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# Phosphor Thermometry with Gallium-substituted YAG:Ce

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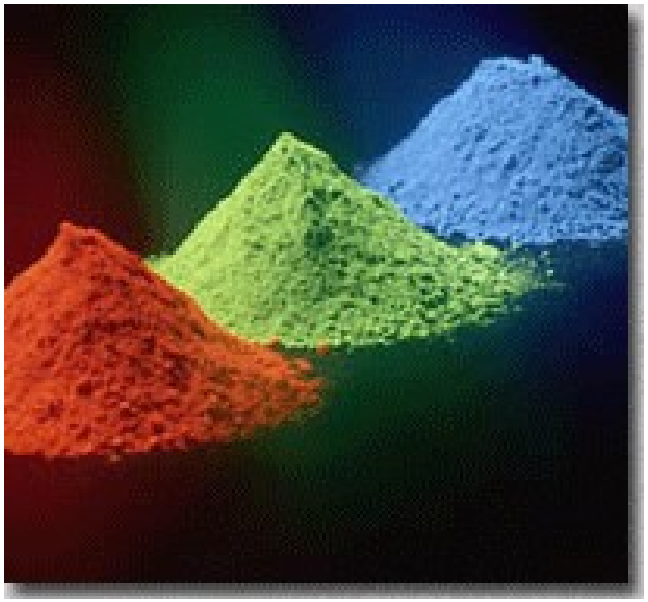
# Rachael Hansel

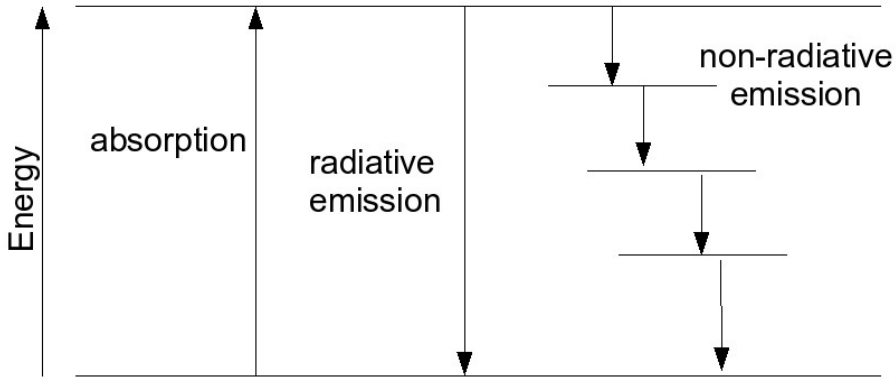
- Vanderbilt University, Nashville Tennessee
- 2nd year Graduate Student
- Interdisciplinary Materials Science Program
- NSF IGERT Fellow
- Thesis Topics:
  - Materials Properties of Thermographic Phosphors
  - Modeling of electronic transitions in phosphors

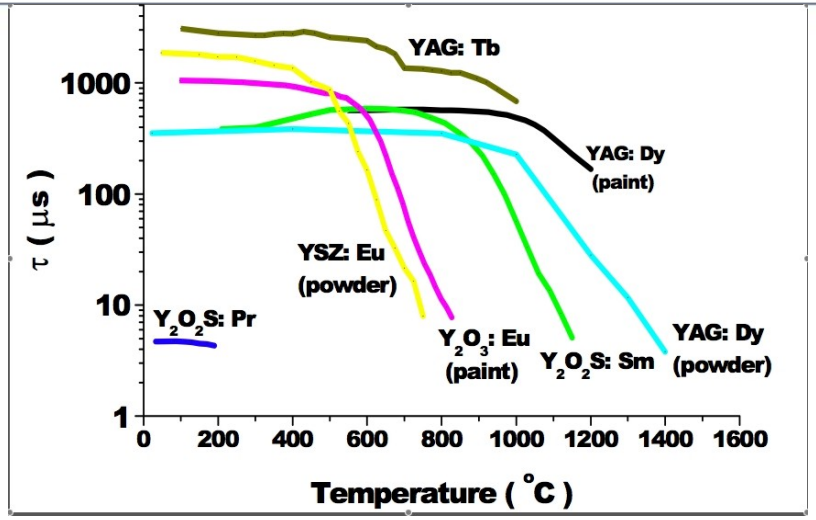
# Phosphors



- Emits photons under stimulation of an external energy source (voltage source, photons)
- Crystalline matrix doped with rare-earth of transition metal ion
- Rare-earth dopant introduces new energy state into the band gap of the host lattice
- Solid-state lighting, LEDs, displays, **Thermographic Phosphors**

# Thermographic Phosphors




Allison et al. Rev. Sci. Instrum. 68(7) 1997

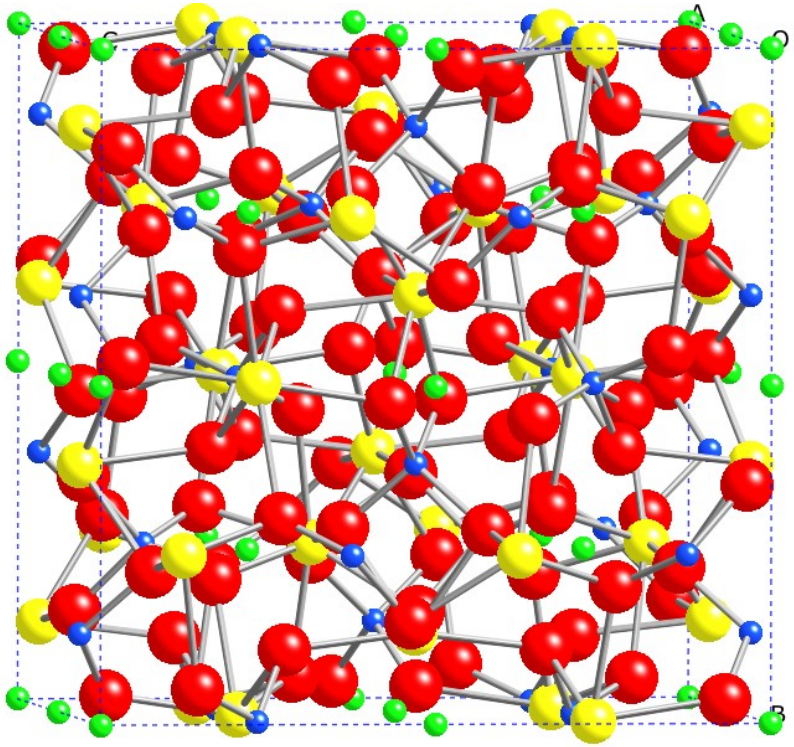
- Special class of phosphors used as non-contact temperature sensors
- Fluorescent lifetime is temperature dependent
- Radiative and non-radiative transitions

$$W_{rad} \quad W_{nr}^{\ 1}$$

- Turbine blades, pressure-sensitive paints, biological systems

# $Y_3Al_5O_{12}$:Ce, YAG:Ce

- Yellow-green emission
- Nanosecond decay lifetime
- $T_{q,\ bulk\ YAG:Ce}$ ~150○C
- $T_{q,\ nanoYAG:Ce}$ ~7○C
- Gallium-substitution for Al atoms
- Blue-shifts emission spectra
- $T_{q,\ nano\ Ga\text{-}substituted\ YAG:Ce}$ =??



# TGP Evaluation Criteria

- $\tau$=lifetime of electronic transition
- $\lambda_{exc}$ = excitation wavelength(s)
- $\lambda_{em}$ = emission wavelength(s)
- $T_q$= temperature at which fluorescence begins to decrease due to thermal effects

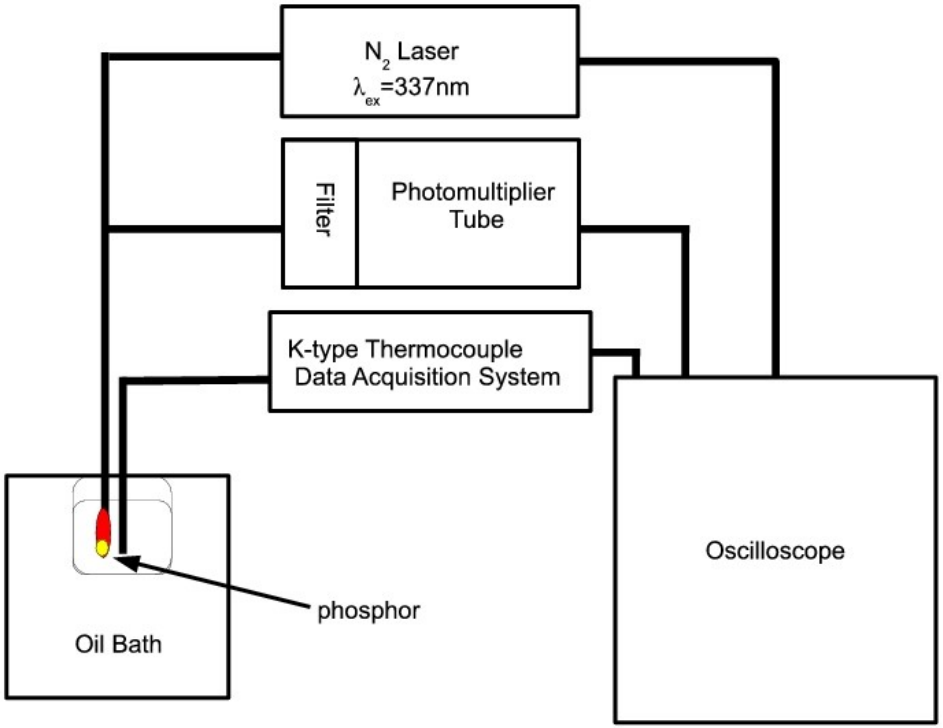
Factors which influence TGP criteria

- Rare-earth dopant
- Host Lattice
- Crystal Size (bulk or nano)
- Fabrication Method

# Changing $T_q$

- 4 samples of nanocrystalline YAG:Ce were made via a combustion reaction
- Two of the samples had $Ga^{3+}$ atom substituted for $Al^{3+}$ atoms in the host lattice
- particle size
  - Ga-substituted samples ~27nm
  - no Ga-substituted samples ~32nm
- Lifetime measurements were determined as a function of temperature used laser-induced fluorescence
- $T_q$ can be lowered by changing the host lattice and particle size

# Temperature-Dependent Fluorescent Experiement

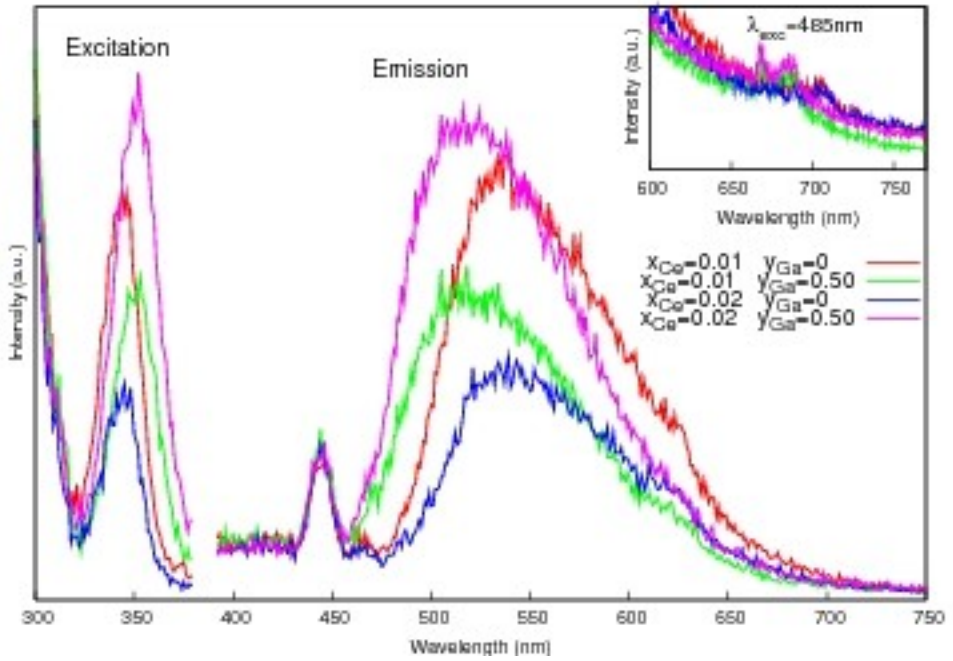



- $N_2$ excitation source
- $\lambda_{exc}$ =337nm
- 540 nm emission filter

# Photoluminescence

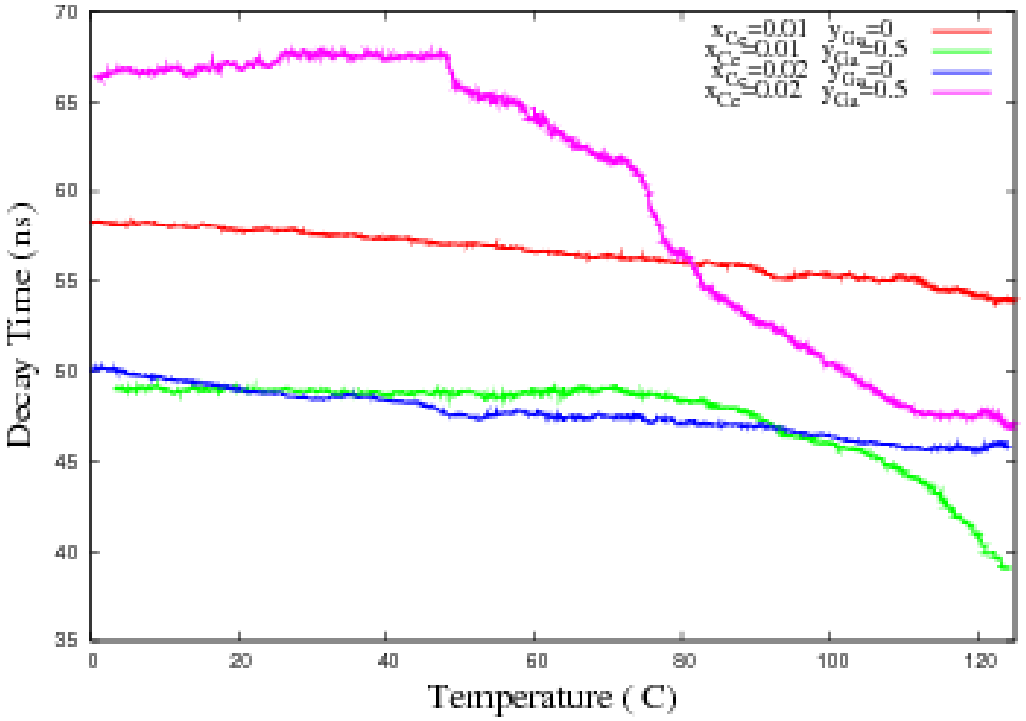
- Intense, broad-band emission, yellow-green emission
- Ga blue shifts emission
- distortion in host lattice

| X (%Ce) | Y (%Ga) | λexc (nm) | λem (nm) |
|---|---|---|---|
| 0.01 | 0 | 343 | 537 |
| 0.01 | 0.5 | 351 | 514 |
| 0.02 | 0 | 343 | 539 |
| 0.02 | 0.5 | 351 | 517 |



# Results

- Ga-substitution:
  - $Ga^{3+}$ increases covalency between Ce-O bond
  - non-emitting electronic states are lower in energy
  - non-emitting states become energetically favorable at lower temperatures
- Size effects:
  - Ga-substituted samples are smaller
  - surface defects introduce energy traps
  - trapped energy released thermally (non-radiatively)



# Conclusions and Future Work

- Ga-substituted YAG:Ce is a good TGP with short decay time for low-temperature applications
- Ga-substitution in YAG lattice lowers quenching temperature because of the decrease in particle size and the change in the host lattice

Future Work:

- Development of high-temperature phosphors, such as YSZ:Dy, for use in turbine engines
- Optimal fabrication method
- DFT modeling of doped/substituted YAG lattice to determine electronic structure

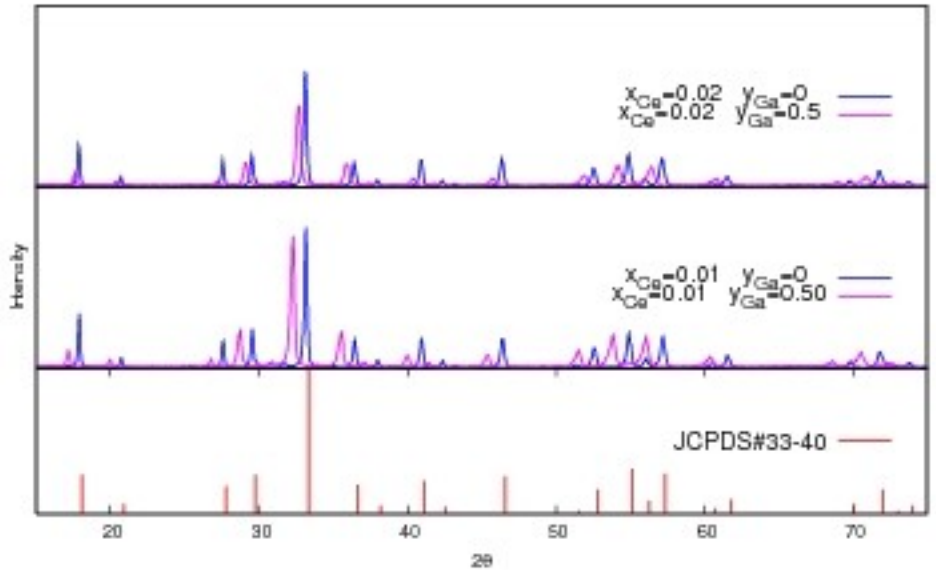
# Supplementary Information

- More Data!!!

# X-ray Diffration (XRD)

- Diffracted X-rays reveal information about crystallographic sturcture
- Ga increases lattice constant and reduces particle size

| X (%Ce) | Y (%Ga) | a (nm) | ACS (nm) |
|---|---|---|---|
| 0.01 | 0 | 1.21 | 37.1 |
| 0.01 | 0.5 | 1.22 | 27.1 |
| 0.02 | 0 | 1.21 | 32.4 |
| 0.02 | 0.5 | 1.23 | 27.3 |



# Transmission Electron Microscopy (TEM)