WWW • BRIGHTER • EU

THALES

External cavities for controling spatial and spectral properties of SC lasers.

J.P. Huignard
TH-TRT

Bright Er - Partners.

WP 3 : External cavities approaches for high brightness.

- RISOE – TUD Dk
- Institut Optique Graduate School – Fr
- THALES Research and Technology – Fr
- UNIPRESS - Poland
- Rainbow Photonics - CH

Bright Er - Objectives

WP 3 : External cavities approaches for high brightness.

Spatial and Spectral filtering of the modes of the cavity

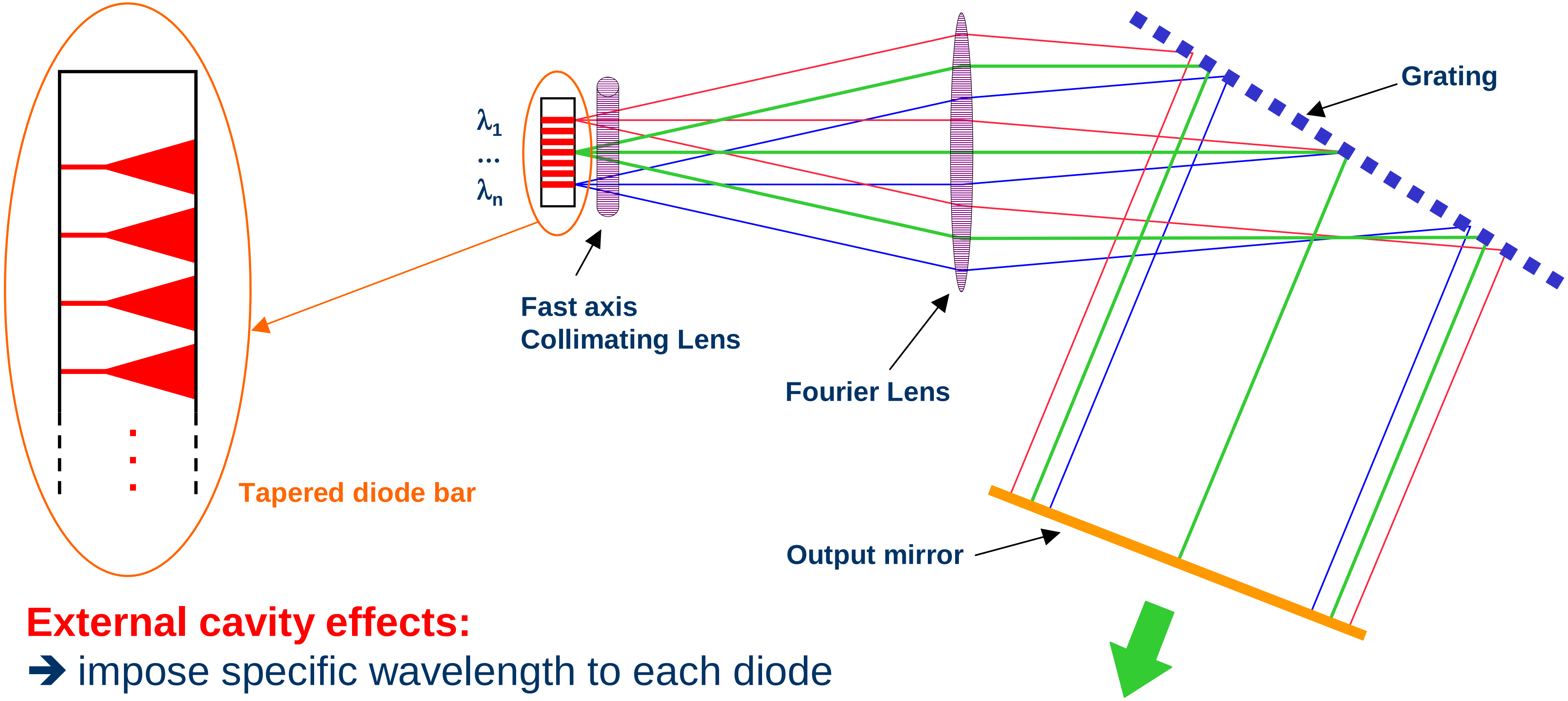
Three different approaches :

- **Incoherent beam combining with wavelength multiplexing**
- **Mode filtering with a fixed or NL volume Bragg grating**
- **Mode filtering due to NL wave mixing in the SC laser**

Wavelength Multiplexing

Wavelength Multiplexing of Tapered Diode Bars /1

Goal: increase the **brightness** (=P/SΩ) of a diode bar
Mean: **spatial superposition** of individual beams
Cost: spectral spreading

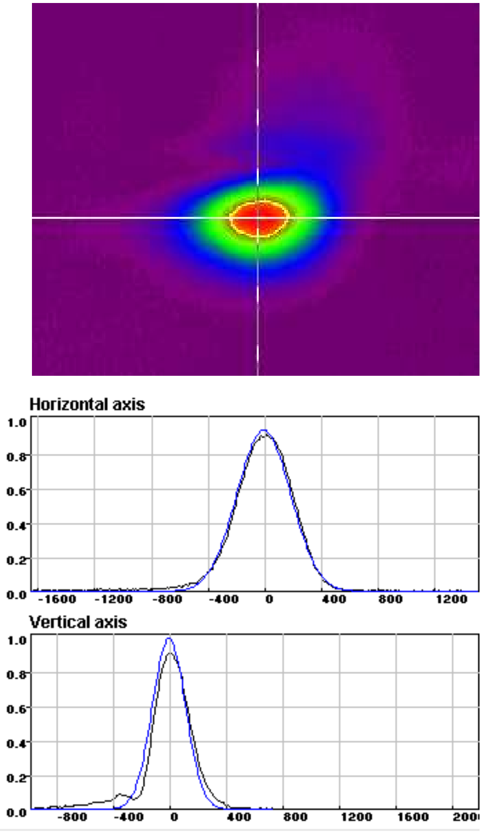


External cavity effects:

➔ impose specific wavelength to each diode
➔ far field of the diodes superimposed onto the grating
➔ flat output mirror impose output beams to be parallel

Wavelength Multiplexing of Tapered Diode Bars /2

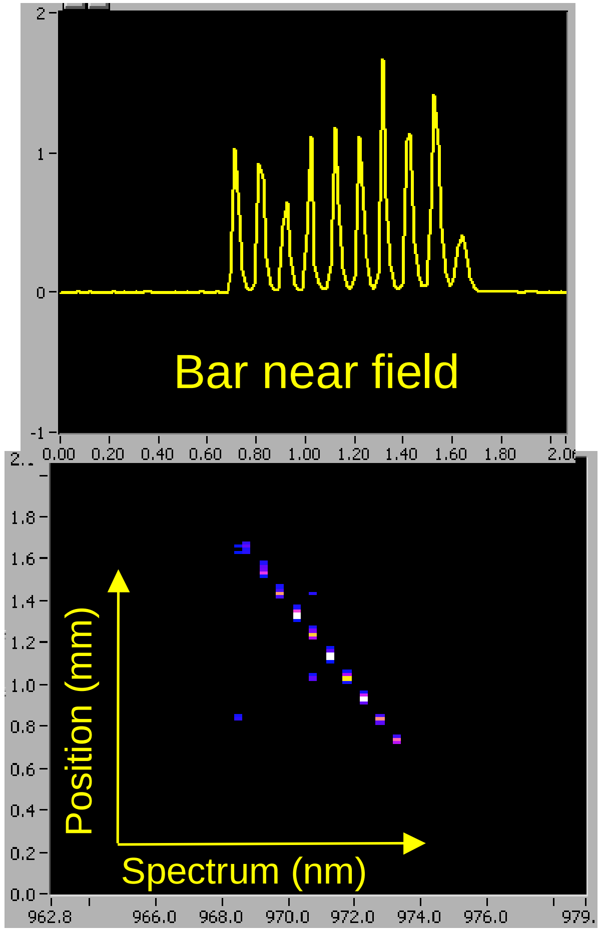
Output cavity focal spot



Bar:
10 emitters
100µm pitch spacing
output coating ~3-5%

Cavity:
Fourier lens = 75mm
output mirror: R=20%

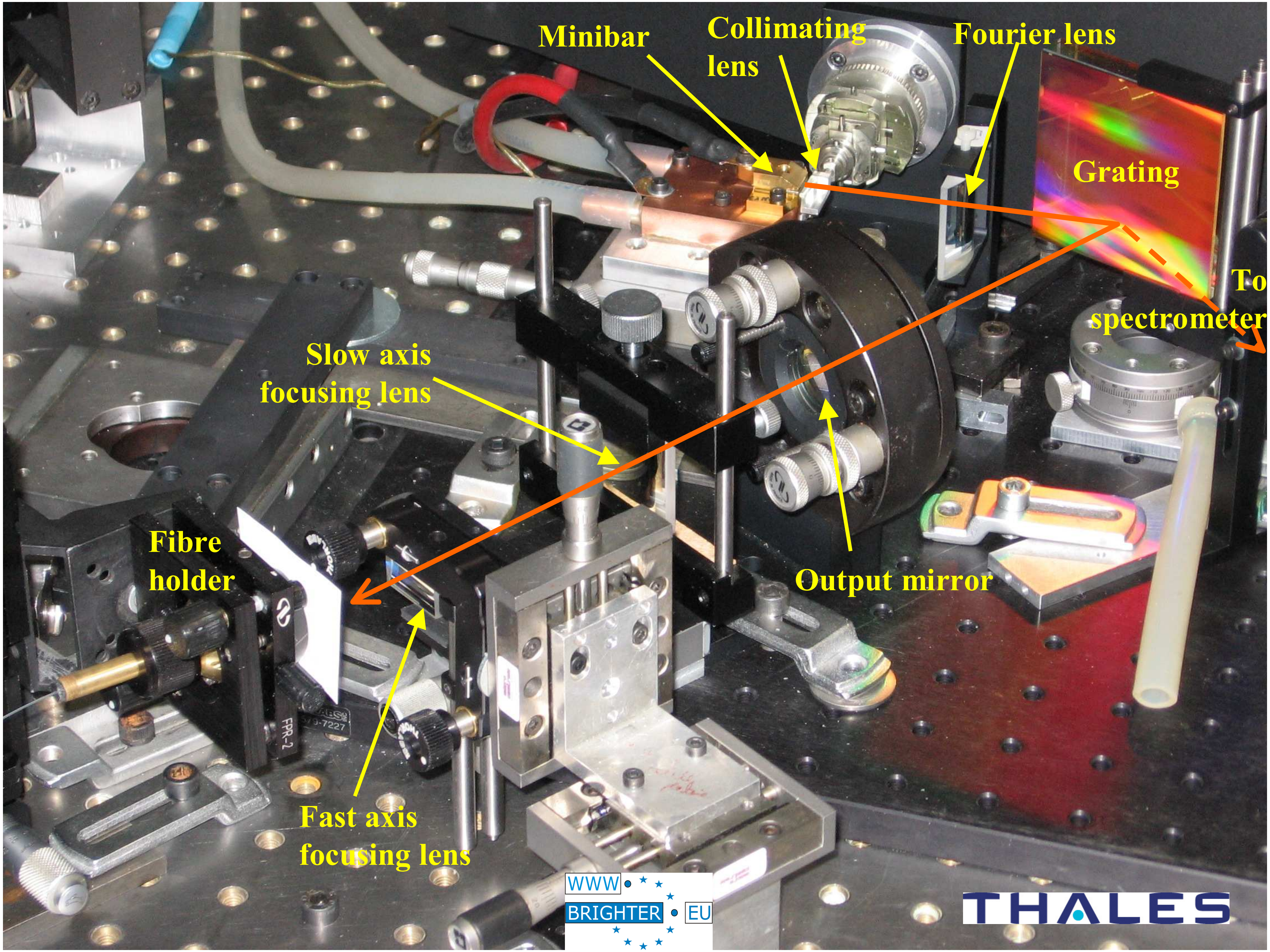
Spectral and spatial analysis of the bar



Next steps:

➔ optical coupling into a small fibre (50µm, NA=0.12) for EDFA pumping

➔ moving from single bar to stack of bars



WWW • BRIGHTER • EU

THALES

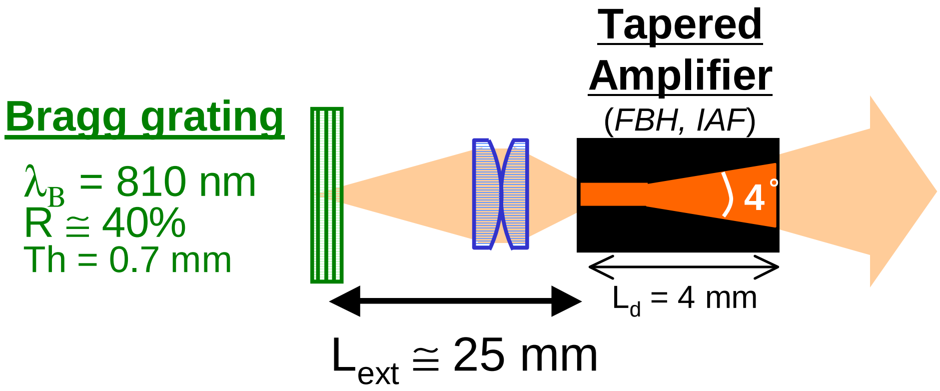
Spectral filtering with a :

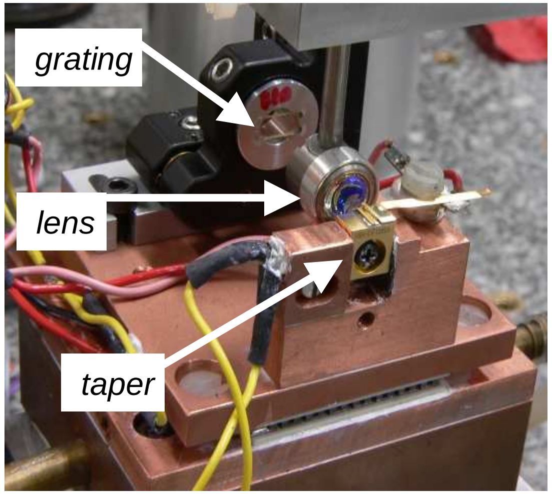
Fixed volume Bragg grating

Dynamic volume Bragg grating

WP3.3 : Extended cavities with fixed gratings

- **Wavelength stabilization of tapered lasers**





Demonstration of a novel compact extended-cavity laser with a Bragg grating

Output power up to 1.8 W @ 810 nm, Slope efficiency = 1.1 W/A, Beam quality $M^2 \leq 1.5$

Linewidth ≤ 0.1 nm, SMSR > 30 dB, Wavelength shift ≤ 0.2 nm

Improved mechanical/thermal stability

Application to

→ extracavity second harmonic generation ***in collaboration with RISØ & RB***

8 mW @ 405 nm, conversion efficiency ≅ 0.85%/W, $M^2 \cong 1$

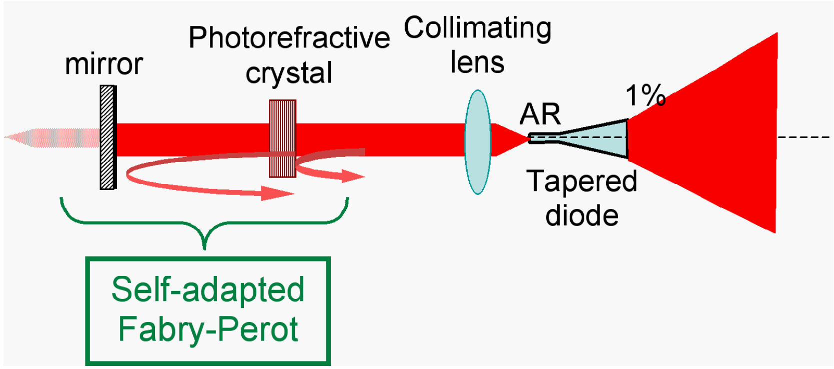
→ **pumping of a new Nd-doped laser crystal at λ = 798 nm**

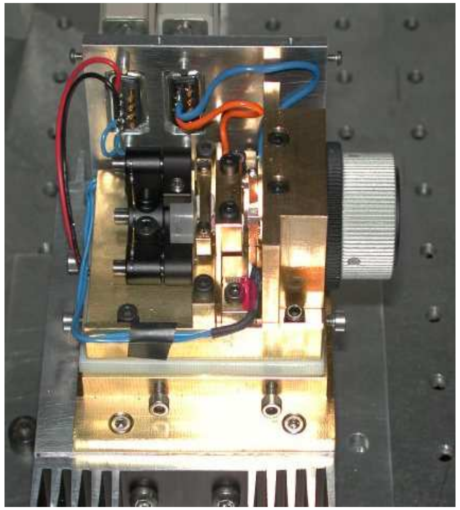
150 mW @ 901 nm

WP3.2 Extended self-organized cavities

With tapered amplifier from FBH and IAF:
Self-organization on the longitudinal structure

Interaction with Unott, FBH and IAF: improvement of beam characteristics





At 960 nm (IAF) or 810 nm (FBH):

- **Single longitudinal mode > 700 mW; SMSR > 30 dB; Coherence > 1 m; $M^2<2$**

Tests outside the lab (ESPCI Paris) on a biomedical experiment

Transfer of this knowledge to a SME (Laserlabs) for commercialisation

Spatial and Spectral mode filtering
NL wave mixing in the SC gain media

General idea :

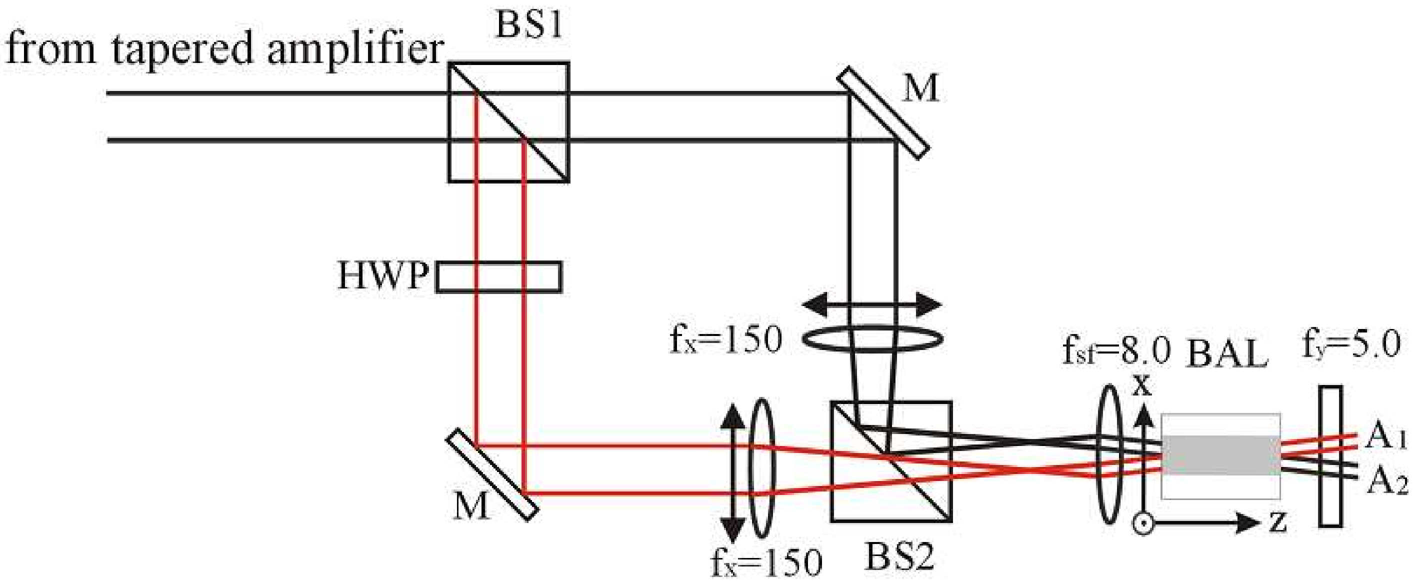
Interference in the SC laser of a pump and probe beam create a gain grating .

Through 2WM / 4WM in we can create a phase conjugate beam

With an external feedback mirror: a phase conjugate oscillator which can provide :

- Spatial / Spectral mode filtering
- Phase distorsion compensation
- Phase locking of lasers of the bar

Experimental setup for TWM



The experimental set-up is arranged like a Mach-Zehnder interferometer. The polarization of the pump beam can be changed by turning the half-wave plate inserted in the pump arm. The angle between the two beams can be adjusted by translating the two cylindrical lenses in the arrow direction. The amplifier is an 810 nm, 2 mm long and 200 μm wide GaAlAs amplifier. Both facets of the amplifier are antireflection coated.

TWM in broad-area amplifier (BAA)

Motivation

- Investigation of the nonlinear process of broad-area diode amplifier.
- To obtain some parameters about the semiconductor material.
- Provide suggestions for fabricating new BALs with better quality.

Origin of the TWM in broad-area amplifier

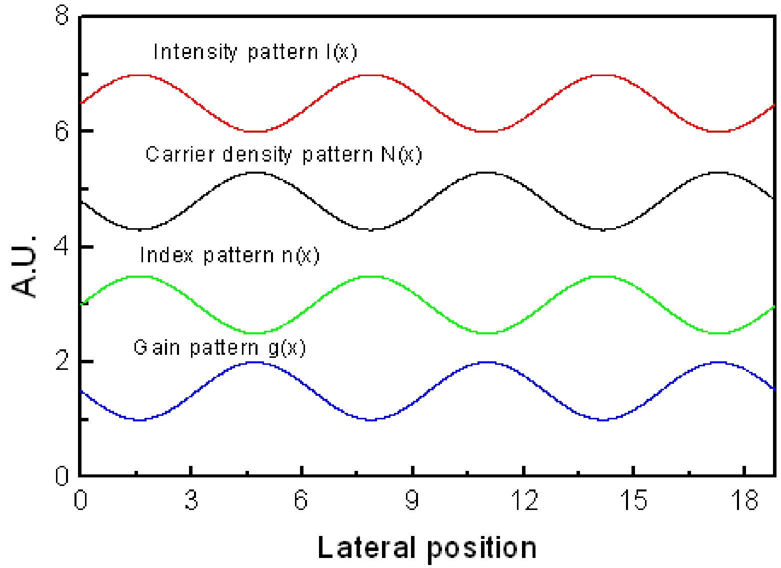


Fig. 1 The relative position of the interference pattern, the carrier density grating, the index and the gain grating formed in the BAA.

Because of the spatial hole-burning effect, a carrier density grating is caused. Thus both a gain and a phase gratings are created. The phase grating has no contribution to the TWM, since it is in phase with the intensity pattern. The gain grating will decrease the optical gain of both beams simultaneously because it is π out of phase with the intensity pattern.

Theory of TWM in broad-area amplifier

Based on the wave equation for the beams, and the rate equation for the carrier density in the amplifer; The coupled-wave equation of TWM is obtianed:

$$\frac{\partial A_1}{\partial z} - i\left[-\frac{\alpha(\beta + i)}{1 + |E|^2/P_s}\right]\left(1 - \frac{|A_2|^2/P_s}{1 + D\tau K^2 + |E|^2/P_s}\right)A_1 = 0 \qquad (1)$$

$$\frac{\partial A_2}{\partial z} - i\left[-\frac{\alpha(\beta + i)}{1 + |E|^2/P_s}\right]\left(1 - \frac{|A_1|^2/P_s}{1 + D\tau K^2 + |E|^2/P_s}\right)A_2 = 0 \qquad (2)$$

In the small signal approximation and the total intensity of the beams is much smaller than the saturation intensity, the analytical solutions are obtained:

$$A_1 = A_{10} \exp[(1 - i\beta)\alpha z] \qquad (3)$$

$$A_2 = A_{20} \exp[(1 - i\beta)(\alpha z - \gamma(e^{2\alpha z} - 1)/2)] \qquad (4)$$

Define the gain of the signal g_{gain} as:

$$g_{gain} = \ln\left(\frac{\left|A_2(z_0)_{coherent\ pump}\right|^2}{\left|A_2(z_0)_{noncoherent\ \ pump}\right|^2}\right) = -\frac{\left(|A_1(z_0)|^2 - |A_{10}|^2\right)/P_s}{1 + D\tau K^2} \qquad (5)$$

Experimental results

The dependence of the gain on the output power of the pump is measured. The experimental results are shown is Fig. 2. It is clearly seen that the gain decreases linearly with the output bump power. The dependence of the gain on the angle between the two beams is also measured. The experimental results are shown in Fig. 3. By fitting the data with Eq. (5) Assuming that τ is 5 ns, the diffusion coefficient D is calculated to be 8.2 cm^2s^{-1}.

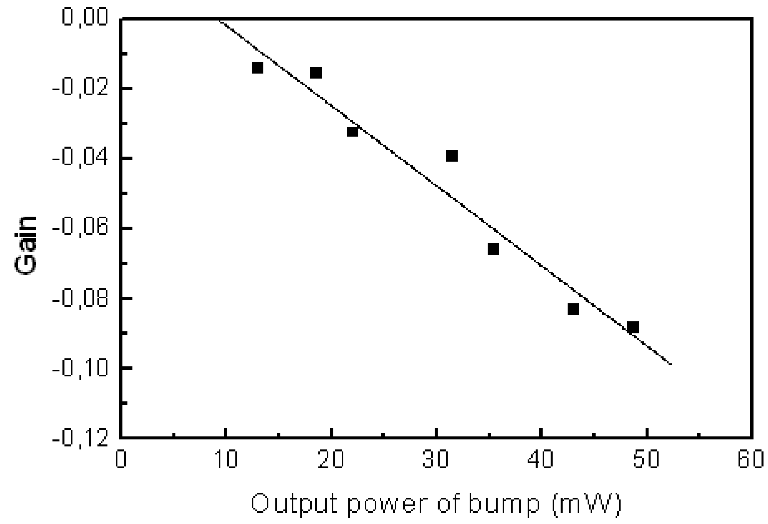


Fig. 2 The gain versus the output power of pump in the semiconductor amplifier.

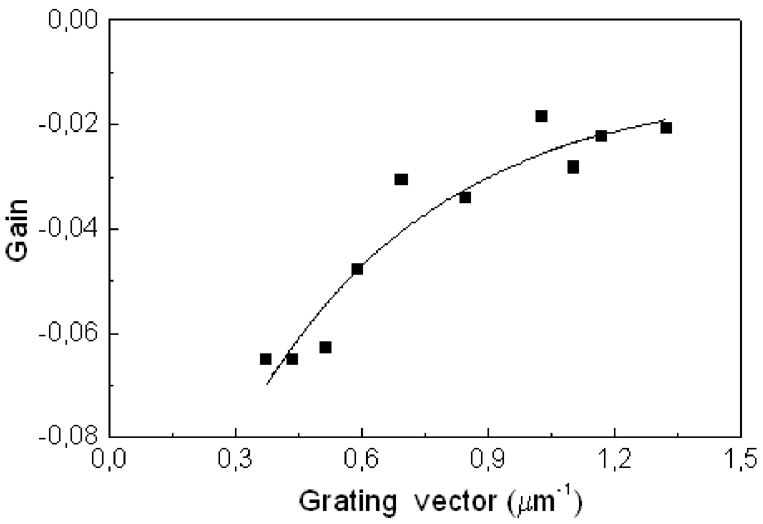


Fig. 3 The gain versus the grating vector in the semiconductor amplifier.

Detail about the theory and experiment refer to the published paper in Opt. Express Vol. 14, 12375 (2006).

Pressure and temperature tuning

UNIPRESS in WP3: temperature and pressure tuning

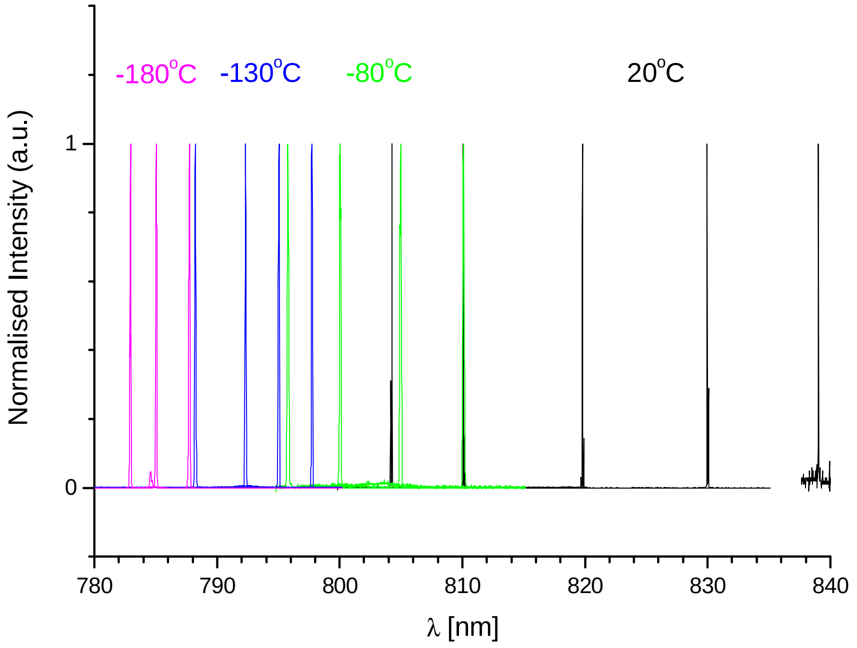
- High pressure and low temperature increase the bandgap in laser-diode active layer, shifting the gain and emission to shorter wavelengths

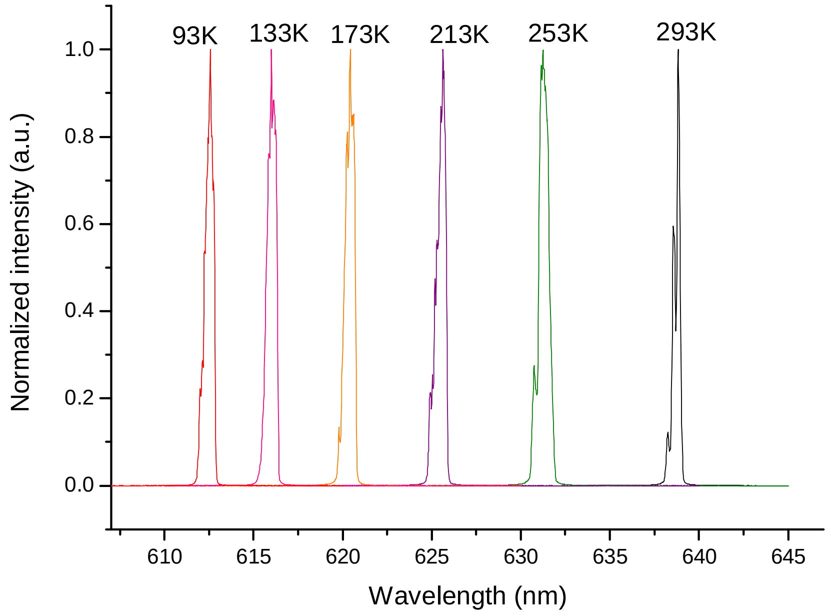
- In BRIGHTER we perform pressure/temperature tuning in external cavity, using gratings or photorefractive crystals for creating external cavity

- **Combining wide-range tuning with external resonator methods allows to combine the merits of both methods**

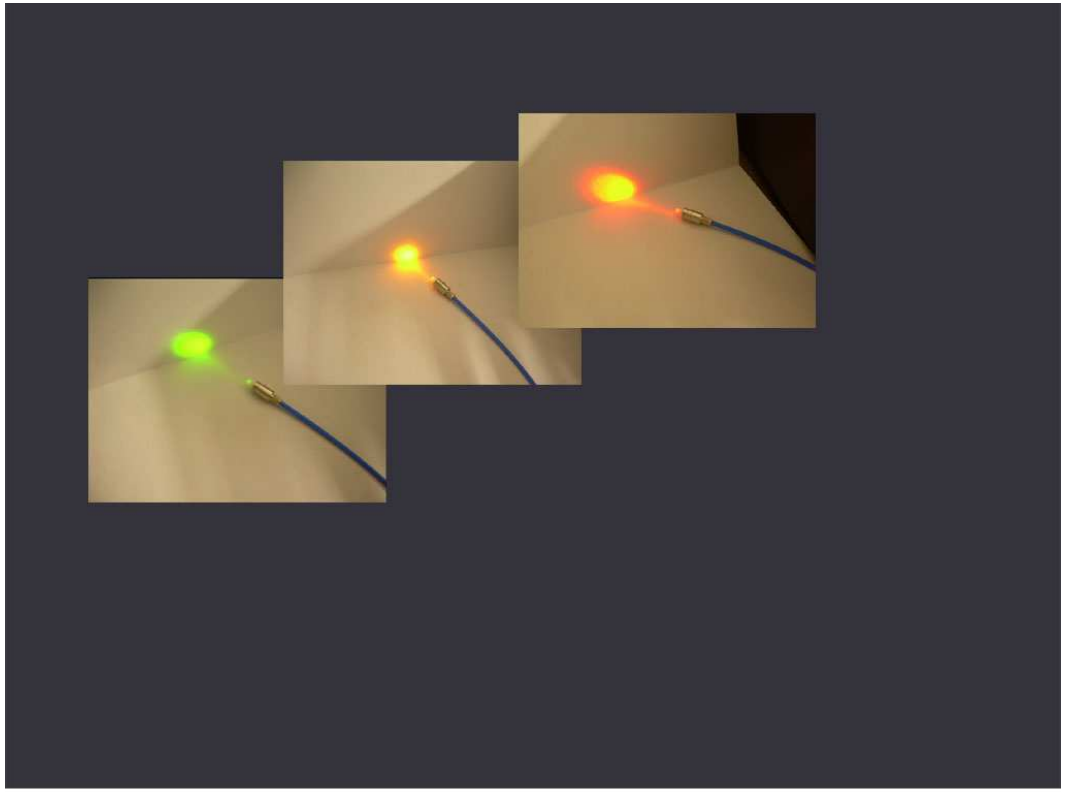
Temperature tuning of red high power Osram lasers to orange

Temperature and external cavity tuning of 830 nm FBH LD with AR coatings





Pressure/temperature tuning of red lasers to yellow- green



Emission from the fiber coupled to red Osram laser (640 nm) tuned to orange (610 nm at 1 kbar) yellow (590 nm at 10 kbar) and greenish (575 nm at 17 kbar). The laser temperature was –150C, emission power 50 mW

UNIPRESS in WP5: degradation rates for temperature cycles

Red lasers from Osram were mounted on Cu, Ag, AlN, and Si and cooled down to 80K over 20 times.

No degradation for AlN and Si submounts (Au/Sn solder), high degradation rate for Cu and Ag but, in most cases, the In solder degraded, not the laser chip!

Bright Er - Conclusions

Very effective methods for mode filtering and increase of the SC Laser brightness : wavelength multiplexing, Bragg gratings

Very significant progress on the NL approaches allowing dynamic mode control with 2WM : large potential to achieve both mode control and phase locking of the individual lasers of a bar