Fonctions Optiques pour les Technologies de l'informatiON

Spectral narrowing of coherent light sources based on gallium nitride laser diodes emitting in the blue range

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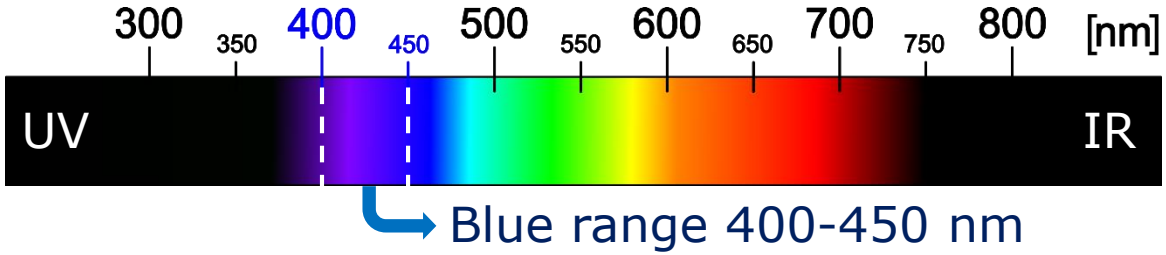
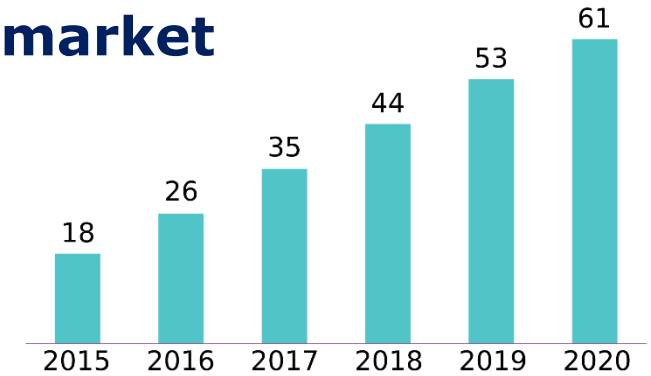
Introduction



Lightning market



Estimated LED penetration of lightning market (%): Global, 2015-2020 [1]

high optical power
low cost
low electrical consumption

[1] Source: Goldman Sachs

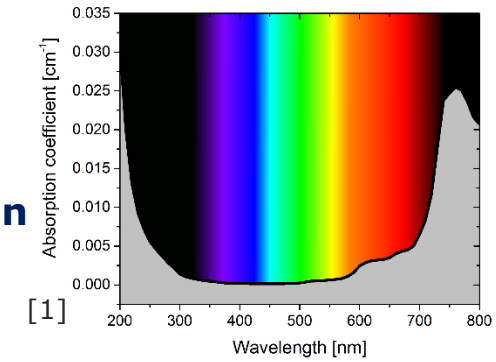
Data storage

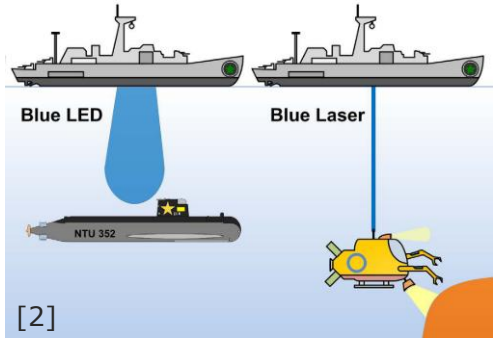
Low noise
compact

780 nm 650 nm 405 nm

Introduction

underwater free space Visible Light Communication (VLC)





[1] *Smith, R. C., & Baker, K. S. (1981). Optical properties of the clearest natural waters (200-800 nm). Applied Optics, 20(2), 177–184.*

[2] *Wu, T. C., Chi, Y. C., Wang, H. Y., Tsai, C. T., & Lin, G. R. (2017). Blue laser diode enables underwater communication at 12.4 gbps. Scientific Reports, 7(January), 1–10.*

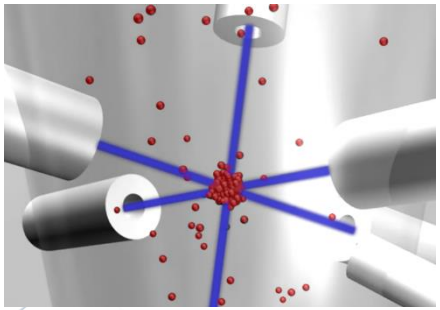
[3] *Paradis, E., Barrett, B., Kumarakrishnan, A., Zhang, R., & Raithel, G. (2008). Observation of superfluorescent emissions from laser-cooled atoms. Physical Review A - Atomic, Molecular, and Optical Physics, 77(4).*

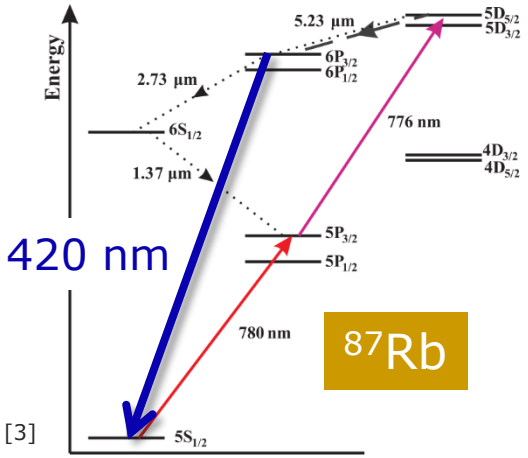
Microplastics detection by Raman spectroscopy

resolution $\propto \lambda$
efficiency $\propto 1/\lambda^4$
Low pigment fluorescence

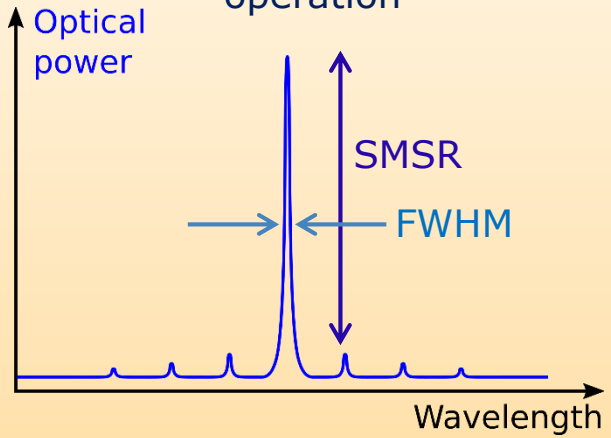
Deep Blue project

Optical clocks (atom cooling) and atom interferometry





Single-Longitudinal-Mode (SLM) operation

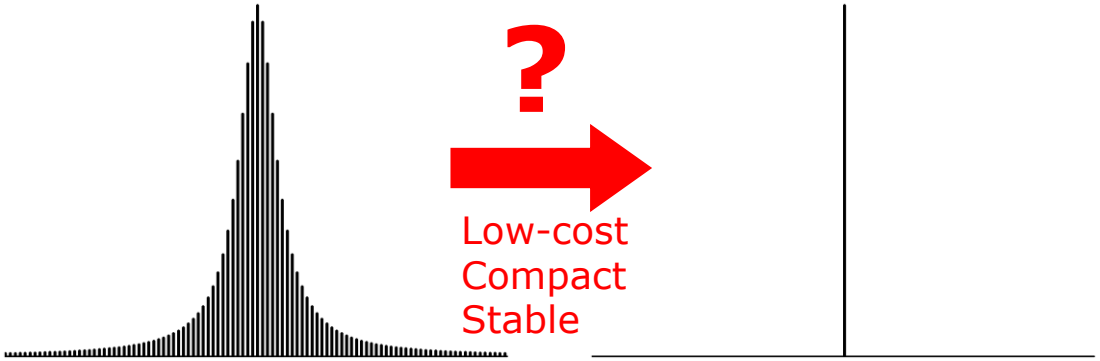


Side Mode Suppression Ratio
>30 dB
Full Width at Half Maximum
< few MHz

Introduction

How to produce stable single mode emission from a commercial GaN laser diode ?

Diode laser

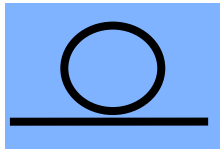


Outline

Fiber Bragg grating blue laser diode

Spectral filtering and narrowing

DeepBlue Project

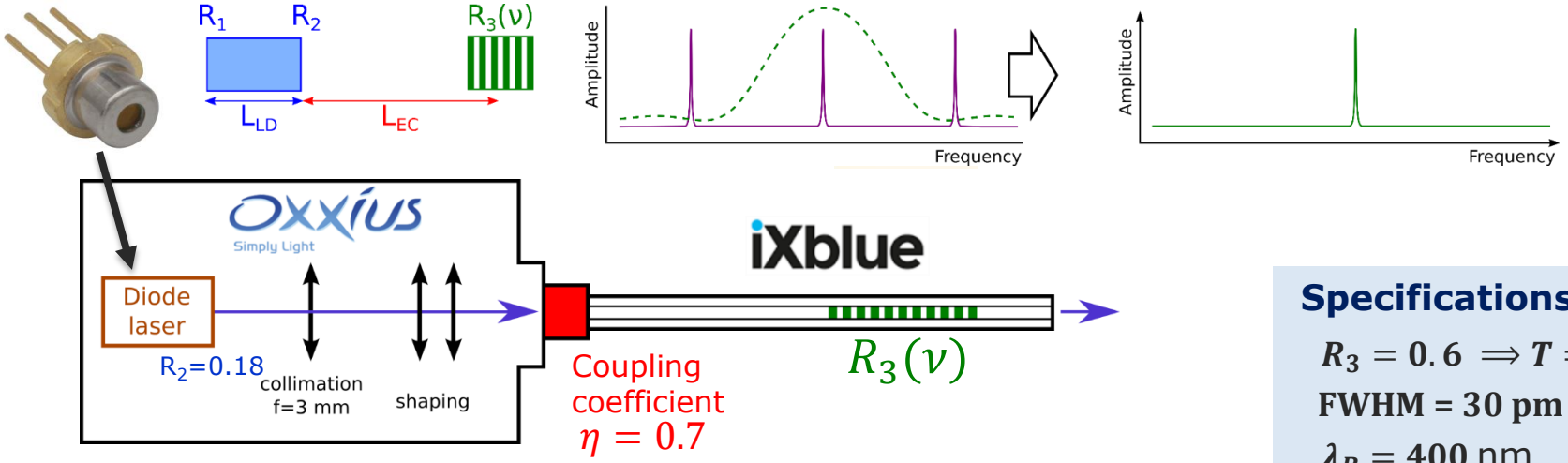


Fiber ring cavity for frequency stabilisation

SingleBlue First-TF Project

Fiber Bragg grating blue laser diode

Get DL spectrum filtering from **high finesse external cavity**?



Laser Diode

No anti-reflection (AR) coating $R_2 \simeq 0.18$

FSR: 35 pm

Emission wavelength: $\lambda \simeq 400$ nm

Specifications

$R_3 = 0.6 \Rightarrow T = -4$ dB

FWHM = 30 pm

$\lambda_B = 400$ nm

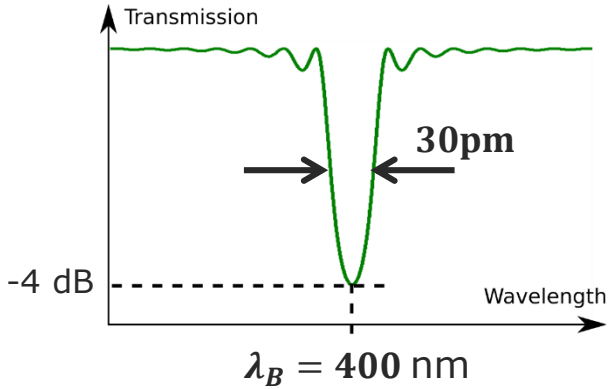
Fiber Bragg Grating (FBG)

No AR coating ⇒ Strong feedback [1] $\eta^2 R_3(\nu) > R_2$

$\Rightarrow R_3 > 0.4$

FWHM < 35 pm

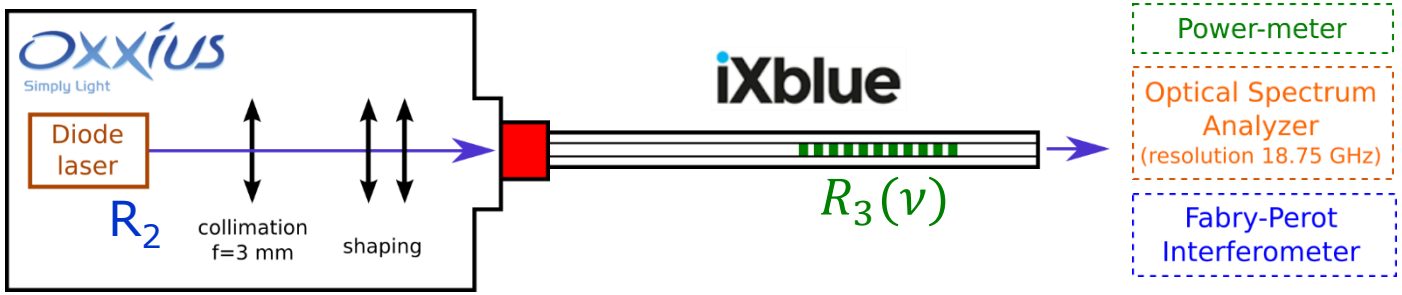
[1] *Park, C. A., Rowe, C. J., Buus, J., Reid, D. C. J., Carter, A., & Bennion, I. (1986). Single-mode behaviour of a multimode 1.55 μm laser with a fibre grating external cavity. Electronic Letters, 22(21), 1132–1133.*



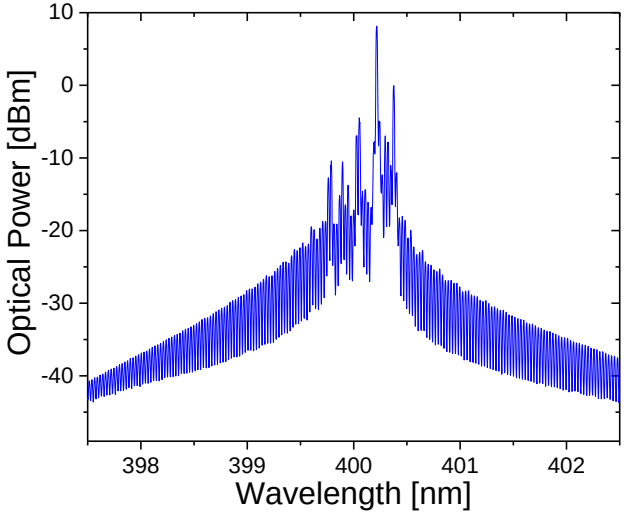
Transposition of FBG **technique** in the **blue range, using standard LD** (no anti-reflection coating)

Fiber Bragg grating blue laser diode

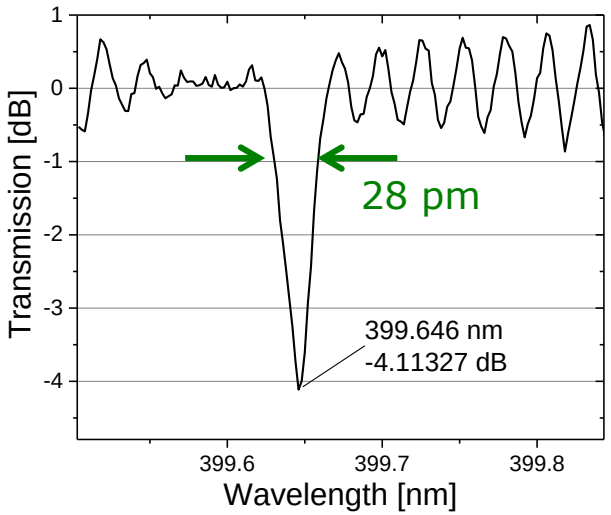
Experimental results



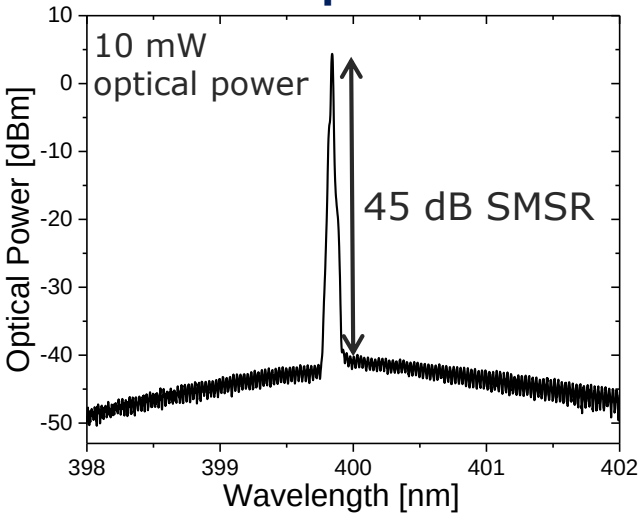
Multimode LD spectrum



FBG transmission



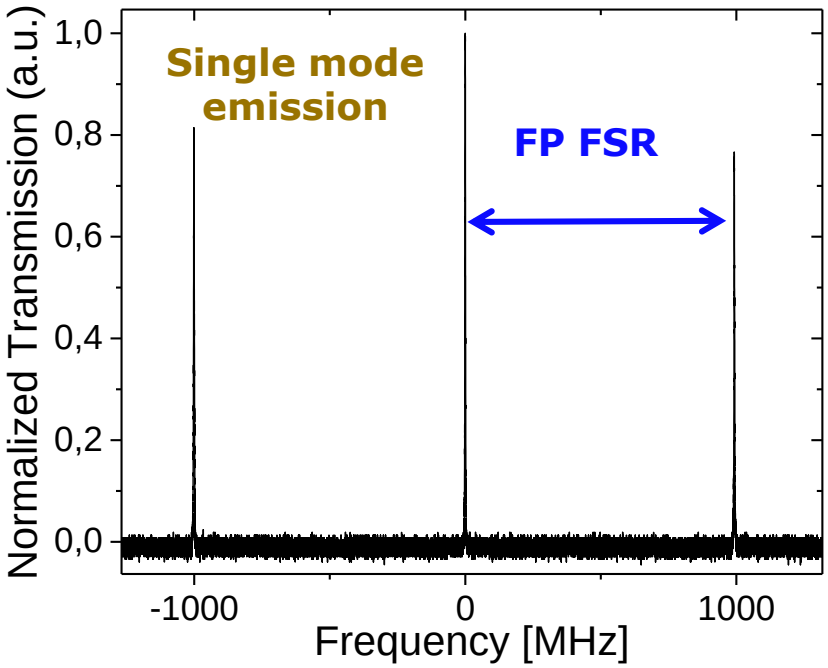
Fiber-Bragg-grating laser SLM operation

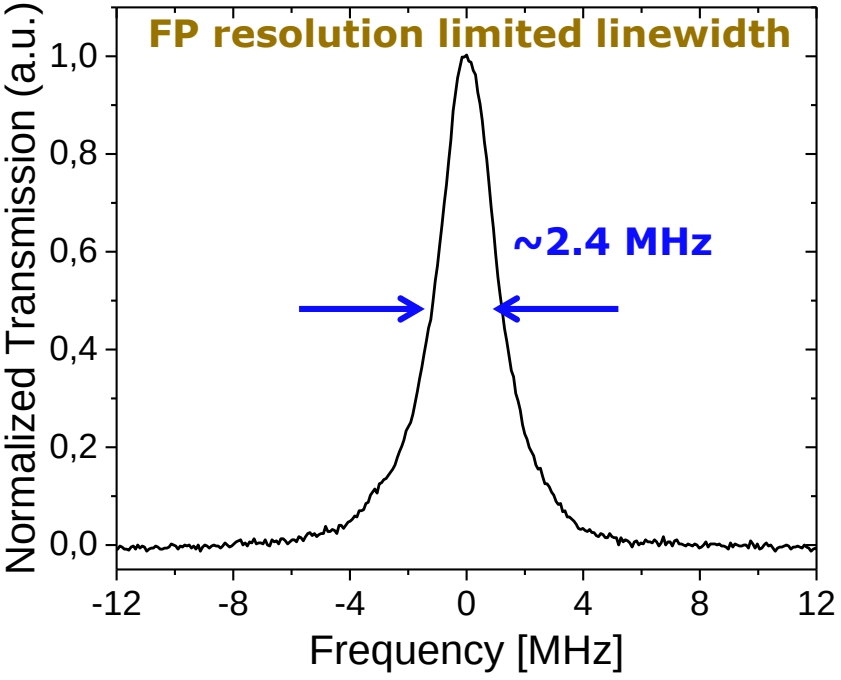


Selection of a distinct longitudinal mode **of the laser diode**

Single frequency operation

- **FP analysis**





Spectral filtering and narrowing

Single frequency operation: FWHM $\leq$ 2.4 MHz

SingleBlue project (Oct.2018 – juin 2019)

Metrological knowhow | **Blue/UV diode laser** | **Industrial transfer**

Short term (>10 ms) stabilisation of ECDL single mode laser emission

Example of fiber-based optical reference at 1.55 µm :

Kefelian et al., «Ultralow-frequency-noise stabilization of a laser by locking to an optical fiber-delay line», Optics letters (2009)
Grüning et al., « All-fiber ring-cavity for frequency stability transfer at 1.55 µm », Applied Optics (2019)
Phung et al., « Temperature control of a PM ring fiber cavity for long-term laser frequency stabilization », ICSO 2018

Possibility to applied those techniques to blue/UV range ?

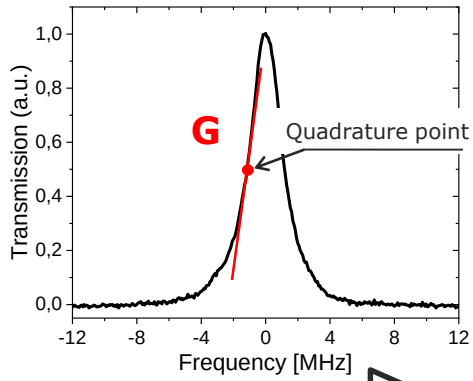
NO → only a very few optical devices available in blue/UV

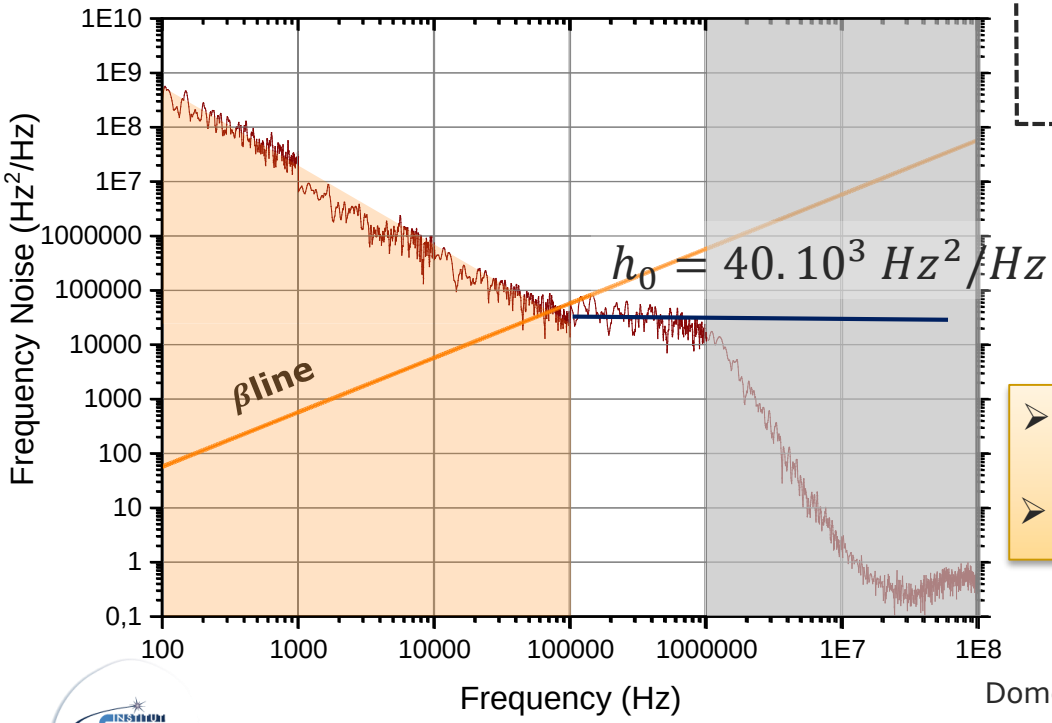
Implies the use of simple stabilisation setups

Free running ECDL laser

Toptica DL pro

Emission wavelength : 420-423 nm
Linewidth : 150 kHz (5µs int. time)





- Intrinsic linewidth : $\pi\, h_0$ = 125 kHz
- Integrated linewidth (@10 ms) : **830 kHz**

Domenico *et al.*, *Appl. Opt.*, 49 (25), pp. 4801-4807, 2010

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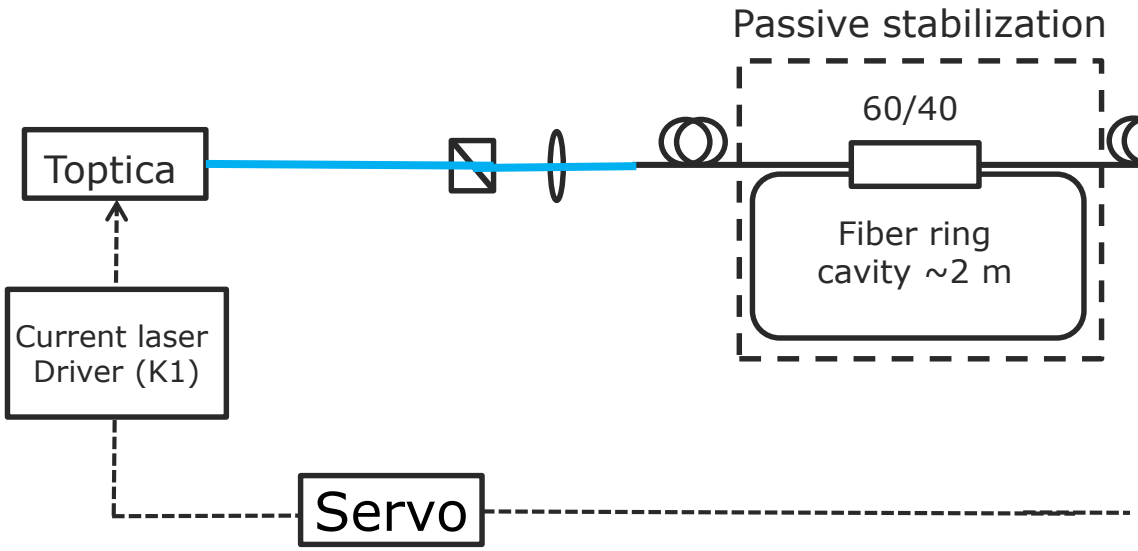
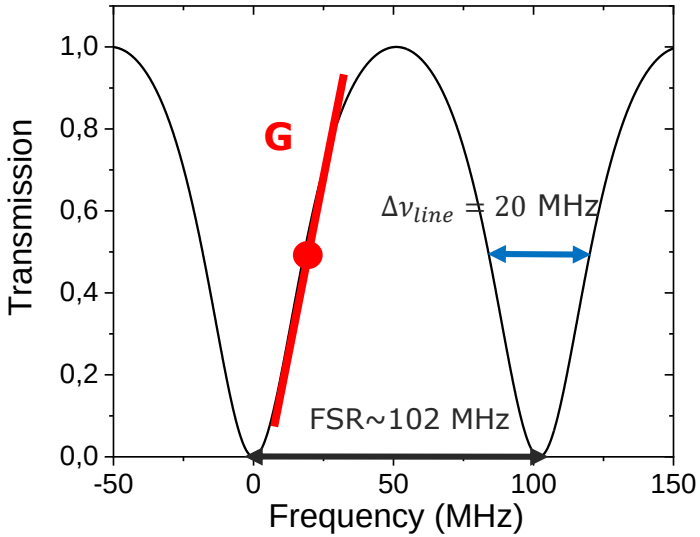
Side-of-fringe configuration

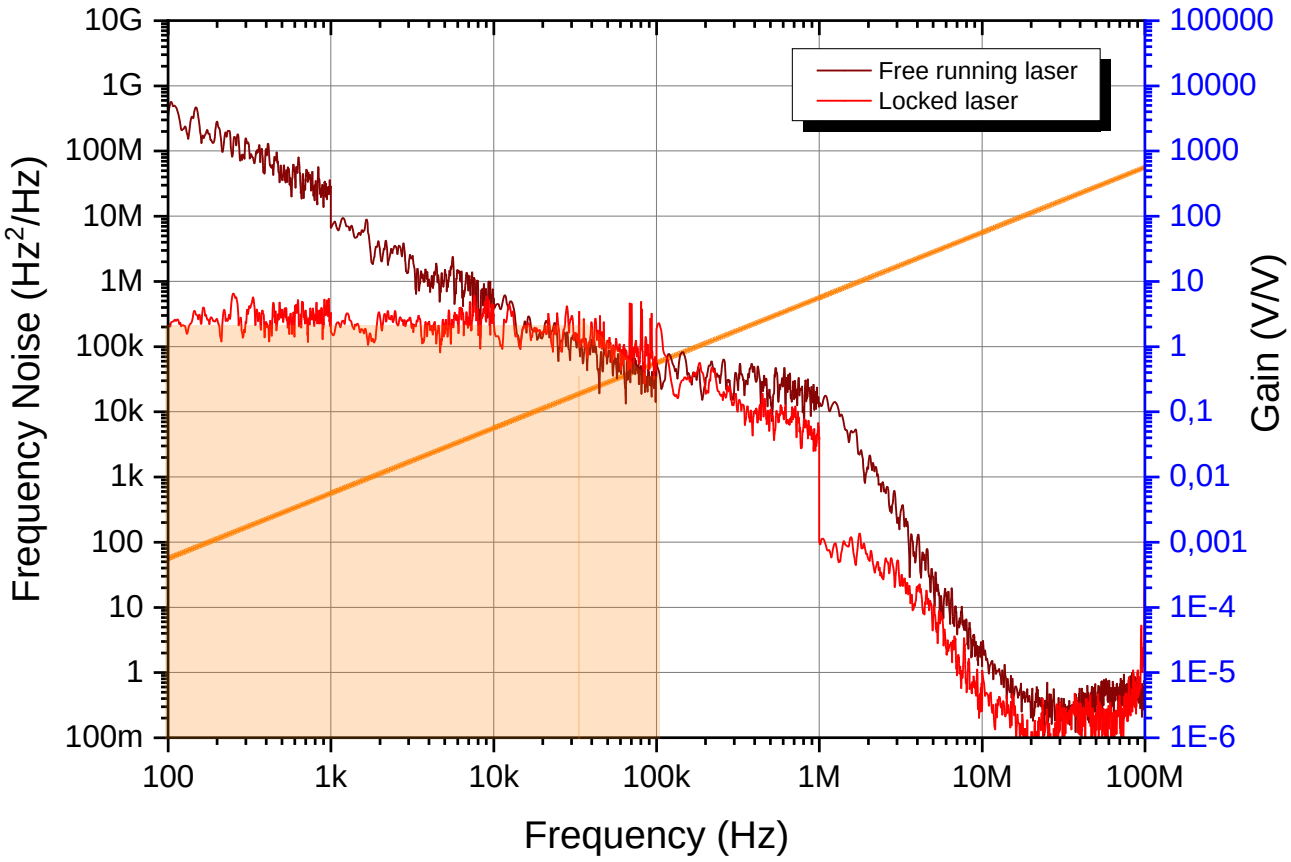
Stability transfer from a fiber ring cavity towards an ECDL Laser





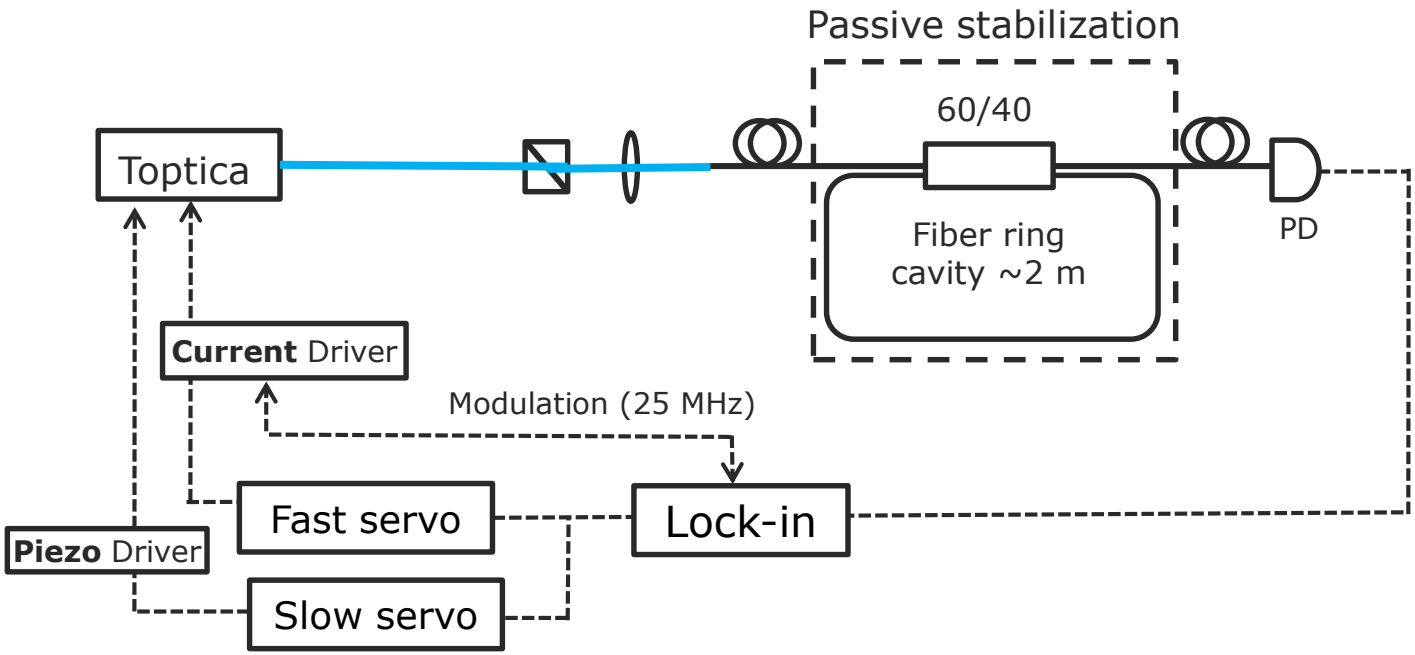
- Fiber ring cavity in critical coupling regime
- Servo: P-I amplifier
- Correction signal applied on the laser current

Side-of-fringe configuration



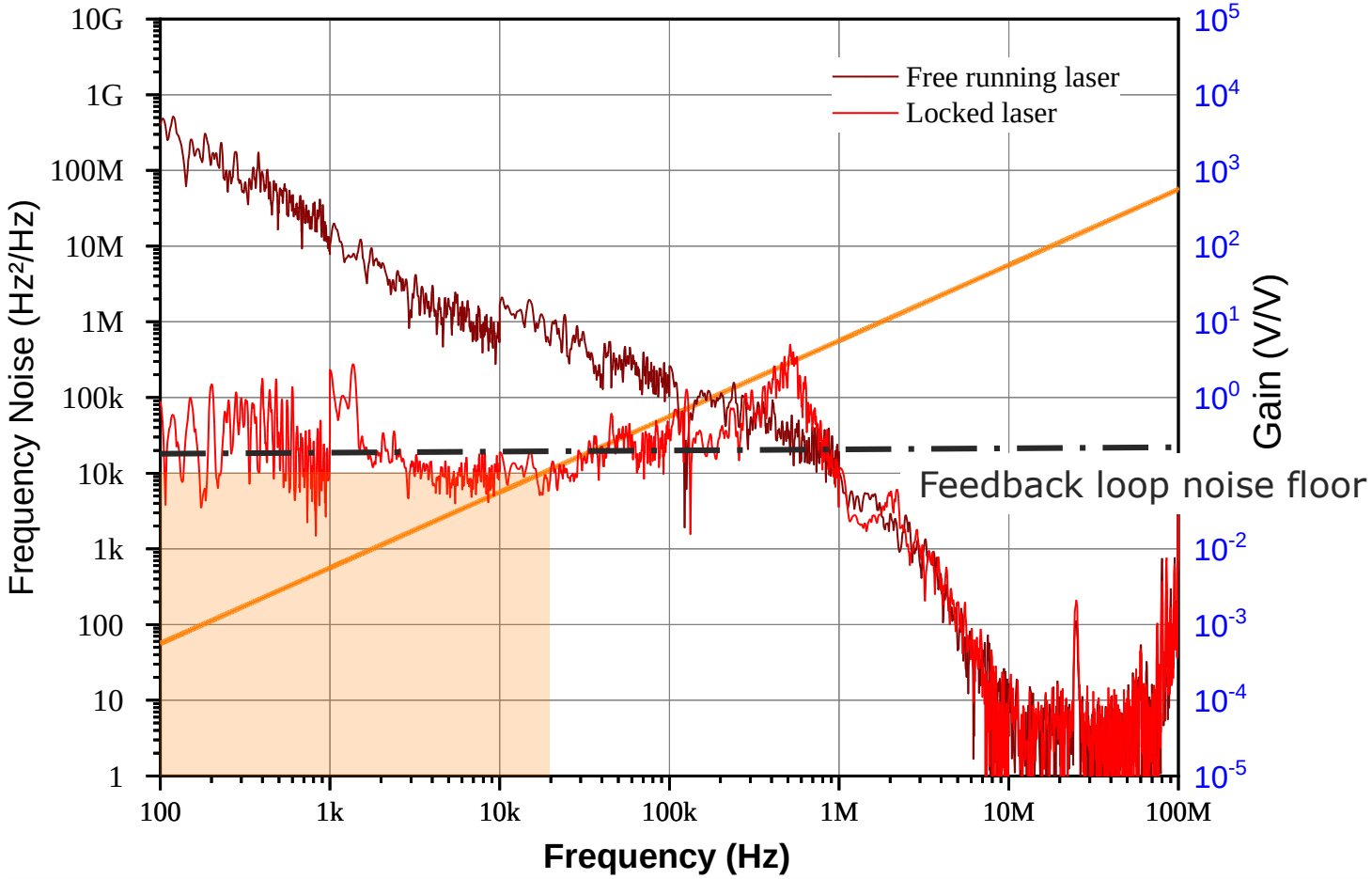
- ~30 dB noise reduction @ 100 Hz
- Integrated linewidth (@10 ms) : 160 kHz (reduction factor 5.1)

Top-of-fringe configuration



- Top of fringe with modulation frequency $f_m \approx \Delta\nu_{line}$
- Correction signal applied on :
  - the laser current for f <500 kHz
  - the laser piezo for f<1 kHz

Top-of-fringe configuration



- ~40 dB noise reduction @ 100 Hz
- Resonance peak at $f_c = 500\,kHz$
- Integrated linewidth (@10 ms) : 39 kHz (reduction factor 21)

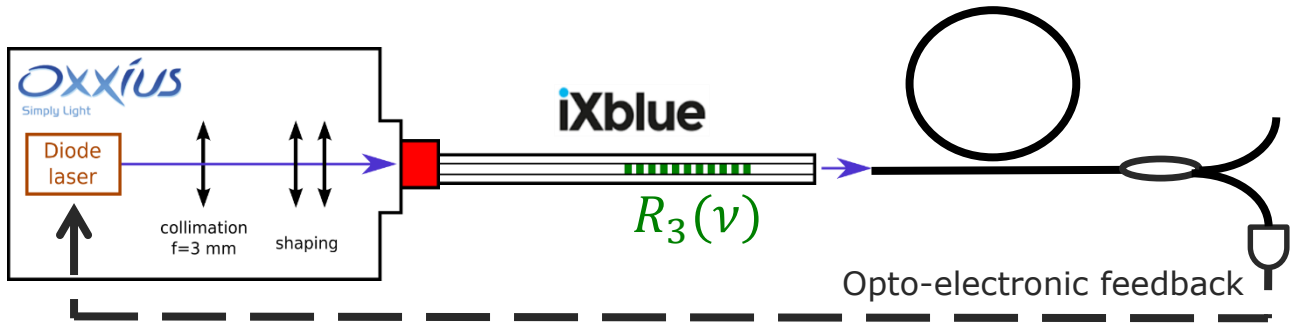
Conclusion

- **Single mode operation of FGL based on InGaN laser diode**

Performances :

Output power $10\ mW$	Emission wavelength 399.6 nm
SMSR 45 dB	Linewidth<2.4 MHz
Fiber output	Gaussian optical beam

- **Stability transfer from a fiber-based optical reference to an ECDL blue laser**
  - Simple stabilisation schemes based on a fiber ring cavity
  - Integrated linewidth (@10 ms) downsizes from 830 kHz to:
    - 160 kHz in side-of-fringe scheme
    - 39 kHz in top-of-fringe scheme



Perspectives

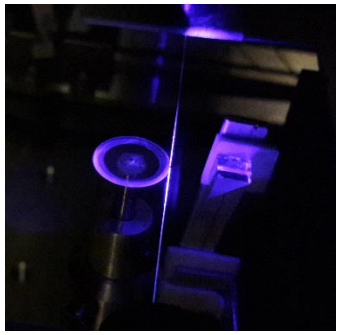
➢ Coherent blue/UV laser sources

- Downsizing the wavelength of FBG laser

UV4Life project
(2019-2022)

- Use of higher finesse cavities to increase laser coherence

ANR Combo (2019-2022)
combo.foton.cnrs.fr



➢ Frequency noise reduction of blue/UV laser sources

- Reducing the noise floor of the feedback loop
- Better acoustic, thermal and mechanical stabilisations of the fiber ring
- Coupling a long term stabilisation on a molecular transition

➢ Institut Foton, Univ. Rennes, Lannion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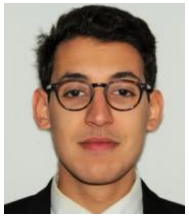
Georges Perin


Dominique Mammez


Pascal Besnard

➢ LPL, Univ. Paris 13, Villetaneuse


Karim Manamanni


Vincent Roncin


Frédéric Du Burck

➢ Partners

OXXIUS Simply Light

iXblue

➢ SingleBlue project funding

FIRST TF

➢ DeepBlue project funding

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