11. Gas Discharge Displays

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11.11 Status and Outlook

11.1 Technologies for Flat Displays

Technology	Efficiency	Max. size	Areas of application
Organic EL	2 lm/W	10“	Automobiles, mobile phones
Inorganic EL	1 lm/W	17“	Instrument displays
FED	5 lm/W	17“	
LCD	4 lm/W	65“	Laptops, monitors, LCD TV
PALC	4 lm/W	40 - 50“	-
LED Array	8 - 10 lm/W	> 100“	Billboards
Projection TV	5 lm/W	50 - 60“	TV
PDP	5 lm/W	~ 152“	TV, scoreboards
CRT	3 lm/W	36“	TV, monitors

Remark: Theoretical limit for white light generation ~ 300 $lm/W_{opt.}$

⇒ Energy efficiency of displays ~ 1 - 5%

11.1 Technologies for Flat Displays

Gas Discharge Displays

152" HDTV-PDP

Properties

Flat and large
(32 - 300 inch)

Thin ~ 100 mm

Lightweight
~ 20 - 30 kg for 42-inch

Large viewing angle
~ 170°

No distortion

Unaffected by external magnetic fields

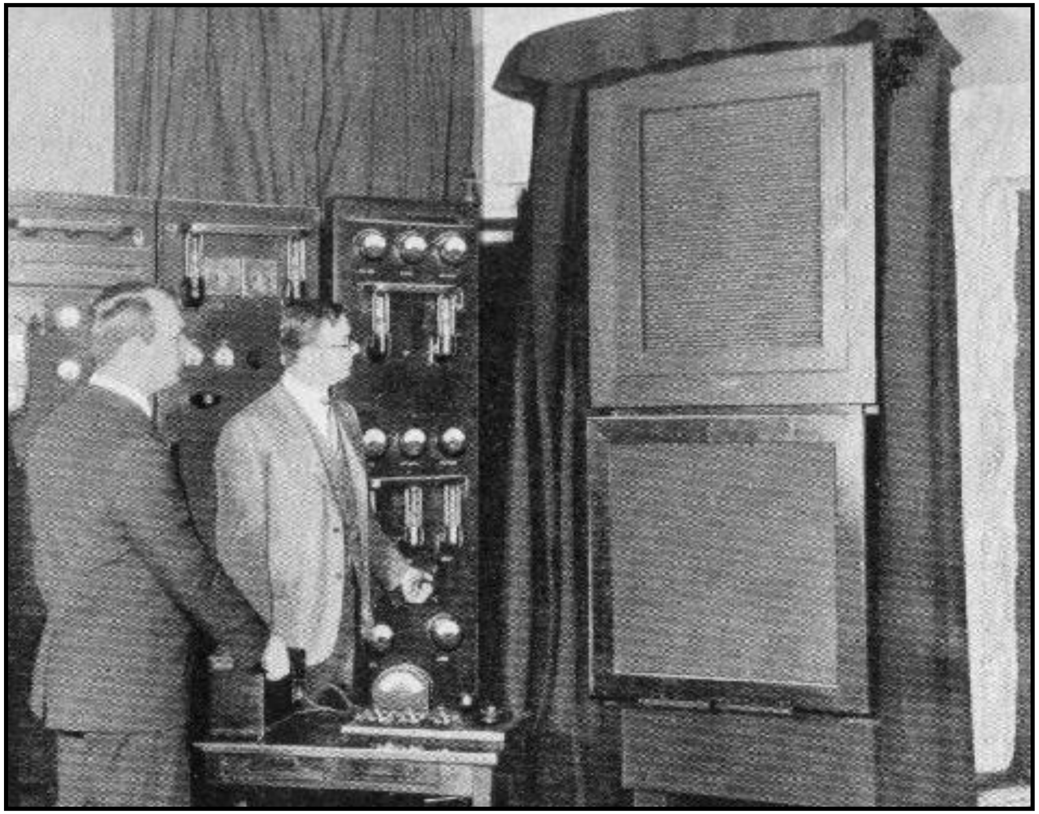
11.1 Technologies for Flat Displays

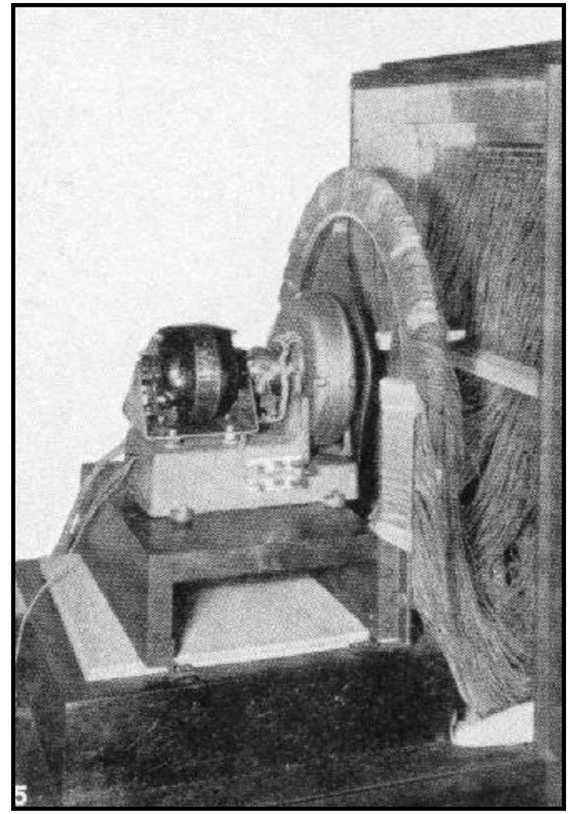
Emissive Display Types

Technology	CRT	PDP
Excitation source	Electron beam	Gas discharge
Excitation energy	(5 -) 20 - 30 keV	6 - 10 eV
Gas pressure	< 10^{-3} mbar	200 - 300 mbar Xe/Ne
Phosphors	Sulfides	Oxides
Viewing angle	> 160°	> 160°
Resolution	EDTV 720 x 480 pixel	UHTV 3840 x 2160 pixel (4K)

11.1 Technologies for Flat Displays

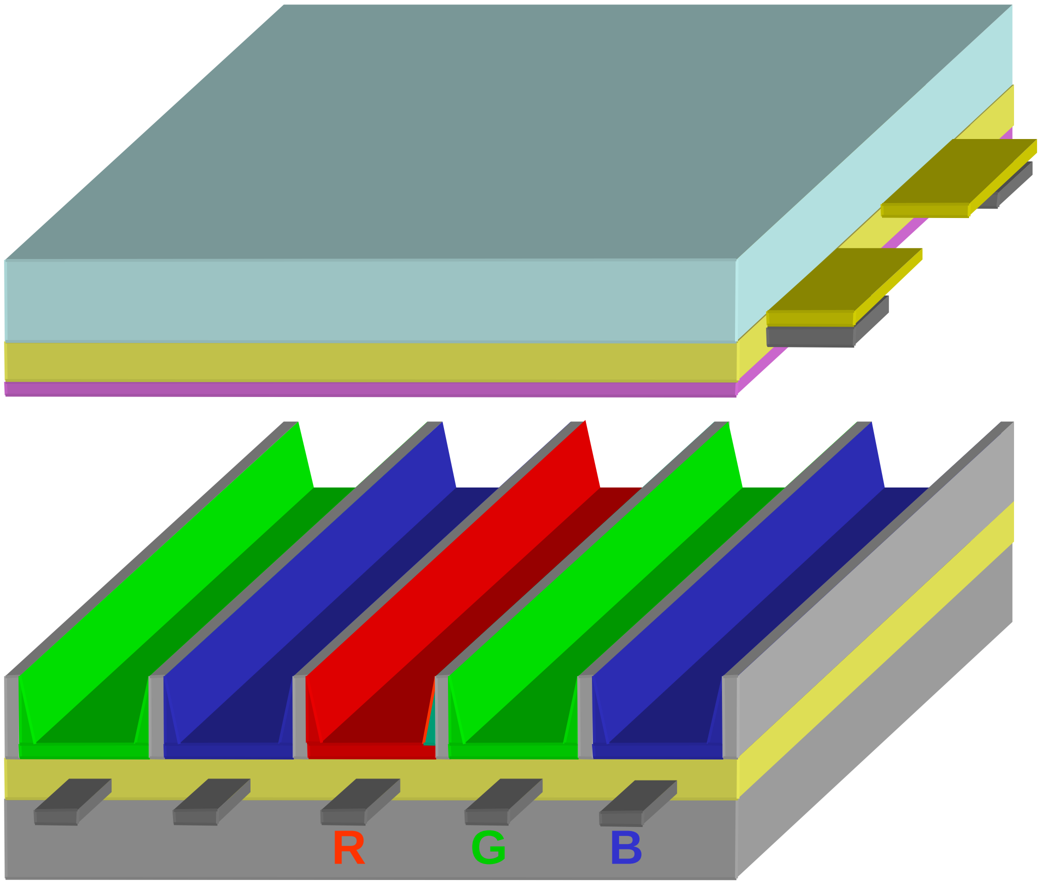
Plasma displays 1929





11.2 Construction of Gas Discharge Displays

Simplified layer structure



Front glass plate

Bus electrode (ITO)

Dielectric

MgO protective layer

RGB phosphor

Dielectric

Address electrodes (Ag)

Rear
glass plate (PD200)

Gas filling ~ 500 Torr Ne with 3 - 5 % Xe

11.2 Construction of Gas Discharge Displays

Structure of a plasma discharge cell

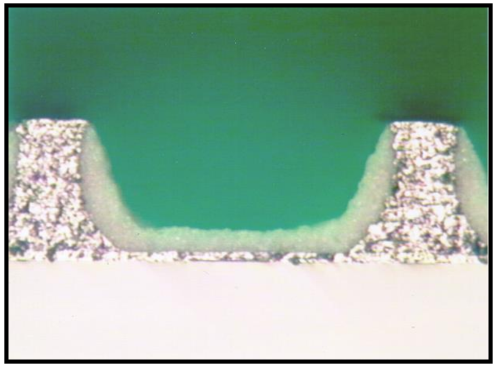
Glass back panel

Structuring by barrier ribs

TiO_2-film as a reflector

Phosphor layer (with additives)

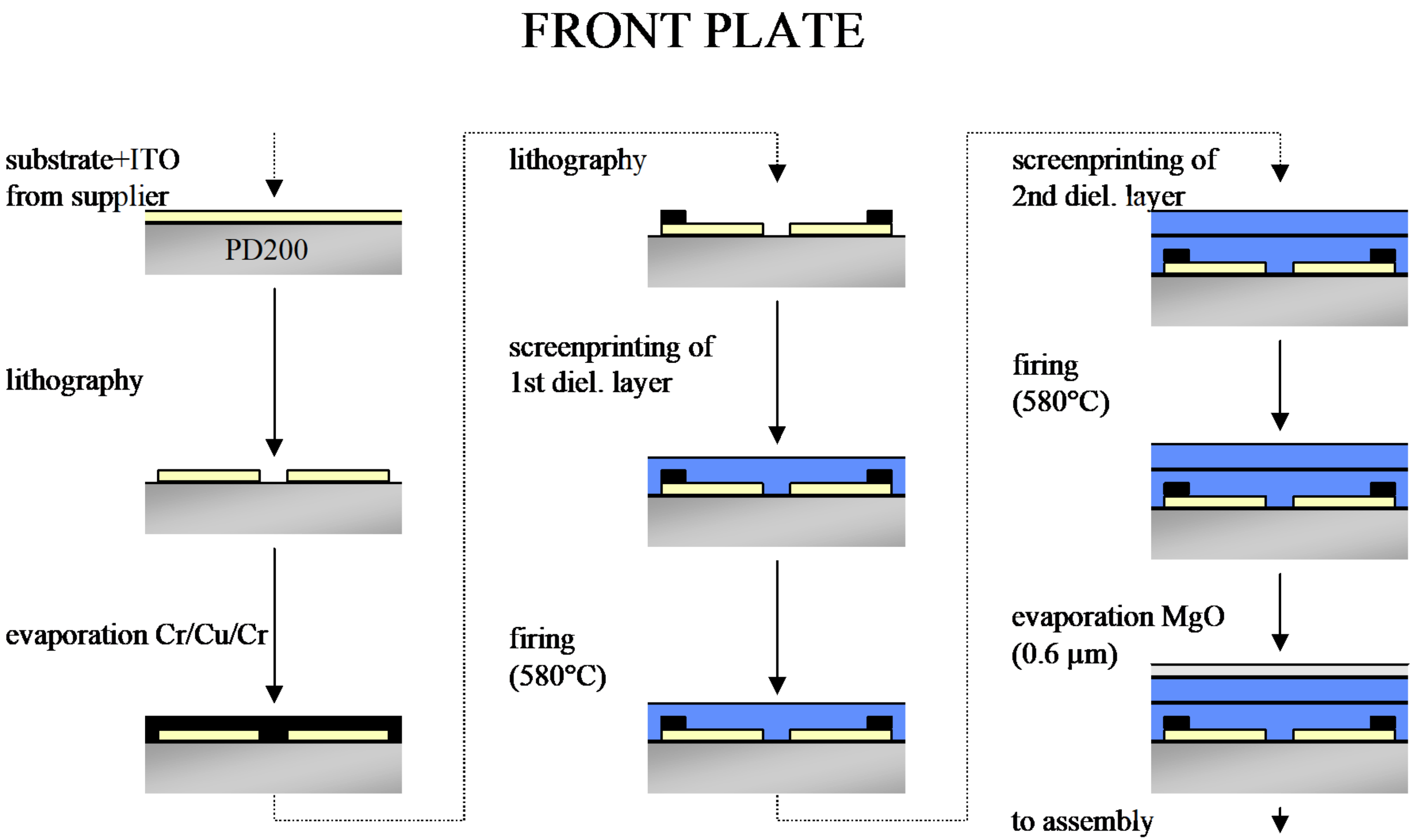
Conical structure



U-shaped structure

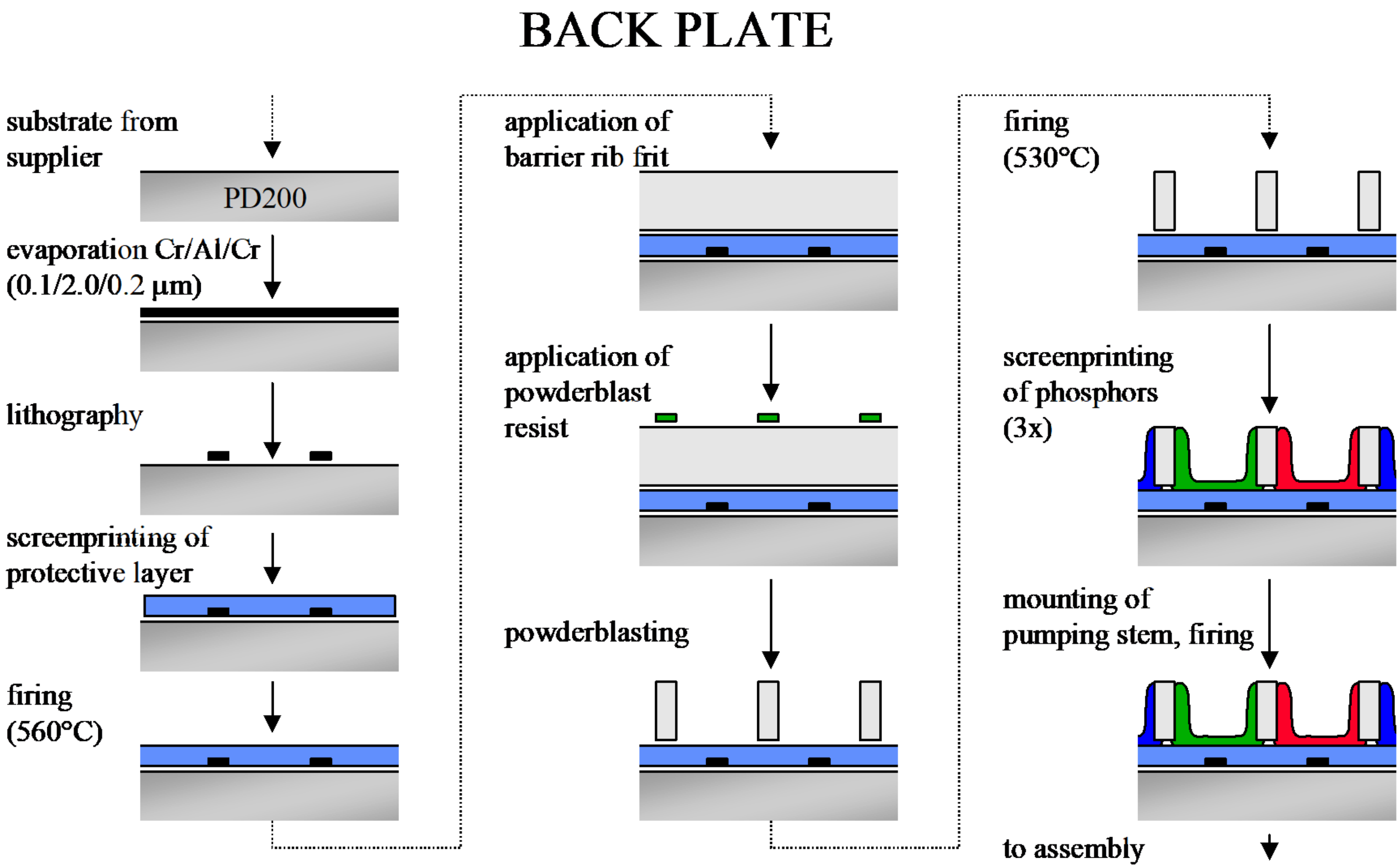
11.3 Manufacturing Process

Preparation of the front plate



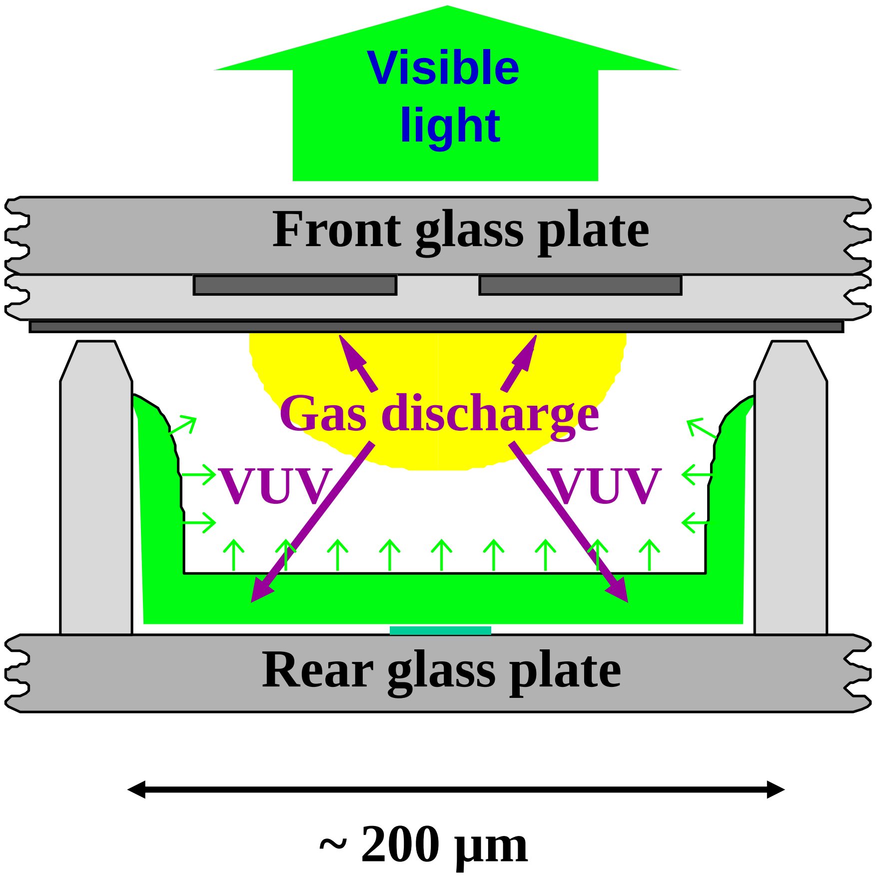
11.3 Manufacturing Process

Preparation of the back plate



11.4 Light Generation in Plasma Displays

Functional principle



Visible light

↑

Phosphor

↑

VUV light

↑

Noble gas discharge

11.4 Light Generation in Plasma Displays

Efficiency of light generation

$$\eta_{display} = \eta_{discharge} \cdot \eta_{UV} \cdot \eta_{phosphor} \cdot \eta_{out\text{-}coupling}$$

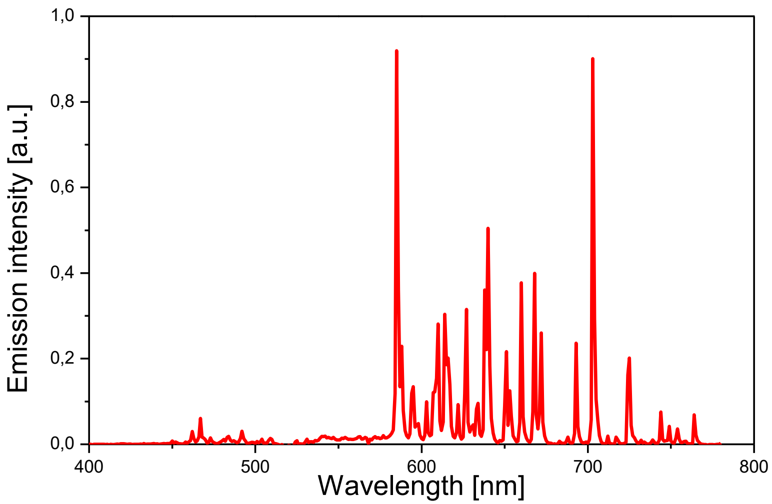
	PDP-cell	*Xe_2*- lamp*	*Hg - lamp*
η_{Plasma}	24 %	70 %	75 %
η_{UV}	40 %	90 %	98 %
$\eta_{Phosphor}$	20 %	25 %	44 %
$\eta_{Coupling\ out}$	50 %	90 %	98 %
$\eta_{Display}$	1.0 %	14 %	30 %
Typ. light output	3 lm/W	40 lm/W	90 lm/W

11.4 Light Generation in Plasma Displays

Light generation in Ne discharges

$Ne + e^- \rightarrow Ne^* + e^-$

$Ne^* \rightarrow Ne + h\nu$(74 nm + vis.)



$Ne^* + Ar \rightarrow Ne + Ar^+ + e^-$
$Ne^* + Xe \rightarrow Ne + Xe^+ + e^-$
(Penning ionization)

- **Monochrome PDPs**
- **Neon discharge lamps**
- **Hg-discharge lamps with Ne-filling "neon lamps"**

Gas mixtures of Ne/Ar or Ne/Xe thus cause a reduction of the ignition voltage by the so-called “Penning effect”

11.4 Light Generation in Plasma Displays

Light generation in Xe/Ne discharge

$Xe(^1S_0) + e^- \rightarrow Xe(^3P_1) + e^-$

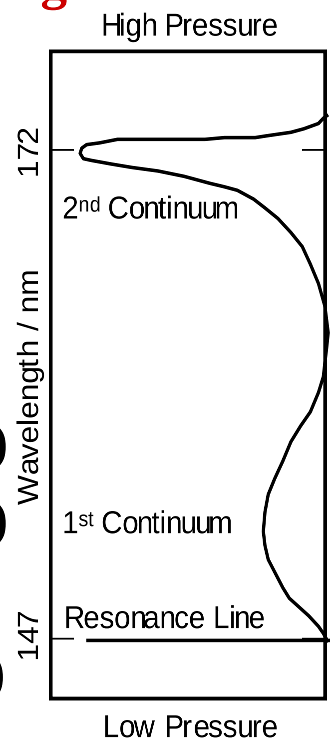
$\rightarrow Xe(^3P_2) + e^-$

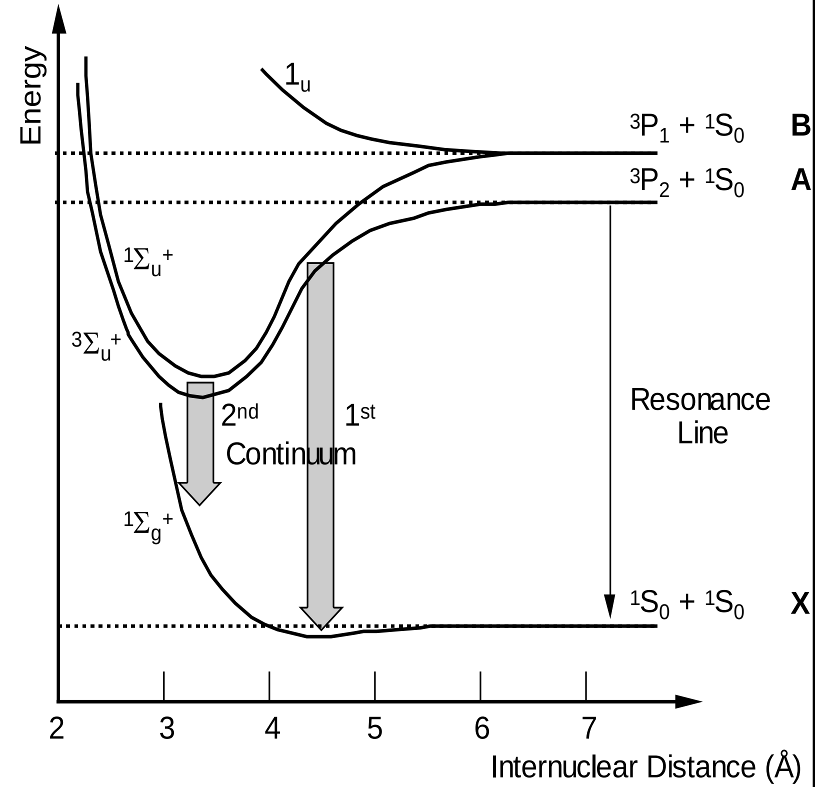
$\rightarrow Xe^{**}$

$Xe^{**} \rightarrow Xe(^3P_1) + h\nu(828\ nm)$

$\rightarrow Xe(^3P_2) + h\nu(823\ nm)$

$Xe(^3P_2) \rightarrow Xe(^1S_0) + h\nu(147\ nm)$





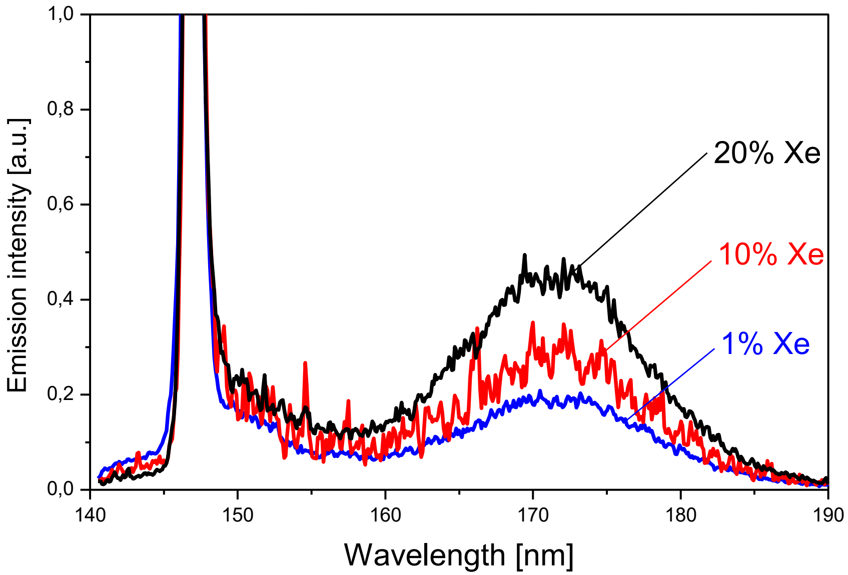
$Xe(^3P_1) + Xe(^1S_0) + M \rightarrow Xe_2^*(^1\Sigma_u^+) + M$ / $Xe(^3P_2) + Xe(^1S_0) + M \rightarrow Xe_2^*(^3\Sigma_u^+) + M$

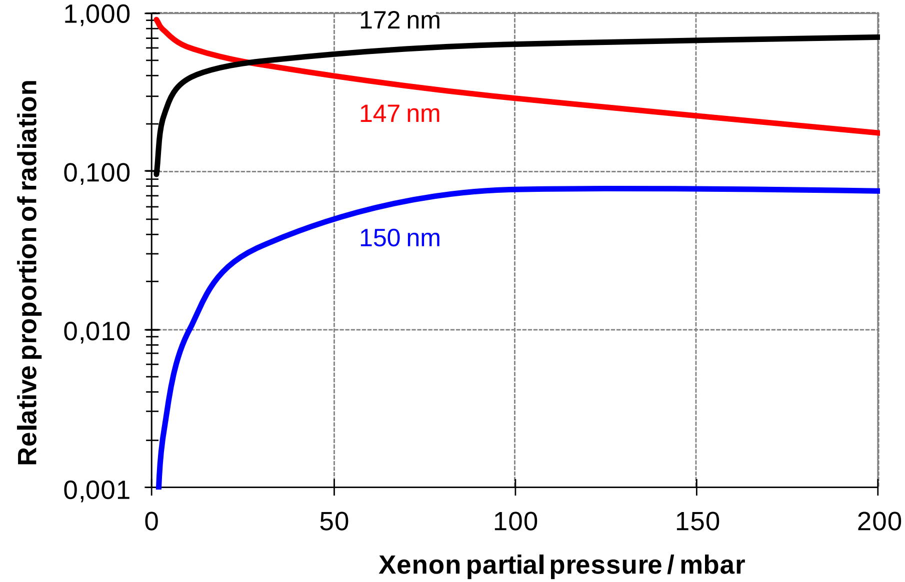
$Xe_2^*(^3\Sigma_u^+) \rightarrow Xe_2^*(^1\Sigma_g^+) + h\nu(150\ nm) \rightarrow 2\ Xe(^1S_0)$

$Xe_2^*(^1\Sigma_u^+) \rightarrow Xe_2^*(^1\Sigma_g^+) + h\nu(172\ nm) \rightarrow 2\ Xe(^1S_0)$

11.4 Light Generation in Plasma Displays

Light generation in Xe/Ne discharge

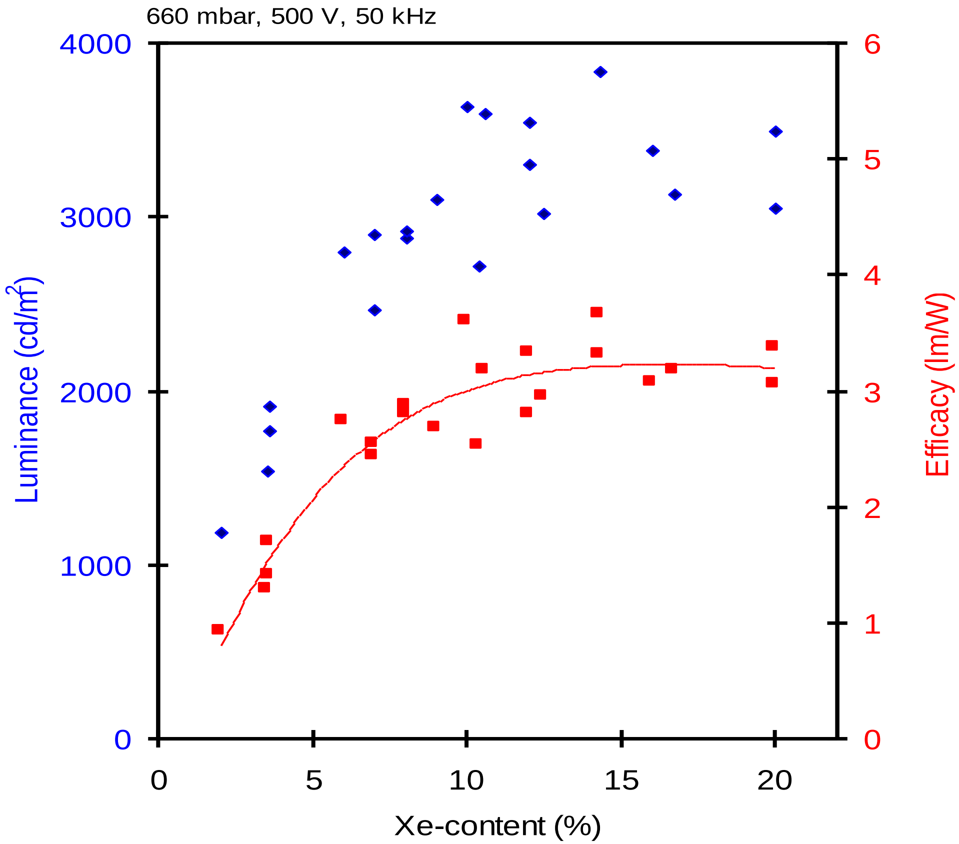


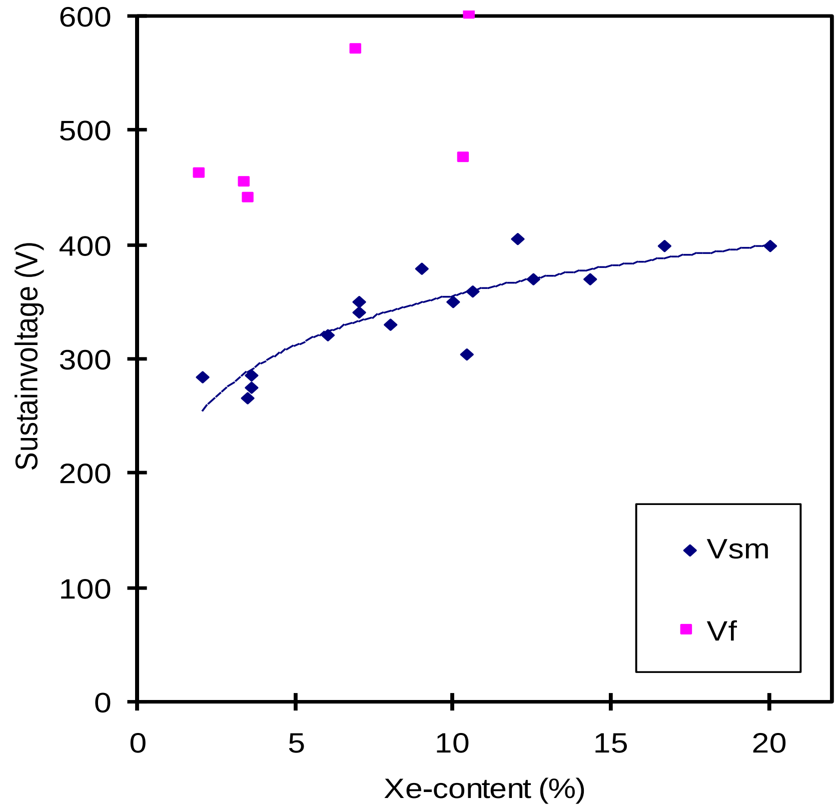


50% Xe_2*-excimer and 50% Xe* resonance emission at 25 mbar Xe partial pressure

PDPs 2005: Xe percentage at 10 - 15% and 300 mbar total pressure, i.e., Xe_2*-excimer radiation predominates

11.4 Light Generation in Plasma Displays





With increasing Xe partial pressure the efficiency and the ignition voltage increases

11.4 Light Generation in Plasma Displays

Dependence on the Xe/Ne partial pressure

100% Ne — Ne/Xe — 100% Xe

Low ignition voltage
~ 300 V

Visible emissions
580 - 720 nm
(Monochrome red)

VUV emission
74 nm

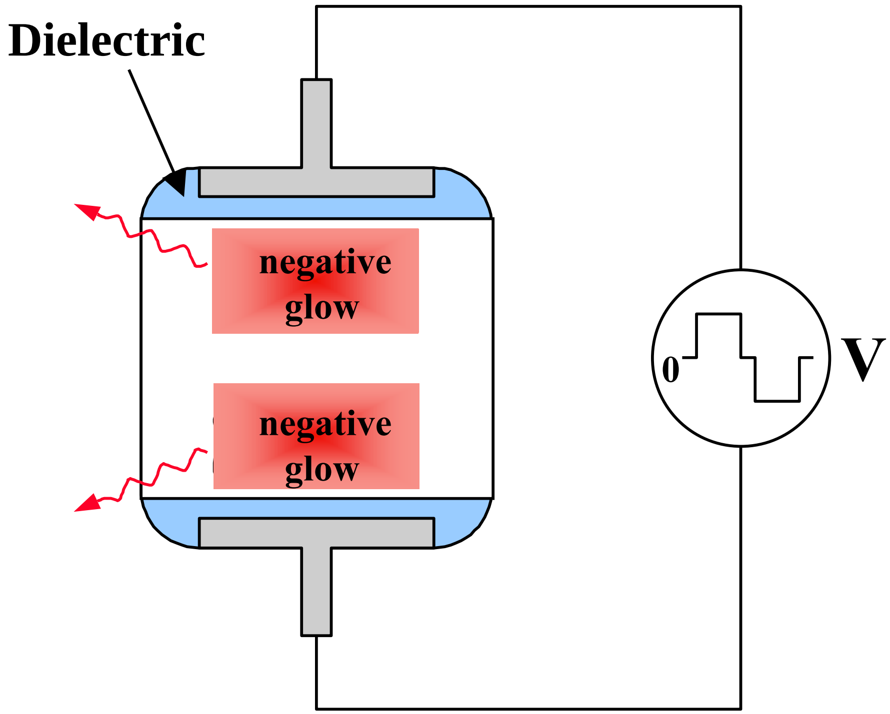
High ignition voltage
~ 2 kV

No visible emission
(colour is defined by the
phosphor)

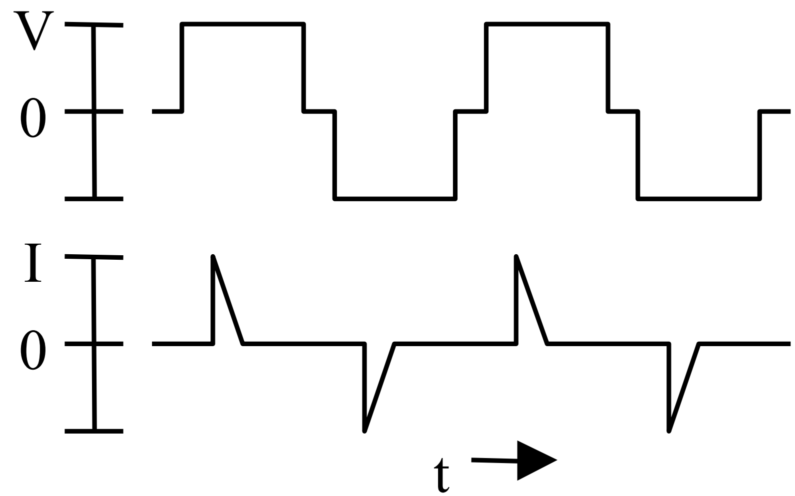
VUV emission
147, 150, 172 nm

Dielectric barrier discharges

Schematic operation of a PDP-cell



Course of voltage and current



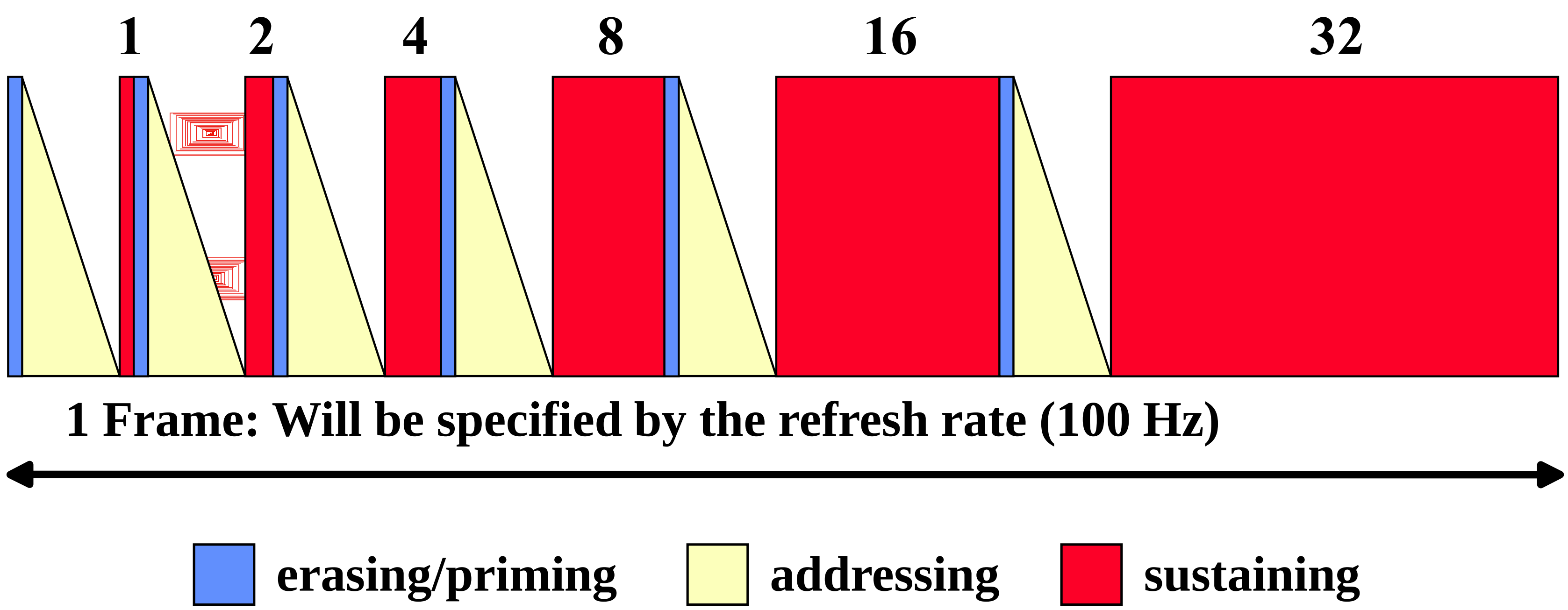
11.5 Operation of the Gas Discharge

Addressing the pixel

Each pixel has 2^n brightness levels

⇒ By 8-bit addressing one obtains 2^8 = 256 brightness levels

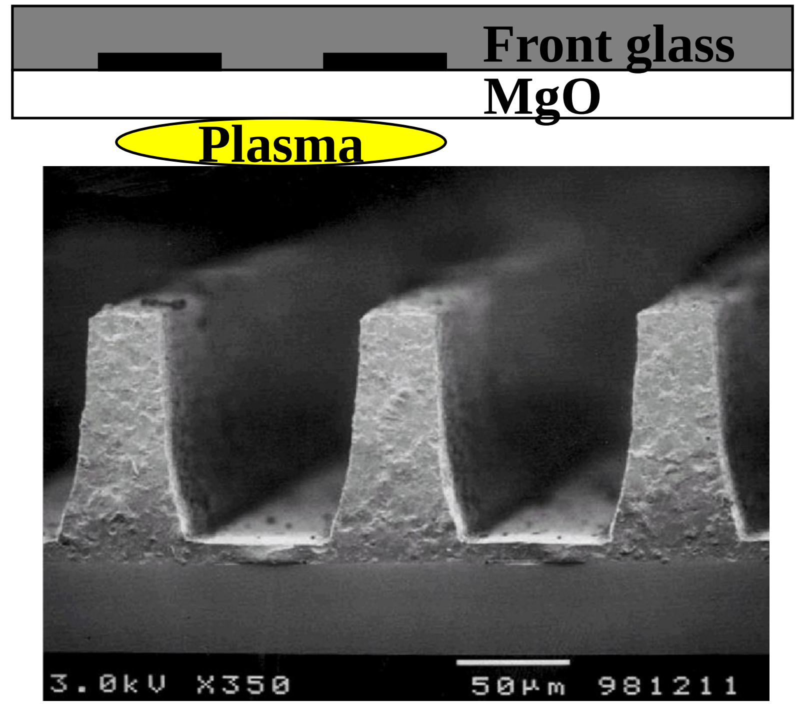
⇒ In a RGB-display there is therefore 256^3 = 16.7 million colours available



11.5 Operation of the Gas Discharge

Influence of the surface on the plasma ignition by ion induced emission of secondary electrons

$$\gamma_i = \frac{\text{Number of emitted electrons}}{\text{Number of ions on the surface}}$$

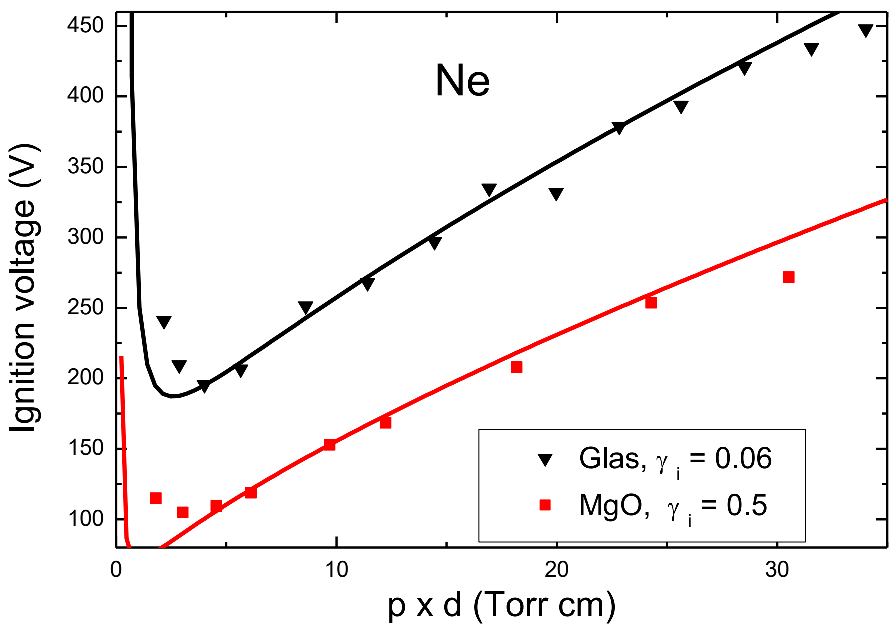


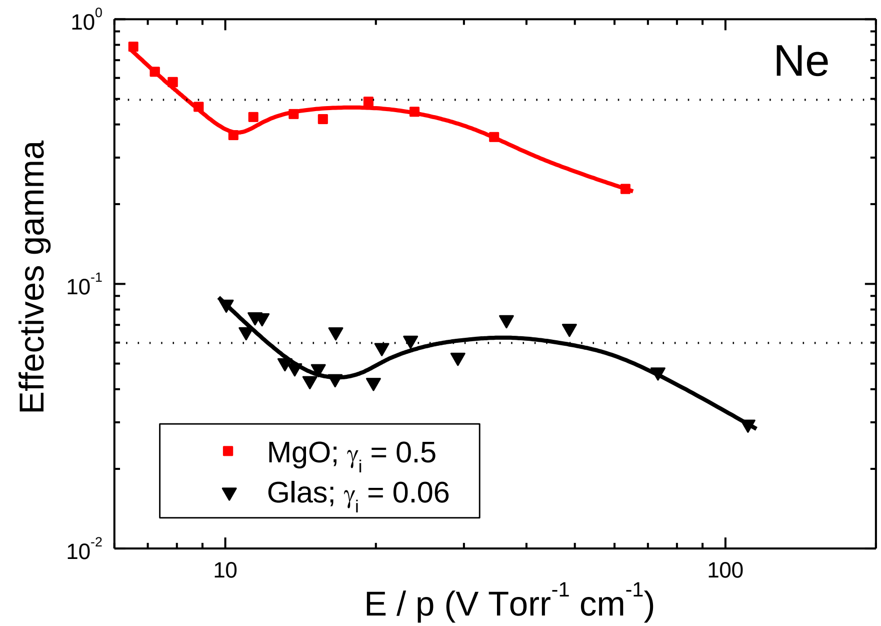
$$V_f = \frac{D^2 \cdot p \cdot d}{\left(\ln \frac{C \cdot p \cdot d}{\ln(1/\gamma_i + 1)} \right)^2}$$

MgO is the material with the highest $\gamma_{Ne} \sim 0.5$

11.5 Operation of the Gas Discharge

Tasks of the MgO protective layer





MgO protective layer causes

- **a protection against sputtering**
- **a reduction of the ignition voltage**

11.6 Selection Criteria for Display Phosphors

Stability

Temperature stability	Sensitivity to oxidation
Stability in suspension	Solubility, surface potential
Plasma stability	Resistance to sputtering
Colour point stability	Photo-oxidation, reduction

Light output

Linearity	Saturation
Efficiency	Quantum yield QA, absorption A

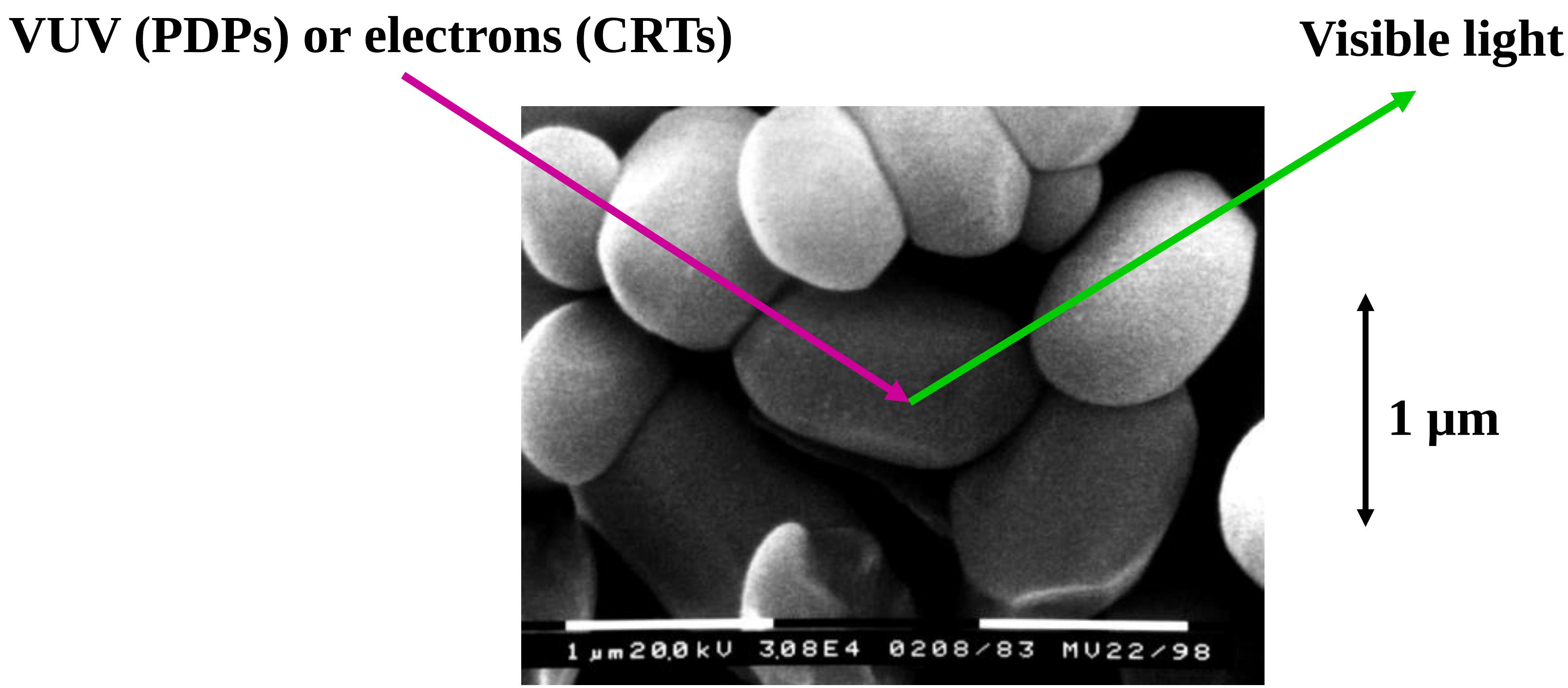
Image quality

Image artifacts	Decay time τ
Colour space	Colour point x, y

Environmental compatibility

Energy efficiency	Quantum yield QA, absorption A
Toxicity	Chemical composition

11.6 Selection Criteria for Display Phosphors

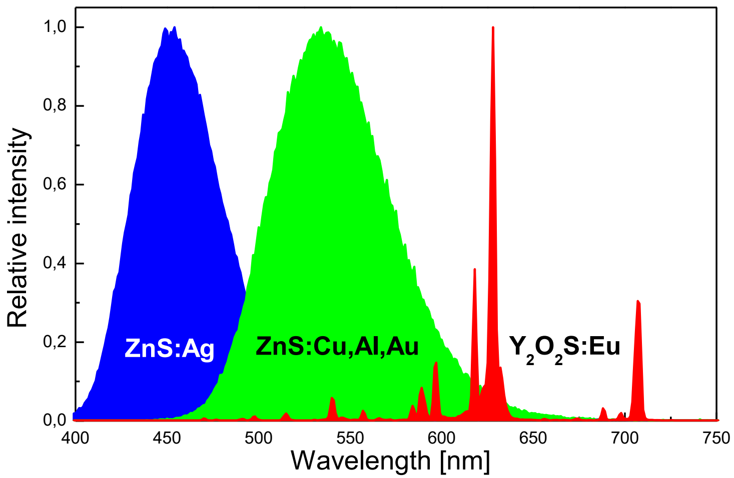


<u>**Plasma Display**</u>

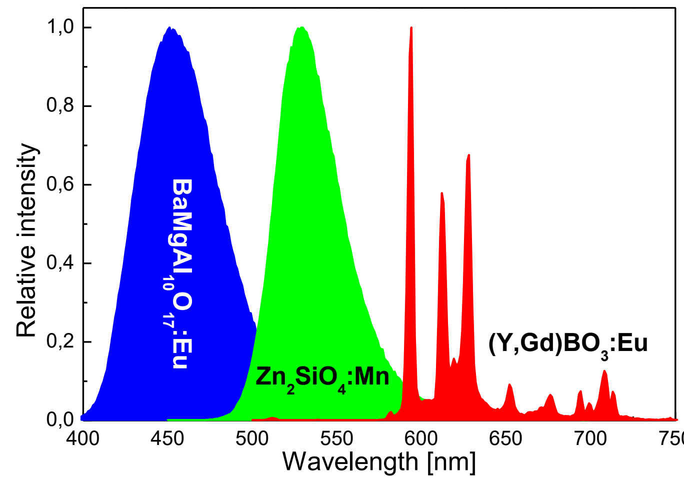
- **High absorption A under VUV excitation, i.e., band gap E_G ~ 6 – 8 eV**
- **High quantum yield QY under VUV excitation, i.e., Eu^{2+}, Tb^{3+}, Mn^{2+}, Eu^{3+}**
- **High light output LO = QY*A**
- **VUV stability**

11.6 Selection Criteria for Display Phosphors

CRT phosphors (sulphides)



PDP phosphors (oxides)



Light output

LO = QE* (1-R)

Energy efficiency

$$\varepsilon = (1-r_b)*\varepsilon_t* h\nu_{em} / \beta E_g$$

~ 15 - 20%

Energy efficiency

$$\varepsilon = LO *N(h\nu_{em})/N(h\nu_{abs})$$

~ 20%

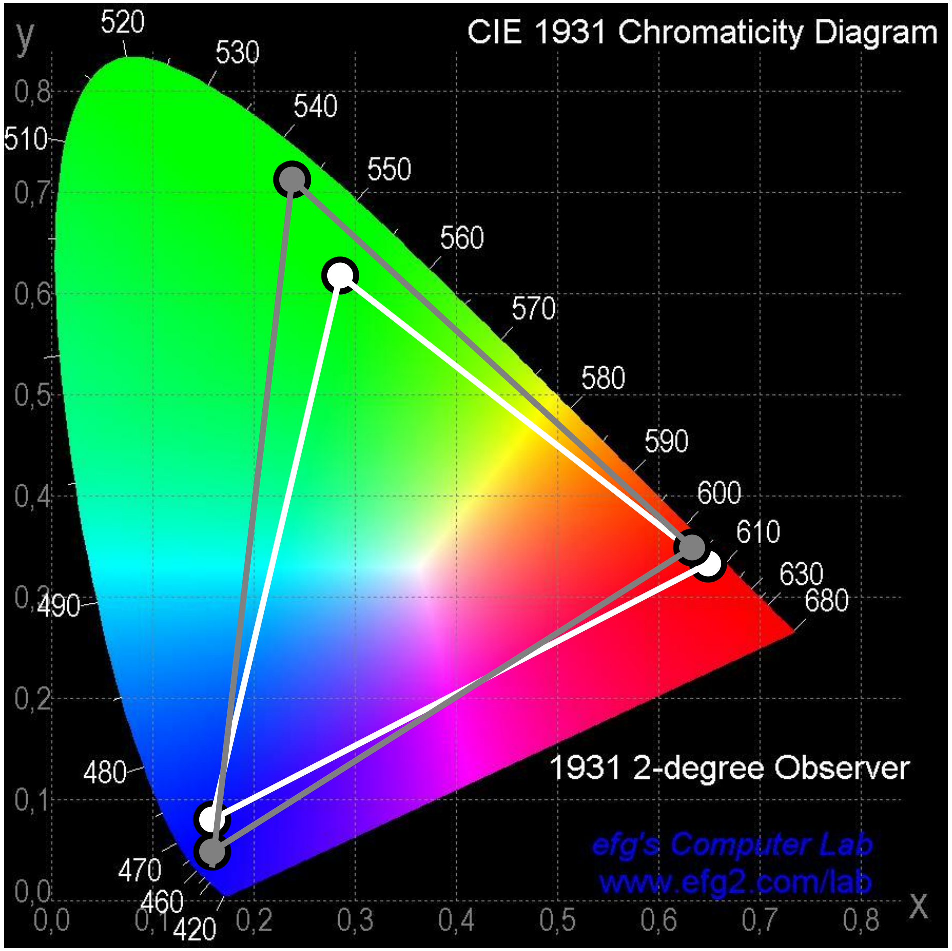
11.7 Phosphors in CRTs and PDPs

Commercial CRT and PDP phosphors

Colour	Chemical composition		x	y	Problem areas
Blue	ZnS:Ag	CRT	0.15	0.08	Sulphur loss
Green	ZnS:Cu		0.29	0.61	Sulphur loss
	$Y_3(Al,Ga)_5O_{12}$:Tb		0.37	0.55	
	Y_2SiO_5:Tb		0.33	0.58	
	Gd_2O_2S:Tb		0.36	0.57	
Red	YVO_4:Eu		0.66	0.33	
	Y_2O_2S:Eu		0.66	0.33	
Blue	$(Y,Gd)(V,P)O_4$	PDP	0.16	0.13	Burn-in
	$BaMgAl_{10}O_{17}$:Eu		0.15	0.06	(stability)
Green	Zn_2SiO_4:Mn		0.25	0.70	Motion artifacts
	$BaMgAl_{10}O_{17}$:Eu,Mn		0.15	0.72	(decay time)
	$BaAl_{12}O_{19}$:Mn		0.19	0.73	
	$(Y,Gd)BO_3$:Tb		0.34	0.62	
Red	$(Y,Gd)BO_3$:Eu		0.64	0.35	Colour gamut
	$(Y,Gd)_2O_3$:Eu		0.65	0.34	(colour point)
	$(Y,Gd)(V,P)O_4$:Eu		0.66	0.33	

11.7 Phosphors in CRTs and PDPs

CIE1931 Colour space



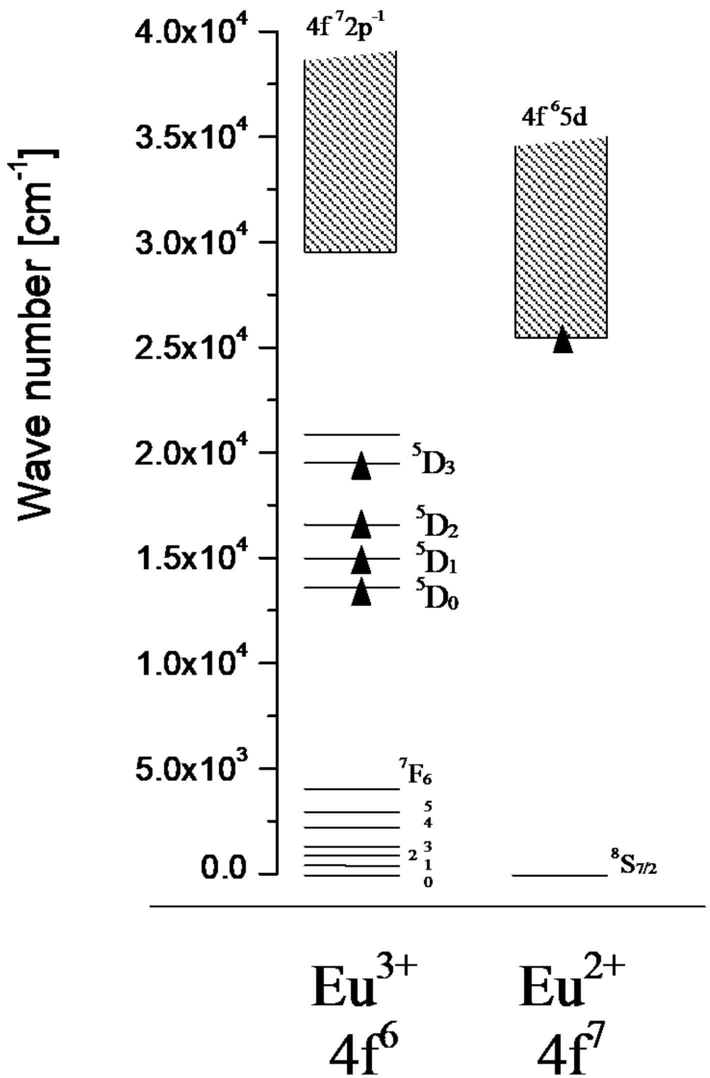
Cathode ray tube (CRTs)
Colour space is defined by the colour points of the phosphor

	x	y
ZnS:Ag	0.15	0.08
ZnS:Cu,Al, Au	0.29	0.61
Y_2O_2S:Eu	0.66	0.33

Plasma displays (PDPs)
Gas filling: Ne, 3 - 15% Xe
Red neon lines reduce colour purity of blue and green phosphor

	x	y
$BaMgAl_{10}O_{17}$:Eu	0.15	0.06
Zn_2SiO_4:Mn	0.25	0.70
$(Y,Gd)BO_3$:Eu	0.65	0.35

11.8 Red PDP Phosphors



Eu^{2+} phosphors

Transition: $4f^65d^1 \rightarrow 4f^7$ (bands)

Position depends on the crystal field

$\tau \sim 1\ \mu s$

Eu^{3+} phosphors

Transition: $^5D_0 \rightarrow {}^7F_J$ (lines)

Inversion symmetry (S_6, D_{3d})

Magnetic dipole transition $^5D_0$ - $^7F_1$

$\Delta J = 0, \pm 1$ ($J_{initial} = 0 \rightarrow J_{final} = 0$ forbidden)

$MeBO_3$:Eu (calcite, vaterite)

$\tau \sim 8 - 16$ ms

No inversion symmetry

Electric dipole transition $^5D_0$ -$^7F_{2,4}$

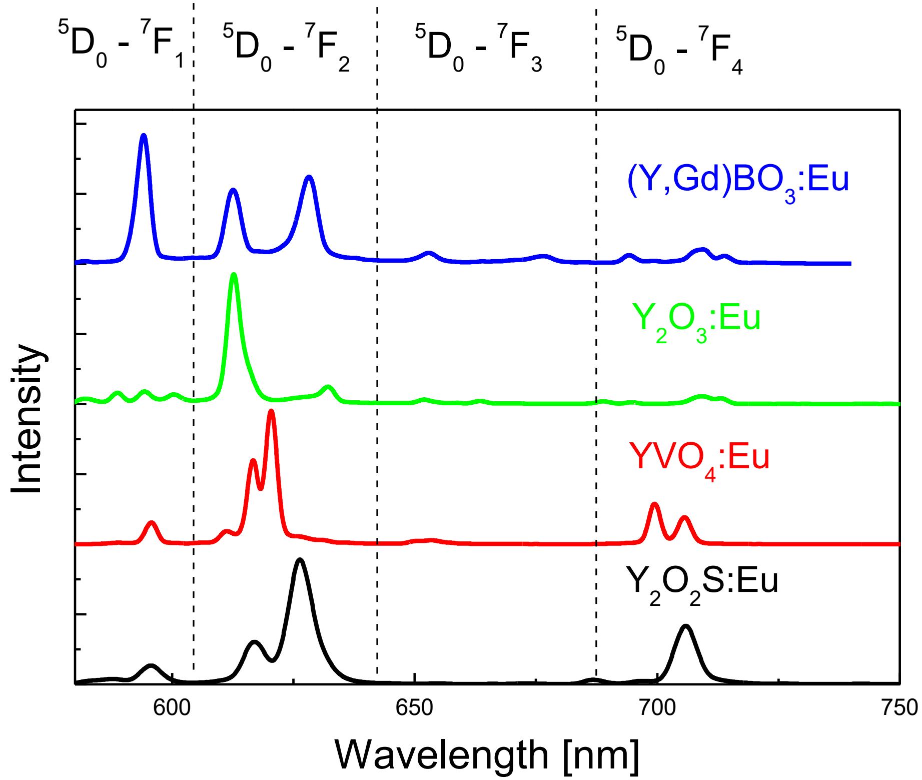
$\Delta J \leq 6$ ($J_{initial} = 0 \rightarrow J_{final} = 2, 4, 6$)

Y_2O_3:Eu (bixbyite), $Y(V,P)O_4$:Eu (xenotime)

$\tau \sim 2 - 5$ ms

11.8 Red PDP Phosphors

Emission spectra and colour points

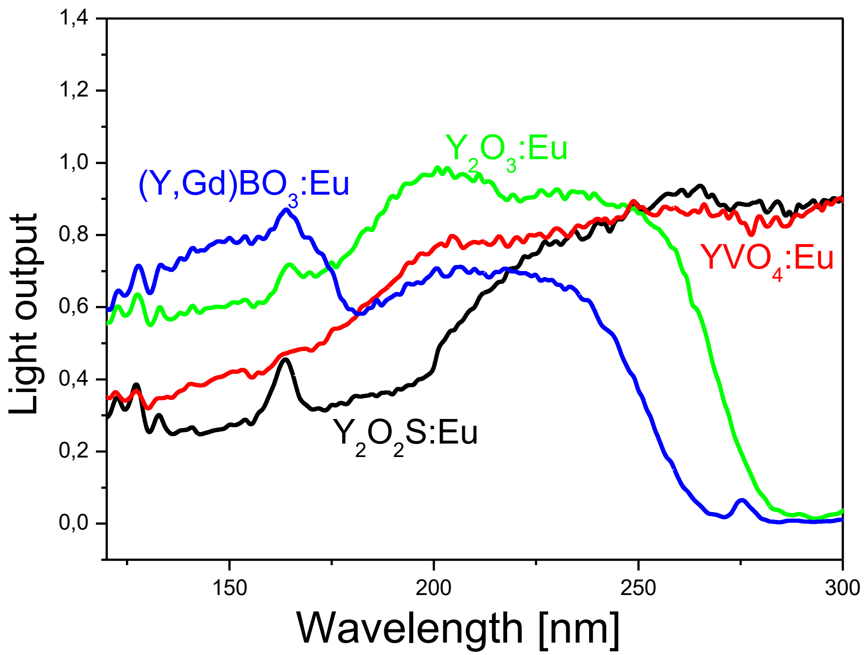


Phosphor	Colour point x, y	
(Y,Gd)BO_3:Eu	0.640	0.360
Y_2O_3:Eu	0.641	0.344
YVO_4:Eu	0.645	0.343
Y_2O_2S:Eu	0.650	0.342

Colour saturation: Y_2O_2S:Eu > YVO_4:Eu > Y_2O_3:Eu > (Y,Gd)BO_3:Eu

11.8 Red PDP Phosphors

Excitation spectra and VUV light output of Eu^{3+}-phosphors



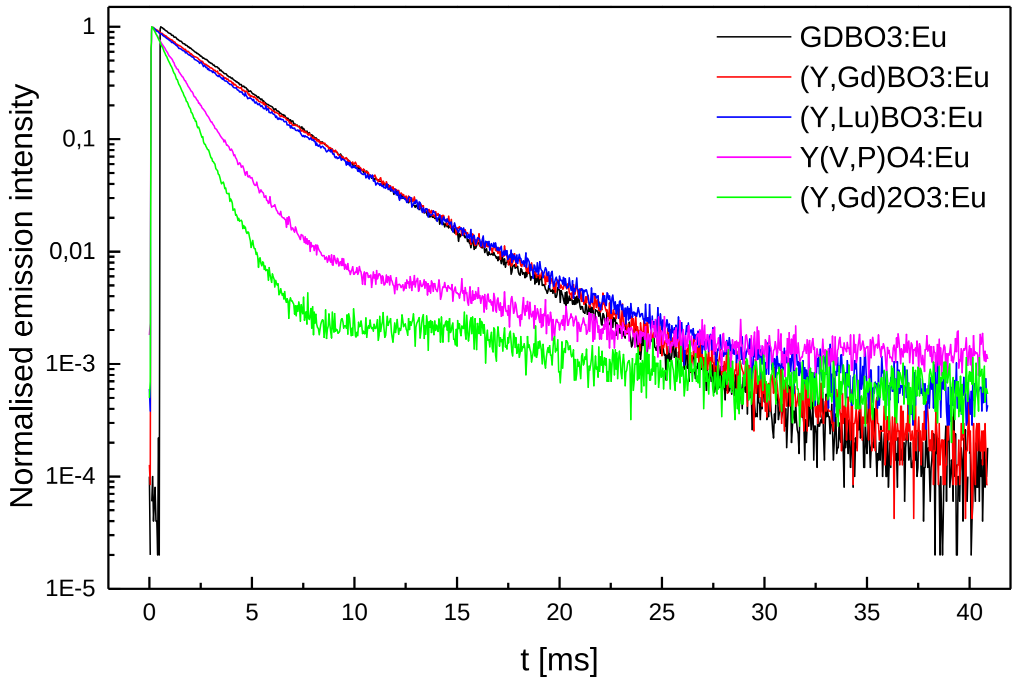
Phosphor	Light output LO 147 nm	172 nm
$(Y,Gd)BO_3$:Eu	0.78	0.75
Y_2O_3:Eu	0.60	0.69
YVO_4:Eu	0.41	0.50
Y_2O_2S:Eu	0.26	0.32

Efficiency ←

Phosphor	$(Y,Gd)BO_3$:Eu	Y_2O_3:Eu	YVO_4:Eu	Y_2O_2S:Eu
Band gap E_G	7.5 eV	5.6 eV	5.0 eV	4.4 eV

11.8 Red PDP Phosphors

Decay time of Eu^{3+}-phosphors



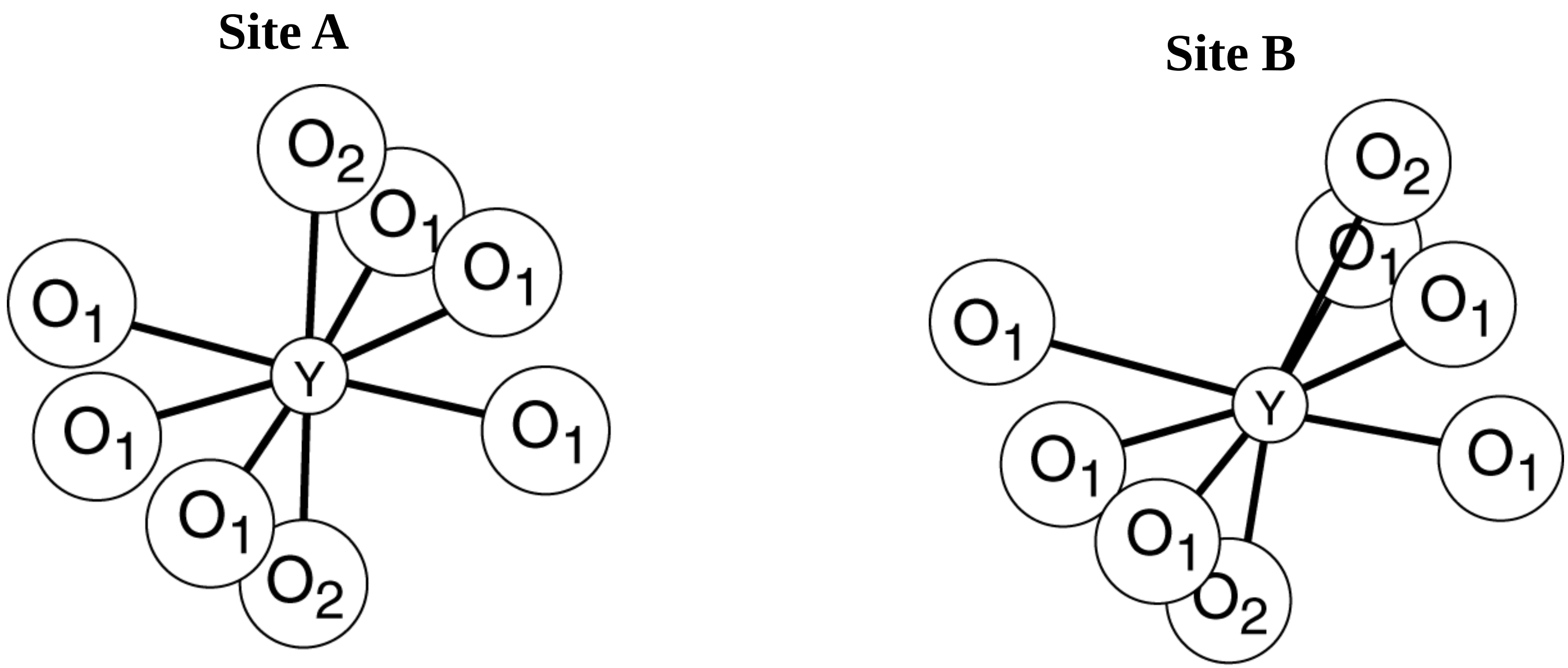
Phosphor	Decay time $\tau_{1/10}$ [ms] (254 nm excitation)
Y_2O_2S:Eu	1.0
Y_2O_3:Eu	2.5
YVO_4:Eu	3.5
$(Y,Gd)BO_3$:Eu	8.5

Decay time decreases with increasing deviation of the inversion symmetry of the crystallographic site of Eu^{3+}

⇒ Relaxation of selection rules!

11.8 Red PDP Phosphors

Local symmetry of Y^{3+} and Eu^{3+} in YBO_3 (vaterite)



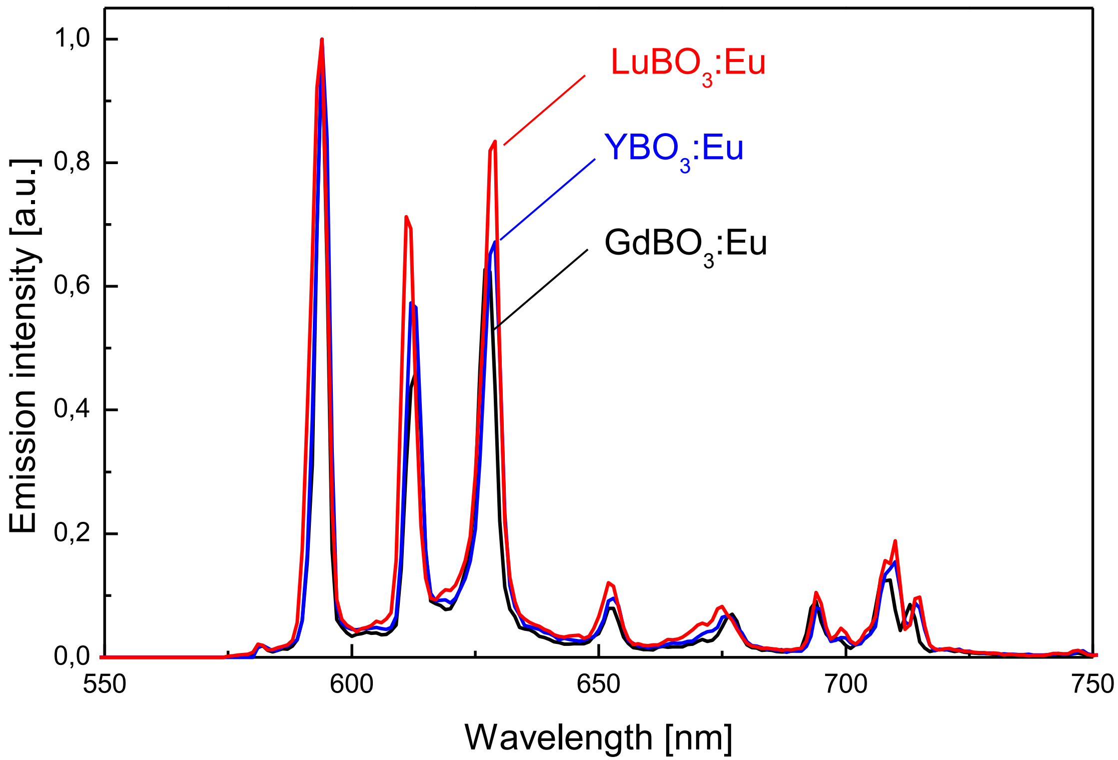
Lit.: J. Solid State Chem. 128 (1997) 261-266

- **Location A: Slight deviation from the S_6 symmetry (C_3)**
- **Location B: Strong deviation from the S_6 symmetry (C_3)**

⇒ $^5D_0$ - $^7F_{2,4}$ emission is observed due to the deviation of the S_6 symmetry

11.8 Red PDP Phosphors

Emission spectra of $LnBO_3$:Eu (vaterite)



585 nm	$^5D_0$ - $^7F_0$
594 nm	$^5D_0$ - $^7F_1$
612, 627 nm	$^5D_0$ - $^7F_2$
650 - 680 nm	$^5D_0$ - $^7F_3$
690 - 720 nm	$^5D_0$ - $^7F_4$

Cation	Radius* [Å]
Lu	1.00
Y	1.04
Gd	1.08
Eu	1.09

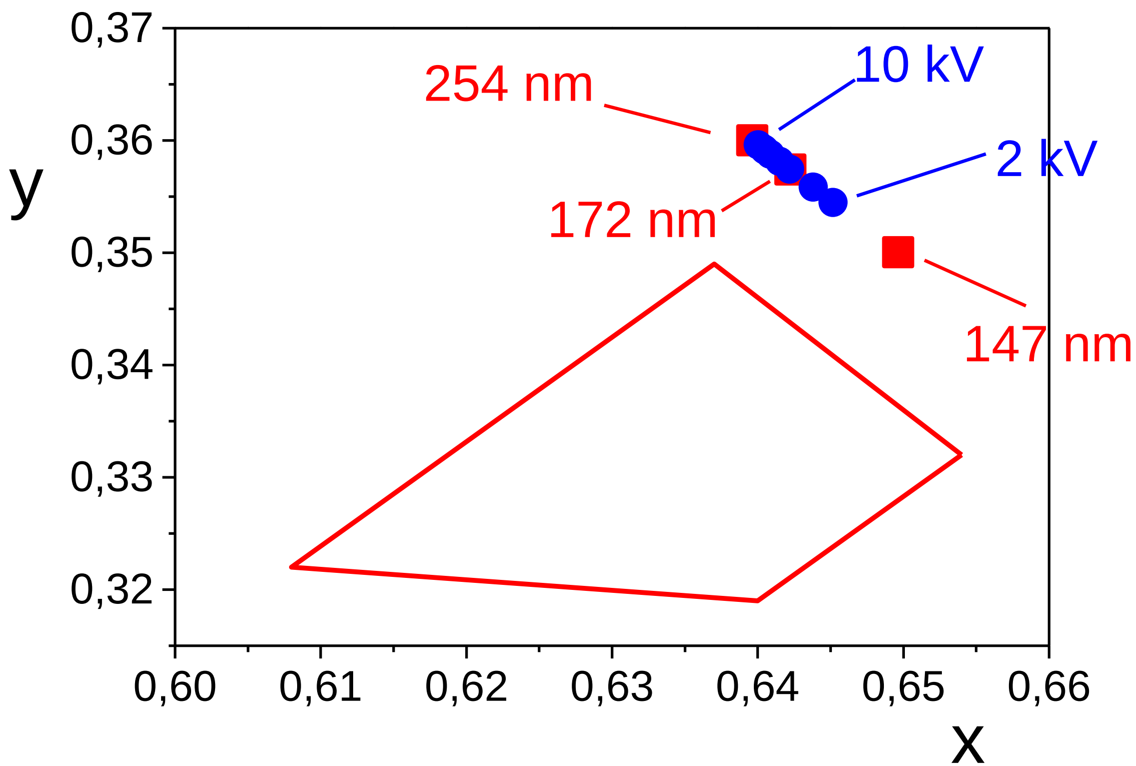
**for CN = 6*

Colour point shifts from orange to red in the series Gd^{3+}, Y^{3+}, Lu^{3+}

Distortion depends on $\Delta r[(Eu^{3+}) - r(Me^{3+})]$

11.8 Red PDP Phosphors

CIE1931 Colour point of $(Y,Gd)BO_3:Eu^{3+}$



Feldman equation:
$R = 0.046 * U^{5/3}/\rho$ [µm]

$\rho(Y,Gd)BO_3:Eu = 5.2\ g/cm^3$

⇒ 10 kV R~ 500 nm

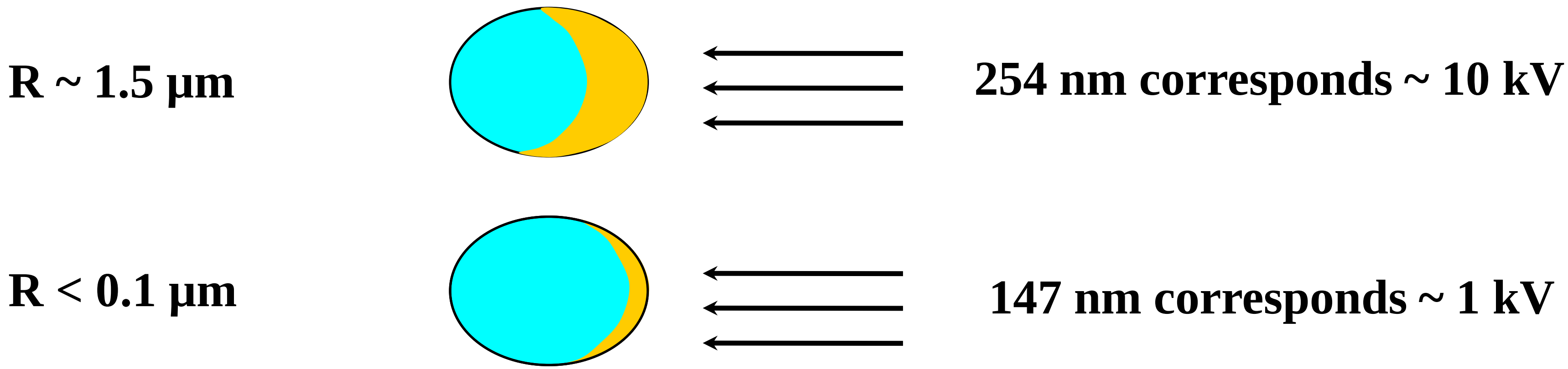
2 kV R ~ 30 nm

Colour point as a function of excitation energy

- **Charge-transfer excitation 254 nm ⇒ x = 0.638, y = 0.360**
- **Band excitation 147 nm ⇒ x = 0.646, y = 0.349**

11.8 Red PDP Phosphors

Penetration depth of VUV radiation in matter



Small excitation volume

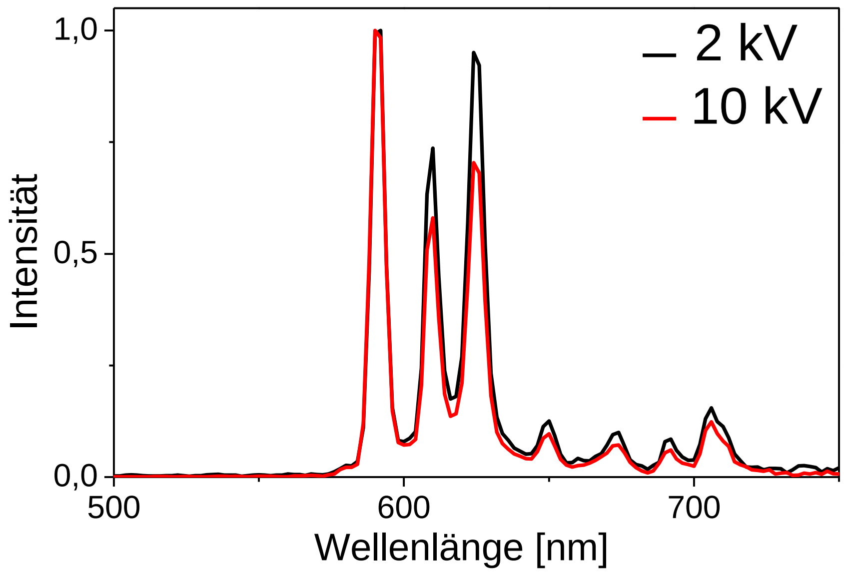
⇒ PDP phosphors are highly charged:

- **Saturation**
- **Strong aging**
- **Surface layer of the particles must be pure phase and highly crystalline**

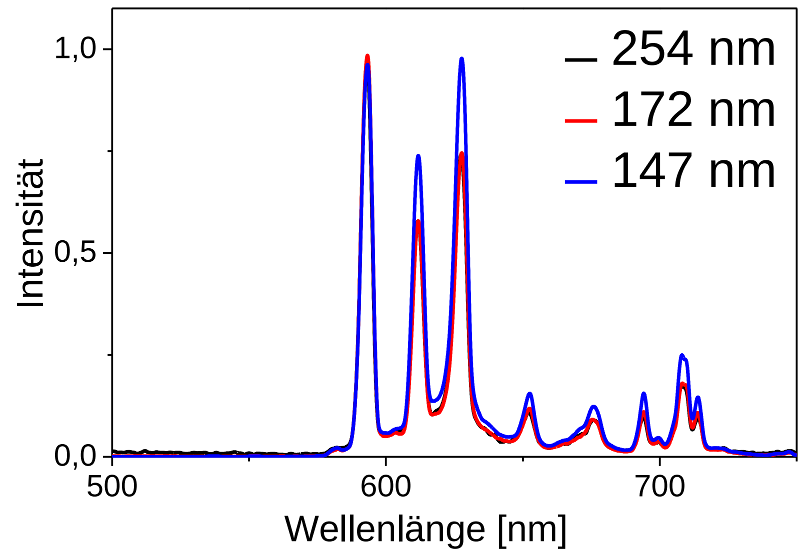
11.8 Red PDP Phosphors

Emission spectra of (Y,Gd)BO_3:Eu

Cathodoluminescence



Photoluminescence

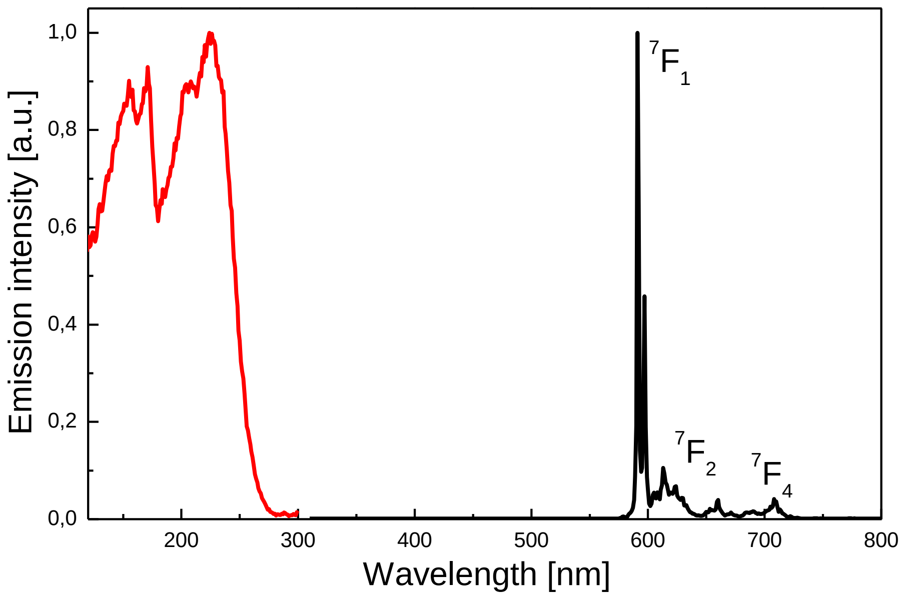


Emission spectrum = f(excitation energy)

11.8 Red PDP Phosphors

Colour points of Eu^{3+}-phosphors

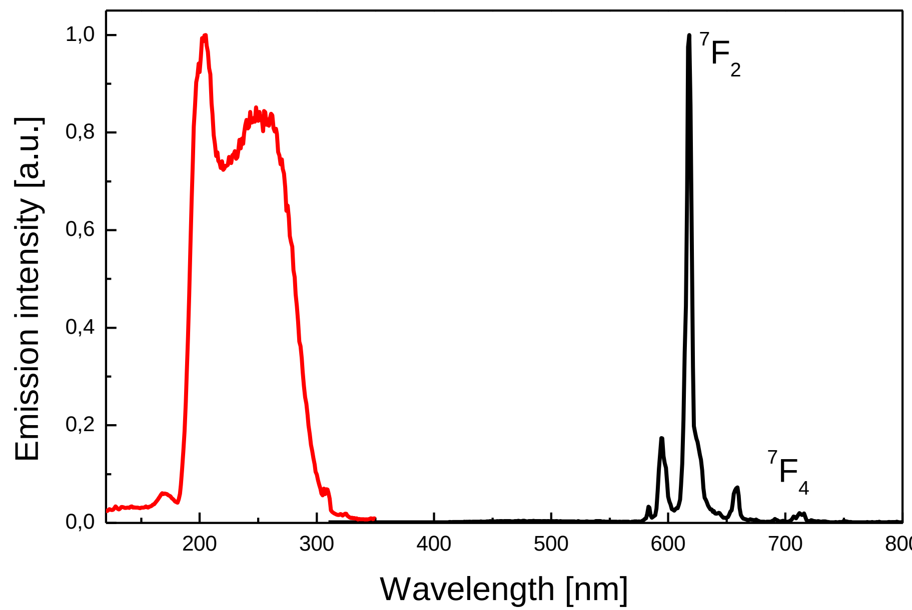
$LuBO_3$:Eu



Trigonal, D_{3d} symmetry

x = 0.61, y = 0.38

CaO:Eu

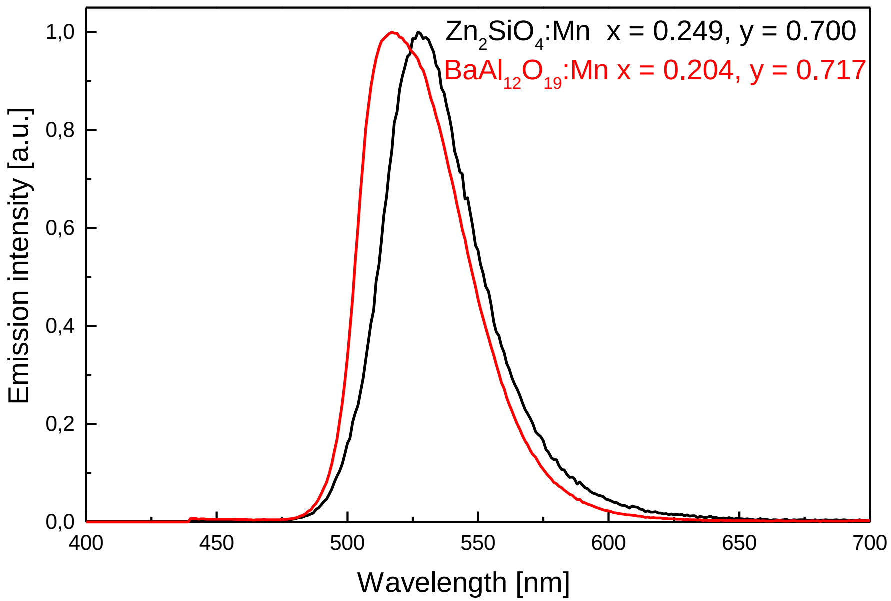


Cubic, O_h symmetry
Cation vacancies
x = 0.64 , y = 0.33

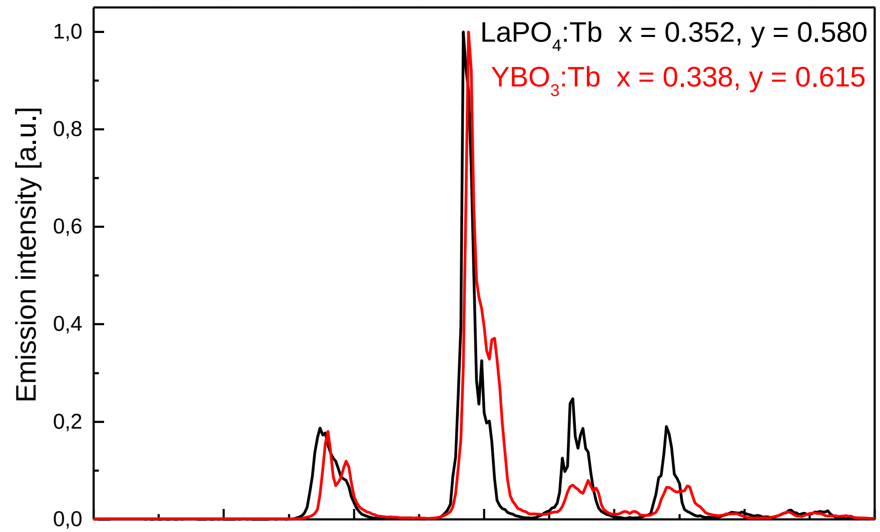
11.9 Green PDP Phosphors

Emission spectra and decay times of Mn^{2+}- and Tb^{3+}-phosphors

Mn^{2+}-phosphors



Tb^{3+}-phosphors



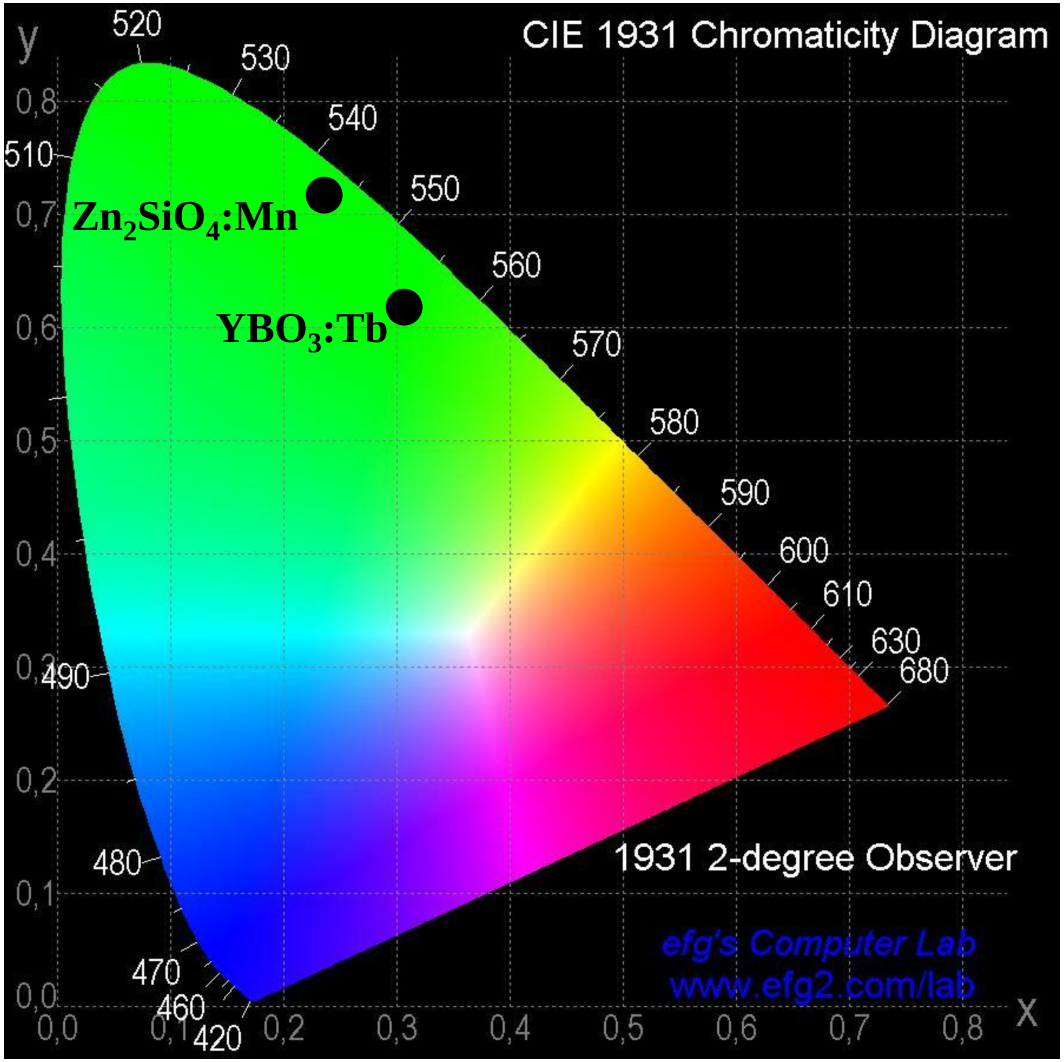
Host lattice	$\tau_{1/10}$ [ms]	Host lattice	$\tau_{1/10}$ [ms]
Zn_2SiO_4	5 - 40	$LaPO_4$	5.5
$BaAl_{12}O_{19}$	5 - 40	$CeMgAl_{11}O_{19}$	7.0
$BaMgAl_{10}O_{17}$	5 - 40	YBO_3	8.5

$\tau_{1/10}$ = f(Mn^{2+}-concentration)

$\tau_{1/10}$ = f(host lattice)

11.9 Green PDP Phosphors

Colour saturation



Mn^{2+}-phosphors

y- coordinate: 0.69 - 0.73

Tb^{3+}-phosphors

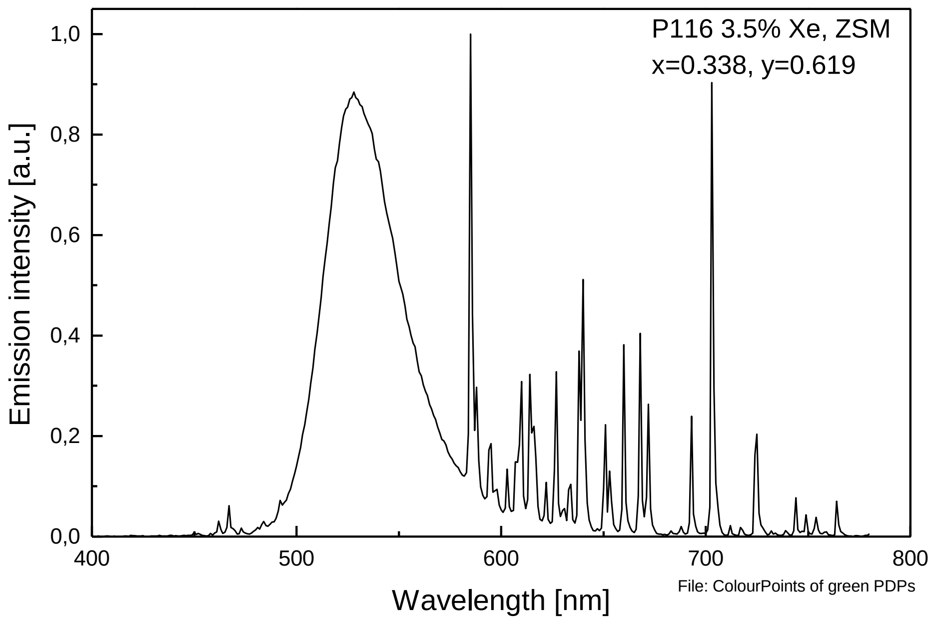
y- coordinate : 0.58 - 0.62

Tb^{3+} has emission-line multiplets at 590 and 620 nm

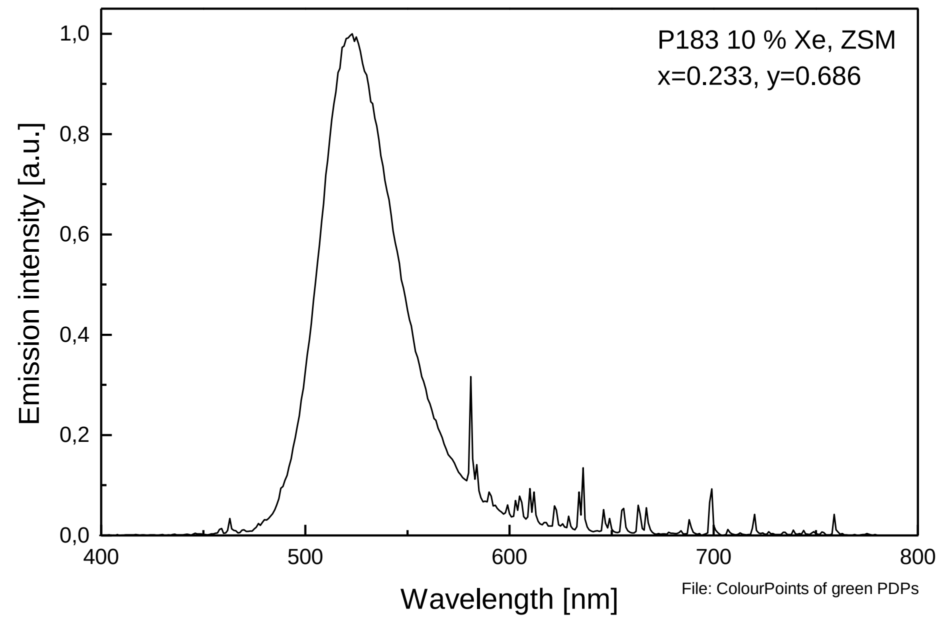
11.9 Green PDP Phosphors

Spectra of the green PDP-pixels with Zn_2SiO_4:Mn

3.5% Xe



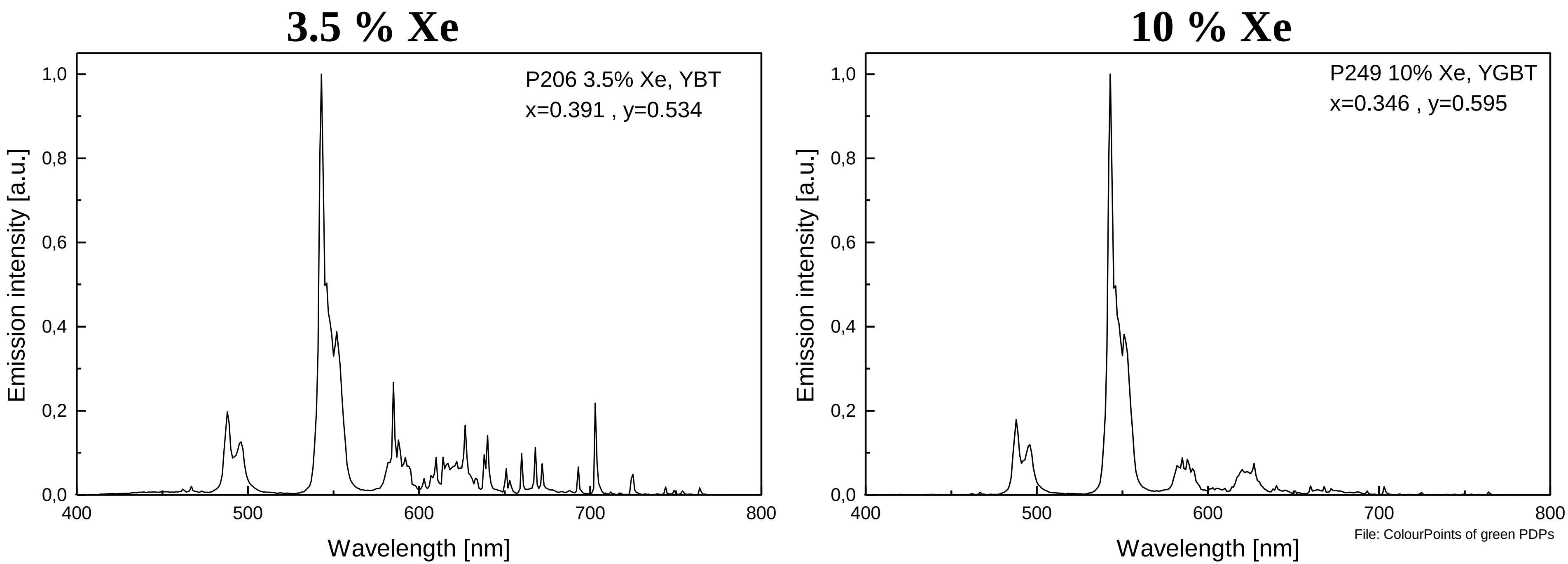
10% Xe



Zn_2SiO_4:Mn	CIE1931 colour point x, y	
• as a powder	0.25, 0.70	
• in PDP 10% Xe	0.23, 0.69	
• in PDP 3.5% Xe	0.34, 0.62	similar to CRT

11.9 Green PDP Phosphors

Spectra of the green PDP-pixels with $(Y,Gd)BO_3$:Tb

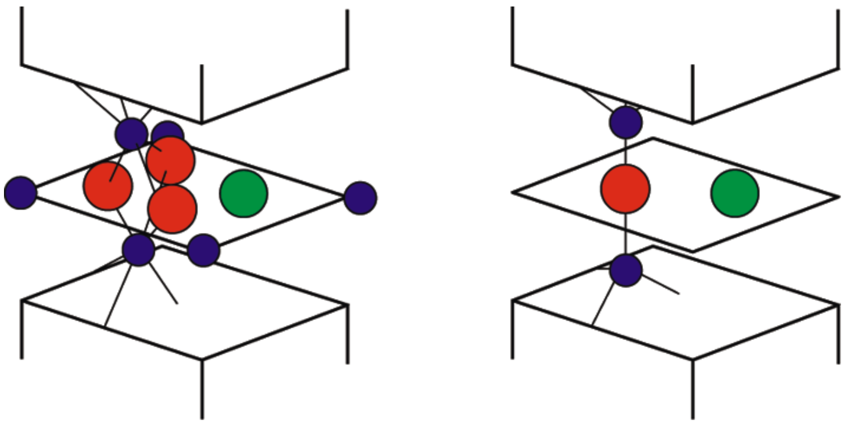


$(Y,Gd)BO_3$:Tb	CIE 1931 colour point x. y	
• as a powder	0.34, 0.62	
• in PDP 10% Xe	0.35, 0.60	similar to CRT
• in PDP 3.5% Xe	0.39, 0.53	

11.10 Blue PDP Phosphors

Phosphors in the system MeO-MgO-Al_2O_3

Construction of the intermediate layer



magnetoplumbite β-alumina

Me = Ba (1.34 Å)	**BAM**
• $BaMgAl_{10}O_{17}$	β-alumina
• $BaMg_3Al_{14}O_{25}$	β-alumina
Me = Sr (1.12 Å)	**SAM**
• $SrMgAl_{10}O_{17}$	β-alumina
• $Sr_2MgAl_{22}O_{36} = SrMgAl_{10}O_{17} + SrAl_{12}O_{19}$ (β-alumina + magnetoplumbite)	
Me = Ca (0.99 Å)	**CAM**
• $CaMgAl_{14}O_{23}$	magnetoplumbite
• $CaMg_2Al_{16}O_{27}$	magnetoplumbite
• $CaMgAl_{10}O_{17}$ (unstable → magnetoplumbite)	β-alumina

11.10 Blue PDP Phosphors

Structure and Composition of $BaMgAl_{10}O_{17}$

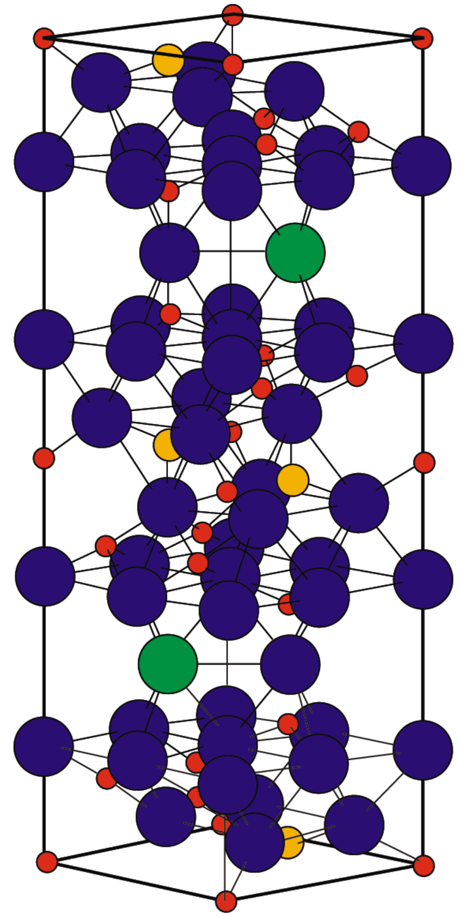
Localization of the europium

- Eu^{2+} Intermediate layers
- Eu^{3+} Spinel blocks

Potential secondary phases

- Al_2O_3
- $BaAl_2O_4$
- $MgAl_2O_4$
- $EuAl_{11}O_{18}$
- $EuAlO_3$
- $EuMgAl_{11}O_{19}$
- $Ba_{0.75}Al_{11}O_{17.25}$
- ….

Unit cell



Spinel block $MgAl_{10}O_{16}$

Intermediate layer BaO

Spinel block $MgAl_{10}O_{16}$

Intermediate layer BaO

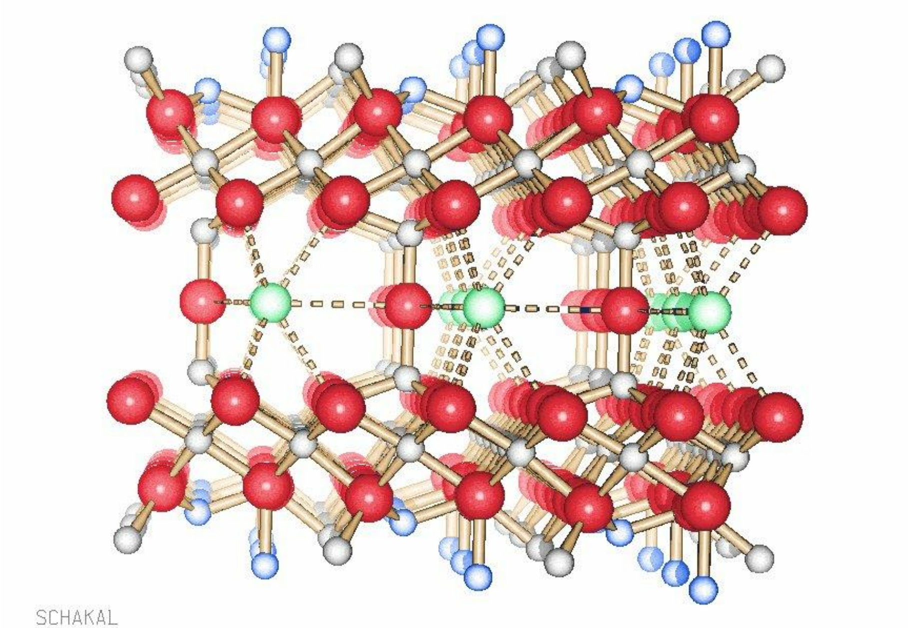
Spinel block $MgAl_{10}O_{16}$

Isostructural to β-alumina $NaAl_{11}O_{17}$

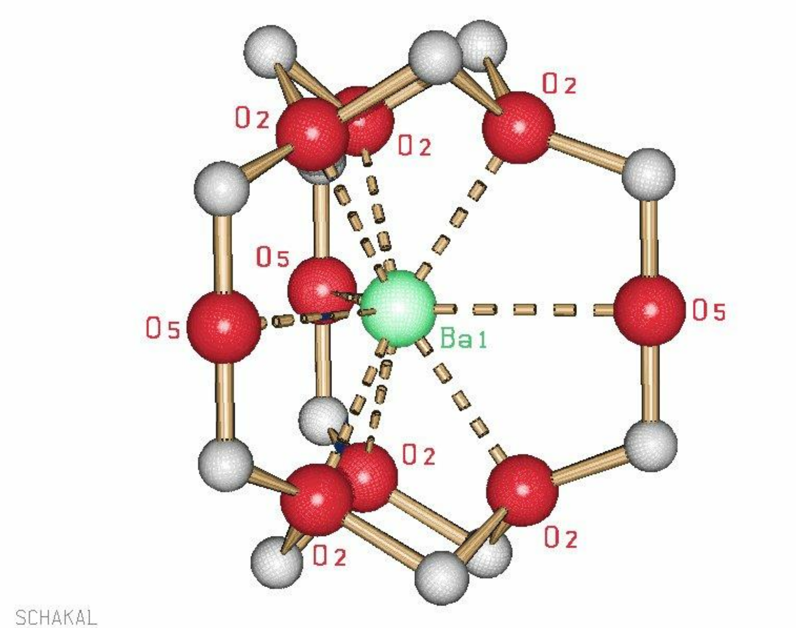
11.10 Blue PDP Phosphors

Structure of $BaMgAl_{10}O_{17}$

Layer structure



Ba^{2+} environment

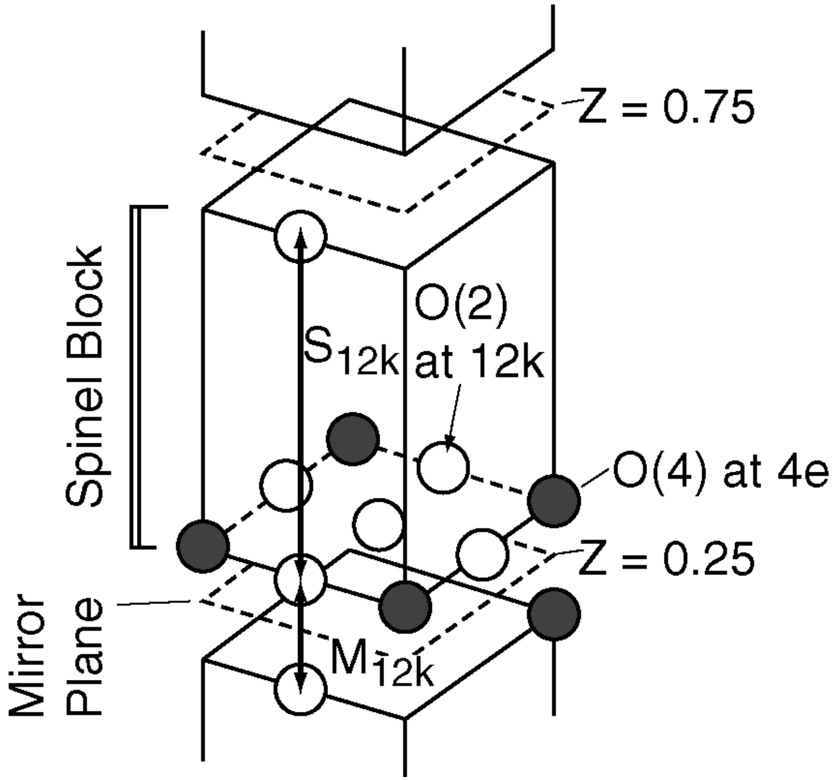


$Ba^{2+}(Eu^{2+})$ is nine-coordinate (tri-capped trigonal prism D_{3h})

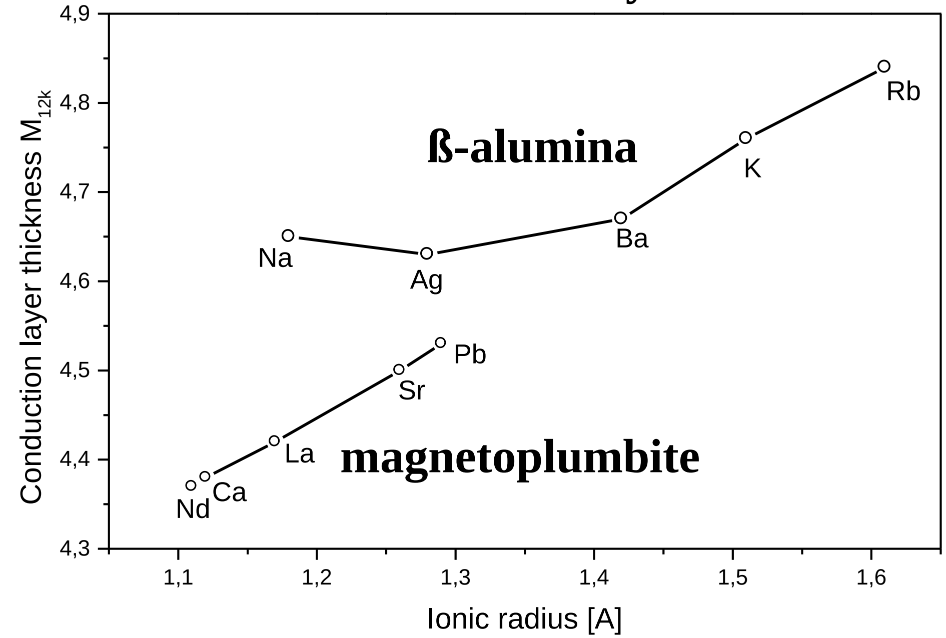
⇒ Relative small crystal field splitting ⇒ Blue emission band

11.10 Blue PDP Phosphors

Thermodynamic stability of the β-alumina phase



Structural influence of the cations in the interlayer

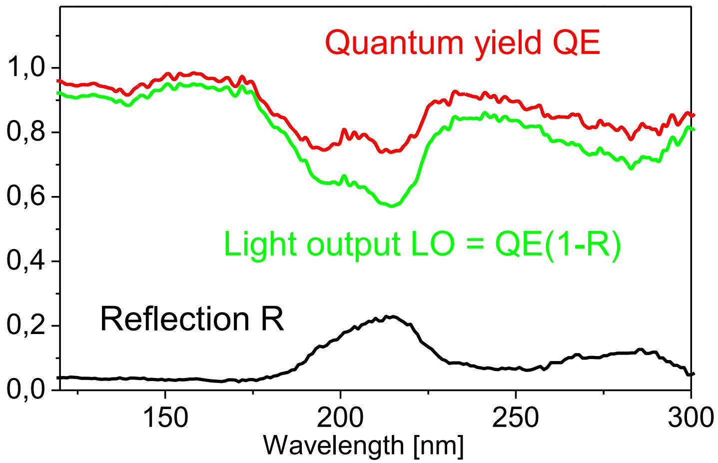


Stability limit of β-alumina phase lies at M_{12k} > 4.6 Å
Eu^{2+} (r_9 = 1.17 Å) is smaller than Sr^{2+} (r_9 = 1.26 Å)
Thus: Eu^{2+}-ion incorporation destabilizes the ß-alumina phase
Incorporation of large cations stabilizes the ß-alumina phase (Rb^+, K^+)

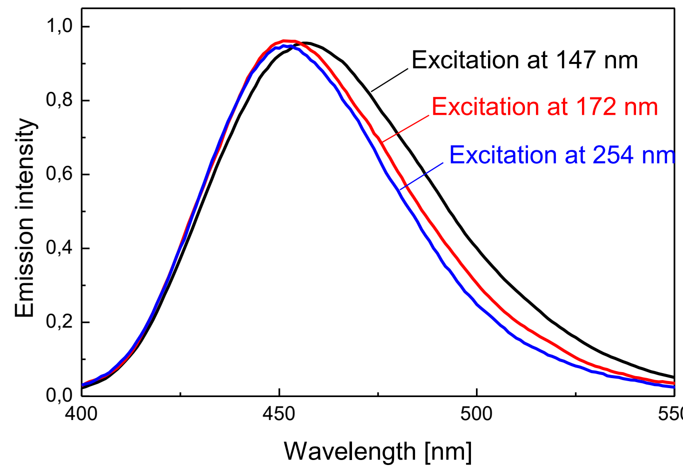
11.10 Blue PDP Phosphors

Luminescence spectra of $BaMgAl_{10}O_{17}:Eu^{2+}$

Efficiency and reflection



Emission spectra as a function of excitation energy



VUV absorption and high quantum yield close to 100 %

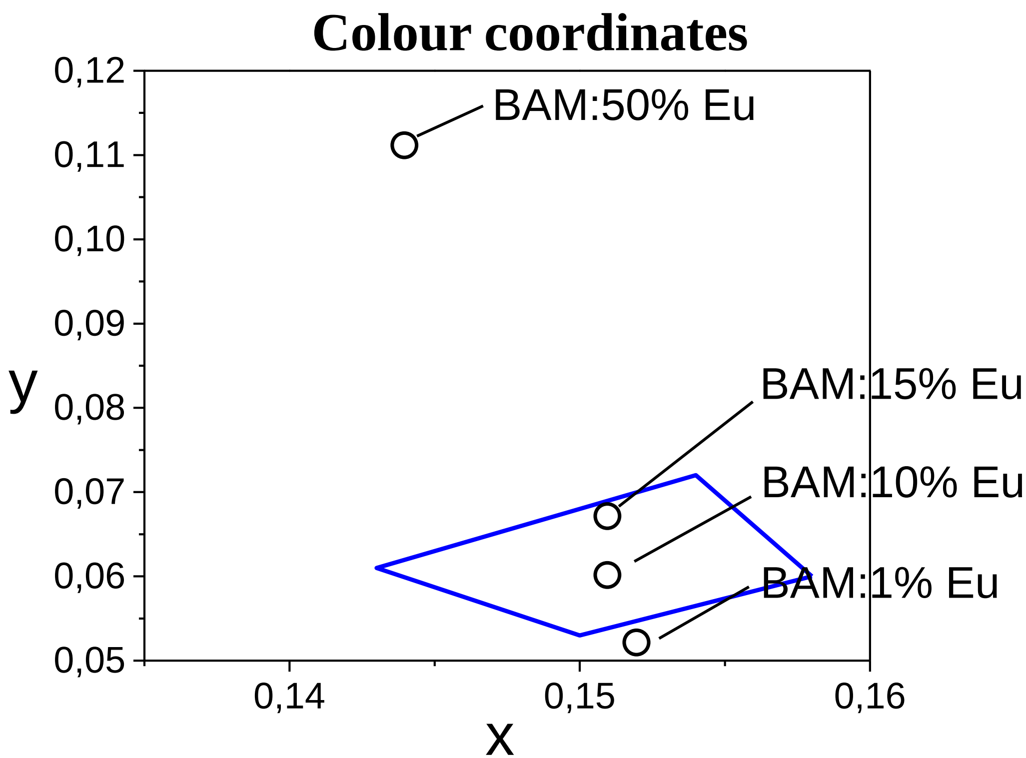
Half-width of the emission band increases with the excitation energy

11.10 Blue PDP Phosphors

CIE1931 Colour point: Influence of the Eu^{2+}-concentration

Cation	Radius [Å]
• Ba^{2+}	1.34
• Sr^{2+}	1.12
• Ca^{2+}	0.99
• Eu^{2+}	1.09

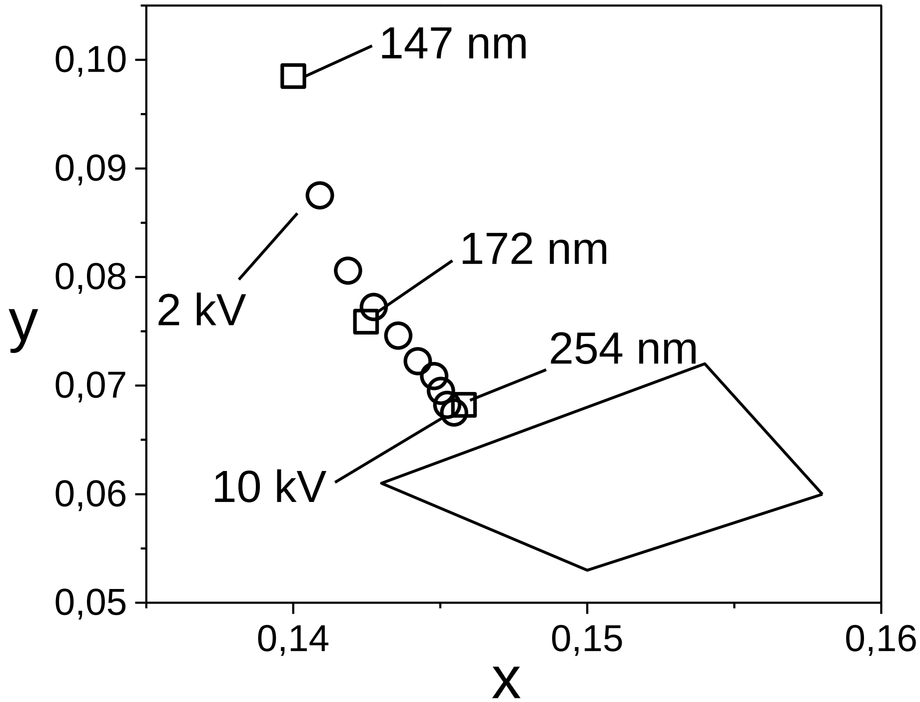
BAM:x%Eu^{2+}	x, y
• 1%	0.152, 0.052
• 10%	0.151, 0.060
• 15%	0.151, 0.067
• 50%	0.144, 0.111



Green shift of the colour point by increasing the Eu^{2+} concentration ⇒ Incorporation of Eu^{2+} destabilizes the BAM phase and leads to the formation of $BaAl_2O_4$:Eu

11.10 Blue PDP Phosphors

CIE1931 Colour point: Influence of the excitation energy



Feldman equation (simplified)

R = 0.046*$U^{5/3}$/ρ [µm]

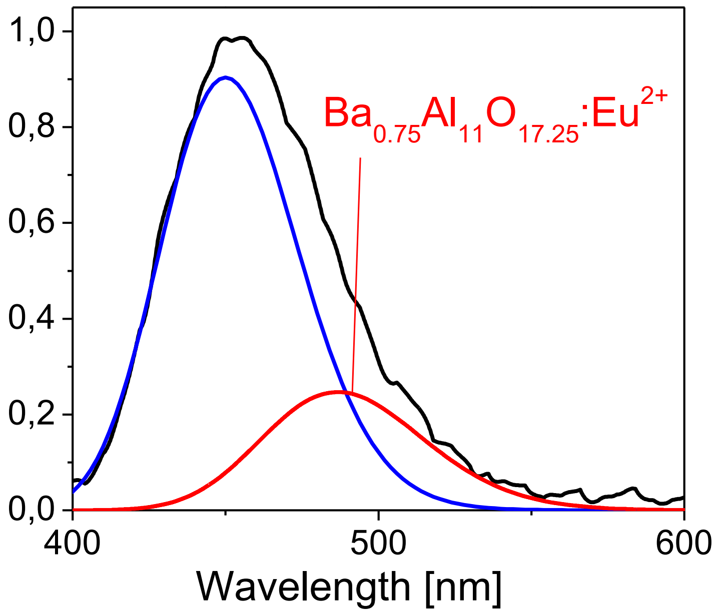
254 nm exc. x = 0.146, y = 0.068 ~ 10 kV electron (400 nm)
Activator excitation ⇒ high penetration depth

147 nm exc. x = 0.140, y = 0.098 ~ 2 kV electron (30 nm)
Band excitation ⇒ low penetration depth

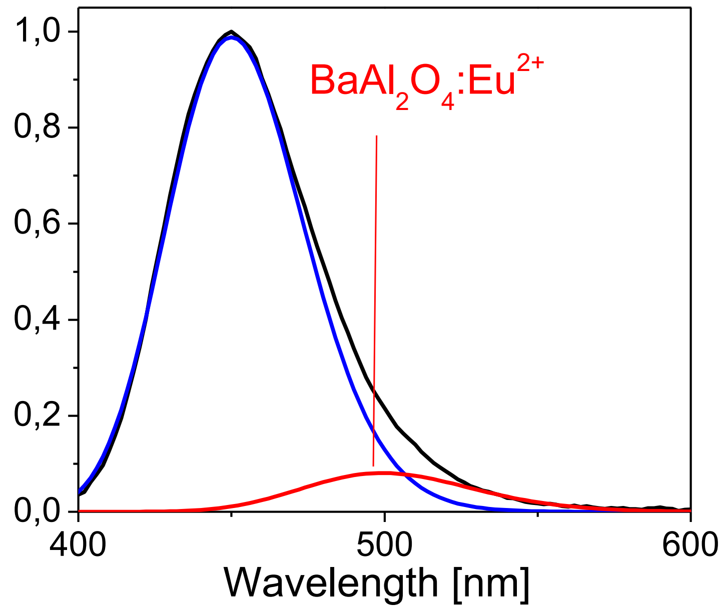
11.10 Blue PDP Phosphors

Cathodoluminescence of $BaMgAl_{10}O_{17}:Eu^{2+}$

2 kV excitation (surface)



10 kV excitation (volume)

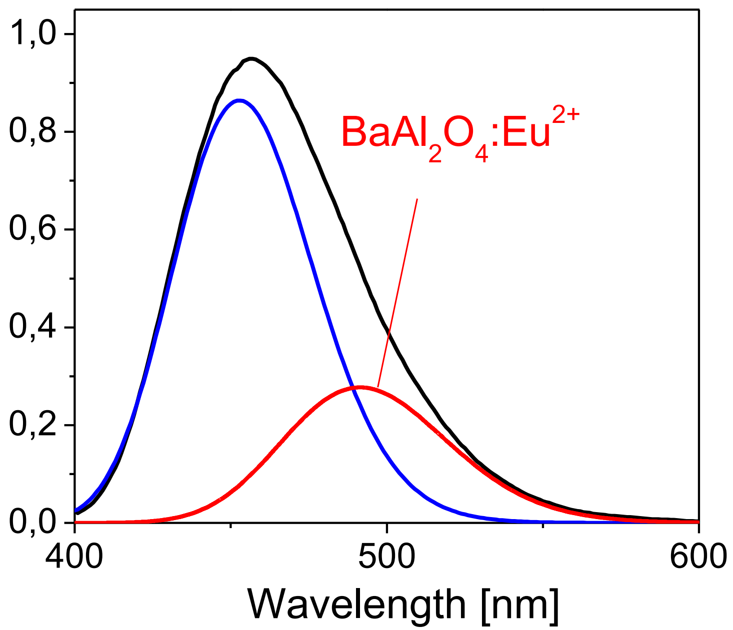


The secondary Eu^{2+} comprising Barium aluminate phases show up in the emission spectrum at low-voltage excitation < 20 kV!

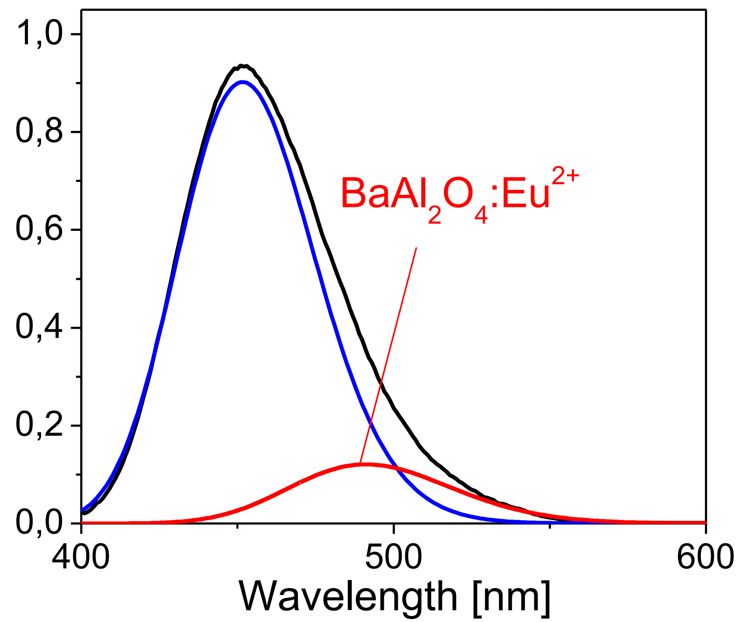
11.10 Blue PDP Phosphors

Photoluminescence of $BaMgAl_{10}O_{17}:Eu^{2+}$

147 nm excitation (surface)



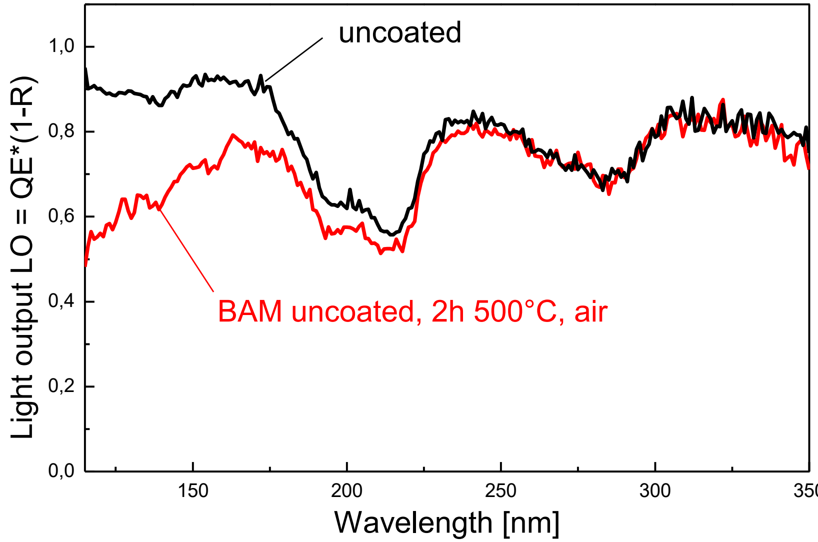
254 nm excitation (volume)



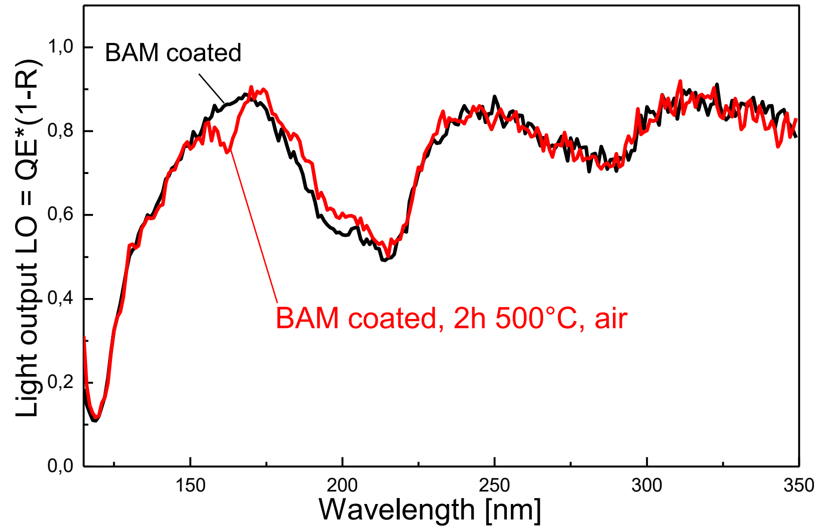
11.10 Blue PDP Phosphors

$BaMgAl_{10}O_{17}:Eu^{2+}$: Stability enhancement by particle coating

Excitation spectra of uncoated powderer



Excitation spectra of coated powder



Particle coating consists of an inert material that acts as a barrier for

a) Oxygen — **No thermal degradation**

b) 74 nm (147 nm) radiation — **Reduced photodegradation**

Coating materials: Al_2O_3, SiO_2, MgO, $MgAl_2O_4$, $AlPO_4$, $Ca_2P_2O_7$, Ca-PP

11.11 Status and Outlook

Comparison of CRTs and PDPs (Status 2008)

	PDP-TV	CRT-TV
Display diagonal	80 cm - 750 cm (32" - 300")	max. 90 cm (max. 36")
Luminance (1% white display)	100 - 150 Cd/m^2	100 - 130 Cd/m^2
Peak luminance (white display)	1000 Cd/m^2	500 Cd/m^2
Efficiency	3 – 5 lm/W	2 - 3 lm/W
Power consumption in typical TV operation	150 - 300 W	200 - 300 W
Lifetime	> 30000 h	> 30000 h
Weight	20 - 30 kg (42”)	≈ 80 kg (36")
Thickness	< 10 cm	≥ 60 cm (36")

11.11 Status and Outlook

Future measures to improve the image quality of PDPs

Gas discharge

- Higher Xe partial pressure (higher driving voltage)
- Optimization of the surfaces (materials with a high γ-coefficient)

Cell geometry and optics

- Improving the conversion of generated VUV photons
- Improving the light out-coupling to the front plate (reflector layers)
- Increasing the contrast: doping of screen’s glass, colour filters, black matrix

Phosphors

- Improving the photostability of the blue phosphor
- Shortening of the decay of the green phosphor
- Improvement of the colour point and shortening of the decay of the red phosphor
- Increasing the contrast of RGB phosphors