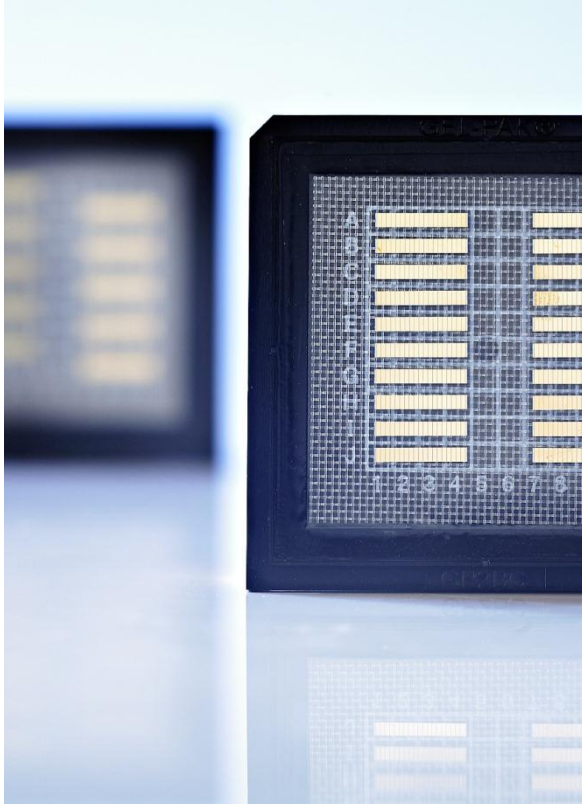
JENOPTIK

Increasing the power density towards IFE requirements: high-power laser diode bars

Speaker Martin Wölz

Outline

- **JENOPTIK and JENOPTIK Diode Lab GmbH**
- Semiconductor laser design
- Solution for 940 nm
- Solution for 880 nm
- Outlook: laser diode stacks



JENOPTIK AG
Divisions and Business Units

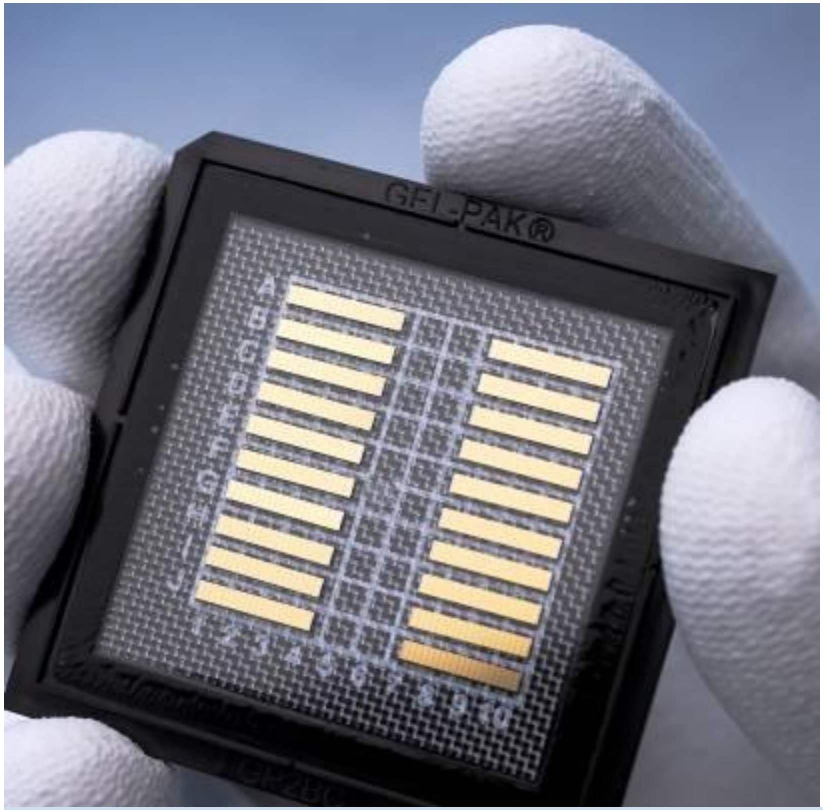
Corporate Center

Lasers & Material Processing	Optical Systems	Industrial Metrology	Traffic Solutions	Defense & Civil Systems
				
• Lasers • Laser Processing Systems	• Optics • Micro Optics • Optoelectronic Systems	• Roughness and contour measurement • Form measurement • Dimensional measurement	• Equipment • Service Providing	• Mechatronics • Sensor Systems

Jenoptik Diode Lab GmbH (JDL)
Semiconductors: Laser Bars & Single Emitters

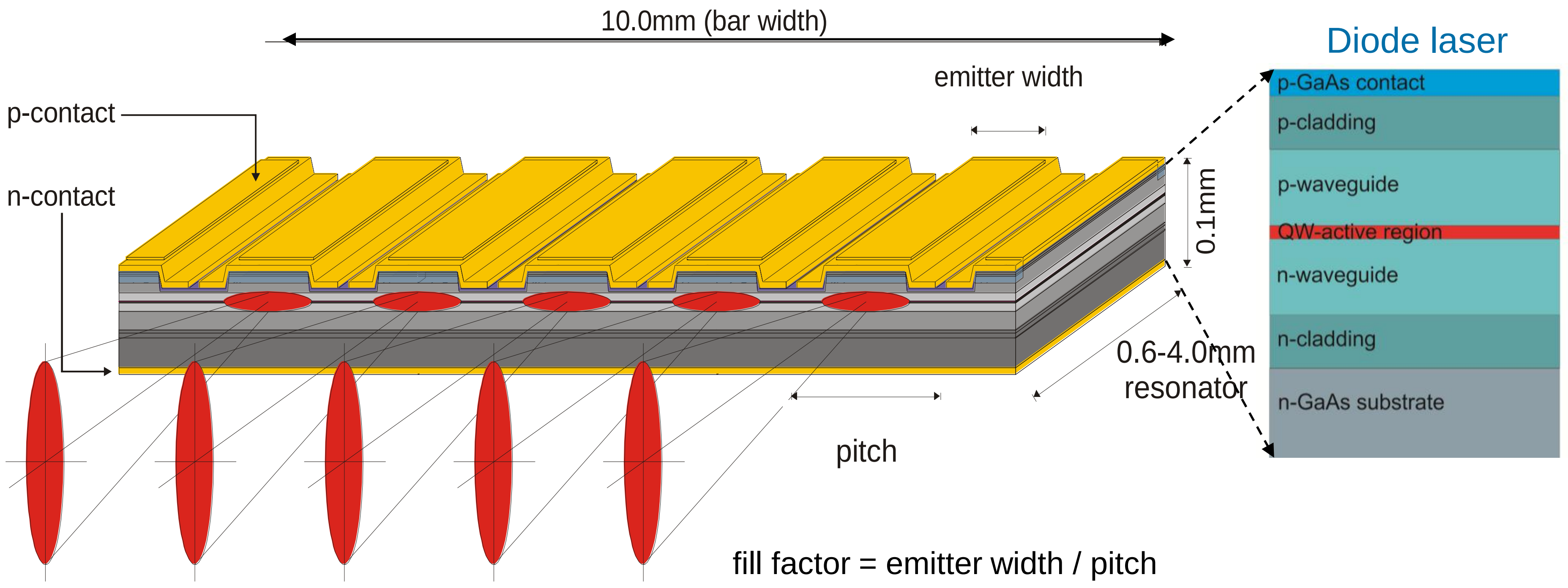
JENOPTIK

- Laser epitaxial structure design
- InGaAlAsP / GaAs-Epitaxy (MOVPE)
- GaAs-process line
- Facet-Coating process
- Single Emitter (SE) and Laser Bar
- Wavelength: 760 nm – 1060 nm
- Power range
  - Single emitter CW: 12 W
  - Bar CW: 200 W
  - Bar QCW: 500 W
- Bare bar sale



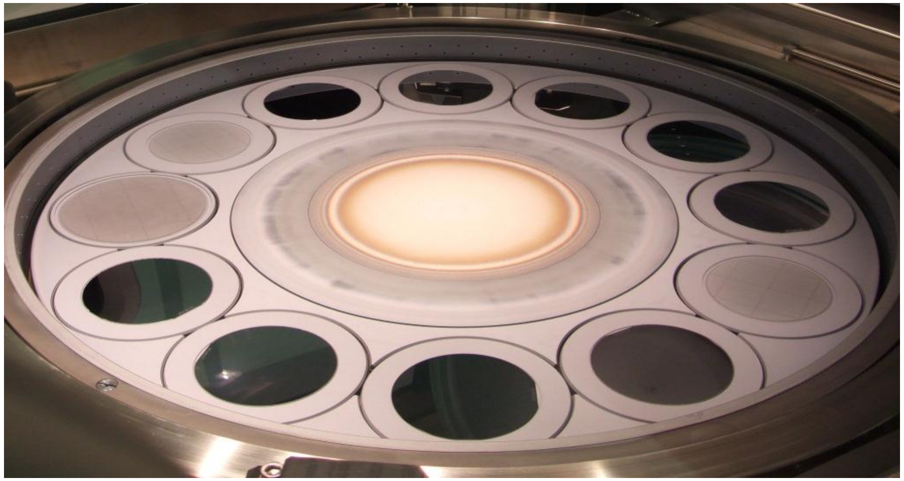
laser diode bars

Introduction
Semiconductor laser diode bar



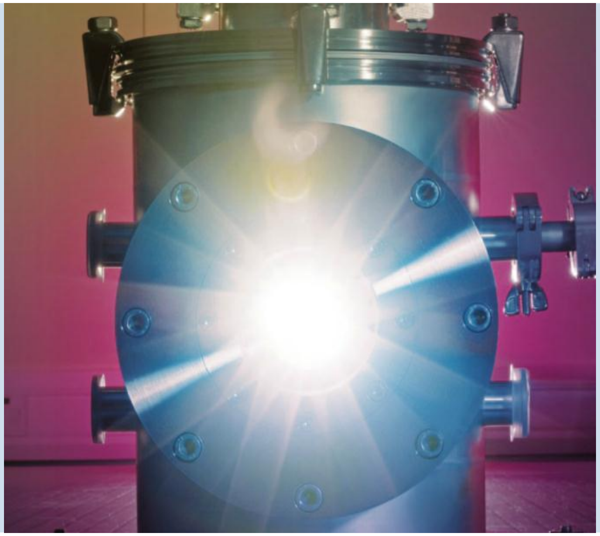
Epitaxy Capabilities at JDL

- Two multiwafer planetary reactors
  - 12 x 3" or 4"
  - 8 x 3" or 4"
- Layer characterisation:
  HRXRD, C-V profiling, EL, PL, SEM, (SIMS)
- Foundry services
- Certified to ISO 9001:2008

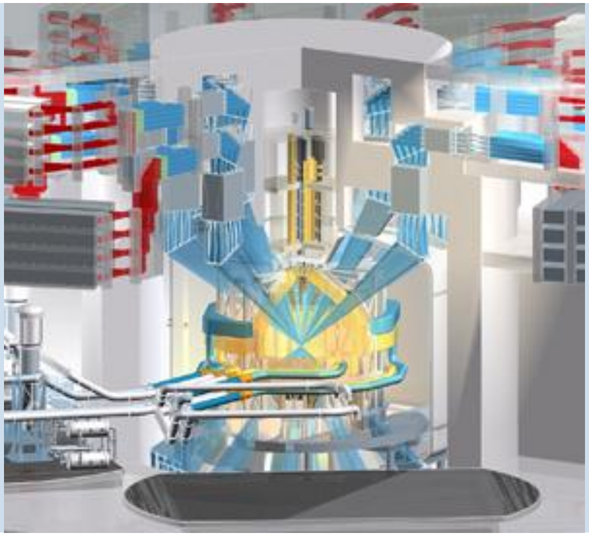


What can we do for high energy class lasers?

JENOPTIK



Mason et al., 7th HEC-DPSSL Workshop (2012)



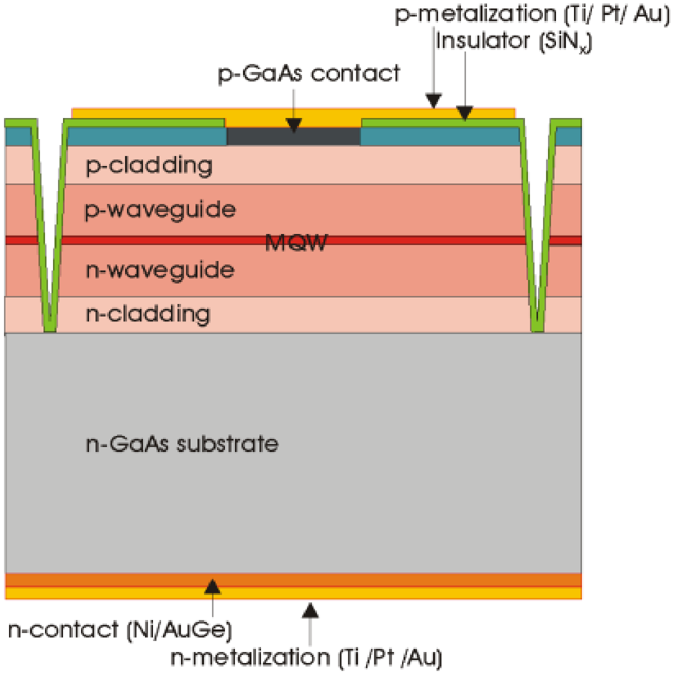
Bayramian et al., Fusion Sci. Technol. *60*, 28 (2011)

- 10 J, 10 Hz **DiPOLE** prototype
  - Yb:YAG, 940 nm, 1ms QCW
  - 40kW pulse power from 192 bars
- 100 J …

- **LIFE**: projected 2.2 MJ, 16 Hz
  - Nd:glass, 880 nm, 200µs QCW
  - 50 GW pulse power from ? bars

increase the power density !

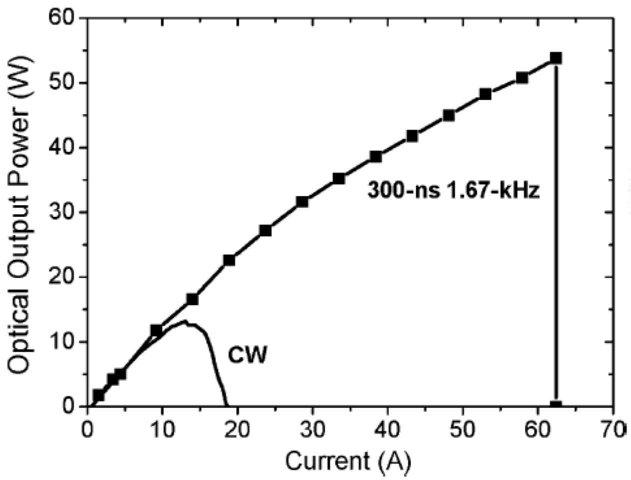
Introduction
Broad area laser diode elements

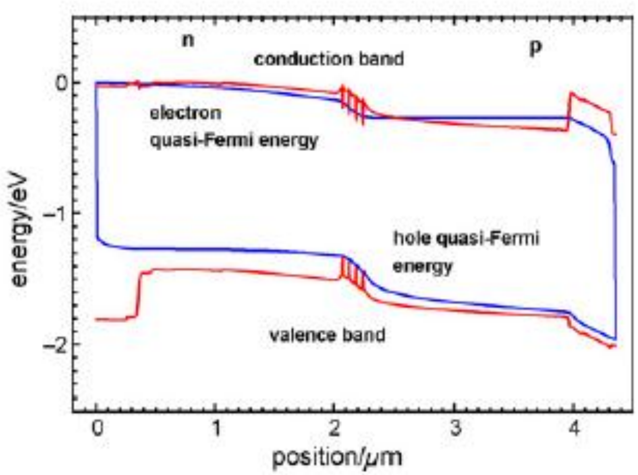


Pietrzak, Dissertation (2011)

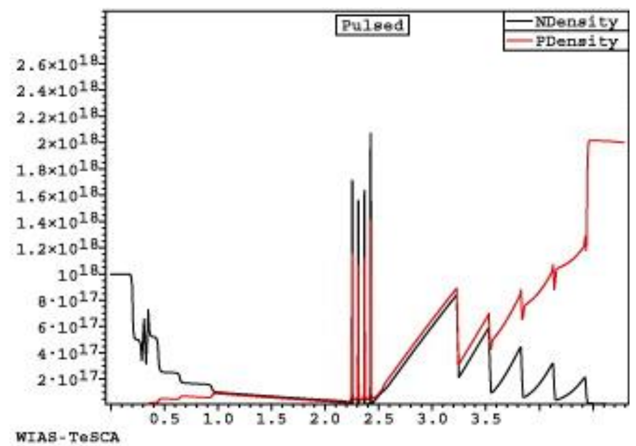
device layout	design parameters	laser performance
vertical	epitaxial layers • thickness • composition (E_g, n)	• wavelength • carrier confinement • vertical mode confinement • gain, absorption • “fast axis“ divergence
lateral	• metal contact • separation of emitters	• current density • lateral mode confinement • “slow axis” divergence
mirrors	• material, thickness • reflectivity	• laser threshold • slope efficiency • reliability

Vertical structure design
Carrier confinement





Pietrzak et al., Semicond. Sci. Technol. *24*, 035020 (2009)



Wenzel et al., New J. Phys. *12*, 085007 (2010)

current-induced heating
+ carrier leakage

→ degraded slope efficiency

band bending

→ reduced effective barrier
→ carrier escape

carrier accumulation

in waveguides
+ claddings

Loss mechanism: bias-induced carrier leakage

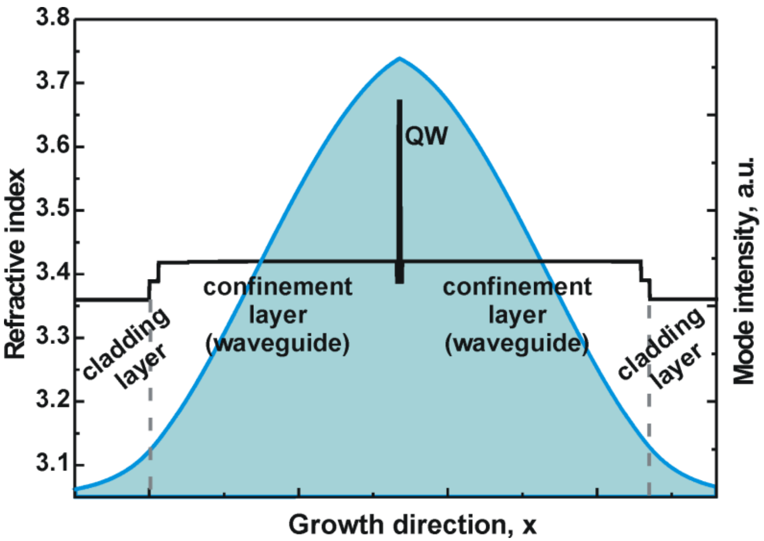
Solution: designs with higher barriers against carrier escape

(must be balanced against series resistance)

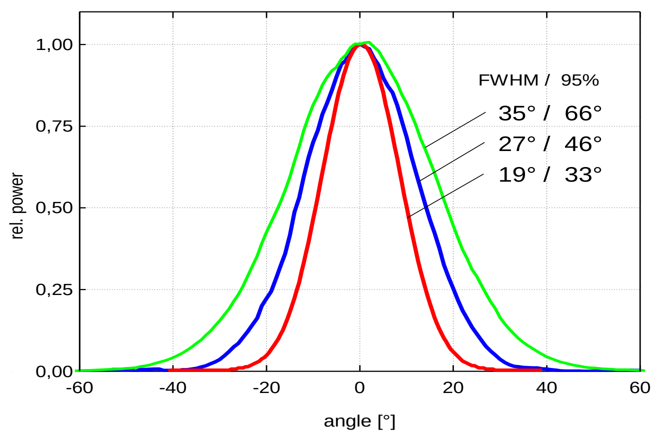
Vertical structure design

Light confinement in large optical cavities

waveguide	thin	thick
overlap of light and charge carriers (confinement)	high Γ	low Γ
efficiency	high η	low η
fast axis divergence	large $\theta_\perp$	small $\theta_\perp$



Pietrzak, Dissertation (2011)



material data			
$\theta_\perp$ (FWHM)	35°	27°	19°
Γg_0 (cm^{-1})	15.3	13.0	11.0
η	67%	60%	58%

Hülsewede et al., Proc. of SPIE, 68760F (2008)

Laser dimensions for QCW application
Resonator length and fill factor

- heat dissipation in active area limits external quantum efficiency
- phenomenological model (char. Temp.)

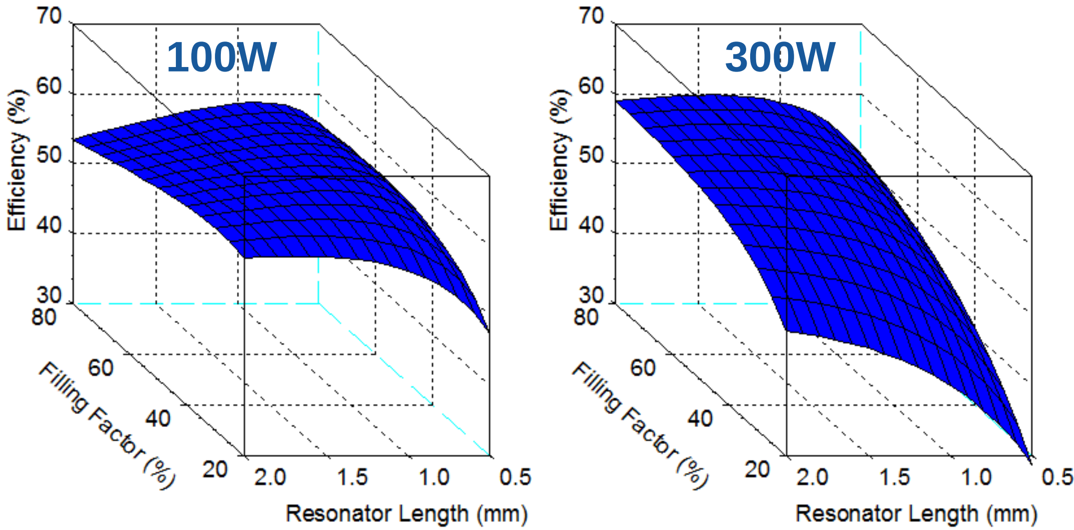
$$I_{thres} \propto e^{\Delta T/T_0}$$
$$\eta_{diff} \propto e^{\Delta T/T_1}$$

Erbert et al., Top. Appl. Phys. 78, Springer (2000)

- **resonator length** (e.g. 808 nm):

  structure-dependent optimum for high conversion efficiency

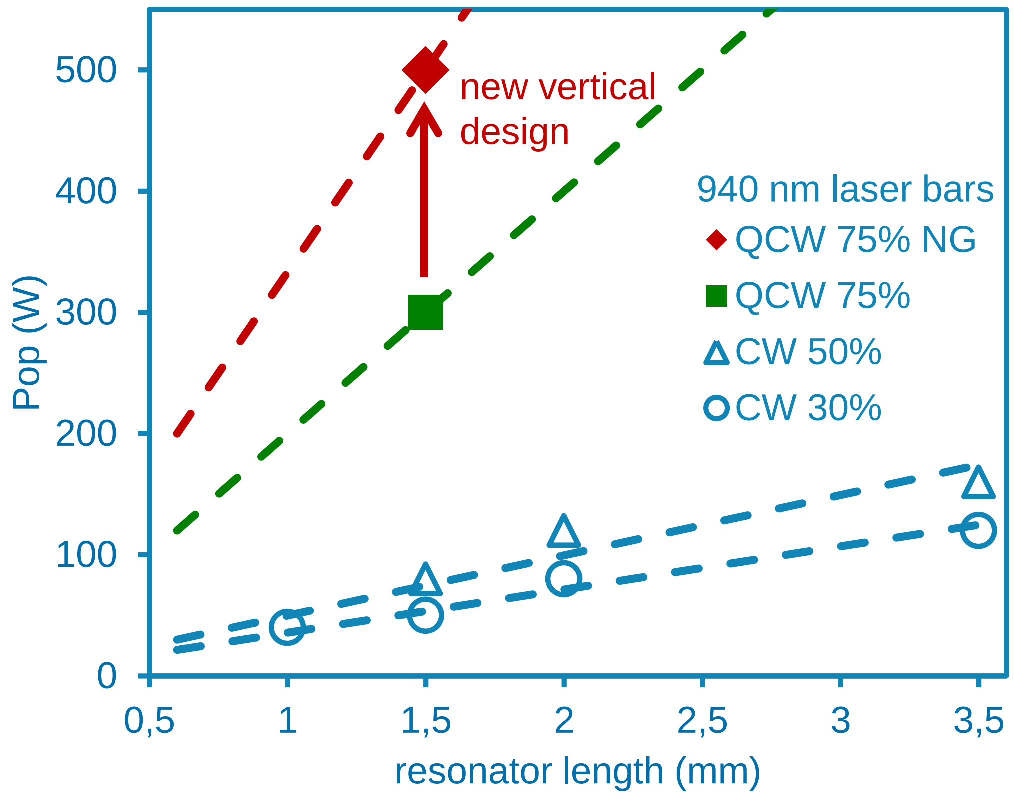
  Deichsel et al., Proc. of SPIE, 68760K (2008)



- **fill factor: maximize to 75%**
  - high efficiency
  - low facet load

JDL New generation QCW bars
Reducing semiconductor “cost per Watt”

- new chip generation (NG) vertical design
- increased P_{op} per chip area
- decreased “cost per Watt”



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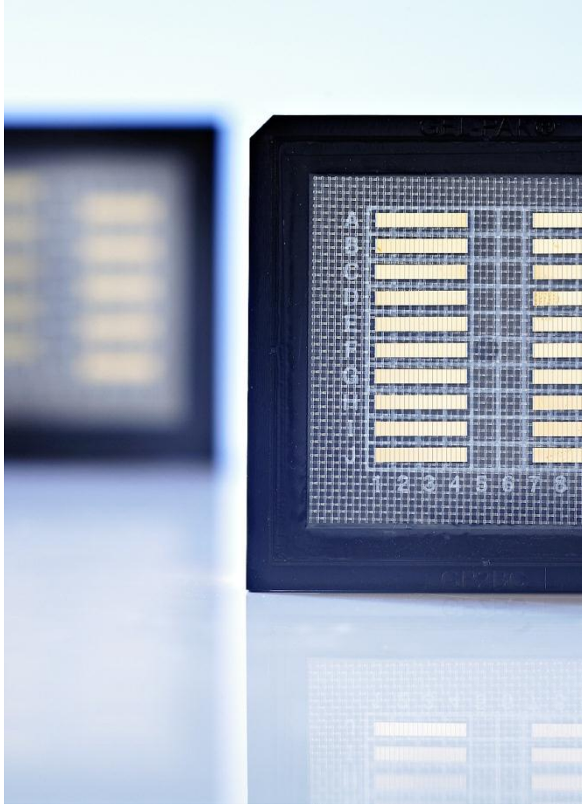


New generation quasi-CW 940 nm Bars (II)
Design

Epitaxy

1. strong carrier confinement
   → reduced slope efficiency degradation
   → P_{max} from 300W to 500W
2. low optical loss α_i
   → longer resonator possible

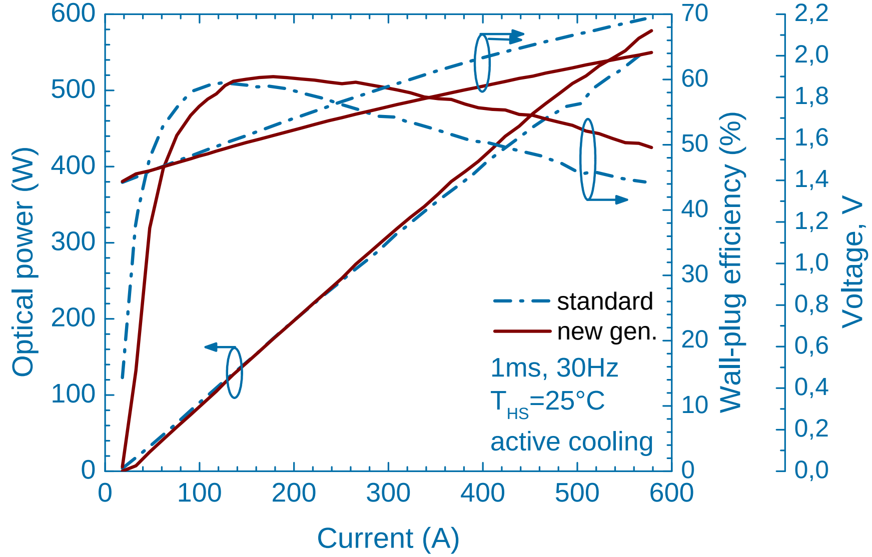
	standard	new gen.
α_i (cm^{-1}) ↘	0,77	0,36

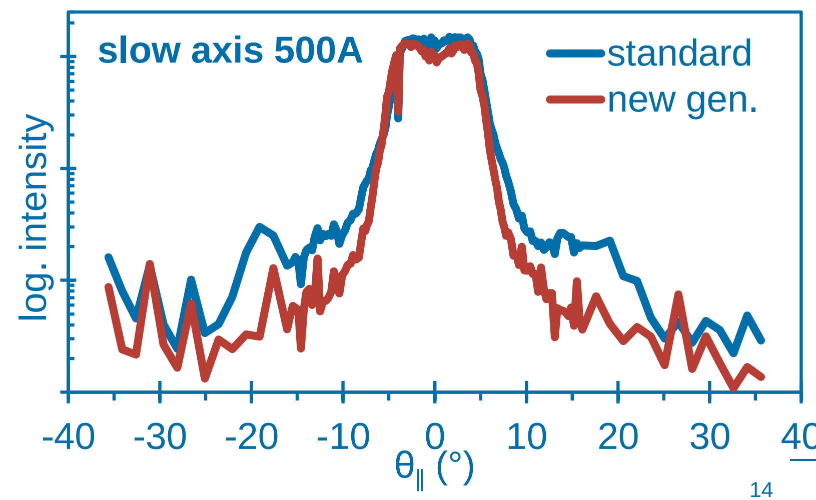
Pietrzak et al., Proc. of SPIE 896528 (2014)

3. thicker waveguide
   → narrow fast axis divergence

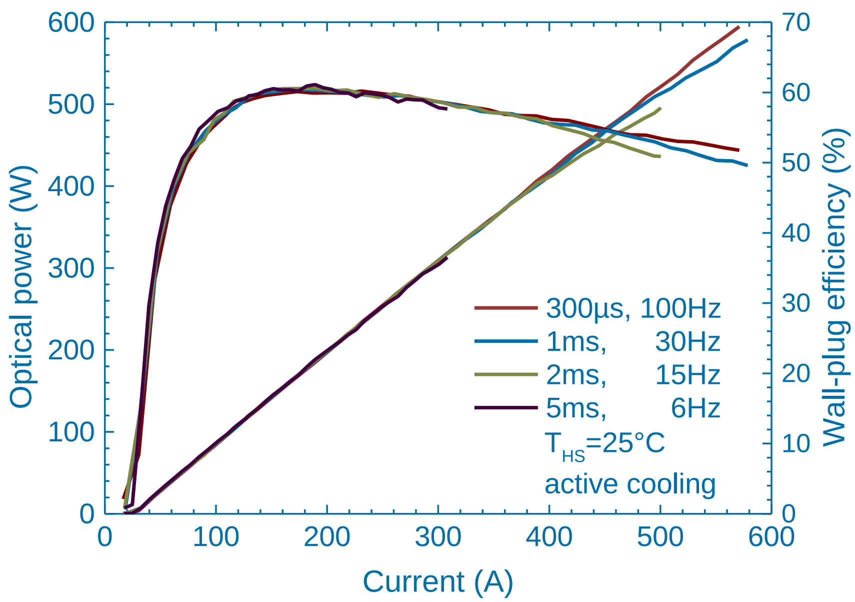
Layout (75% fill factor)

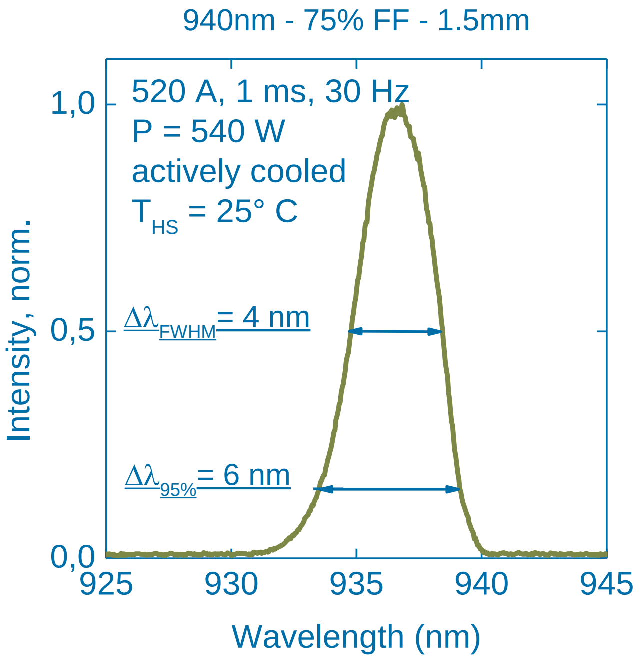
4. 37 x 190µm emitters
5. better lateral mode confinement
   → narrow slow axis divergence





New generation quasi-CW 940 nm Bars (III)
Design limits



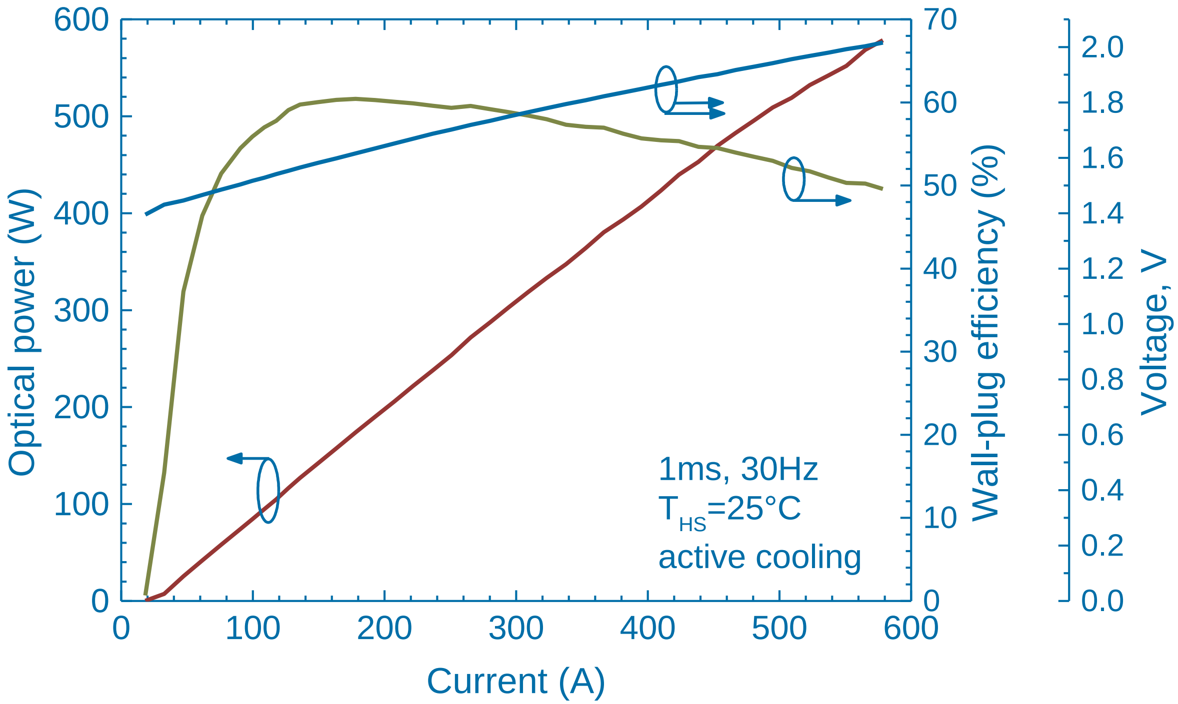


- no thermal roll-over up to 500W at 1ms, 30Hz
- longer pulse accessible with longer resonator

- $\Delta\lambda_{FWHM}$ = 4 nm at P_{max}

New generation quasi-CW 940 nm Bars (IV)

Power-voltage-current characteristic



Measurement conditions:

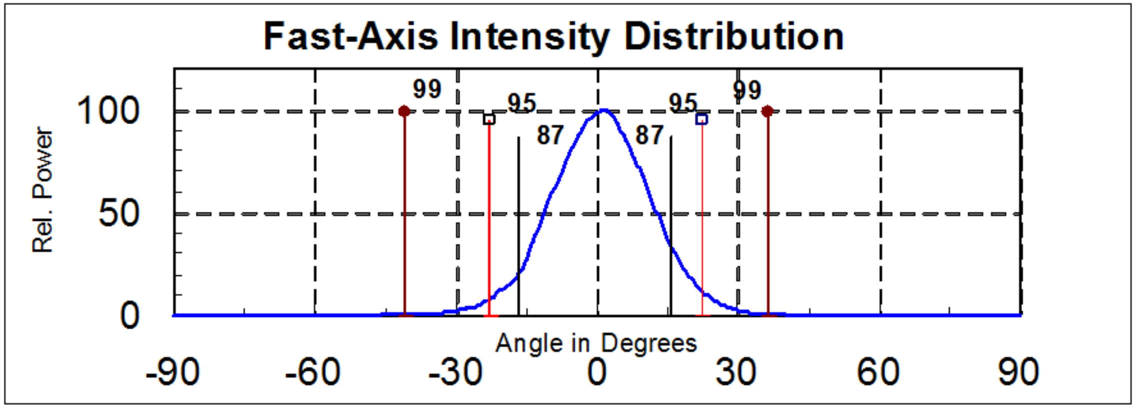
1ms, 30Hz, T=25°C

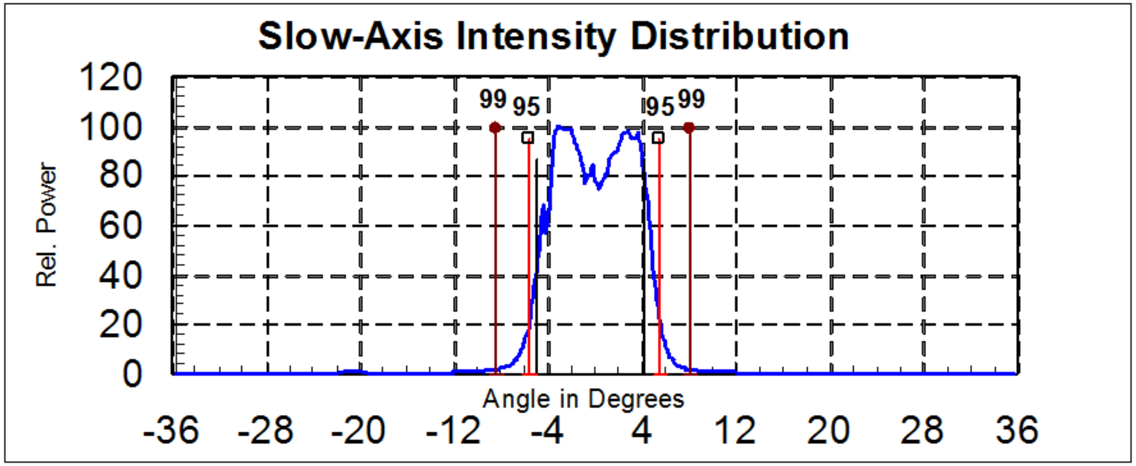
- P_{op} = 500 W
- I_{op} = 485 A
- S_{op} = 1.17 → 0.85 W/A
- η_{max} = 60%
- η_{op} = 53%

- 75% FF, L=1.5 mm (37 Emitters, W = 190 µm)
- In progress: lifetime test at P_{op} = 400W operation
- Next: qualification and release for 500W operation, JDL-BAB-75-37-940-TE-500-1.5

New generation quasi-CW 940 nm Bars (V)

Far-field profiles





Measured at:
I= 500A (1ms, 18ms, T=25°C)

Fast axis:

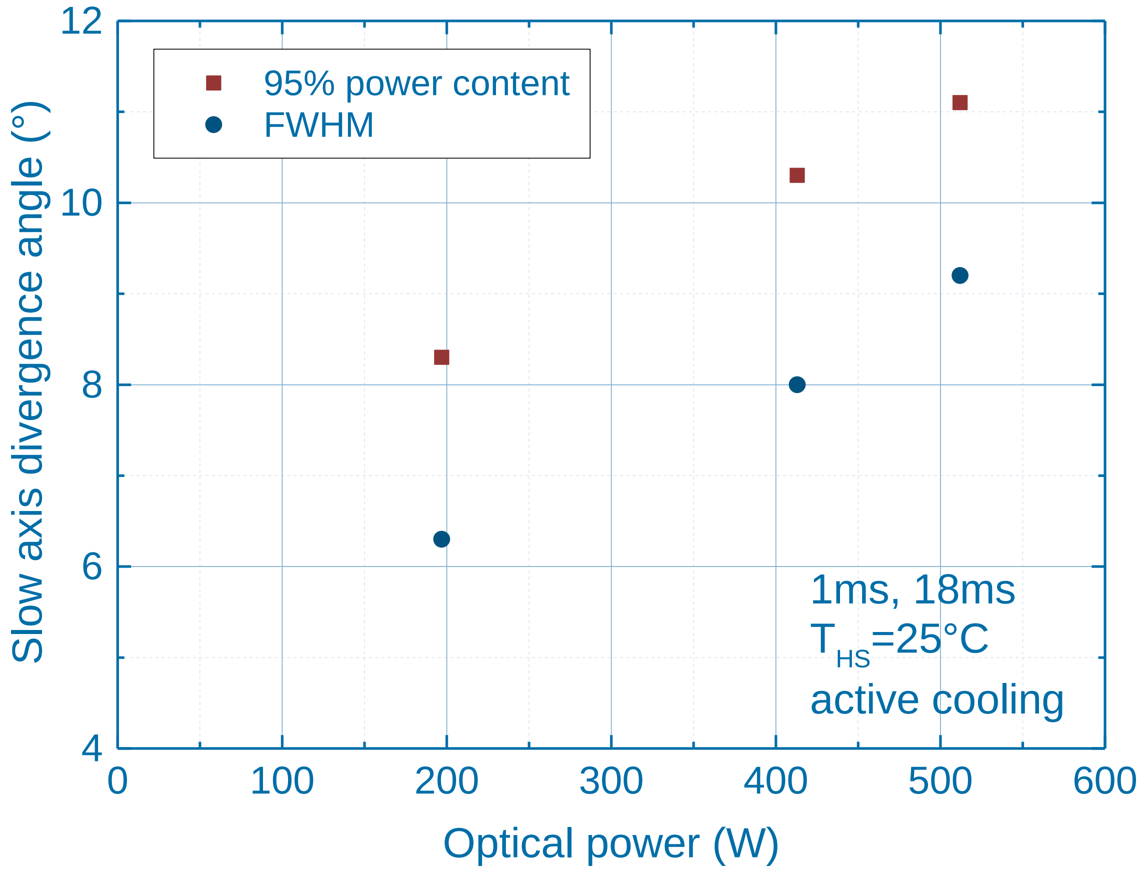
- θ_{FWHM} = 22.5°
- $\theta_{95\%}$ = 45.5°

Slow axis:

- θ_{FWHM} = 9.2°
- $\theta_{95\%}$ = 11.1°

New generation quasi-CW 940 nm Bars (VI)
Slow axis

Measurement conditions: 1ms, 18ms, T=25°C



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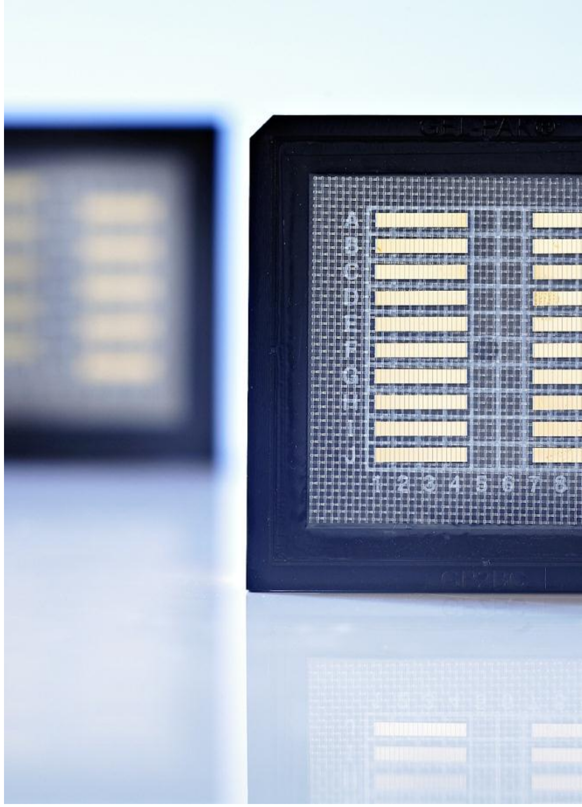


New generation quasi-CW 880 nm Bars (I)
Design

Epitaxy:
Pietrzak et al., Proc. of SPIE 896528 (2014)

1) better carrier confinement
   → high internal efficiency η_i
   → higher P_{op}
2) thick waveguide
   → narrow fast axis divergence
3) high α_i negligible for short resonator

		reference	new gen.
J_{th} (mA/cm²) *	↗	166	253
η_d (%) *		87	86
η_i (%)	high	97,5	97,7
Γg_0 (cm^{-1})	↗	12,7	21,4
α_i (cm^{-1})	high	0,91	1,04
J_0 (mA/cm²)		88	169,1

* 1.6 mm resonator
Mobarhan, Newport App. Note (1999)

Layout as for 940 nm:

75% 37E 190µm 1.5mm
→ narrow slow axis divergence

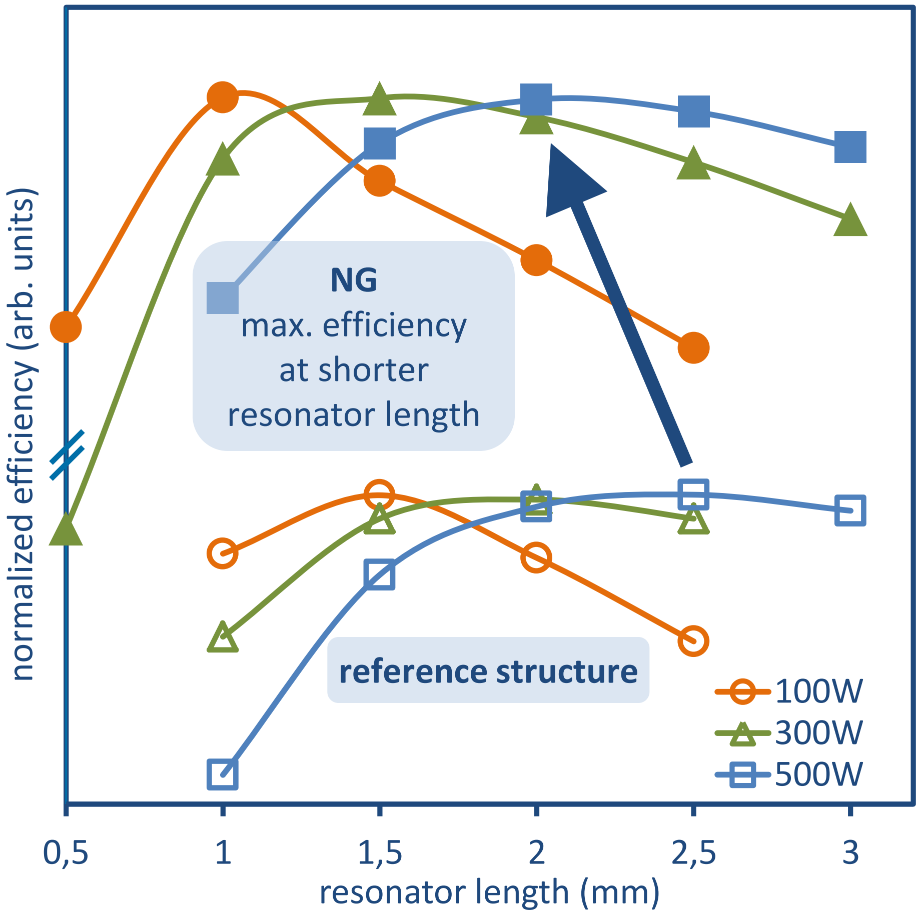
New generation quasi-CW 880 nm Bars (II)

Better efficiency → reduced "cost / Watt"

- recall phenomenological model based on char. Temp.

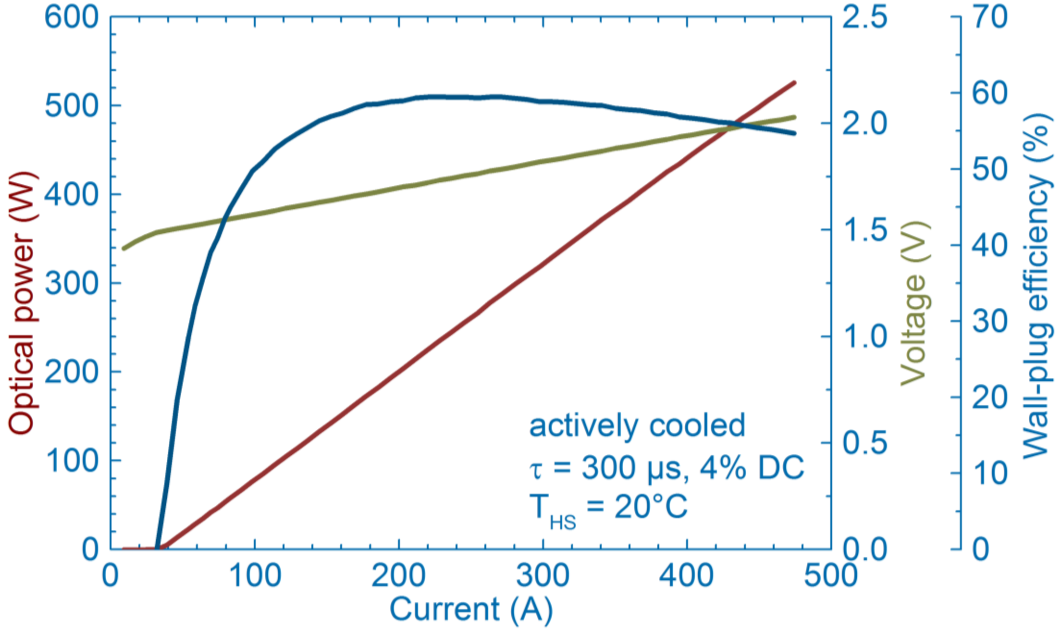
$$I_{thres} \propto e^{\Delta T/T_0}$$
$$\eta_{diff} \propto e^{\Delta T/T_1}$$

- input parameters T_0, T_1
- new generation (NG) structure has efficiency maximum for smaller chip

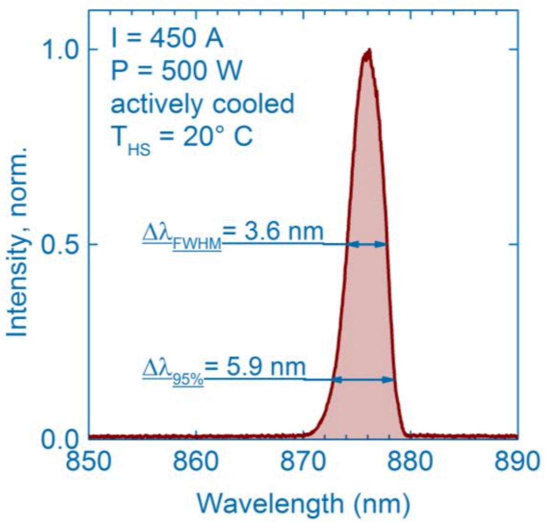


New generation quasi-CW 880 nm Bars (III)

Power-voltage-current characteristic



- P_{op} = **500 W**
- I_{op} = 450 A
- S_{op} = 1.21→1.17 W/A
- WPE_{max} = 59.5%
- WPE_{op} = 55%



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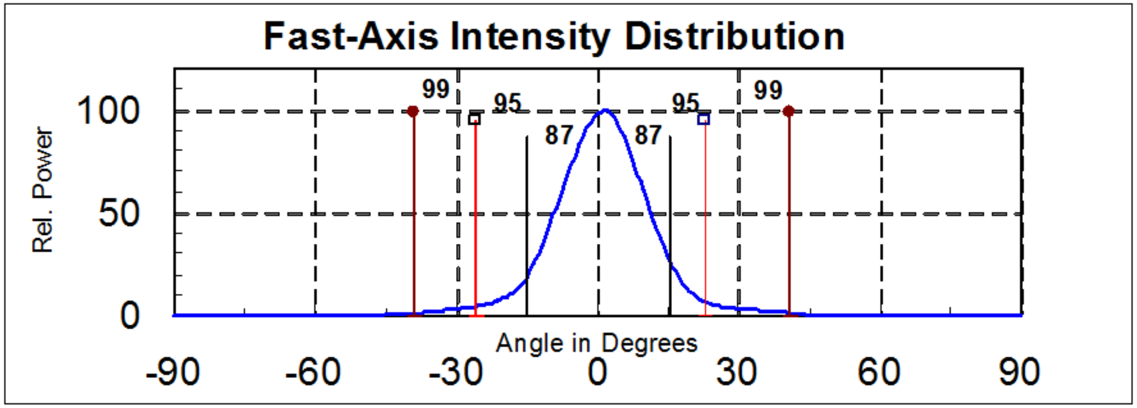
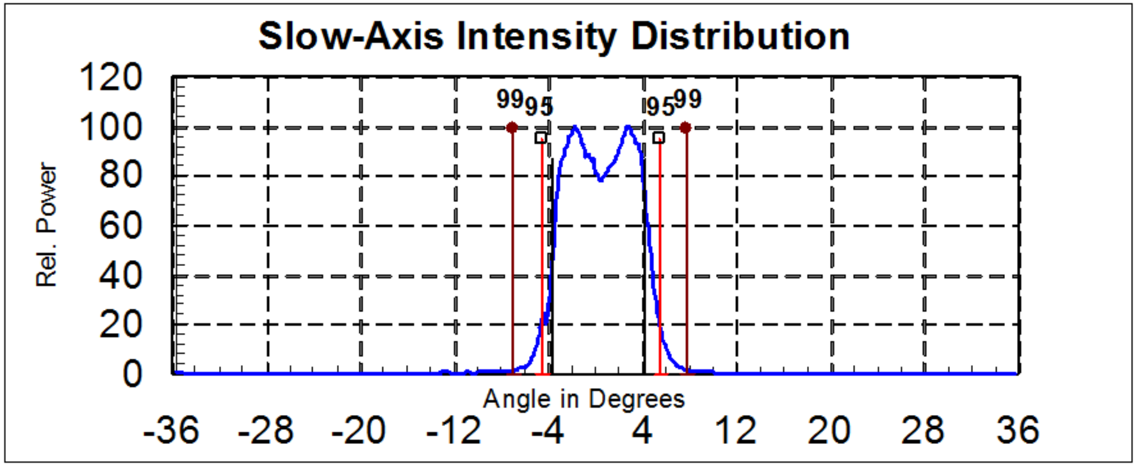
  JDL-BAB-75-37-880-TE-500-1.5

New generation quasi-CW 880 nm Bars (IV)

Far-field profiles





Measured at:
I= 400A (300µs, 10ms, T=25°C)

Fast axis:

- θ_{FWHM} = 20.5°
- $\theta_{95\%}$ = 47.0°

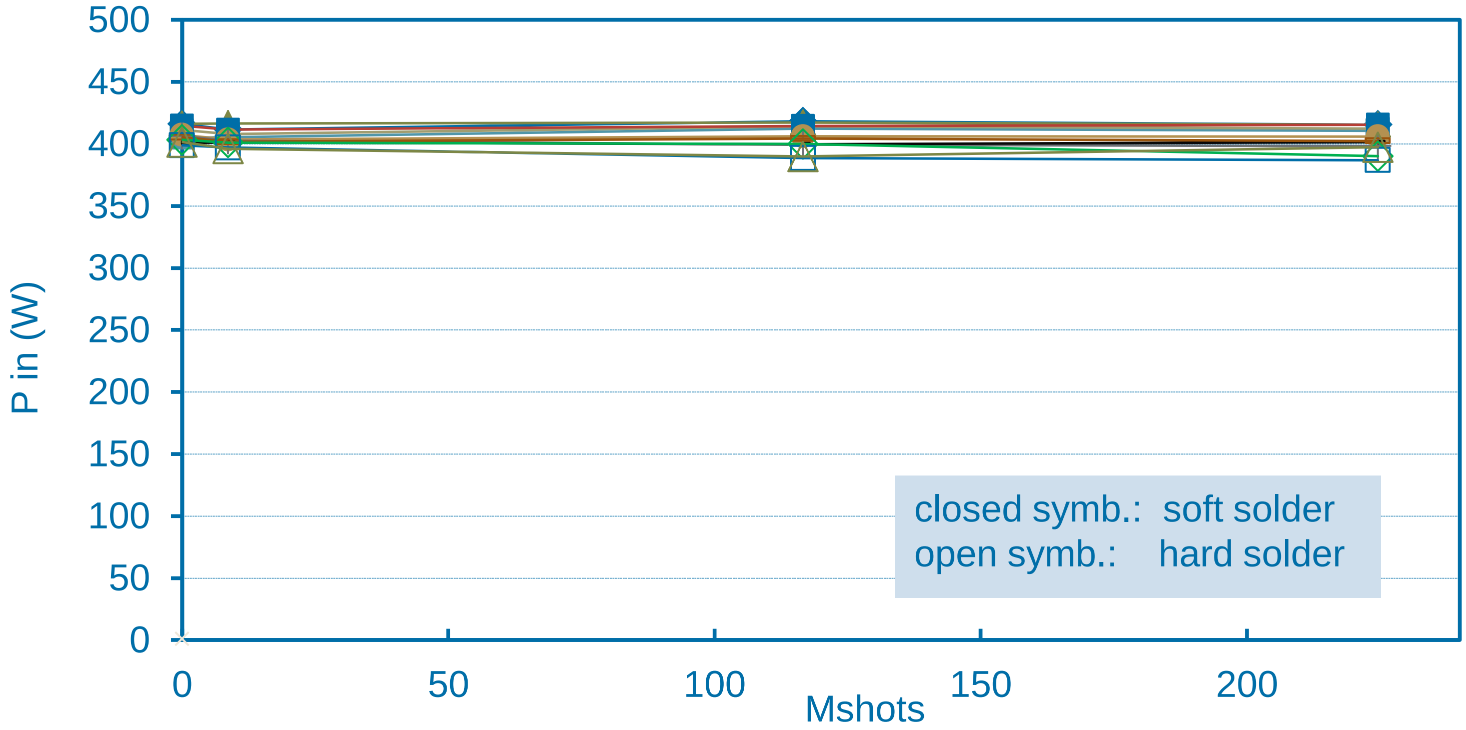
Slow axis:

- θ_{FWHM} = 8.3°
- $\theta_{95\%}$ = 10.0°

New generation quasi-CW 880 nm Bars (V)

Lifetime test

- device under test: JDL B-75-37-880-TE-500-1.5 on microchannel cooler
- conditions: 400A, 300µs, 100Hz (3% d.c.), 25°C
- 224 Mshots as of March, 2014, ongoing



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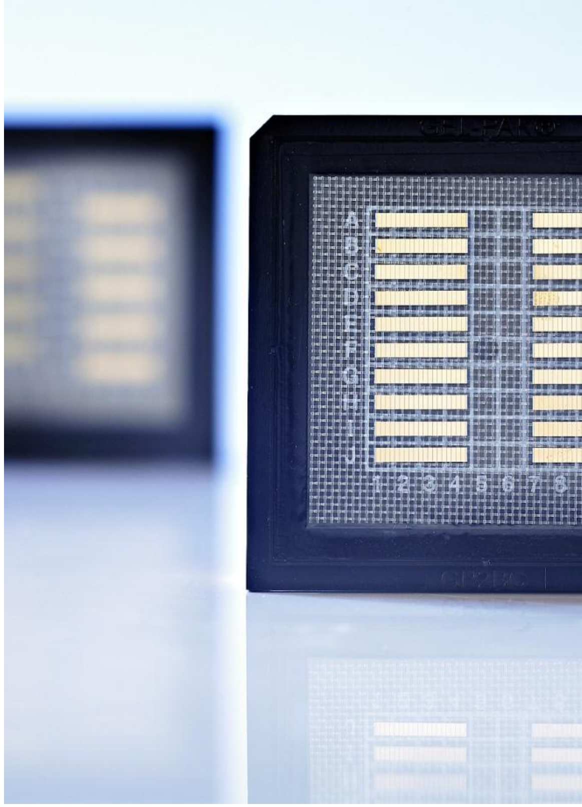
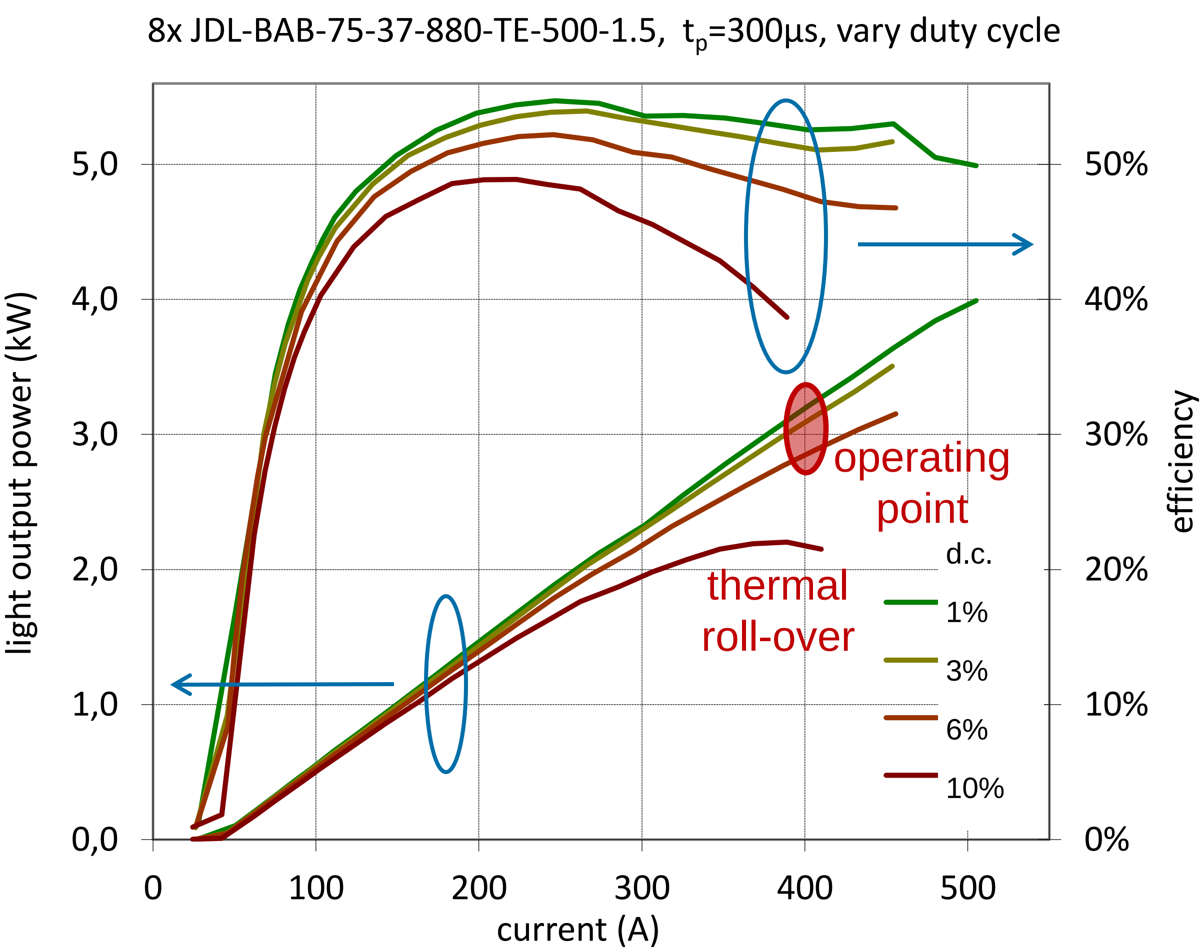
- **Outlook: laser diode stacks**
  → poster tomorrow 15:00 – 16:25



Passively cooled laser diode stacks
for pulsed operation

- 880 nm QCW bars
- 8 x in series
- next generation JenLas® *QCW* stack technology



- t_p = 300µs
- DC 1%
  3%
  6% ← limit
  10%

Acknowledgement

QCW laser diode development:

- **Agnieszka Pietrzak, Ralf Hülsewede, Martin Zorn, Olaf Hirsekorn**
  Jenoptik Diode Lab GmbH, Berlin
- *Ferdinand-Braun-Institut, Berlin*

diode laser qualification:

- **Jens Meusel**
  Jenoptik Laser GmbH, Jena

diode laser stack assembly:

- **Alex Kindsvater, Matthias Schröder**
  Jenoptik Laser GmbH, Jena

Summary

- Jenoptik Diode Lab GmbH

  development, production and bare bar sale

- new high-power laser bars for QCW operation
  - JDL-BAB-75-37-**940**-TE-500-1.5
  - JDL-BAB-75-37-**880**-TE-500-1.5

- lifetime test started

- Outlook: laser diode stacks

  → poster tomorrow 15:00 – 16:25