UT-BATTELLE

Phosphor Thermometry *Tutorial*

by

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What is a phosphor?

- A phosphor is a chemical material that, when stimulated by absorption of energy – often in the form of photons – will emit photons – usually at lower energy (longer wavelength) than the stimulating source.

- In appearance, a phosphor is usually a fine white or pastel-colored powder. There are two general types of phosphors: organic and inorganic. This presentation deals with inorganic. The majority of thermometry applications in our experience have used inorganic phosphors. Organic fluorescing materials may have advantages in certain situations.

What is a phosphor? (continued)

- Inorganic phosphors consist of:
  - Host material: e.g., oxide, garnet, sulfide, oxysulfide, vanadate, germanate, etc.
  - Activator material (aka dopant or impurity): usually rare-earth or transition metal elements.
  - An advantage of these dopants is that, typically, the emission consists of narrow bands.

Typical phosphor characteristics

- Must survive hazardous chemical environments
- Cannot be water soluble
- Durable
- Easy to apply
- Not easily detected or noticed without specialized equipment
- There are a wide variety of ceramic phosphors which fit these characteristics.

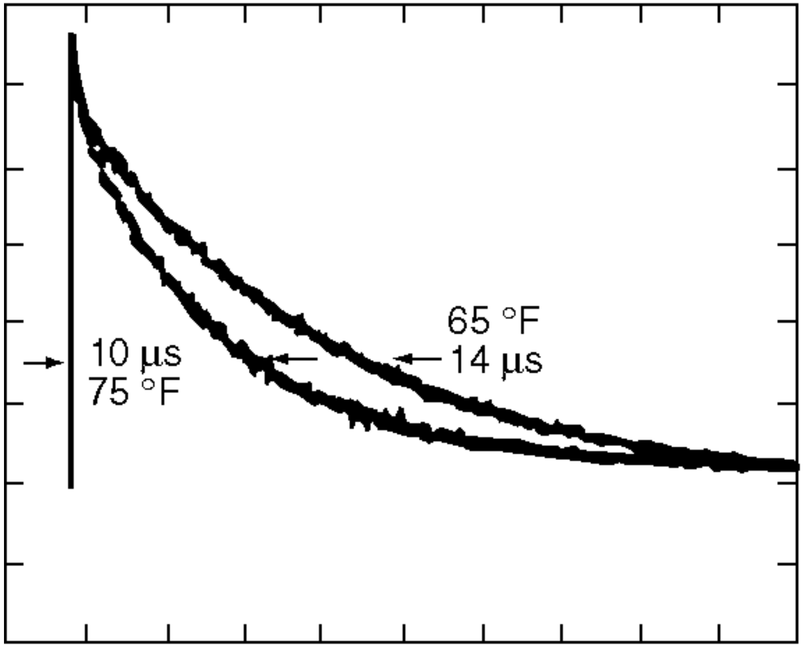
Background

- Phosphors became technologically and industrially important with the introduction of fluorescent lamps in 1938.
- Thermometry use suggested in German patent in 1938. First peer-reviewed article, to our knowledge, appeared in 1949.
- Between approximately 1950 to 1980, it was not widely used. Its most common use was for aerodynamics applications.
- Advances in lasers, microelectronics, and other supporting technologies enabled additional commercial as well as scientific uses.

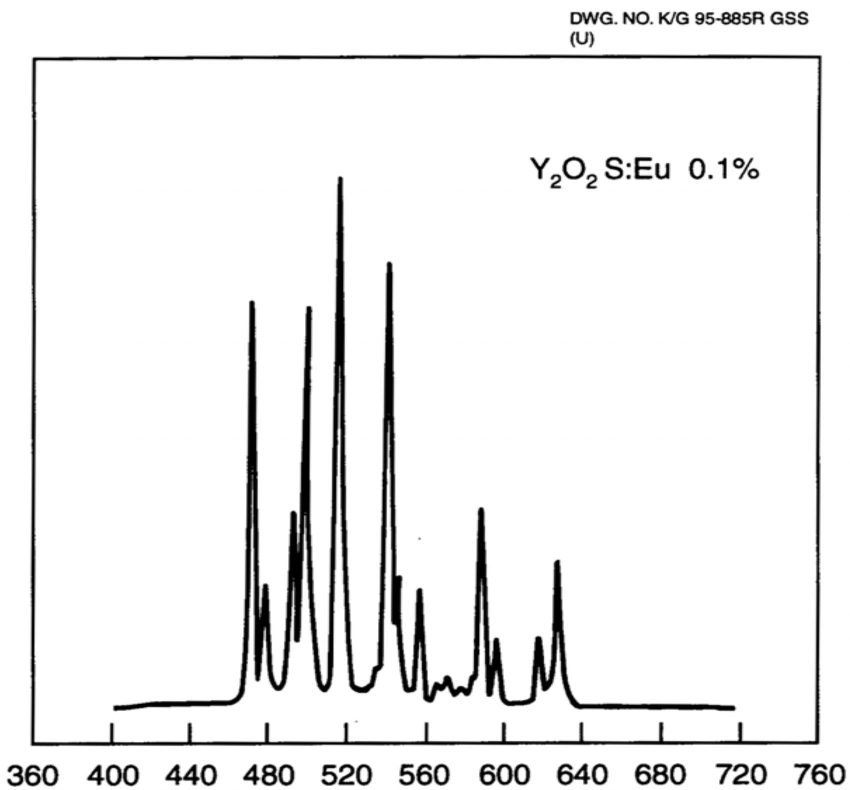
Various phosphor characteristics are affected by temperature

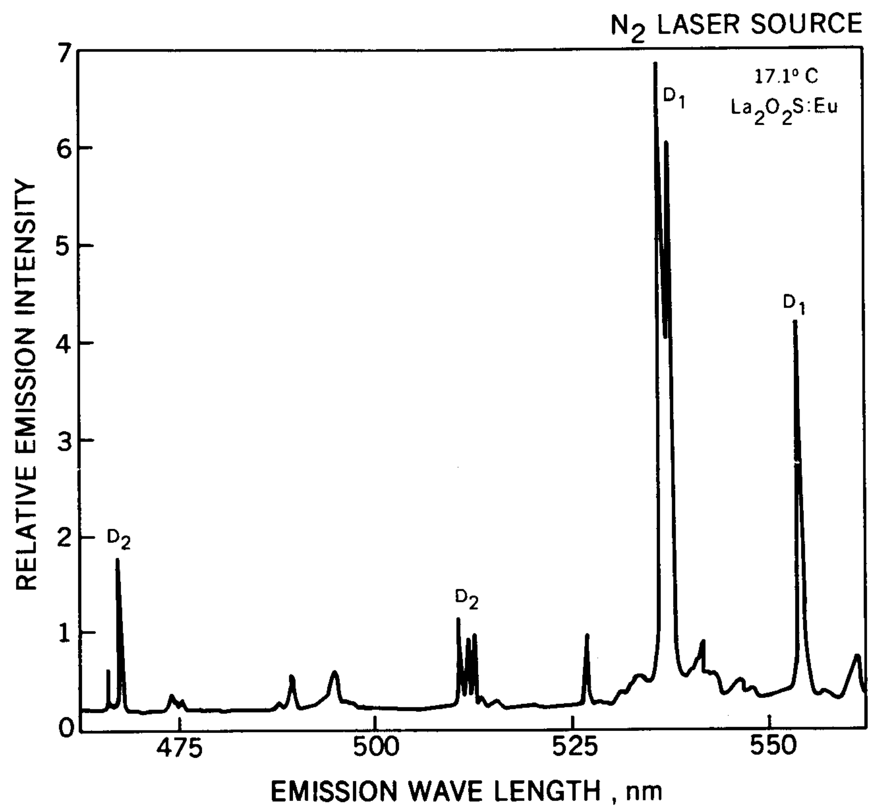
1. Decay Time
2. Line shift and broadening
3. Ratio of emission lines
4. Emission distribution
5. Absorption band width and position
6. Excitation band width and position

ORNL-DWG 97-1687 EFG



Typical fluorescence spectra for rare-earth doped phosphors





Factors that affect fluorescence

- Dopant (activator) concentration may change the phosphor emission spectrum. Dopant concentration that maximizes fluorescence varies with dopant and host. At high concentrations, the emission characteristic lifetime may vary from a simple single exponential. Rise times are also affected by dopant concentration.

- Characteristic size of phosphor particles affects intensity and lifetime of fluorescence when size is around 5 microns or less. For Y_2O_3:Eu, e.g., decay time increases from 440 to 600 microseconds when particle size decreases from 0.42 to 0.11 microns.

Factors that affect fluorescence (continued)

- **Impurities:** Deliberately added rare-earth impurities may either increase or degrade fluorescence efficiency, depending on how energy levels match. The literature contains information on which pairings favor enhancement.
- **Magnetic Field:** At least one tesla is usually required to observe a change in fluorescence spectra and the material must be very cold, say 20 K.

Decay time vs temperature for selected phosphors

DWG. NO. K/G 96-569 GSS
(U)

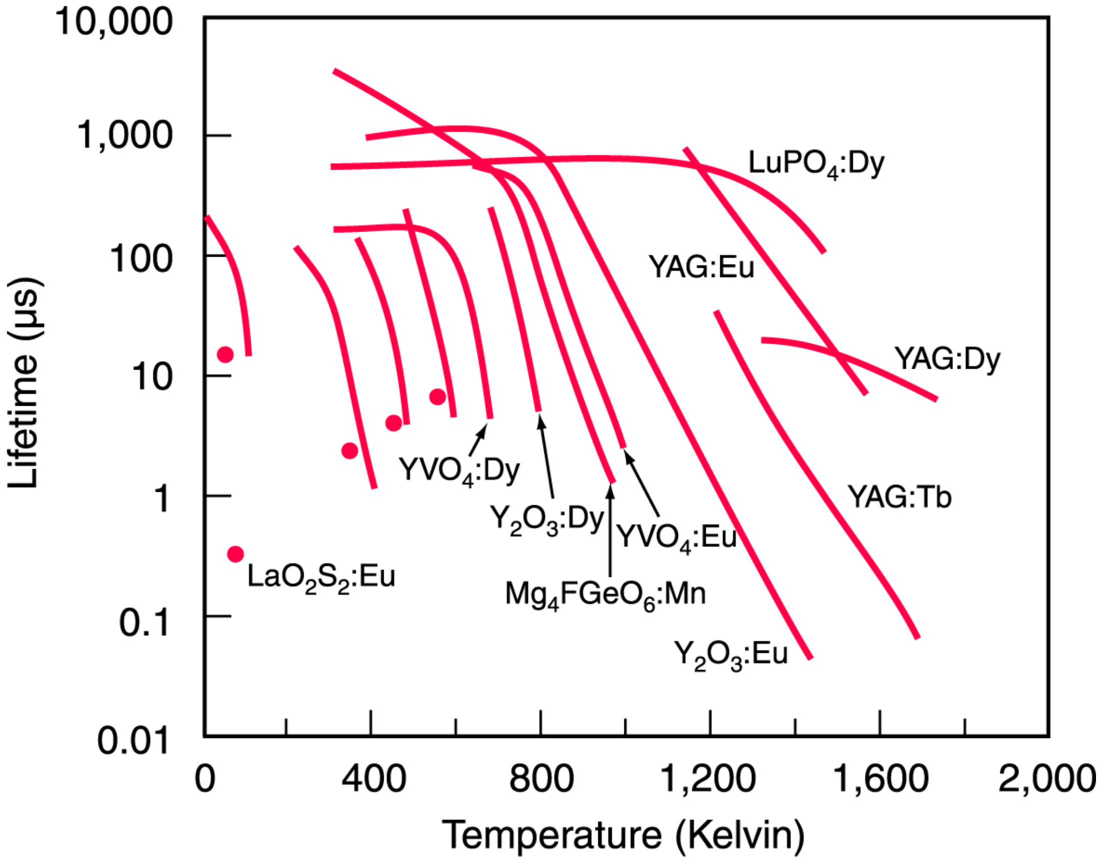
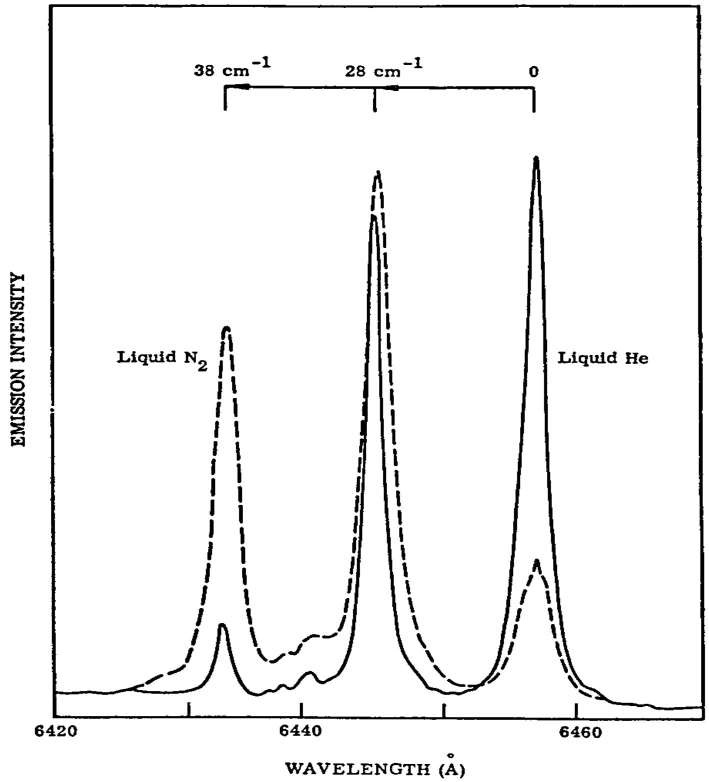


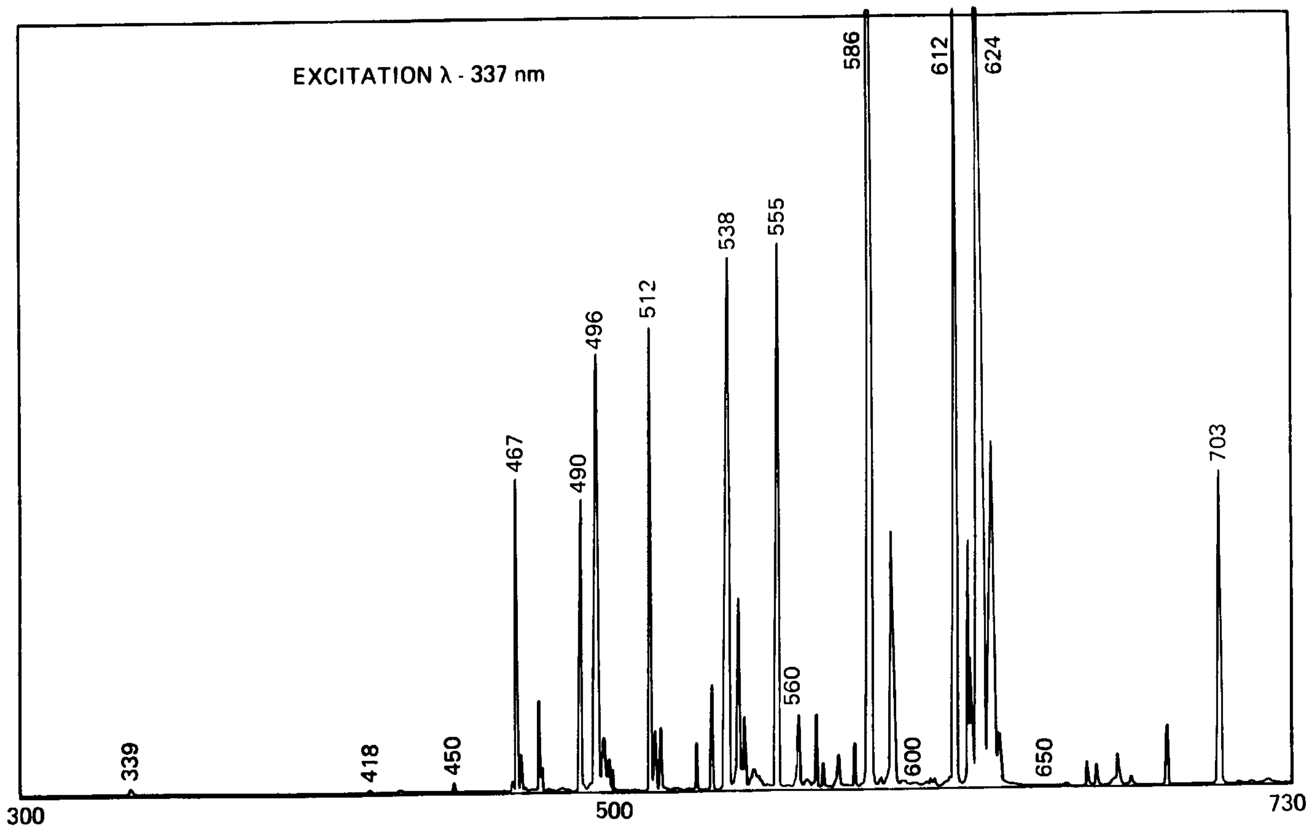
Figure 12. Lifetime versus temperature of selected phosphors.

Intensities of emission bands are a function of temperature

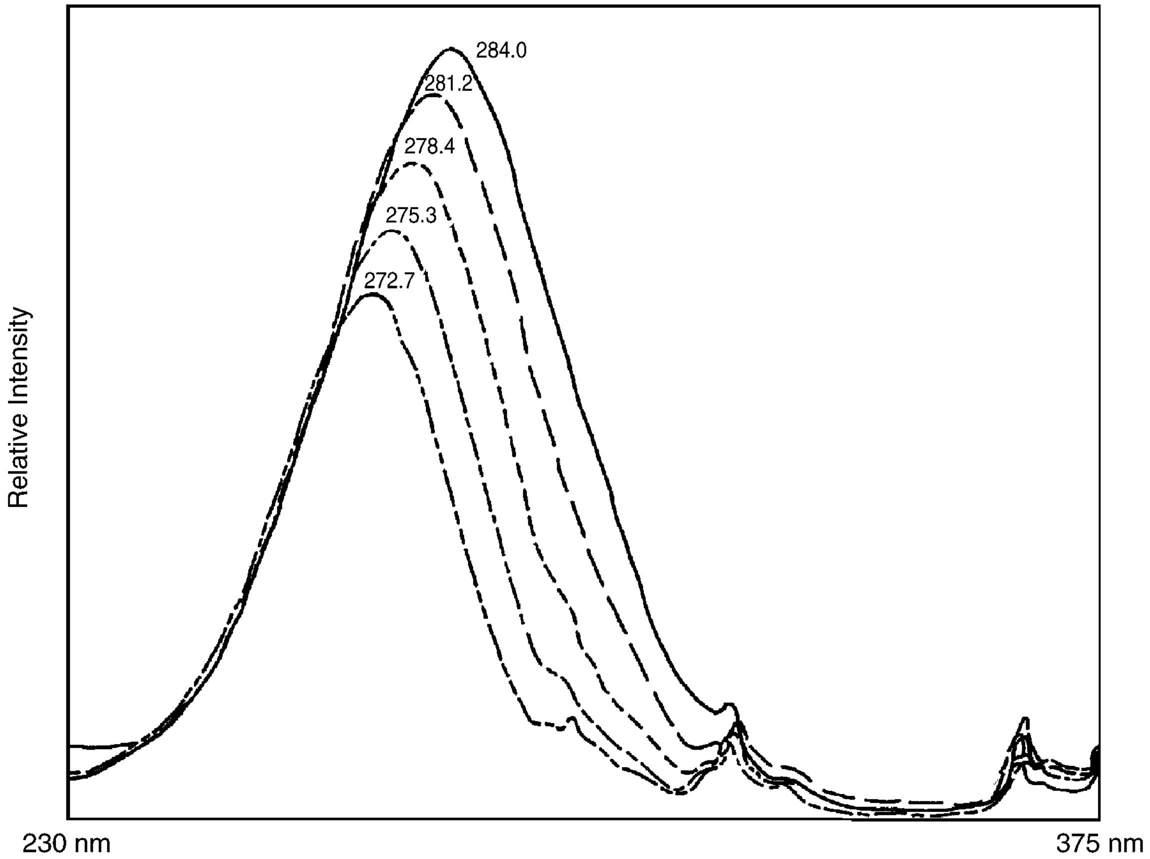


- Change in intensity at cryogenic temperatures

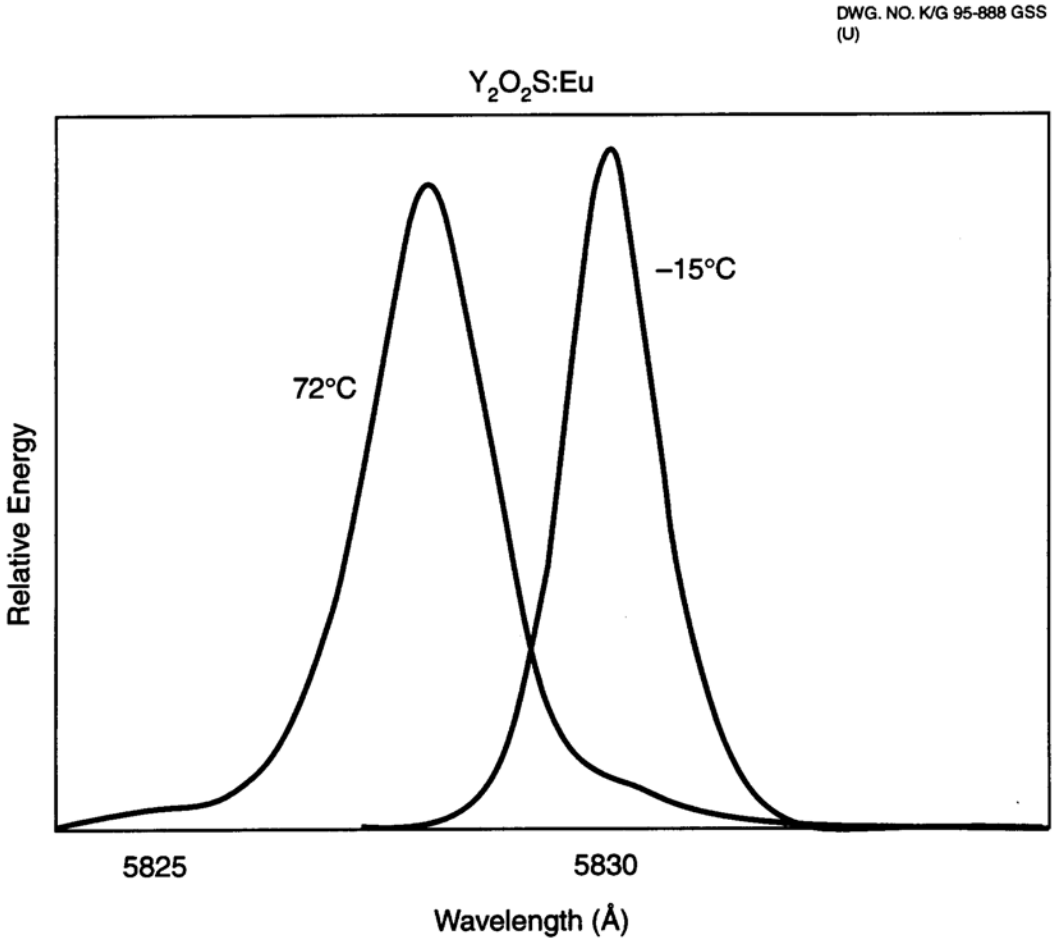
La_2O2S:Eu at low temperature



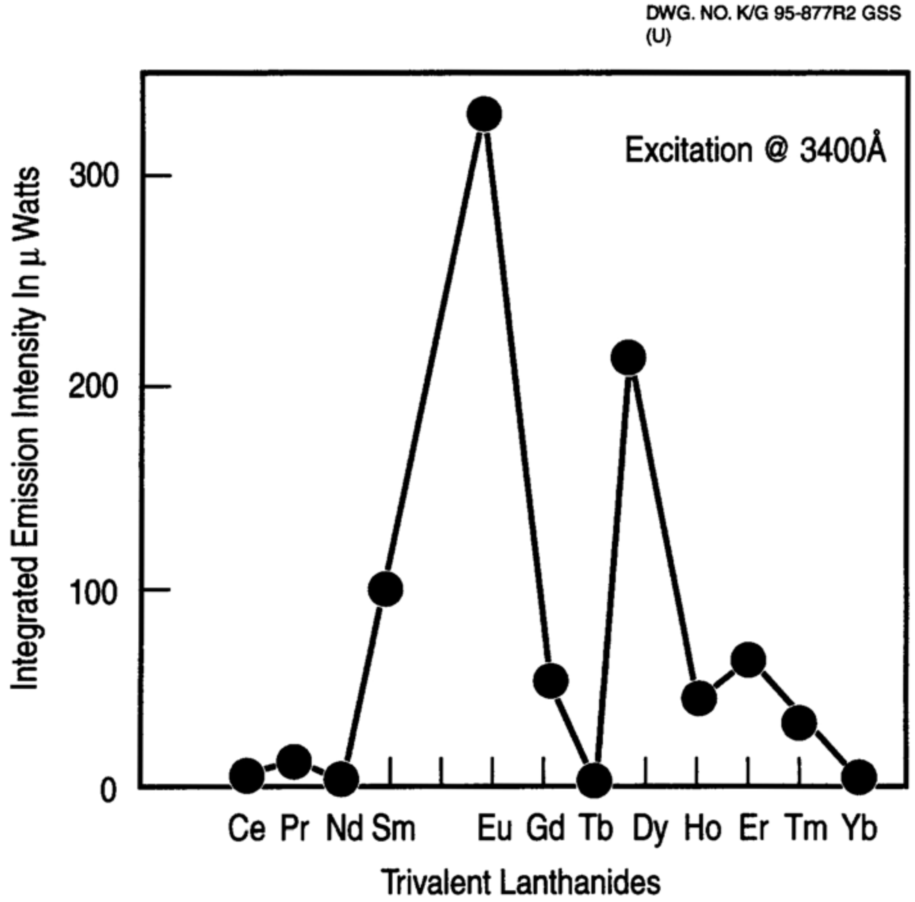
Temperature dependence of excitation (Y_2O_3:Eu)



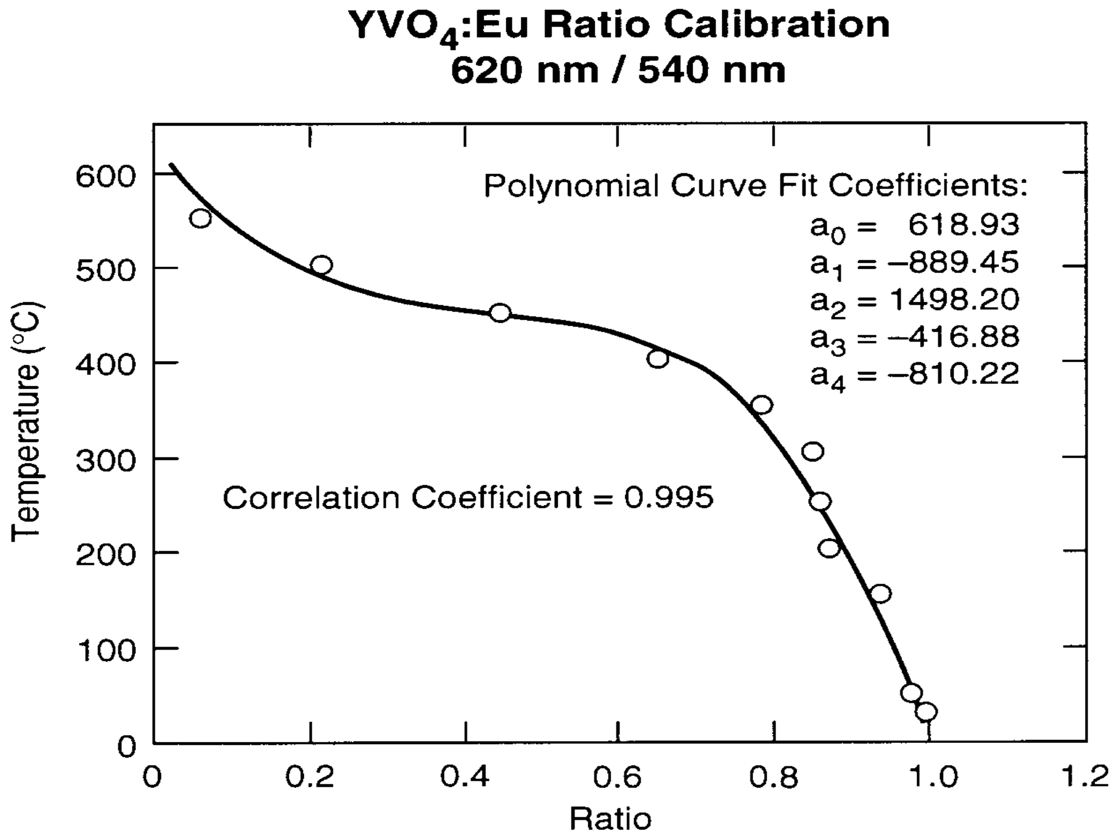
Temperature dependent line position and bandwidth



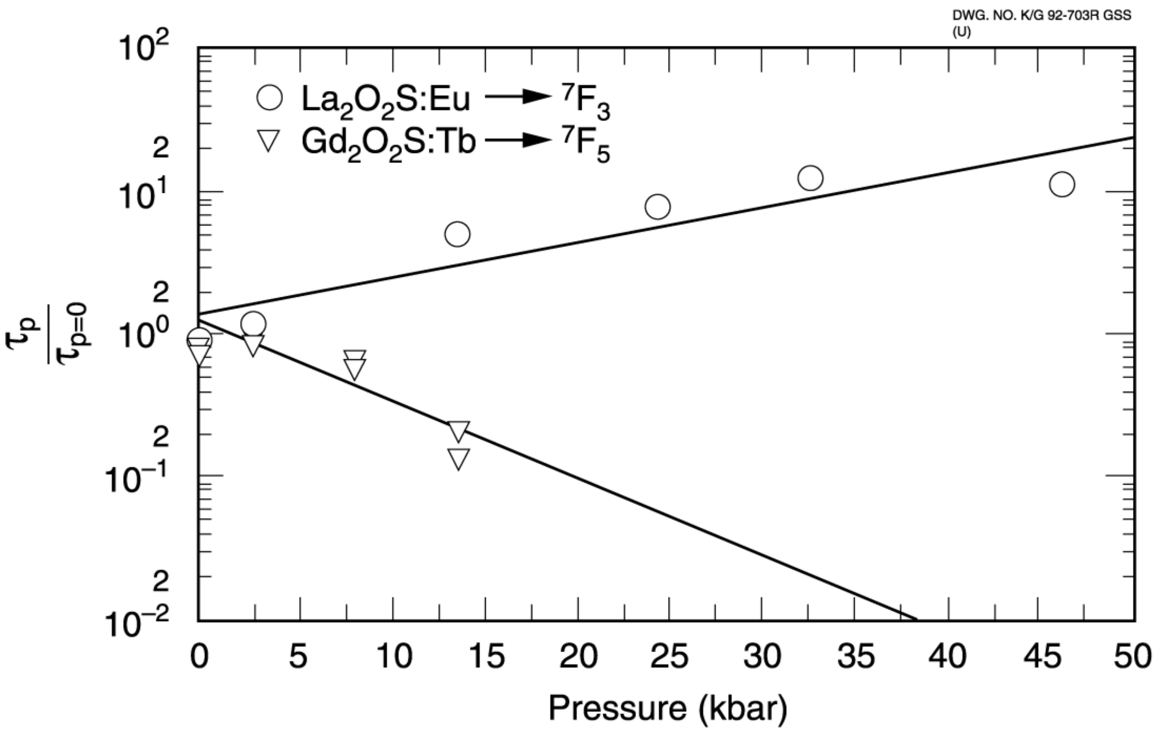
Emission intensity versus rare-earth dopant in YVO_4



Example of ratio data

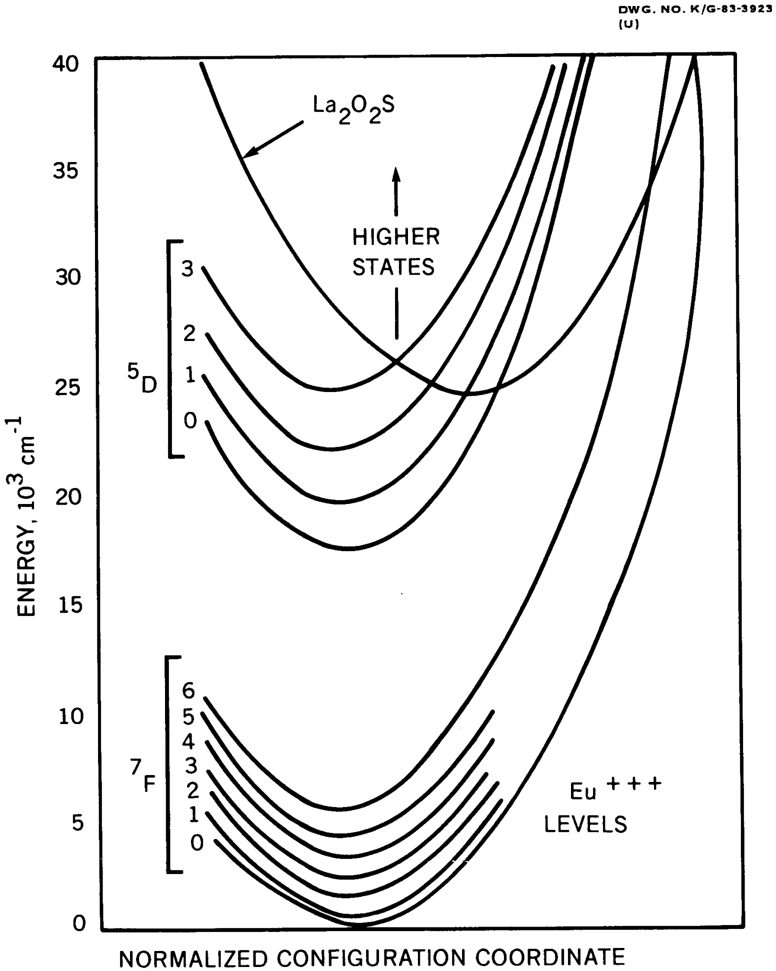


Pressure dependence of two pressure-sensitive phosphors



- **Pressure vs decay time for $La_2O_2S:Eu$ (top curve) and $Gd_2O_2S:Tb$ (lower curve)**

Origin of temperature dependence



- **Charge Transfer State Model**

Model of temperature and pressure dependence

$$tau := \left[a_1 + a_2 \cdot \left[\exp\left[\frac{-(P \cdot q + Ects) \cdot h \cdot c}{k \cdot T}\right]\right]\right]^{-1}$$

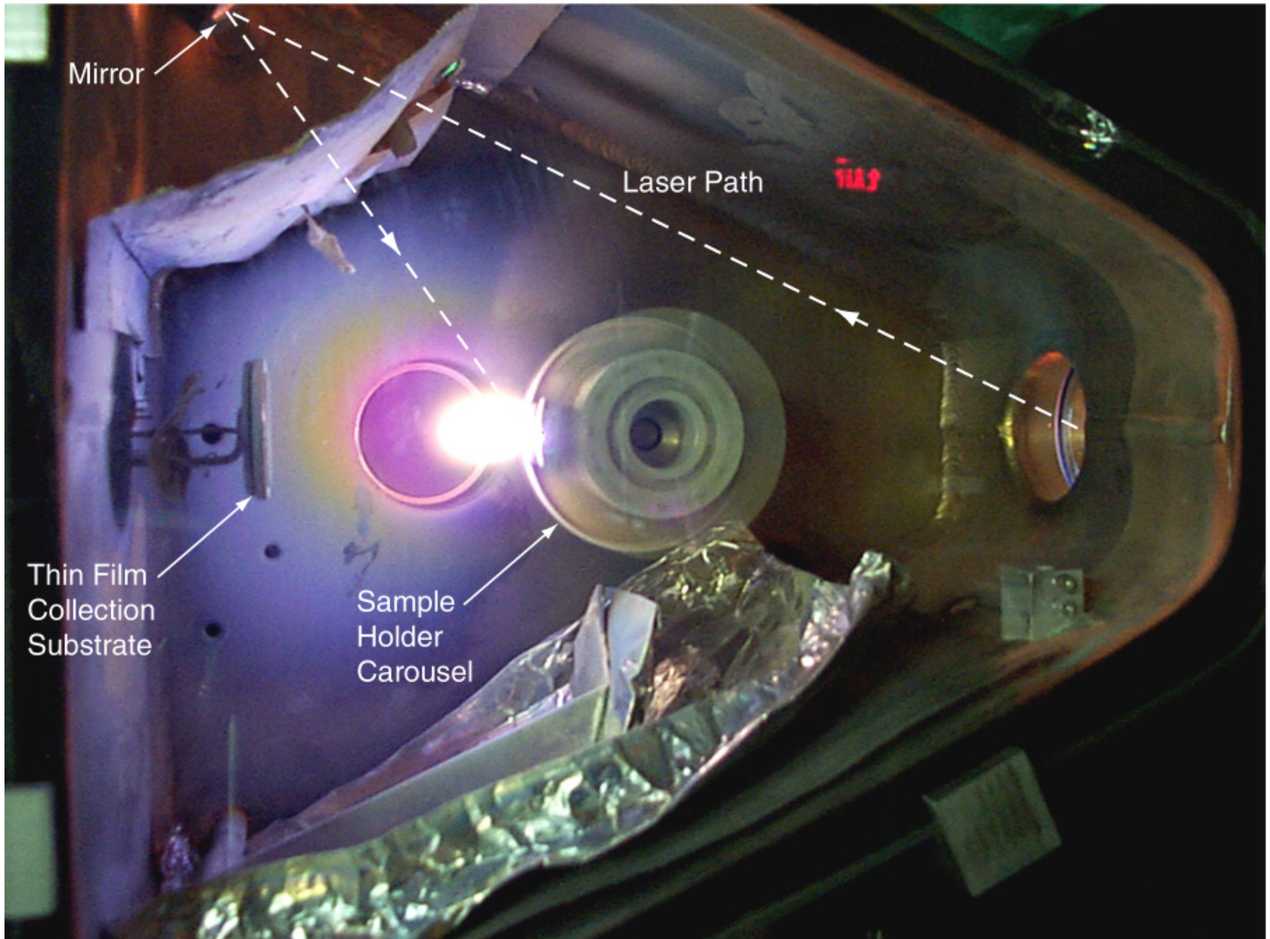
- A model was developed, resulting in the equation above, that predicts the decay time, tau, versus both pressure and temperature for La_2O_2S:Eu. Three of the parameters, a_1, a_2, and Ects; are obtained from fitting to temperature vs decay time data. The reciprocal of the low temperature decay time, a_1, is 6369 sec^{-1}. The transfer rate ratio, a_2, from the excited $^5D_2$ emitting state is 10^{12}; and Ects = 3370 cm^{-1} is the effective energy difference between the $^5D_2$ state and the charge transfer state. k is the Boltzmann constant, h is Planck's constant, and c the speed of light. T is the temperature in Kelvin. P is the pressure in psi. q is obtained empirically, it is the slope of the pressure versus decay time curve. Here q = $2.73 * 10^{-3}$ $psi^{-1} * (cm^{-1})^{-1}$.

Phosphor selection criteria

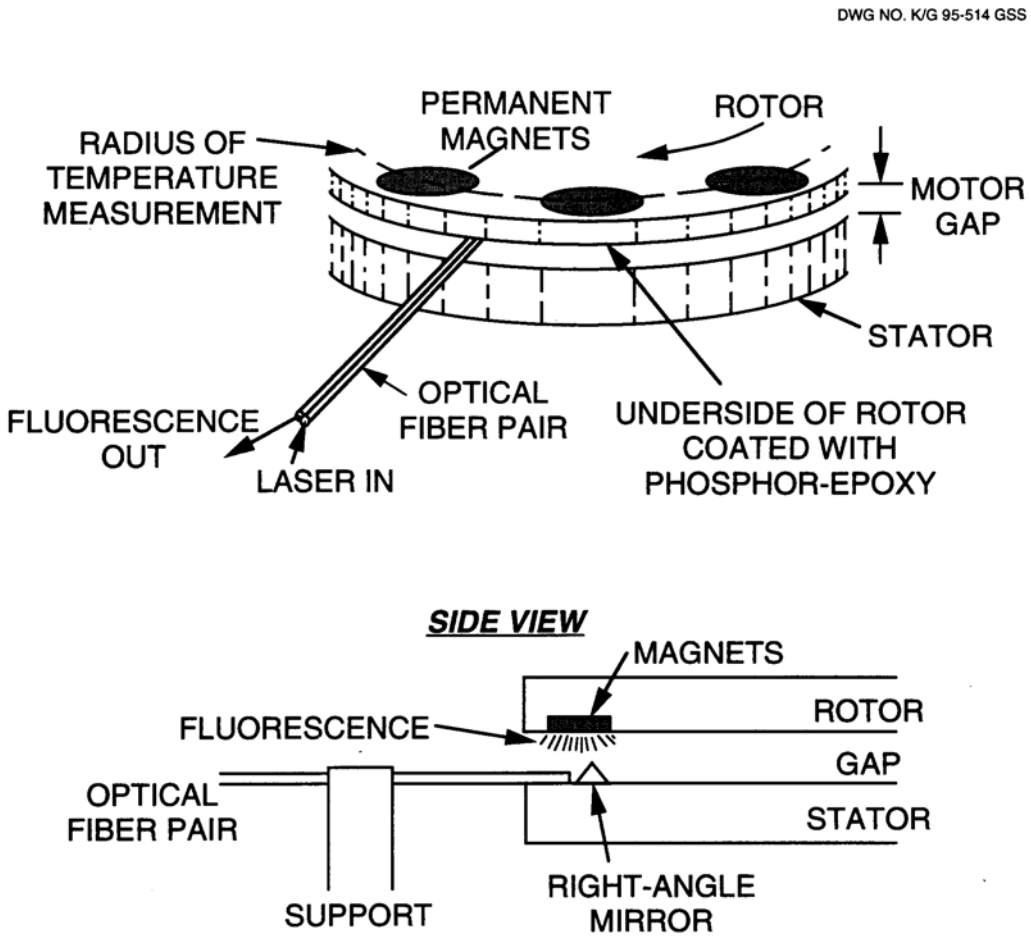
1. Temperature Range of Application
2. Chemical compatibility
3. Target stationary or moving
4. Measurement Method used: decay time or ratio
5. Surface preparation considerations
6. Imaging or point measurements required

Pulsed laser deposition (PLD) can be used to apply phosphor coatings

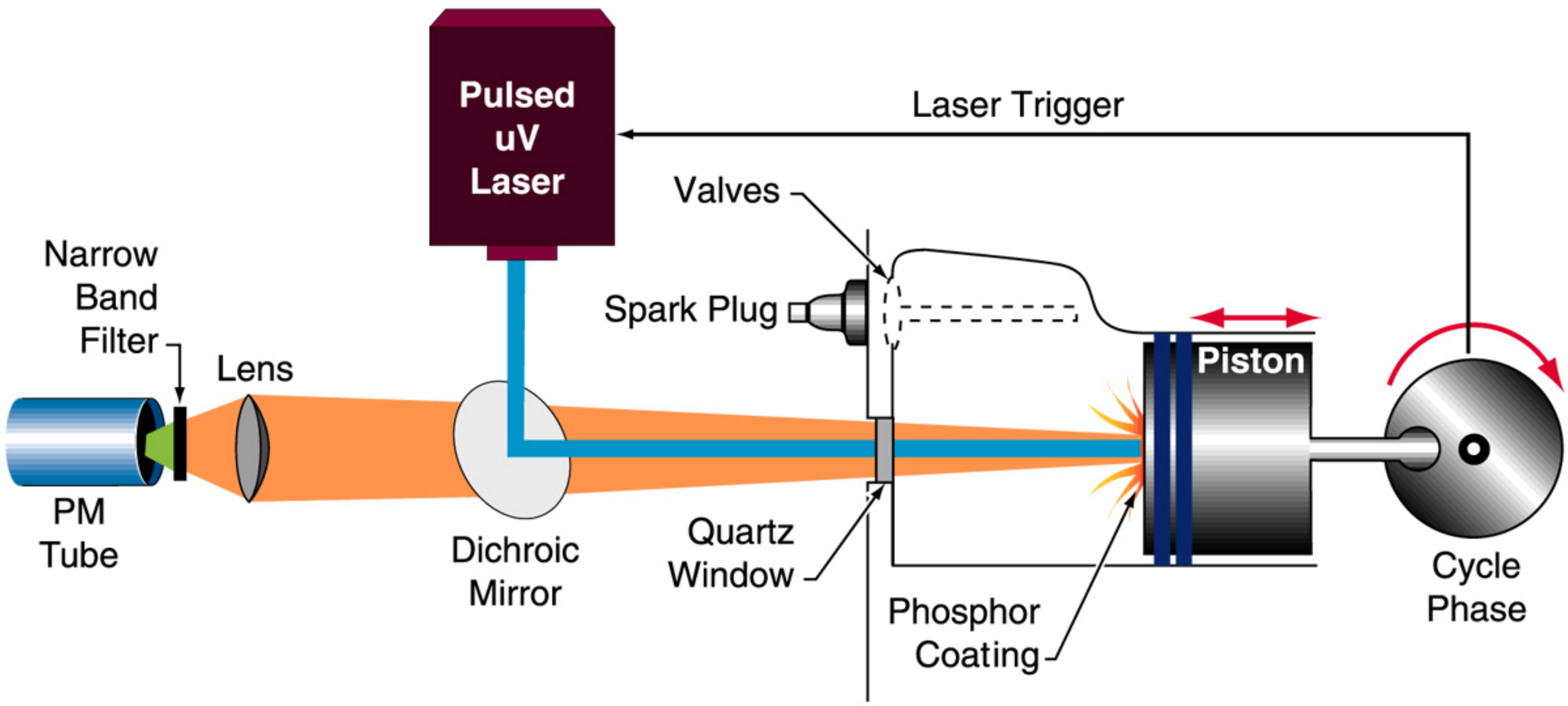
ORNL 98-1810C EFG



Permanent magnet motor

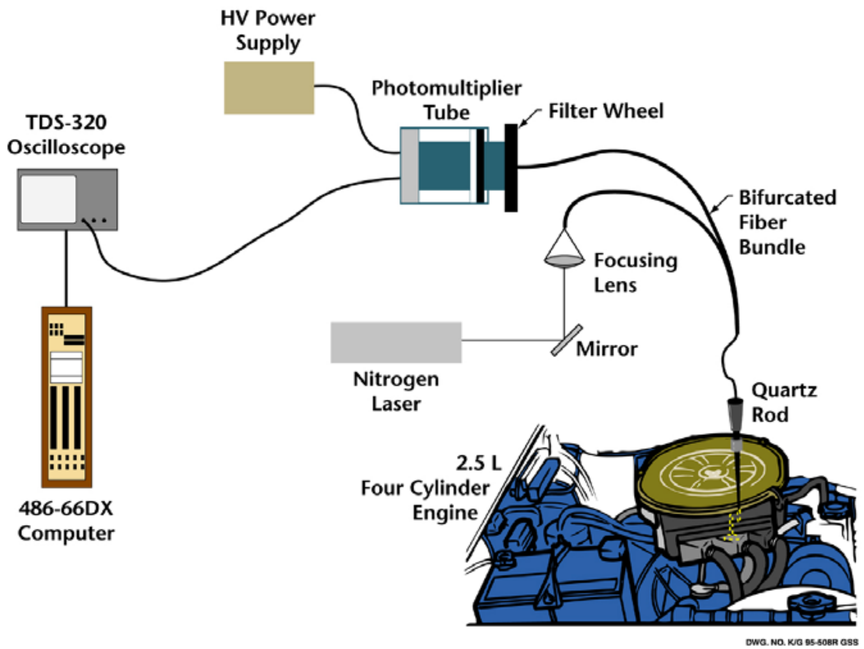


Set-up for piston measurement

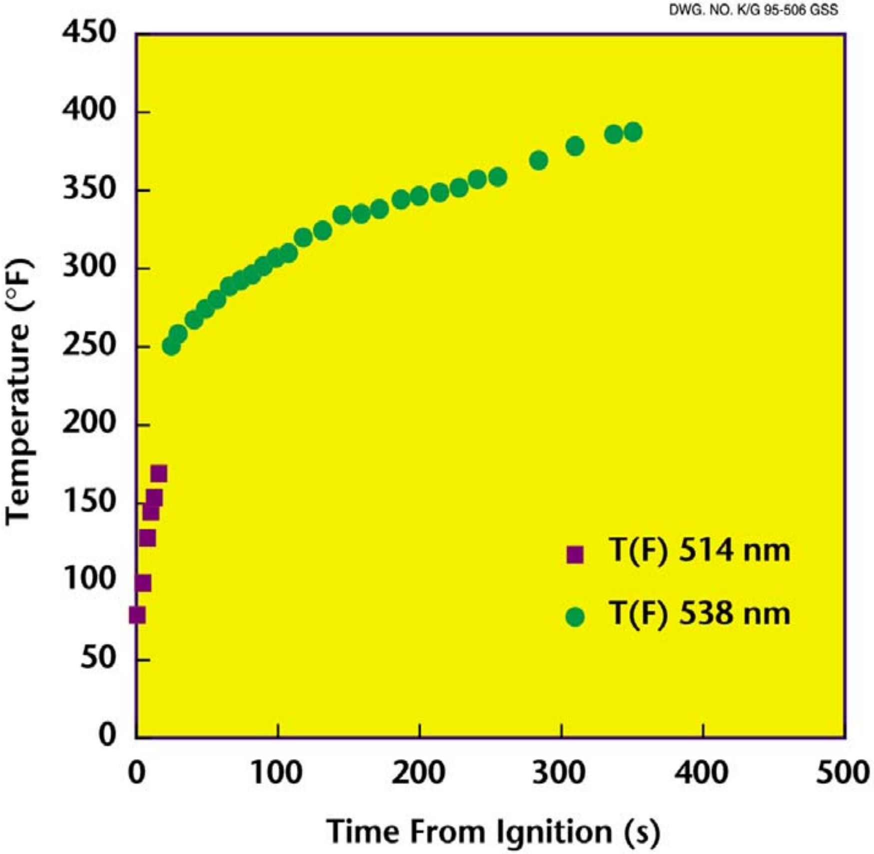


Fluorescing piston

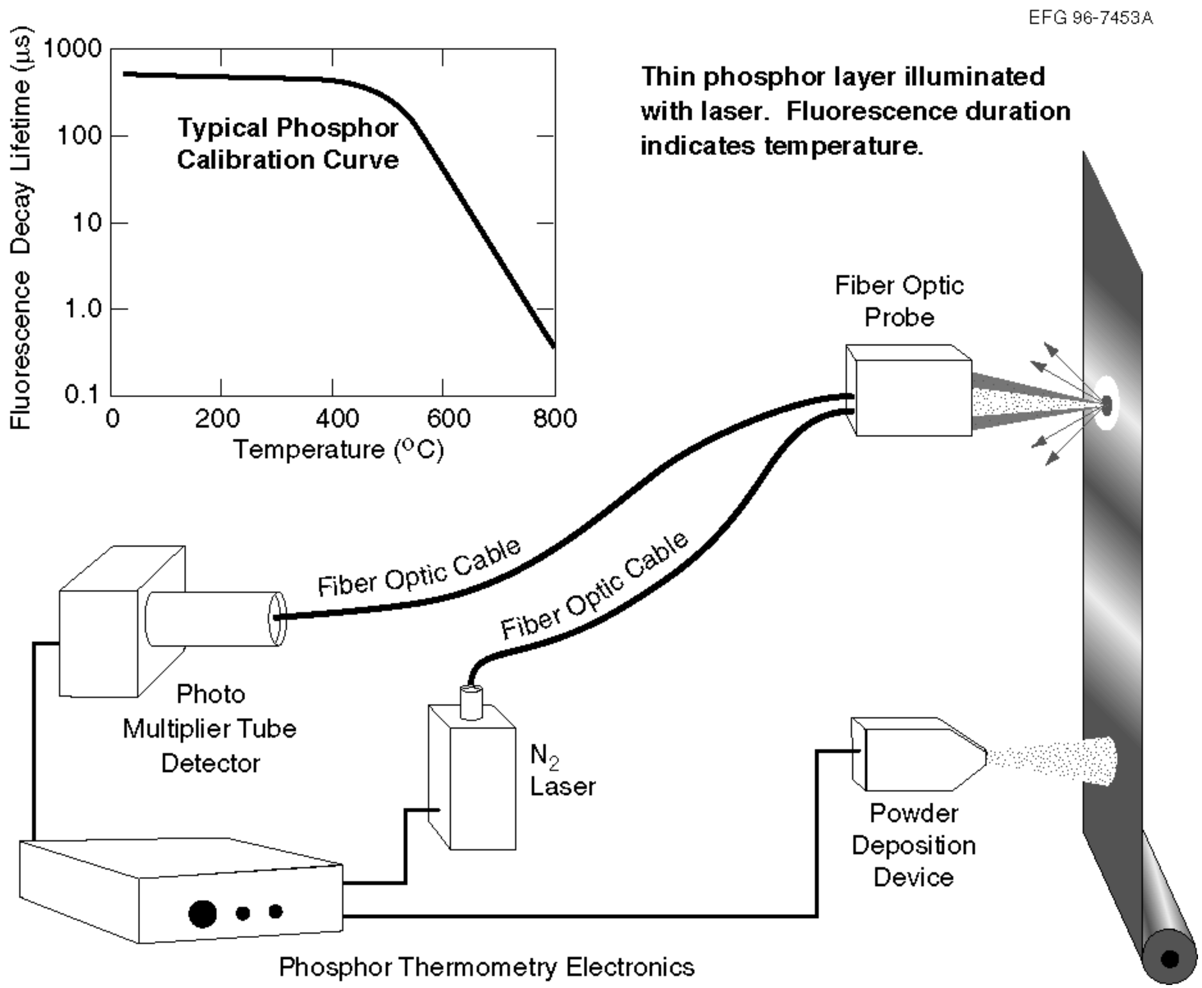
Intake valve setup



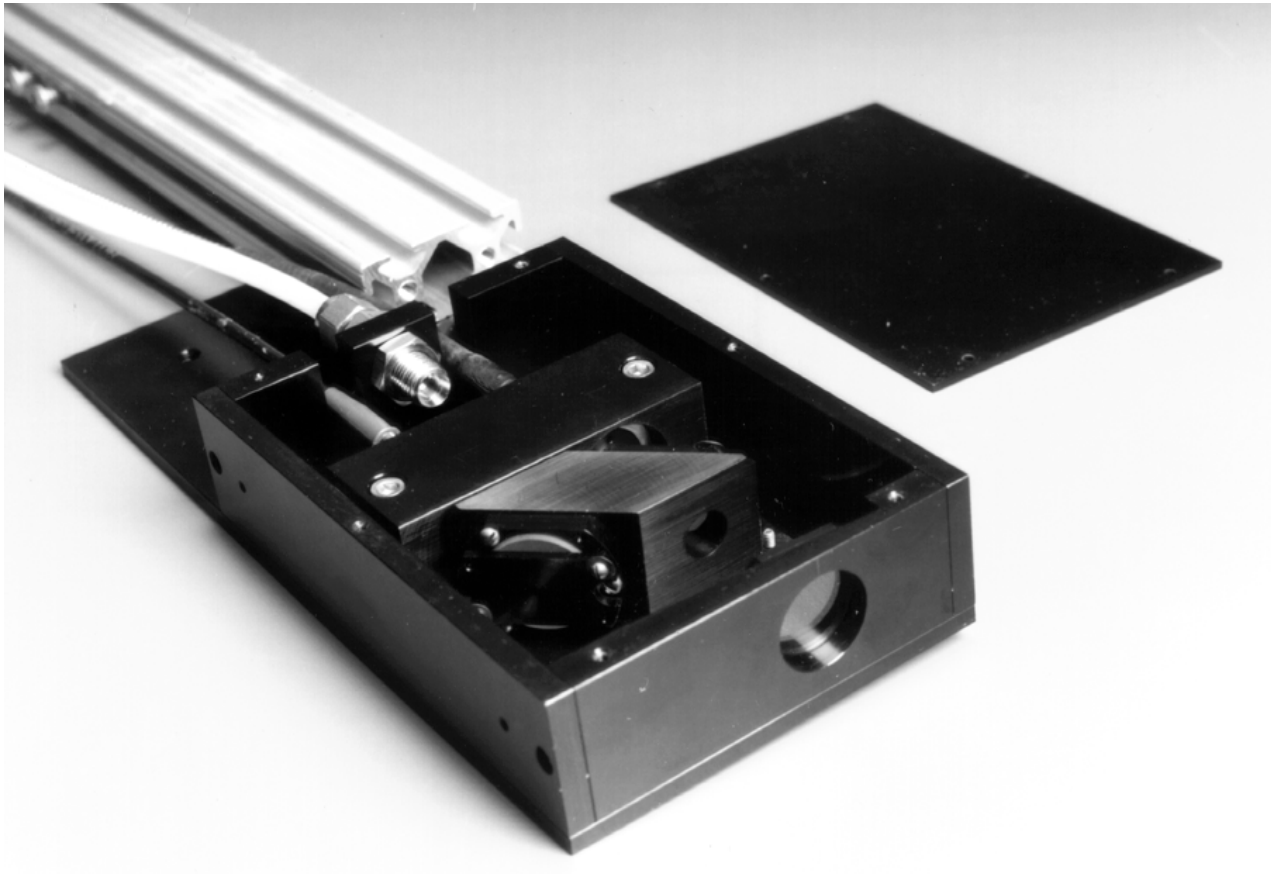
Intake valve results



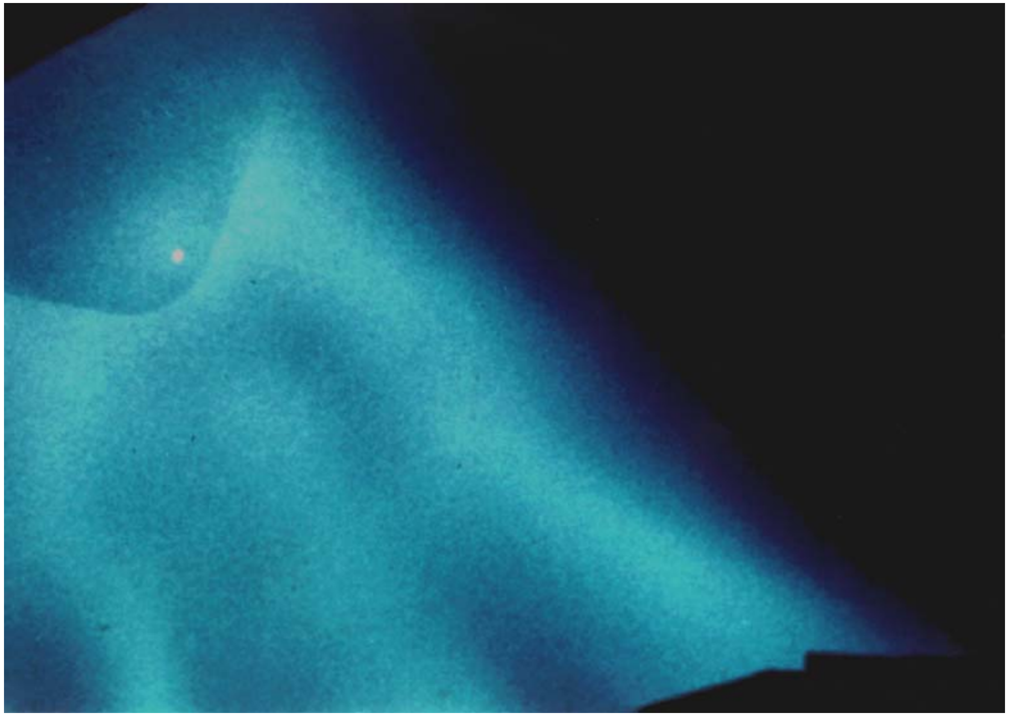
Galvanneal steel temperature



Optics for galvanneal steel

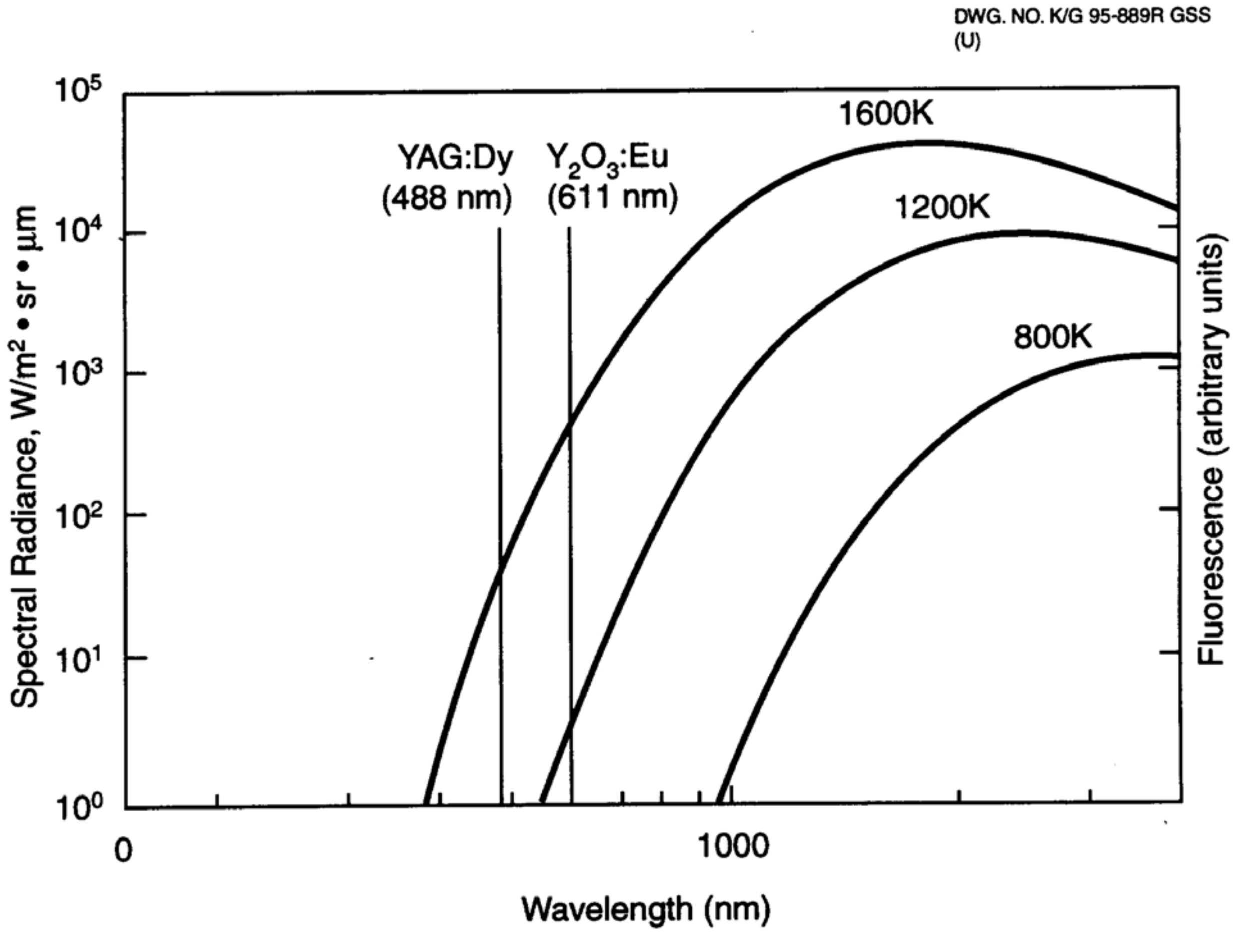


Phosphor emission in afterburner flame

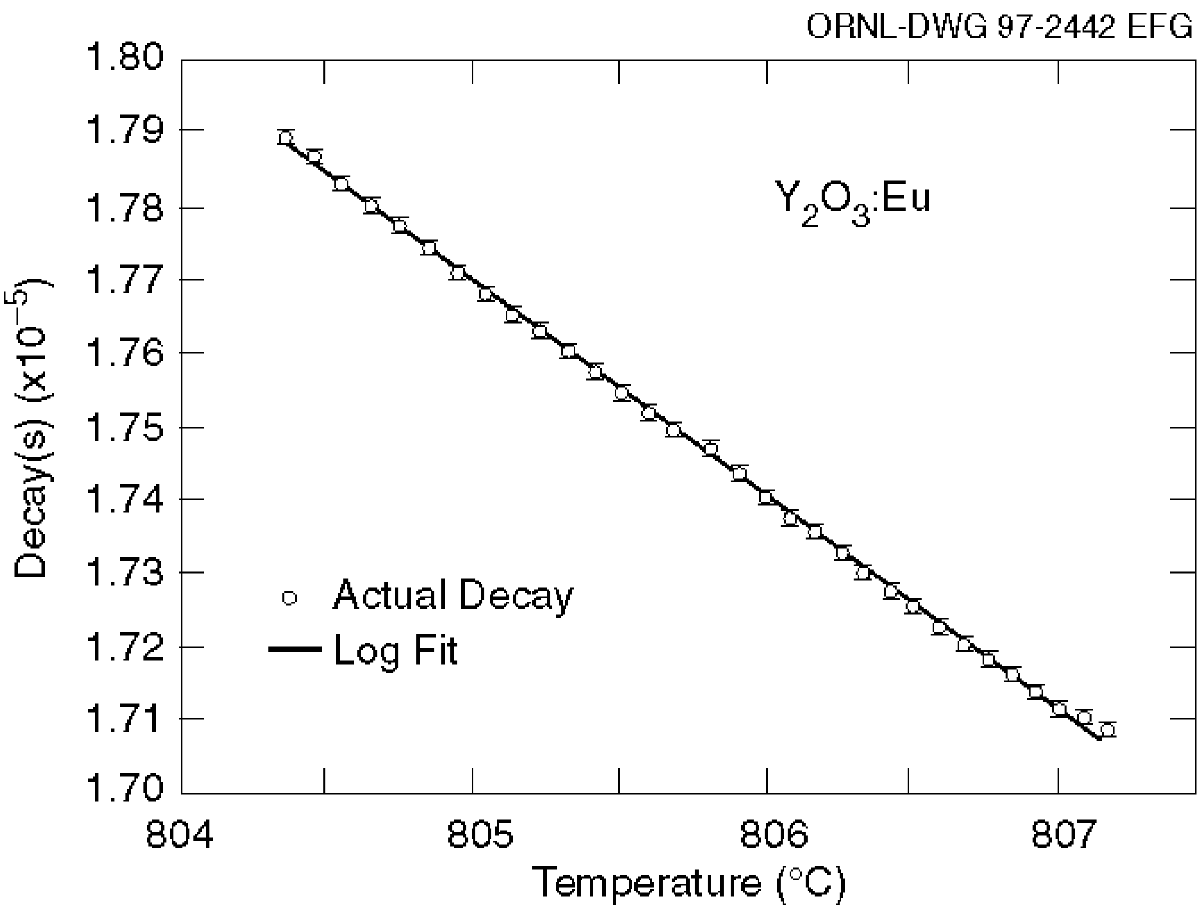


- **Afterburner flame impinging on a variable-area extractor. The white spot is phosphor luminescence.**

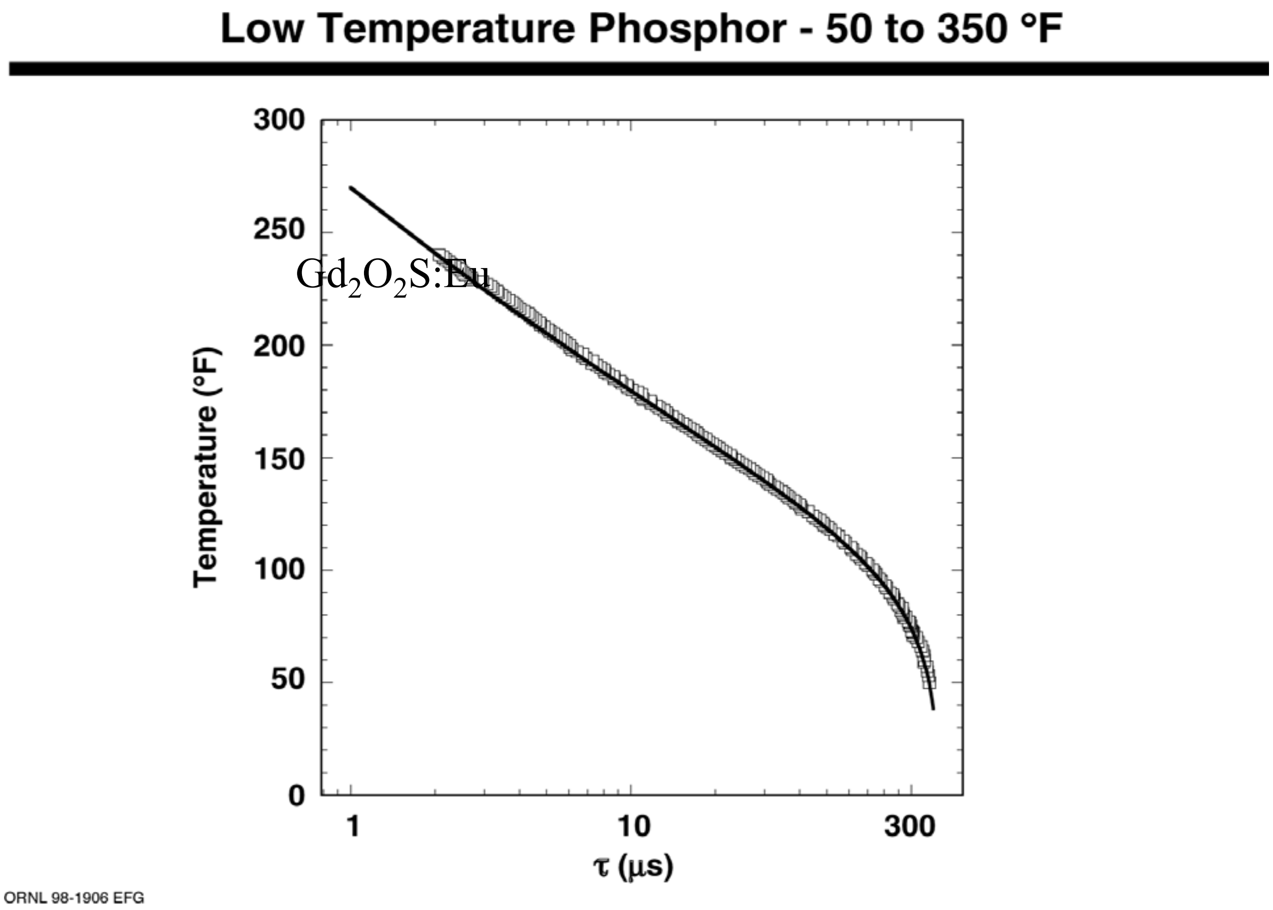
Blackbody vs fluorescence emission



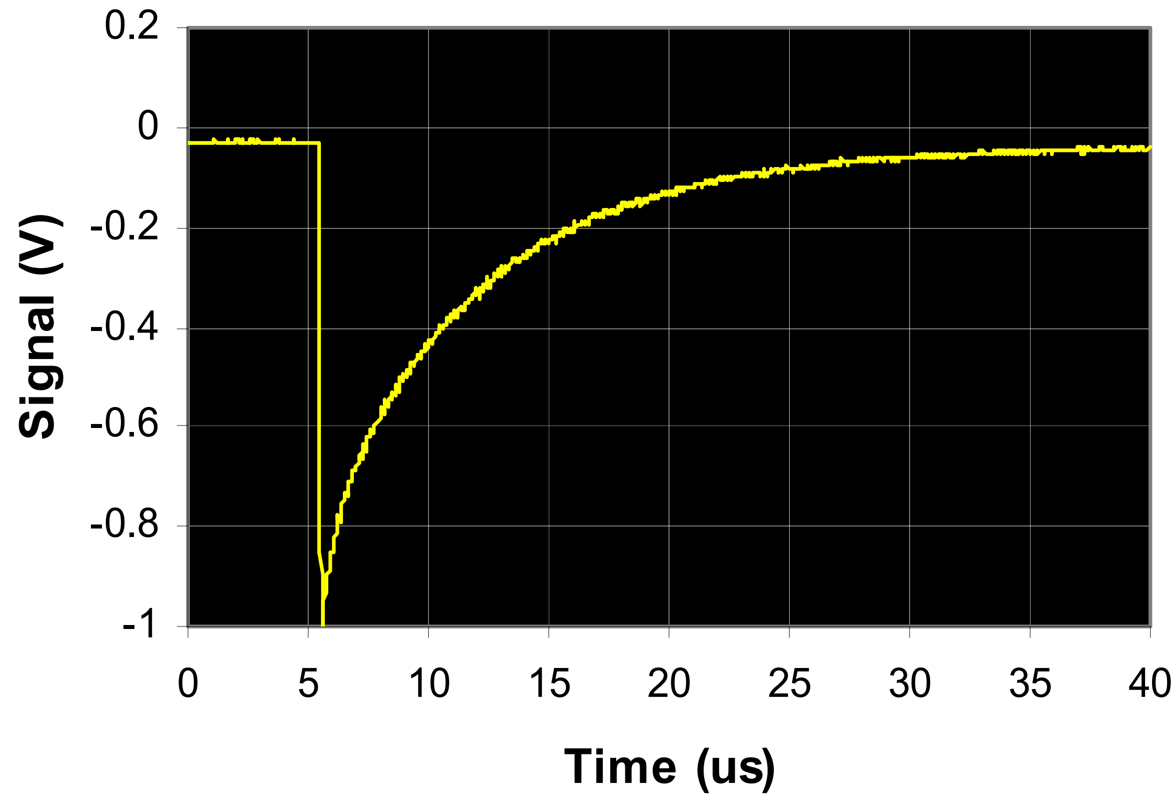
Precision limits are <10 mK for some phosphors and conditions



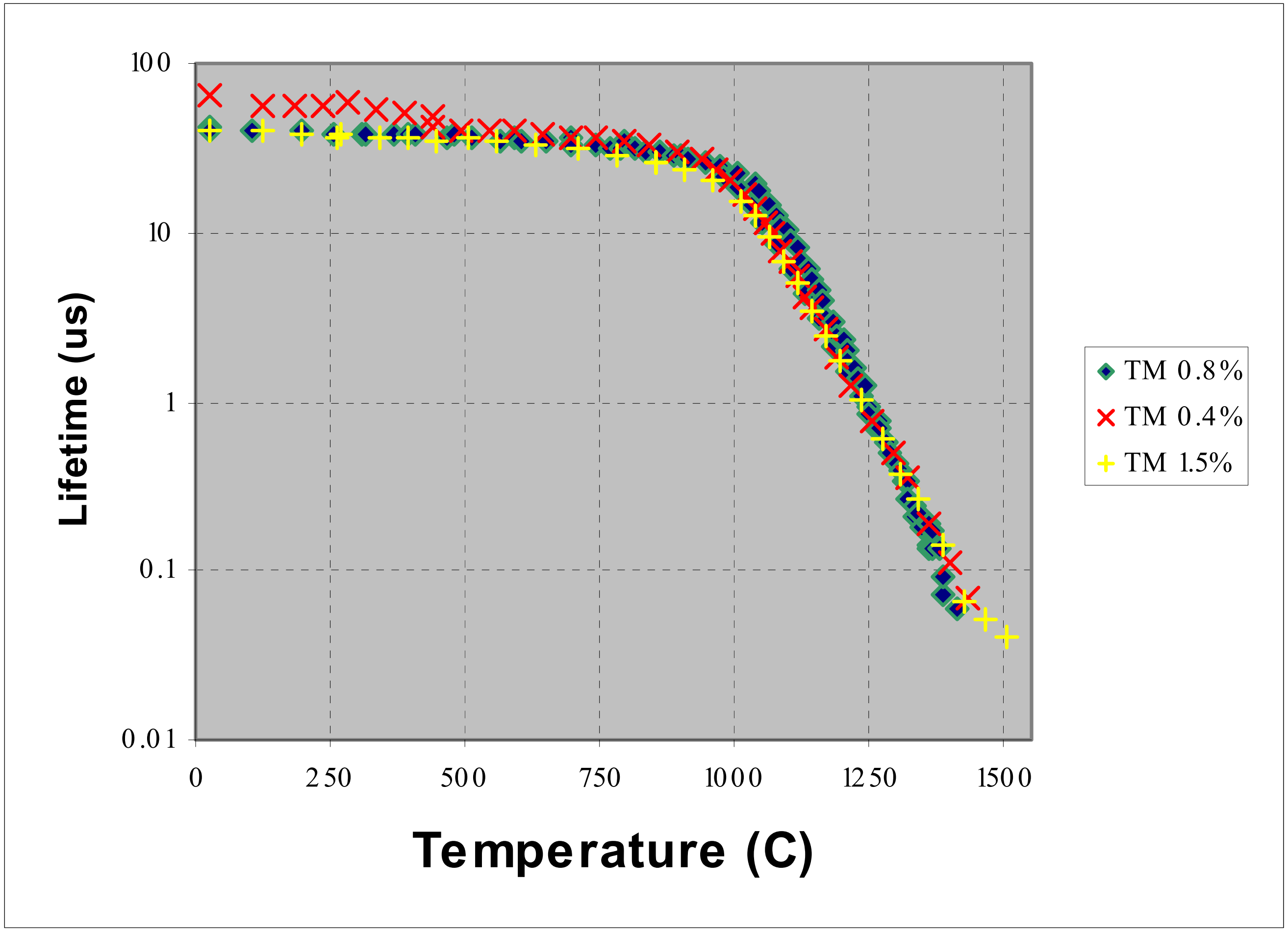
Low-temperature response



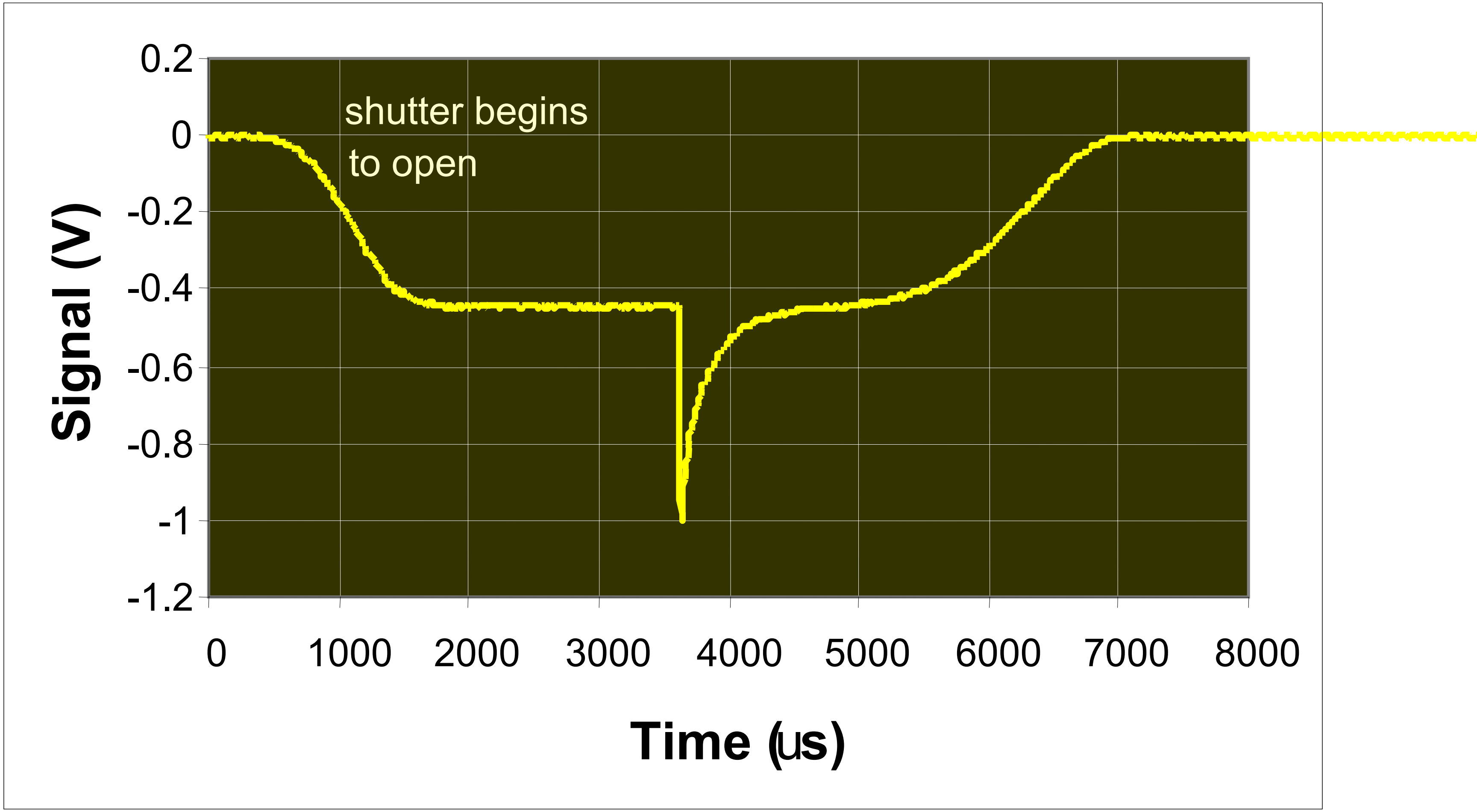
Averaged signal data of 460-nm emission from YAG:Tm at 1092 C



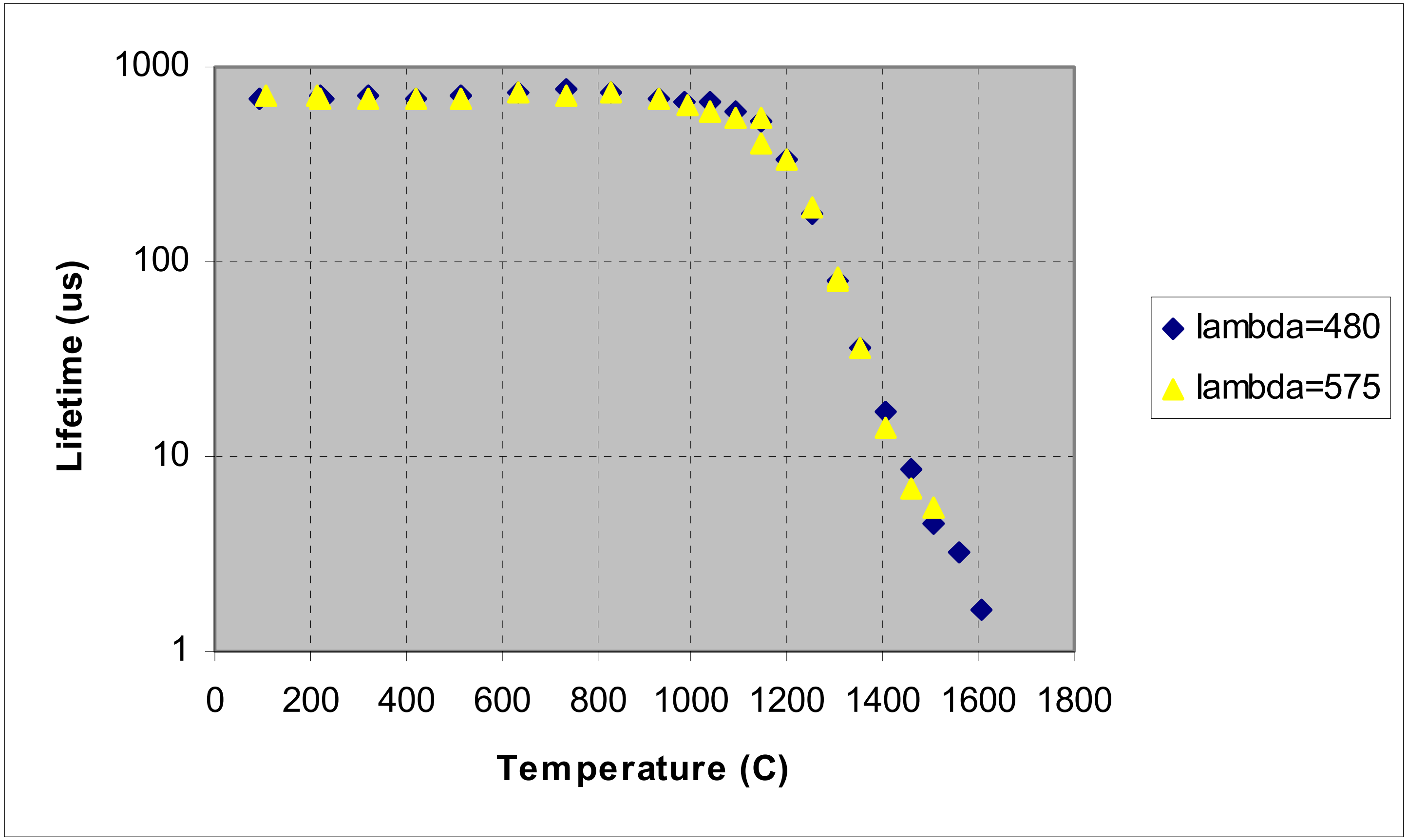
YAG:Tm temperature response



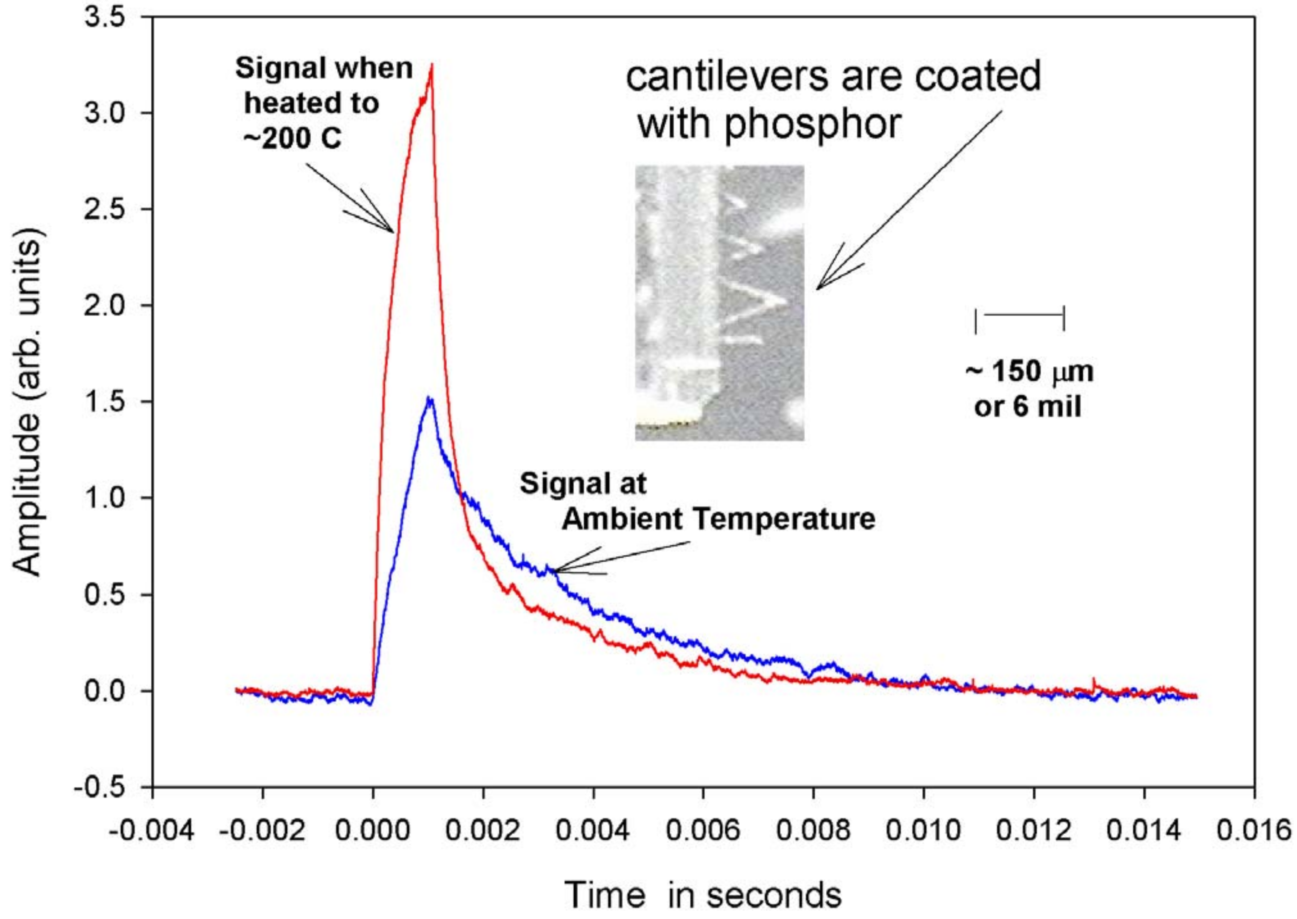
YAG:Dy 453-nm emission on blackbody background at 1306 C



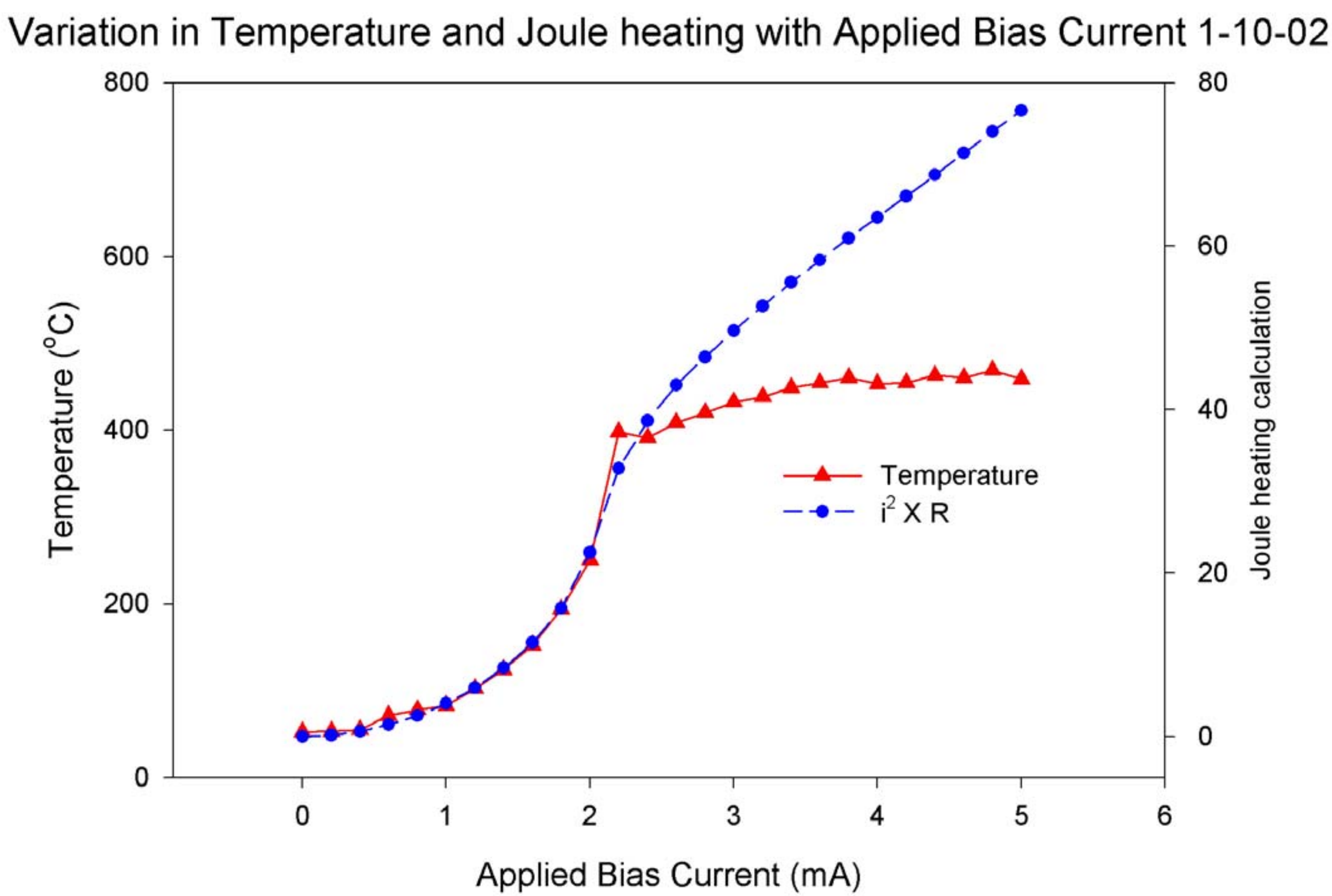
YAG:Dy temperature response



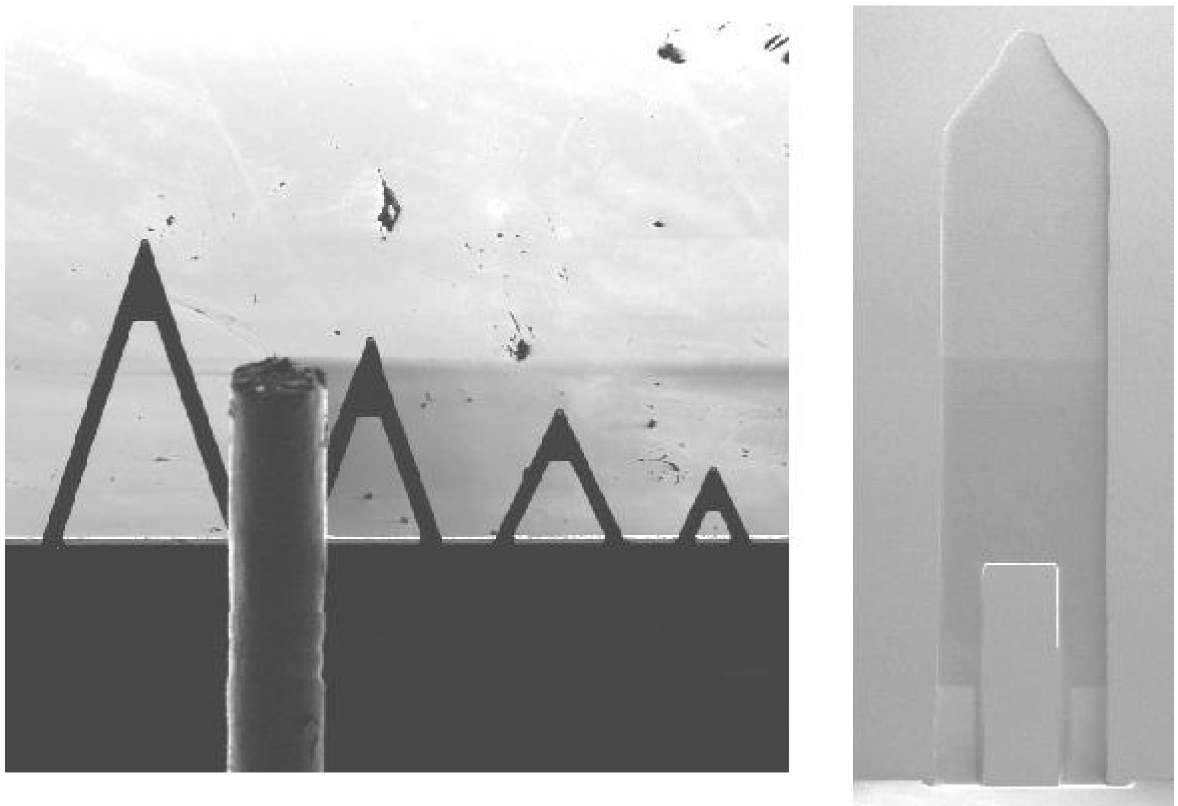
Fluorescent lifetimes change when cantilever is heated



Measured energy compared with measured temperature in a micro-cantilever



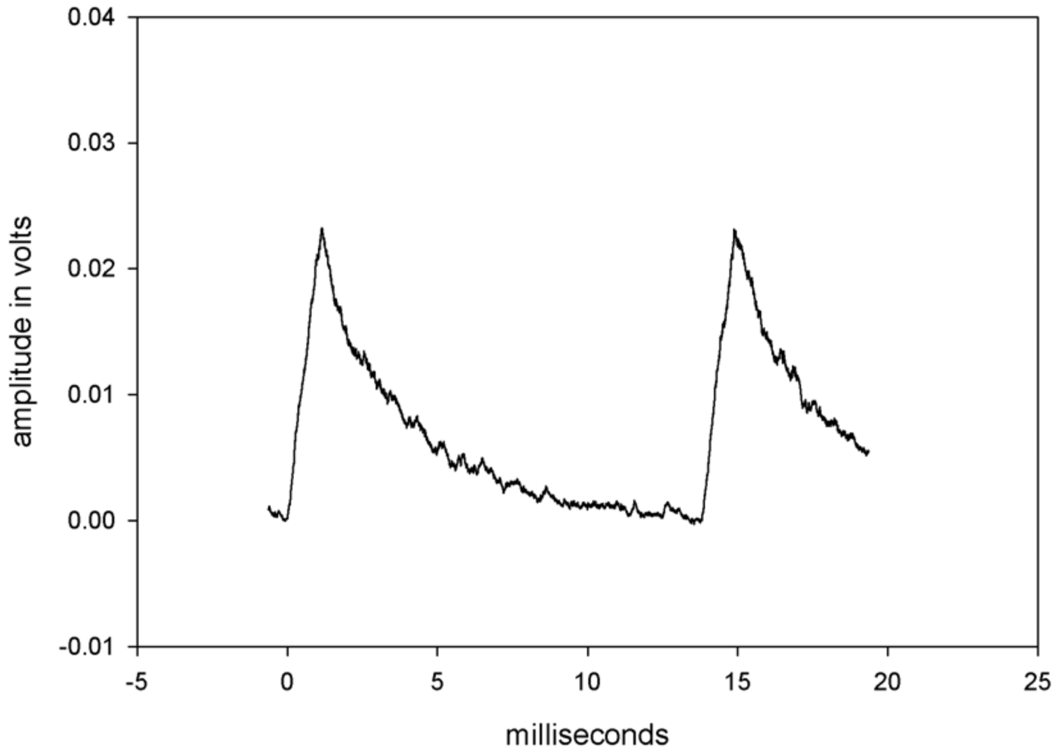
Micro-cantilevers



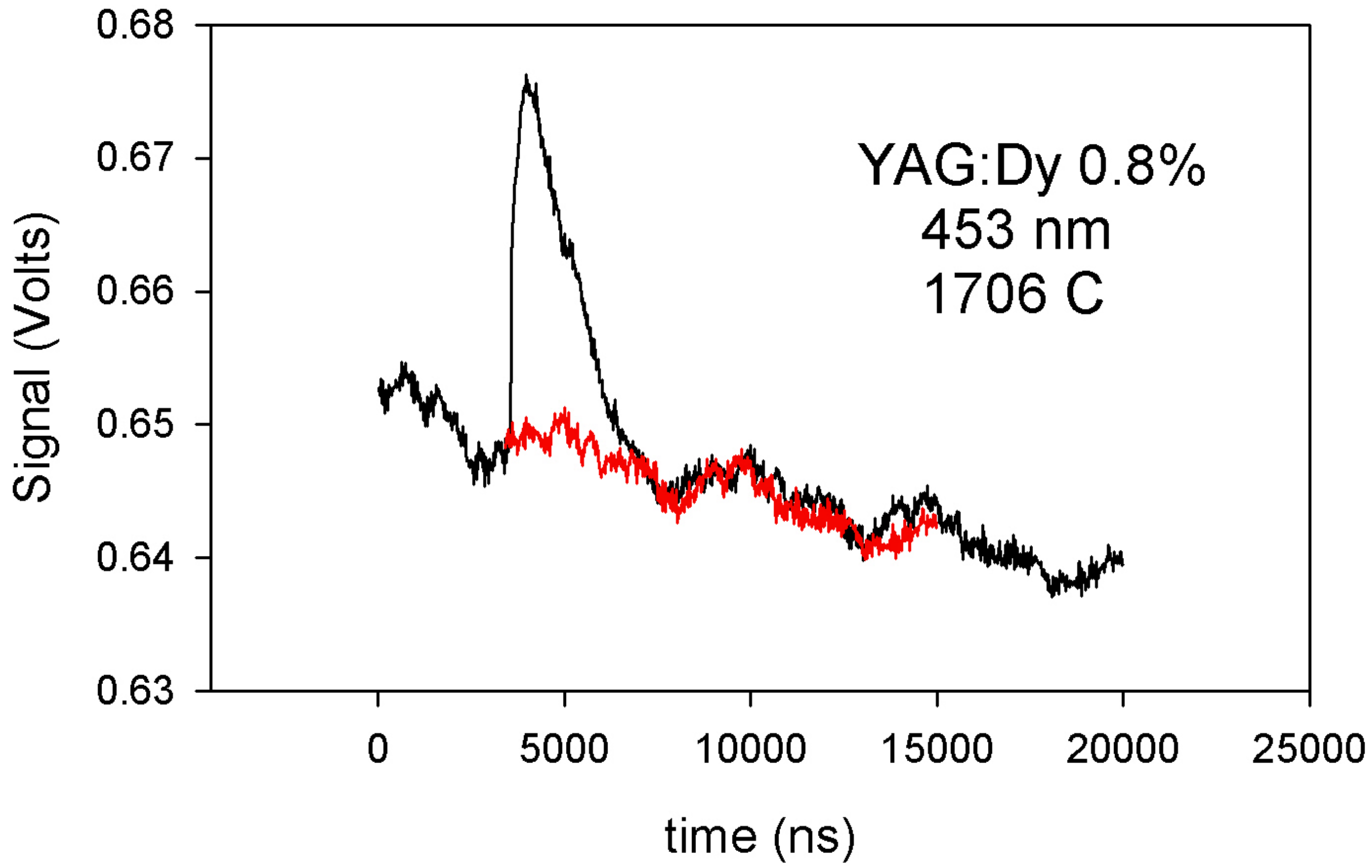
(a) (b)

LED-induced fluorescence from a micro-cantilever

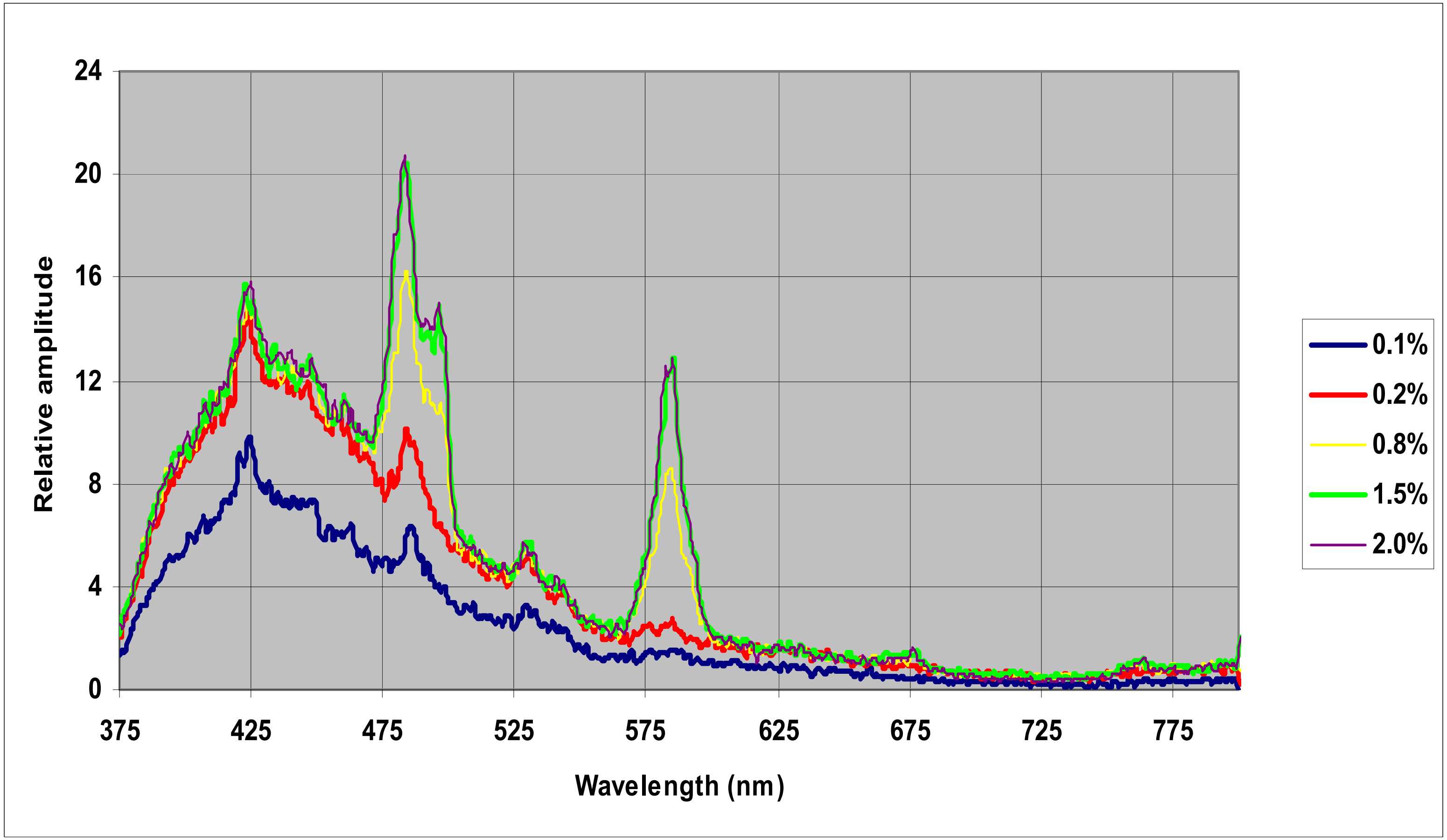
fluorescence from microcantilever coated with phosphor
(excited with ~2 ms duration square wave pulse from blue LED)



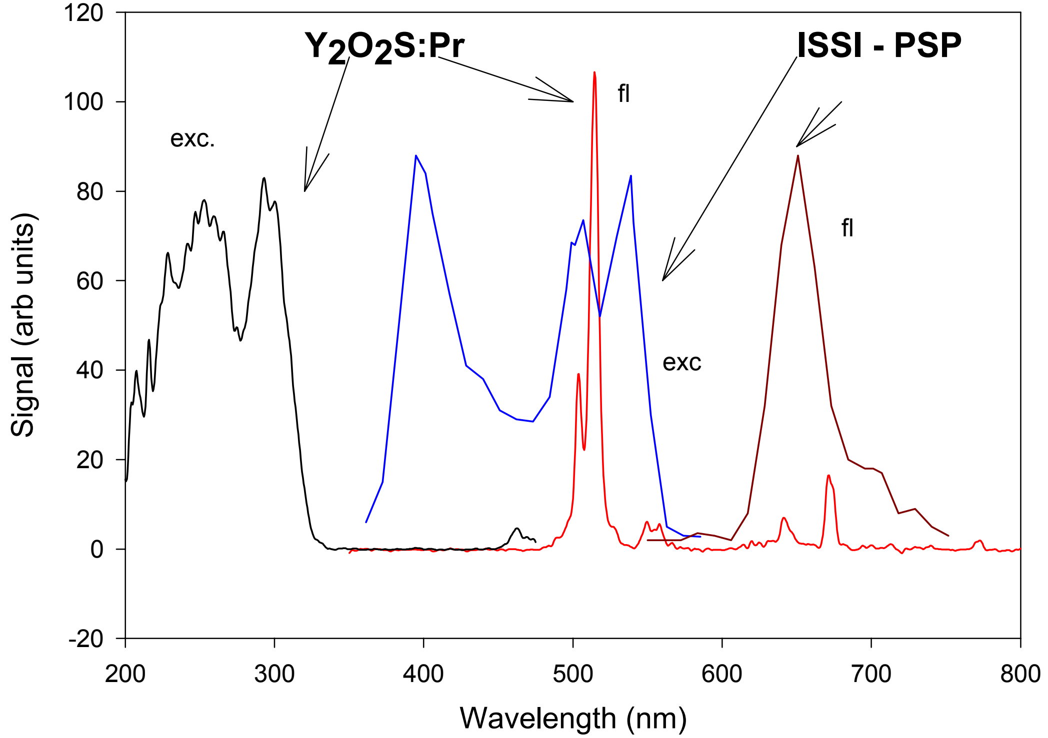
Signal & background at 1706 C



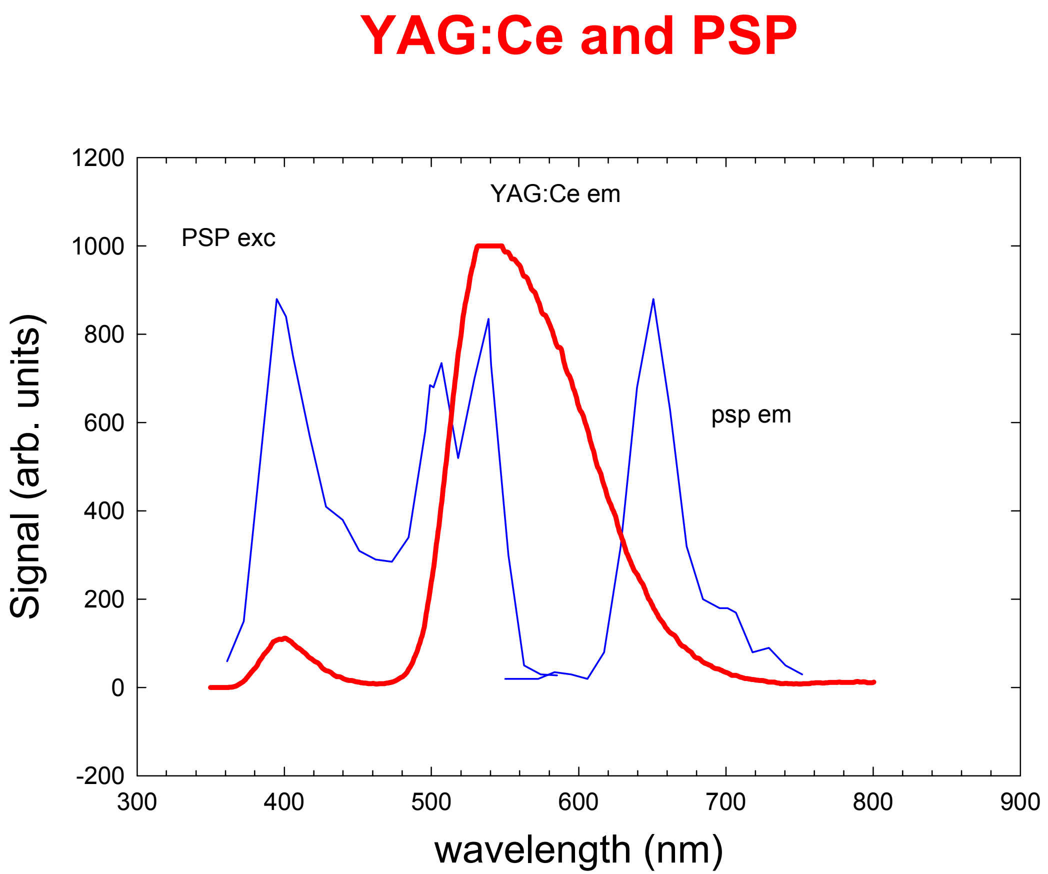
YAG:Dy emission strengths vary with dopant concentration



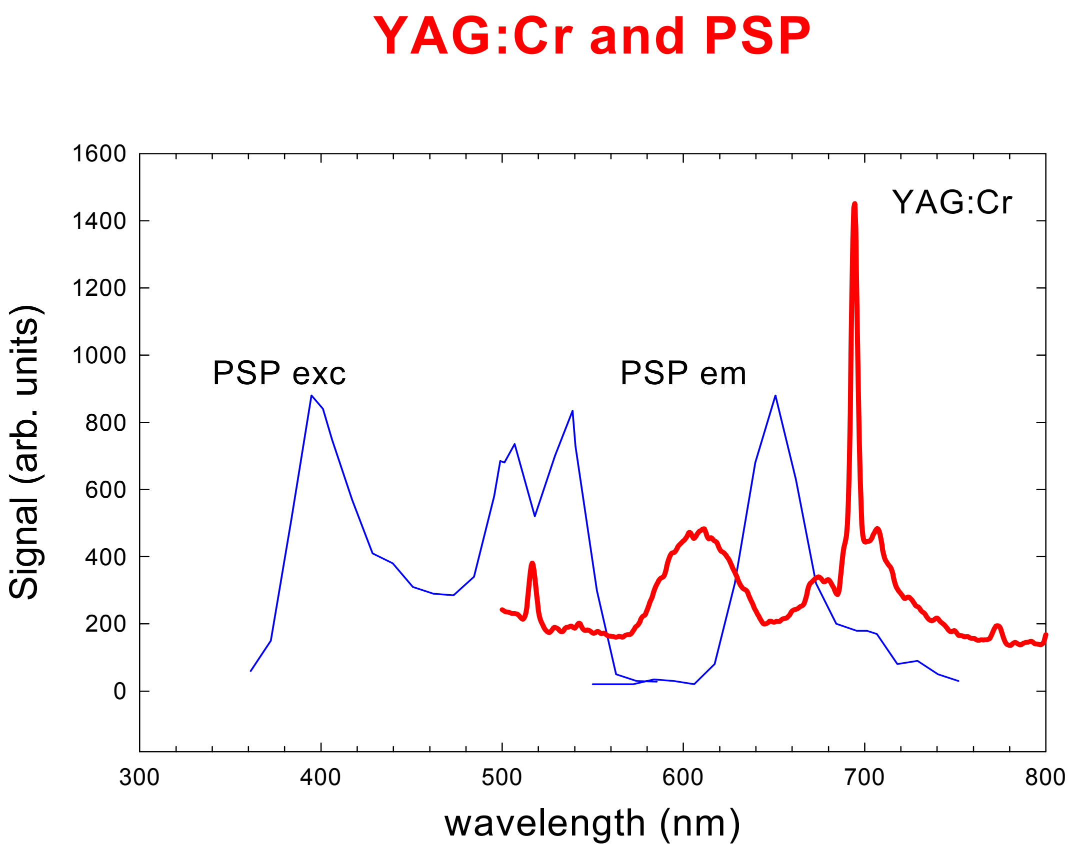
Emission bands of Y_2O_2S:Pr and pressure sensitive paint (PSP)



Emission bands: YAG:Ce and PSP

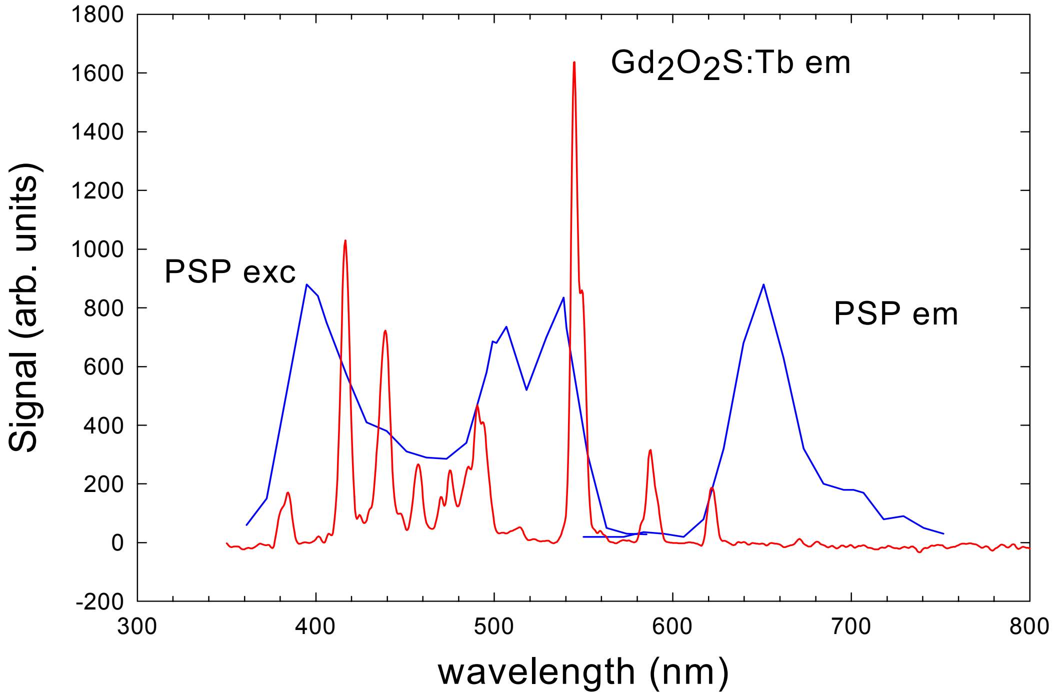


Emission bands: YAG:Cr and PSP



Emission bands: Gd_2O_2S:Tb

Gd_2O_2S:Tb (low Tb concentration) and PSP



Bibliography of phosphor chemistry and physics

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