Introduction to lasers

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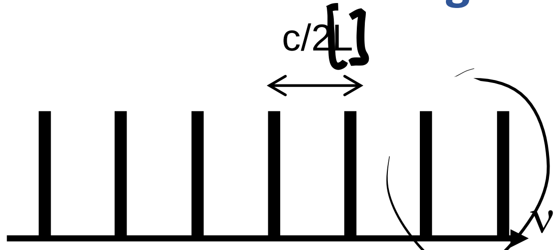
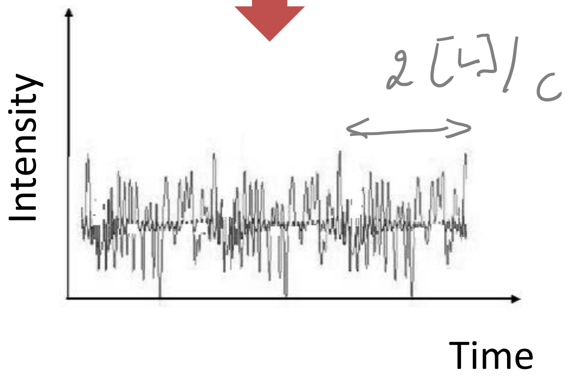
Chapter 5: Laser operating regimes

I. Continuous-wave regime



Longitudinal modes / φ_j are random

F. T. Fourier Transform



http://optique-ingenieur.org

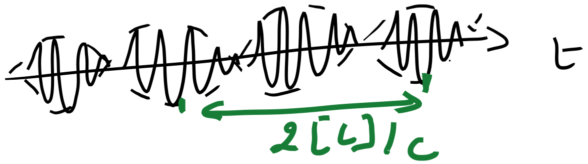
- Periodic temporal noise
- « Temporal speckle » →Duration of grains~1/B

B = spectral bandwidth of emission

To complete

Beating between 2 frequencies ν_1 ν_2

$\nu_2 - \nu_1 = \frac{c}{2[L]}$



→ Temporal signal : beating between longitudinal modes
→ Complex beating with a periodic structure ($\frac{2[L]}{c}$)
because modes are distributed periodically ($\frac{c}{2[L]}$)

This temporal beating depends on the phase φ_j
≠ between the longitudinal modes.

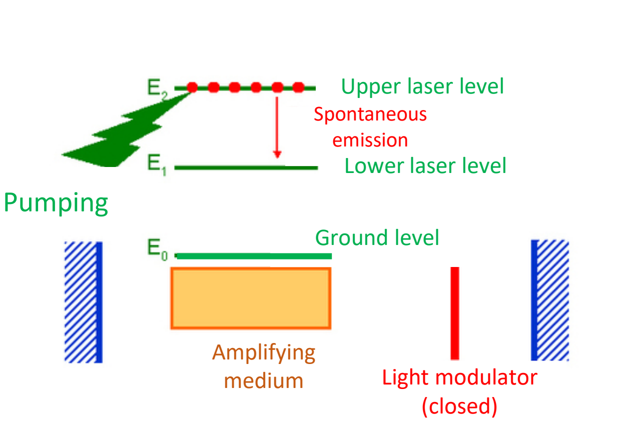
CW regime → φ_j are random ⇒ Intensity = kind
of periodic noise

$$E(M,t) = \sum_{0}^{N} E_{0j} \cos(\omega_j t - k_j z + \varphi_j)$$

↳ plane wave assumption

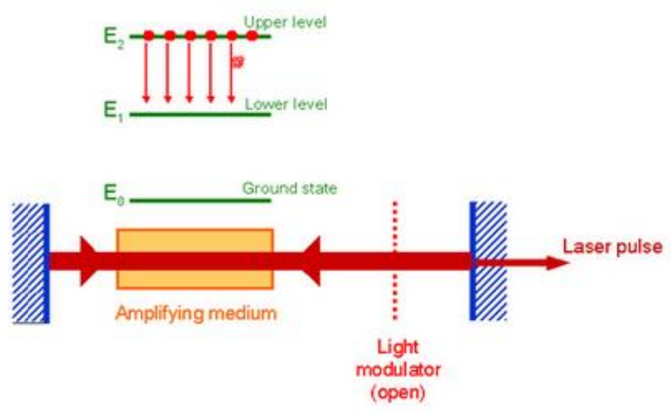
II. Q-switch regime

high ⇓ energy pulses

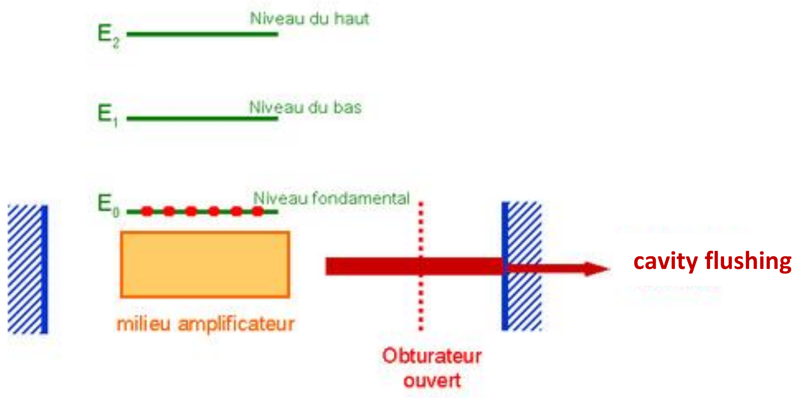


1) Energy storage

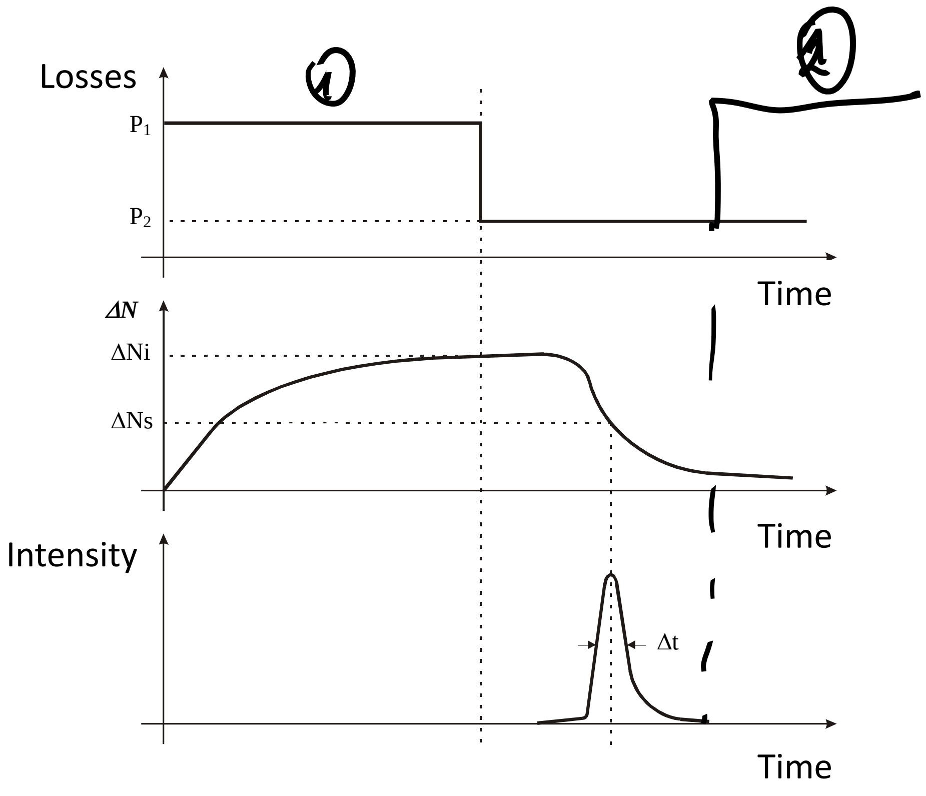
http://optique-ingenieur.org



2) Beginning of the pulse



3) End of the pulse



Typical pulse duration: ns – 100 ns
Typical repetition rate: Hz – 50 kHz

To complete

laser oscillations are periodically stopped because of loss modulation inside the cavity

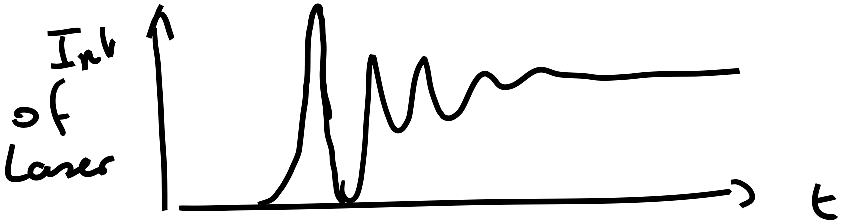
(1) : $\alpha_t > \gamma_0$ → No laser oscillation but energy storage

(2) : when $\Delta N \simeq$ cst (population inversion saturation) commutation of losses ("closed" modulator → "open" modulator) $\gamma_0 >> \alpha_t$ ⇒ beginning of the pulse

(3) gain saturation decreases the pulse energy ⇒ end of the pulse : new commutation of the losses to the "closed" state.

↳ Active Q-switch regime

Comment :



Relaxation oscillations when only 1 commutation ($P_2 \to P_1$)

Example of light modulator

Accousto-optic moulator

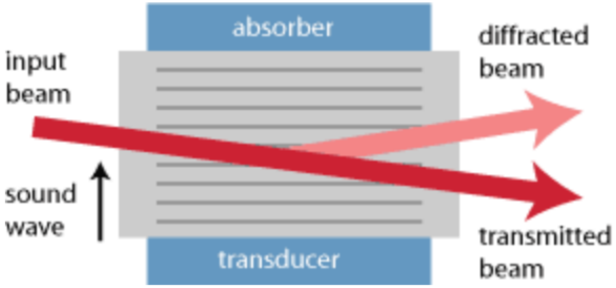
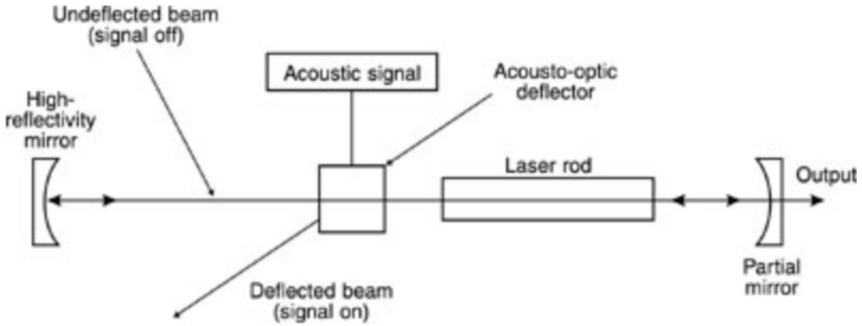


Figure 1: Schematic setup of a non-resonant acousto-optic modulator. A transducer generates a sound wave, at which a light beam is partially diffracted. The diffraction angle is exaggerated; it is normally only of the order of 1°.

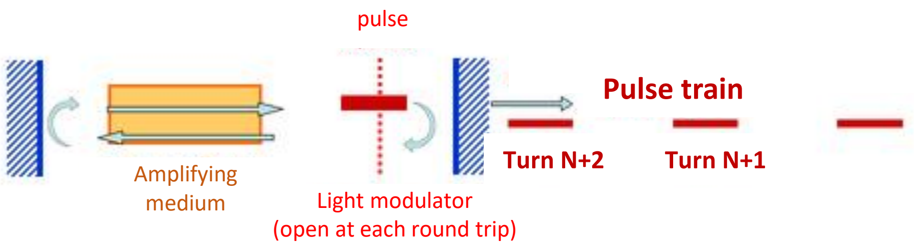
https://www.rp-photonics.com/acousto_optic_modulators.html

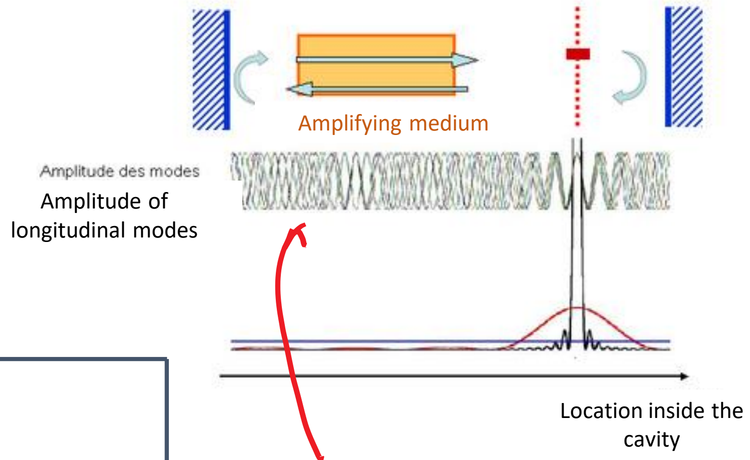


Application of an acousto-optic Q-switch in a solid-state laser

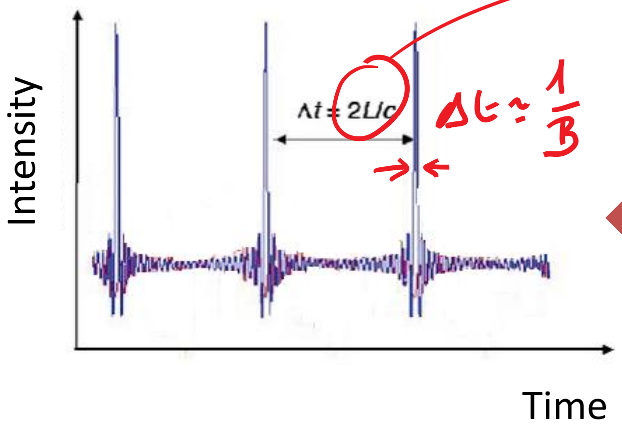
https://pe2bz.philpem.me.uk

III. Mode lock regime = SYNCHRONISATION OF THE LONGITUDINAL MODES.

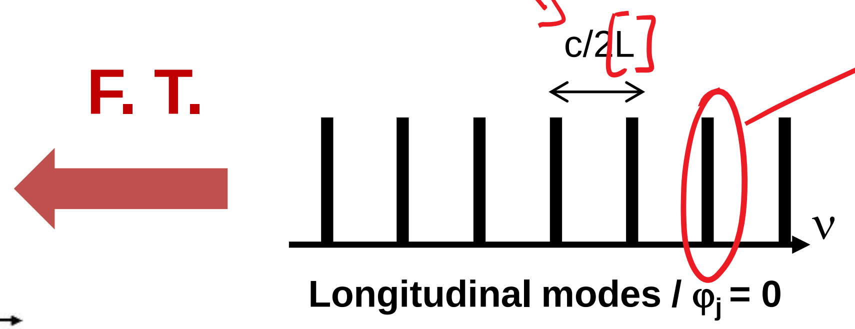




sinus fuct



$\Delta t = \frac{1}{B}$



B

Typical pulse duration: 10fs – 1 ps
Typical repetition rate: MHz – GHz

$$Rep = \frac{c}{2[L]} = \frac{1}{t_{RT}}$$

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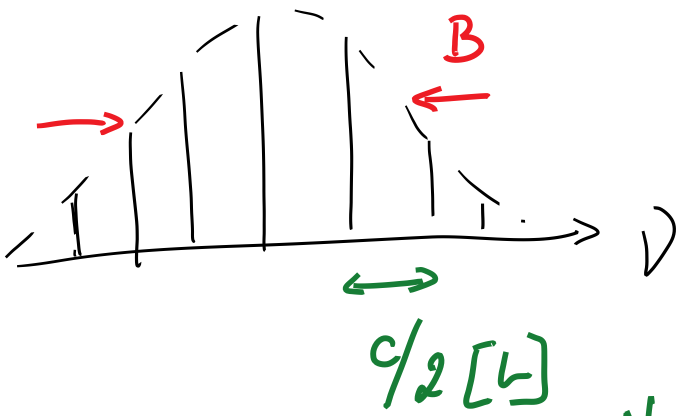
To complete

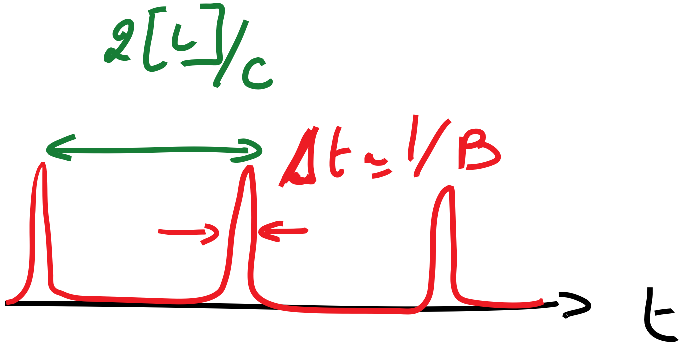
For mode lock regime $\Rightarrow$ synchronization of longitudinal modes $(\nu_j) \Rightarrow \varphi_j = 0$

$$\boxed{E(M,t) = \sum_N E_0 \cos\left(2\pi\nu_j t - k_j z\right)} \quad \text{with} \quad k_j = \frac{2\pi}{\lambda_j} = \frac{2\pi\nu_j}{c}$$

When the longitudinal modes are in phase, it exists a place inside the cavity where all the fields are in phase $\Rightarrow$ pulse



F.T $\Rightarrow$



Pulse train

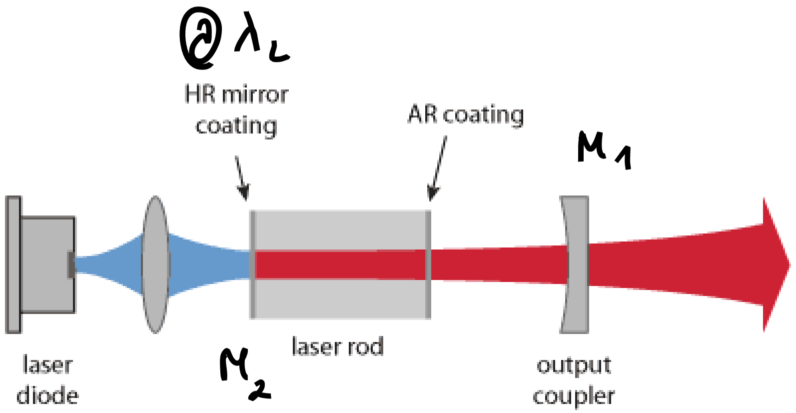
the larger is B the shorter are the pulses!

i.e. many longitudinal modes

Note: Modulation of the losses ≡ Free spectral range of the cavity

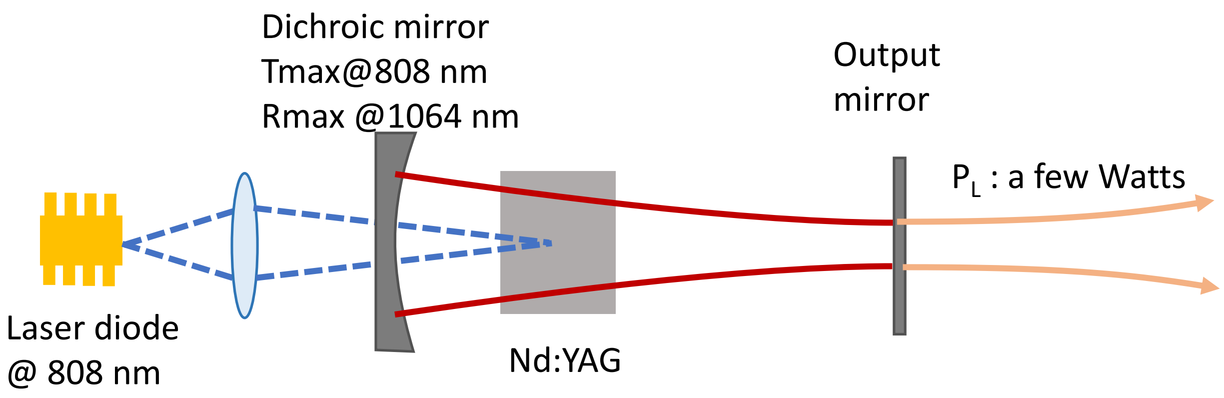
Chapter 6: Some solid-state lasers

❑Typical set up of a end-pumped solid-state laser



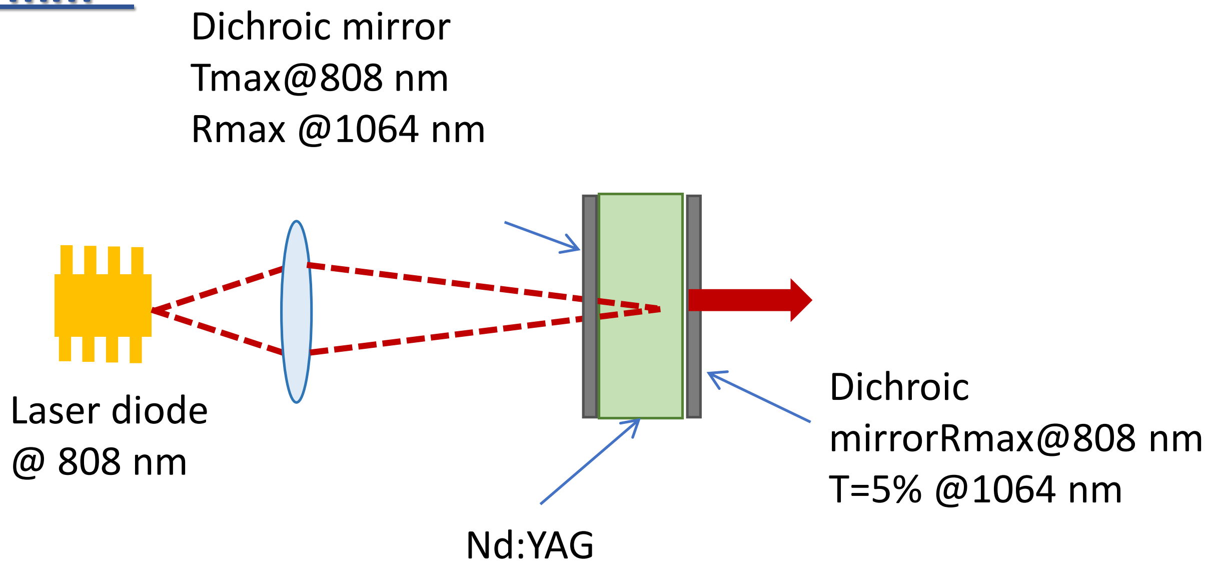
https://www.rp-photonics.com/end_pumping.html

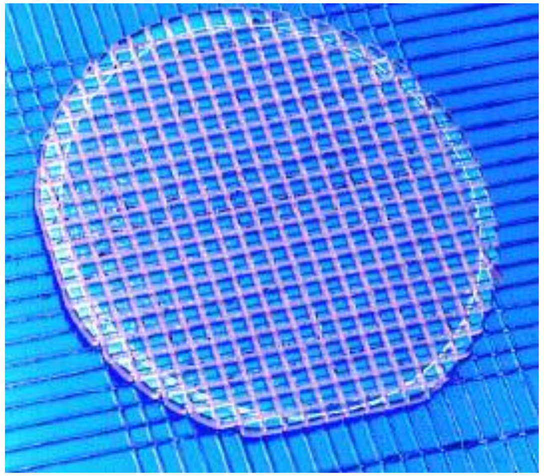
Suitable for Gaussian single-mode operation : higher-order modes then have too low gain to reach the laser threshold.



- Free space cavity, ~1m long
- Other end-pumping scheme

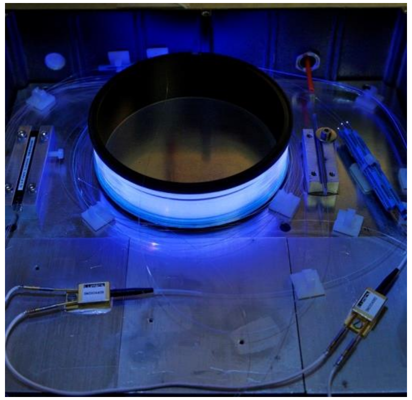
❑ Laser chip (~1 mm 3)



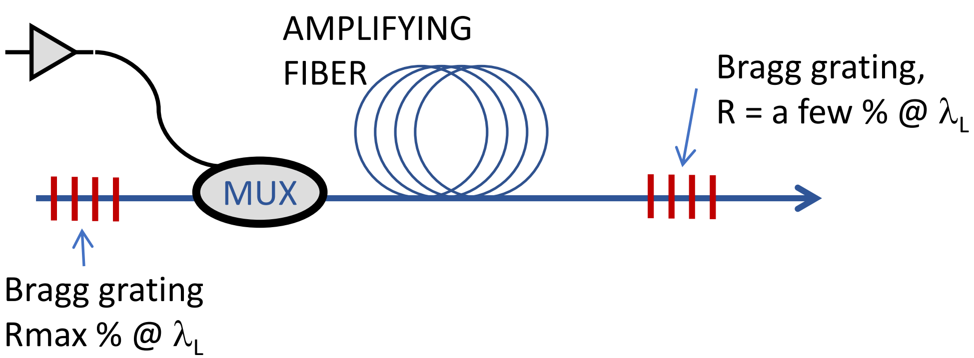


High reflectivity coatings deposited on the crystal
→ monolithic system
→ no adjustment required
Mass production on a one-inch wafer

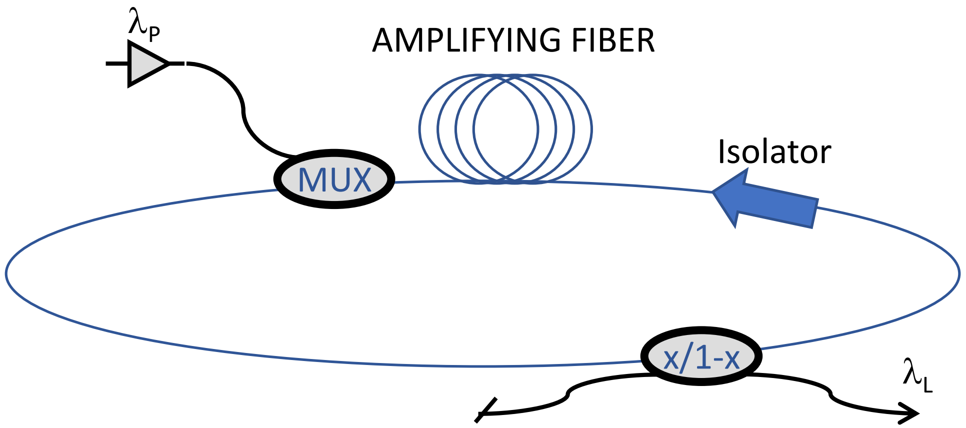
❑Fiber lasers



- Amplifying fiber
- Modal selection by the optical guide
- High ratio (exchange surface with the environment)/(doped volume) + index gradients due to thermal effects << Δn of the fiber
- Low sensitivity to thermal effects
- High electrical/optical efficiency
- Power rising mainly limited by non-linear effects
- Compactness, environmental resistance (climatic, vibration), Maintenance free (the entire optical fiber setups without lenses, mirrors)



Fabry Perot cavity

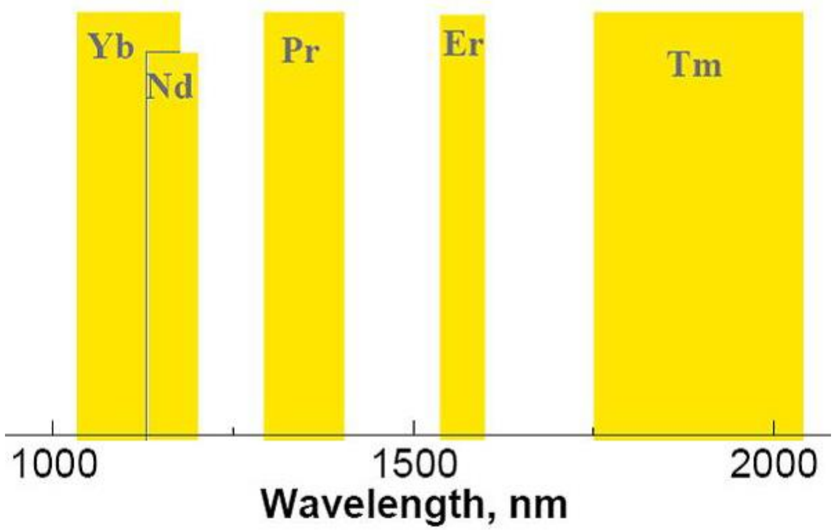


Ring cavity

Rare-earth doped fibers

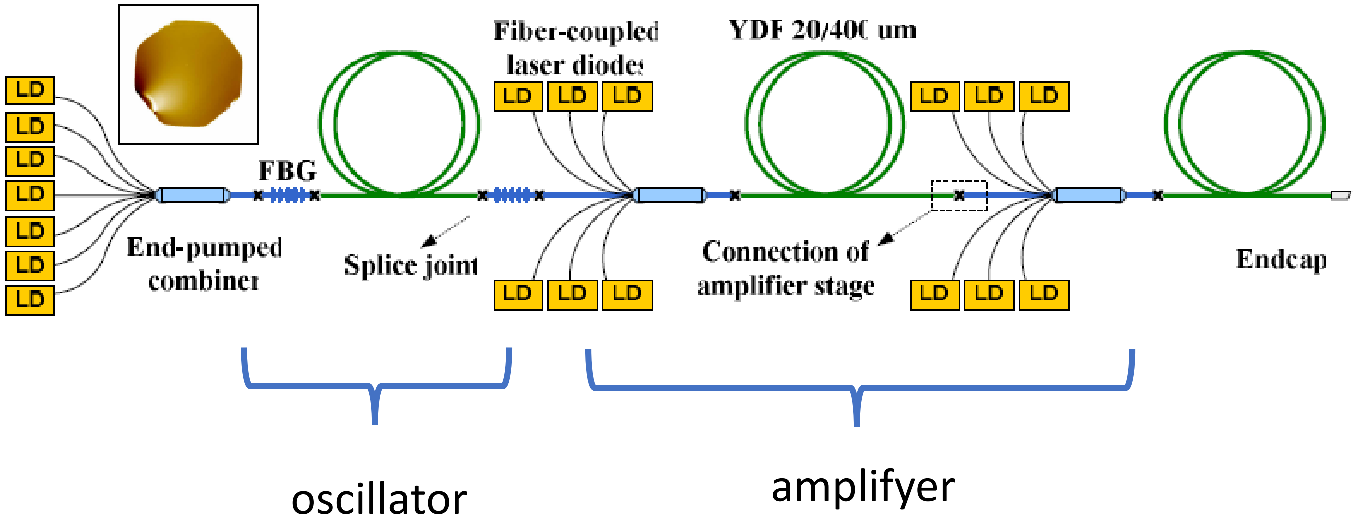
- Optical-to-optical efficiencies (typical):
  - Yb-doped fused silica fibers: 70% – 85%
  - Tm-doped fused silica fibers: 50% - 65%
  - Er and Er/Yb doped silica fibers: 20% - 40%

- Er: 1.55µm, minimum loss, telecom/eye-safe
- Yb: 1µm, high efficiency, ~1ms life-time, broad bandwidth.
- Tm: 2µm, eye-safe



MOPA configuration (Master Oscillator Power Amplifier)

For high power fiber laser



27 oct 2008, vol. 16/ optics express 17864

Conclusion

Laser light –> High capability to be focused in:

- Space domain → Gaussian beam (flat phase)
- Time domain → Mode-lock regime (flat phase in the spectral domain)

$\hat{P}$ = peak power = $\frac{E}{\Delta t}$

$\bar{P}$ = average power = $\frac{E}{2[L]/c}$

$2[L]/_{c}$ = t_{RT}

t_{RT} : Round trip duration

E : energy; Δt : pulse duration

$\hat{P}.\Delta t = \bar{P}.t_{RT}$

With $t_{RT} = \frac{1}{Rep}$

$$\boxed{\hat{P} = \frac{\bar{P}.}{\Delta t.Rep}}$$

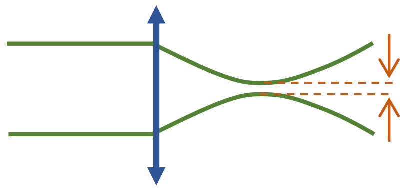
Rep = repetition rate

$\bar{P}$ = 10W

$\Delta t = 1ps$

$Rep = 100MHz$

$\hat{P} = 10^5 W$



$\lambda \Longrightarrow s = \lambda^2$

Average power density at the focus:

$$\frac{\bar{P}}{s} = \frac{10}{(0.5.10^{-4})^2} = 4GW/cm^2\text{!!}$$

Peak power density at the focus:

$$\frac{\hat{P}}{s} = 400TW/cm^2\text{!!}$$

~from a nuclear plant!