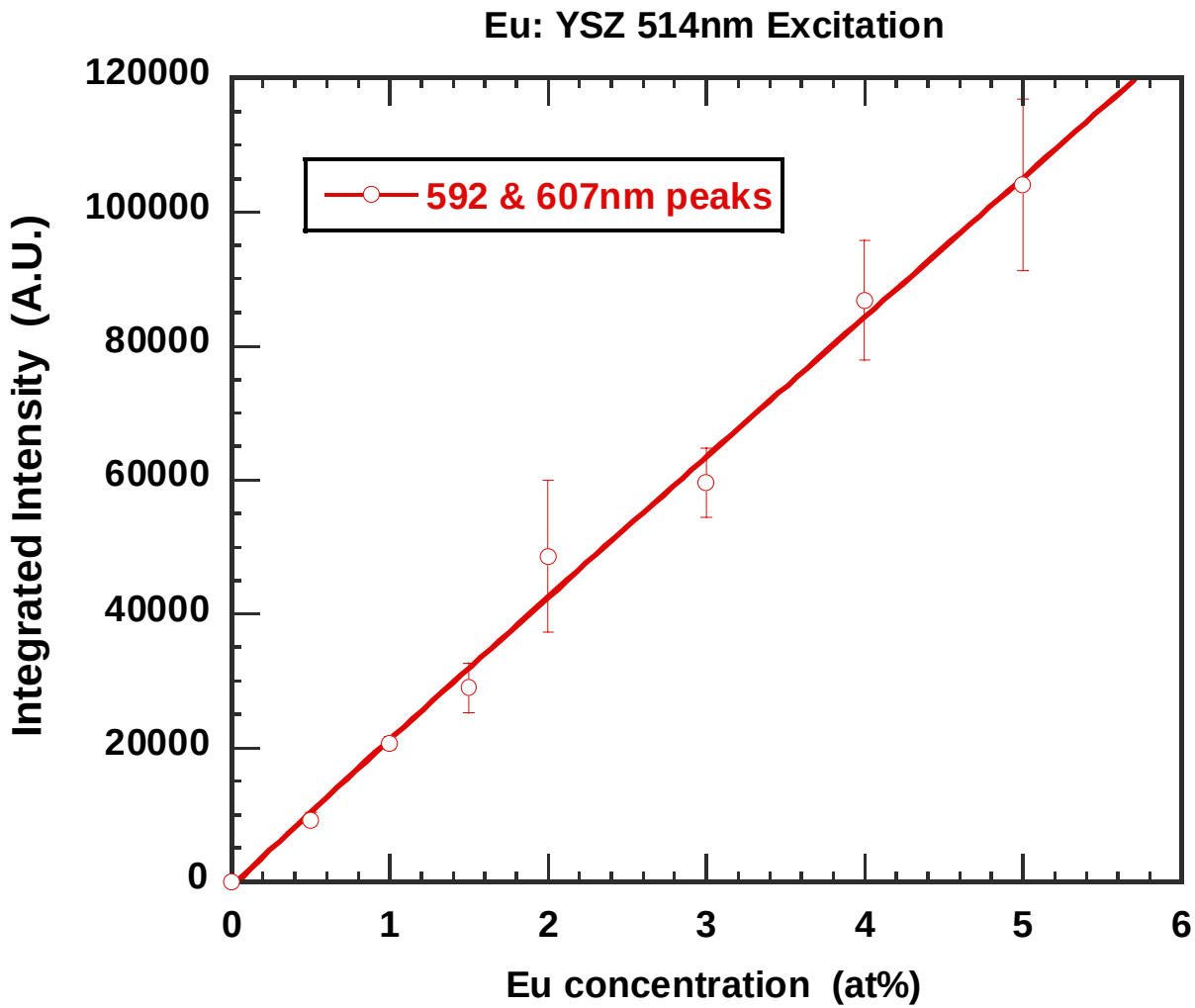




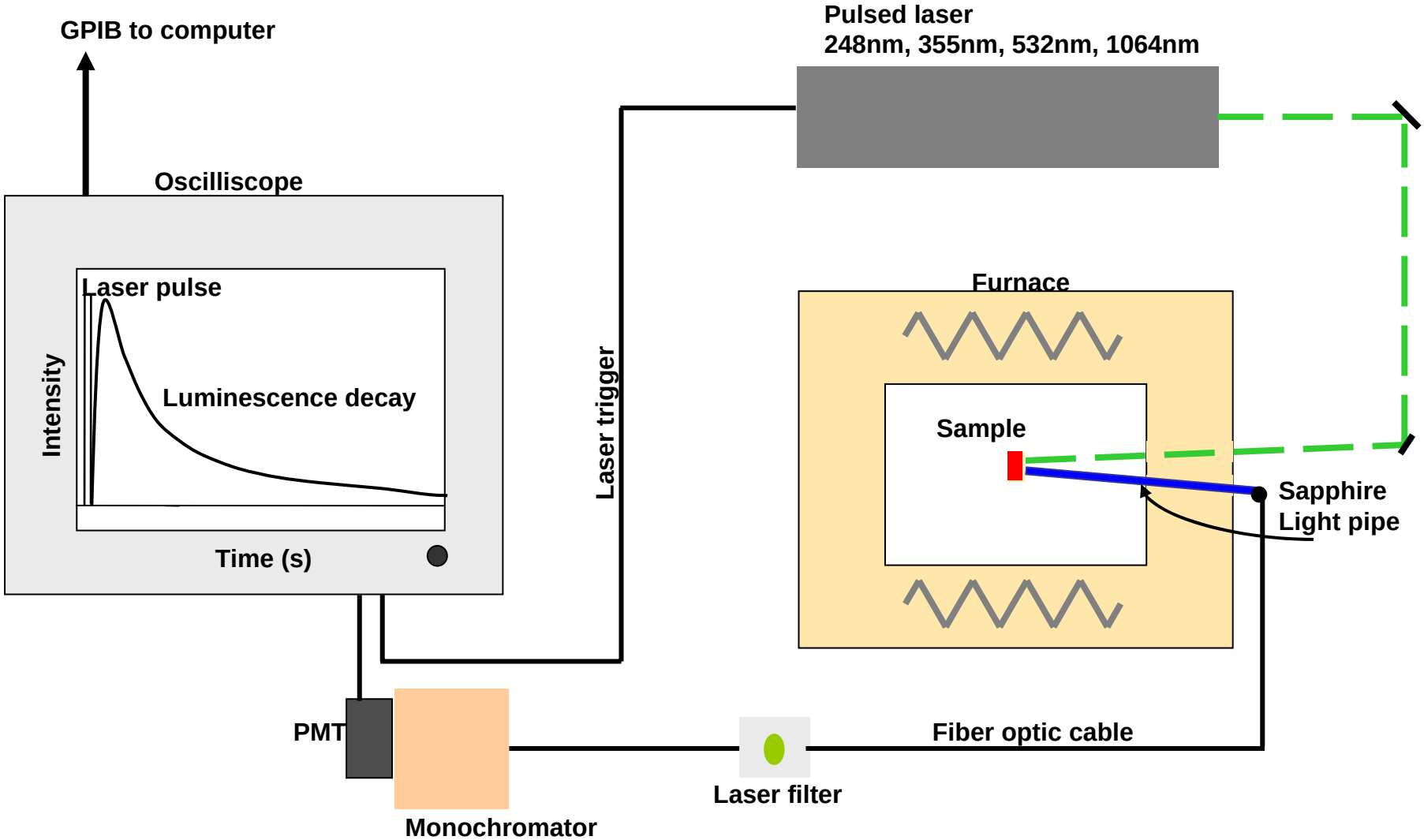
Eu-doped YSZ Luminescence



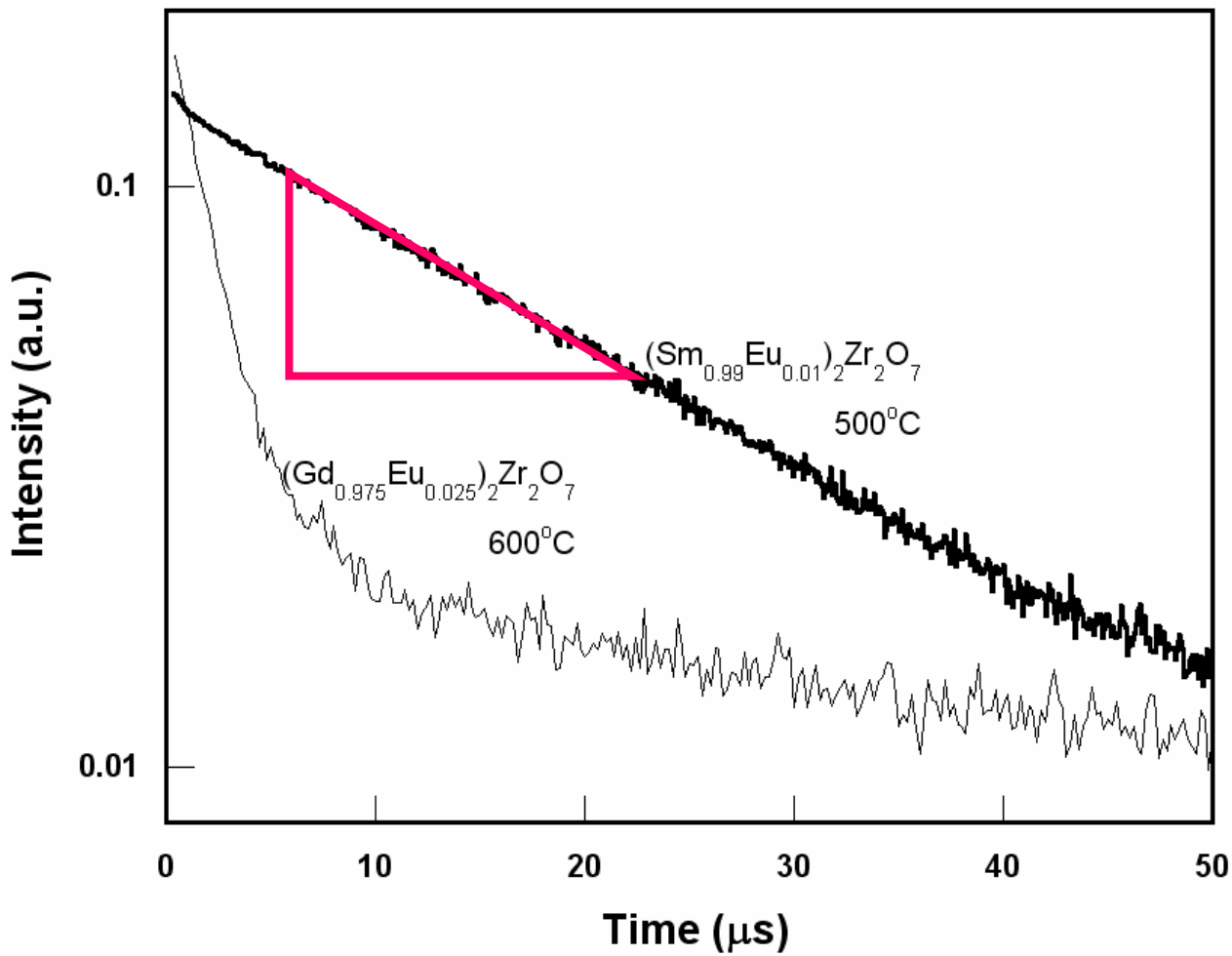
Luminescence Dependence on Concentration Eu-doped YSZ



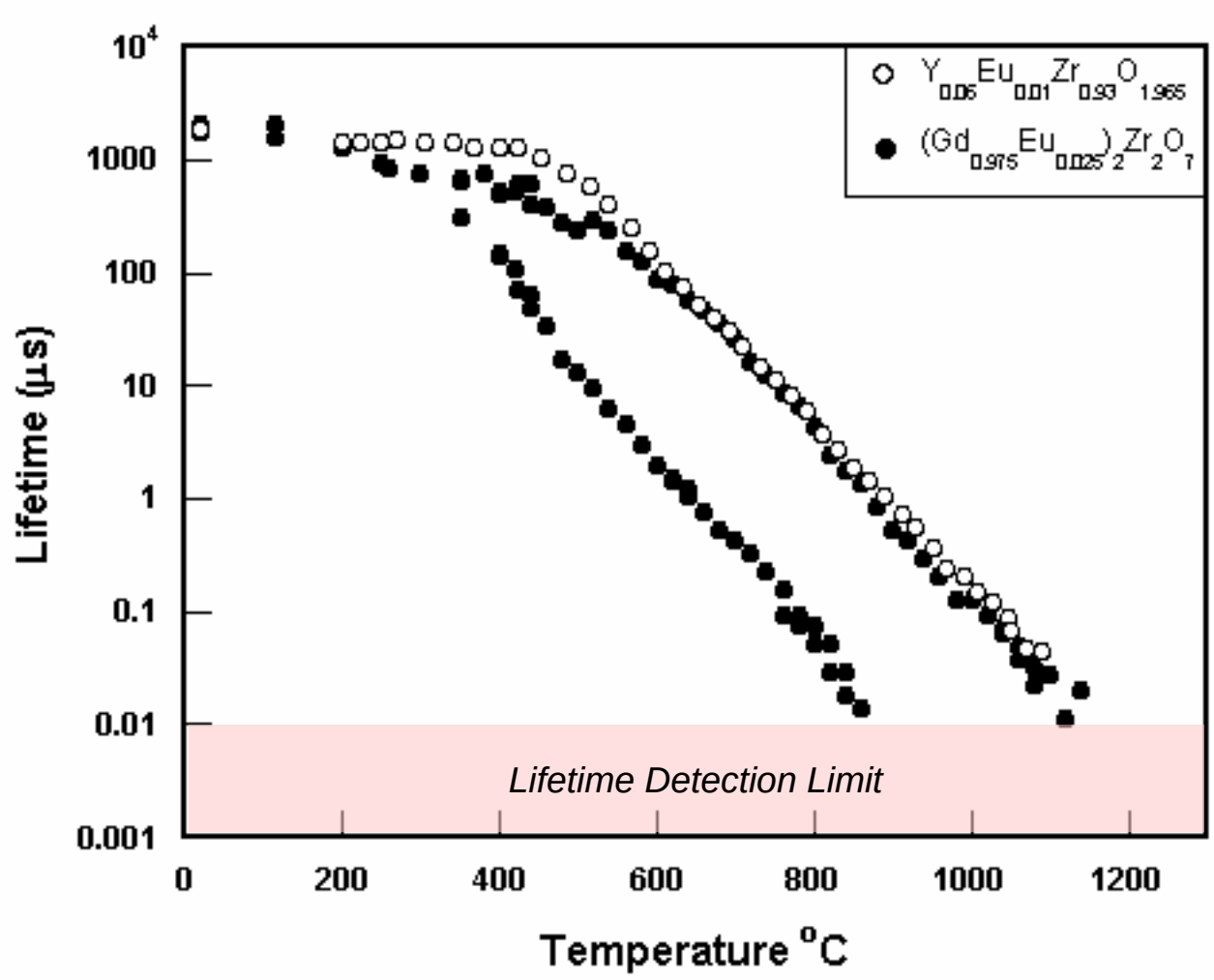
Experimental Arrangement for High Temperature Measurements



Representative Luminescence Decays



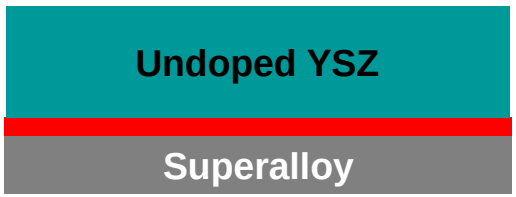
Temperature Dependence of Luminescence Lifetime

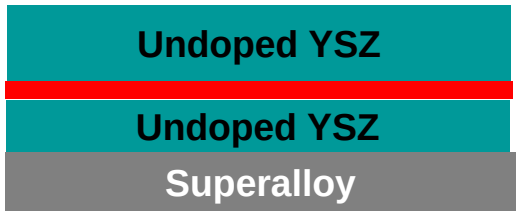


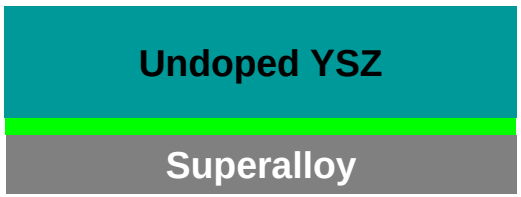
Sensors Coatings Studied

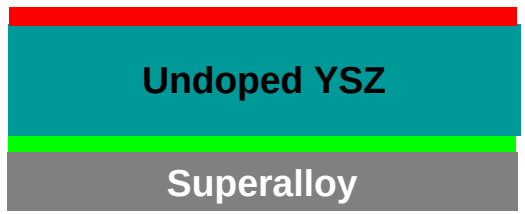
Eu:YSZ layer

Er:YSZ layer









Coatings prepared by electron-beam evaporation

Summary

- Several substitutional rare-earth chromophores identified for TBC sensing applications.
- “Red-line” sensor in EB-PVD TBC system demonstrated.
- “Rainbow sensor” concept for wear and erosion monitoring demonstrated. Next step is to implement using plasma-sprayed TBCs
- Temperature-dependent lifetime of Eu-doping of YSZ and GZO demonstrated to at least 1150^{o}C.
- Luminescence properties correlated to phase equilibria in the Eu-substituted YSZ and GZO systems.
- Alternative rare-earth chromophores for in-situ temperature monitoring being investigated.