Laser diodes: emerging technologies and new materials

Olivier Gauthier-Lafaye

Outline

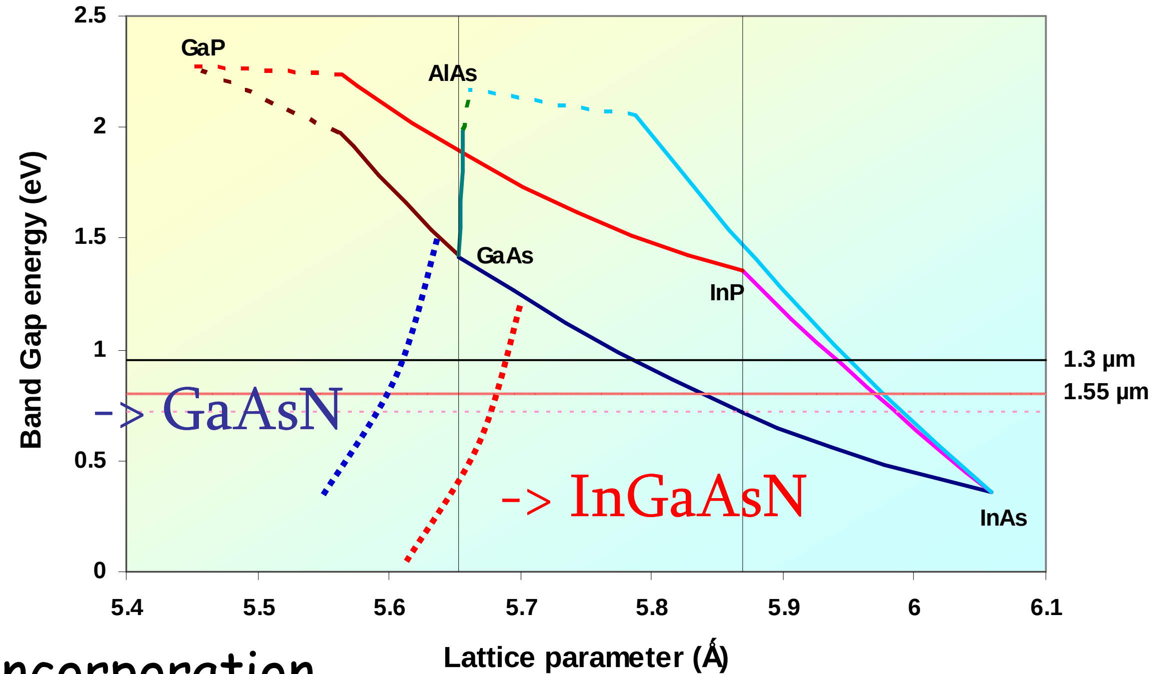
- New materials
  - In the NIR :
    - Dilute nitrides
    - Quantum dots
  - At longer wavelengths
    - Sb based and QC lasers

- New optical cavities
  - « generic », single growth, DFB processing
  - Surface emitting lasers
  - Photonic crystal lasers : towards integrated photonics

GaInNAs/GaAs material system

Advantages :

Lower Gap : long wavelength on GaAs
High CB offset -> Higher T0,
High electron m* -> higher differential gain

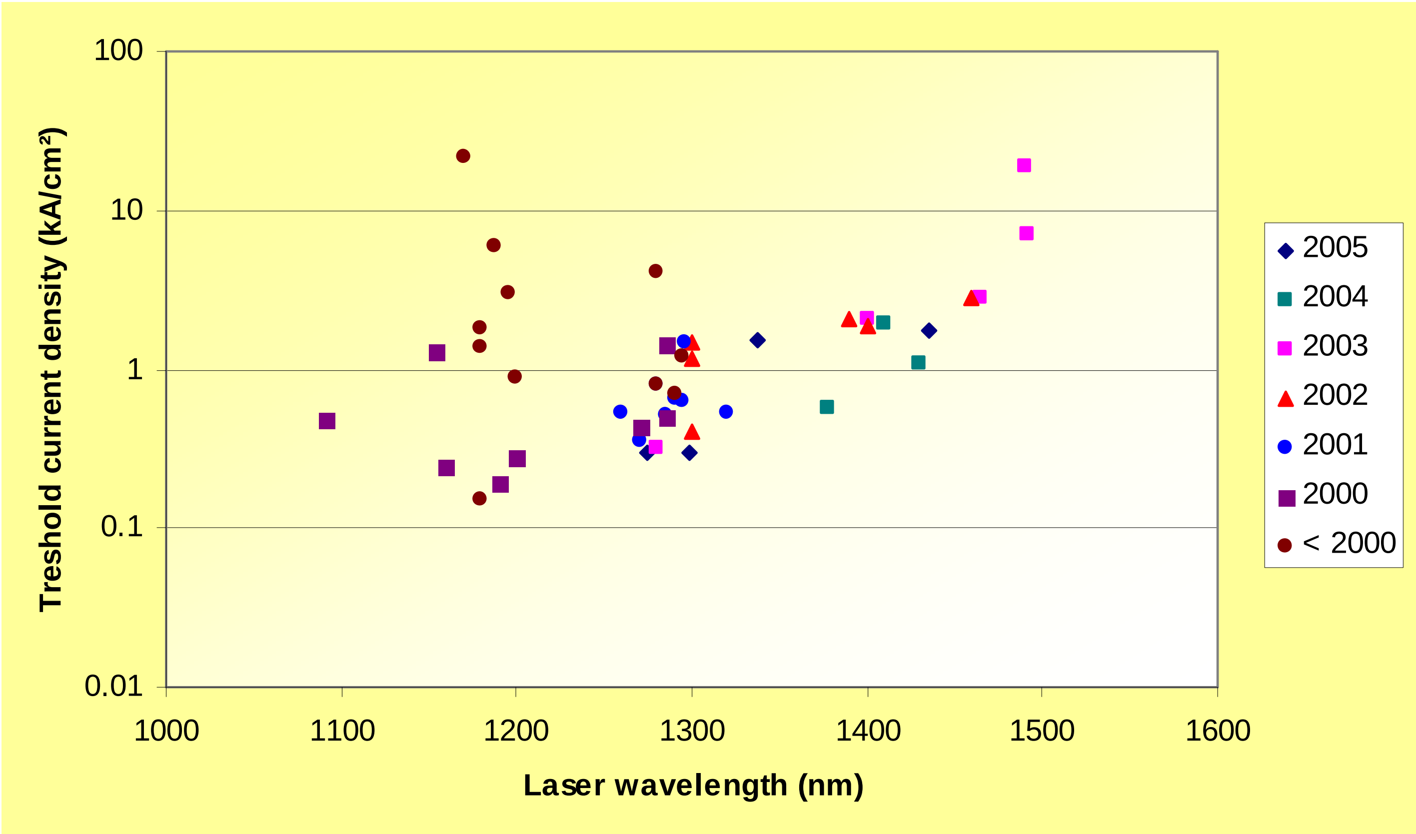


- Difficult N incorporation
- Highly strained material

→

- Low T growth

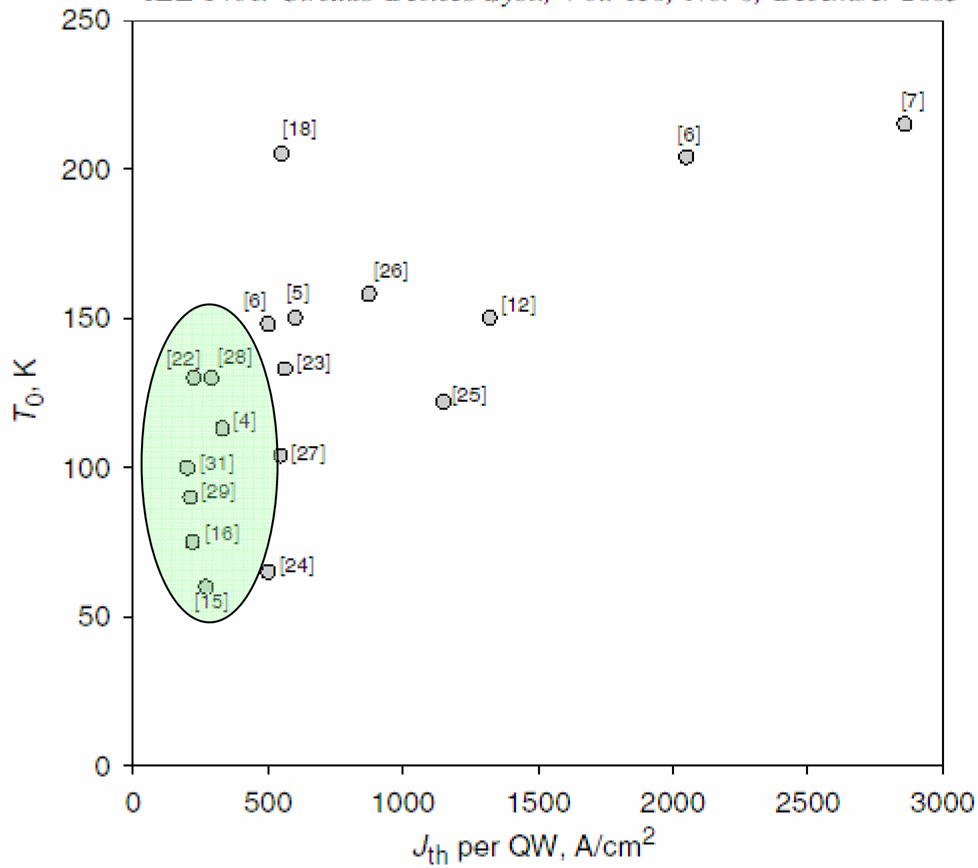
GaInNAs/GaAs based edge emitting lasers : main results



GaInNAs based edge emitting lasers : main results

R. Fehse, I. Marko and A.R. Adams

IEE Proc.-Circuits Devices Syst., Vol. 150, No. 6, December 2003

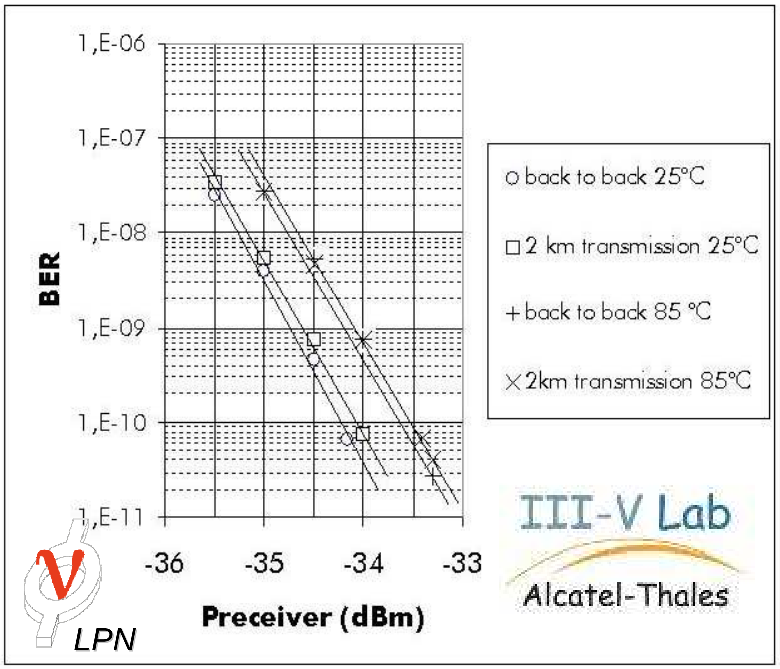


On « good » lasers, T0 ~ 100 K

GaInNAs based lasers : dynamic properties

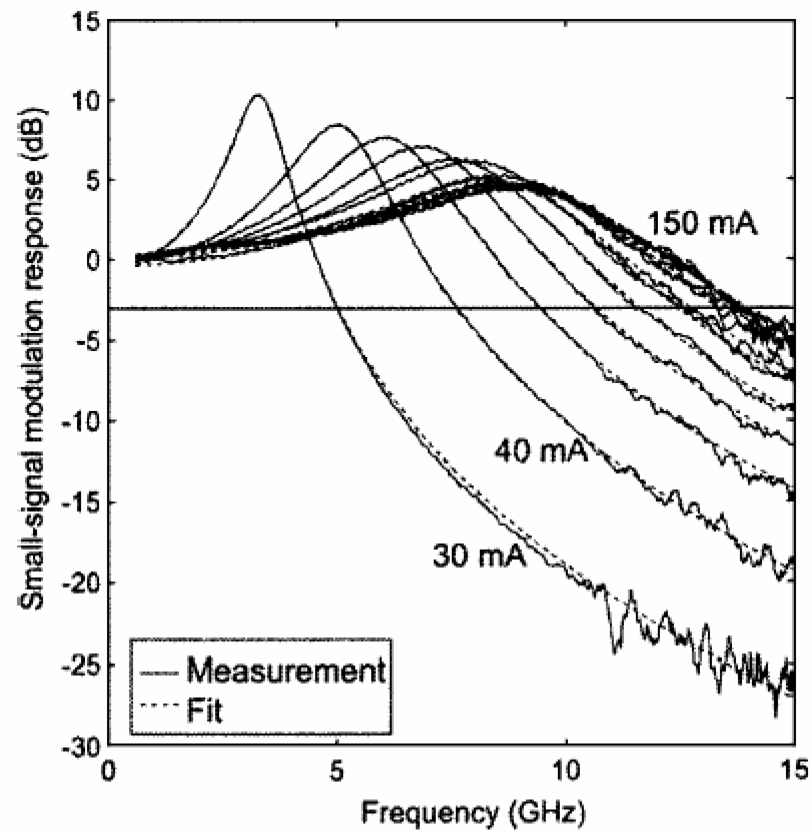
TQW 1.3µm laser

- 2.5Gb/s 2km fiber transmission



DQW 1.3µm laser

Wei *et al.*
Appl. Phys. Lett. **88**, 051103 (2006)



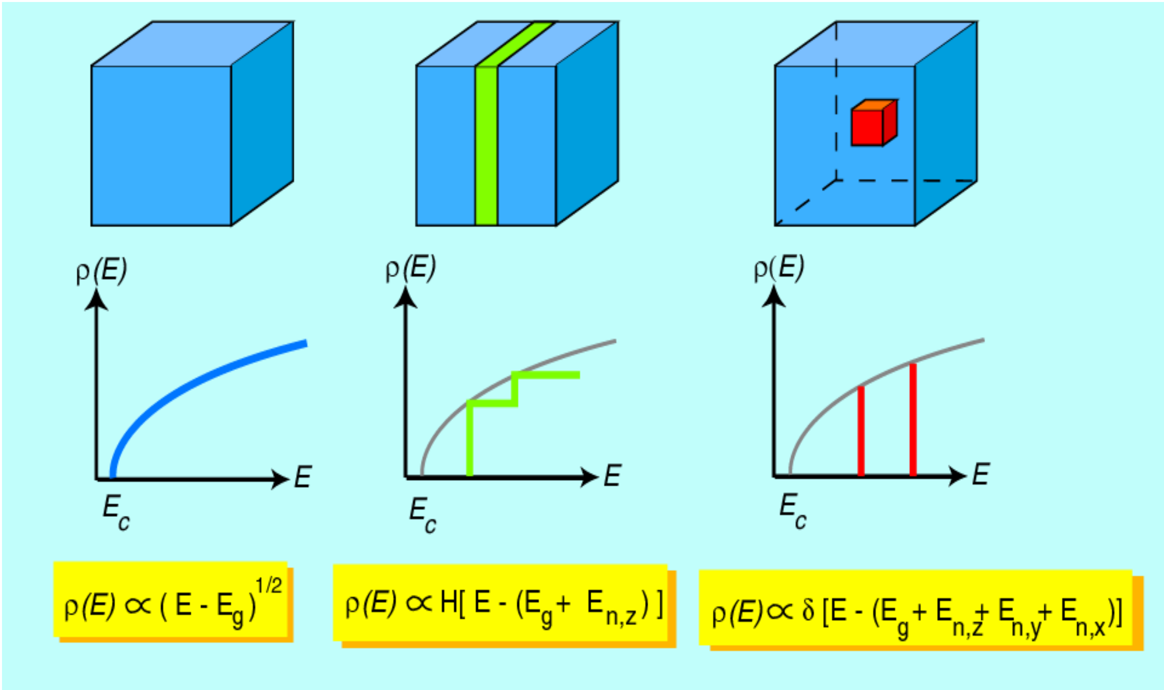
GaInNAs over GaAs : main perspectives

- VCSELs like lasers :
  - Should be the dedicated application (Bragg mirrors). However only few results. (5 and 10 Gbit/s @ 20°C demonstrated, in 2002 and 2003)

- Edge emitting lasers :
  - T_0 ~ 100K.
  - Novel material system. Still need a more mature material, especially regarding QW barriers (GaAsP, AlGaAs…?)
  - Definetely extending the reach of GaAs based lasers
  - And now developping on InP substrates

Qdots based lasers

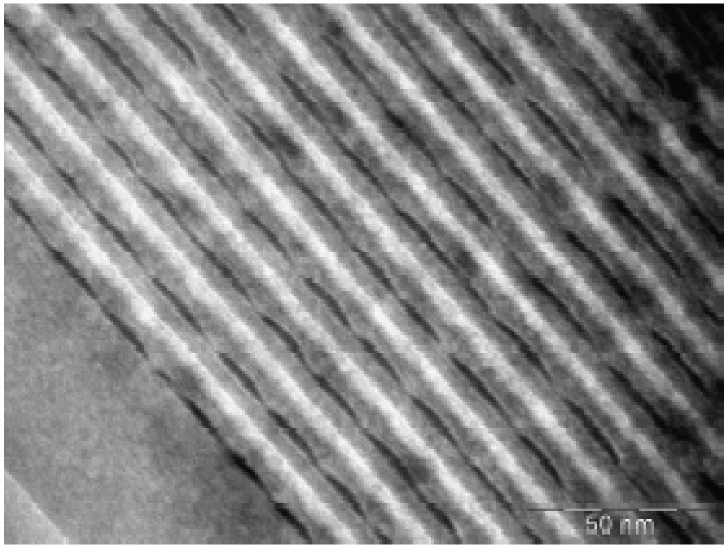
- Qdots : the « ultimate confinement ? »



- *Delta like density of states -> **Ultra low threshold***
- *"Atomic" states -> **Very high T0***
- *Symetric gain -> symetric dispersion curve -> **Chirp free laser***
- *Very high differential gain -> **very high modulation bandwidth***

Qdots based lasers : materials

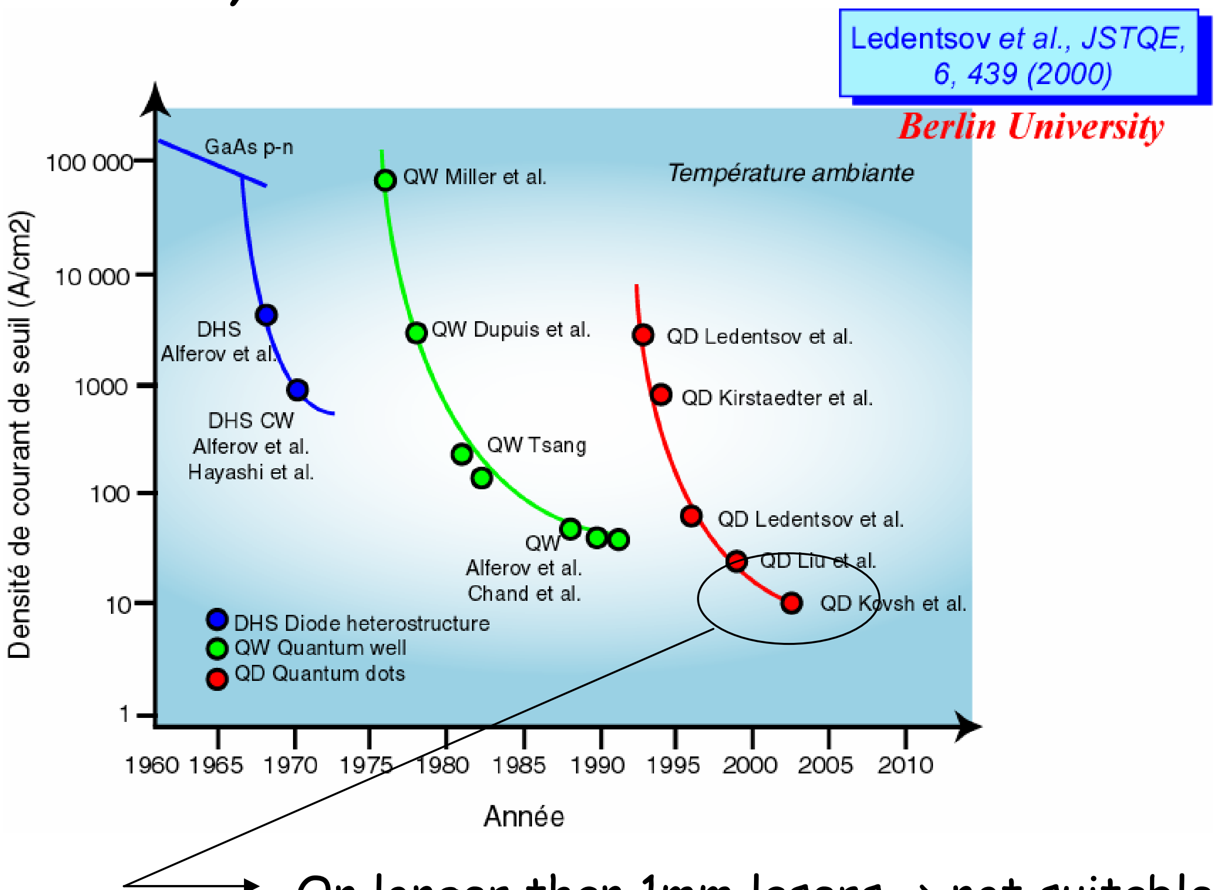
- Self organized growth
- In(Ga)As over GaAs
  - More mature than any other
  - 900 nm to 1.3 µm wavelength
  - Multiple layers…..
- InAs over InP 100 or 311
  - « newer » material
  - 1.55µm to longer wavelength
  - Compatible with telecom technologies (on 100 InP)



Qdash InAs/InP
(F. Lelarge JNMO 2006)

Qdots based lasers

- *Delta like density of states -> Ultra low threshold*

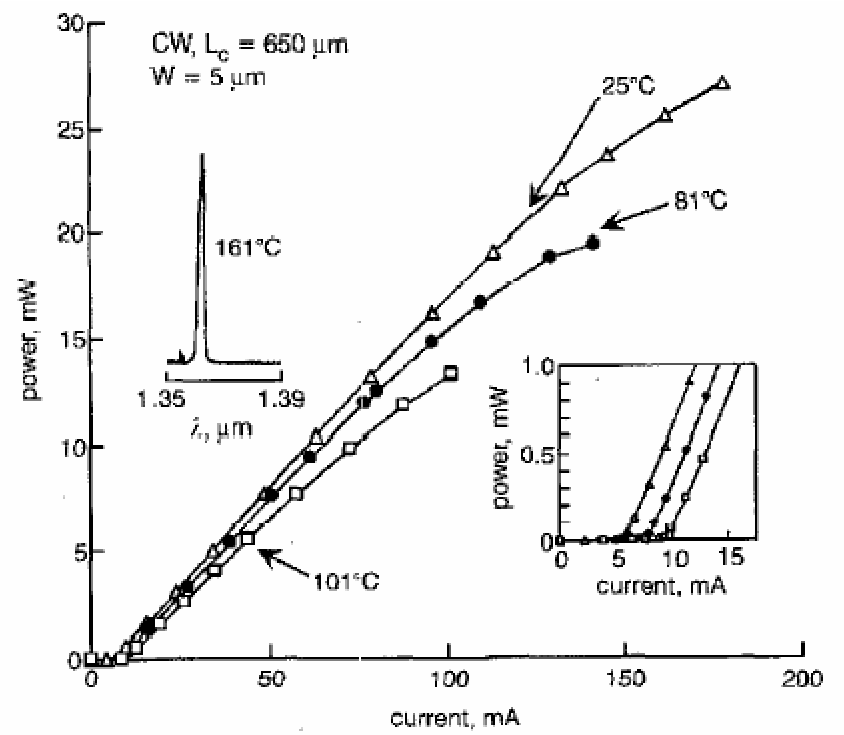


On longer than 1mm lasers -> not suitable for high bandwidth modulation

Qdots based lasers

- *Atomic" states -> Very high T0*

Carriers dispersion within VB states with temperature.



O.B. Shchekin, J. Ahn and D.G. Deppe

ELECTRONICS LETTERS 4th July 2002 Vol. 38 No. 14

- **Increase of maximum gain**
- **Lower T sensitivity**

BUT

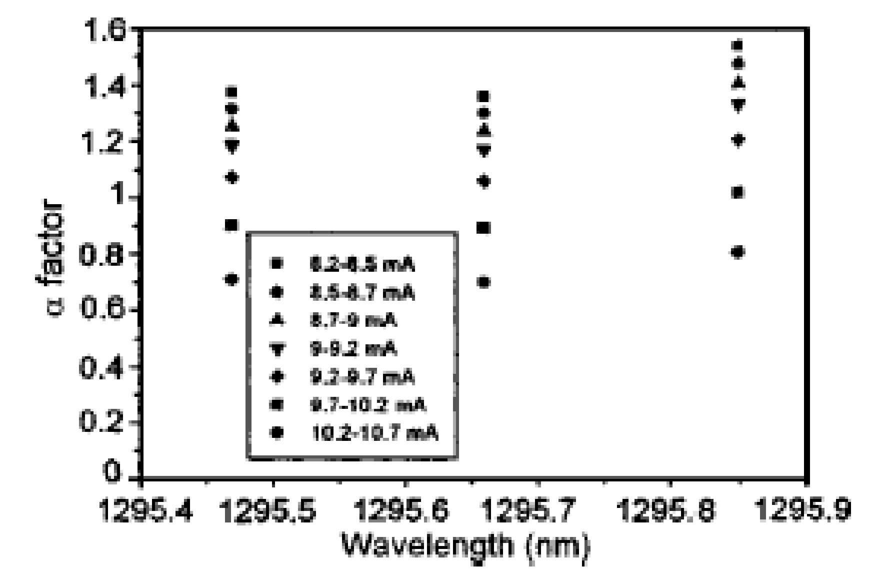
- **Higher optical losses**
- **Lower external efficiency**

Q Dots based lasers

Symetric gain -> symetric dispersion curve -> null Henry factor

Gain saturation, higher CB states contribution -> **towards Henry factor engineering**

Static and dynamic measurements of the α-factor of five-quantum-dot-layer single-mode lasers emitting at 1.3 μm on GaAs



211115-2 Martinez *et al.*

Appl. Phys. Lett. **86**, 211115 (2005)

Giant linewidth enhancement factor and purely frequency modulated emission from quantum dot laser

B. Dagens, A. Markus, J.X. Chen, J.-G. Provost, D. Make, O. Le Gouezigou, J. Landreau, A. Fiore and B. Thedrez

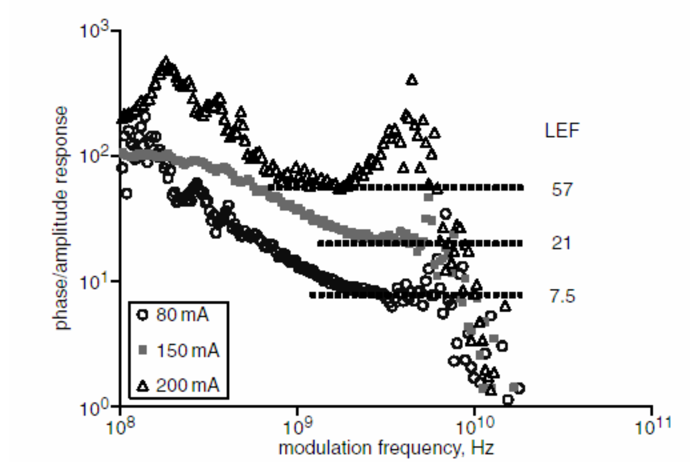


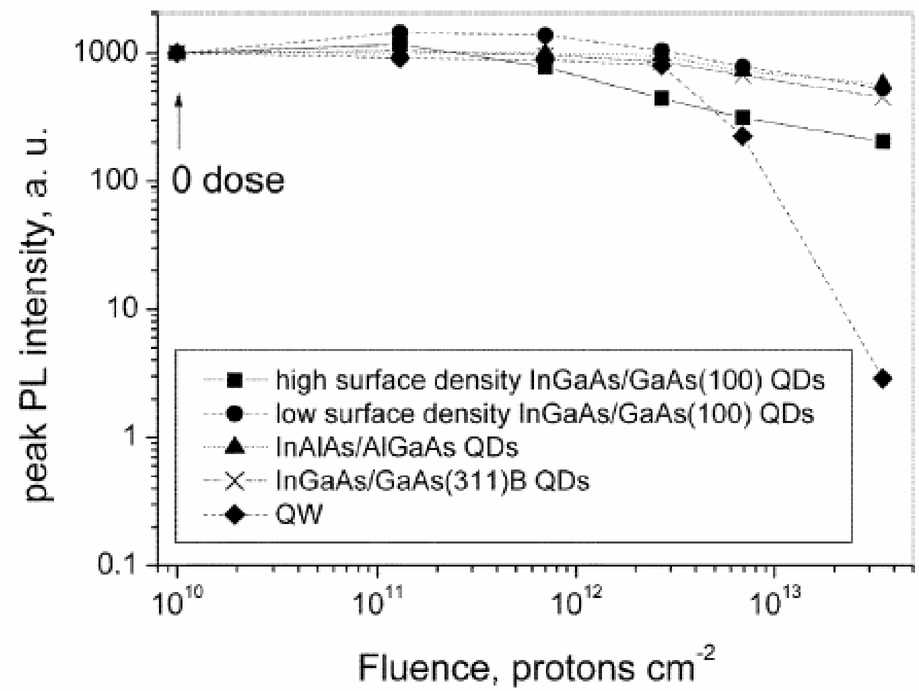
Fig. 2 *Linewidth enhancement factor (LEF) measurement on filtered GS lasing modes with interferometric method, below ES threshold*

ELECTRONICS LETTERS 17th March 2005 Vol. 41 No. 6

Q-Dots based lasers : Conclusions

- Qdots as an active material
  - Low threshold demonstrated
  - Sufficiently high gain demonstrated (DFB lasers, even a VCSEL, but with more than 10 QD planes)
  - Bandwidth and Henry factor : still to be optimized

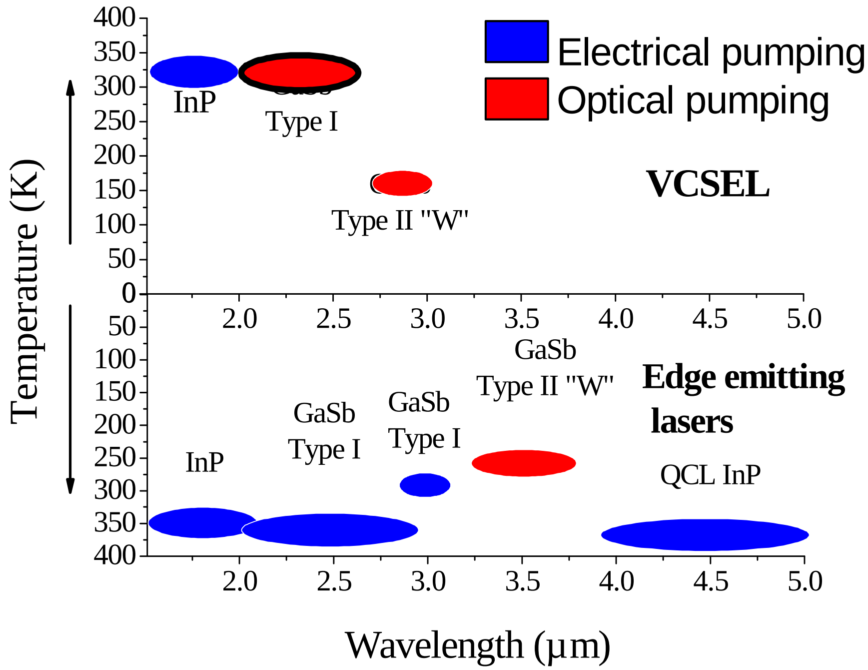
- High robustness already demonstrated :

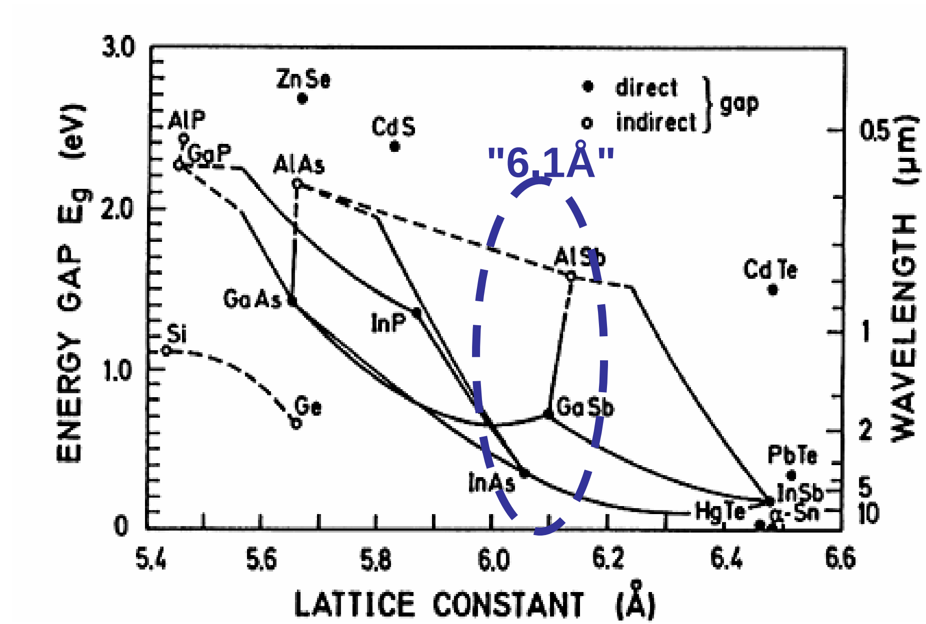


LEON *et al.*: EFFECTS OF PROTON IRRADIATION ON LUMINESCENCE EMISSION

IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 49, NO. 6, DECEMBER 2002

Towards longer wavelengths





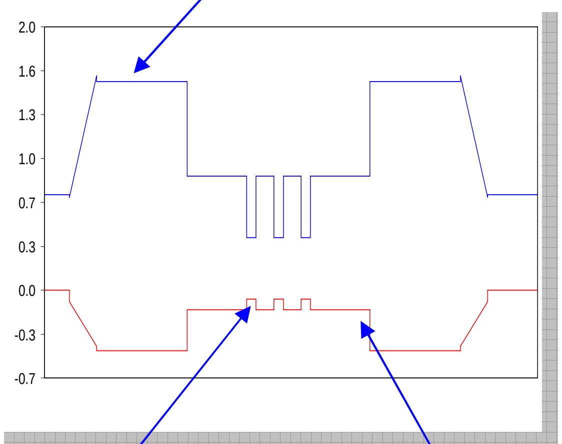
- **Mid-IR:**
  - Numerous applications
  - Few semiconductor-based devices operating at room-temperature.
- **Semiconductor technology**: Sb-based III-V compounds

  GaSb, AlSb, InAs, InSb and their alloys

High-power bipolar laser diodes

$\lambda \sim 2.3$ µm, cw

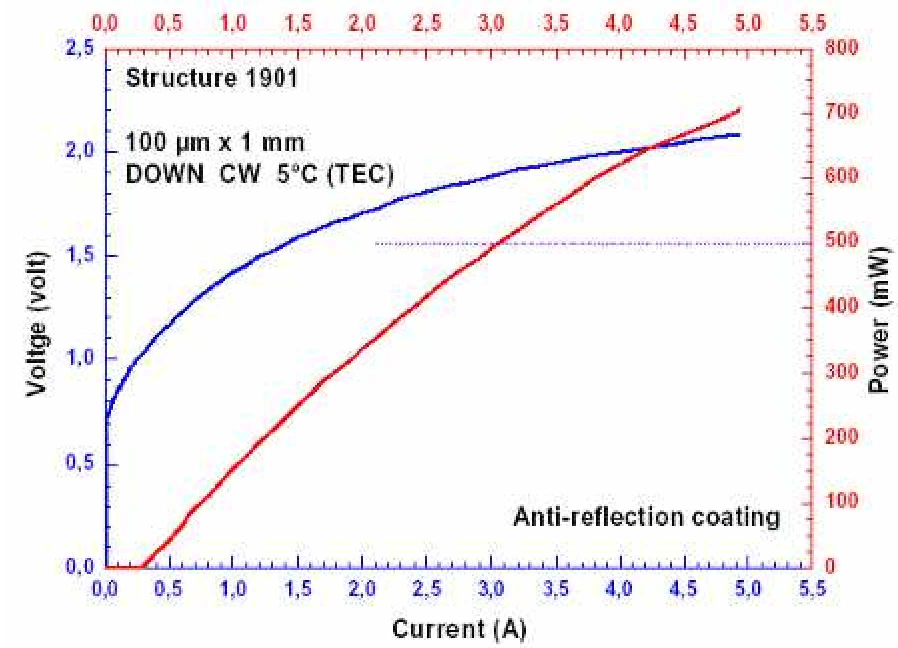
2 claddings (1.5 µm)
$Al_{0.90}Ga_{0.10}As_{0.08}Sb_{0.92}$



3 quantum wells (11nm)
$Ga_{0.64}In_{0.36}As_{0.13}Sb_{0.87}$

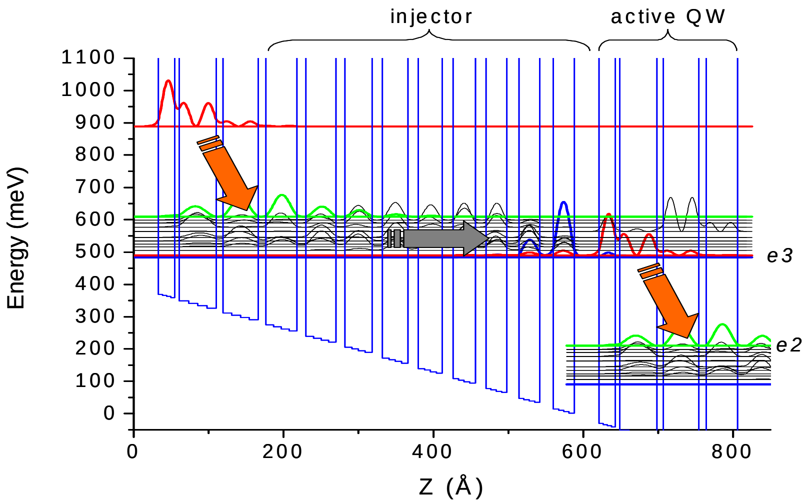
1 waveguide (0.9 µm)
$Al_{0.25}Ga_{0.75}As_{0.02}Sb_{0.98}$

See Next speech

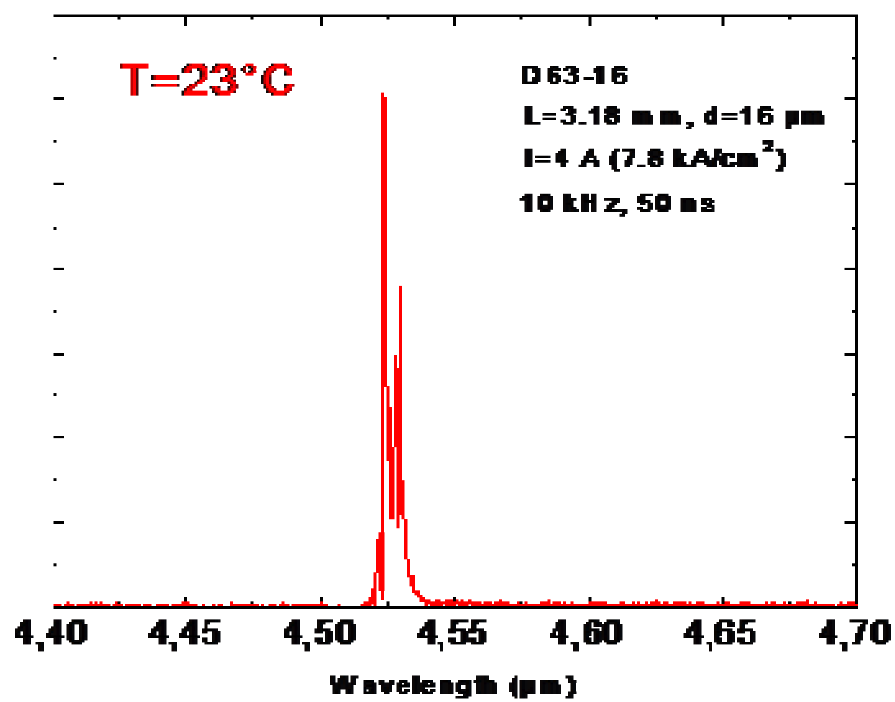


P= 700 mW/face
(collab. Thales-RT)

Quantum cascade lasers : from MIR



Laser: 25 – 30 periods of « injector + active QW »



First InAs/AlSb QCLs 300K

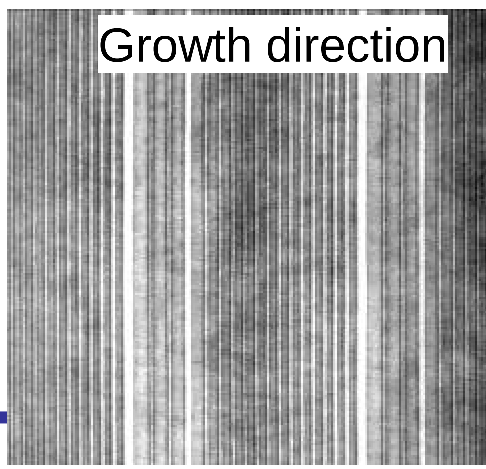
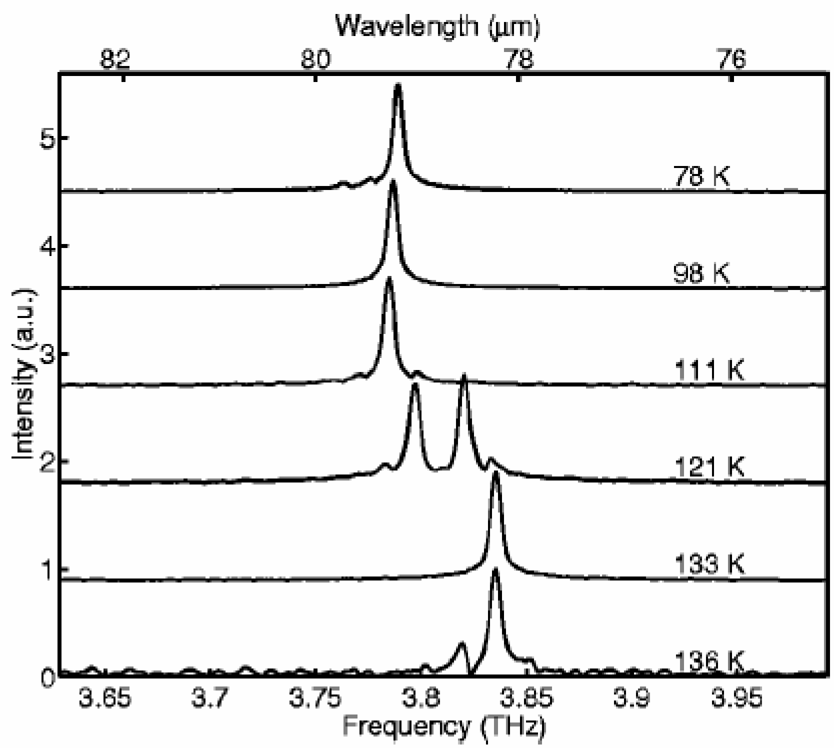


Photo TEM: A. Ponchet, CEMES

To the Terahertz domain

Terahertz quantum-cascade laser operating up to 137 K



Williams *et al.*

Appl. Phys. Lett., Vol. 83, No. 25, 22 December 2003

Long wavelength can be acheived :

-λ is fixed by QW thickness

-Low losses metallic waveguides

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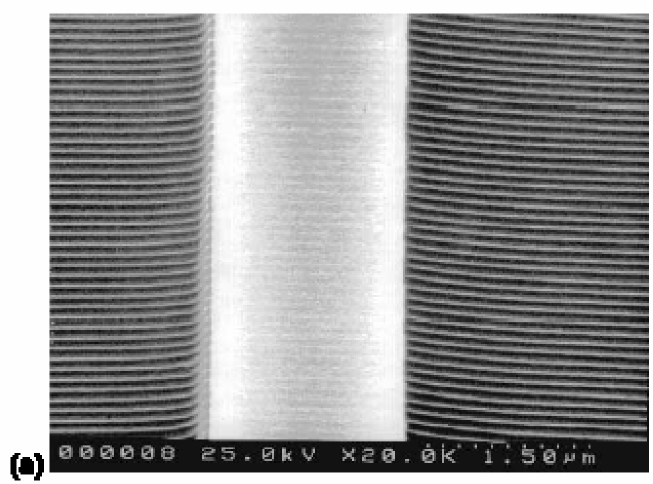
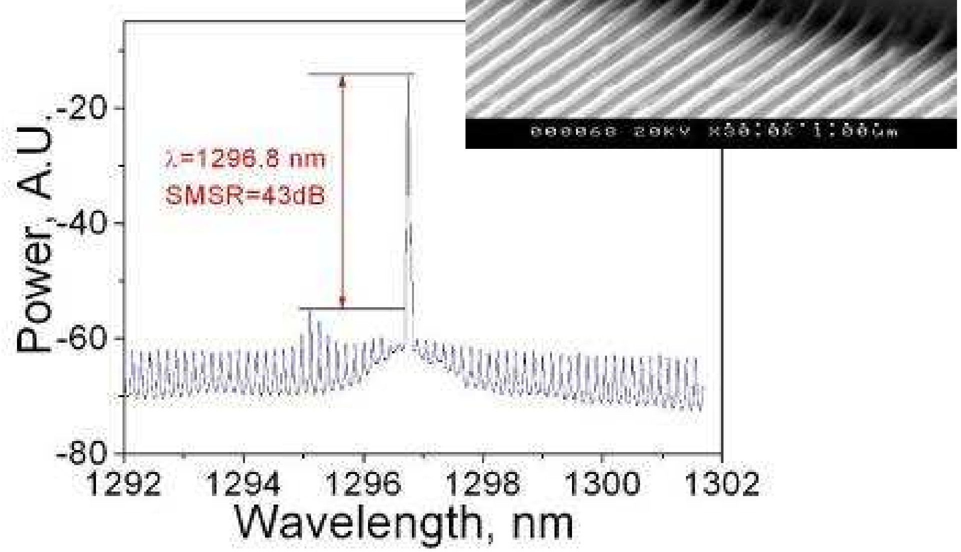
A « Generic » DFB cavity



Dry etched laser ridge with Cr grating.

M. Kamp et al. / Optical Materials 17 (2001) 19–25

InAs/GaAs Qdots laser, LPN

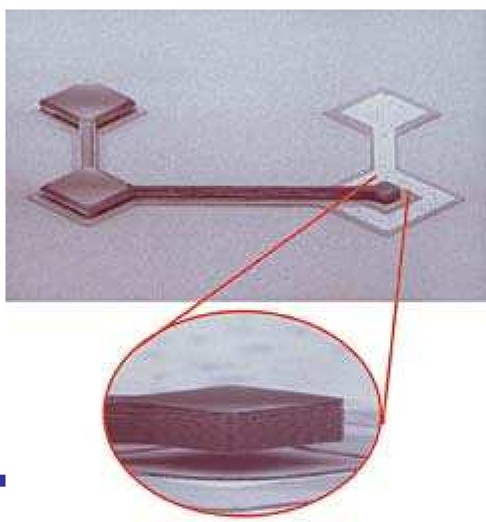


Chromium Metallic lateral grating :

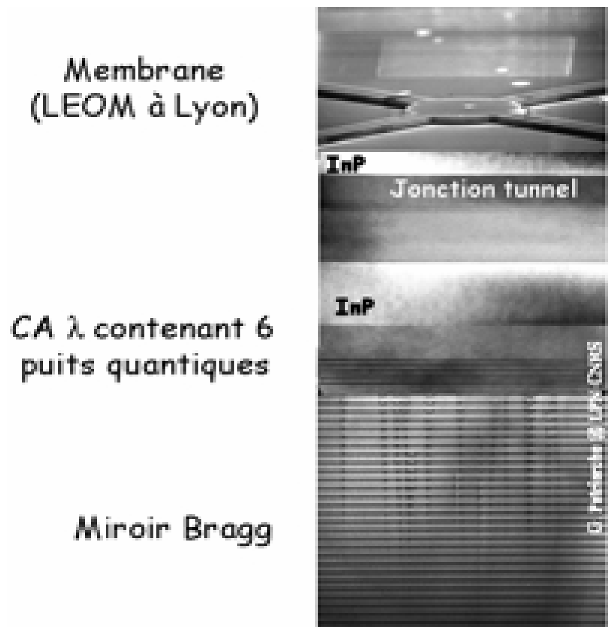
- Generic technology
- Single growth process
- Coupling through metallic absorption :
  single mode DFB laser
  yet low losses

External cavity VCSEL (VECSEL)

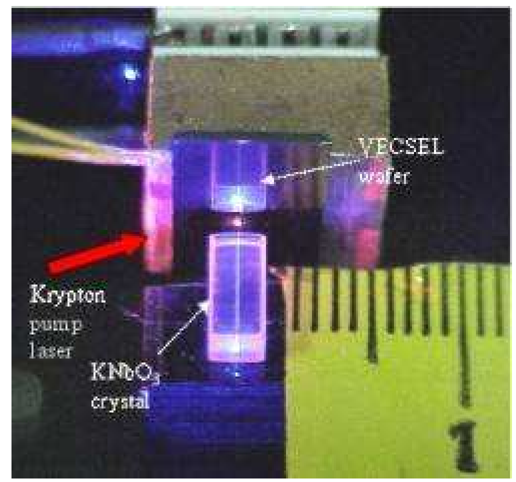
- Transverse mode selectivity and robustivity, good Beam Quality
- Wavelength tunability
- Air-based cavity -> sensing
- Intracavity nonlinear Optics (Mode locking)
- Increased beam diameter over VCSEL,
- Demonstrated from 403nm to $\lambda > 2\mu$m



Bandwidth9 / Berkeley



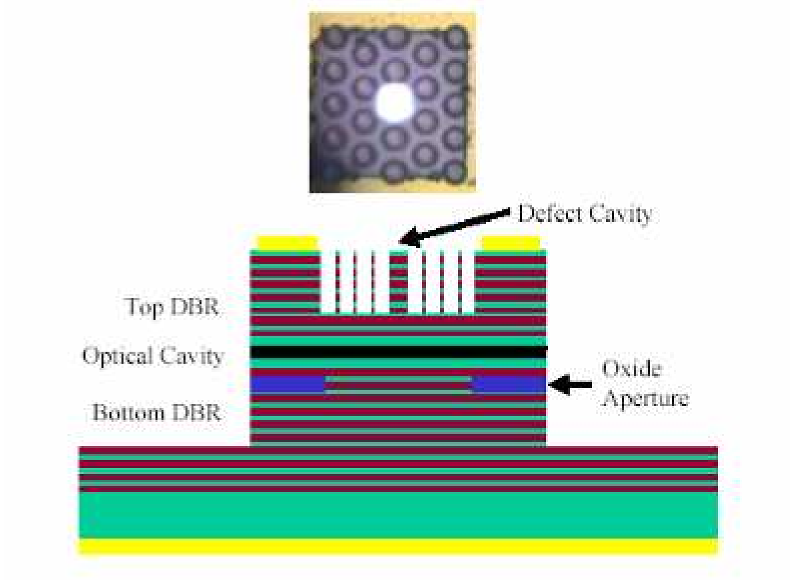
LPN / LEOM



430nm Optically Pumped VECSEL
Sandia

Photonic crystals for surface emission

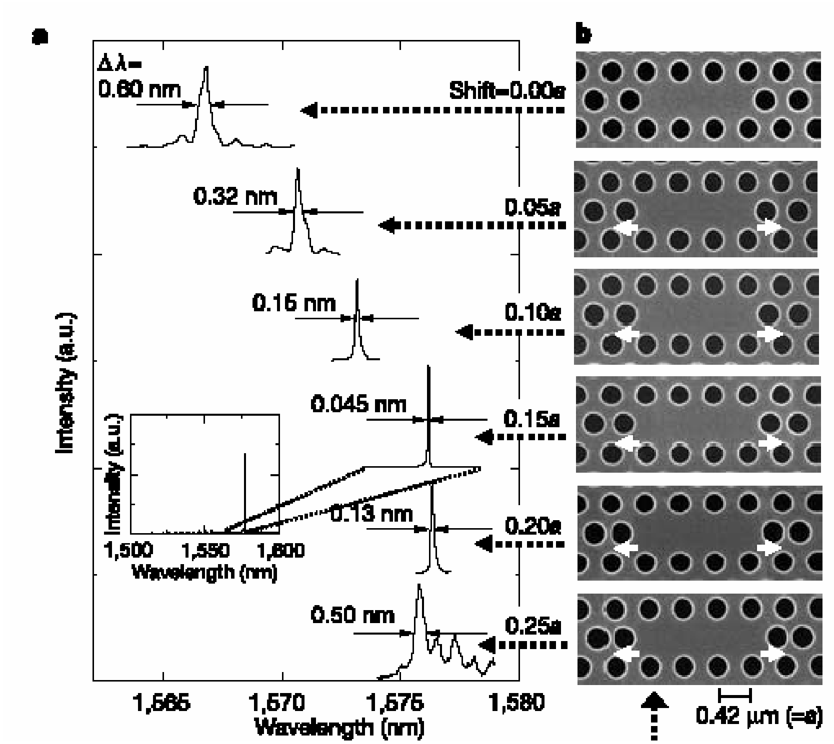
Photonic Crystals :
-Periodic structure
- Acts as step-index
- Benefits
    - Single mode supported
    - Higher power devices
    - Large aperture devices
    - More efficient devices



http://vcsel.micro.uiuc.edu/

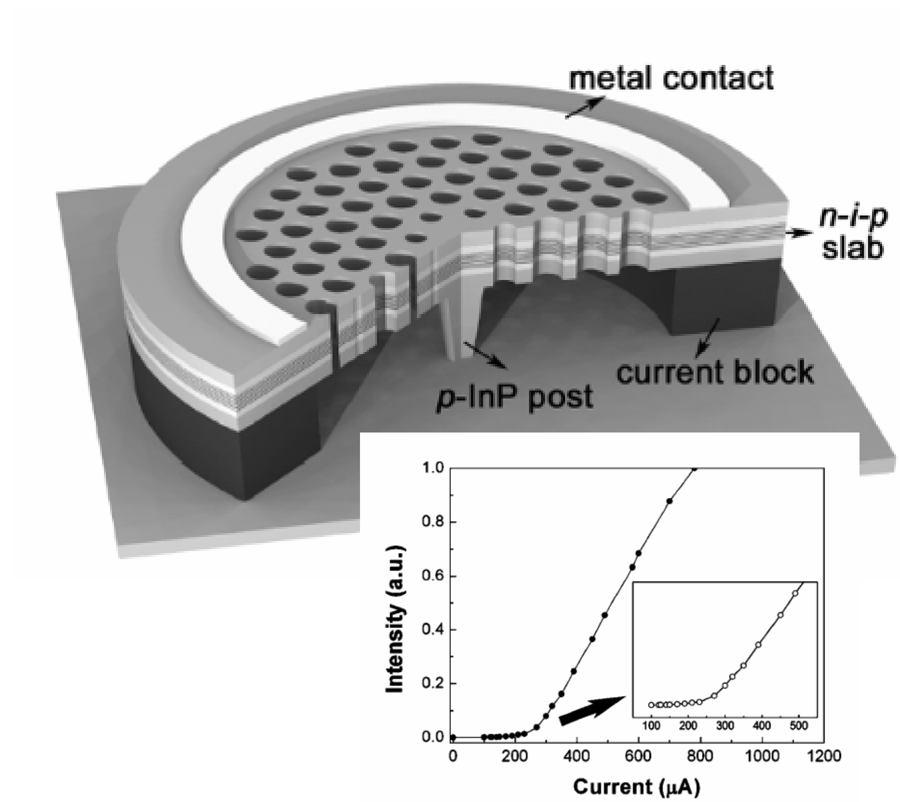
Surface emitting lasers : High Q cavities with PhCs

Record high Q cavities : 10^6



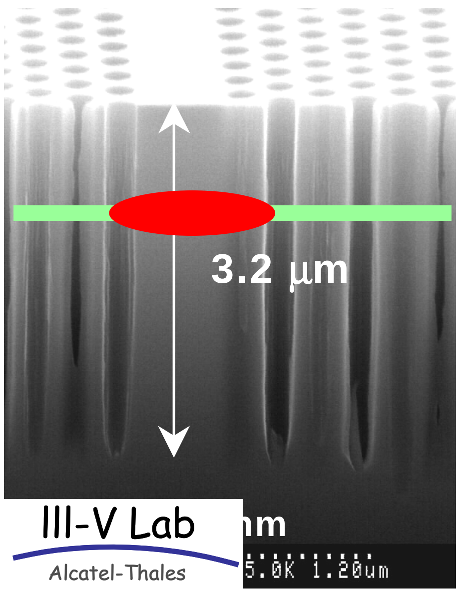
Y. Akahane & al., *Nature*,
(**425**) 2003, pp. 944-947

Electrically driven



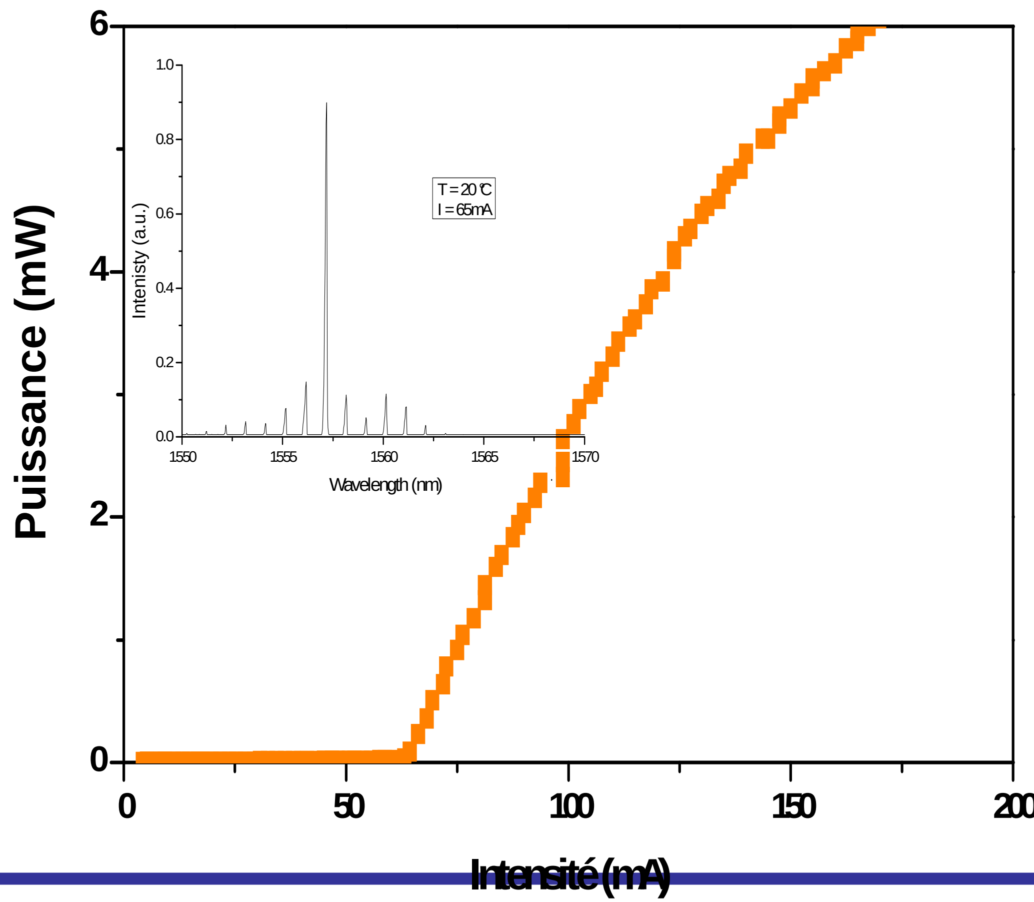
Hong-Gyu Park & al., IEEE JQE (**41**) 2005, pp 1131

In plane lasers with photonic crystal waveguide

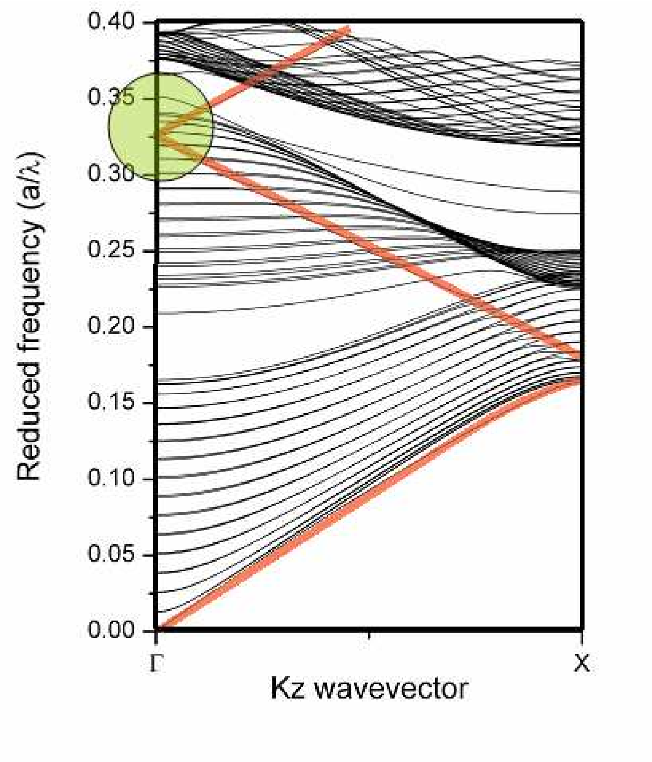


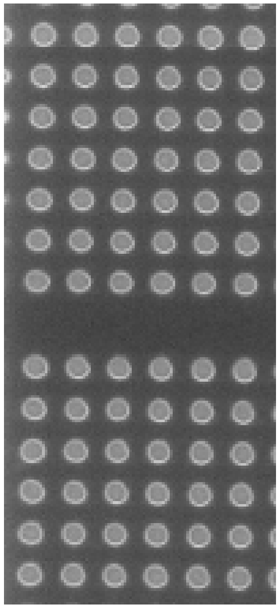
Projet RNRT CRISTEL

Hexagonal lattice, W5 waveguide
RNRT CRISTEL project result



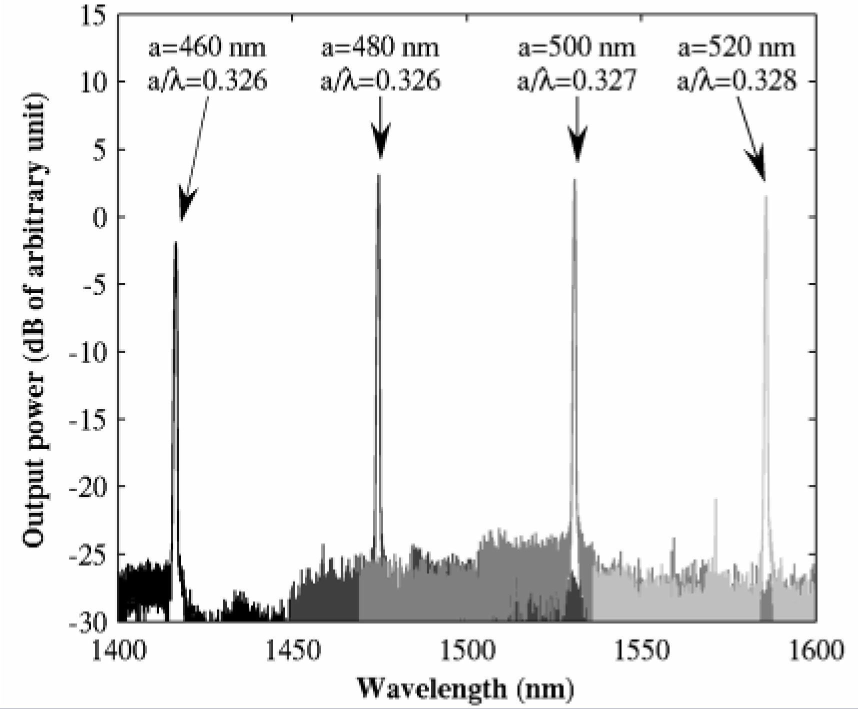
Photonic crystal DFB lasers





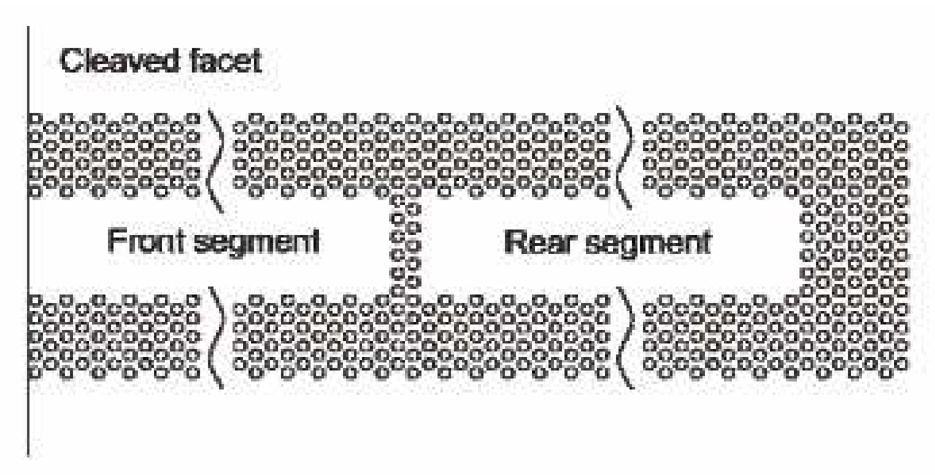
Square lattice of holes in PMMA (LAAS-CNRS)
period = 250 nm

Optical spectra of W1 square lattice lasers
Checoury & al., IEEE JSTQE, (**11**) 2005, pp1180

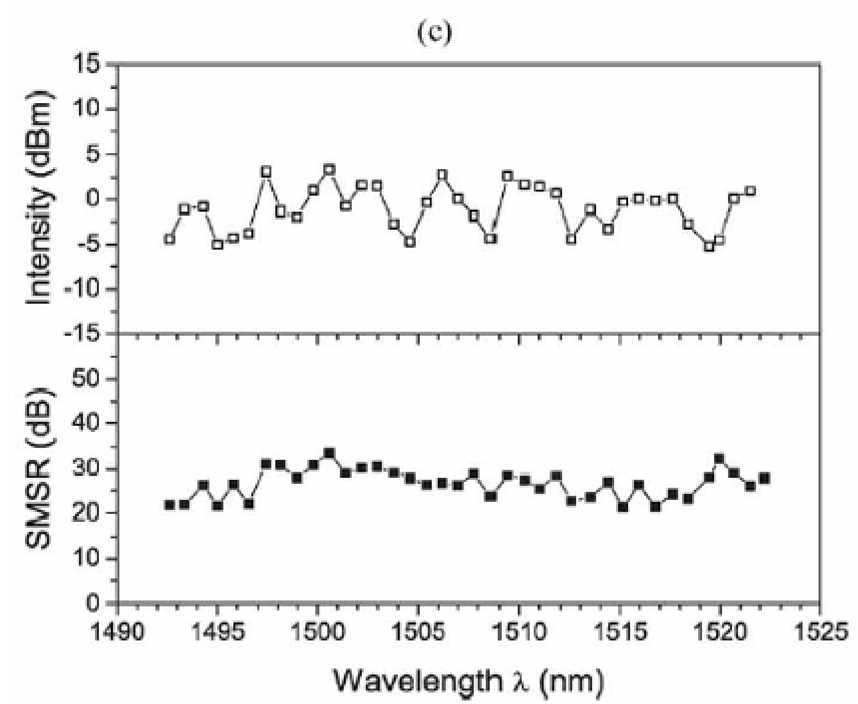


Integrated photonics with PhCs

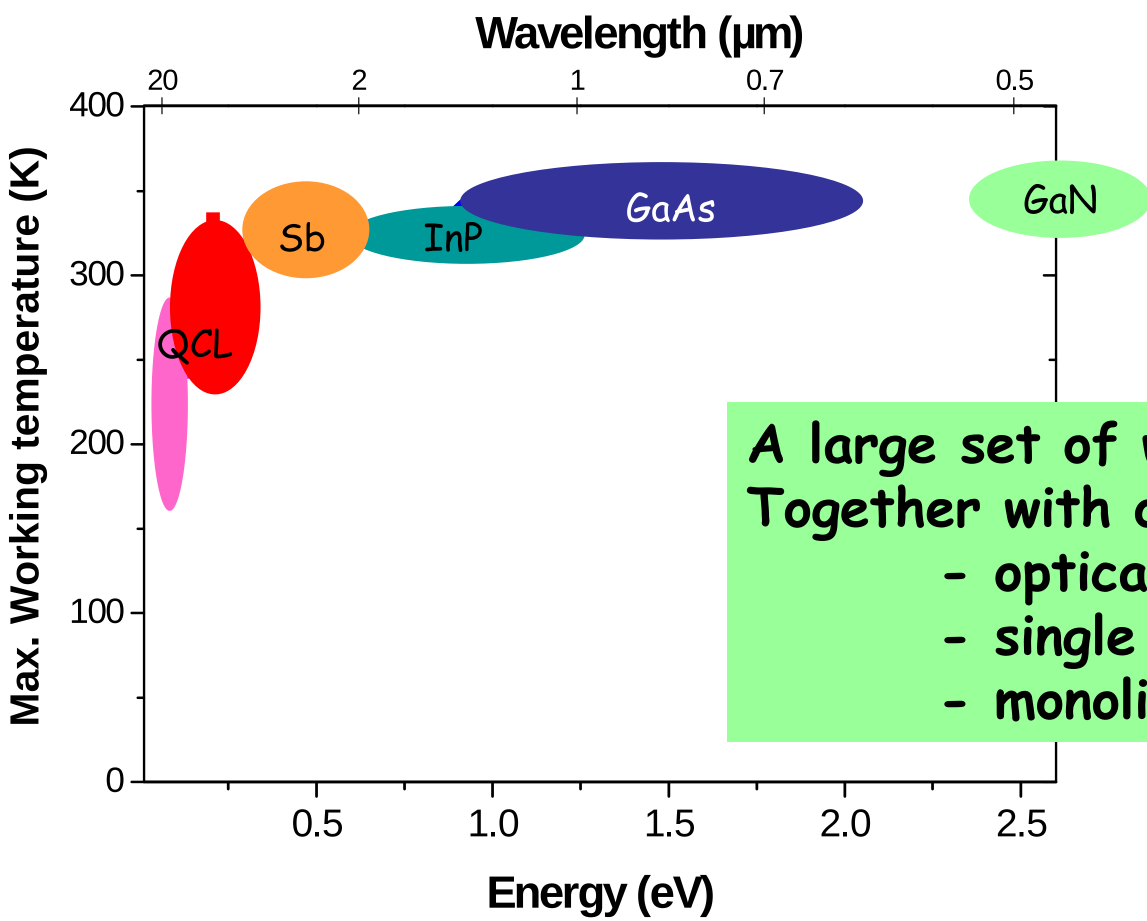
- 2 section all photonic crystal laser



S. Mahnkopf & al., *IEEE JQE*, (**40**) 2004 pp. 1306



Conclusion



A large set of wavelengths
Together with optimized cavities for :
- **optical beam quality**
- **single frequency emission**
- **monolithic integration**