Phosphor Thermometry with Gallium-substituted YAG:Ce

Rachael Hansel\textsuperscript{1}, Steve Allison\textsuperscript{2}, Greg Walker\textsuperscript{1,3}

\textsuperscript{1} Interdisciplinary Graduate Program in Materials Science, Vanderbilt University, Nashville, TN

\textsuperscript{2} Oak Ridge National Laboratory, Oak Ridge, TN

\textsuperscript{3} Department of Mechanical Engineering, Vanderbilt University, Nashville, TN
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

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

\[ W_{rad} - W_{nr} \]

• Turbine blades, pressure-sensitive paints, biological systems

$Y_3\text{Al}_5\text{O}_{12}:\text{Ce}$, $\text{YAG:Ce}$

- Yellow-green emission
- Nanosecond decay lifetime
  - $T_q$, bulk YAG:Ce $\sim 150^\circ\text{C}$
  - $T_q$, nano YAG:Ce $\sim 7^\circ\text{C}$
- Gallium-substitution for Al atoms
- Blue-shifts emission spectra
- $T_q$, nano Ga-substituted YAG:Ce $= ??$
TGP Evaluation Criteria

• $\tau =$ lifetime of electronic transition
• $\lambda_{\text{exc}} =$ excitation wavelength(s)
• $\lambda_{\text{em}} =$ 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 $\text{Ga}^{3+}$ atom substituted for $\text{Al}^{3+}$ atoms in the host lattice
- particle size
  - Ga-substituted samples $\sim 27\text{nm}$
  - no Ga-substituted samples $\sim 32\text{nm}$
- 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 Experiment

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

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

<table>
<thead>
<tr>
<th>X (%Ce)</th>
<th>Y (%Ga)</th>
<th>( \lambda_{\text{exc}} ) (nm)</th>
<th>( \lambda_{\text{em}} ) (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.01</td>
<td>0</td>
<td>343</td>
<td>537</td>
</tr>
<tr>
<td>0.01</td>
<td>0.5</td>
<td>351</td>
<td>514</td>
</tr>
<tr>
<td>0.02</td>
<td>0</td>
<td>343</td>
<td>539</td>
</tr>
<tr>
<td>0.02</td>
<td>0.5</td>
<td>351</td>
<td>517</td>
</tr>
</tbody>
</table>
Results

- **Ga-substitution:**
  - $\text{Ga}^{3+}$ 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
More Data!!!
X-ray Diffraction (XRD)

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

<table>
<thead>
<tr>
<th>X (%Ce)</th>
<th>Y (%Ga)</th>
<th>a (nm)</th>
<th>ACS (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.01</td>
<td>0</td>
<td>1.21</td>
<td>37.1</td>
</tr>
<tr>
<td>0.01</td>
<td>0.5</td>
<td>1.22</td>
<td>27.1</td>
</tr>
<tr>
<td>0.02</td>
<td>0</td>
<td>1.21</td>
<td>32.4</td>
</tr>
<tr>
<td>0.02</td>
<td>0.5</td>
<td>1.23</td>
<td>27.3</td>
</tr>
</tbody>
</table>
Transmission Electron Microscopy (TEM)