High-Power Al-Free Active Region (λ = 852nm) DFB Laser Diodes For Atomic Clocks and Interferometry Applications

Vincent Ligeret, François-Julien Vermersch, Shailendra Bansropun, Michel Lecomte, Michel Calligaro, Olivier Parillaud, Michel Krakowski

Presented by Michel Krakowski

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May 11, 2006 – WORKSHOP Laser Diodes in Space - France

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Thales Research & Technology

Our Objective

- ***Growing need for diode lasers at 852nm***
  - ***atomic clocks, gyroscopes in positioning systems***
  - ***Satellite, base station, submarine***
- ***Disadvantages of extended cavity laser configurations for space applications***
  - ***mechanical stability and precise optical alignment in space environment***
- ***Our goal: a single frequency and single mode reliable laser diode***

852nm Al free active region laser : motivations

- Better reliability (1)

  - Litterature

    - With a structure in InGaAsP/GaAs at 0.8µm, no failures which could be attributed to a catastrophic growth of dark line defects have been observed to occur in these diodes.

      "D.Garbuzov and all "High-Power 0.8µm InGaAsP-GaAs SQW Lasers",IEEE Journal of quantum electronics, vol 27, pp 1531-1536, 1991

    - Quantum-well, lattice-matched InGaAsP lasers emitting at 0.8 µm are shown to exhibit resistance to 100 dark-line growth.

      "S.L Yellen ans all", Dark-line resistant aluminium free diode laser at 0.8µm, *IEEE Photonics Technology Letters*, **4**(12), pp1328-1330, December 1992

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852nm Al free active region laser : motivations

- Better reliability (2)
  - Our experience
    - Very long lifetest on Al free broad area laser at P=1W, I=1.4A, T_j=40℃ without any preliminary burn in test :
      - 808nm : 35000hours (4 years) without any degradations
      - 980nm : 28600hours (3 years and 3 months) without any degradations.

- Easier implementation of epitaxial regrowth on gratings for Distributed Feedback (DFB) laser structure

852nm laser structure : realisations

- ***Broad Area laser***
  - ***Allow to determine the quality of the epitaxial structure (internal efficiency, internal loss, transparency current density)***
- ***Ridge Fabry-Perot laser diode***
  - ***Single spatial mode emisison***
- ***Distributed Feedback Laser diode***
  - ***Spectral single mode emission***

I) Al free active region laser structure

II) Broad area AR/HR coated 2mm laser diode

III) Fabry-Perot Ridge AR/HR coated 2 mm laser diode

IV) DFB Ridge 2mm laser diode

- Emission at 854nm : 150mW optical power (AR/HR)
- Emission at 852.12nm : D_2 line (as cleaved)

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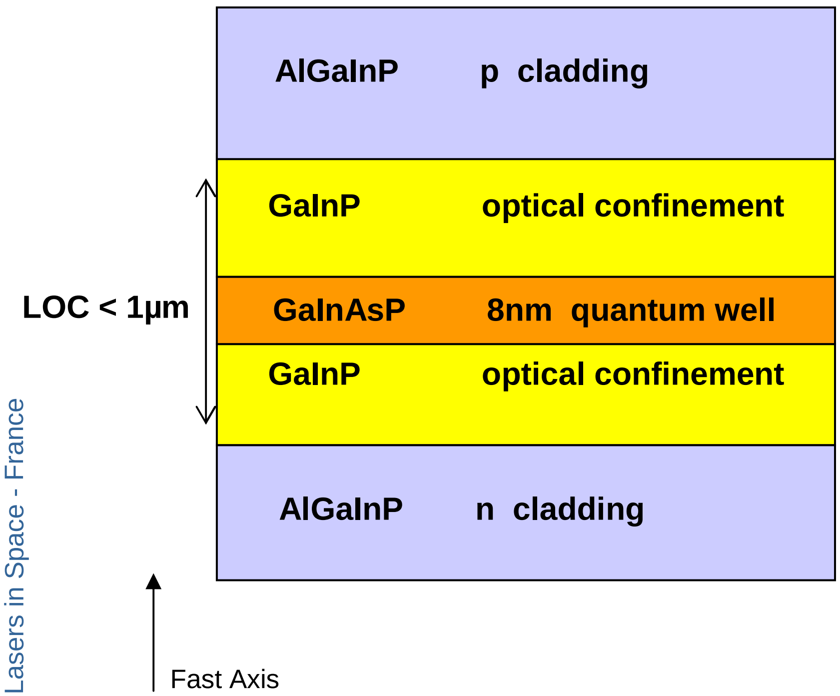
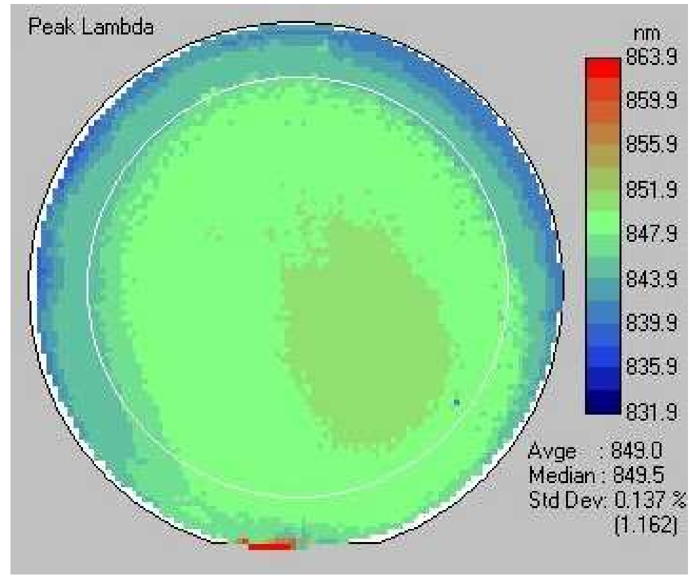
852nm Al free active region laser structure



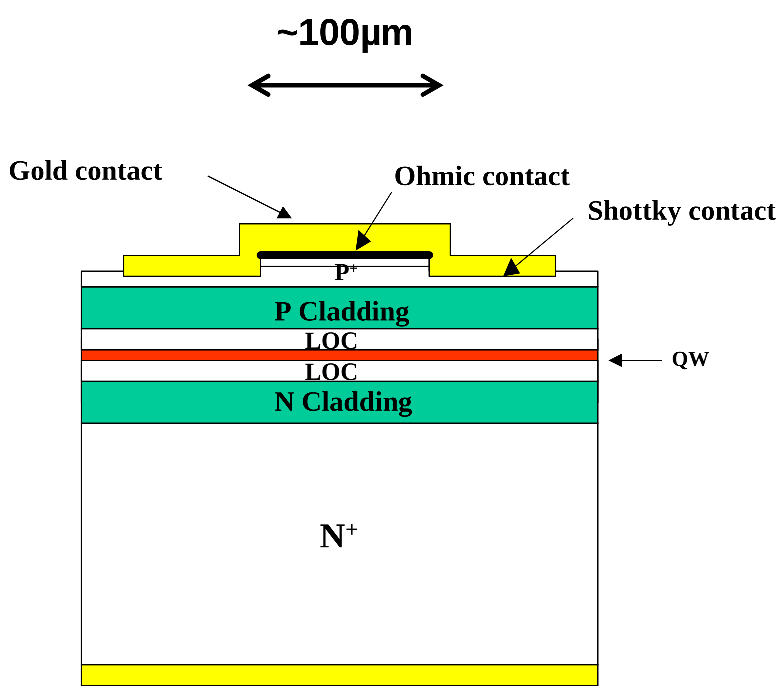


Standard deviation below 1.2nm

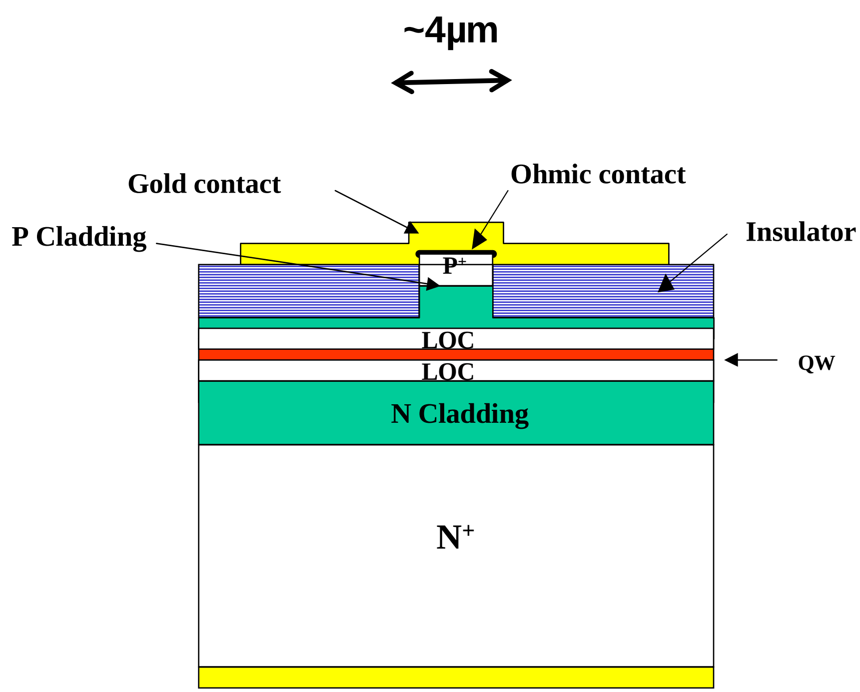
Large Optical Cavity Structure

- $J_0 = 100\ A/cm^2$
- $\alpha_i < 3\ cm^{-1}$
- $\eta_i = 94\ \%$

Device structure



Broad area laser



FP Ridge laser

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Device realisation : principal steps

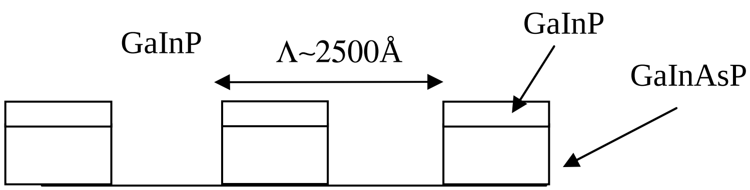
- ***initial epitaxy including active region***

- ***grating definition***
  - ***holography***
  - ***dry etching (Reactive Ion Etching : RIE) (1:1 ratio)***
  - ***wet chemical selective etching (1:3 ratio)***

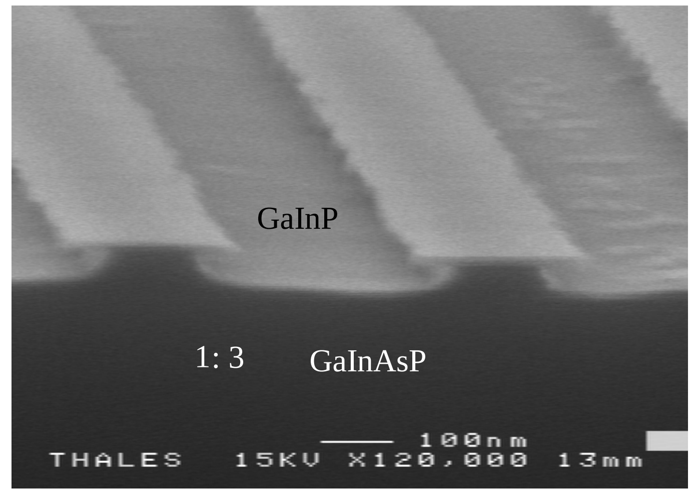
- ***epitaxial regrowth of p cladding and p+ contact layers***

- ***ridge realisation***

Device realisation : grating



$$\lambda_B = \frac{2 \times n_{eff} \times \Lambda}{m}$$



Schematic of the Bragg grating structure

SEM image of grating structure

$m = 2$

$n_{eff} = 3.26$

Λ around 2500Å

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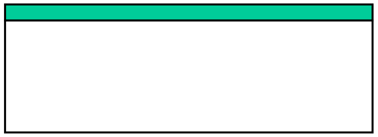
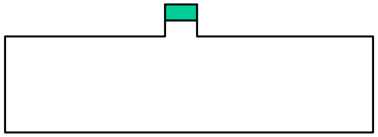
Device realisation : ridge

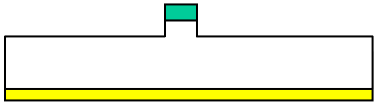
Ohmic contact metallisation



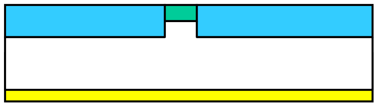
Ridge definition (photolithography,Ion beam etching, Chemical etching)



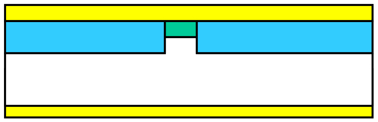
Back surface thinning and polishing, back contact metallisation



BCB Polymer planarisation



P side contact metallisation



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I) Al free active region laser structure

II) Broad area AR/HR coated 2mm laser diode

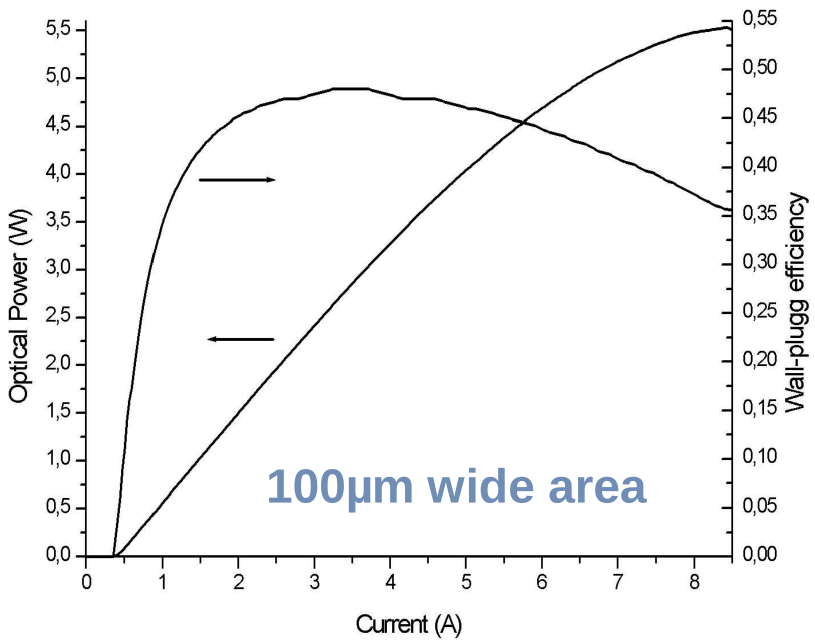
III) Fabry-Perot Ridge AR/HR coated 2 mm laser diode

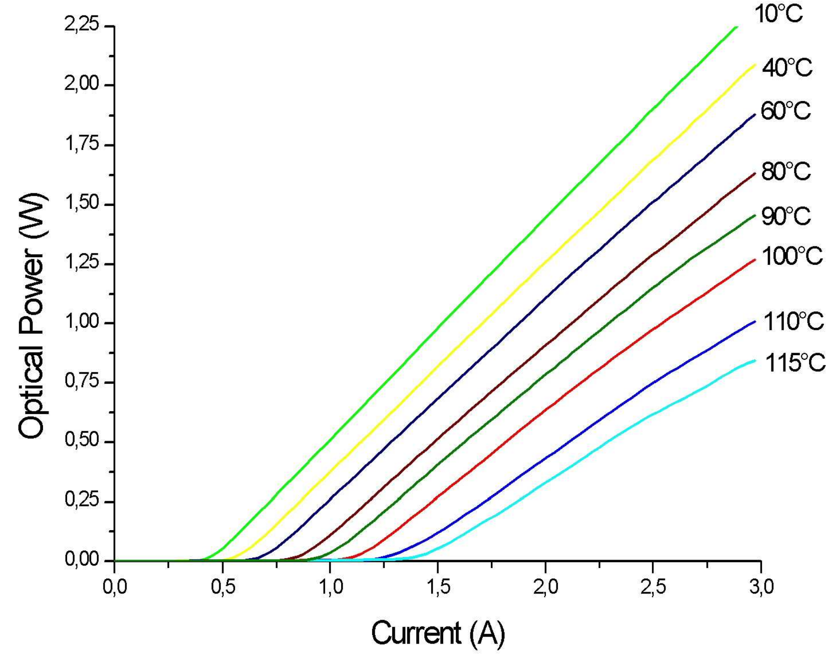
IV) DFB Ridge 2mm laser diode

- Emission at 854nm : 150mW optical power (AR/HR)
- Emission at 852.12nm : D_2 line (as cleaved)

Light current characteristics L(I)

5.5W CW 8.5A 15°C





- I_{th} = 490 mA
- J_{th} = 245 A/cm²
- η = 0.93W/A
- T_0 = 116K

- Laser emission up to at least 115°C
- 1.4W obtained at 100°C and I=3.6A

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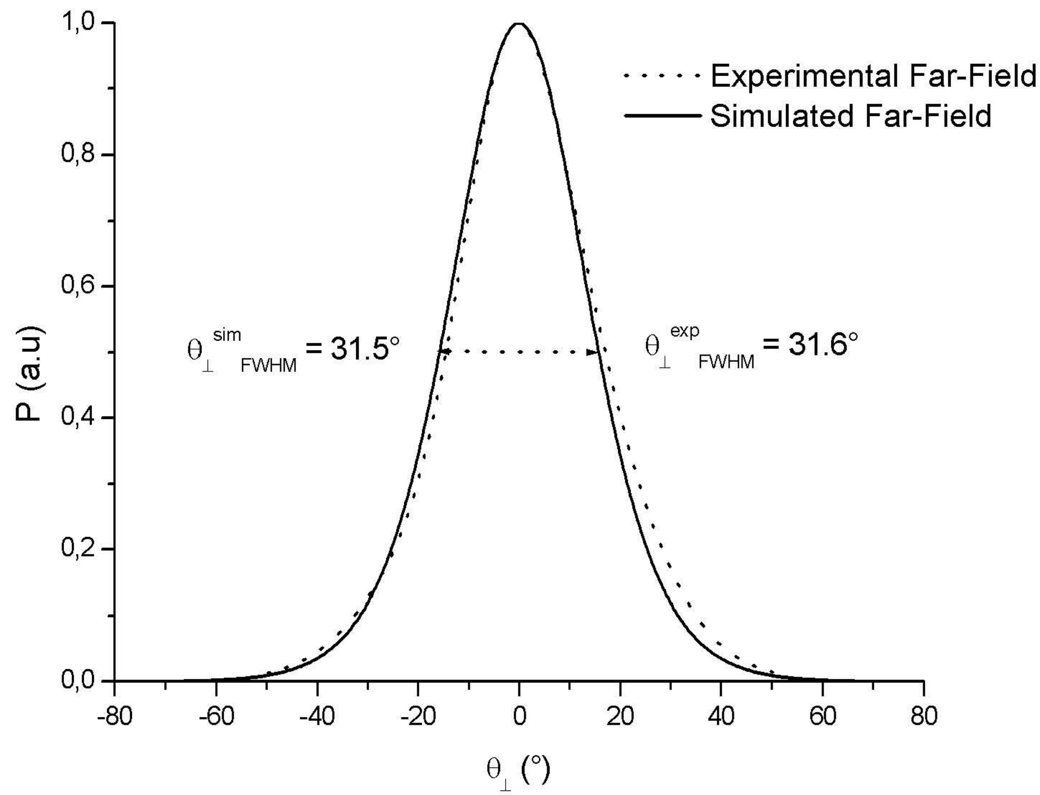
Far field in the fast axis



- *Very stable with the output power*
- *No beam steering*
- *No signs of higher order modes*

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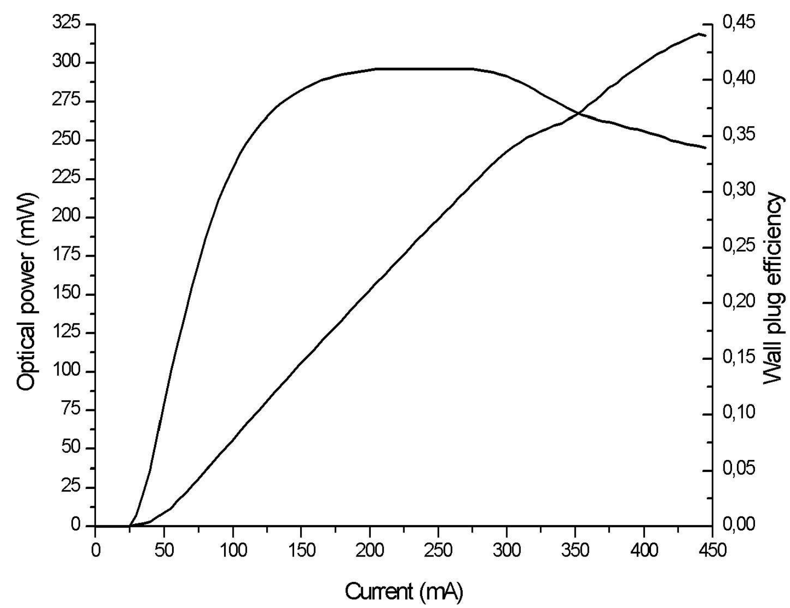
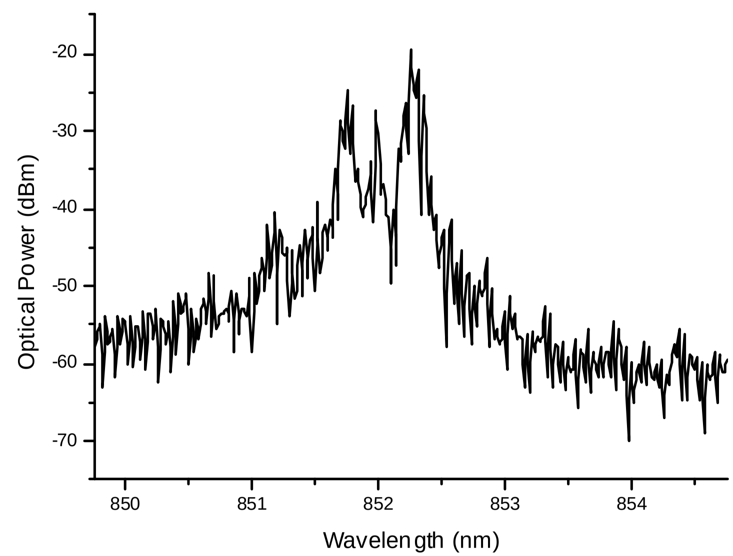
L(I) and optical spectrum

Up to 250mW kink free at 20℃



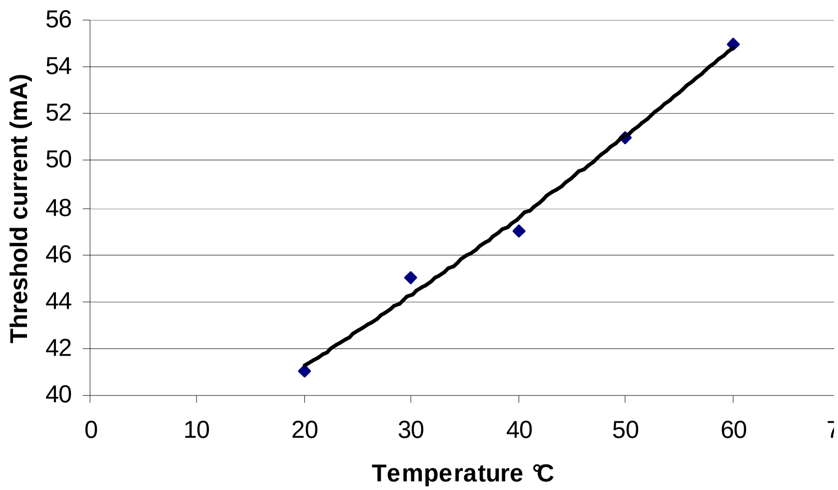


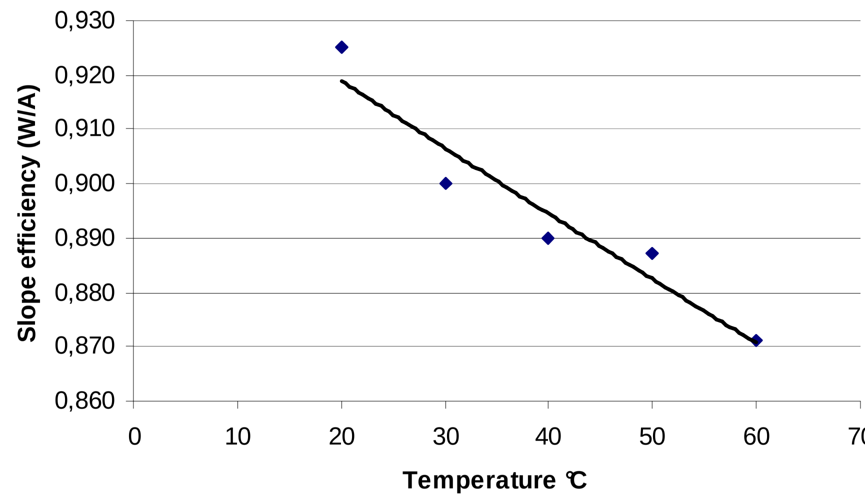
P= 50mW, I=120mA, T= 20℃

- I_{th} = 40mA
- η = 0.9W/A
- Max wall-plug Eff. = 0.40
- T_0 = 140K

- 852nm

Determination of T_0 and T_1





$$I_{th}(T') = I_{th}(T)\exp\left(\frac{T'-T}{T_0}\right)$$

$$\eta(T') = \eta(T)\exp\left(\frac{T-T'}{T_1}\right)$$

=> T_0 = 140K

=> T_1 = 500K

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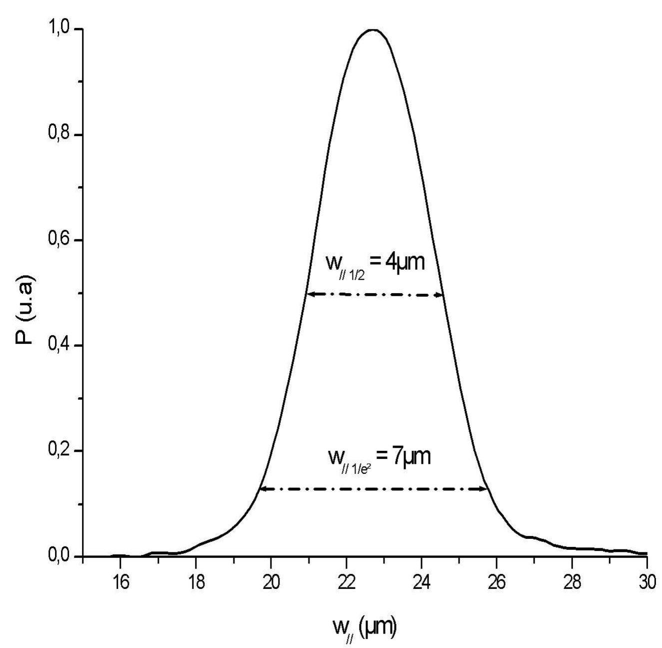
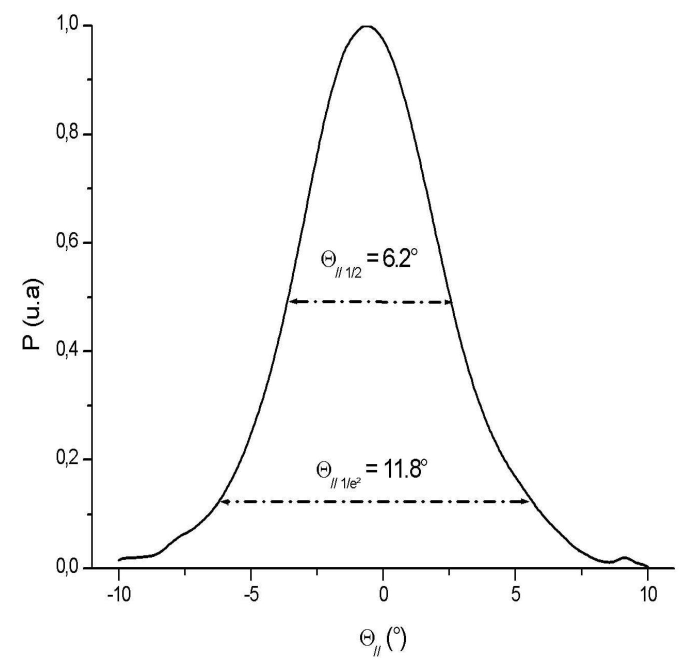
Near and far field in the slow axis





P=230mW, I=280mA, T=20°C

- **For beams with gaussian intensity profiles :**

$$M^2 = \frac{\pi}{4\lambda}\theta_{1/e^2} w_{01/e^2} \qquad (1)$$

Where θ_{1/e^2} the full divergence of the far-field at 1/e² and W_{01/e^2} the full width of the near-field at waist at 1/e²

- **In case of real beam :**

M² calculation with the second moment product of the far-field σ_{sx} and of the near-field σ_{x0} profiles :

$$M^2 = 4\pi\sigma_{x0}\sigma_{sx} \qquad (2)$$

Where σ_{x0} is the second moment of the near-field intensity profile at the waist and σ_{sx} the second moment of the far-field intensity profile

(cf A.E.Siegman, « New developments in laser resonators », invited paper, SPIE Vol. 1224 Optical Resonators 1990)

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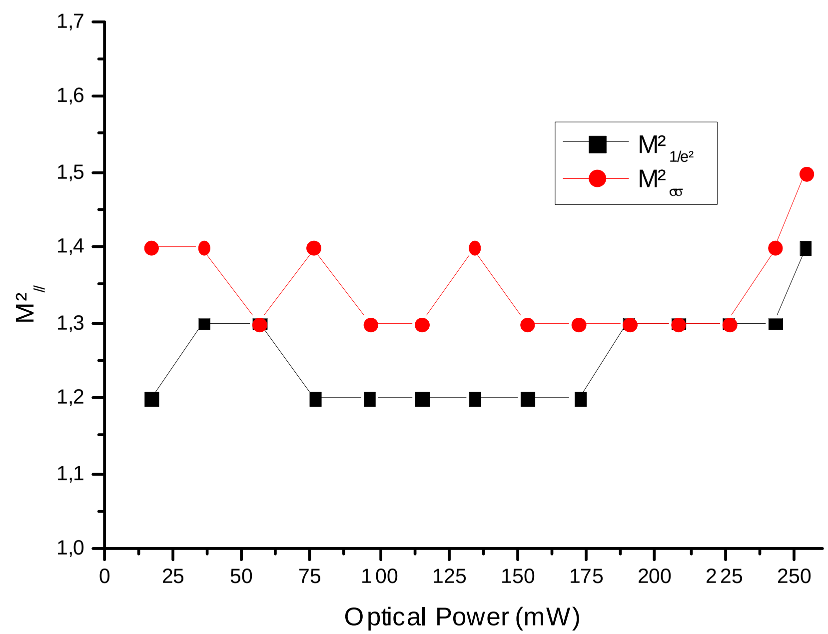
M^2 in the slow axis direction



➢ **230mW monomode (I=280mA)**

$$M^2_{1/e^2} = 1.3 \qquad M^2_{\sigma\sigma} = 1.3$$

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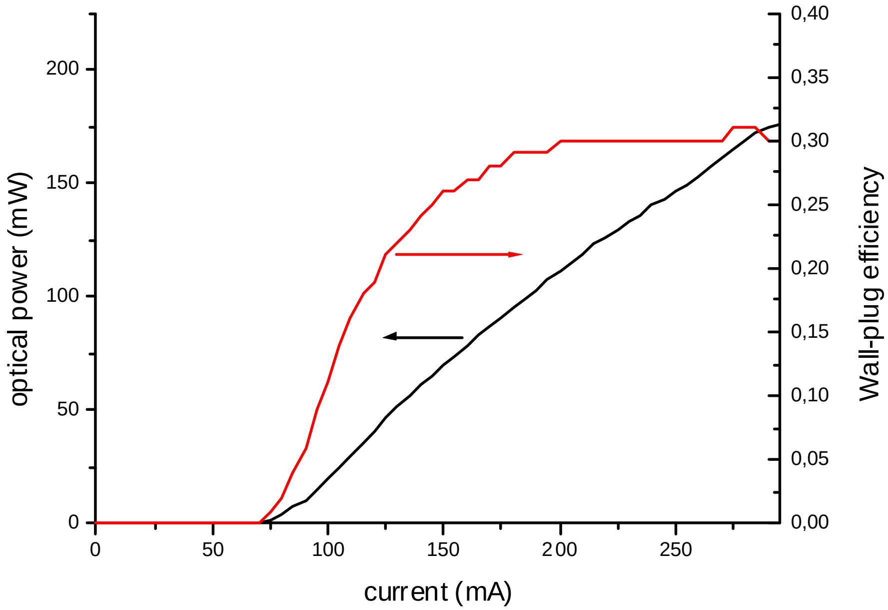
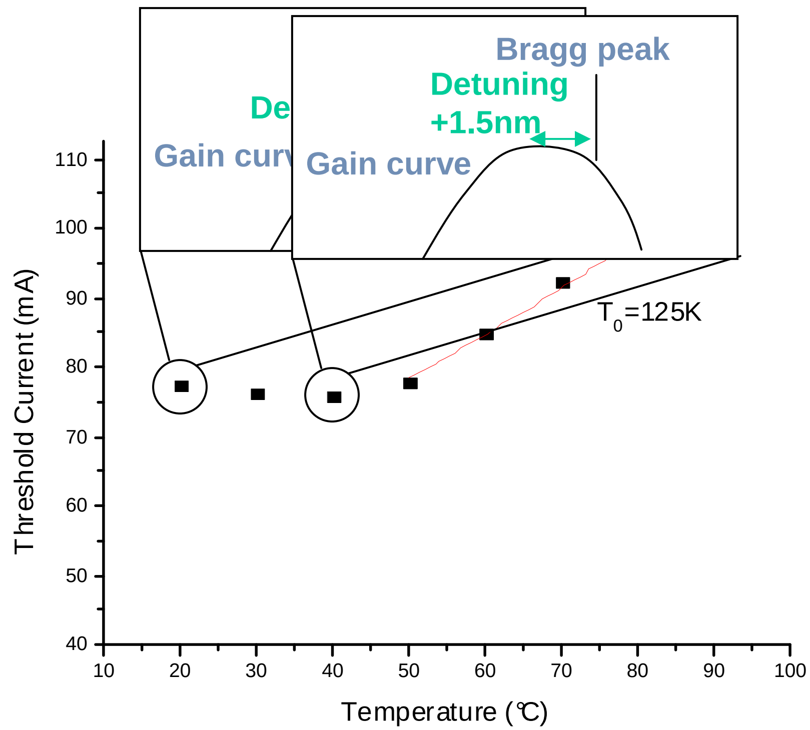
- Emission at 854nm : 150mW optical power (AR/HR)
- Emission at 852.12nm : D_2 line (as cleaved)

Up to 150mW kink free at 20℃





- I_{th} = 80mA
- η = 1.05W/A

- T_0 = 125K

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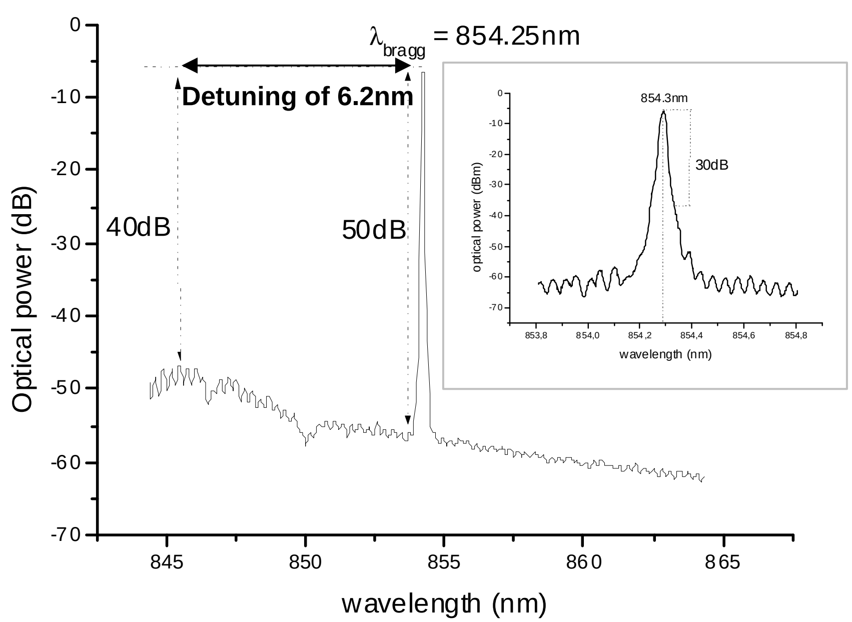
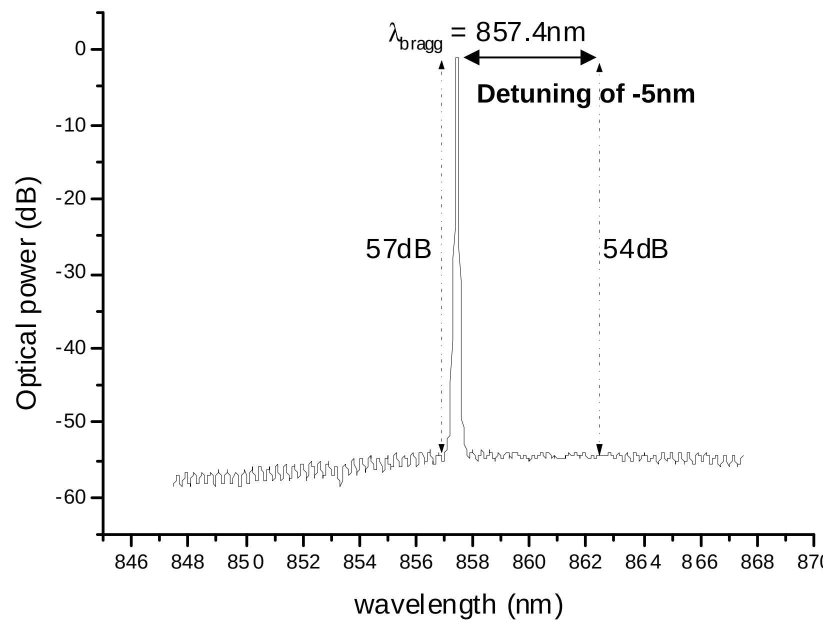
P= 153mW, I=260mA, T= 20℃



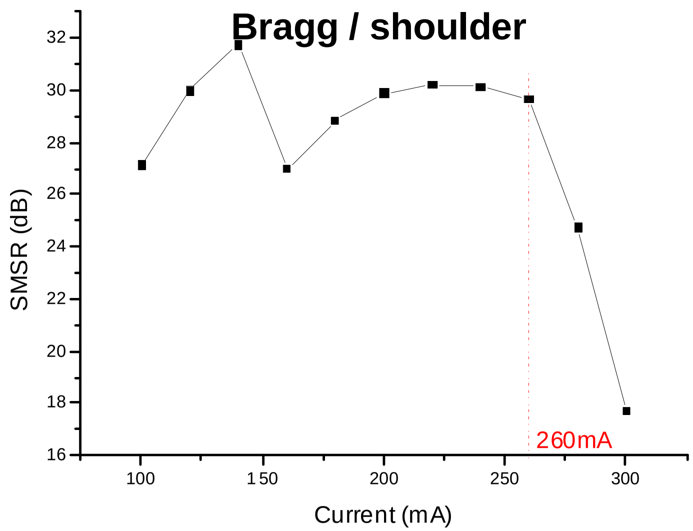
I=200mA, T= 80℃

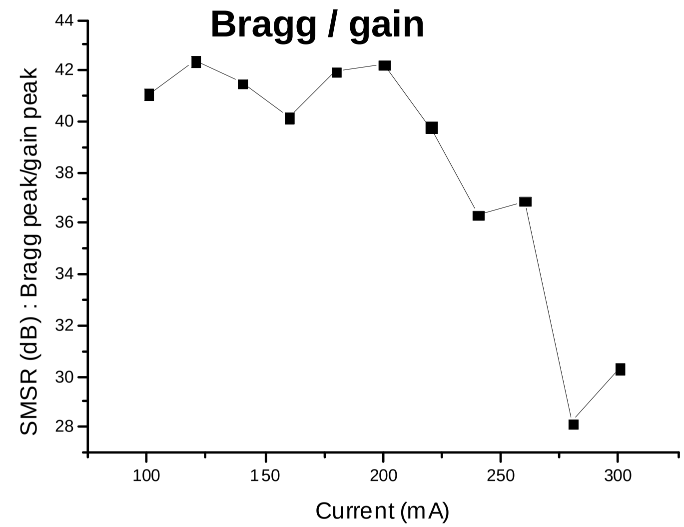


- **153mW at 854.25nm**

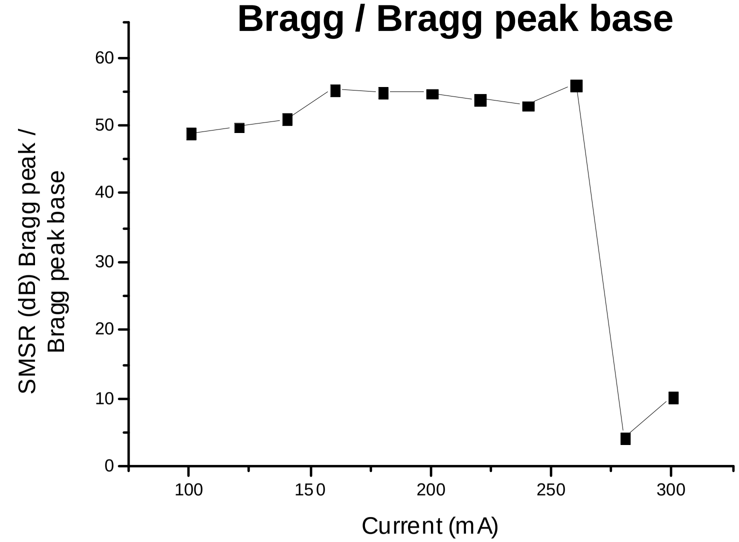
  (I= 260mA, 20℃)

SMSR as function of current : 20℃



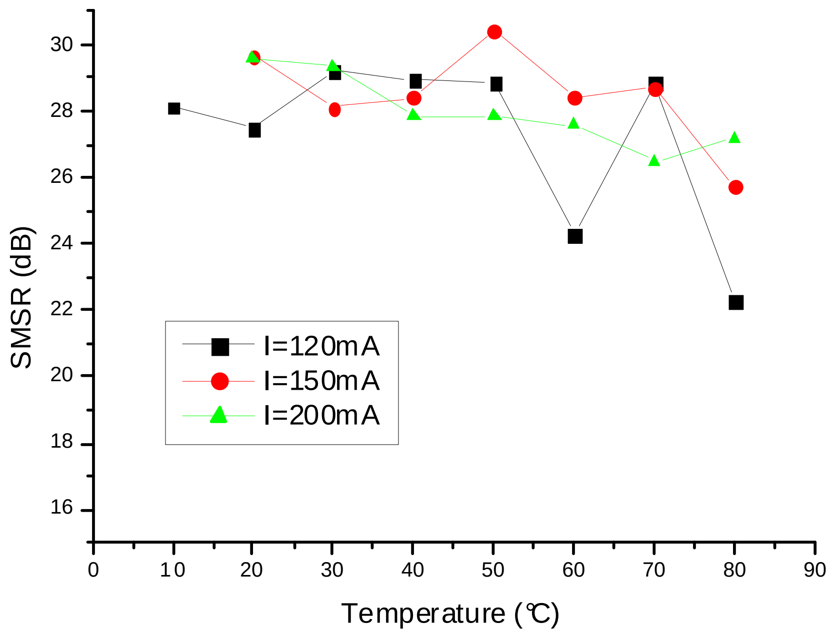


- up to 153mW SMSR around 30dB

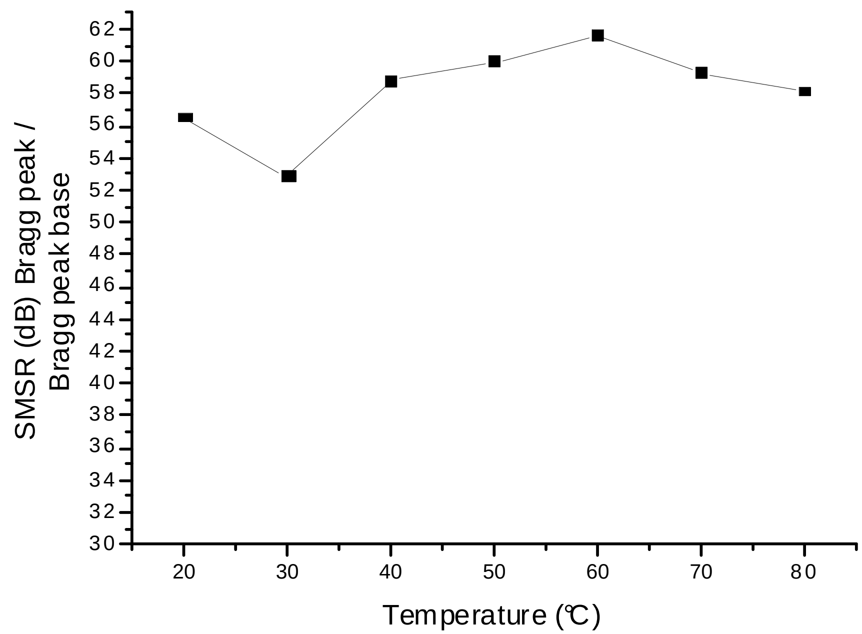


SMSR as function of temperature

Bragg / shoulder



Bragg / Bragg peak base

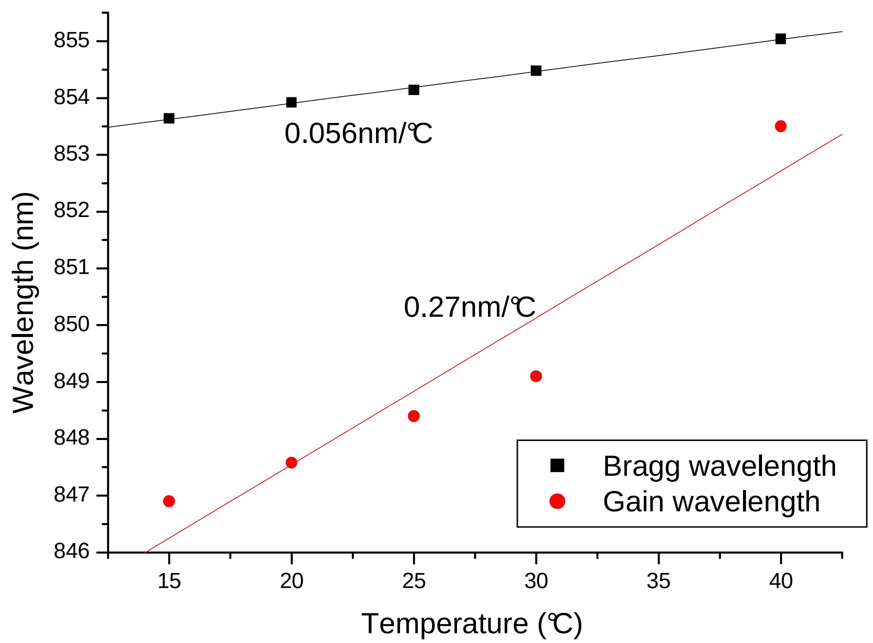


up to 70℃ SMSR around 30dB

I=200mA, SMSR between Bragg peak and the gain curve around the Bragg peak

Variation of Bragg wavelength

Evolution of Bragg relative to gain wavelength



Detuning 15℃ : 6.7nm

Detuning 40℃ : 1.5nm

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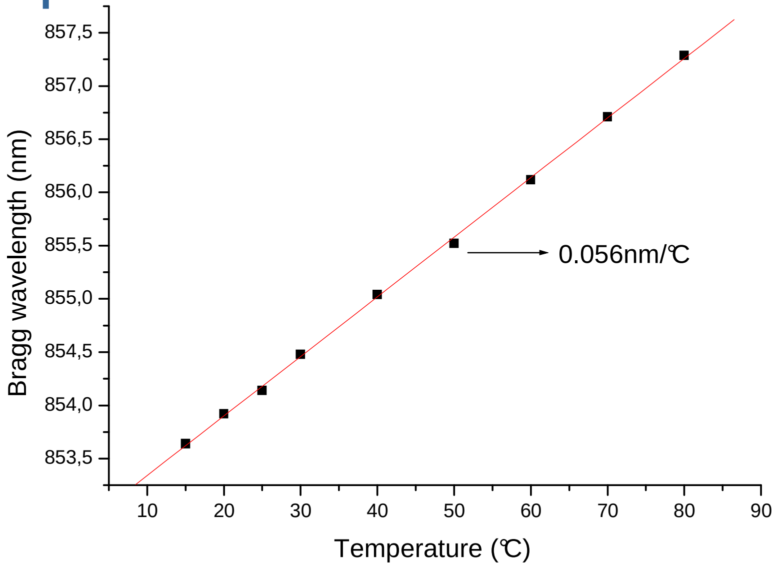
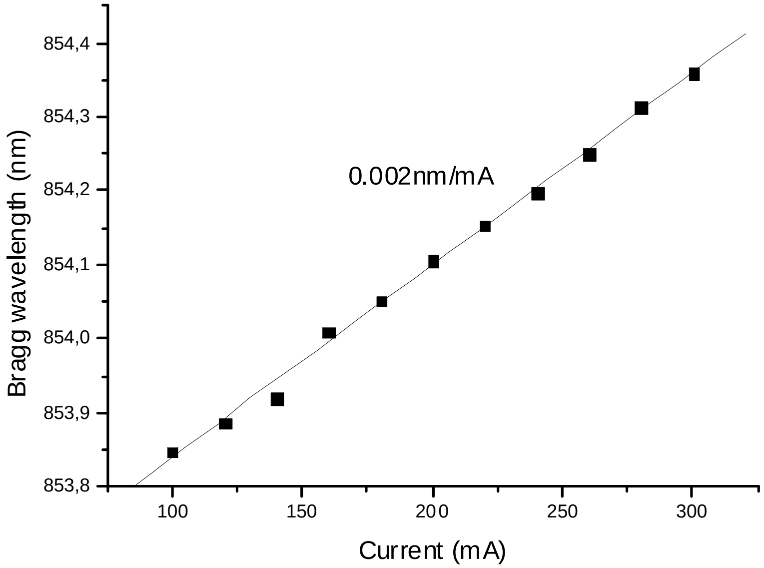
Variation of Bragg wavelength





- Variations of Bragg wavelength as functions of temperature (I = 120mA)
- Variation of Bragg wavelength as function of current (T= 20°C)

$$Rth = \frac{\Delta T}{P_{elec} - P_{optical}} \qquad Rth = \frac{\dfrac{d\lambda_b}{d(UI - P_0)}}{\dfrac{d\lambda_b}{dT}}$$

UP	37K/W

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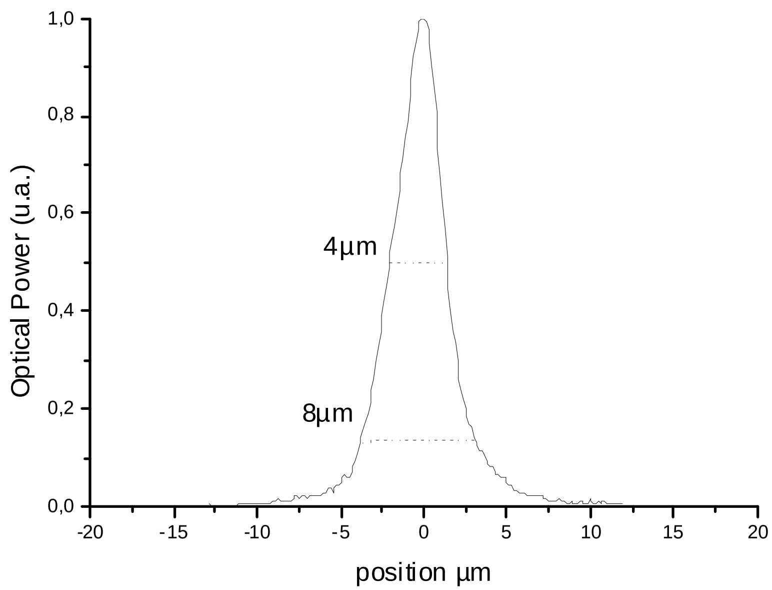
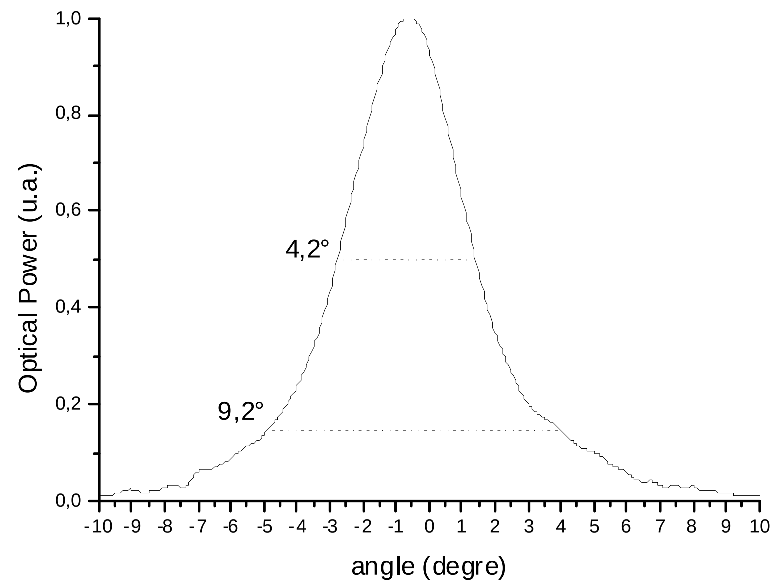
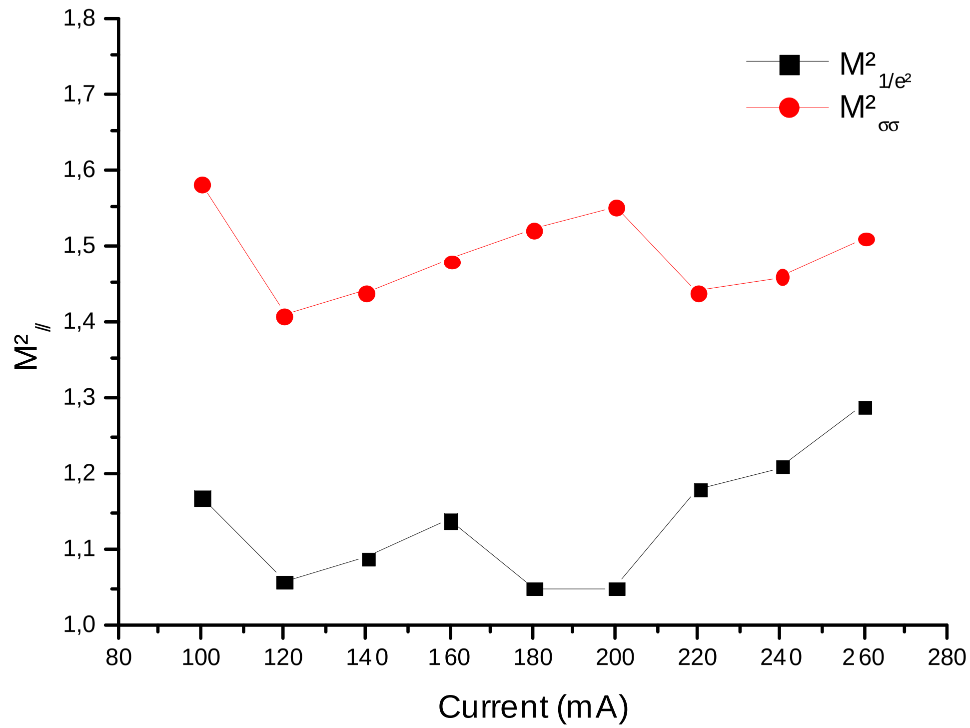
Near and far field in the slow axis





P=153mW, I=260mA, T=20°C

M² in the slow axis direction



- 153mW monomode (I=260mA)

$$M^2_{1/e^2} = 1.3 \qquad M^2_{\sigma\sigma} = 1.5$$

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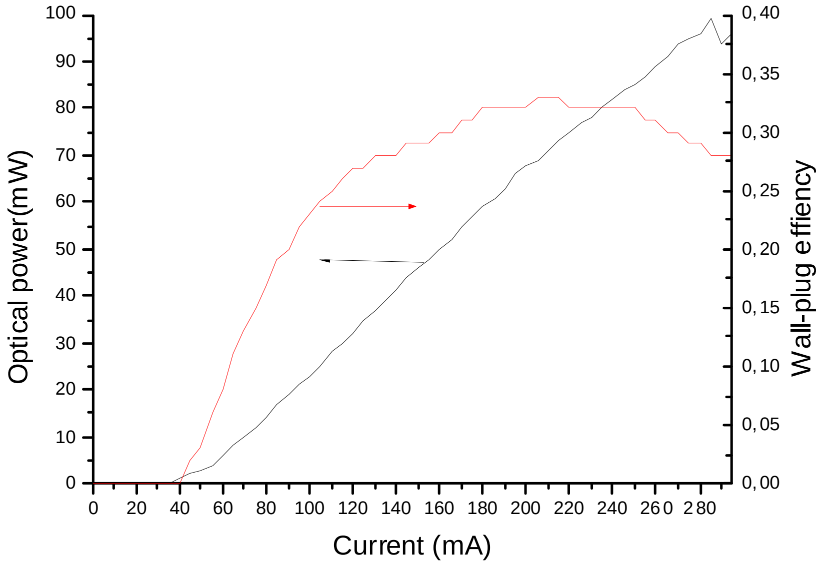
- Emission at 854nm : 150mW optical power
- Emission at 852.12nm : D_2 line : adjustment of the grating pitch

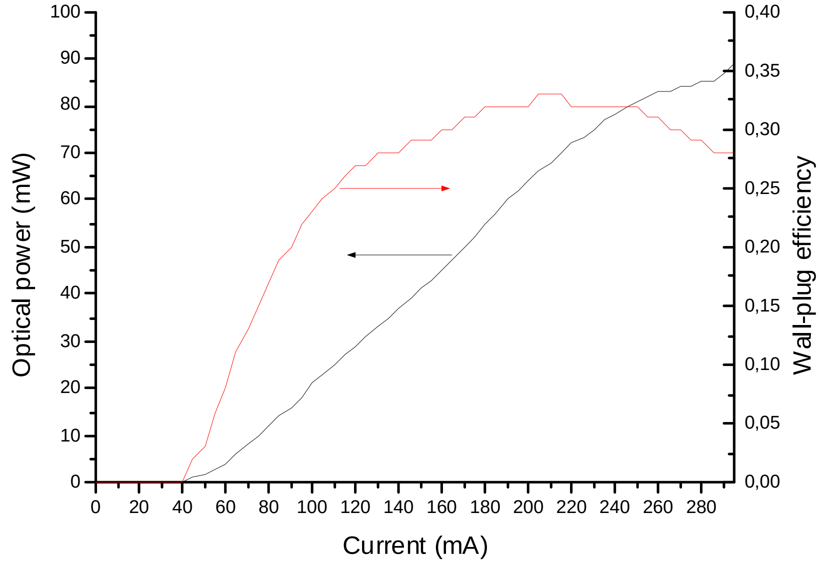
L(I) characteristics

Up to 85mW kink free at 20℃



- I_{th} = 46mA
- η = 0.44W/A

Up to 75mW kink free at 37℃



- I_{th} = 52mA
- η = 0.40W/A

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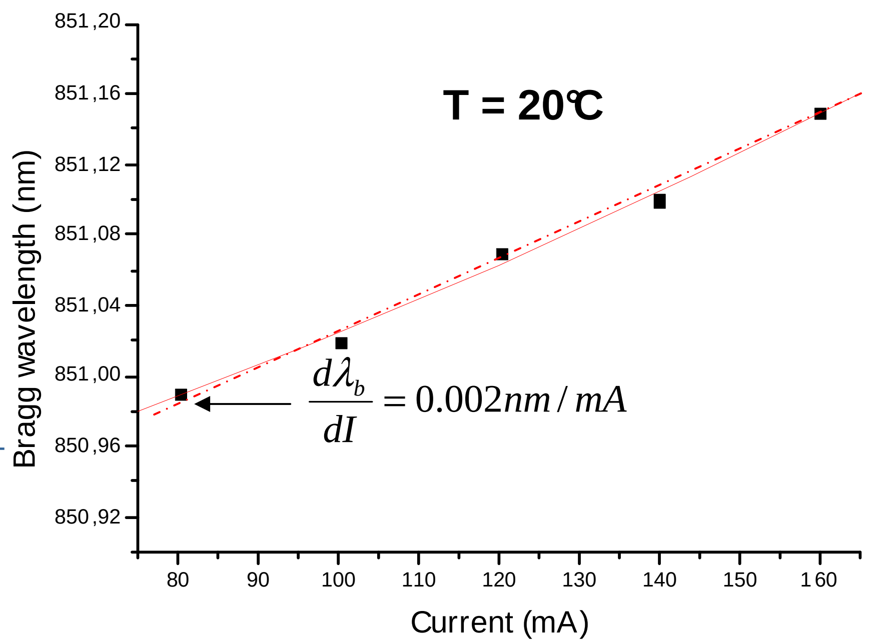
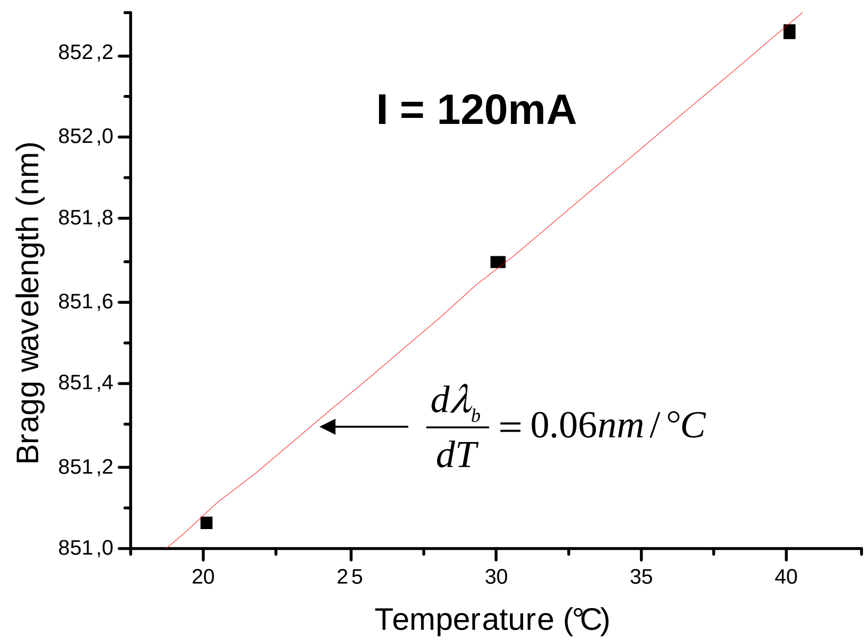
Variation of Bragg wavelength at 20℃

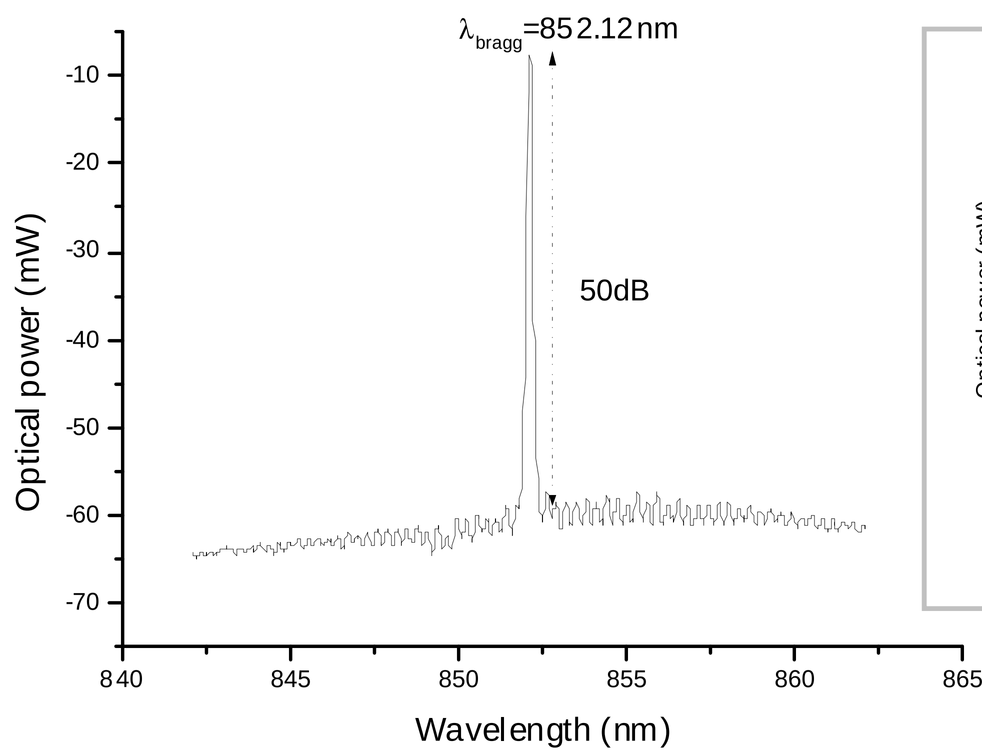


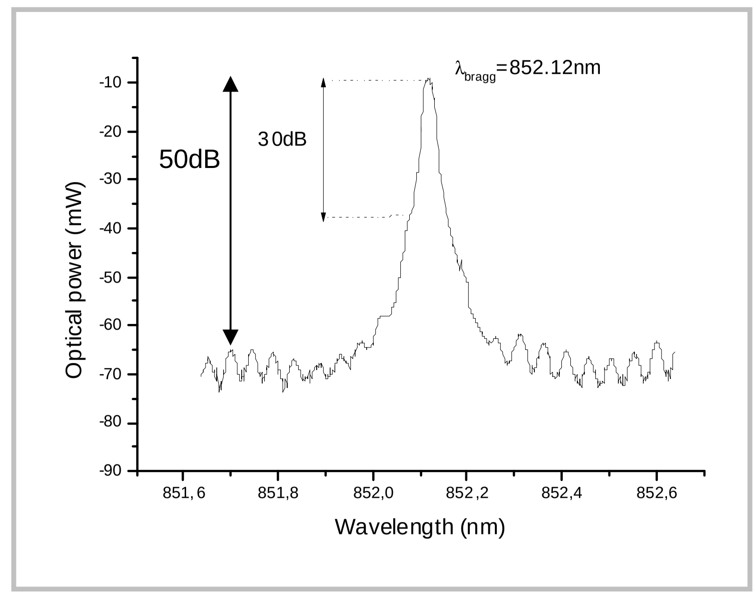


852.12nm at 37℃ and 140mA

UP	40K/W
DOWN	25K/W

Obtention of D2 line

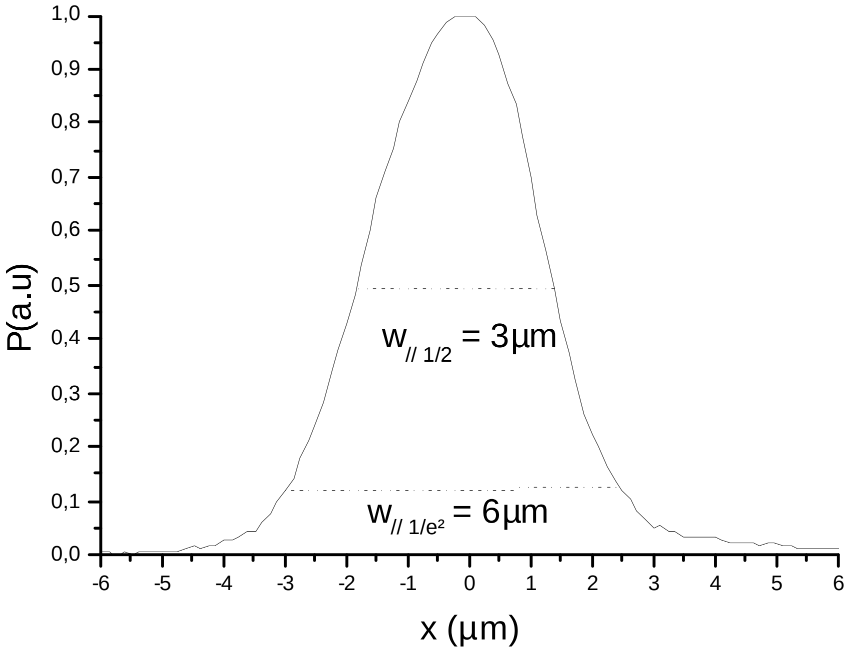


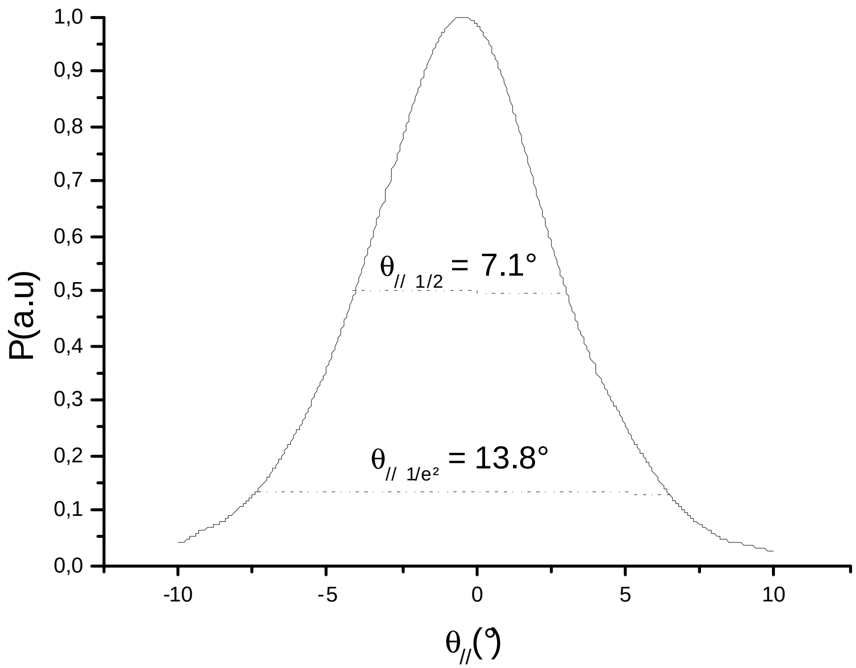


➢ **40mW at 852.12nm**

(I= 140mA, 36.9°C)

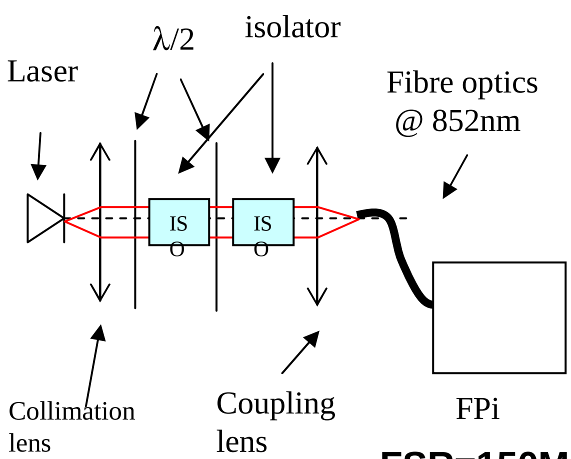
Near and far field in the slow axis : 852.12nm





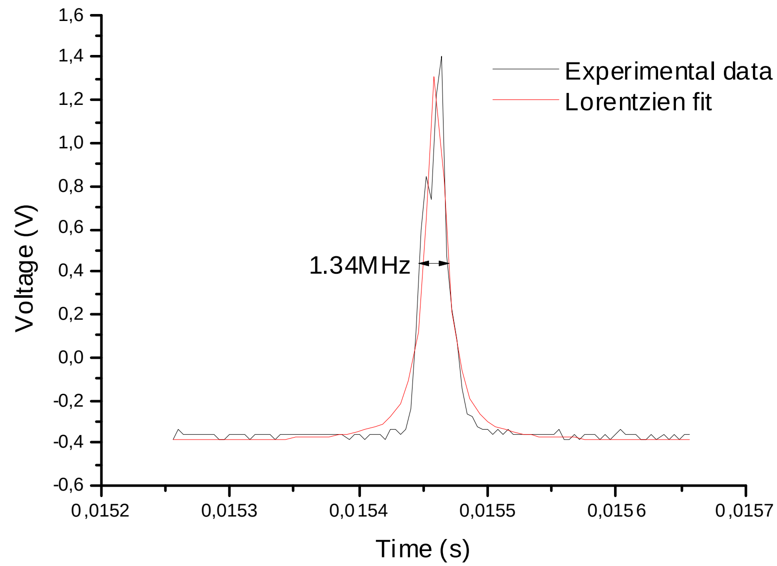
P=40mW, I=140mA, T=36.9°C

M^2_{1/e^2} =1.3 $M^2_{\sigma\sigma}$ =1.5



FSR=150MHz

Resolution = 750kHz

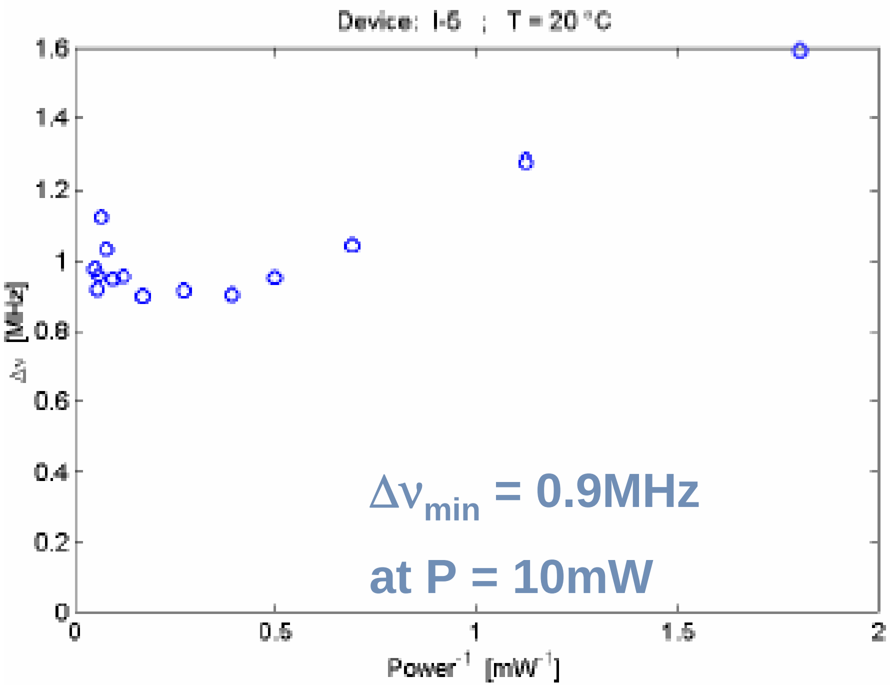


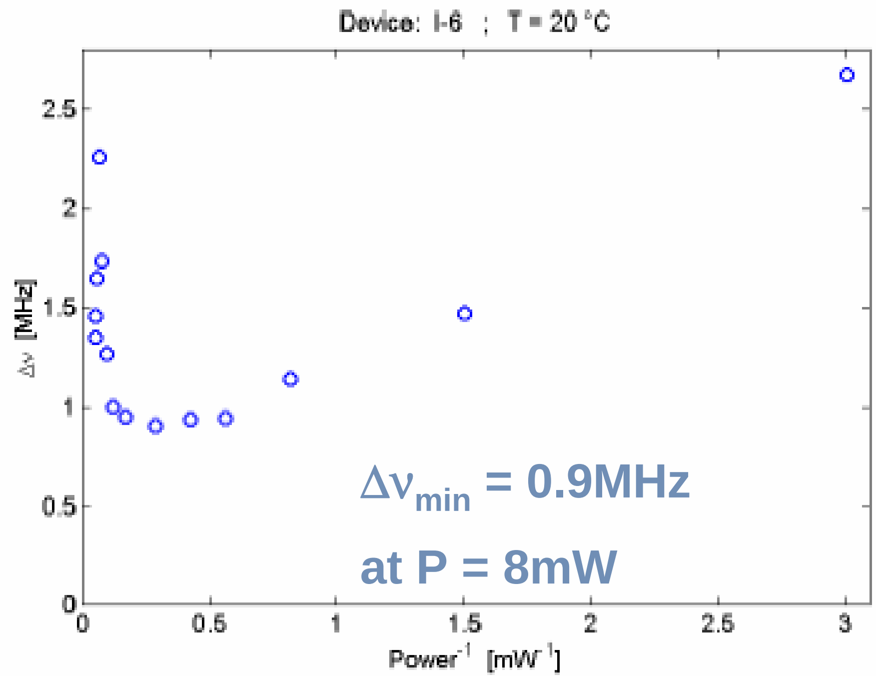
Schematic of the linewidth measurement setup

single peak of the interferogram (30mW)

➢ **low linewidth Δν < 2MHz**

Linewidth : Measurements at Pavia





➢ **minimum linewidth value Δν = 900kHz**

Guido Giuliani : University of Pavia

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Conclusion

- **Broad area laser:**
  - **Low optical losses (<3 cm^{-1})**
  - **High internal quantum efficiency (0.95)**
  - **Low transparency current density (100A/cm^2)**
  - **High optical power : 5.5W for AR/HR coated 2mm long broad area laser diode**

- **Ridge Fabry-Perot laser:**
  - **250mW single spatial mode for AR/HR coated 2mm long ridge diode with M^2_{1/e^2}=1.3**
  - **Lasing emission at 852nm (P=145mW, T=15℃)**

- **Laser emission DFB (AR/HR coated):**
  - **854.3nm with a SMSR over 30dB up to 153mW**
  - **SMSR over 30dB up to 70℃**
  - **153mW single spatial mode for AR/HR coated 2mm long DFB diode with M^2_{1/e^2}=1.3 and M^2_{σ}<1.5**
  - **Low value of Bragg wavelength evolutions in current and temperature**
  - **Low linewidth : $\Delta\nu$ < 2MHz, minimum linewidth value $\Delta\nu$ = 900kHz**

- **Laser emission DFB uncoated at 852nm**
  - **852.12nm at 40mW with a SMSR over 30dB**

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Future work

- Long term ageing for reliability assessment
- Tests under irradiations
- Improvement of linewidth measurement