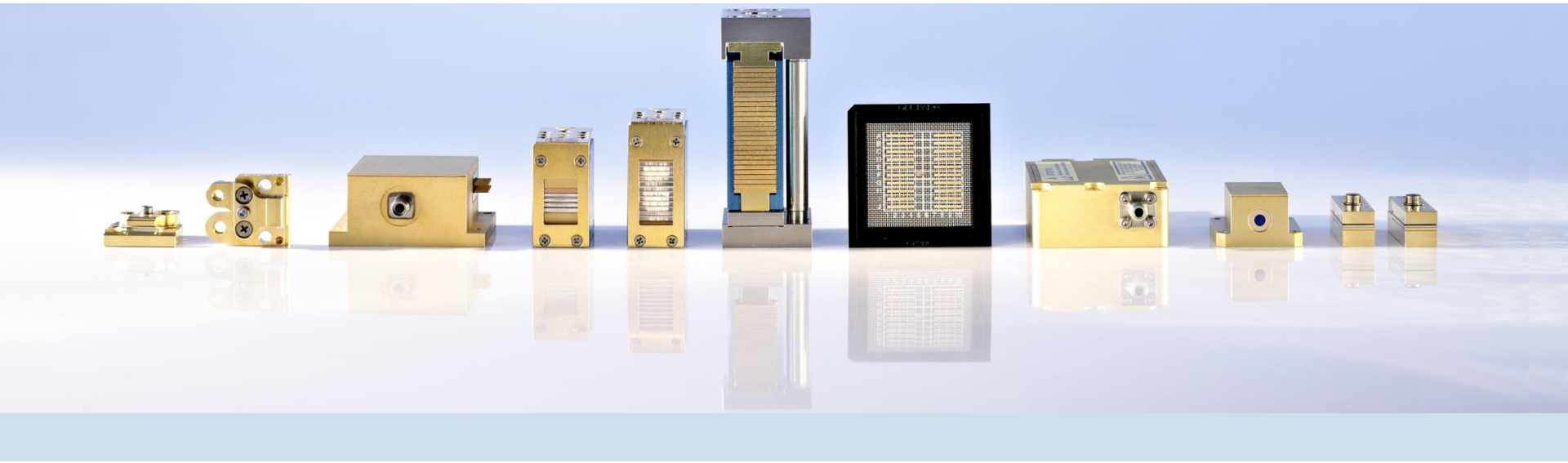
JENOPTIK

Laboratory performance and industrial quality:

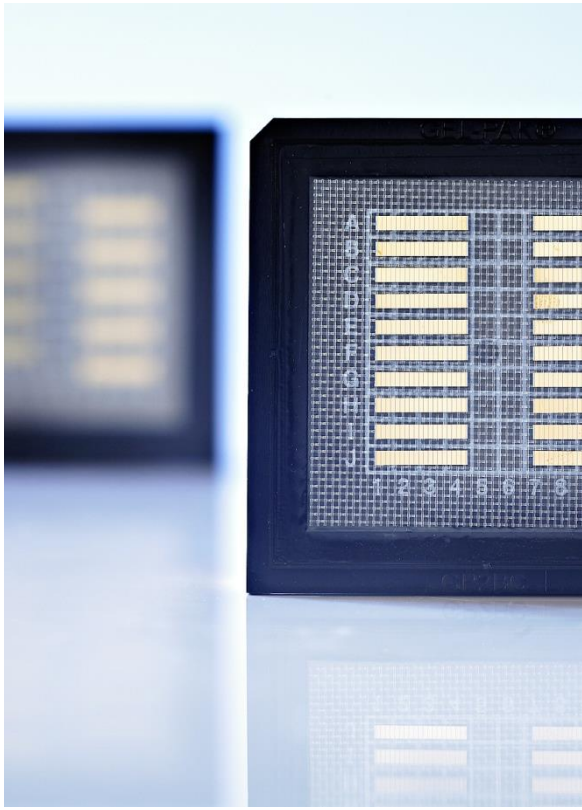
Pump diodes for High-Energy Lasers



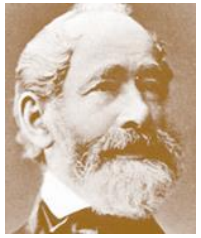
Speaker Martin Wölz

Outline

- **JENOPTIK AG**
- Research-to-industry transfer: Diode Lab GmbH
- Laser diodes for HEC-DPSSL
- Laser diode stacks
- Outlook: mass production



JENOPTIK AG
History



1846/1866

Carl Zeiss
University mechanic and entrepreneur; founded the workshop for precision mechanics and optics in Jena in **1846**

Ernst Abbe
Innovator and reformer; in 1867 scientific director of and in 1875 partner in the Zeiss workshop

1945 - 1948

1945/46: Transfer of patents and dismantling of parts of the company by the U.S. and Soviet armies.

1946: A new Zeiss Company is founded in Oberkochen.

The Zeiss plant in Jena, East Germany, is converted into state property.

1991

Carl Zeiss Jena GmbH gives rise to the creation of Jenoptik GmbH.

- 17,000 employees are dismissed
- Demolition, renovation and development of former Zeiss production sites

1996/1998

In 1996
Jenoptik GmbH was converted into a joint stock corporation.

Going public: June 16, 1998

JENOPTIK AG
Divisions and Business Units

Corporate Center

Lasers & Material Processing	Optical Systems	Industrial Metrology	Traffic Solutions	Defense & Civil Systems





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Key Figures 2013

	Sales (M€)	EBIT (M€)	Employees
Jenoptik Group	600.3	52.7	3433
Lasers & Optical Systems	224.7	24.6	1391

JENOPTIK Division: Lasers & Material Processing
Business Unit: Lasers

Lasers

Laser Processing Systems

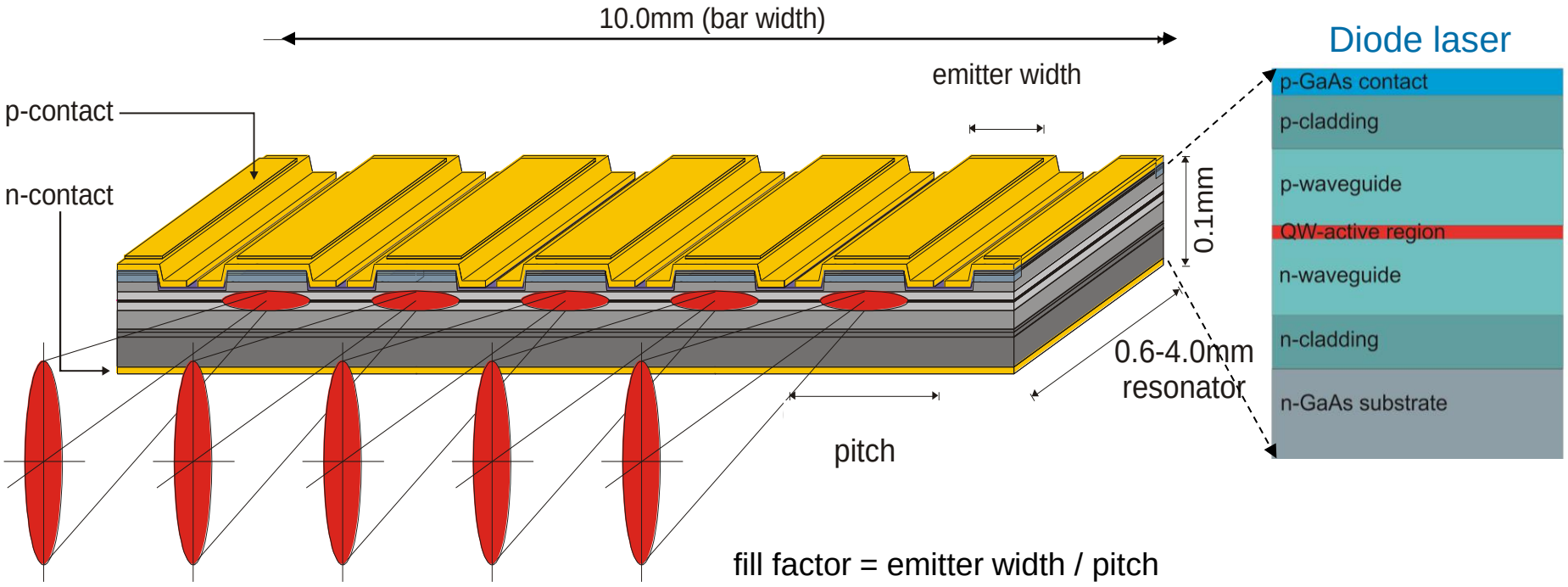
Epitaxy

Processing

Mounting

JENOPTIK Diode Lab GmbH
Berlin

Introduction
Semiconductor laser diode bar



fill factor = emitter width / pitch

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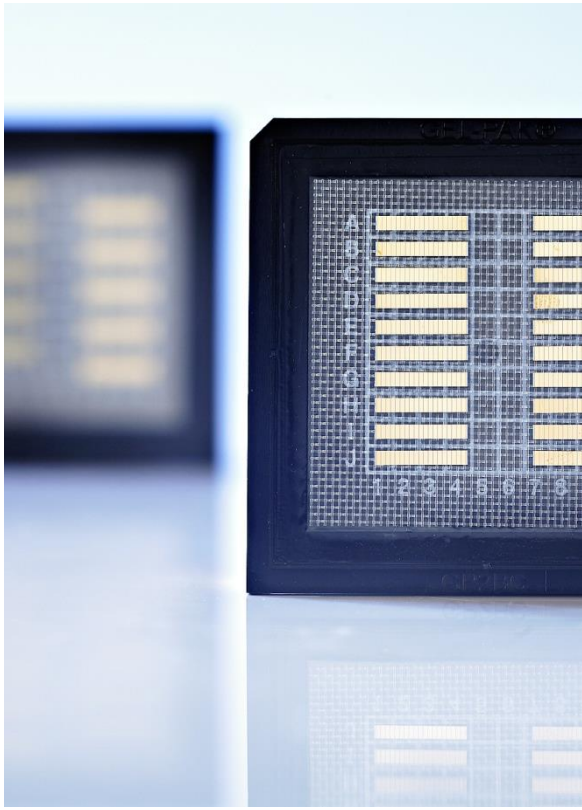


Research-to-industry transfer
JENOPTIK Diode Lab GmbH

1997 **Joint diode laser development**

Leibniz Ferdinand-Braun-Institut
leader in laser diode development

JENOPTIK Laserdiode GmbH
experienced in LD packaging, test and qualification

2002 Formation of JENOPTIK Diode Lab GmbH
- transfer research results into production
- employees from FBH join new company
- FBH shares clean-room facilities

2004 8 types of high-power diode lasers qualified for production
decision to build independent production facility

2006 20 employees

2007 Start of production

2009 Acquisition of TES AG epitaxial services

2014 47 employees

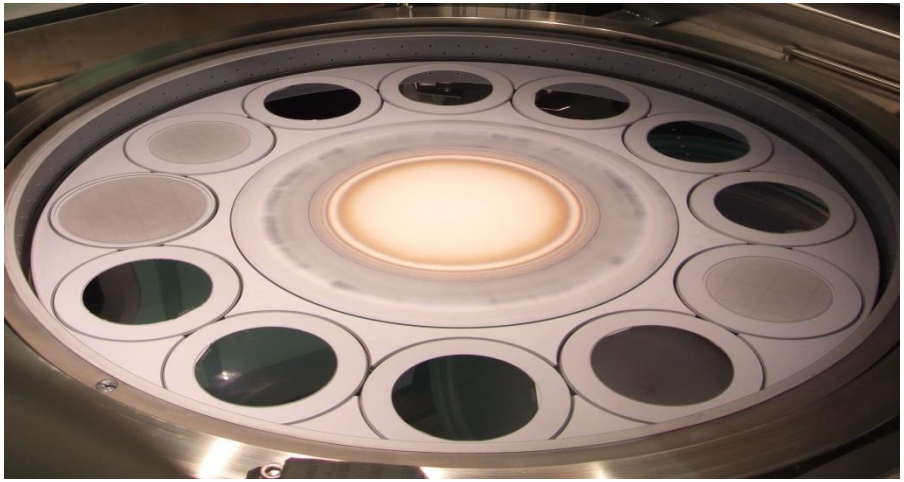
Public projects
BRIMO
HEMILAS

Recruiting

Development contracting

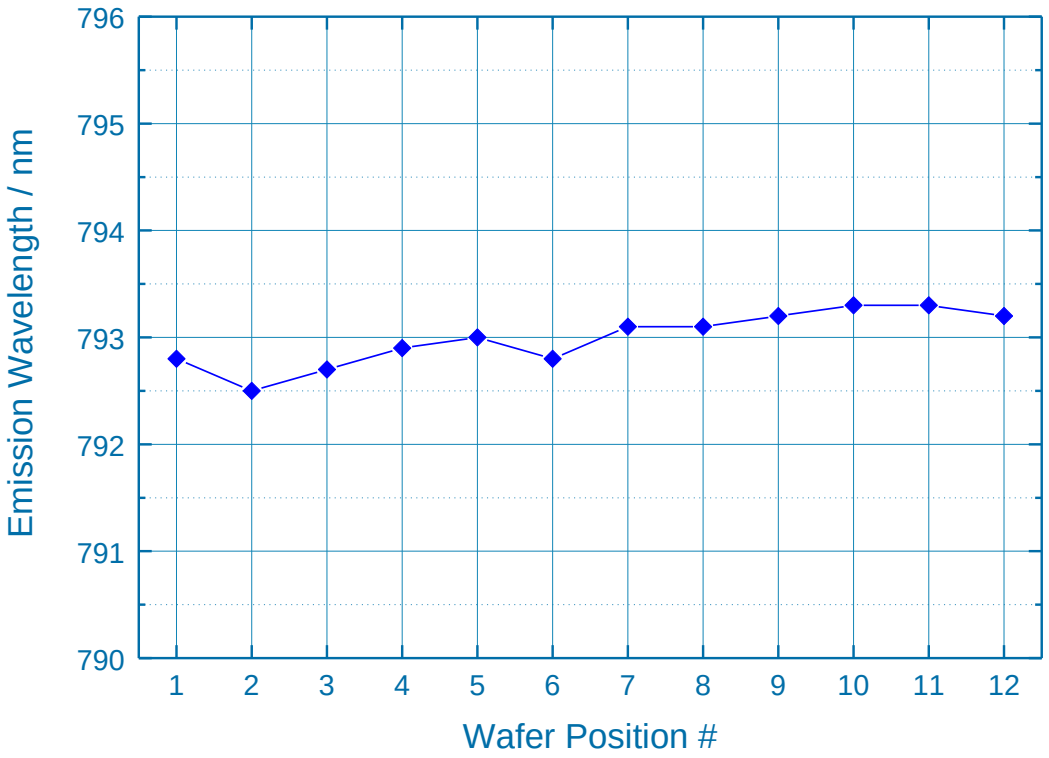
Epitaxy Capabilities at JDL

- 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

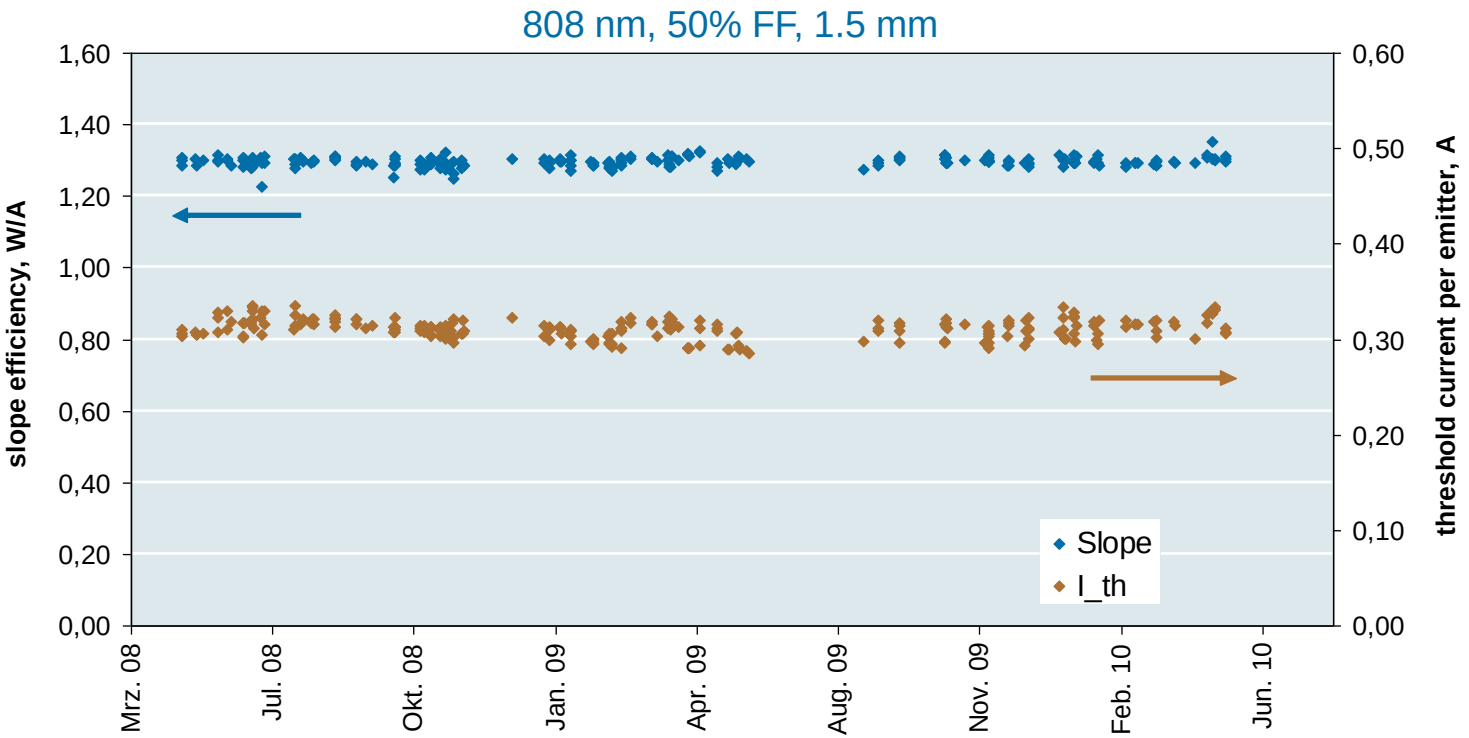


Reproducibility
Electro-optical characteristics

wafer-to-wafer wavelength reproducibility: better than 1 nm



Reproducibility
Electro-optical characteristics



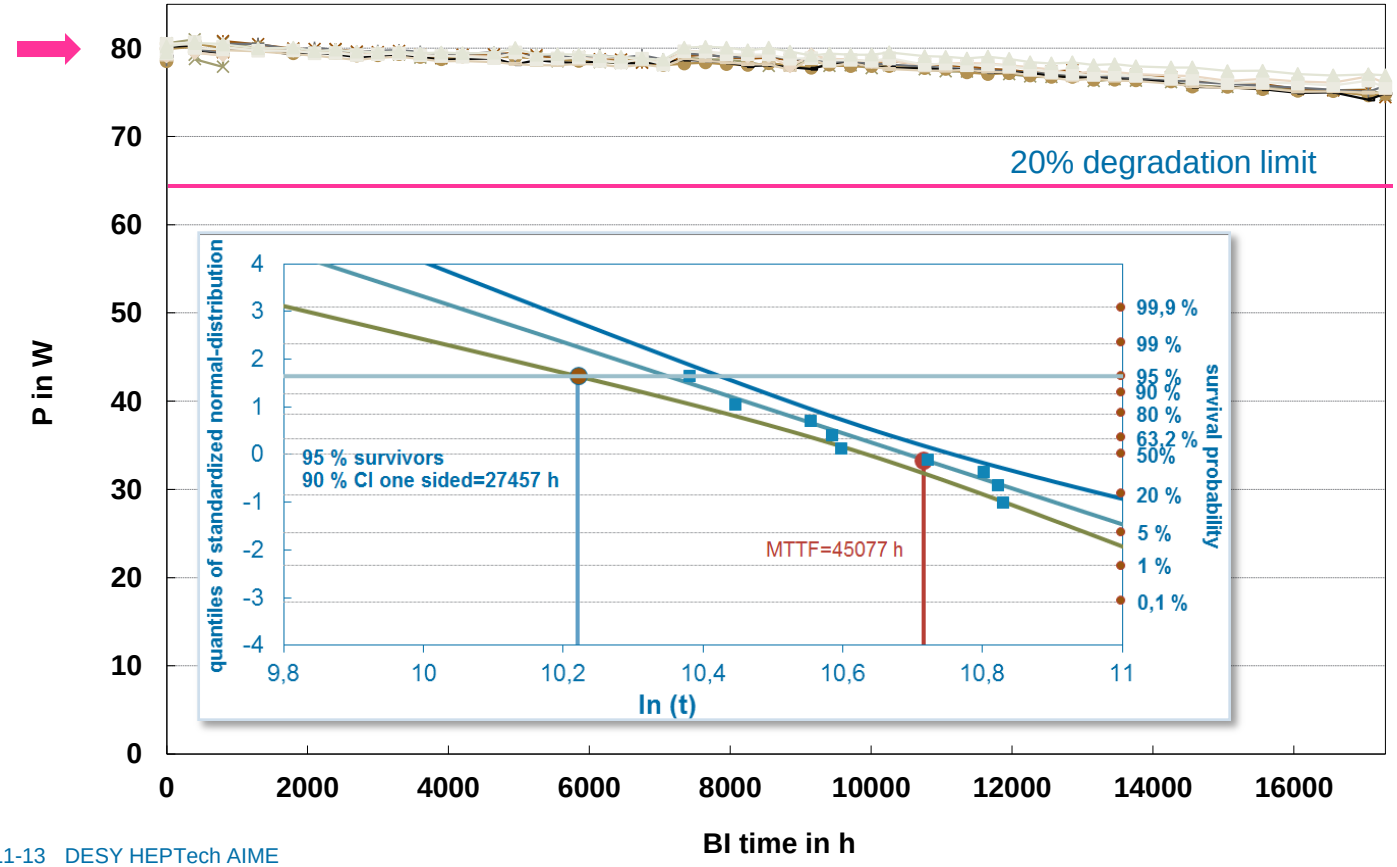
Stability over 2.5 years : σ slope ± 1 % σ I_{th} ± 3 %

M. Zorn et al., Proc of SPIE 7918-27 (2011)

Reproducibility
Reliability

808nm, 50%, 2mm

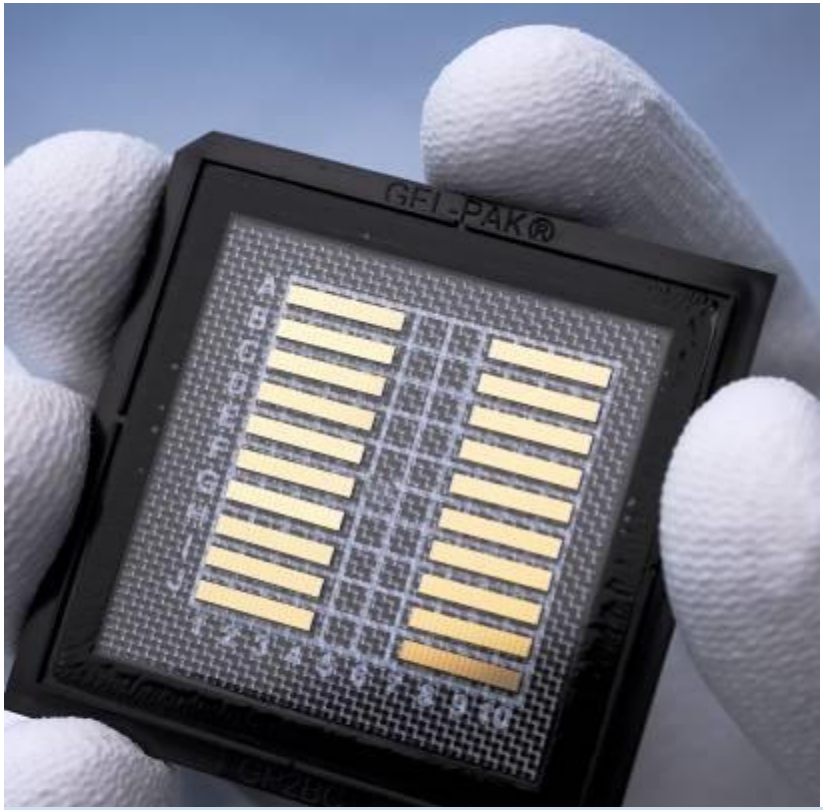
- 27000 h min. lifetime (95% of devices degrade less than 20%)
- 45000 h MTTF



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

- 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

  (**QCW = Quasi Continuous Wave, pulsed operation**)
- Bare bar sale



laser diode bars

Outline

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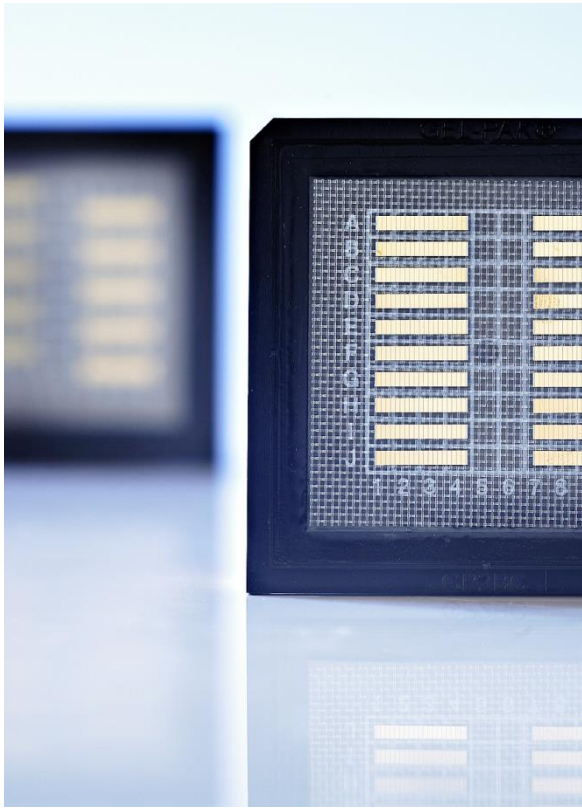
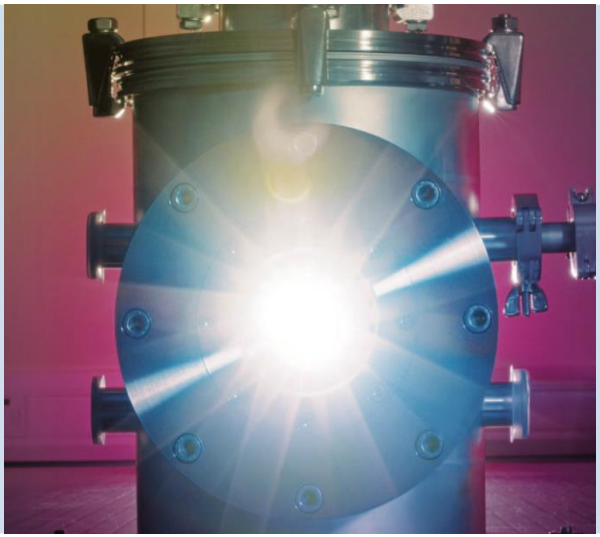
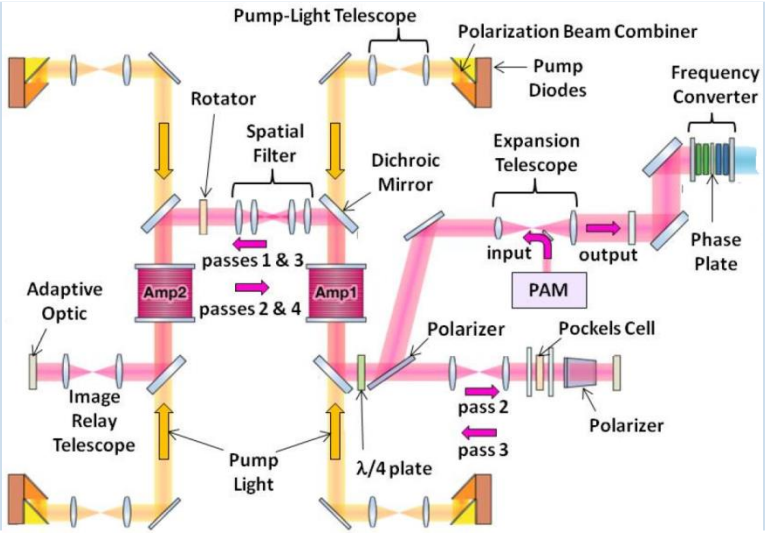
- Research-to-industry transfer: Diode Lab GmbH
- **Laser diodes for HEC-DPSSL**
- Laser diode stacks
- Outlook: mass production



What can we do for high energy class lasers?



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



Erlandson et al., Opt. Mater. Express *1*, 1341 (2011)

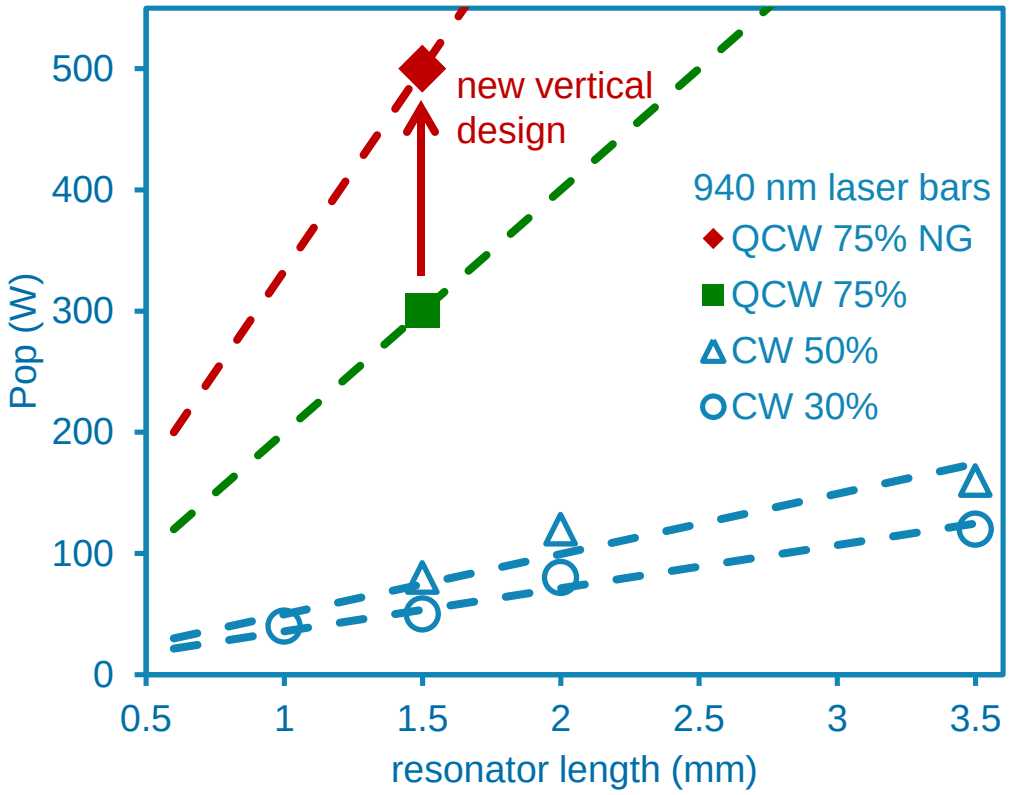
- **Mercury design**
- 10 J, 10 Hz: DiPOLE prototype
  - Yb:YAG 200K, 940nm, 1.2ms QCW
  - 40 kW pulse power from 192 bars
- 100 J …

- **LIFE pump architecture**
  - 200 J, 10 Hz: ELI Beamlines L3
  - Nd:glass RT, 880 nm, 300µs QCW
  - 3.2 MW pulse power, ca. 10.000 bars

Increase the power density of QCW bars !

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

- New chip generation (NG) vertical design
- Targets
  1) increased P_{op} per chip area
  2) decreased “cost per Watt”
- Vertical structure (epitaxy) designed by FBH:
  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



New generation quasi-CW 880 nm Bars (II)

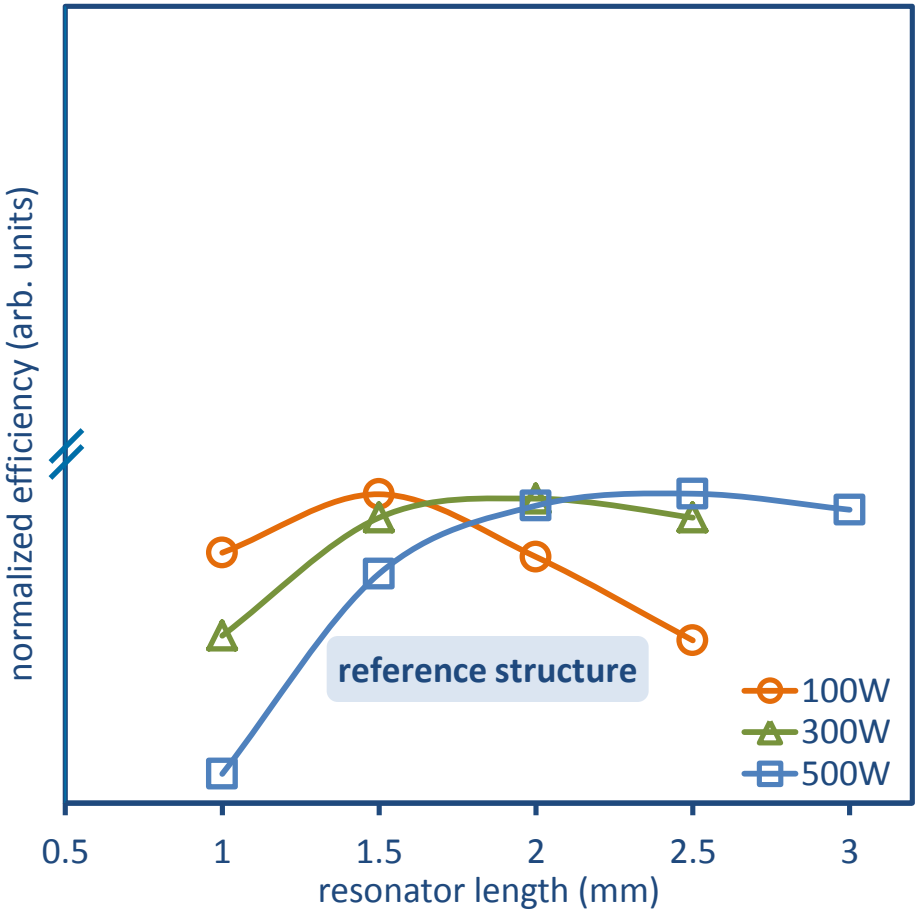
Better efficiency → reduced “cost / Watt”

- 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)

- input parameters T_0, T_1



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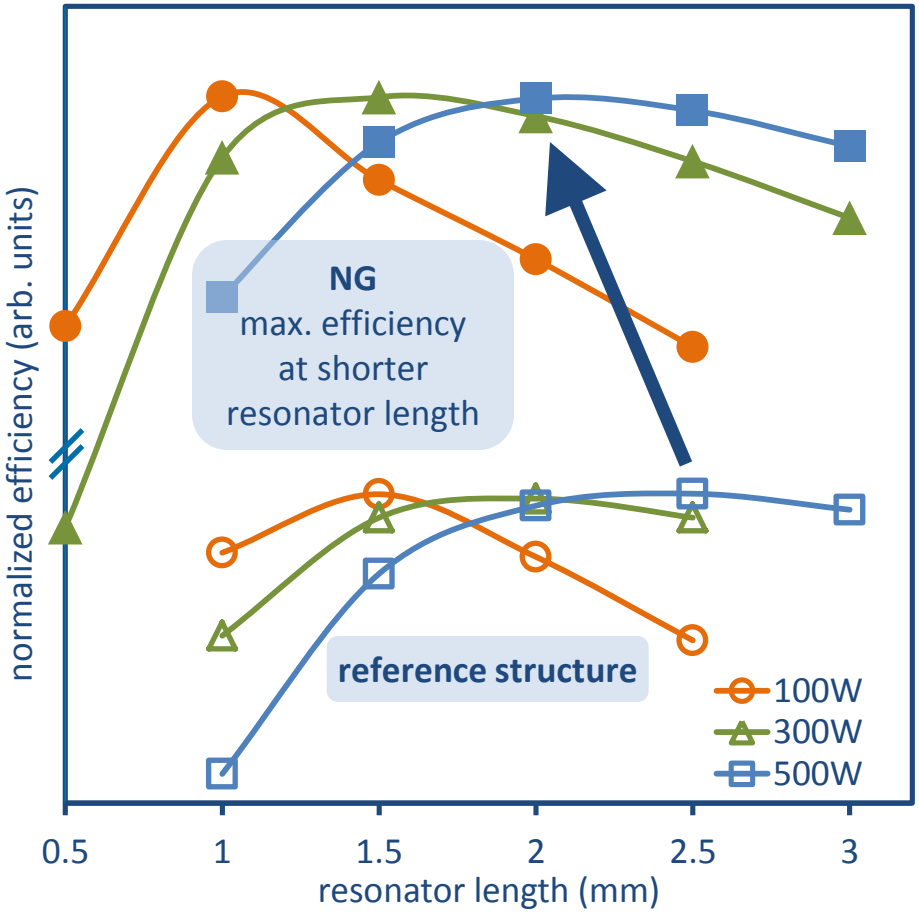
- recall phenomenological model based on char. Temp.

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

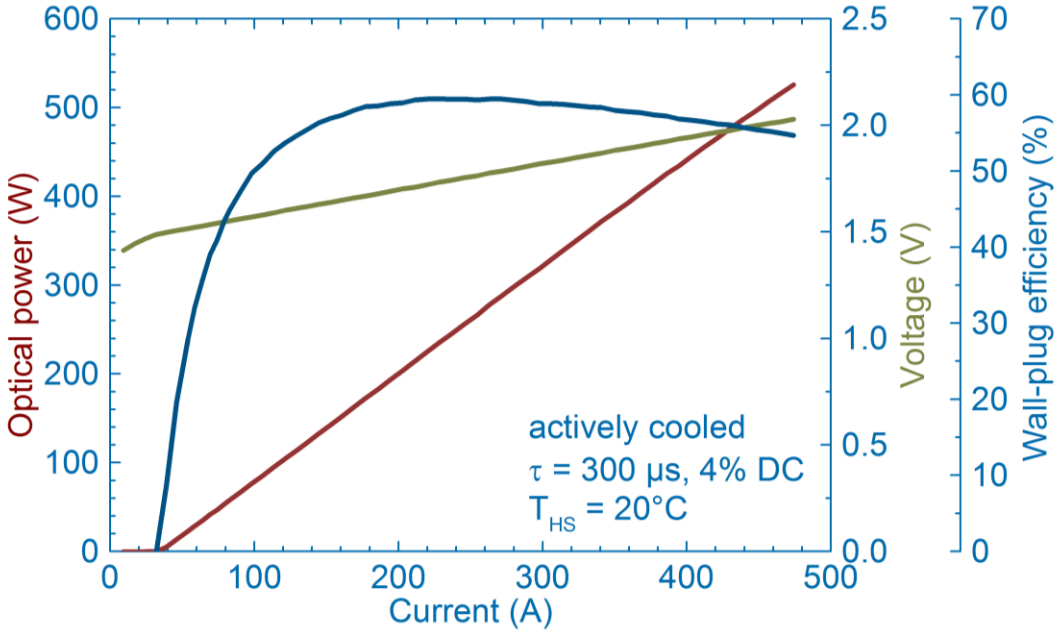
- input parameters T_0, T_1

- new generation (NG) structure has efficiency maximum for smaller chip



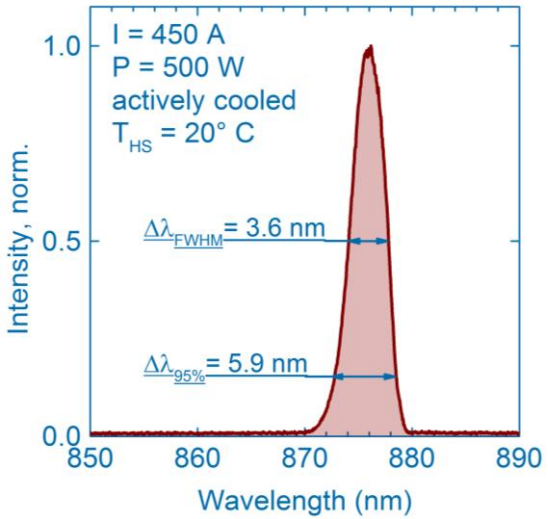
New generation quasi-CW 880 nm Bars (III)

Power-voltage-current characteristic

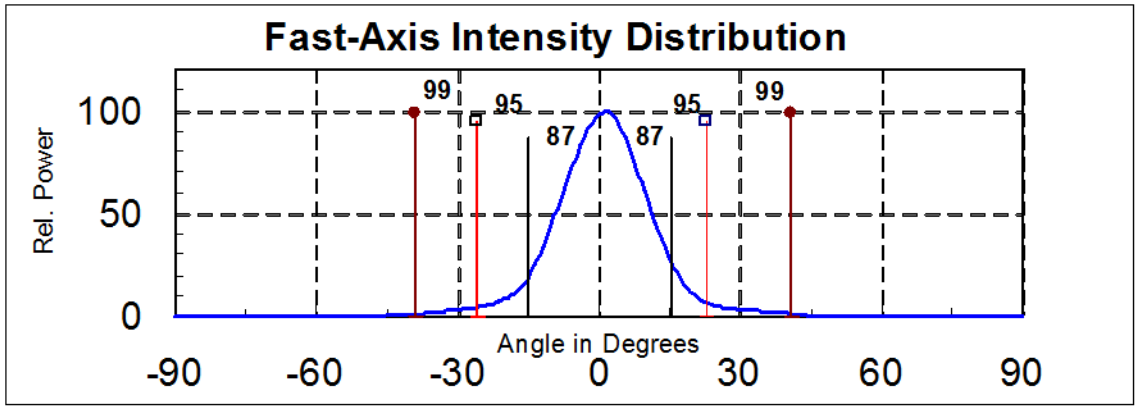


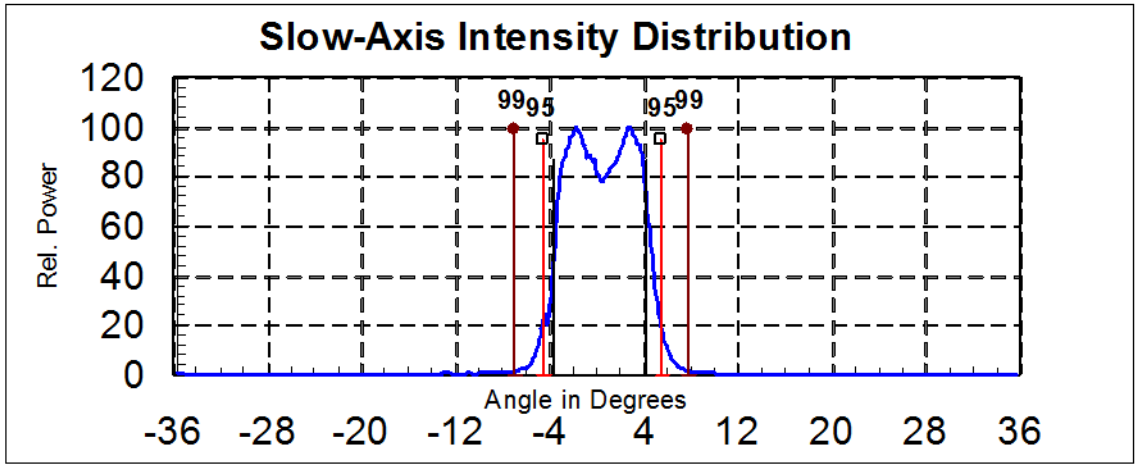
- 75% FF, L=1.5 mm (37 Emitters, W = 190 µm)
- JDL-BAB-75-37-880-TE-500-1.5

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



New generation quasi-CW 880 nm Bars (IV)
Far-field profiles





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

Fast axis:

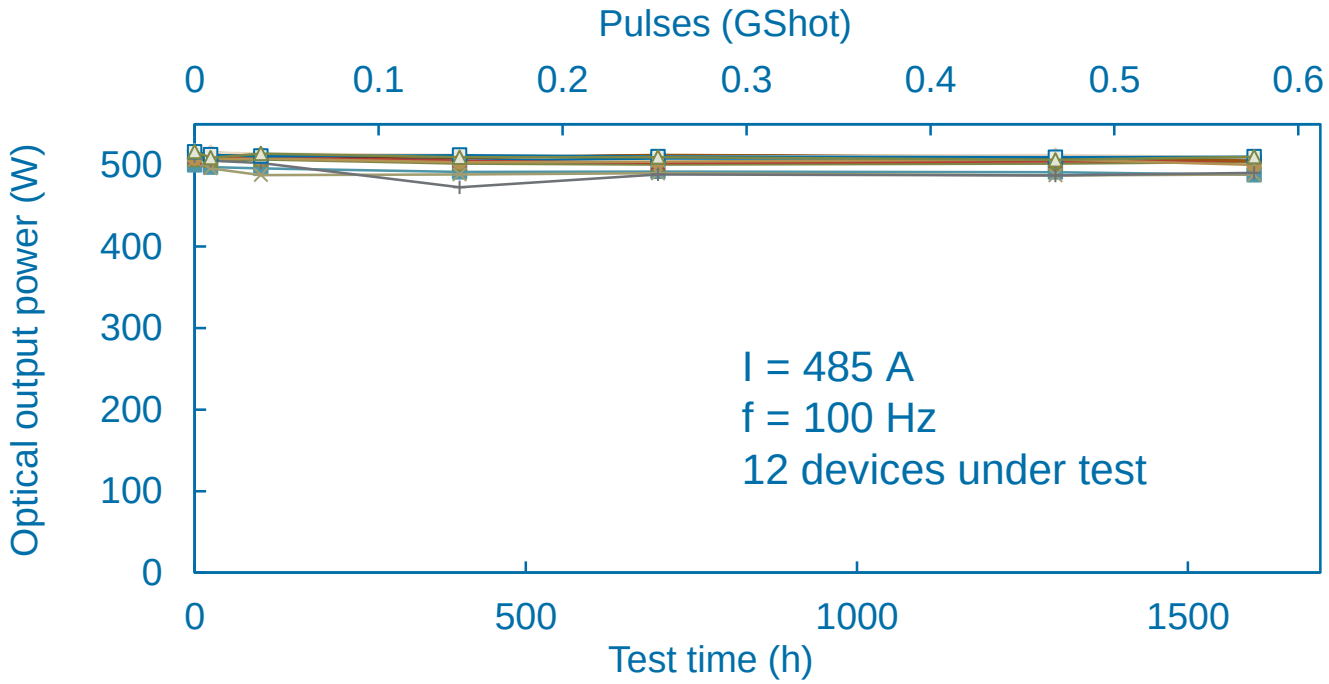
- θ_{FWHM} = 20.5°
- $\theta_{95\%}$ = 47.0°

Slow axis:

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

New generation quasi-CW 880 nm Bars (V)
Lifetime test

- device under test: JDL-BAB-75-37-880-TE-500-1.5 on microchannel cooler
- conditions: 485A, 300µs, 100Hz (3% d.c.), 25°C
- 0.8 Gshots as of Oct, 2014, ongoing



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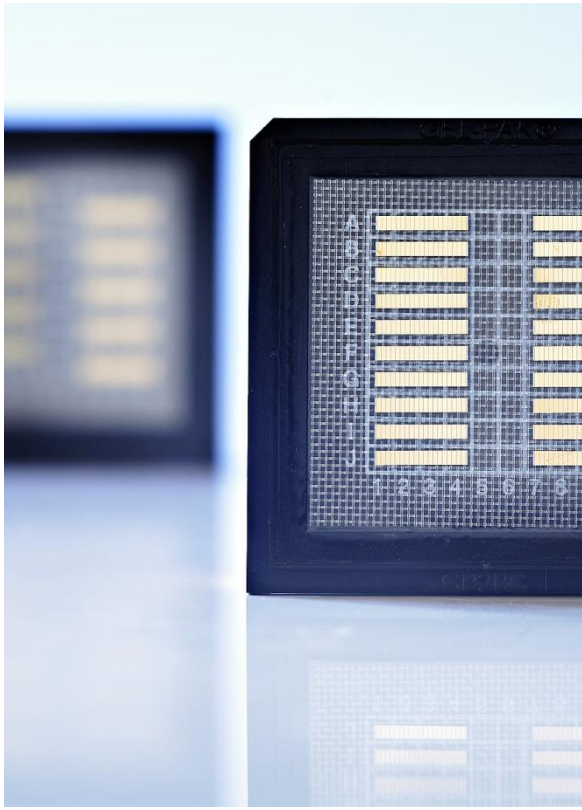
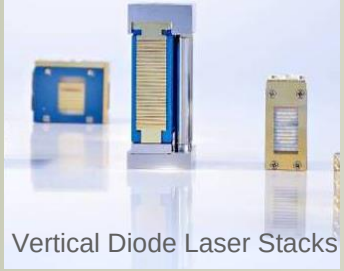
- **Laser diode stacks**
- Outlook: mass production



Diode Laser Stacks

Features

- Used in direct applications, laser pumping, medical and research applications
- 4 to 25 laser bars vertical
  2 to 4 bars horizontal
- cw power per bar:
  50 – 80 W l 808 nm
  50 – 120 W l 9xx nm
- qcw power per bar:
  100 – 300 W l 808 & 9xx nm
- Capacity: thousands p.a.


Vertical Diode Laser Stacks

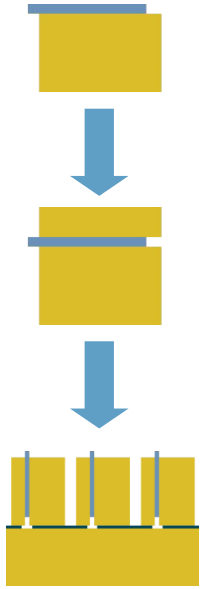

qcw Stacks


Horizontal Diode Laser Stacks

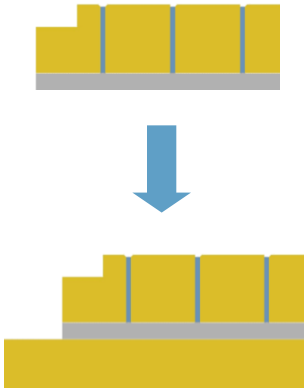
Passively cooled QCW laser diode stacks

- QCW, *quasi continuous wave*, pulsed operation, t ≈ ms
- Semiconductor laser in stationary operation
- Low duty cycle → thermal equilibrium not reached → high pulse power

Catalog product



JenLas® *QCW*



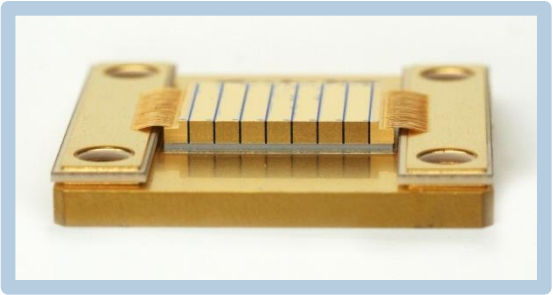
CTE-matched

Lab demonstrator

- New cost-efficient mounting technology
- Flexible arrangement of laser emitters

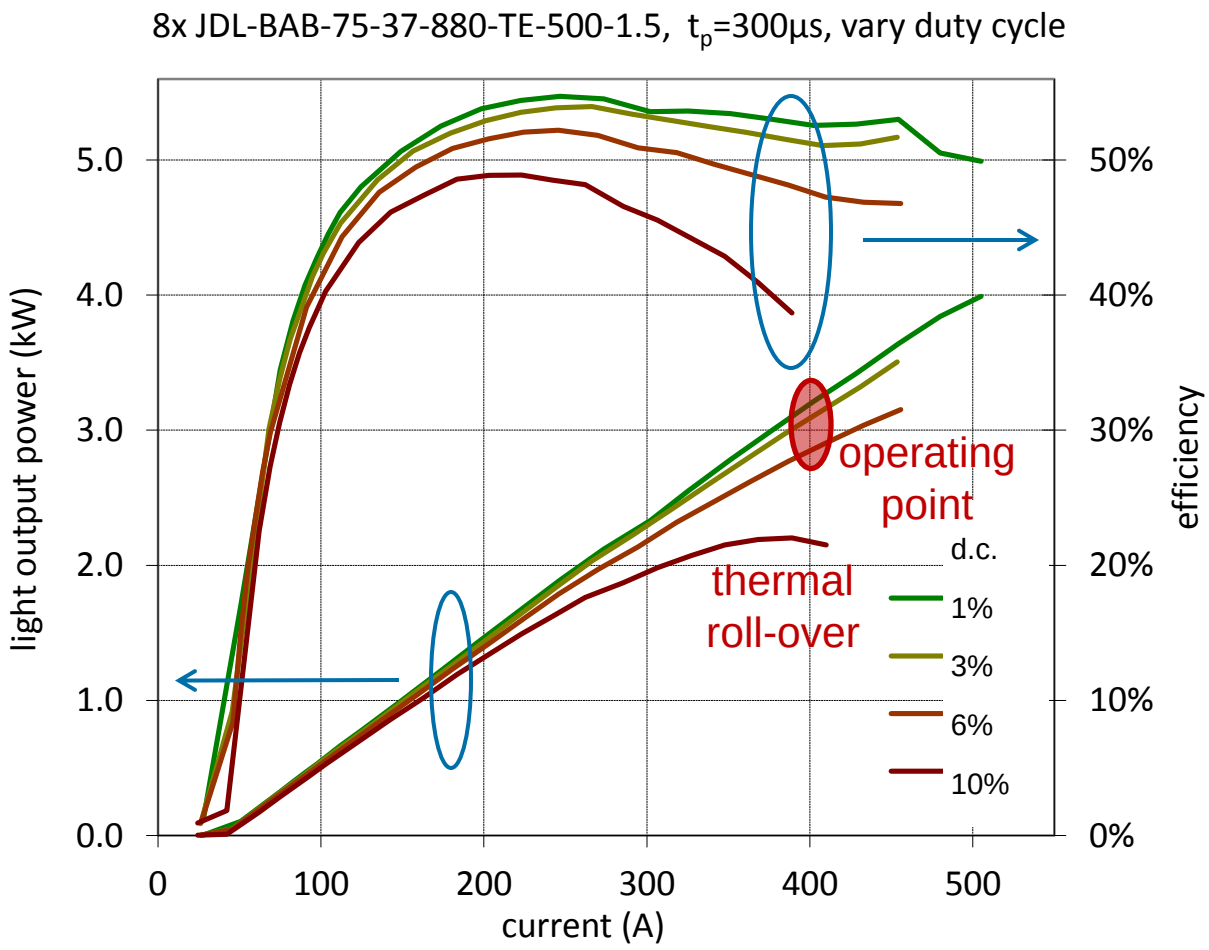
Passively cooled laser diode stacks
for pulsed operation

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



- t_p = 300µs
- DC 1%
  3%
  6%
  10%

limit



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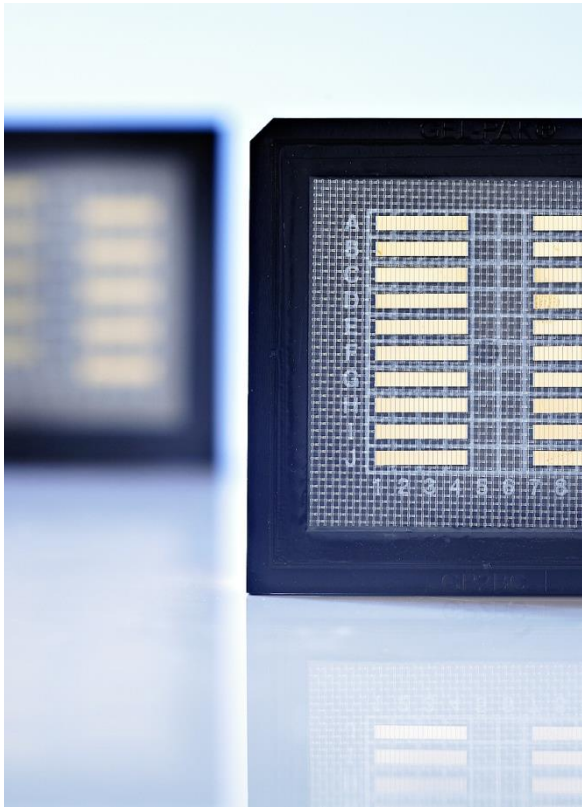
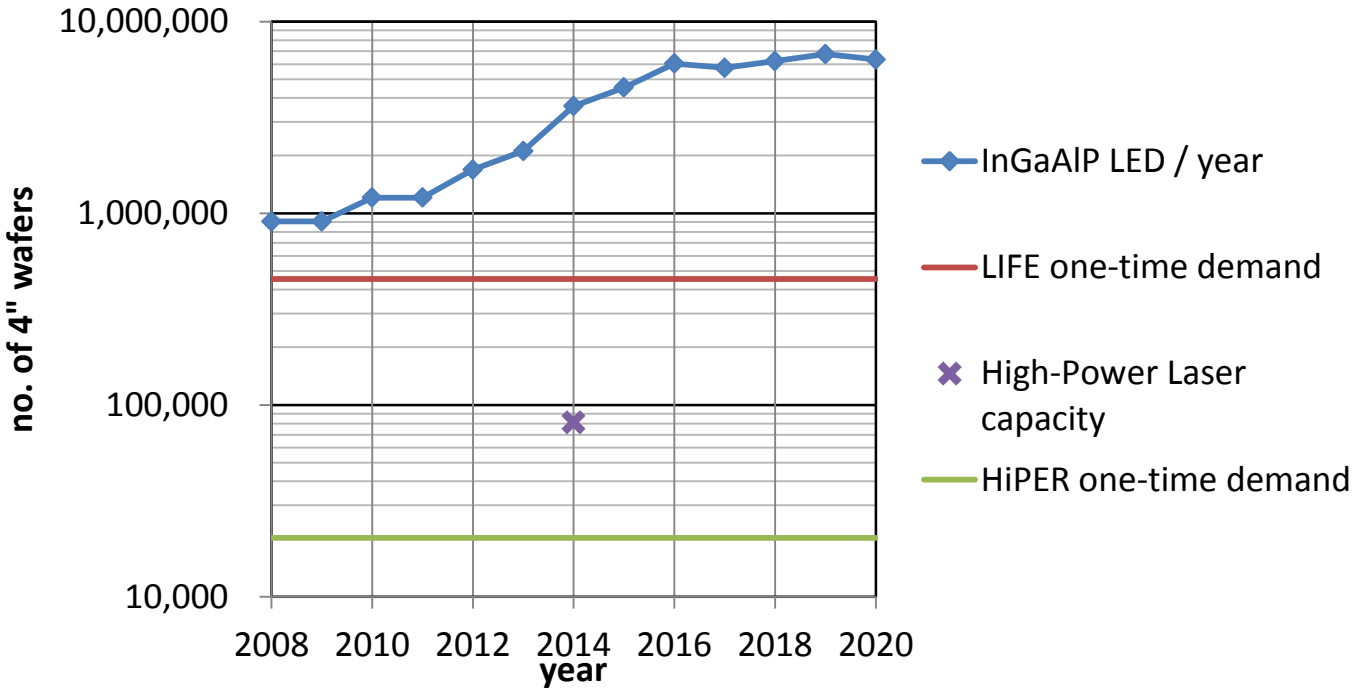
- **Outlook: mass production**



Outlook: mass production
GaAs-based laser diodes

- Laser confinement nuclear fusion schemes challenge laser diode supply world-wide
- Lesson learned from red LED ramp-up:
  world-wide capacity can be doubled in two years if supported by demand
  (or by government programs)



Summary

- Jenoptik Diode Lab GmbH

  FBH spin-off

  development, production and bare bar sale

- new 500W laser bars for QCW operation

- next generation laser diode stacks
  - JenLas® *QCW*
  - standard layout available summer 2015