



2014 DOE Solid-State Lighting R&D Workshop

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NEW EFFICIENT, COMPACT VEHICULAR LIGHTING SYSTEM USING HIGH-POWER SEMICONDUCTOR LASER DIODES

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**BMW
GROUP**



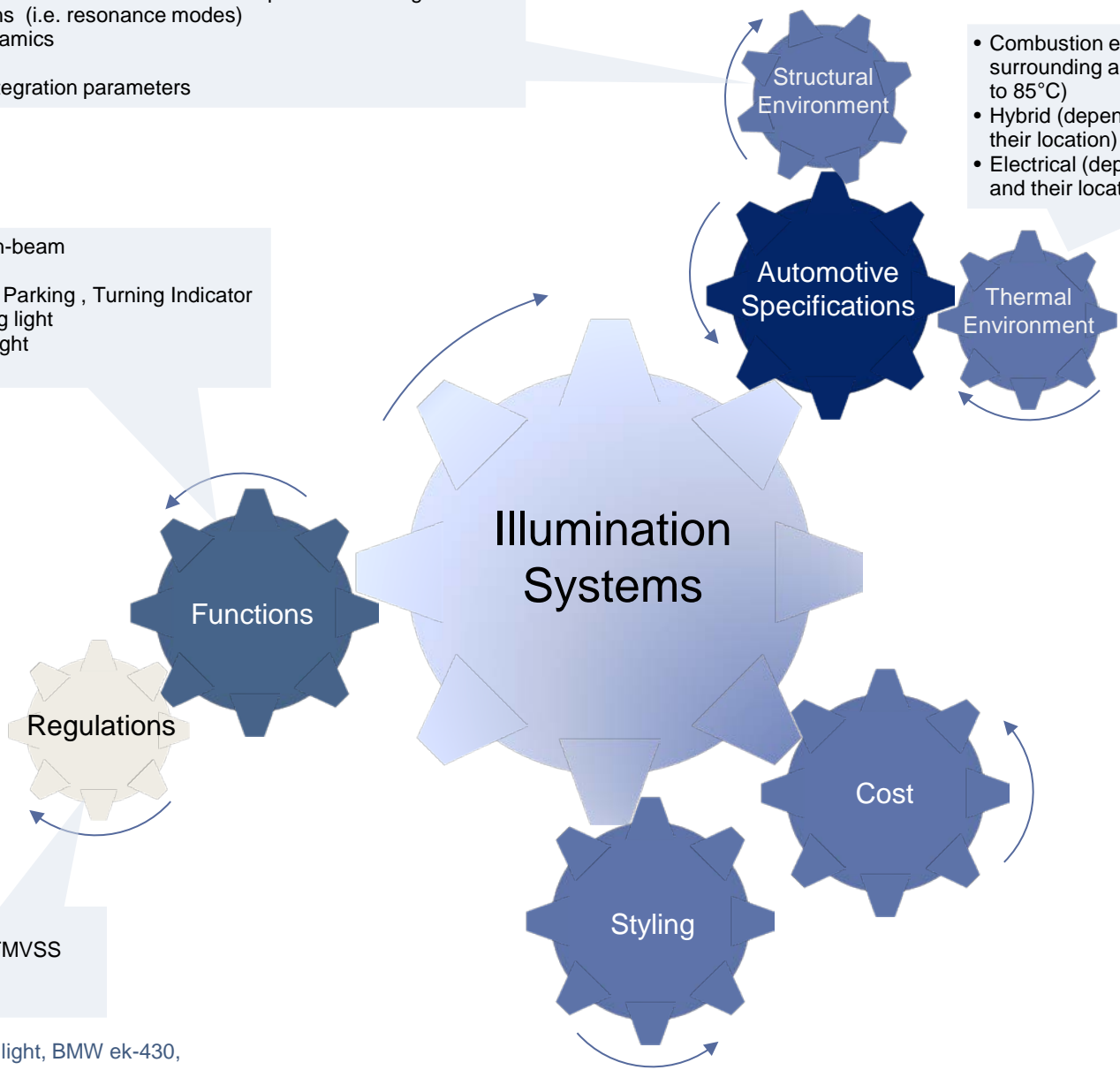
VEHICULAR LIGHTINGS SYSTEMS



- Weight
- Dimensions allocated to the headlamp within the target car
- Vibrations (i.e. resonance modes)
- Aerodynamics
- Safety
- Other integration parameters

- Combustion engine (typ. temperature surrounding a headlamp ranges from -40°C up to 85°C)
- Hybrid (depends on the batteries efficiency and their location)
- Electrical (depends on the batteries efficiency and their location)

- Low-beam, high-beam
- Fog lamps
- Cornering light, Parking , Turning Indicator
- Daytime running light
- Adaptive headlight
- Motorway light

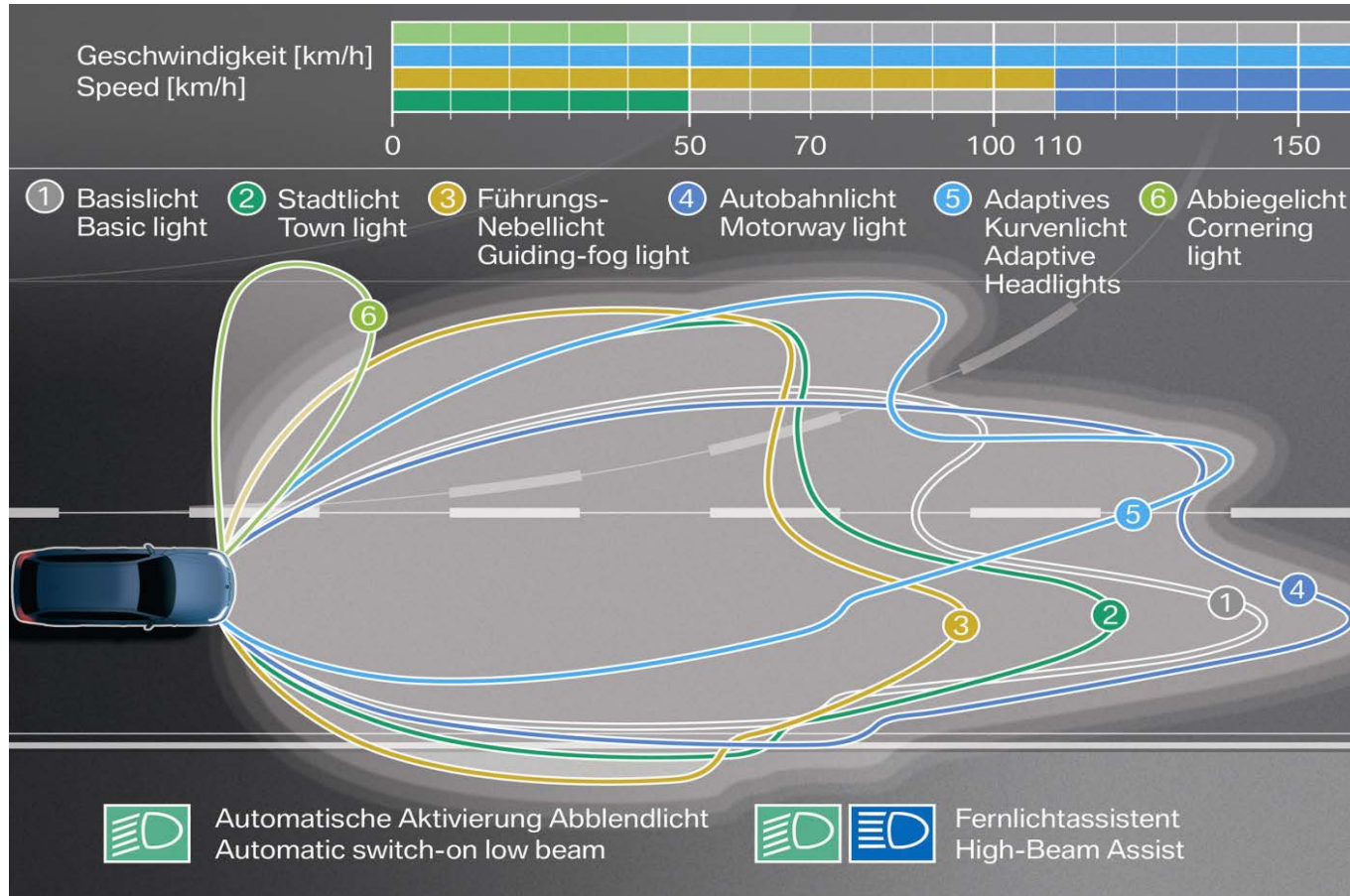


- Europe: ECE
- USA : SAE, FMVSS
- CN
- JPN

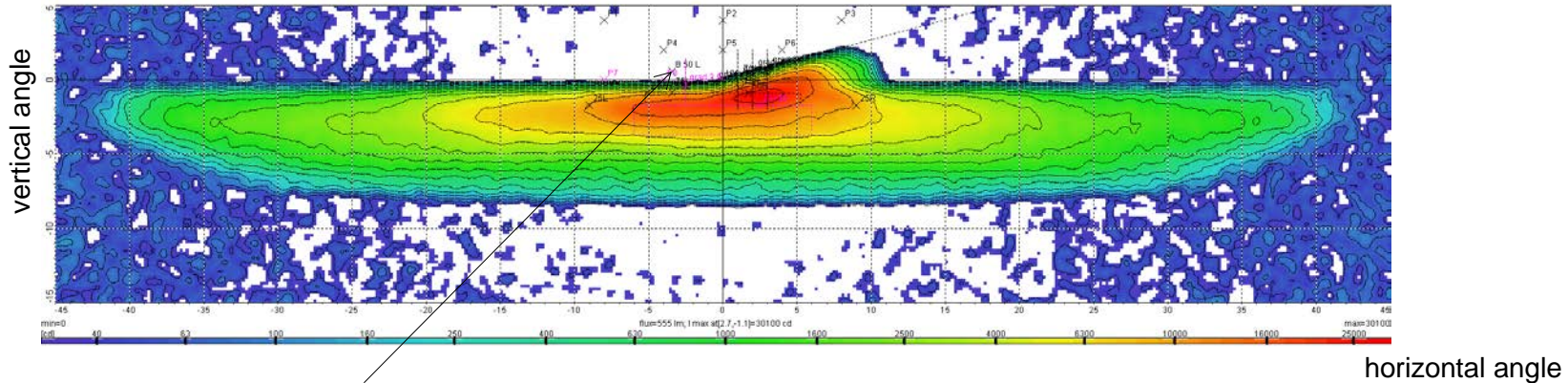
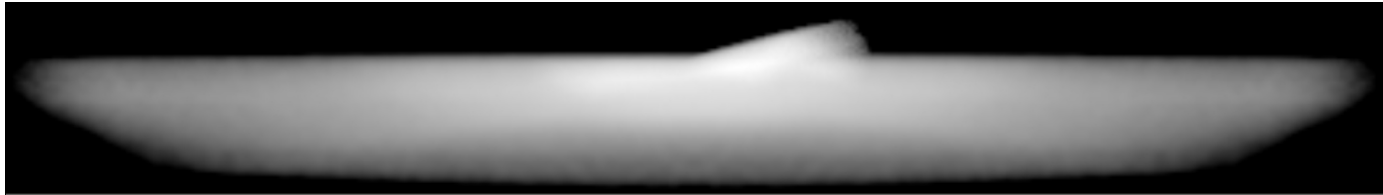
VISIBILITY & SAFETY: AUTOMOTIVE LIGHTING FUNCTIONS



Bird view representation of different lighting functions



EXAMPLE: ECE LOW-BEAM ILLUMINATION PATTERN



Luminous intensities are defined in a series of defined points with a tolerance

Regulation: ECE low beam R112 Class A headlamp ES							
name	value OK [lx/25]	min [lx/25]	max [lx/25]	test pos./area	H,H/V,V [deg]	found pos. [deg]	
B 50 L	0.01 OK	0.00	0.40	-3.4,0.6			
75R	24.63 OK	6.00	---	1.1,-0.6			
75L	5.32 OK	---	12.00	-3.4,-0.6			
50L	13.14 OK	---	15.00	-3.4,-0.9			
50R	40.35 OK	6.00	---	1.7,-0.9			
25L	16.41 OK	1.50	---	-9.0,-1.7			
25R	14.54 OK	1.50	---	9.0,-1.7			
HV	0.38 OK	---	0.70	0.0,0.0			
Z III	0.43 OK	---	0.70				1.1,0.3
Z IV	12.61 OK	2.00	---	-5.2,5.2 / -1.7,-0.9			-5.1,-0.9
Z I<20	37.96 ??	---	20.00	-6.0,6.0 / -3.7,-1.7			2.5,-1.7
P1+P2+P3	0.05 ??	0.30	---	-8.0,4.0 ; 0.0,4.0 ; 8.0,4.0			
P4+P5+P6	0.02 ??	0.60	---	-4.0,2.0 ; 0.0,2.0 ; 4.0,2.0			
P1	0.03 OK	---	0.70	-8.0,4.0			
P2	0.01 OK	---	0.70	0.0,4.0			
P3	0.01 OK	---	0.70	8.0,4.0			
P4	0.01 OK	---	0.70	-4.0,2.0			
P5	0.00 OK	---	0.70	0.0,2.0			
P6	0.00 OK	---	0.70	4.0,2.0			
P7	0.03 ??	0.10	0.70	-8.0,0.0			
P8	0.03 ??	0.20	0.70	-4.0,0.0			
grad H 5L-5R	0.74 OK	0.08	---	-5.0,5.0 / -0.2,-0.2			-0.5,-0.1
grad 2 5L	0.69 ??	0.13	0.40	-2.5,-2.5 / -1.5,1.5			-2.5,-0.3
grad 1R	0.85 OK	0.08	---	1.0,1.0 / -2.0,2.0			1.1,0.3
grad 2R	0.72 OK	0.08	---	2.0,2.0 / -2.0,2.0			2.1,0.7
grad 3R	0.62 OK	0.08	---	3.0,3.0 / -2.0,2.0			3.1,0.9

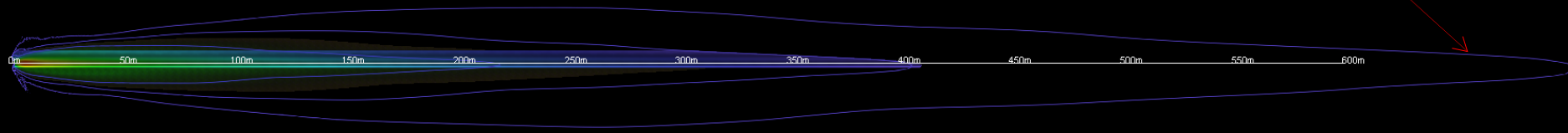
- Non-homogeneous light distribution in the far-field
- Hotspot Luminous Intensity ~ 30000cd
- Contrast ~ 20:1

MOTIVATIONS: VISIBILITY & SAFETY ENHANCEMENT



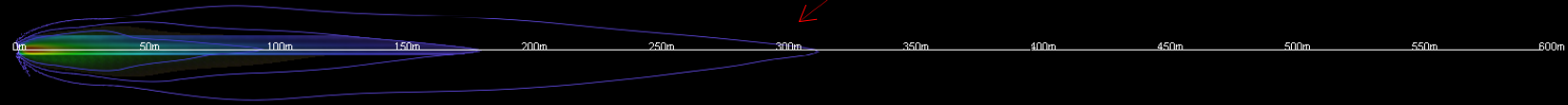
GOAL: Extending the visibility range to the maximum tolerated by the regulations

1 iso-lux line lies above 600m



1 iso-lux line at 300m

Visibility range corresponding to an LED high-beam



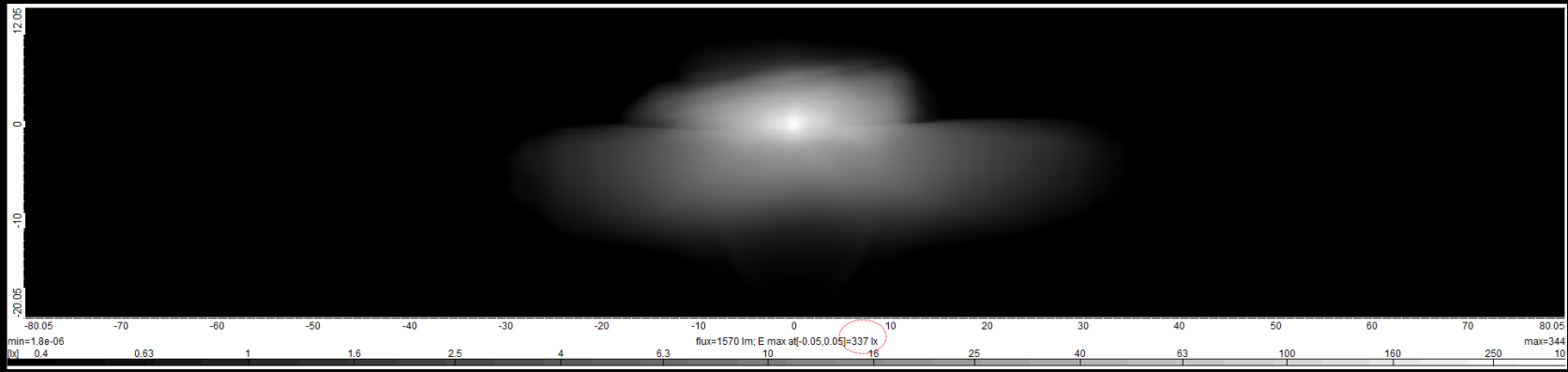
Visibility range corresponding to a low-beam



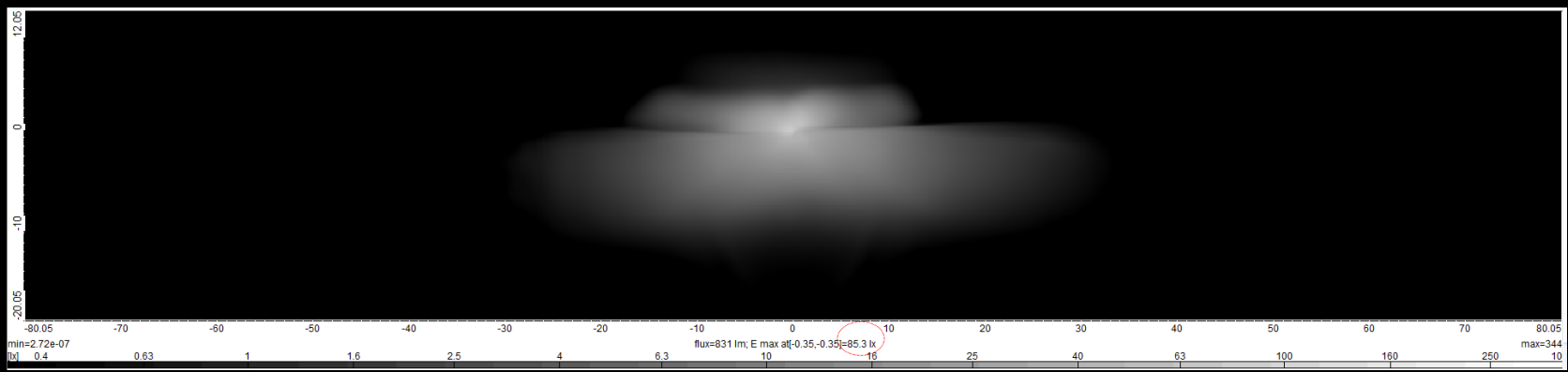
MOTIVATIONS: VISIBILITY & SAFETY ENHANCEMENT



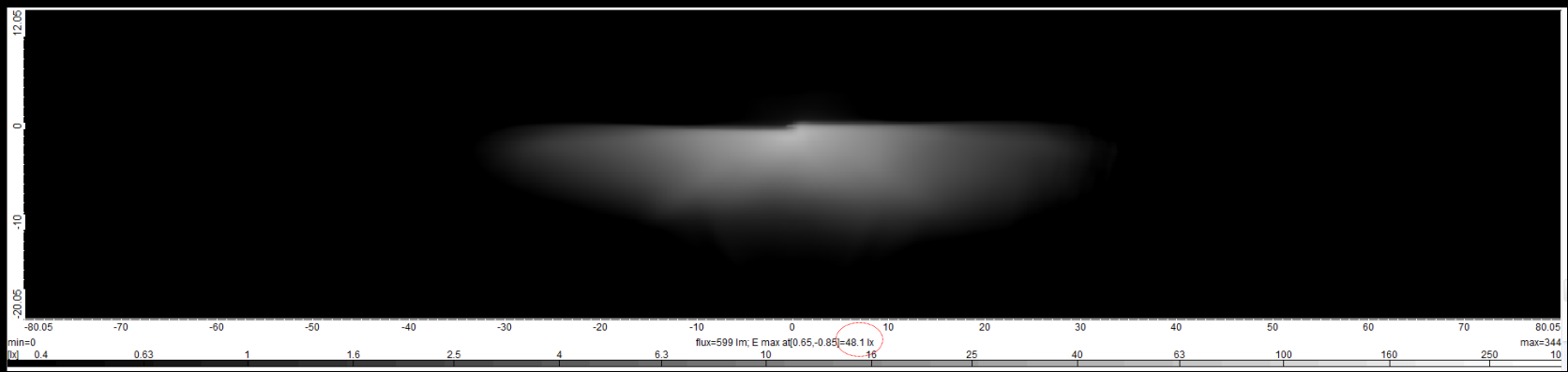
LED high-beam with the laser booster provides 337lux on the road



LED high-beam provides 85lux on the road



Low-beam provides 48lux on the road



MOTIVATIONS: VISIBILITY & SAFETY ENHANCEMENT



The central luminous intensity can be described as following *:

$$I_{hot-spot} = A N \eta L_{source}$$

$I_{hot-spot}$: luminous intensity of the hot-spot

A : lit aperture of the secondary optics

N : number of the emitting points (or chips)

η : 'collection' efficiency

(Ratio of the luminous flux on the road to the luminous flux produced by the light source)

L_{source} : luminance of the source

NOTE: the equation was derived assuming no aberrations

* J. Jiao and B. Wang, "Étendue Concerns for Automotive Headlamps Using White LEDs" in *Third International Conference on Solid State Lighting 234*; Proc. SPIE 5187, 234-242, (2004).



PRINCIPLE (I)

2 -- PHOSPHOR ASSEMBLY:

- Phosphor material:
- Cooling system of the phosphor to avoid limitations due local heating such temperature quenching.

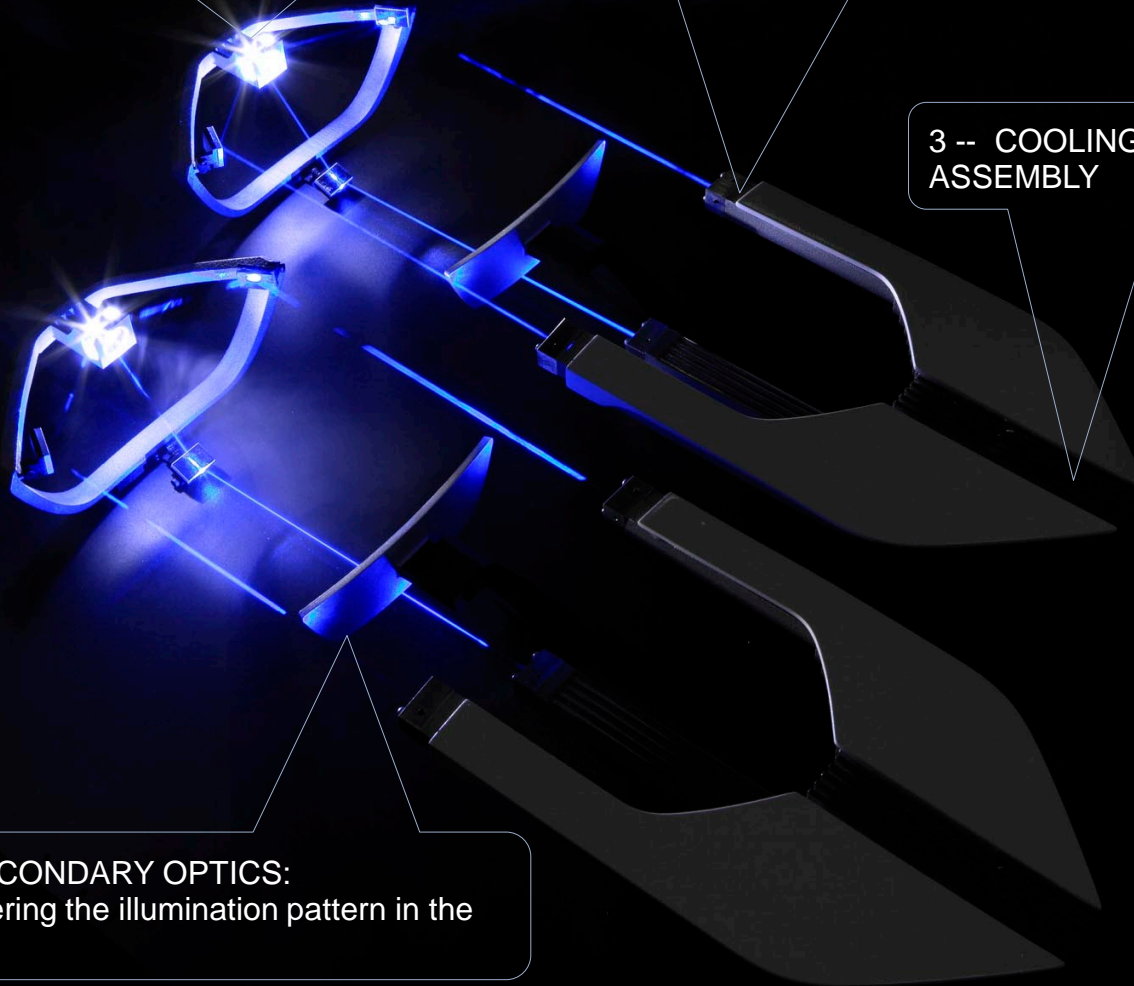
1-- LASER DIODE ASSEMBLY:

- High-power blue laser diode:
 - $440\text{nm} \leq \lambda \leq 460\text{nm}$ @ $-40^\circ\text{C} \leq T_o \leq 80^\circ\text{C}$
 - Power: $1\text{W} - 1.5\text{W}$ @ $-40^\circ\text{C} \leq T \leq 80^\circ\text{C}$
- Primary optics : Collimating/Finite Conjugate Lens

3 -- COOLING SYSTEM of the LD ASSEMBLY

4 -- SECONDARY OPTICS:

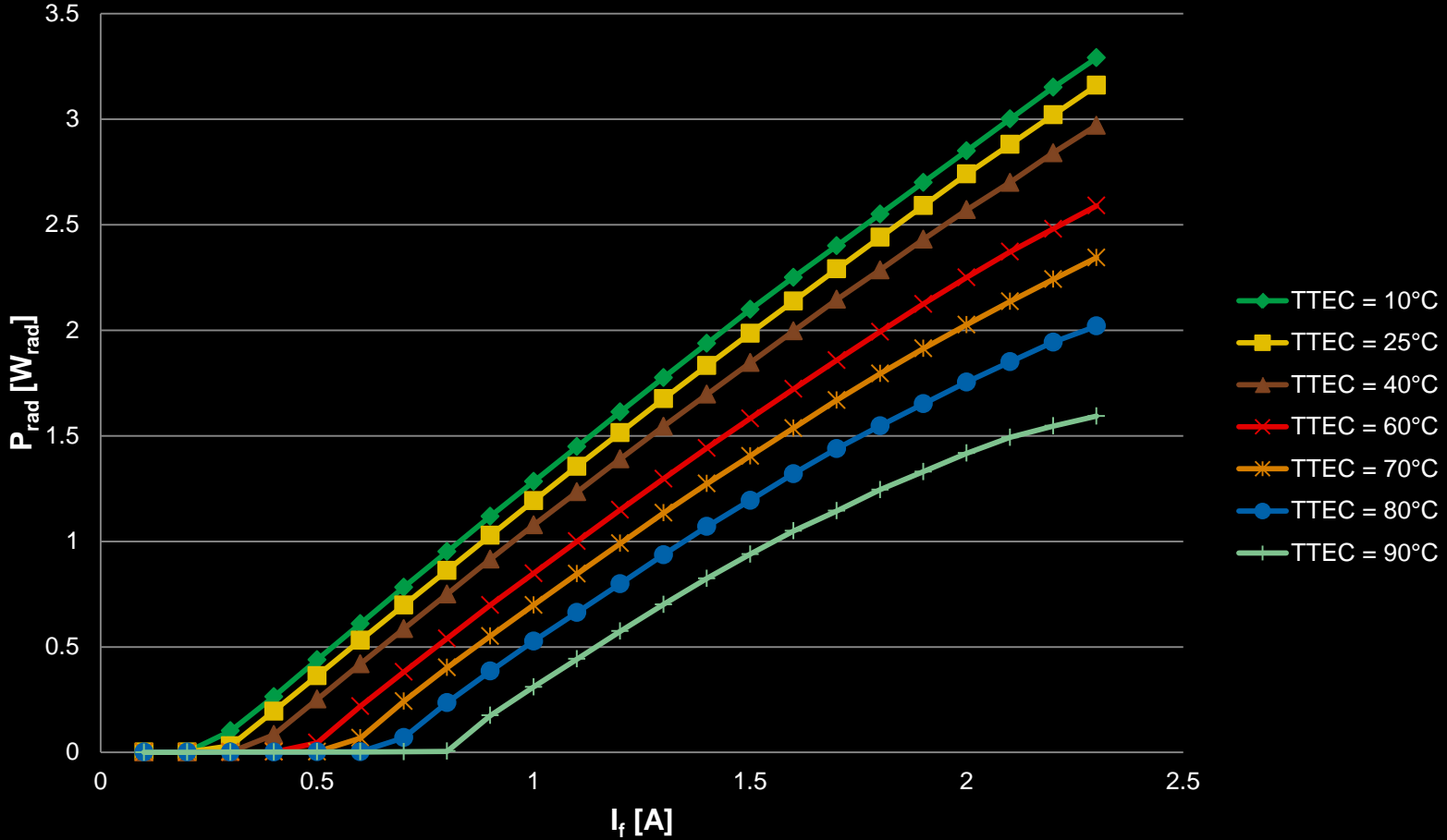
Engineering the illumination pattern in the far-field



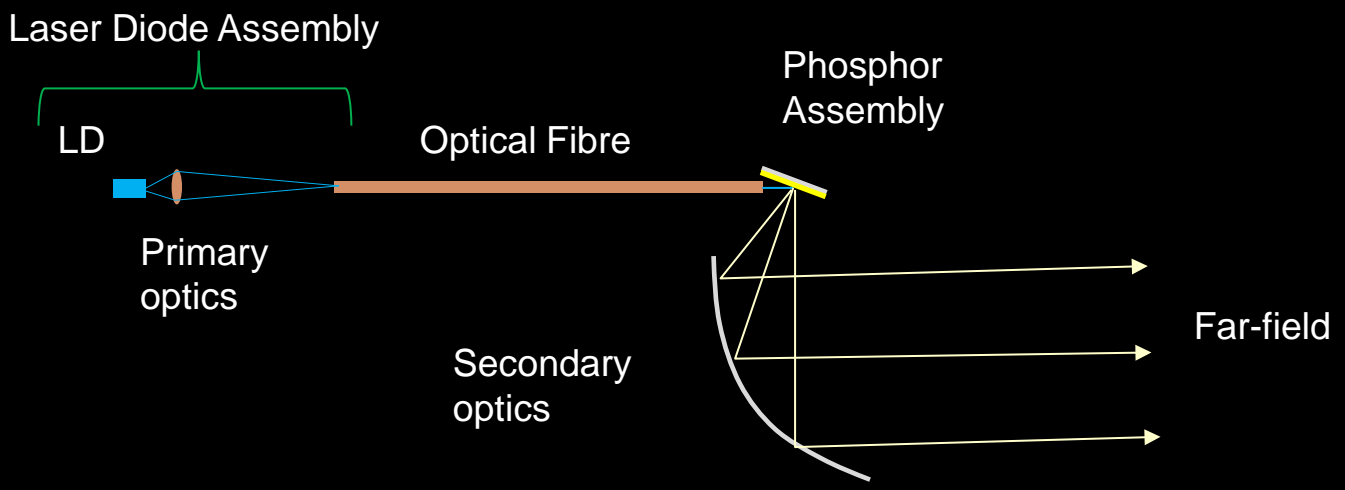
THERMAL EFFECTS



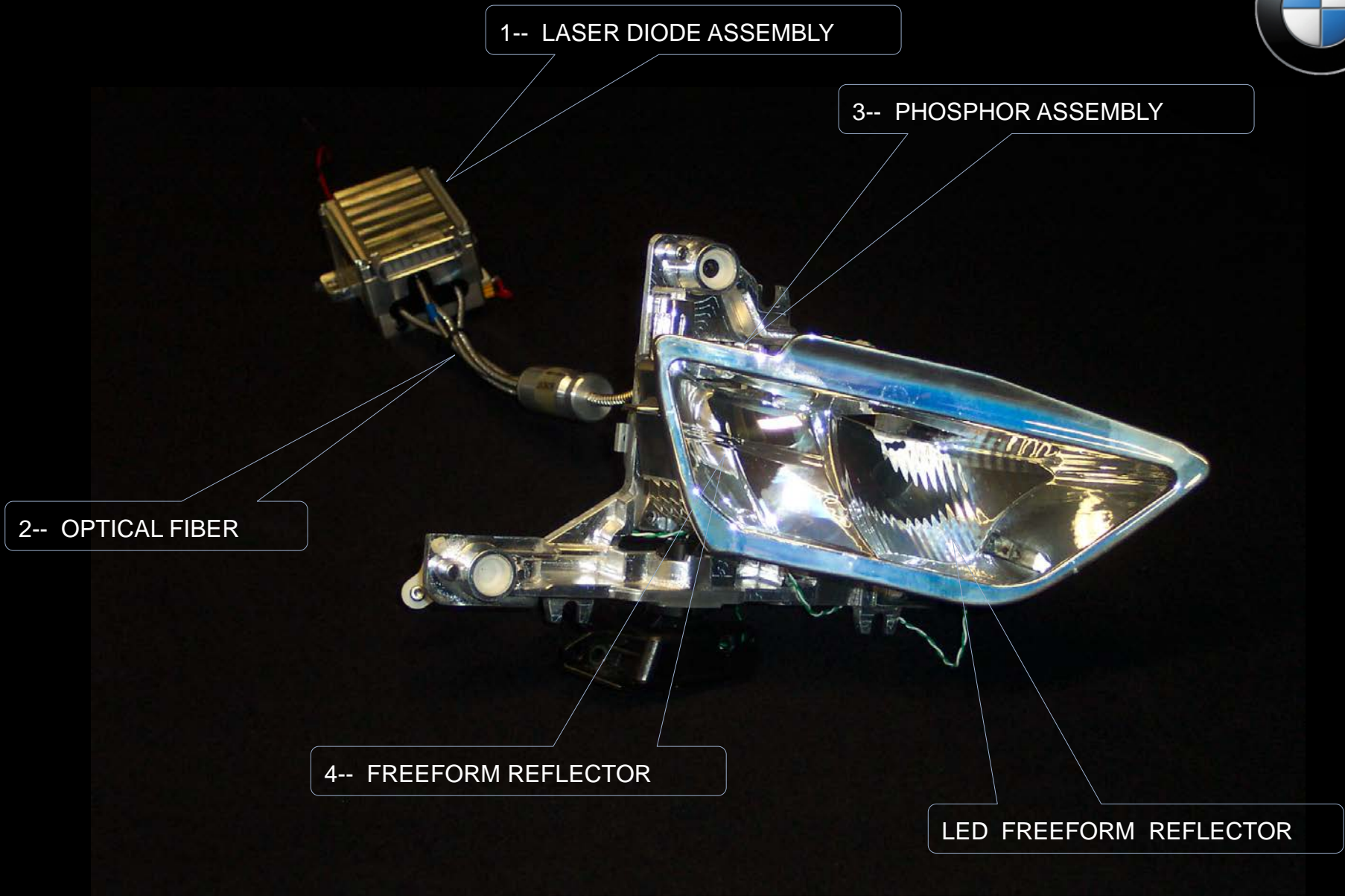
High-power blue laser diode Continuous wave driving mode



PRINCIPLE (II)



IMPLEMENTATION



PHOSPHOR ASSEMBLY



OPTIMIZED PHOSPHOR



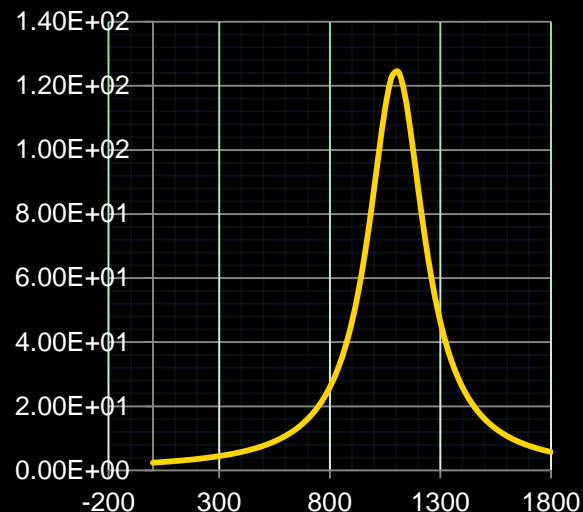
PERFORMANCES



- Lambertian
- FWHM 350 μ m
- Phosphor conversion efficiency is about 300lm/W
- Quenching temperature is over 220 $^{\circ}$ C

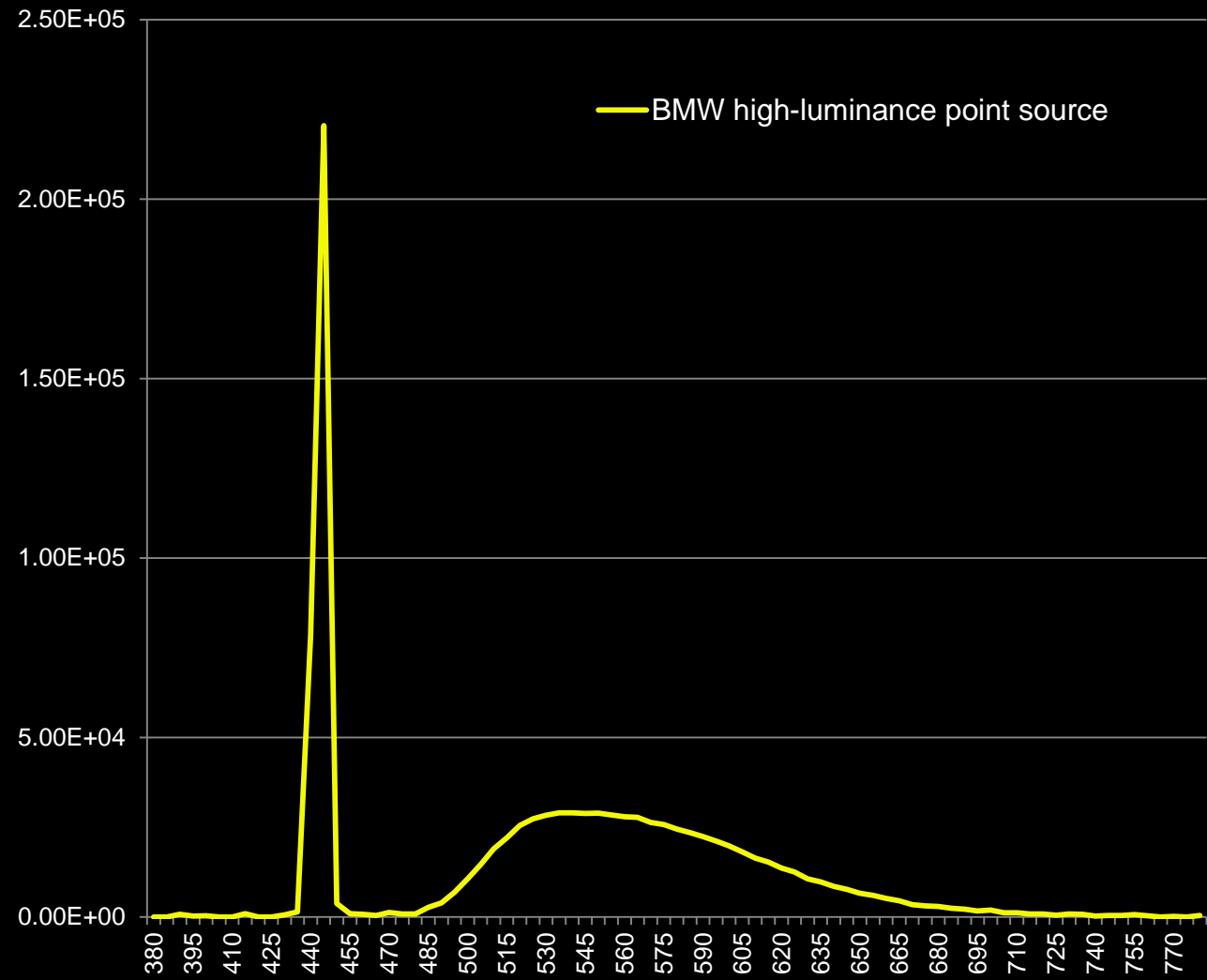


spatial distribution

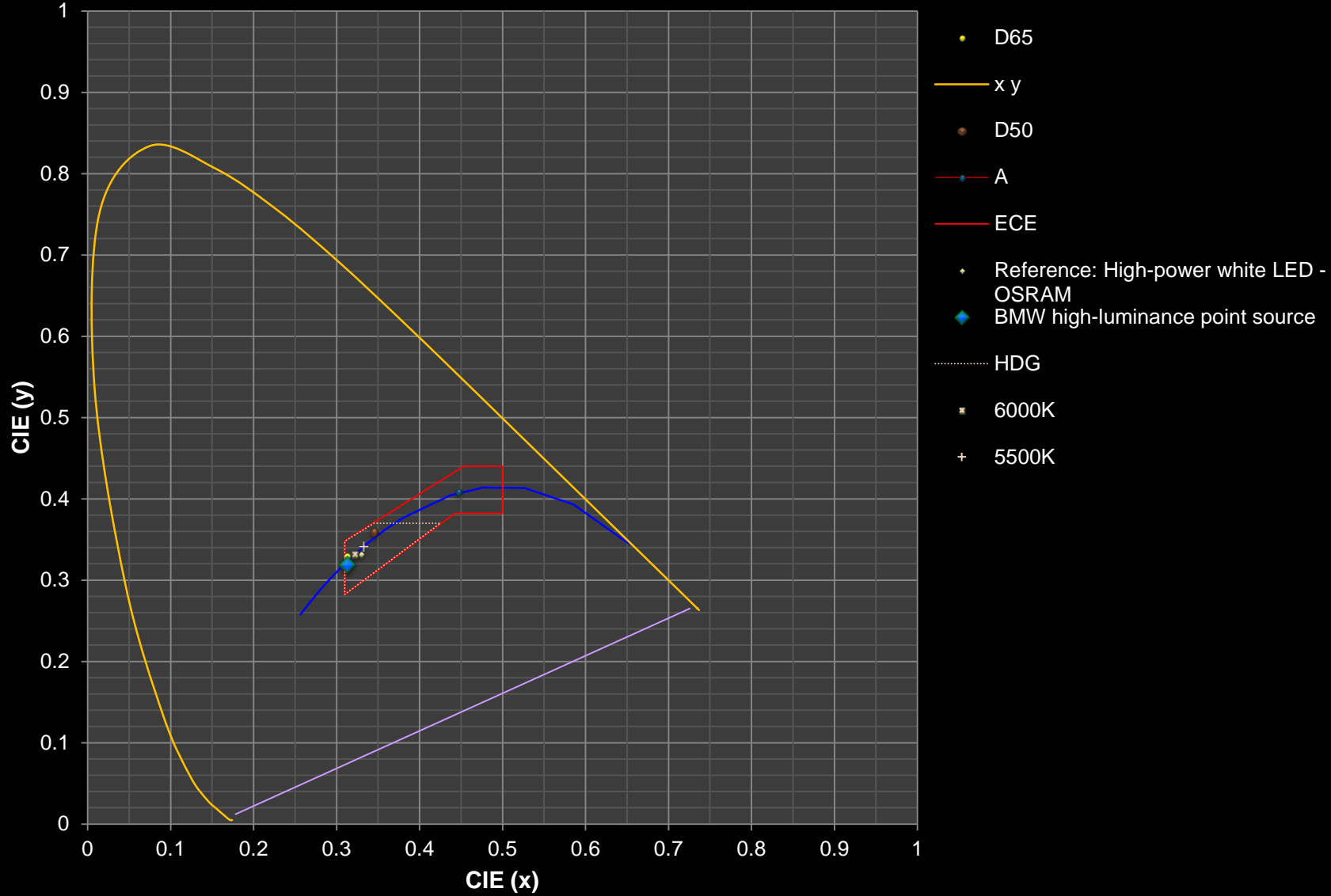


	Units	High-luminance laser-based white light source	Automotive certified pc-LED
Luminous Flux	<i>lm</i>	741	200
Peak Luminance	<i>cd/mm²</i>	3000	n.a.
Averaged Luminance	<i>cd/mm²</i>	834	40-49
Emitting surface	<i>mm</i>	0.35	1

BROADBAND SPECTRUM



ECE COLOR COORDINATES



High-Beam Laser-Light Booster Integrated in BMW i8



LED low-beam



LED high-beam



LED high-beam combined with the
laser-based spot (**laser booster**)



SUMMARY

- The newly developed high-luminance white phosphor-converted point source has a:
 - Luminous flux 741lm @25°C (500lm @80°C);
 - Average Luminance 834cd/mm² @25°C (560cd/mm² @80°C);
 - Efficacy: 43lm/W @25°C (33lm/W @80°C);

- The source was used in an illumination system having a:
 - Collection efficiency ranging from 55% to 75%
 - Lit aperture: $\phi < 27\text{mm}$
 - Quasi-collimated output beam: $\pm 2^\circ$

- High-beam Laser-light Booster enables to :
 - reach the maximum illuminance value of 344lux tolerated by the ECE regulations (*§6.22.9.4 of the ECE Regulation N° 48 Rev 9*) was reached
 - extend the range of visibility up to 600m, ...
 - ... from within a small package

FUTURE ...



→ New lighting functions such as marking lighting

→ Market vs. regulations:

- 344lx ECE vs. 128lx SAE
- night vision system in automotive sector
- adaptive functions

→ Dependence on the GaN technology (in general) and the blue laser diode technology (in particular):

- WPE of the blue laser diode increases from 25% to 37%
- Wafer size & COST





THANK YOU FOR YOUR
ATTENTION

