Yb:CaF_2 Diode-Pumped Regenerative Amplifier: Study and Optimization of Pulse Duration Versus Repetition Rate

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Outline

- $Yb^{3+}:CaF_2$ crystal
  - Spectroscopy
  - Thermal properties
- Ultrashort amplifier
  - Experimental setup
  - Q-switch regime
  - Regenerative amplifier configuration
- Conclusion

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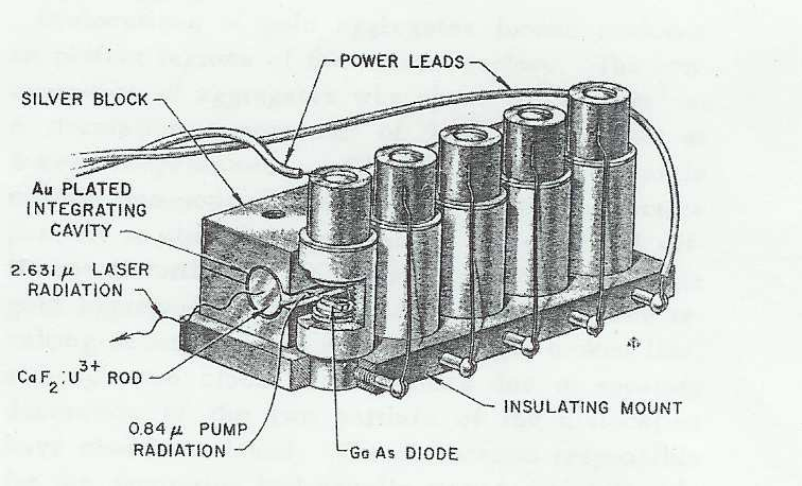
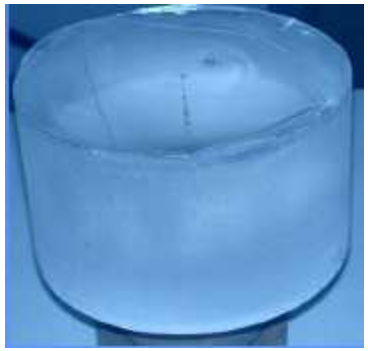
"A new old laser material "

First ceramic and diode-pumped solid-state lasers were based on CaF_2 host matrix !!!



(Artist representation)

Doped Yb:CaF_2 up to ϕ200 mm (Korth GmbH)



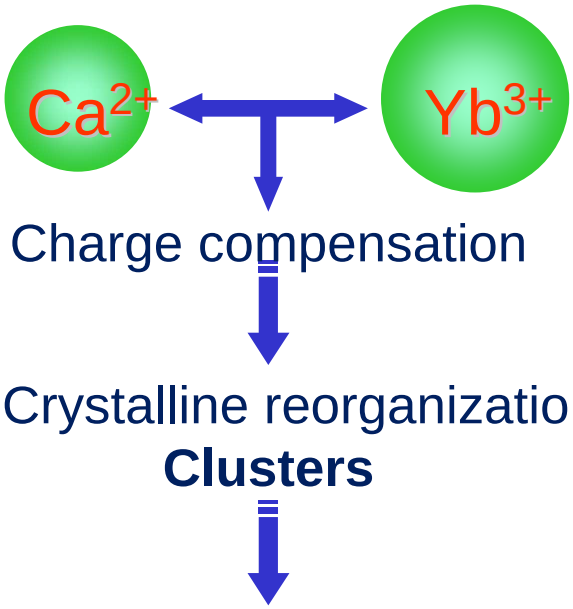
→ S.E. Hatch, et al.
"Hot-pressed polycrystalline $CaF_2:Dy^{2+}$ laser "
Appl. Phys. Lett. 5 pp 153-154. (1964)

→ R. J. Keyes, et al.
"Injection Luminescent pumping of $CaF_2:U^{3+}$ with GaAs diode lasers"
Appl. Phys. Lett. 4 pp 50-51. (1964).

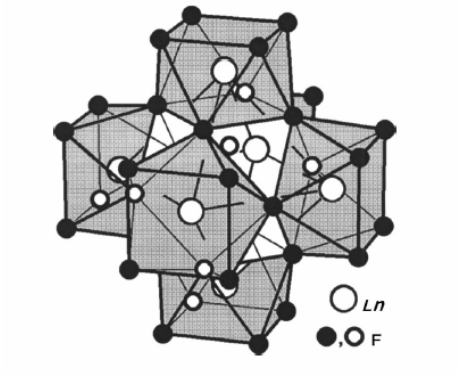
→ V. Petit, et al.
"CW and tunable laser operation of Yb^{3+} doped CaF_2"
Appl. Phys. B (2004).

→ M. Siebold, et al.
"Yb:CaF_2 – A New Old Laser Material"
Appl. Phys. B (2009).

Spectroscopy

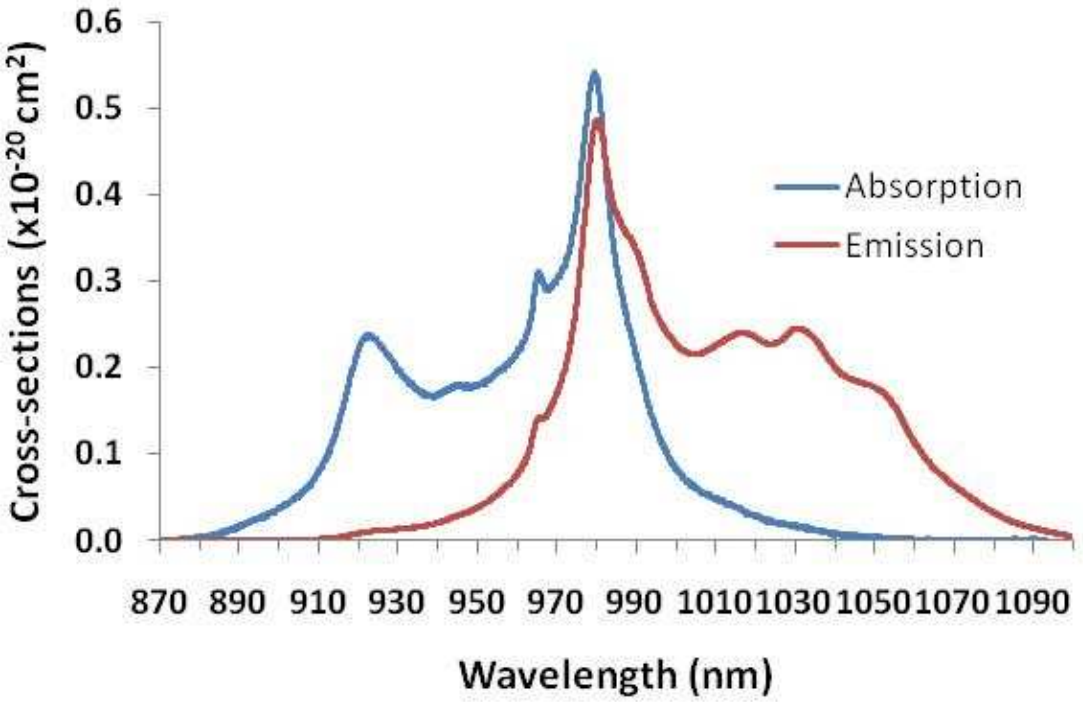


Broad absorption and fluorescence spectra



Hexameric cluster

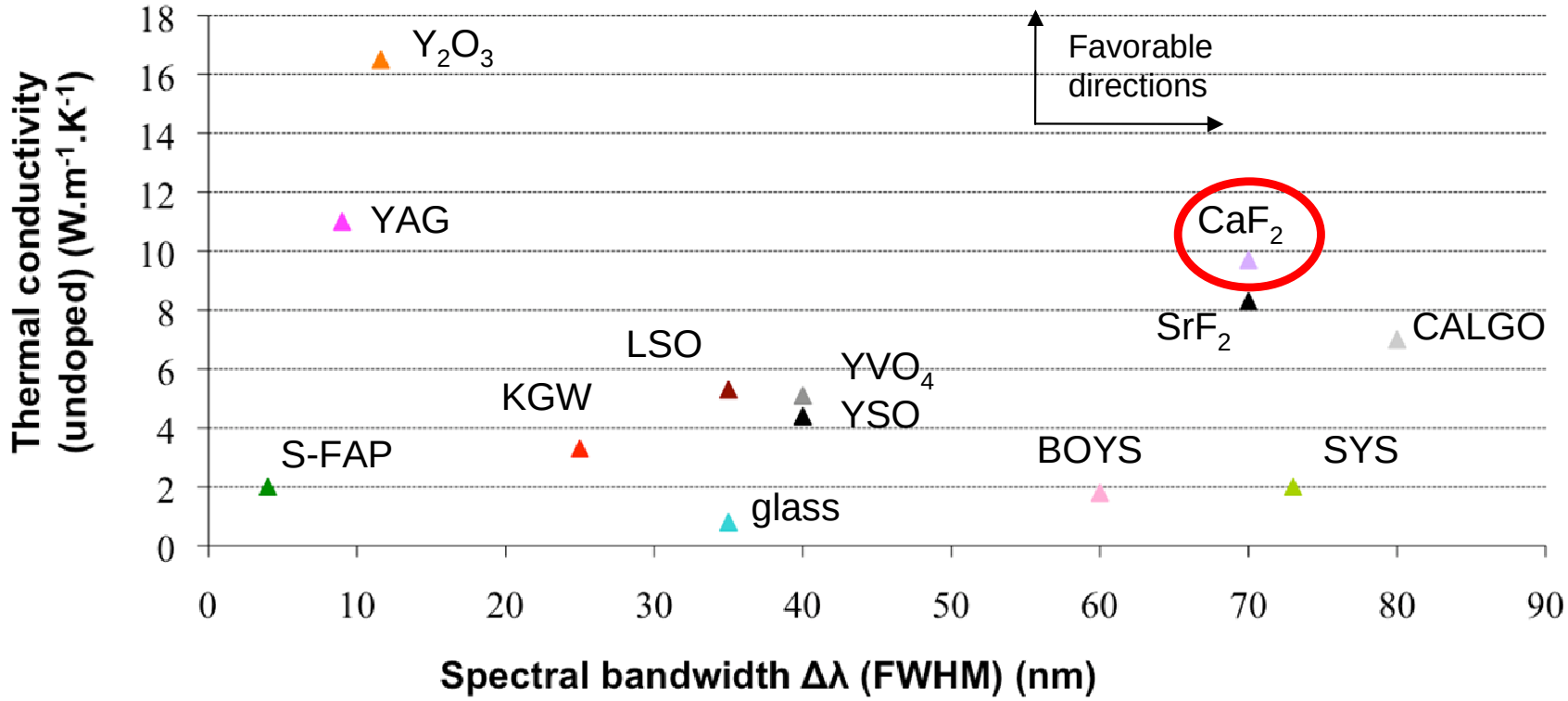
V. Petit et al (Appl. Phys. B, 2004)



- **Diode pumping**
- **Tunability / ultrashort pulses**
- **Long emission lifetime (2.4 ms)**

Thermal properties

	Undoped crystal	~ 2.7%-Yb-doped crystal
Thermal conductivity ($W.m^{-1}.K^{-1}$)	9.7	6
Thermo-optic coefficient (10^{-6} K^{-1})	- 17.8	- 11.3



Potential laser material

- Long fluorescence lifetime (2.4 ms)
- High quality crystal with large diameter

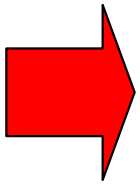
→ Energetic pulses (*)

- Smooth optical bands
- Relatively large cross sections
- Cryo-cooled perspective

→ Femtosecond pulses (**)

- High thermal conductivity
- High quality crystal with very
- Low parasitic nonradiative effect

→ High average power pulses (***)



- **$Yb:CaF_2$ based HEC-DPSSL broadband CPA pump for the ILE front end OPCPA system**
- **Diode-pumped regenerative amplifier**

*M.Siebold et al "Terawatt diode-pumped $Yb:CaF_2$ laser", Opt. Letters **33**(23), 2770–2772 (2008)

F. Friebel et al "Diode-pumped 99 fs $Yb:CaF_2$ oscillator", Opt. Letters **34(9), 1474–1476 (2009)

***J. Boudeile et al "Thermal behaviour of ytterbium-doped fluorite crystals under high power pumping", Opt. Express **16**, 10098-10109 (2008)

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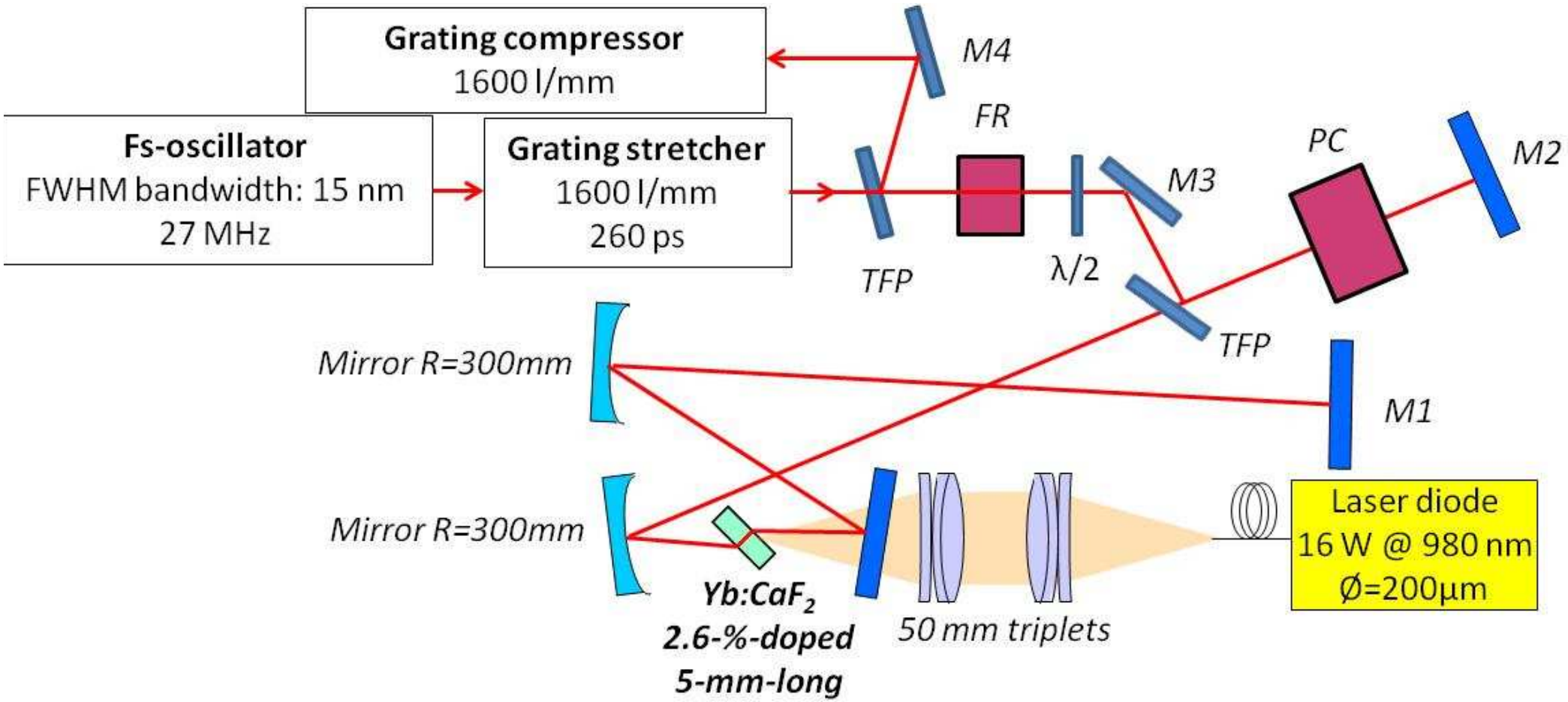
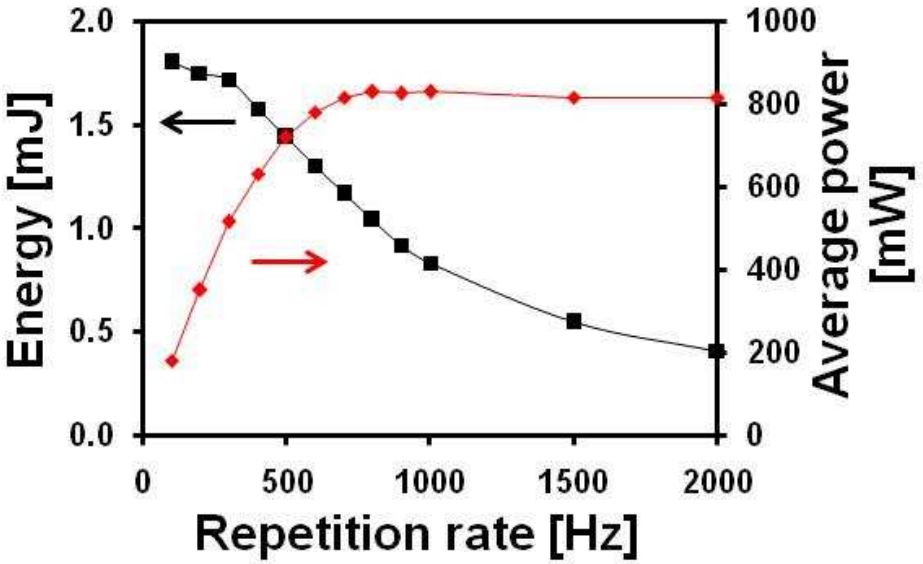
Experimental setup

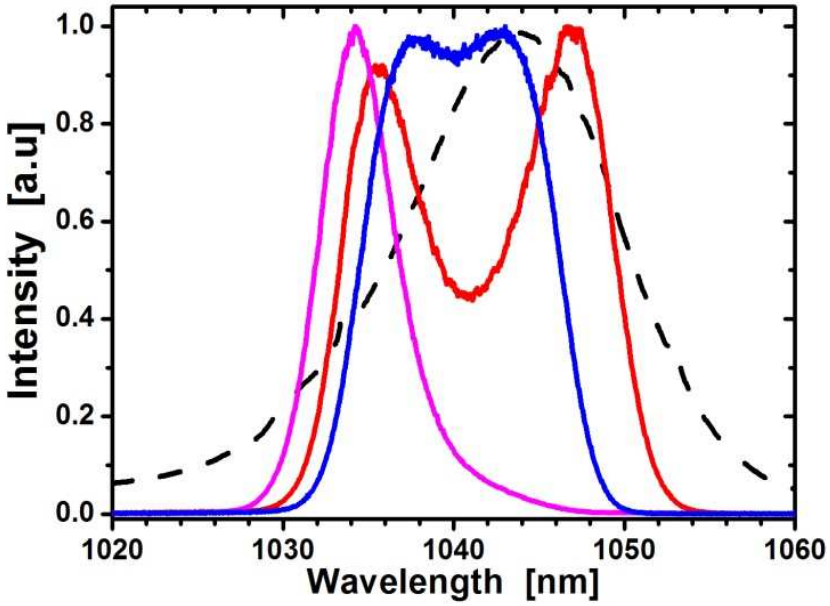
Diode-pumped CPA laser chain



Amplitude SYSTEMES

Q-switch regime (non injected)





Normalized output pulse spectrum at 500 Hz

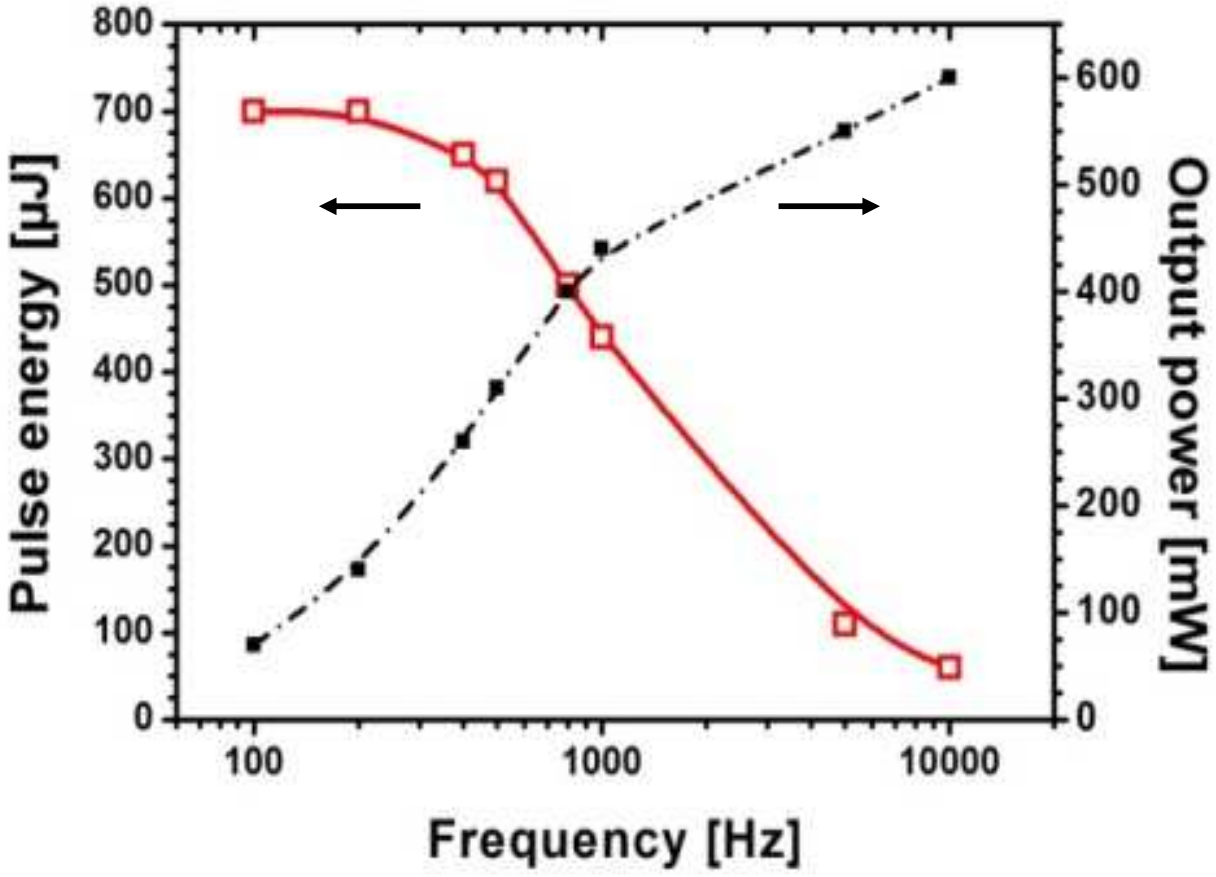
In Q-switch regime :

- maximal output energy 1.8 mJ at 100 Hz
- maximal average power : 850 mW above 800 Hz
- maximal spectral bandwidth : 16 nm centered at 1040 nm at 500 Hz

⟶ Optimal repetition rate energy/power : 500 Hz (fluo lifetime 2.4 ms)

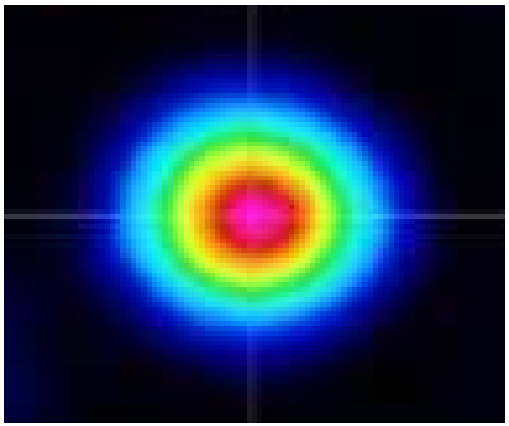
⟶ Optimization of the injection spectrum : **broadband oscillator centered around 1043 nm (Yb:GALGO)**

Regenerative amplifier configuration



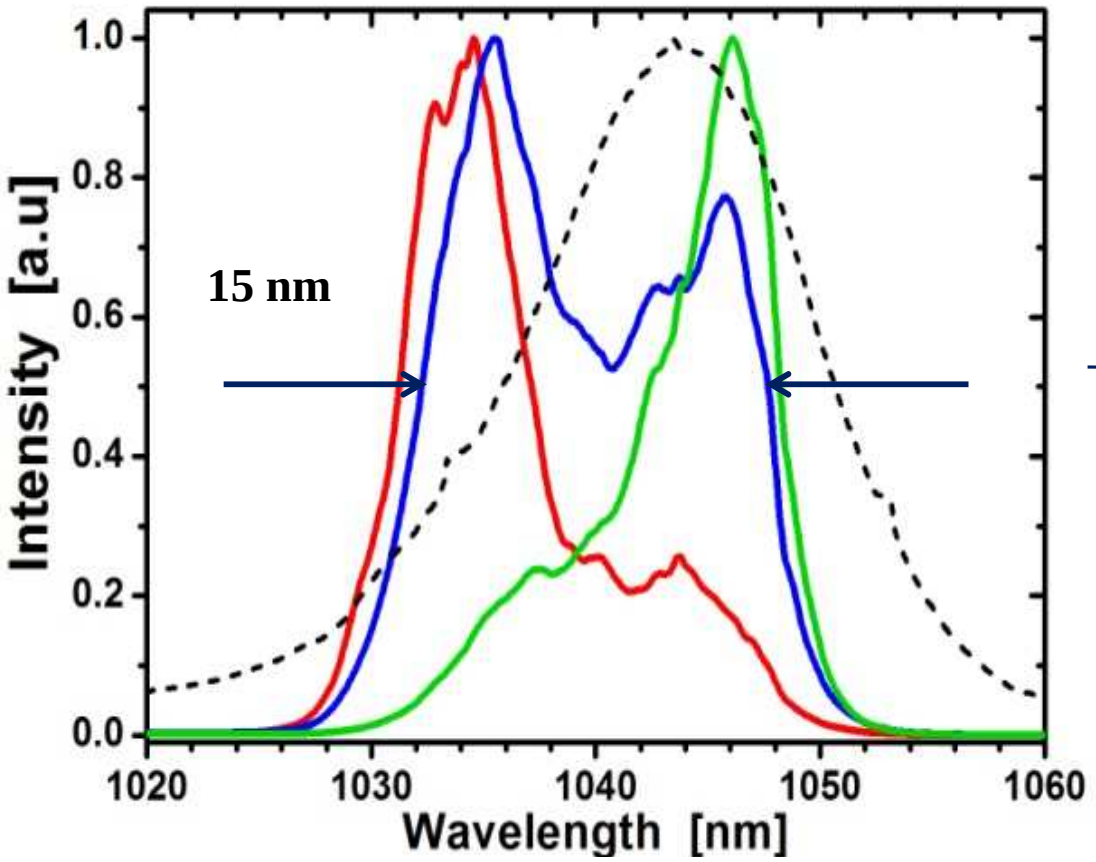
- Maximum energy plateau up to 300 Hz : **1.6 mJ / 700 µJ** (uncompressed / compressed)

- Higher repetition rate : 10 kHz **1.4W / 0.6W** (uncompressed / compressed)



Beam profile :
Gaussian shape with $M^2 < 1.1$

Spectral bandwidth



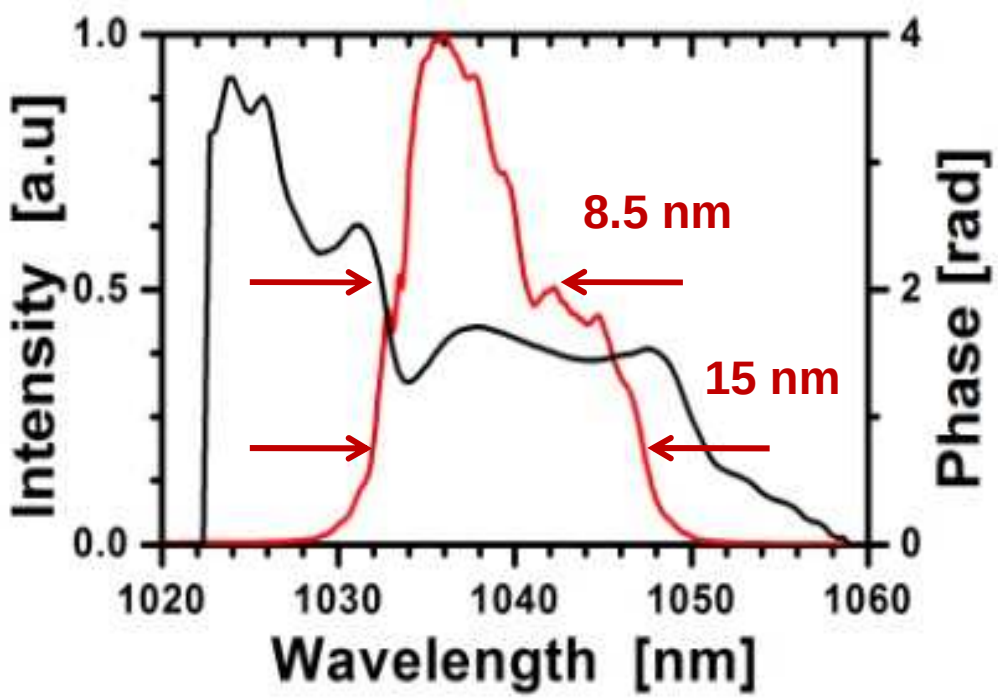
Spectral shaping depending on repetition rate and extraction time

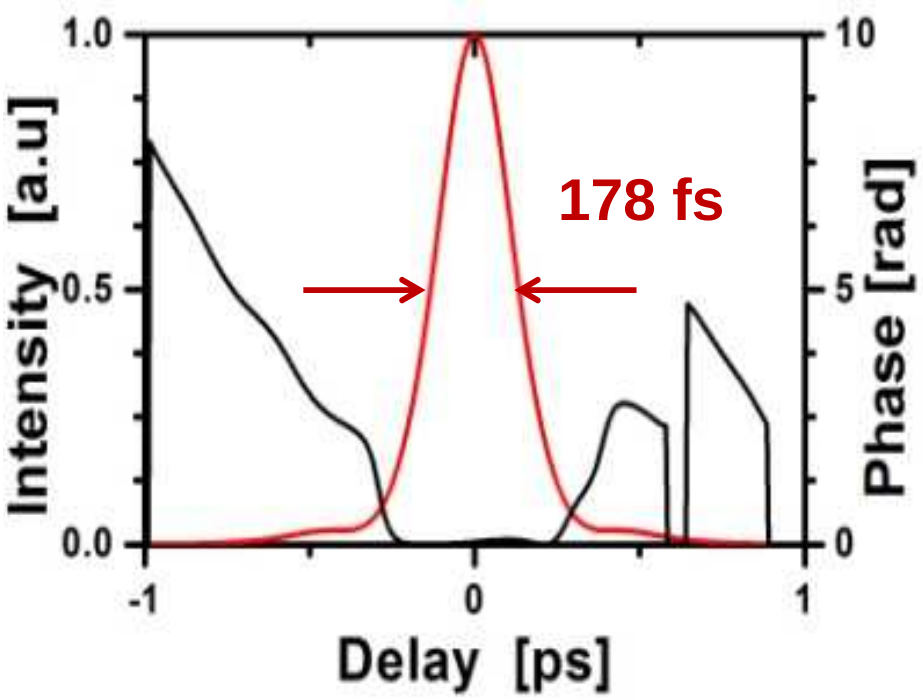
→ Low Δn, maximal gain ~ **1045 nm**
High Δn, maximal gain ~ **1035 nm**

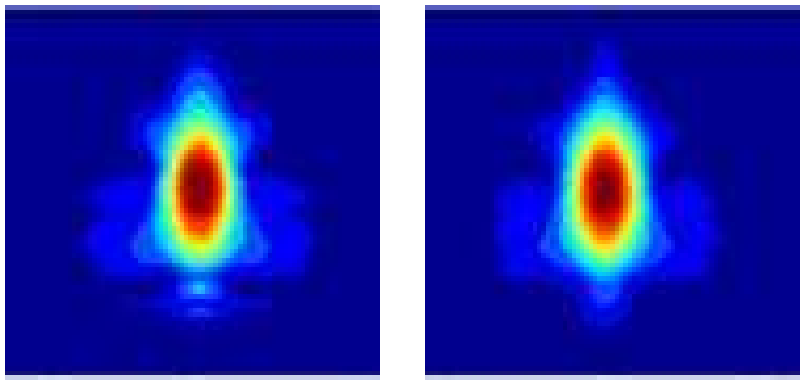
500 Hz repetition rate for different time of extraction:
1.35 µs, 300 µJ (red curve)
1.7 µs, 620 µJ (blue curve)
2.2 µs, 580 µJ (green curve)
Short dash curve : oscillator spectrum

Spectral bandwidth up to **15 nm** (below 1 kHz)

SHG FROG trace at 500 Hz





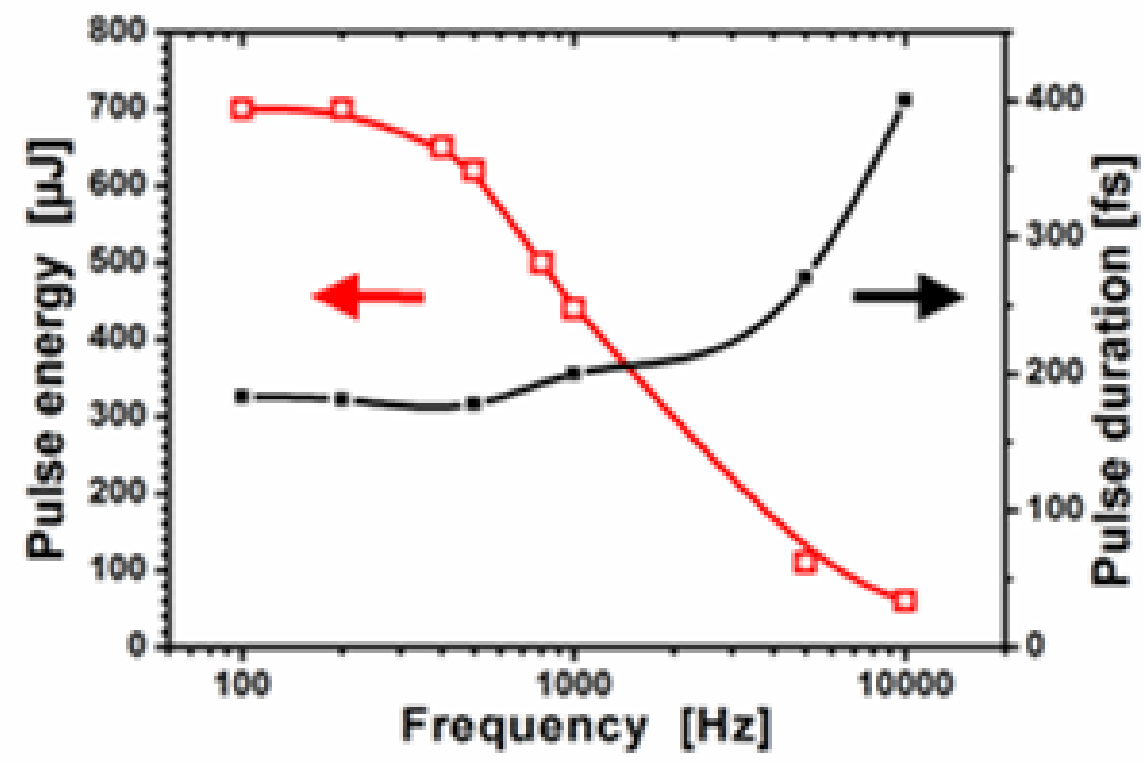


Measured *Retrieved*

At **500 Hz** repetition rate :

- pulse duration : **178 fs**
  >90% temp. Strehl ratio
  >95% main peak
- pulse energy : **1.4 mJ before compression**
  620 µJ after compression
- optical-to-optical efficiency : **4.5 %**

Pulse duration vs rep. rate



-Up to 1 kHz : pulse duration below 200 fs

- 10 kHz : 400 fs, narrower spectrum shifted at 1045 nm

S. RICAUD et al
«Short pulse and high repetition rate diode-pumped Yb:CaF_2 regenerative amplifier"
Optics Letters, Vol. 35, Issue 14, pp. 2415-2417 (July 2010)

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Conclusion

- Diode-pumped room-temperature regenerative Yb:CaF_2 amplifier operating at low and high repetition rate.

- Short pulses up to 1 kHz repetition rate (178 fs at 500 Hz).

- Maximum extracted energy : 1.6 mJ / 0.7 mJ (before / after compression).

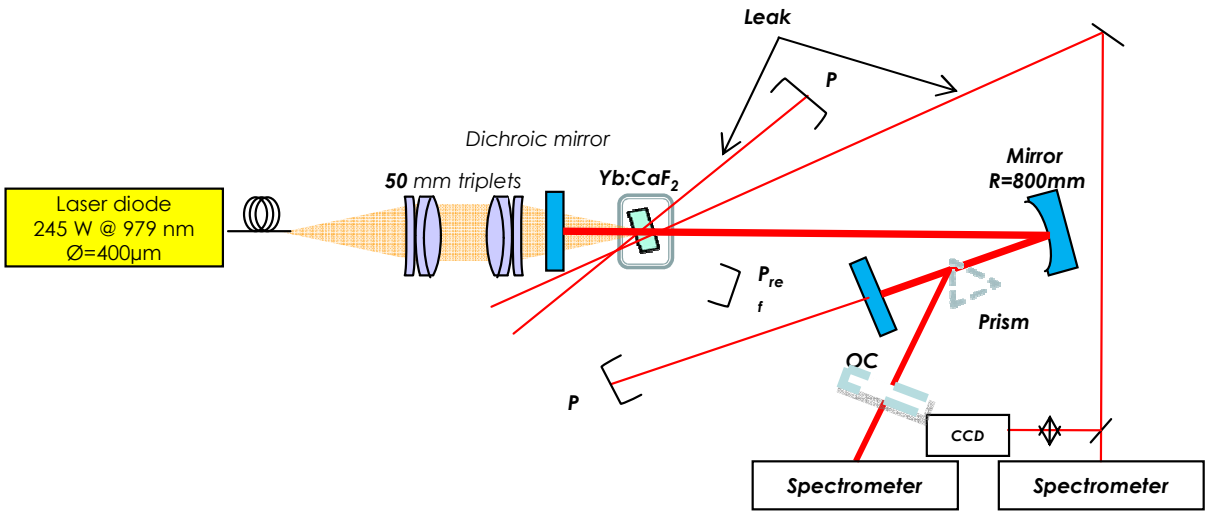
- Highest average power : 1.4 W / 0.6 W (before / after compression).

- Optical to optical efficiency ranging from 5 to 10%.

…Potential for sub-100 fs pulses with spectral shaping and high order phase control
…cryo-cooled setup (oscillator), multipass booster (200mJ/100Hz)

Thank you !!!

DPSSL cryo Yb:CaF_2



Experimental small signal gain: max 3.1
Population Inversion β=0.42.