VUV Phosphors for Plasma Display Panels and Excimer Discharge Lamps

Thomas Jüstel
University of Applied Sciences Münster

Materials Valley Workshop
January 20th, 2011
Plasma Display Panels 1929
Outlines

1. Introduction
2. Xe and Xe/Ne Discharges
3. Inorganic luminescent materials
4. Phosphors for plasma display panels
5. Phosphors for Xe$_2^*$ discharge lamps
6. Application areas
7. Conclusions
1. Introduction
- Light Generation in PDPs and Discharge Lamps -

PDP pixel

Lamp burner

Xe/Ne excimer discharge

Xe$_2^*$ excimer discharge

Prof. Dr. T. Jüstel, University of Applied Sciences Münster, Germany
2. Xe and Xe/Ne Discharges

Radiation generation (Xe)

\[
\text{Xe} + e^- \rightarrow \text{Xe}^{(3P_1)} + e^- \\
\rightarrow \text{Xe}^{(3P_2)} + e^- \\
\rightarrow \text{Xe}^{**}
\]

\[
\text{Xe}^{**} \rightarrow \text{Xe}^{(3P_1)} + h\nu(828 \text{ nm}) \\
\rightarrow \text{Xe}^{(3P_2)} + h\nu(823 \text{ nm})
\]

\[
\text{Xe}^{(3P_1)} \rightarrow \text{Xe} + h\nu(147 \text{ nm})
\]

\[
\text{Xe}^{(3P_1)} + \text{Xe} + M \rightarrow \text{Xe}_2^* + M
\]

\[
\text{Xe}_2^* \rightarrow 2 \text{Xe} + h\nu(150 \text{ nm and } 172 \text{ nm})
\]

Application of 50–90% Ne reduces discharge ignition voltage \(\rightarrow\) plasma displays
2. Xe and Xe/Ne Discharges

Radiation generation (Ne)

\[
\text{Ne} + \text{e}^- \rightarrow \text{Ne}^* + \text{e}^- \\
\text{Ne}^* \rightarrow \text{Ne} + h\nu(74 \text{ nm} + \text{vis.}) \\
\text{Ne}^* + \text{Ar} \rightarrow \text{Ne} + \text{Ar}^+ + \text{e}^- \\
\text{Ne}^* + \text{Xe} \rightarrow \text{Ne} + \text{Xe}^+ + \text{e}^- \\
\text{(Penning Ionisation)}
\]

monochrome plasma displays
2. Xe and Xe/Ne Discharges

Features
- No Hg (EU legislation issue?)
- Noble gas discharge ⇒ “chemically inert”
- Instant light
- Arbitrary design ⇒ GLS-look-a-like, tubular, flat, co-axial, etc.
- T-independent light output
- Long lifetime even for fast switching cycle scheme
- Emission mainly in the Vacuum Ultraviolet (VUV)
2. Xe and Xe/Ne Discharges

Features

![Emission intensity vs Wavelength graph]

**Xe**

- Hg emission: $Q_{D_{Hg}} = 0.47$
- **Tb**$^{3+}$ Phosphor

**Xe**

- Xe emission: $Q_{D_{Xe}} = 0.32$

Burner / cell efficiency

$$\varepsilon = \varepsilon_{\text{discharge}} \times QD \times QE \times \eta_{\text{escape}}$$

- $QD(Hg) = 0.47$
- $QD(Xe_2^*) = 0.32$
- Hg discharge: $\varepsilon = 30\%$
- Xe$_2^*$ discharge: $\varepsilon = 20\%$

Problem areas of Xe/Ne excimer discharge driven light sources + displays

- Large quantum deficit (QD) $\Rightarrow$ reduces wall plug efficiency
- VUV radiation $\Rightarrow$ causes severe photodegradation
3. Inorganic Luminescent Materials

Requirements on VUV phosphors

- Very good crystallinity
- High purity (99.99% or better)
- Homogeneous distribution of activator and sensitisier ions

Absorption process related to
Optical centres (impurities)
- activators (A)
- sensitisers (S)
- defects (D)

Host lattice (band edge)

Energy transfer often occur prior to emission process!
3. Inorganic Luminescent Materials

Fundamental aspects: Simplified energy level schemes of selected RE ions

Line emission from
- \( \text{Pr}^{3+} \)
- \( \text{Nd}^{3+} \)
- \( \text{Sm}^{3+} \)
- \( \text{Eu}^{3+} (\text{Eu}^{2+}) \)
- \( \text{Gd}^{3+} \)
- \( \text{Tb}^{3+} \)
- \( \text{Dy}^{3+} \)
- \( \text{Ho}^{3+} \)
- \( \text{Er}^{3+} \)
- \( \text{Tm}^{3+} \)
- \( \text{Yb}^{3+} \)

Band emission from
- \( \text{Ce}^{3+} \)
- \( \text{Pr}^{3+} \)
- \( \text{Nd}^{3+} \)
- \( \text{Eu}^{2+} \)
- \( \text{Yb}^{2+} \)
- \( \text{Tl}^+, \text{Pb}^{2+}, \text{Sb}^{3+}, \text{Bi}^{3+} \)
3. Inorganic Luminescent Materials

Fundamental aspects: Energy distance between the $4f^n$ and $4f^{n-1}5d^1$ configuration

Free ion: $\text{Eu}^{2+}$, $\text{Ce}^{3+}$, $\text{Pr}^{3+}$, $\text{Nd}^{3+}$

$4f^{n-1}5d^1$ level @ $34000 \text{ cm}^{-1}$, $50000 \text{ cm}^{-1}$, $62000 \text{ cm}^{-1}$, $70000 \text{ cm}^{-1}$

Only RE ions and some main group element ions are applicable in luminescent materials showing UV emission
4. Phosphors for Plasma Display Panels

**Quality Issues**

*Production compatibility*
- Temperature stability
- Suspension stability
- Sensitivity towards oxidation
- Solubility, surface potential

*Performance*
- Brightness
- Color point stability
- QE, particle morphology, saturation
- VUV Stability

*Image quality*
- Motion artefacts
- Color gamut
- Decay time
- Color point (stability)

*Environment*
- Energy efficiency
- Toxicity
- QE, particle morphology
- Chemical composition
4. Phosphors for Plasma Display Panels

- Efficient Red Emitting Phosphor -

$\text{Y}_2\text{O}_3: \text{Eu}^{3+}$

Low-pressure Hg discharges

$(\text{Y,Gd})\text{BO}_3: \text{Eu}^{3+}$

Xe excimer discharges

![Graphs showing emission spectra for different phosphors and excitation sources.](image)
4. Phosphors for Plasma Display Panels

Colour points and decay times

<table>
<thead>
<tr>
<th>Phosphor</th>
<th>x</th>
<th>y</th>
<th>τ [ms]</th>
</tr>
</thead>
<tbody>
<tr>
<td>BaMgAl&lt;sub&gt;10&lt;/sub&gt;O&lt;sub&gt;17&lt;/sub&gt;:Eu</td>
<td>0.148</td>
<td>0.068</td>
<td>&lt; 1</td>
</tr>
<tr>
<td>Y(V,P)O&lt;sub&gt;4&lt;/sub&gt;</td>
<td>0.161</td>
<td>0.133</td>
<td>&lt; 1</td>
</tr>
<tr>
<td>BaMgAl&lt;sub&gt;10&lt;/sub&gt;O&lt;sub&gt;17&lt;/sub&gt;:Mn</td>
<td>0.140</td>
<td>0.695</td>
<td>12</td>
</tr>
<tr>
<td>Zn&lt;sub&gt;2&lt;/sub&gt;SiO&lt;sub&gt;4&lt;/sub&gt;:Mn</td>
<td>0.233</td>
<td>0.702</td>
<td>10</td>
</tr>
<tr>
<td>(Y,Gd)BO&lt;sub&gt;3&lt;/sub&gt;:Tb</td>
<td>0.324</td>
<td>0.615</td>
<td>8</td>
</tr>
<tr>
<td>LaPO&lt;sub&gt;4&lt;/sub&gt;:Ce,Tb</td>
<td>0.350</td>
<td>0.582</td>
<td>3</td>
</tr>
<tr>
<td>(Y,Gd)BO&lt;sub&gt;3&lt;/sub&gt;:Eu</td>
<td>0.636</td>
<td>0.357</td>
<td>8</td>
</tr>
<tr>
<td>Y&lt;sub&gt;2&lt;/sub&gt;O&lt;sub&gt;3&lt;/sub&gt;:Eu</td>
<td>0.640</td>
<td>0.346</td>
<td>2.5</td>
</tr>
<tr>
<td>Y(Y,P)O&lt;sub&gt;4&lt;/sub&gt;:Eu</td>
<td>0.657</td>
<td>0.330</td>
<td>1</td>
</tr>
</tbody>
</table>
4. Phosphors for Plasma Display Panels

VUV phosphors

Presently applied shortcoming Novel materials based on host lattices with suitable band edge

**BaMgAl_{10}O_{17}:Eu** stability **BaMg_{3}Al_{14}O_{25}:Eu**

**Zn_{2}SiO_{4}:Mn** decay time **Sr_{6}BP_{5}O_{20}:Eu**

**(Y,Gd)BO_{3}:Eu** color point **BaAl_{2}Si_{2}O_{8}:Eu**

**CaAl_{2}O_{4}:Eu** **LaPO_{4}:Tm**

**BaAl_{12}O_{19}:Mn**

**BaMg_{3}Al_{14}O_{25}:Mn**

**(Y,Gd)_{2}SiO_{5}:Eu**
5. Phosphors for Xe₂⁺ Discharge Lamps

- Discharge efficiency ~ 65%
- Hg free
- Fast switching cycles
- Temperature independent
- Dimmable
- High lifetime
- Mainly VUV emission

Potential application areas
- Photocopier lamps: RGB or B/W
- LCD Backlighting: RGB
- Medical skin treatment: UV-A/B
- Photochemistry: UV-A/B/C
- Disinfection: UV-C
- Ultra pure water: -
- Surface/wafer cleaning: -

(Quartz) glass

Features

<table>
<thead>
<tr>
<th>Wavelength [nm]</th>
<th>Intensity [a.u.]</th>
</tr>
</thead>
<tbody>
<tr>
<td>147</td>
<td>Resonance Line</td>
</tr>
<tr>
<td>150</td>
<td>1st Continuum</td>
</tr>
<tr>
<td>172</td>
<td>2nd Continuum</td>
</tr>
</tbody>
</table>

- 190 - 700 nm
5. Phosphors for Xe\textsubscript{2}\textsuperscript{*} Discharge Lamps

VUV phosphors for white Xe\textsubscript{2}\textsuperscript{*} discharge lamps

BaMgAl\textsubscript{10}O\textsubscript{17}:Eu 80 lm/W\textsubscript{opt.}

LaPO\textsubscript{4}:Ce,Tb 500 lm/W\textsubscript{opt.}
(Y,Gd)BO\textsubscript{3}:Tb 530 lm/W\textsubscript{opt.}

(Y,Gd)BO\textsubscript{3}:Eu 275 lm/W\textsubscript{opt.}
(Y,Gd)\textsubscript{2}O\textsubscript{3}:Eu 290 lm/W\textsubscript{opt.}

Luminous efficiency < 50 lm/W\textsubscript{el.}

Challenges related to VUV phosphors for Xe\textsubscript{2}\textsuperscript{*} discharge lamps

a) Lamp efficacy → Down conversion phosphors
b) VUV stability → Particle coatings (MgO or Al\textsubscript{2}O\textsubscript{3})
c) Color point stability → Optimised blue phosphor
d) Novel application areas → UV phosphors
5. Phosphors for Xe$_2^*$ Discharge Lamps

Down conversion phosphors: Single ion mechanism on Pr$^{3+}$

**First fluorides:** YF$_3$:Pr und NaYF$_4$:Pr  
(J.L. Sommerdijk et al., J. Lumin. 8 (1974) 341)  
$^1S_0 - ^3P_1, ^1I_6$ at 407 nm  
$^3P_0 - ^3H_6, ^3F_2$ at 615 nm

**Oxidic phosphors:** Host lattices with Ln$^{3+}$ sites having high coordination number  
SrAl$_{12}$O$_{19}$:Pr, LaMgB$_5$O$_{10}$:Pr, and LaB$_3$O$_6$:Pr  
(A. Srivastava et al., GE)
5. Phosphors for Xe$_2^*$ Discharge Lamps

Down conversion phosphors: Pair mechanism in Gd$^{3+}$-Eu$^{3+}$ or Gd$^{3+}$-Er$^{3+}$

- Discovered by A. Meijerink et al. in 2000
- Internal quantum efficiency about 195% in LiGdF$_4$
- External quantum efficiency about 30 – 35% at 202 nm due to competitive host lattice absorption, which does not result in luminescence (low transfer efficiency!)

![Energy level diagram](image-url)
5. Phosphors for Xe$_2^*$ Discharge Lamps

VUV Stability

- Phosphor degrades due to
  - VUV radiation
  - Direct contact to the discharge
- Low penetration depth of VUV radiation
- Xe$_2^*$ adheres to phosphor surface, electron take-up is difficult as phosphor surface is too electronegative (low PZC, e.g. silicates or SiO$_2$)
- Xe$_2^+$ is stabilised by strong Lewis acids (SbF$_5$, SiO$_2$) and absorbs in the UV-A/B and red spectral range

Consequences

- No silicate phosphors!
- Coating by alkaline materials
  - Al$_2$O$_3$ or MgO as protective coating

<table>
<thead>
<tr>
<th>Sample</th>
<th>C 1s</th>
<th>O 1s</th>
<th>Si 2p</th>
<th>Y 3p$_{3/2}$</th>
<th>Xe 3d$_{5/2}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y-phosphor (as made)</td>
<td>1.1</td>
<td>70.2</td>
<td>28.7</td>
<td>&lt; 0.05</td>
<td>&lt; 0.1</td>
</tr>
<tr>
<td>SiO$_2$ coated Y-phosphor after 100 h lamp operation</td>
<td>0.3</td>
<td>68.7</td>
<td>28.4</td>
<td>&lt; 0.05</td>
<td>2.6</td>
</tr>
</tbody>
</table>

(a)JACS 102 (1980) 2856
(b) E. Riedel, Modern Inorganic chemistry
5. Phosphors for Xe$_2^*$ Discharge Lamps

Color point stability (blue phosphor)

Improved BaMgAl$_{10}$O$_{17}$:Eu,(Mn) by application Mg$^{2+}$ excess during synthesis

*Color point stability (blue phosphor)*

Alternative materials

- BaAl$_2$Si$_2$O$_8$:Eu        435 nm
  (*Chem. Mater. 2006*)
- LaPO$_4$:Tm               454 nm
  blended with BaMgAl$_{10}$O$_{17}$:Eu
  (*J. Luminescence 2005*)

---

**Graph 1:**
- **a** (Y,Gd)BO$_3$:Eu
- **b** Zn$_2$SiO$_4$:Mn
- **c** BaMgAl$_{10}$O$_{17}$:Eu standard
- **d** BaMgAl$_{10}$O$_{17}$:Eu improved

**Graph 2:**
- Excitation spectrum
- Emission spectrum

---

**Sample V1382**

---

Prof. Dr. T. Jüstel, University of Applied Sciences Münster, Germany
5. Phosphors for Xe$_2^*$ Discharge Lamps

### UV Phosphors – Host lattices and activators

<table>
<thead>
<tr>
<th>VUV</th>
<th>UV-C</th>
<th>UV-B</th>
<th>UV-A</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 nm</td>
<td>200 nm</td>
<td>280 nm</td>
<td>320 nm</td>
</tr>
</tbody>
</table>

**Host lattices**

- Fluorides
- Phosphates
- Borates
- Silicates
- Aluminates

**Suitable activators**

- Nd$^{3+}$, Tl$^+$
- Pb$^{2+}$, Pr$^{3+}$, Bi$^{3+}$
- Gd$^{3+}$, Bi$^{3+}$, Pr$^{3+}$, Ce$^{3+}$
- Tm$^{3+}$, Pb$^{2+}$, Ce$^{3+}$
5. Phosphors for Xe$_2^*$ Discharge Lamps

UV-A Phosphors

UV-A emitting phosphors for UV-C excitation (LP Hg discharge lamps)
VUV Efficiency: \( \text{LaMgAl}_{11} \text{O}_{19}:\text{Ce} > \text{YPO}_4:\text{Ce} \sim \text{BaSi}_2 \text{O}_5:\text{Pb} > \text{Sr}_2\text{MgSi}_2\text{O}_7:\text{Pb} \)

UV-A emitting phosphor for VUV excitation
\( \text{Lu}_3\text{Al}_5\text{O}_{12}:\text{Tm} \)  Emission @ 292 and 352 nm, exc. max. at 170 nm
5. Phosphors for Xe\textsubscript{2}\textsuperscript{*} Discharge Lamps

**UV-B Phosphors – Gd\textsuperscript{3+} emitter**

Sensitisation by the host lattice (suitable band gap!)

Example: YAl\textsubscript{3}(BO\textsubscript{3})\textsubscript{4}:Gd

(*NEC patent US2005/001024*)

Sensitisation by co-dopants

Bi\textsuperscript{3+} \rightarrow large lattice position (e.g. La\textsuperscript{3+}) required

Ce\textsuperscript{3+} \rightarrow suitable 4f5d state pos. required

Pr\textsuperscript{3+} \rightarrow suitable 4f5d state pos. required

Nd\textsuperscript{3+} \rightarrow suitable 4f5d state pos. required

Example: GdPO\textsubscript{4}:Nd

(*Philips patent EP06112503*)
5. Phosphors for $\text{Xe}_2^*$ Discharge Lamps

UV-B Phosphors – $\text{Gd}^{3+}$ emitter

$\text{LaMgAl}_{11}\text{O}_{19}:30\%\text{Gd}^{3+}$

QE(172 nm) close to 100%!

![Graph showing light output and emission spectrum of $\text{LaMgAl}_{11}\text{O}_{19}:\text{Gd}$ vs $\text{LaPO}_4:\text{Ce}$ (NP806).]
5. Phosphors for Xe₂* Discharge Lamps

UV-C Phosphors - Bi³⁺ and Pb²⁺ emitter

(Ca,Mg)SO₄:Pb, SrSiO₃:Pb ⇒ sensitivity towards water, Xe up-take

(Y,Lu)PO₄:Bi ⇒ good chemical stability + high VUV efficiency
5. Phosphors for $\text{Xe}_2^*$ Discharge Lamps

VUV to VUV down converting phosphors - $\text{Nd}^{3+}$ emitter

**YPO$_4$:Nd**

- **Emission spectrum**
- **Excitation spectrum**

**LiYF$_4$:Nd**

- **Emission spectrum**
- **Excitation spectrum**

Emission maxima at 190 + 240 + 278 nm
5. Phosphors for Xe₂* Discharge Lamps

Phosphor converted Xe₂* excimer discharge lamp for disinfection

Requires UV-C emitting phosphor with a high conversion efficiency and a large integral overlap with germicidal action curve
⇒ e.g. Pr³⁺ or Bi³⁺ activated materials

<table>
<thead>
<tr>
<th>Phosphor</th>
<th>( \lambda_{\text{max}} ) [nm]</th>
<th>GAC overlap [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>YPO₄:Pr</td>
<td>233</td>
<td>78</td>
</tr>
<tr>
<td>YPO₄:Bi</td>
<td>241</td>
<td>71</td>
</tr>
<tr>
<td>YAlO₃:Pr</td>
<td>245</td>
<td>71</td>
</tr>
<tr>
<td>YBO₃:Pr</td>
<td>263</td>
<td>61</td>
</tr>
<tr>
<td>Line @</td>
<td>265</td>
<td>100</td>
</tr>
<tr>
<td>Line @</td>
<td>311</td>
<td>0</td>
</tr>
</tbody>
</table>
6. Application Areas

Lamps without phosphor \( \Rightarrow \) solely 172 nm radiation
Lamps with VUV phosphors \( \Rightarrow \) spectrum can be defined by the phosphor in accordance to application area

<table>
<thead>
<tr>
<th>Application area</th>
<th>Required emission</th>
<th>Embodiments from</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hg-free CFL-i</td>
<td>White (tricolour blend)</td>
<td>-</td>
</tr>
<tr>
<td>Backlighting of LCDs</td>
<td>White or UV-A</td>
<td>Osram, Hitachi, Stanley</td>
</tr>
<tr>
<td>Photocopier / scanner</td>
<td>White or UV-A</td>
<td>NEC, Ushio</td>
</tr>
<tr>
<td>Purification</td>
<td>VUV</td>
<td>Heraeus, Ushio, Radium</td>
</tr>
<tr>
<td>Disinfection</td>
<td>UV-C</td>
<td>-</td>
</tr>
<tr>
<td>Tanning</td>
<td>UV-A</td>
<td>-</td>
</tr>
<tr>
<td>Photochemistry</td>
<td>UV-B or UV-A</td>
<td>-</td>
</tr>
</tbody>
</table>

XERADEX (Radium)
6. Application Areas

Xe Discharge lamps - Copiers and scanners

Color ⇒ Tetrachromatic phosphor blend
- BaMgAl$_{10}$O$_{17}$:Eu
- Zn$_2$SiO$_4$:Mn
- LaPO$_4$:Ce,Tb
- (Y,Gd)BO$_3$:Eu

B/W ⇒ single phosphor
- LaPO$_4$:Ce,Tb
6. Application Areas

Xe Discharge lamps - LCD Backlighting

Prof. Dr. T. Jüstel, University of Applied Sciences Münster, Germany
### 6. Applications Areas - UV Radiation

<table>
<thead>
<tr>
<th>VUV</th>
<th>UV-C</th>
<th>UV-B</th>
<th>UV-A</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 nm</td>
<td>200 nm</td>
<td>280 nm</td>
<td>320 nm</td>
</tr>
<tr>
<td>12.5 - 6.9 eV</td>
<td>6.2 – 4.5 eV</td>
<td>4.5 - 3.9 eV</td>
<td>3.9 – 3.1 eV</td>
</tr>
</tbody>
</table>

- **Cleavage of H₂O and O₂ into radicals**
- **Ozone formation**
- **Cleavage of C-C, C-H, C-O bonds**

- **Excitation of C=C bonds**
- **Excitation of nucleobases**
- **Cleavage of O₃, ClO₂ and H₂O₂**

- **Vitamin D production**
- **Transcription of repair enzymes**
- **Melanosome formation (skin)**

- **Photocatalytic reactions**
- **Melanine oxidation (skin)**
- **Decomposition of organic pigments**
- **Activation of photocatalytical pigments**

- **Waver cleaning**
- **Photochemistry**
- **Disinfection of air, H₂O and surfaces**
- **Photochemistry**

- **Treatment of skin diseases, e.g. psoriasis**
- **Tanning**
- **Photochemistry**

- **Water and air purification @ TiO₂ photocatalyst, form. of OH⁻ and O₂ radicals**
- **Tanning**
- **H₂O₂ production in-situ**

---

Prof. Dr. T. Jüstel, University of Applied Sciences Münster, Germany
6. Application Areas

**Xe₂⁺ Discharge lamps for disinfection and Purification purposes**

![Emission spectrum of Xe excimer with wavelength and absorption coefficients](image)

- Convert to 190 - 200 nm to improve penetration depth
- Convert to 200 - 280 nm to improve GAC overlap
6. Application Areas

Phosphor converted $\text{Xe}_2^*$ excimer discharge lamp

Requires development and optimization of UV-C phosphors with a large GAC overlap

$\Rightarrow$ e.g. Pr$^{3+}$ or Bi$^{3+}$ activated phosphors

- LaPO$_4$·Pr 225 nm
- KYF$_4$·Pr 232 nm
- YPO$_4$·Pr 233 nm
- YPO$_4$·Bi 241 nm
- YAIO$_3$·Pr 245 nm
- KY$_3$F$_{10}$·Pr 249 nm
- LuBO$_3$·Pr 257 nm
- YBO$_3$·Pr 261 nm
- Y$_2$SiO$_5$·Pr 270 nm

Best practice UV-C phosphor so far: YPO$_4$·Bi
Lamp efficiency: 30%
7. Conclusions

VUV phosphors as luminescent converters for Xe(Ne) discharges

- UV: Ce\(^{3+}\), Pr\(^{3+}\), Nd\(^{3+}\), Gd\(^{3+}\), Tm\(^{3+}\)  
  TI\(^{+}\), Pb\(^{2+}\), Bi\(^{3+}\)
- Blue: Eu\(^{2+}\), Ce\(^{3+}\)  
  Bi\(^{3+}\)
- Green: Tb\(^{3+}\)  
  Mn\(^{2+}\)
- Red: Eu\(^{3+}\)  
  Mn\(^{2+}\), Mn\(^{4+}\)

Plasma display panels

- Long-term stability of phosphors with redox active activators is an issue
- Phosphor blends as a trade-off between color point and efficiency
- Red phosphor with a deep red color point is still required (Mn\(^{4+}\)?)

Xe Excimer discharge lamps

- Luminous efficiency limited to 40 – 50 lm/W
- Down conversion phosphors are not within immediate reach
- Niche products: Photocopying, surface cleaning, backlighting, etc.
- Novel UV phosphors might open attractive application areas for Xe\(_{2}\)* lamps
- UV-A phosphor with a high VUV efficiency is LaMgAl\(_{11}\)O\(_{19}\):Ce
- Gd\(^{3+}\) activated UV-B phosphors can be sensitised via host lattice or Nd\(^{3+}\), Bi\(^{3+}\)
- LuAG as a host lattice yields stable and efficient UV phosphors (Gd\(^{3+}\), Tm\(^{3+}\))
- YPO\(_{4}\):Bi and YPO\(_{4}\):Nd are the most efficient UV-C and VUV phosphors so far
Acknowledgement

Research Group “Tailored Optical Materials“
Dr. Helga Bettentrup, Hendrik Busskamp, Danuta Dutczak, Linda Eickhoff, David Enseling, Rolf Gerdes, Benjamin Herden, Jagoda Kuc, Stephanie Möller, Dr. Julian Plewa, Tatjana Rat, Dr. Dominik Uhlich

Suppliers of high purity Rare Earth Compounds

Thanks to you for your kind attention…..