

Red emitting broad area lasers and bars for the photodynamic therapy



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Introduction

Application of high-power red-emitting diode lasers:

- Light sources for the photodynamic therapy
e.g. $\lambda = 652 \text{ nm}$: Foscan® - biolitec Pharma
- Laser display applications
- Pumping of fs – solid-state lasers (Cr:LiSAF/Cr:LiCAF)

650 nm laser structure challenging:

- Low barrier height for electrons and holes
 - ↳ High temperature sensitivity ($T_0 \approx 60 \text{ K}$)
 - ↳ Relatively small internal efficiencies ($\eta_i \approx 0.8$)
 - ↳ Large transparency current density ($j_{\text{TR}} \approx 300 \text{ kA/cm}^2$)
- Quaternary AlGaInP waveguide layers necessary
 - ↳ Reduced crystal quality
 - ↳ Reduced facet stability
 - ↳ Large series resistance

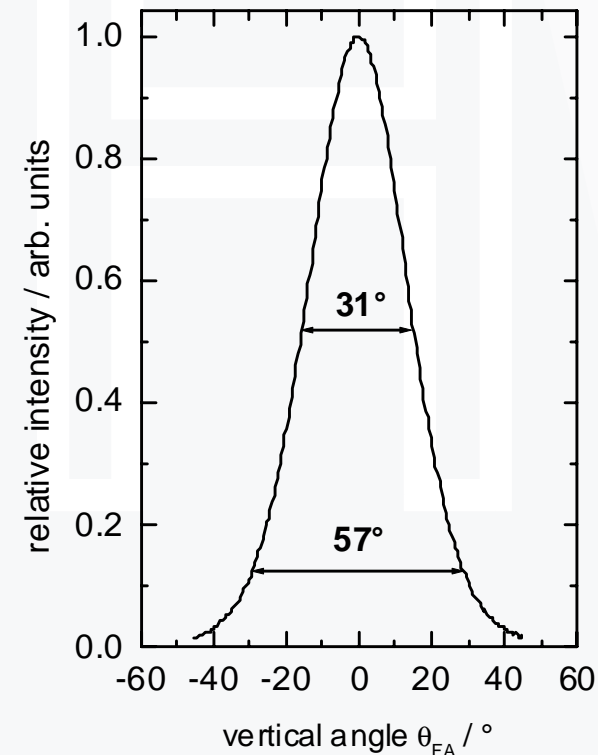
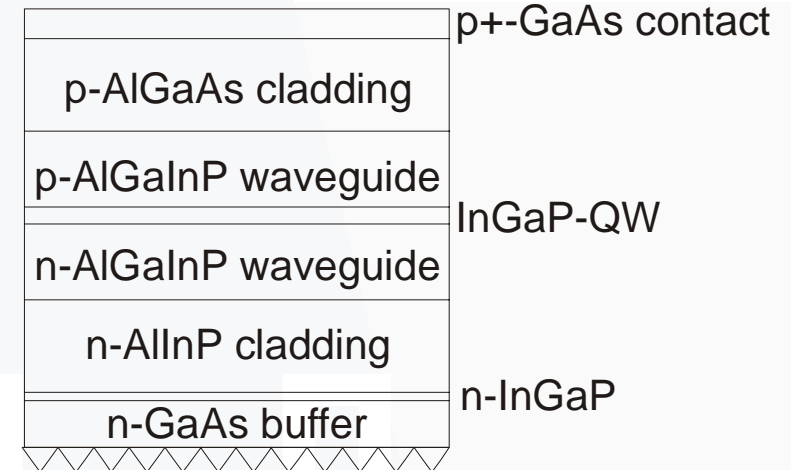
State of the art

	State of the art	BRIGHT
Vertical far field angle Θ_{FA} (FWHM) / °	40	
Operating temperature T_{op} / °C	10 ... 20	
Broad area lasers (100 μm stripe width)		
Maximal output power P_{max} / W	2 ¹	
Conversion efficiency η_c	0.37 ¹	
Reliable operation (P_{rel} / mW) / h	500 mW / 4000 h ²	
Laser Bars		
Width / mm; Emitter; Emitter width / μ m	10; > 20; 60 μ m	
Maximal output power P_{max} / W	12 ³	
Conversion efficiency η_c	0.3 ³	
Reliable operation (P_{rel} / W) / h	7 W / 900 h ⁴	

1. S. Orsila *et al.* SPIE 3628, 203 – 208 (1999))
2. http://catalog.osram-os.com/media/_en/Graphics/00029998_0.pdf
3. J.S. Osinski *et al.* *Electronics Letters* 34, 2336-2337 (1998)
4. D. Imanishi *et al.*, 19th ISLC 2004

650 nm laser structure

- InGaP SQW or DQW as active region
- AlGaInP waveguide layers
- Asymmetric cladding layers
 - n-AlInP cladding
 - p-AlGaAs cladding
 - C-doping; Standard processing
- Vertical far field:
 - $\Theta_{FA} = 31^\circ$ (FWHM); 57° ($1/e^2$)
- Material data:
 - internal efficiency $\eta_i \approx 0.85$
 - internal losses SQW $\alpha_i \approx 1 \text{ cm}^{-1}$
 - DQW $\alpha_i \approx 2 \text{ cm}^{-1}$
 - characteristic temp. $T_0 \approx 60 \text{ K}$



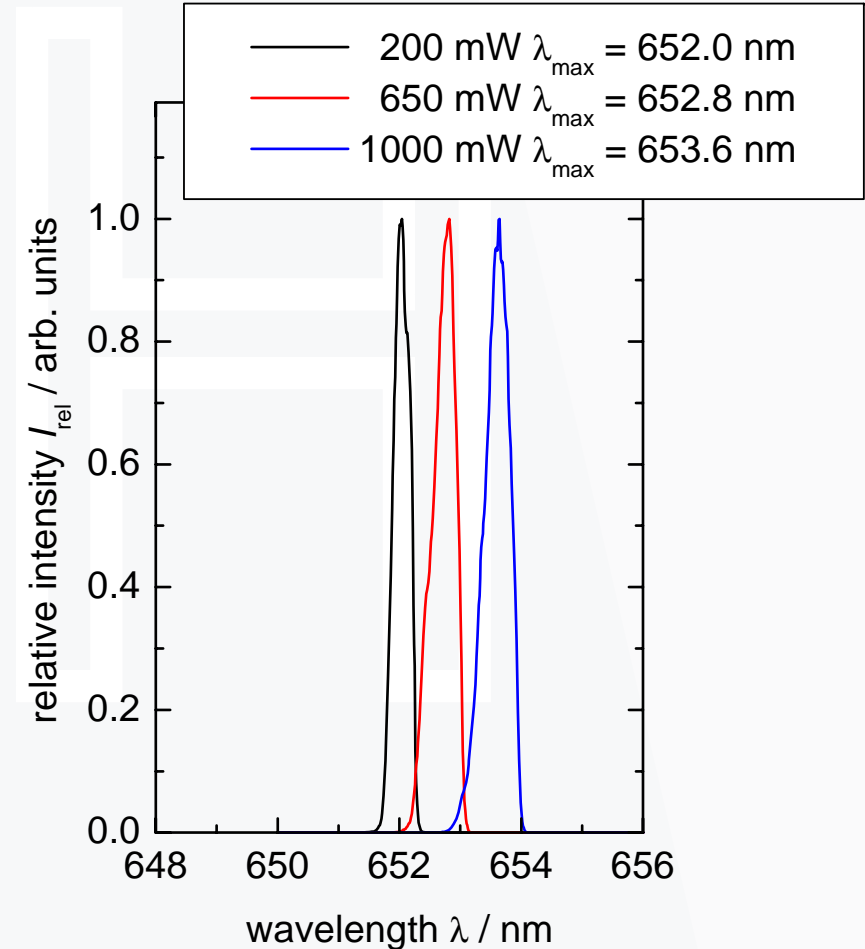
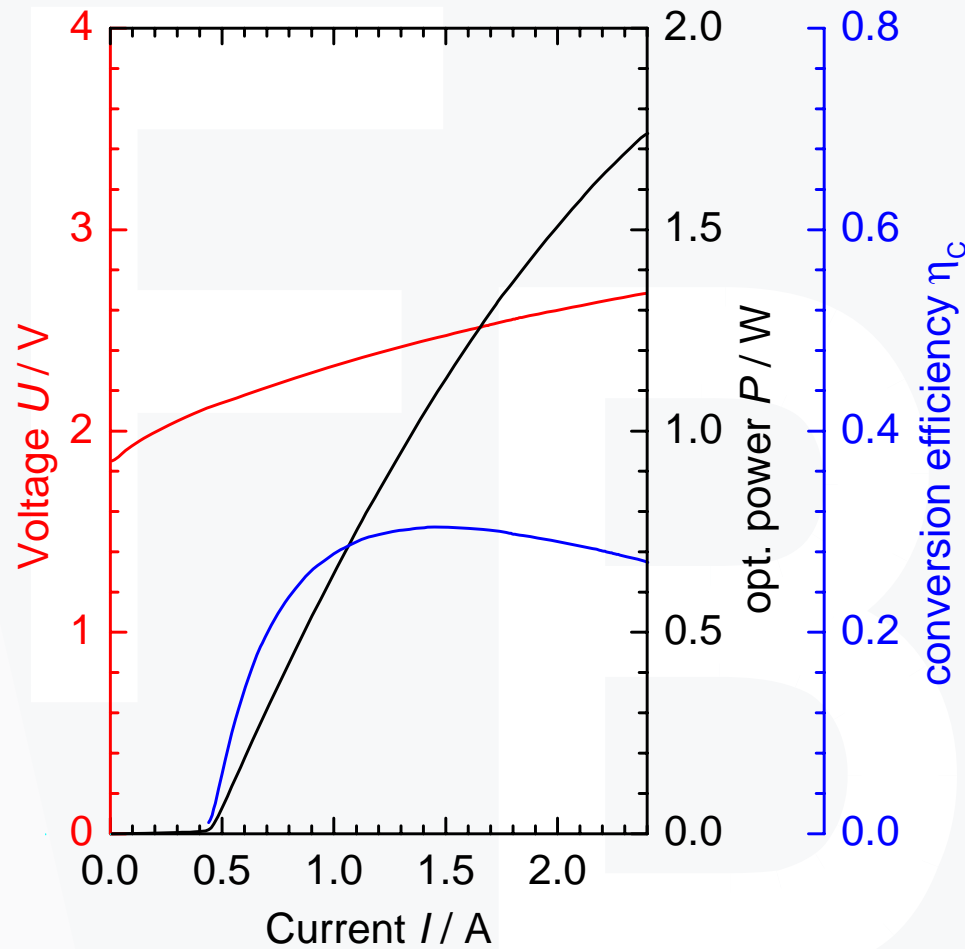
650 nm broad area lasers

100 μm x 750 μm ; DQW; $T = 15^\circ\text{C}$: $I_{\text{th}} = 453 \text{ mA}$

$S = 1.0 \text{ W/A}$

$\eta_{\text{C-max}} (1.1 \text{ W}) = 0.3$

$P(2.4 \text{ A}) = 1.7 \text{ W}$



650 nm broad area lasers – aging test

100 μm x 750 μm ; DQW

Reliable operation at $T = 15^\circ\text{C}$

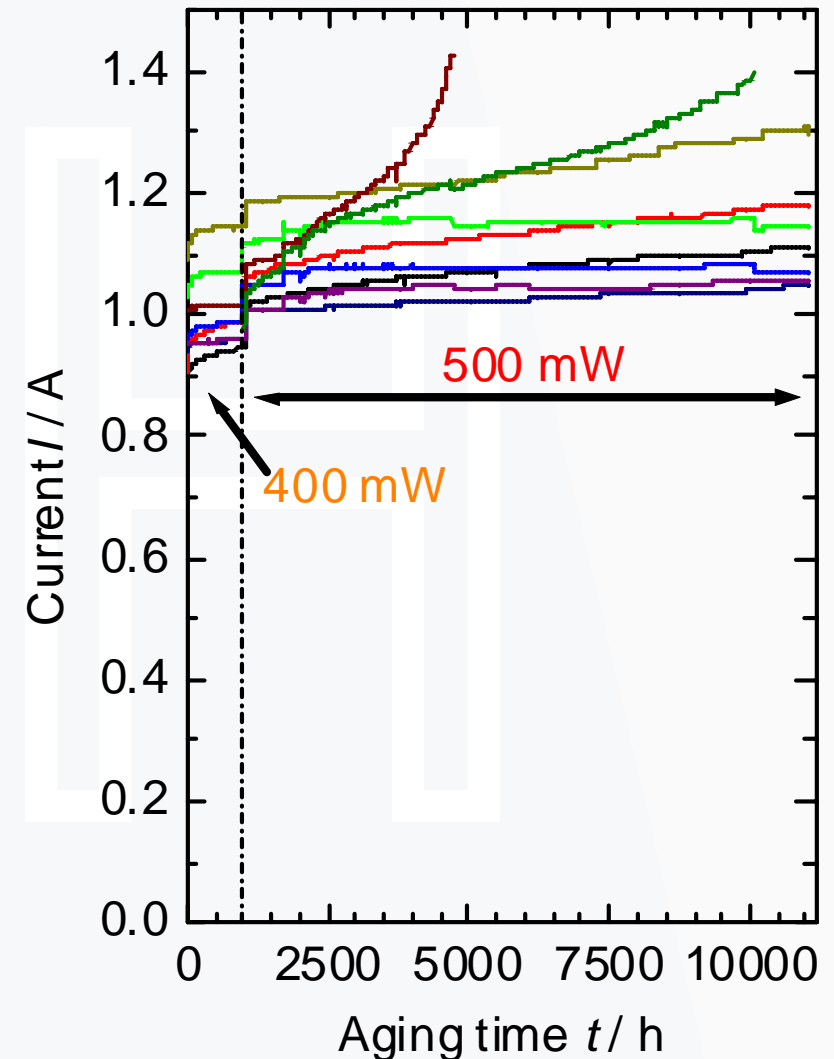
400 mW (4 mW/ μm): 9(9) - $t = 1000$ h

500 mW (5 mW/ μm): 7(9) - $t = 10000$ h

MTTF – 40000 h

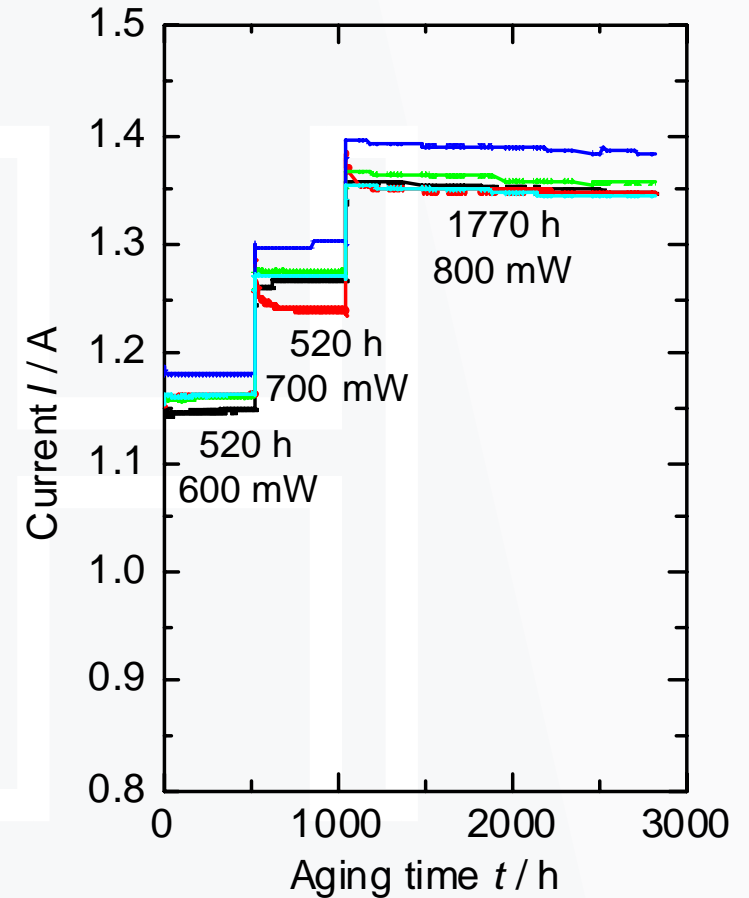
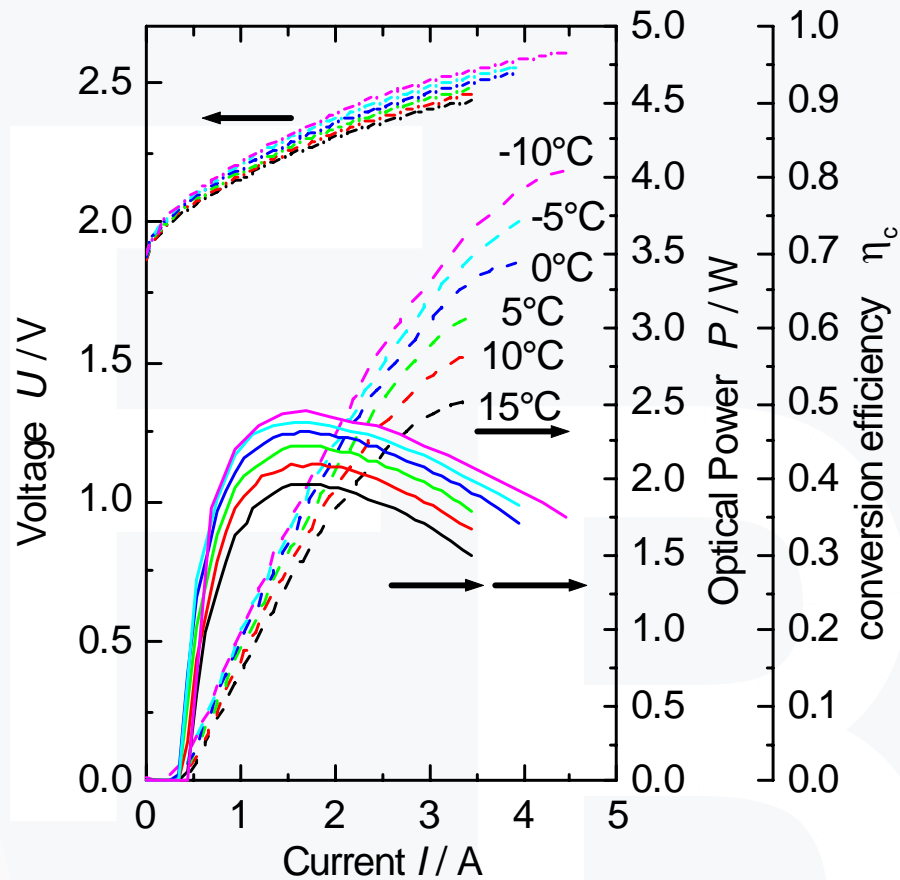
No COD failures

- ↪ Lifetime sufficient for medical applications
- ↪ and close to the demands for display application



650 nm broad area lasers

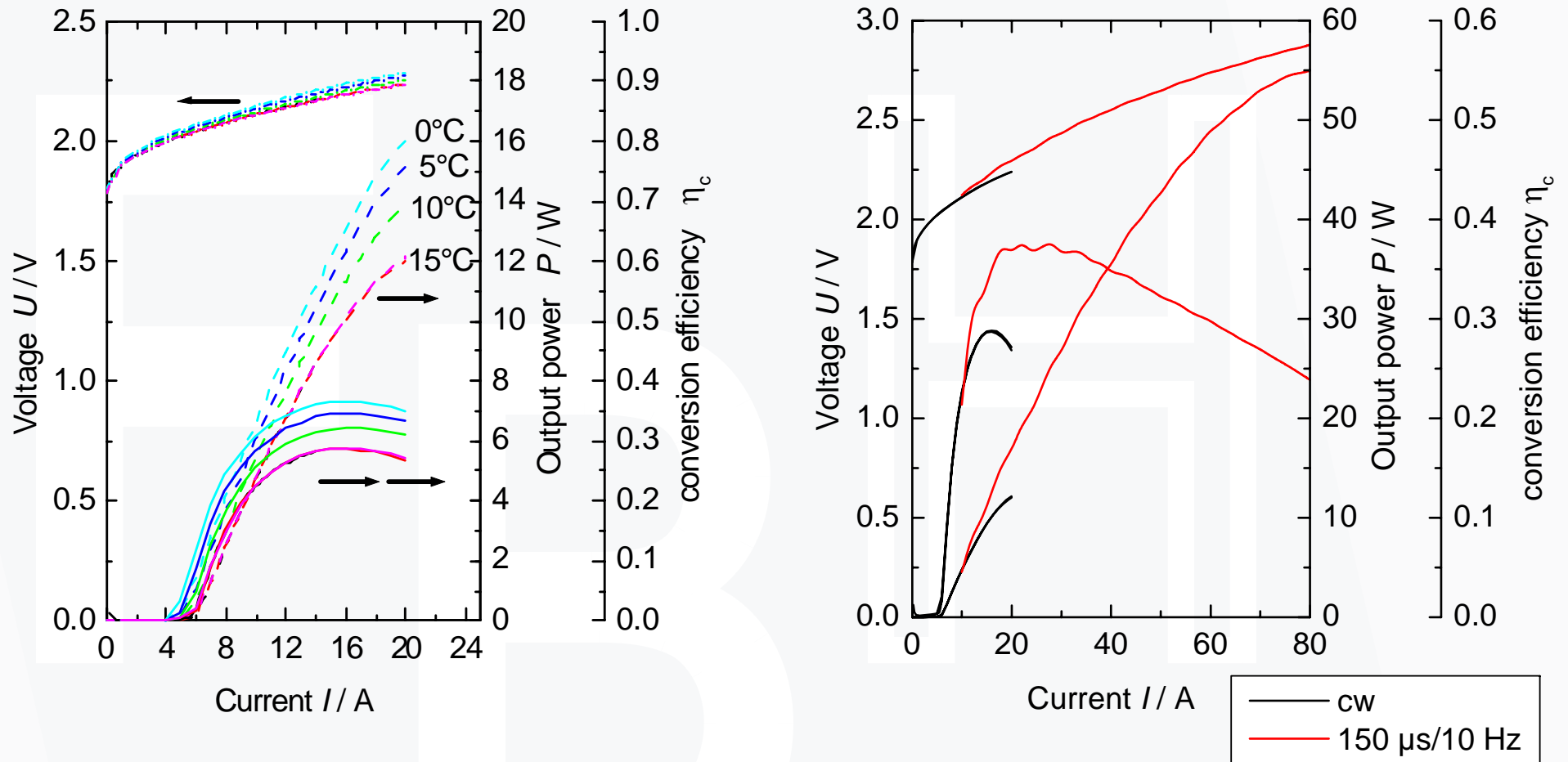
100 μm x 1500 μm ; SQW; $R_f = 4\%$; $T = 15^\circ\text{C}$



- Output power – 2.5 W at 15°C; Facet stability – 40 mW/ μm ;
- Conversion efficiency – 0.39 ... 0.49; Reliability: 800 mW 5(5) - $t > 2000$ h

650 nm laser diode bars

SQW; 5 mm wide; 10 x 100 μm x 1500 μm ; $R_f = 4\%$; $0^\circ\text{C} \leq T \leq 15^\circ\text{C}$



- CW-output power 12.1 W at 15°C and 16 W at 0°C; $\eta_c = 0.29$ (15°C) ... 0.39 (0°C)
- QCW-output power 55 W at 15°C (150 μs , 10 Hz)

650 nm laser diode bars

SQW;

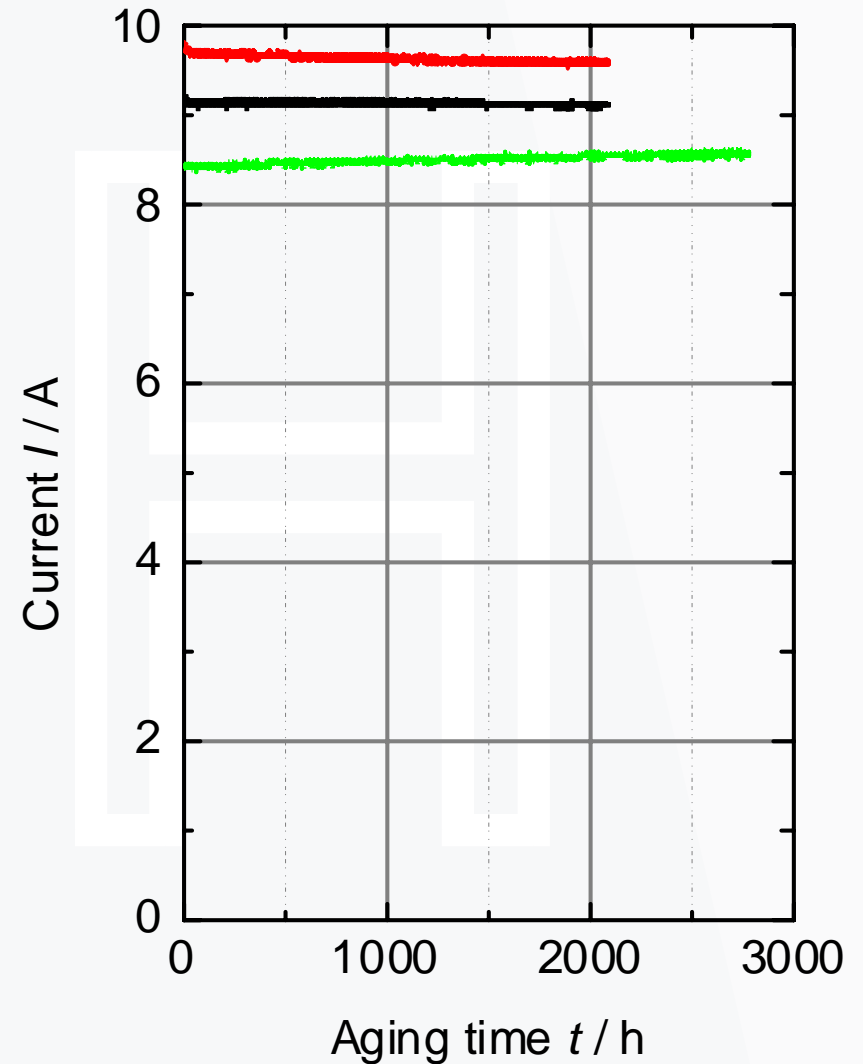
6 mm wide; 12 x 60 μm x 1500 μm

$R_f = 4\%$

Aging test at $T = 15^\circ\text{C}$; $P = 5\text{ W}$

All three devices with $t \geq 2100\text{ h}$

Test still running.



Summary – Results for 650 nm lasers

	State of the art	BRIGHT
Vertical far field angle Θ_{FA} (FWHM) / °	40	31
Operating temperature T_{op} / °C	10 ... 20	15
Broad area lasers (100 μm stripe width)		
Maximal output power P_{max} / W	2	3.1
Conversion efficiency η_c	0.37	0.39
Reliable operation (P_{rel} / mW) / h	500 mW / 4000 h	500 mW / 10000 h 800 mW / > 2000 h
Laser Bars		
Width / mm; Emitter; Emitter width / μ m	10; > 20; 60 μ m	5; 10; 100 μ m
Maximal output power P_{max} / W	12	12
Conversion efficiency η_c	0.3	0.29
Reliable operation (P_{rel} / W) / h	7 W / 900 h	5 W / 2600 h

Summary

- Features sufficient for the application of the devices for PDT applications.
- Reliability for laser display applications almost reached.
- QCW output power suitable for the pumping of fs-Cr:LiSAF lasers.
- Broad area lasers and bars are available.

Acknowledgment

- All colleagues at the FBH
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