# Wavelength Stabilized High-Power Quantum Dot Lasers


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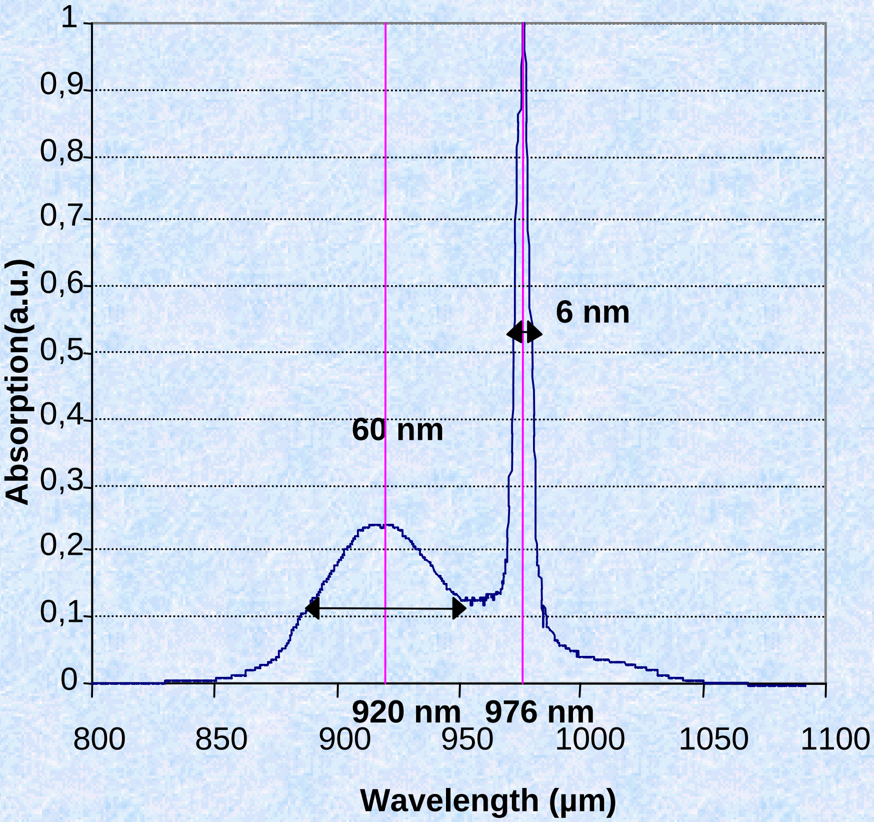
# Outline

- Spectral gain profile engineering by dot geometry control
- Broad area device characteristics
- Tapered QD lasers
- Single mode tapered QD lasers with temperature stable emission wavelength and device performance
- Summary

# Motivation for Uncooled Pump Lasers

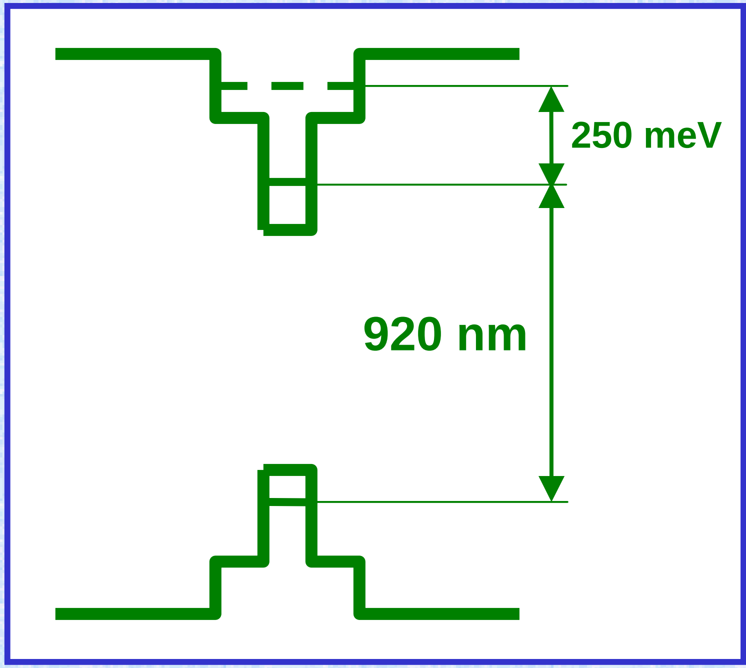
- Major costs in high power pump modules: Peltier cooler
- External wall plug efficiency of pump module dominated by Peltier cooler consumption.
- Strong cost reduction possible by passive cooling
- Passive cooling with QW laser impossible due to wavelength shift (> 20 nm between 0 – 65 °C)
- 920 nm favourable due to broader absorption band
- High power 920 nm QD laser with temperature shift < 10 nm possible

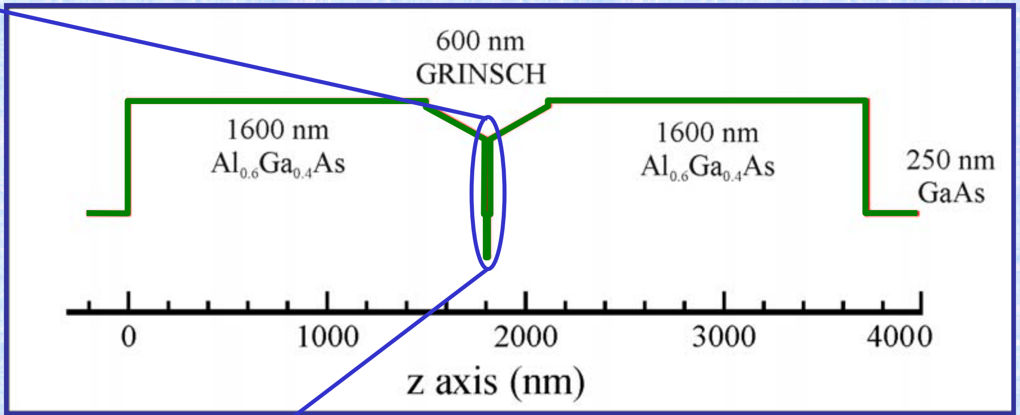
**Absorption spectrum of Yb fibre**




measured by Alcatel

# Laser Design for 920 nm Emission




**920 nm:** 5.2 ML $Ga_{0.49}In_{0.51}As$ in 6 nm GaAs QW

- A single quantum dot layer is used embedded in a 6 nm GaAs QW.
- The laser structure concerning carrier confinement and optical waveguide is designed for 920 nm laser emission

**Why QD active region?**

→ allows gain function engineering by additional geometrical parameters, e.g., QD density, dot size and dot size distribution

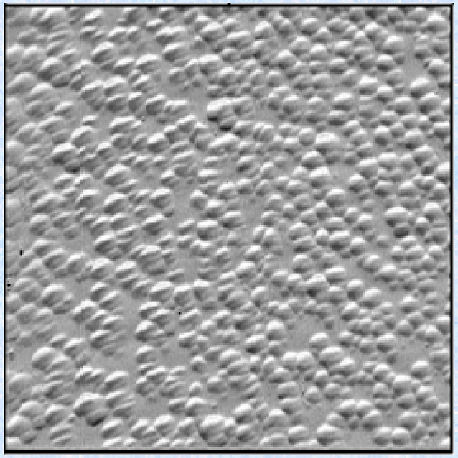
→ internal temperature compensation and broad band gain function

# Dot density control by growth temperature

- $In_{0.6}Ga_{0.4}As$ QDs with fundamental transitions energy of around 1.3 eV
- AFM images of uncovered quantum dots on GaAs surfaces

$T_{substrate}$ = 480 °C

1x1μm

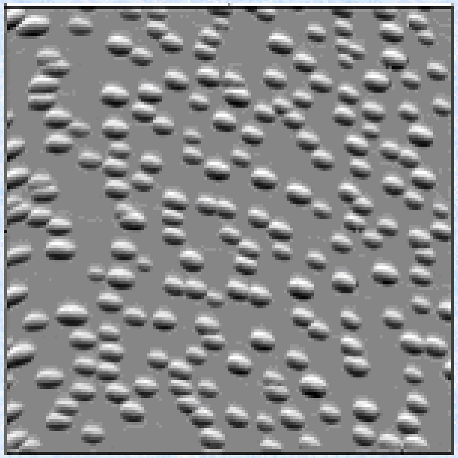


Dot density:

$6 \times 10^{10}$ $cm^{-2}$

$T_{substrate}$ = 510 °C

1x1μm

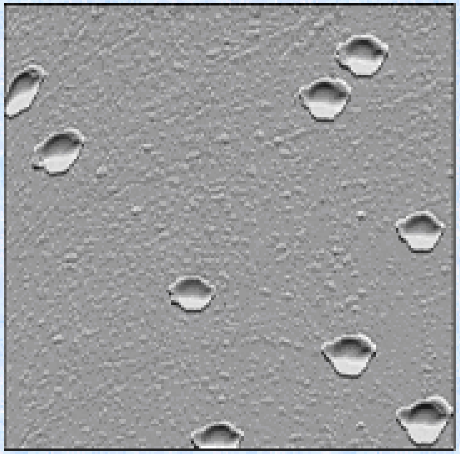


Dot density:

$2 \times 10^{10}$ $cm^{-2}$

$T_{substrate}$ = 530 °C

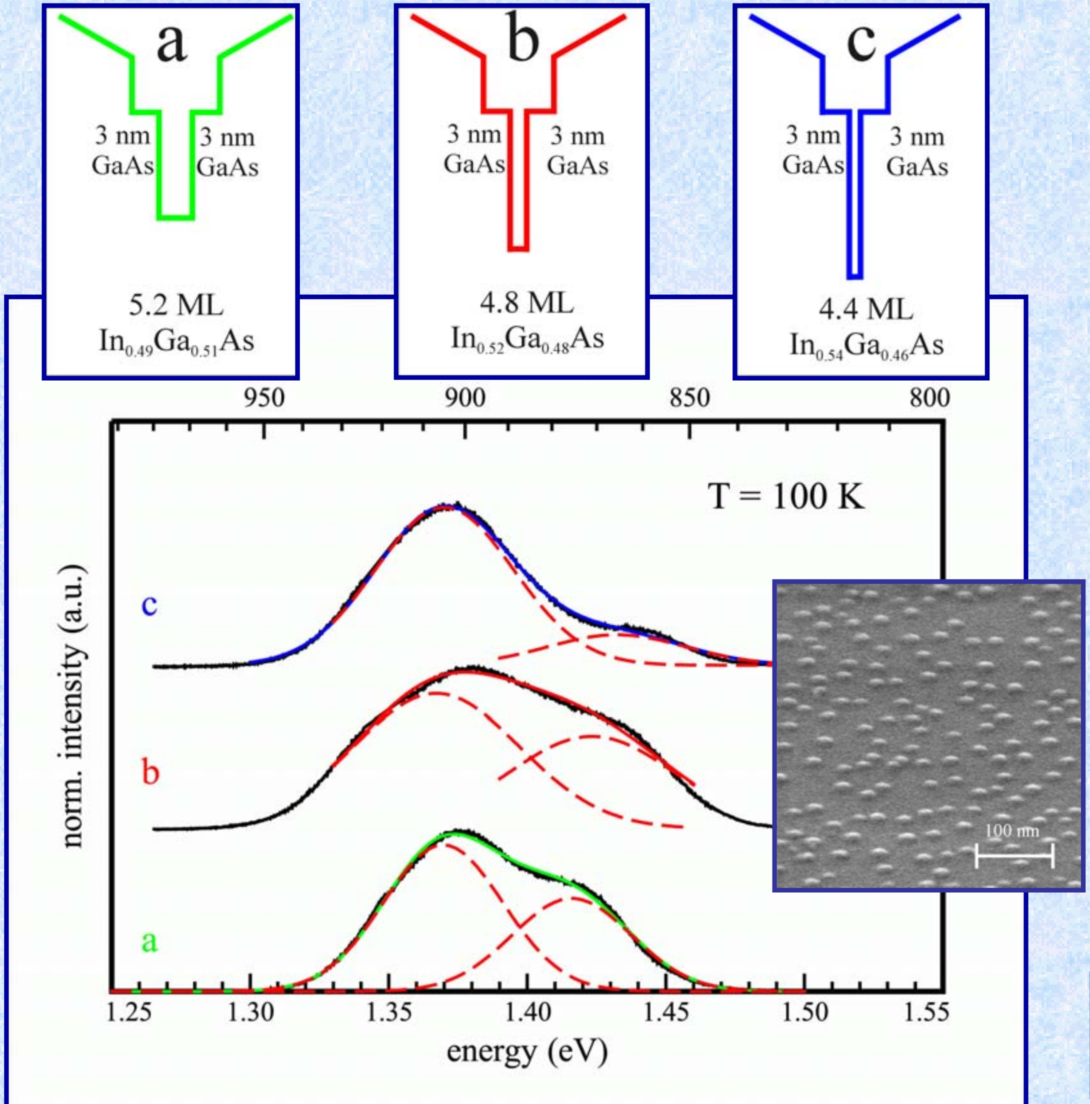
1x1μm



Dot density:

$< 10^{9}$ $cm^{-2}$

# Control of Dot Size by Layer Thickness




**Photoluminescence measurement of different QD samples at high excitation powers:**

energy separation between ground and first excited state increases with decreasing dot size:

a) $\Delta x \approx 47$ meV

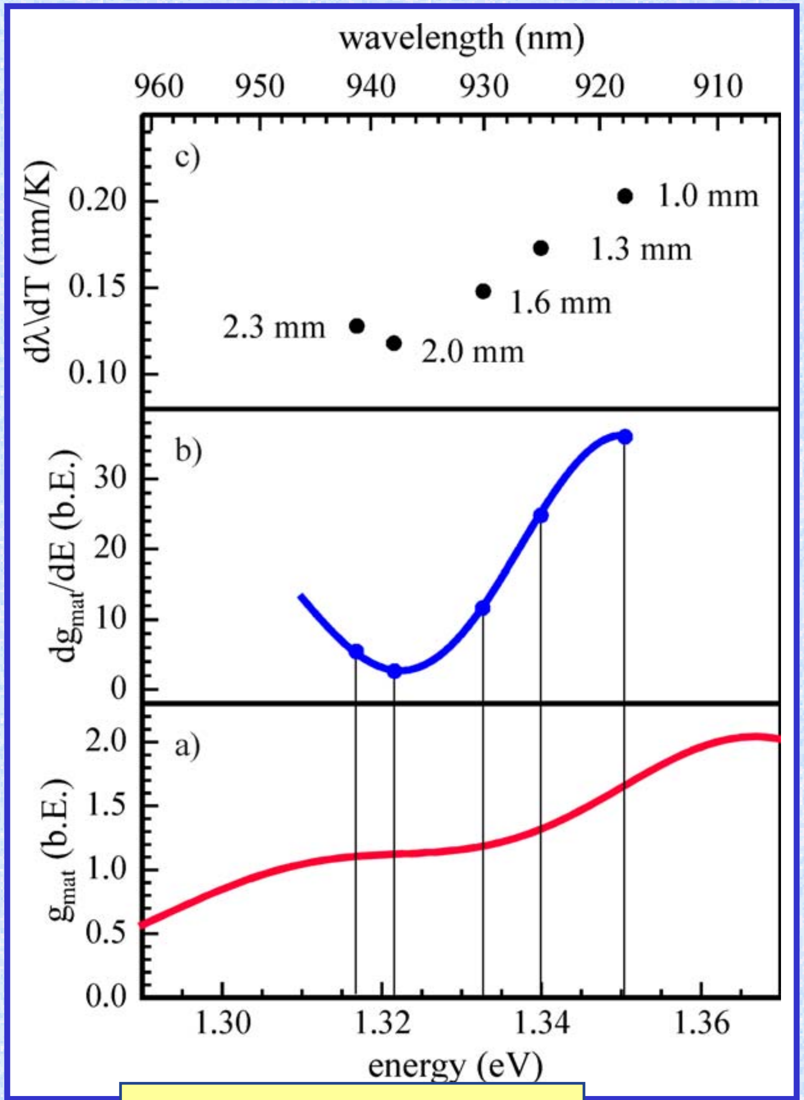
b) $\Delta x \approx 56$ meV

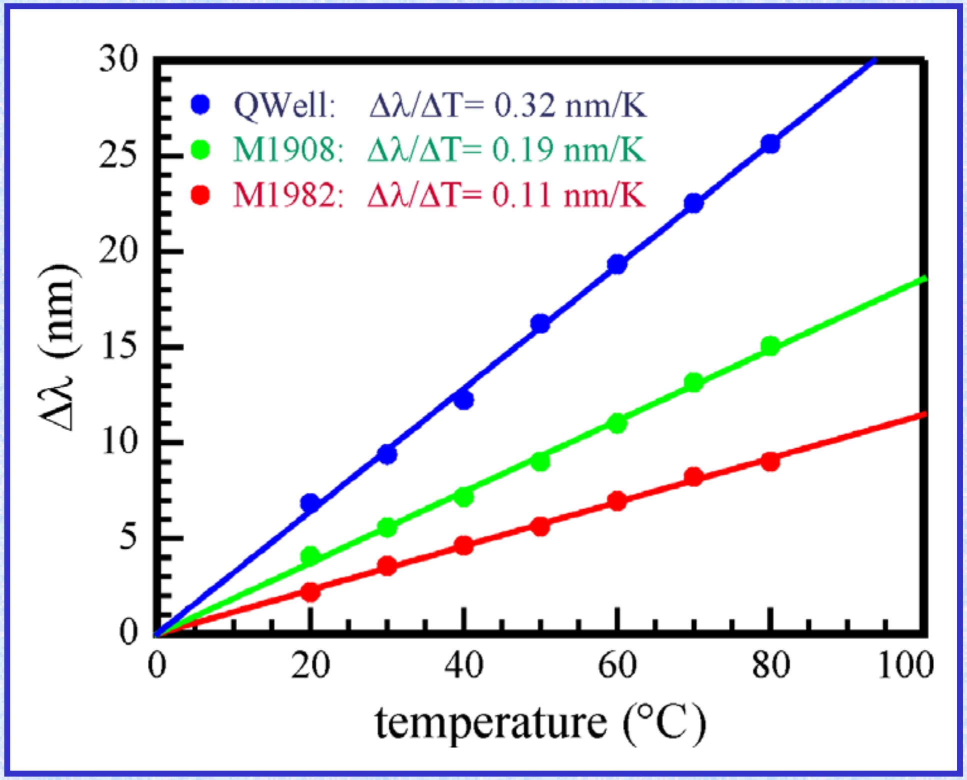
c) $\Delta x \approx 65$ meV

⇒ **small QDs promising for tailoring gain spectrum of QD lasers**

J.P. Reithmaier et al.,
phys. stat. sol. B 234, 3981 (2006)

# Temperature Stability

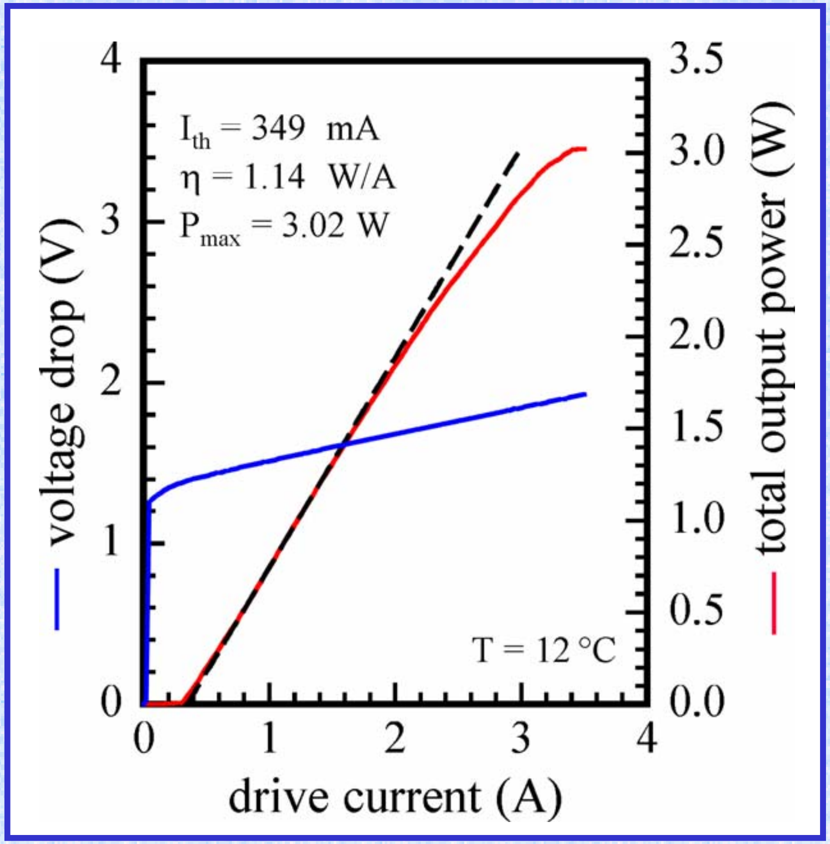


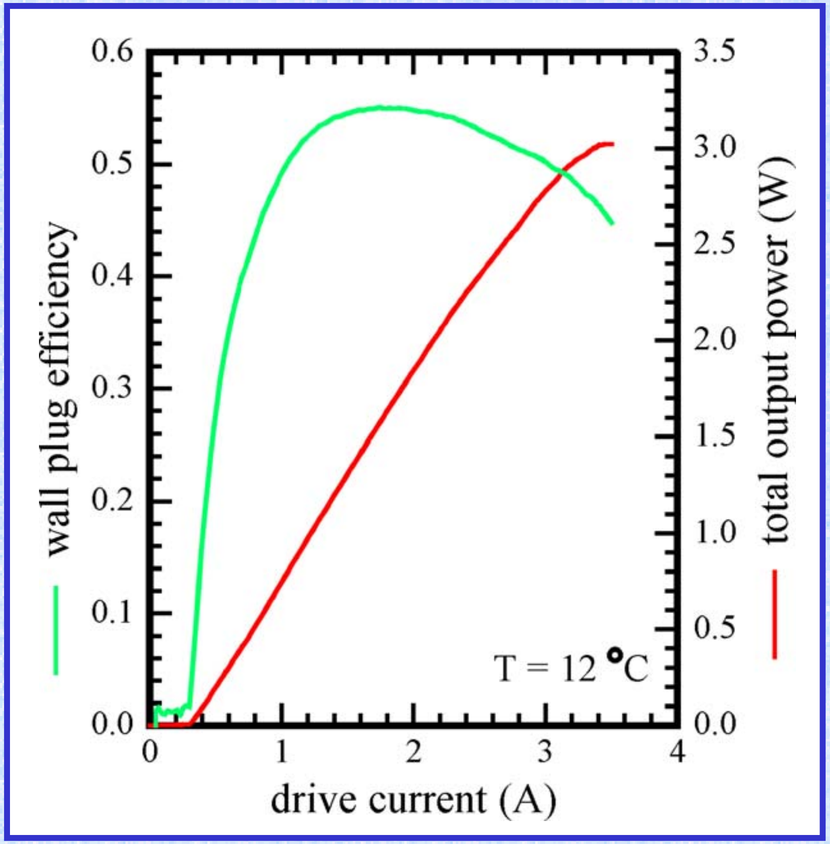




- Flat gain profile
- Very low temperature dependence of emission wavelength (0.11 nm/K) (recent value: 0.09 nm/K)

Basic effect described in APL 81, 217 (2002)

# High Power Measurement Data of BA QD Lasers




As-cleaved device,
1 mm long, 100 µm wide

wall-plug efficiency up to 55 % at 1.5 W

S. Deubert et al, EL 41, 1125 (2005)

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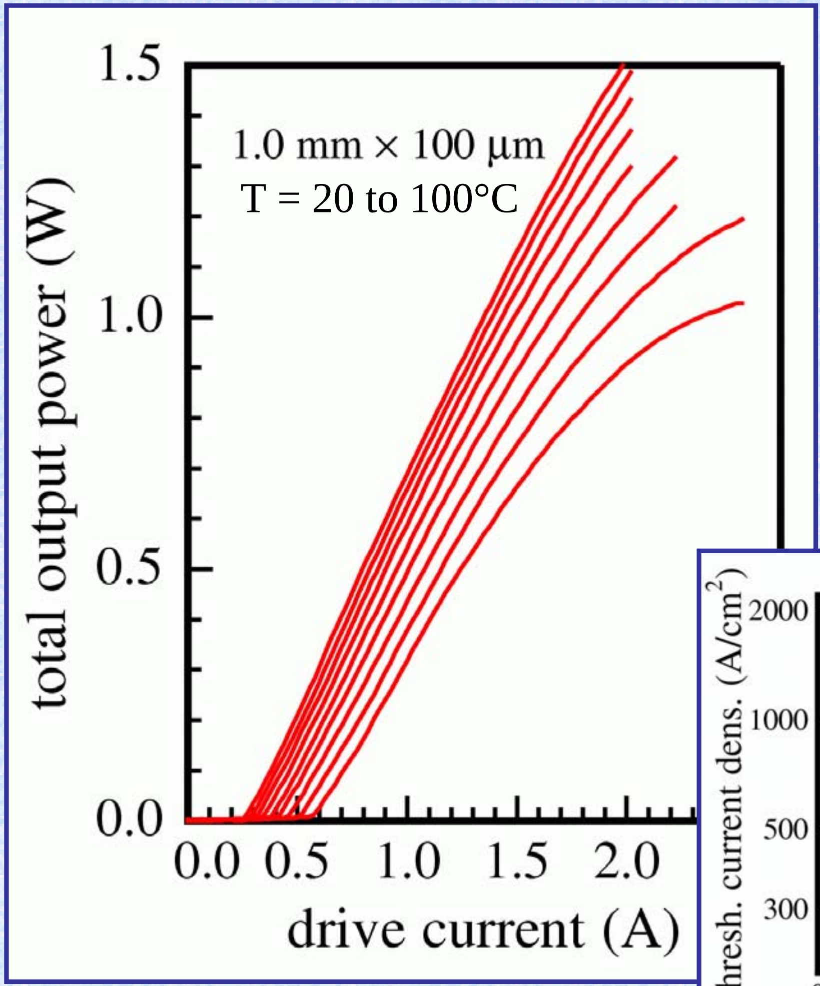
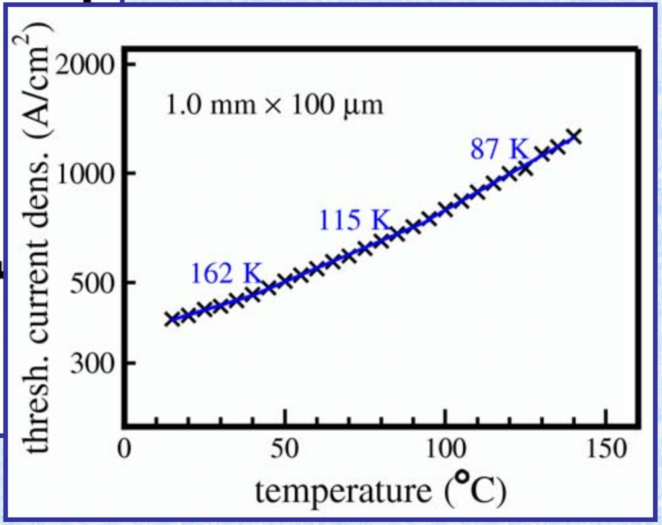
# High Temperature Stability of Laser Performance




**CW operation of a 1.0 mm × 100 µm:**

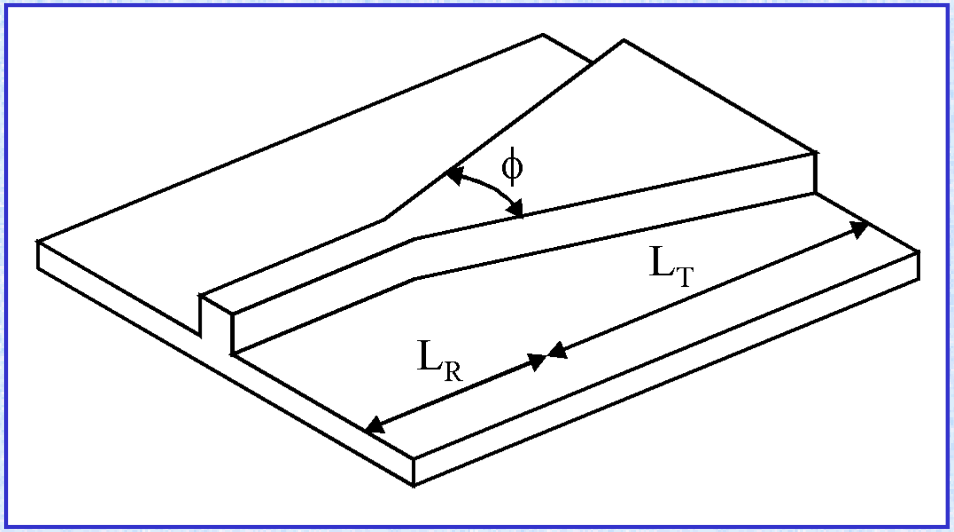
- Temperature from 20 to 100°C in steps of 10°C
- High temperature stability of threshold and efficiency
- Emission wavelength at about 915 nm
- Output power of P > 1 W @ 100°C



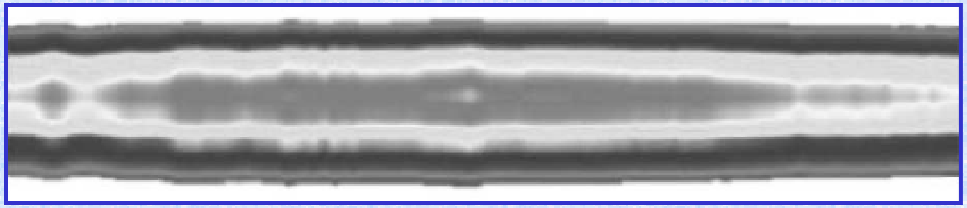

**Pulsed operation**

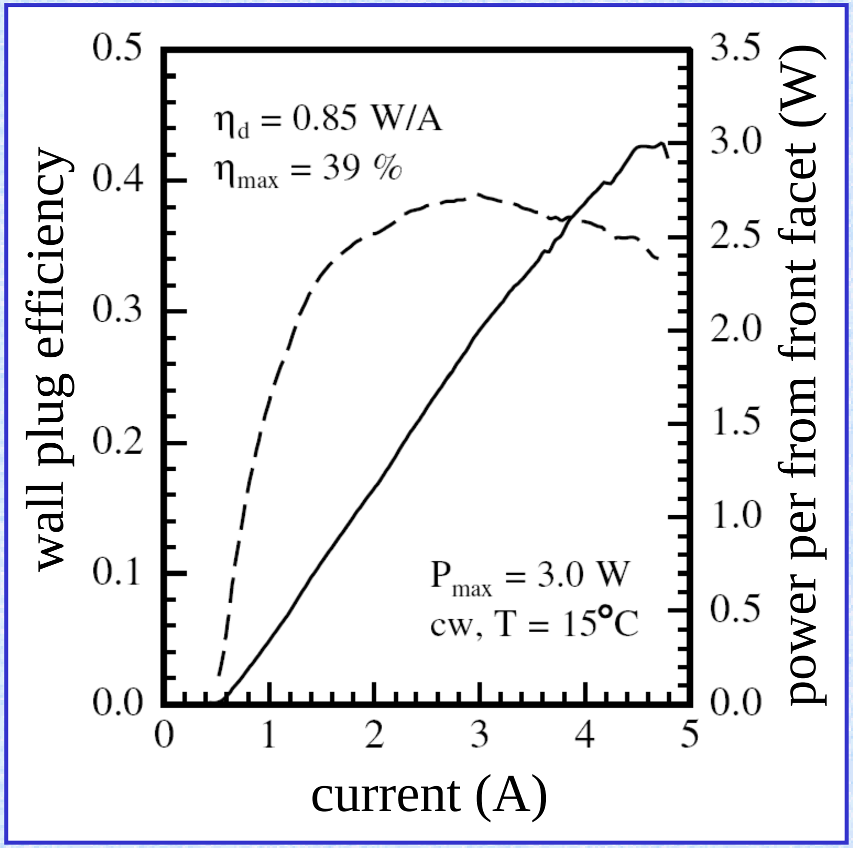
- $T_{max}$ > 140 °C
- High $T_0$ of 162 K up to 40 °C and > 150 K up to 60 °C

# 920 nm Tapered QD Lasers




**Near field intensity profile at $P_{cw}$ = 1 W**



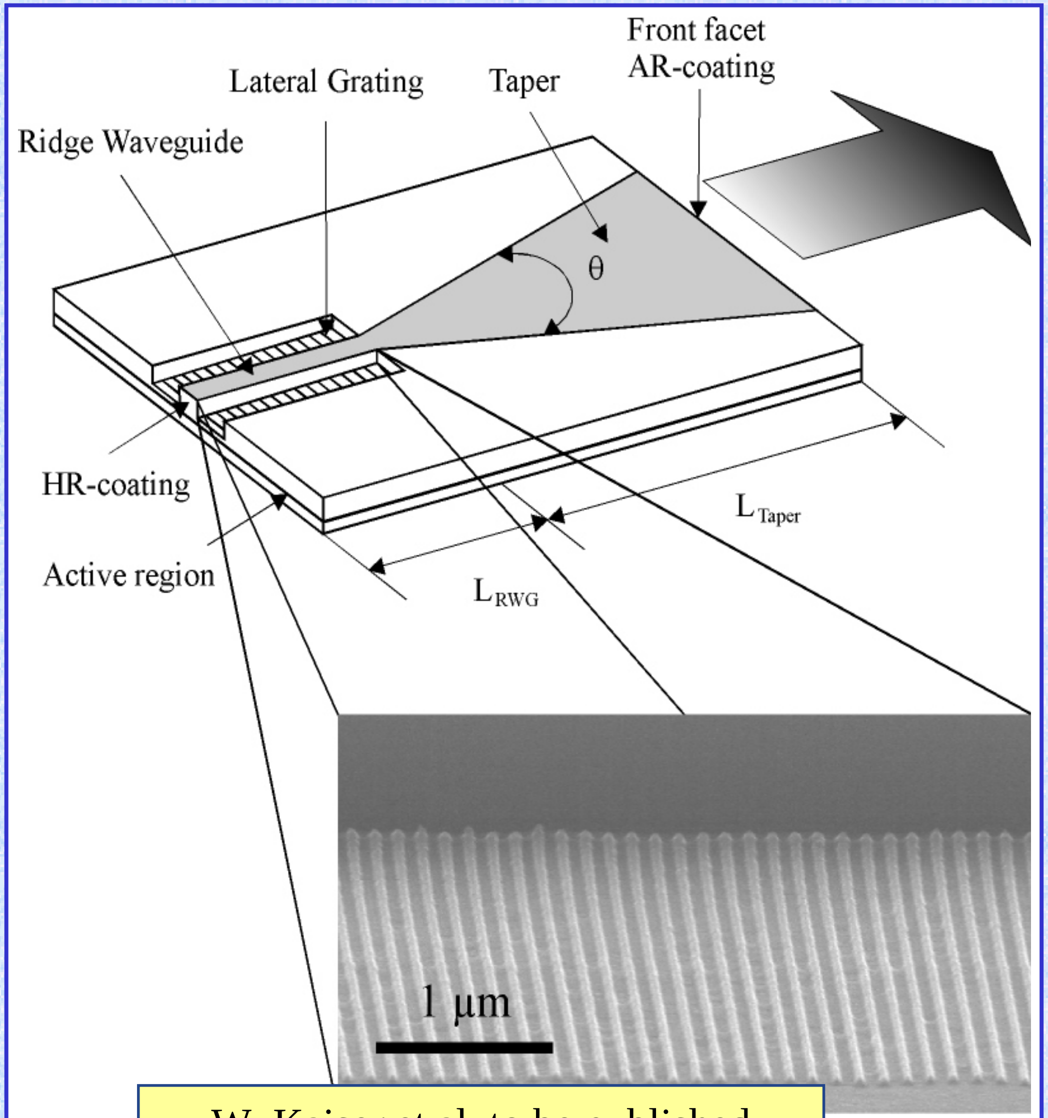



- High single lobe output power
- $M^2$ = 2.4 at 1 W output power
- About 4 times higher brilliance than BA-lasers (50 $MWcm^{-2}sr^{-1}$)

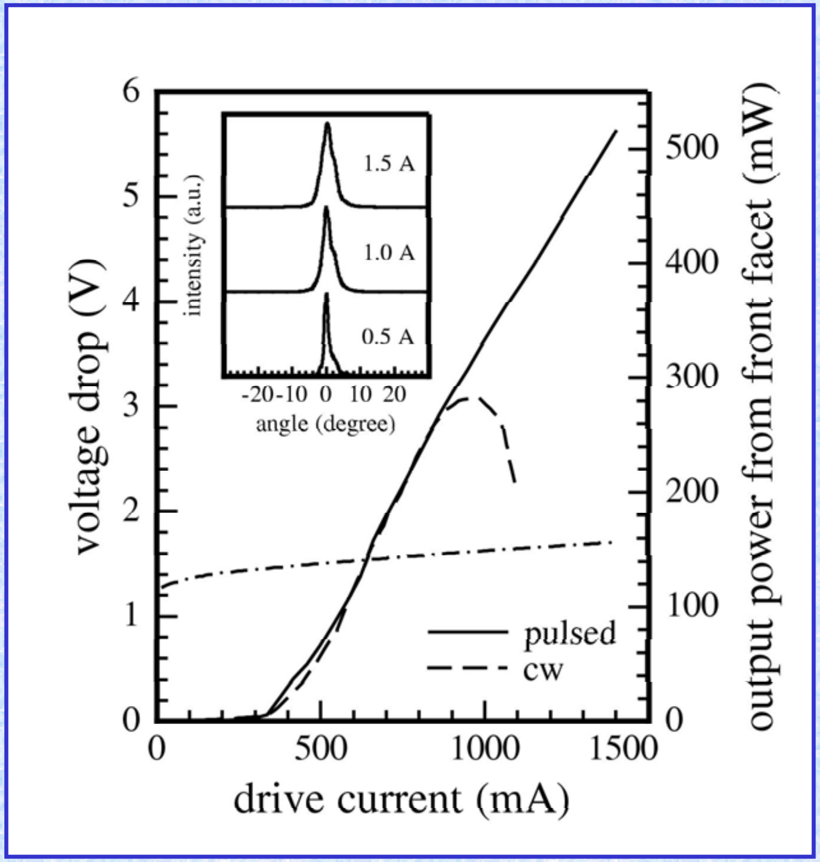
- Tapered lasers with $L_R$ = 1 mm, $L_T$ = 2 mm, $\phi$ = 6°
- $P_{max}$ = 3W, wall plug eff. up to 39 %

W. Kaiser et al, to be published

# Single Mode QD Tapered Lasers

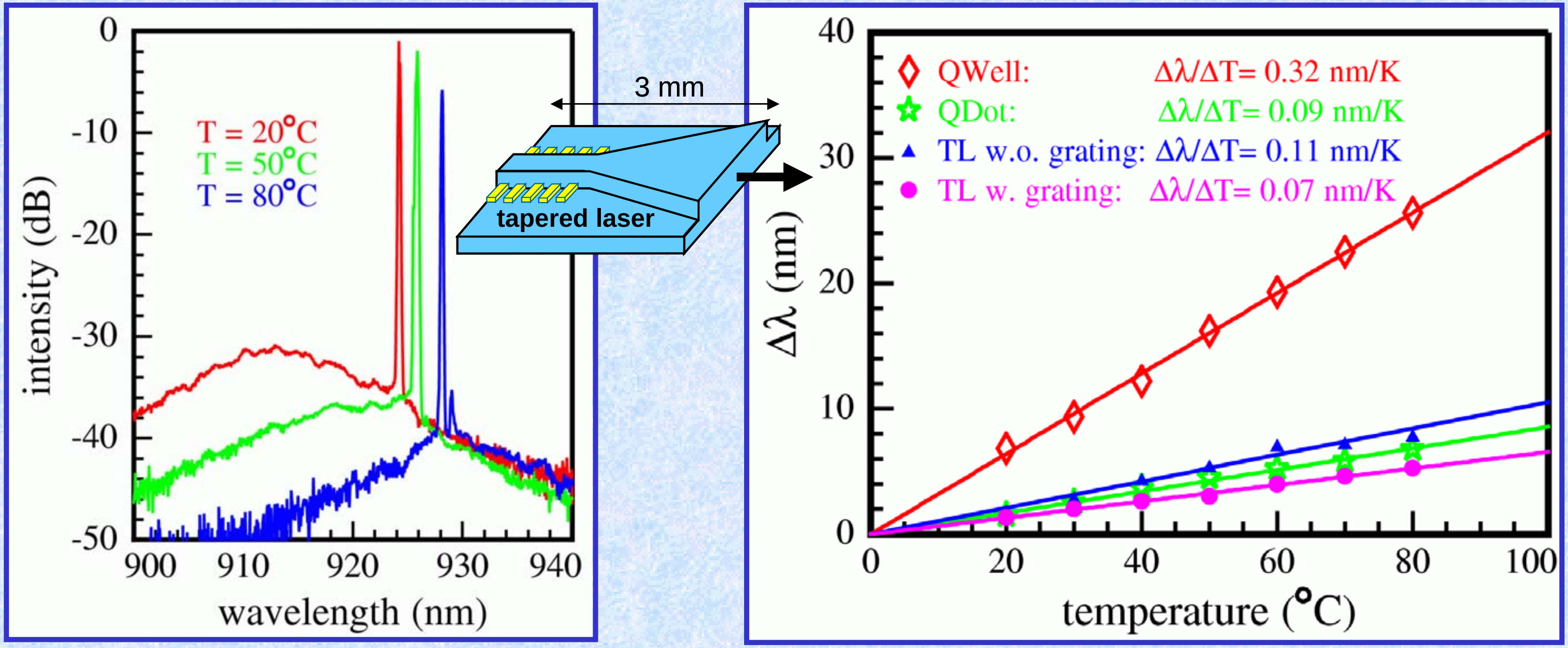



W. Kaiser et al, to be published




- Lateral gratings fix emission wavelength
- Single mode emission up to 500 mW

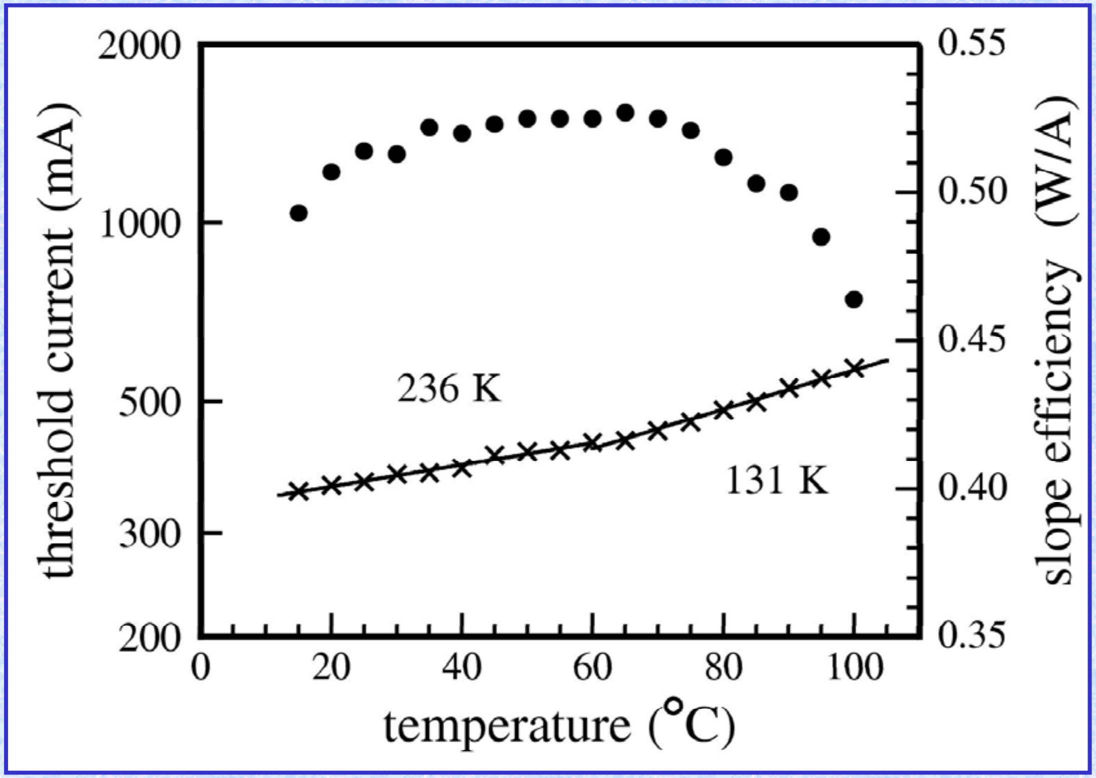
# Wavelength Stabilized QD Lasers with Gratings




- Tapered lasers with lateral gratings
- Single mode emission between 20 to 80 °C due to temperature insensitive gain function
- Temperature stable emission wavelength (0.07 nm/K)
- Temperature dependence of QD material at same order than refractive index change

Kaiser et al., CLEO, Long Beach (May, 2005)

# Temperature Stable Laser Performance




- Constant slope efficiency between 20 – 80 °C
- High $T_0$ value up to operation temperatures of 100 °C
- Improvement also due to nearly coincident temperature development of gain and grating period

W. Kaiser et al, to be published

# Summary

- **QD Growth**
  - Control of dot density and dot size by basic growth parameters (temperature, In-content, ML deposition)

- **High power 920 nm QD lasers**
  - internal temperature compensation by dot tailoring
  - BA lasers: → $P_{cw} > 3$ W, $\eta_{wp} = 55\%$
  - Tapered lasers: → $P_{cw} = 3$ W, $\eta_{wp} = 39\%$ (taper losses)
    → $M^2 = 2.4$ at 1 W
  - Single mode lasers: → $P > 500$ mW, $d\lambda/dT = 0.07$ nm/K
    → improved temperature independent device performance

# Thank you for your kind attention