Tunable millijoule laser based on $Yb:CaF_2$: from nanosecond to femtosecond

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Outline

- Company activity
- Technology and products
- Motivations
- Experimental results
- Conclusion

Company

- Created in 2000

- >100 employees in ultrafast lasers

- 20M€ turnover

- Products sold in more than 20 countries

- Industrial and scientific lasers

-Applications in medical, semiconductor, pharmaceutics




Company

Amplitude Systemes - Bordeaux
Compact femtosecond lasers

Amplitude Technologies - Paris
High power femtosecond lasers

Amplitude Laser - Boston
U.S. sales and support

Amplitude SYSTEMES

Nothing but ultrafast

- A broad range of technologies
    - Ti:Sapphire lasers — Amplitude TECHNOLOGIES
    - Yb solid-state lasers — Amplitude SYSTEMES
    - Yb fiber lasers — Amplitude SYSTEMES

Amplitude SYSTEMES

Ti:Sa high intensity lasers

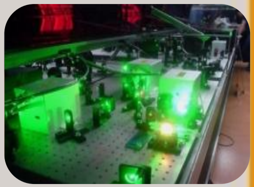
Technology :

Ti:Sa : short pulses (30fs) reduces the required energy for a given peak power

Green pumps @10Hz : cost effective flash-pumped technology

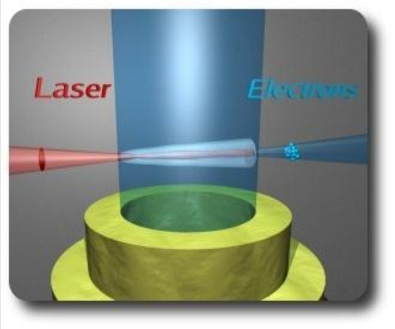
Temporal contrast is a key issue

→ 0,1-1PW commercially available (3-30J 30fs)

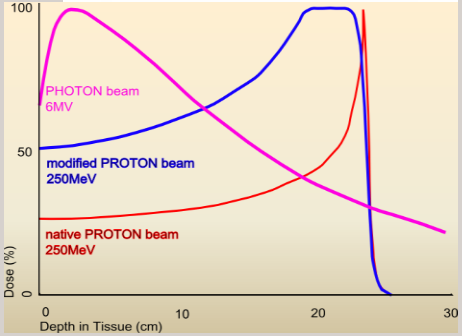


Applications :

- *Electron acceleration*
  Compact accelerators,
  wake-field regime



- *Proton acceleration,*
  Cancer therapy



- Interface with LINAC, synchrotrons, *future of X-FEL*

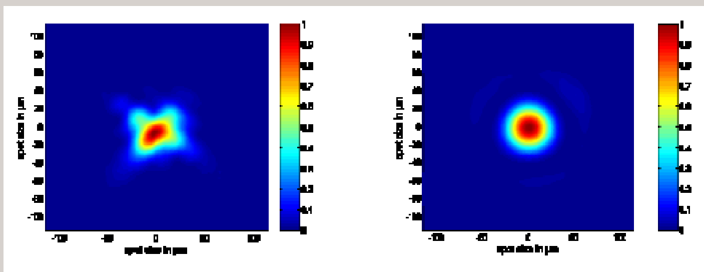
Ti:Sa ultrafast lasers

Higher repetition rates, from 100Hz to 5kHz

Short pulses < 30fs

CEP stabilization is a key technology

At high average power, cryo cooling is used

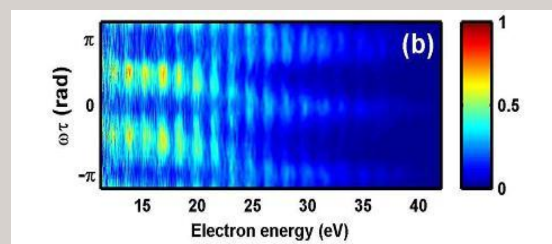


Water cooling *Cryogenic cooling*

Applications

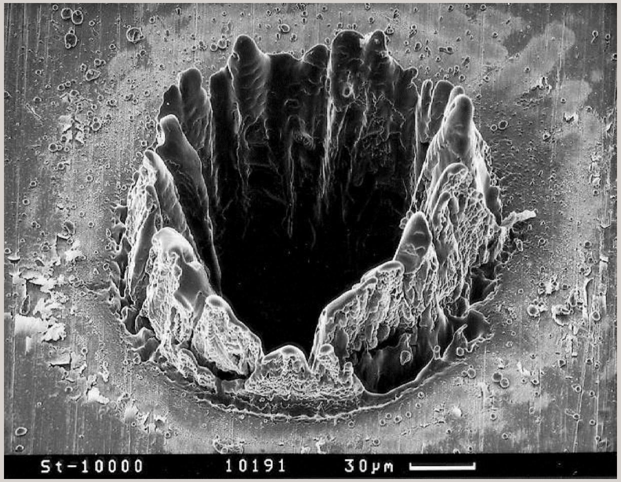
- High order harmonic generation,

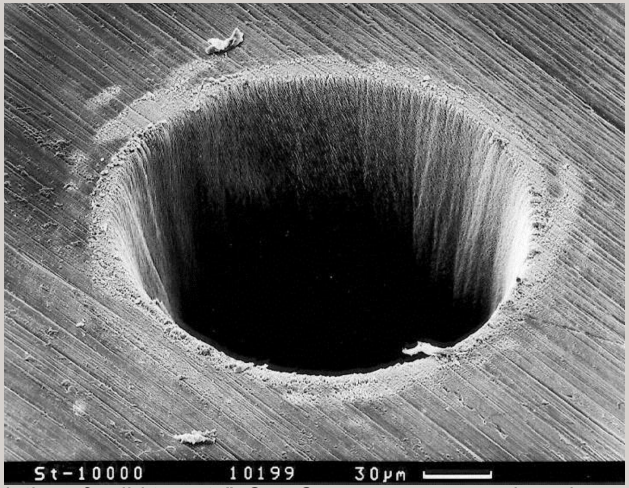
  Attosecond physics



- Photoinjectors for LINAC
- Femtochemistry, femtosecond spectroscopy

Ultrafast lasers for industry?





C. Momma, B.N. Chichkov, S. Nolte, A. Tünnermann, "Short-pulse laser ablation of solid targets", Opt. Commun. ***129****, 134 (1996)*

Nanosecond pulses (3,3ns)

- Large Heat Affected Zone (HAZ)
- Lack of reproductibility
- Need to adapt wavelength to material

Femtosecond pulses (200 fs)

- Low ablation threshold
- Limited HAZ
- Efficient and stable process
- Interaction with transparent materials is possible through multiphoton absorption

Typical heat transfer dynamics ~5 ps from electrons to lattice
Multiphoton process allows interaction with any material

→ High quality micromachining of metal, glass…

Technology

A new generation of ultrafast lasers

- We want:
  - *A compact, reliable, high performance femtosecond laser*

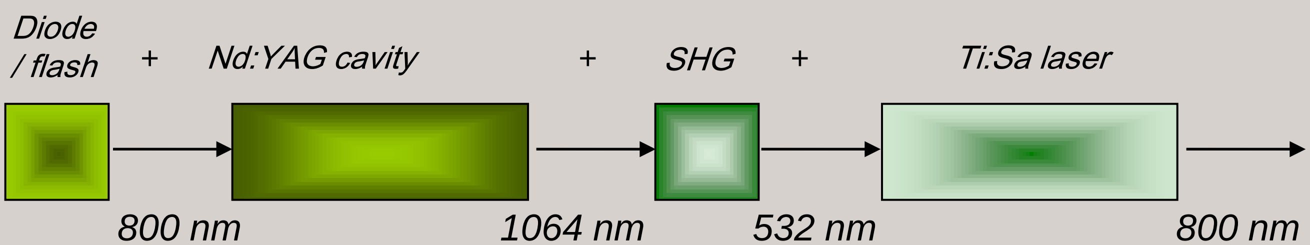
- We need:
  - *Direct diode pumping*
  - *Broadband laser material*
  - *Efficient optical scheme*

- We use:
  - *Ytterbium as the active ion*
  - *All solid-state system*
  - *Small footprint optical cavities*

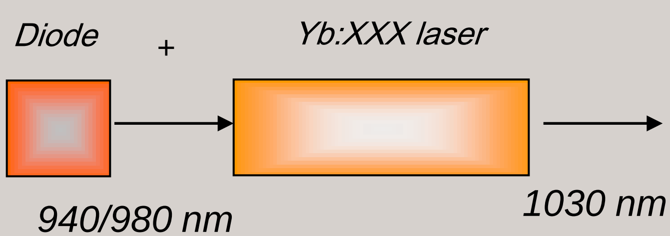
Ytterbium lasers : The new generation of Femtosecond laser!

- Direct diode pumping capability

Traditional femtosecond lasers :

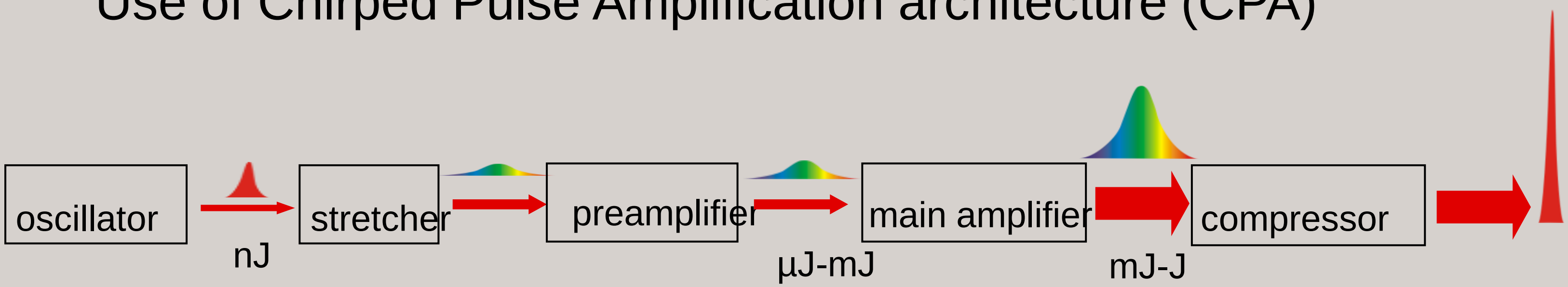


Amplitude Systemes femtosecond lasers :



Laser architecture

Femtosecond intense lasers : nonlinear issues
Use of Chirped Pulse Amplification architecture (CPA)



Oscillator :

- self starting using Semiconductor Nonlinear Mirror
- compact using diode-pumping & dispersive mirrors
- Crystal based : pure soliton pulses, 10-500nJ energy
- Fiber based : compact, lower energy

Amplifiers :

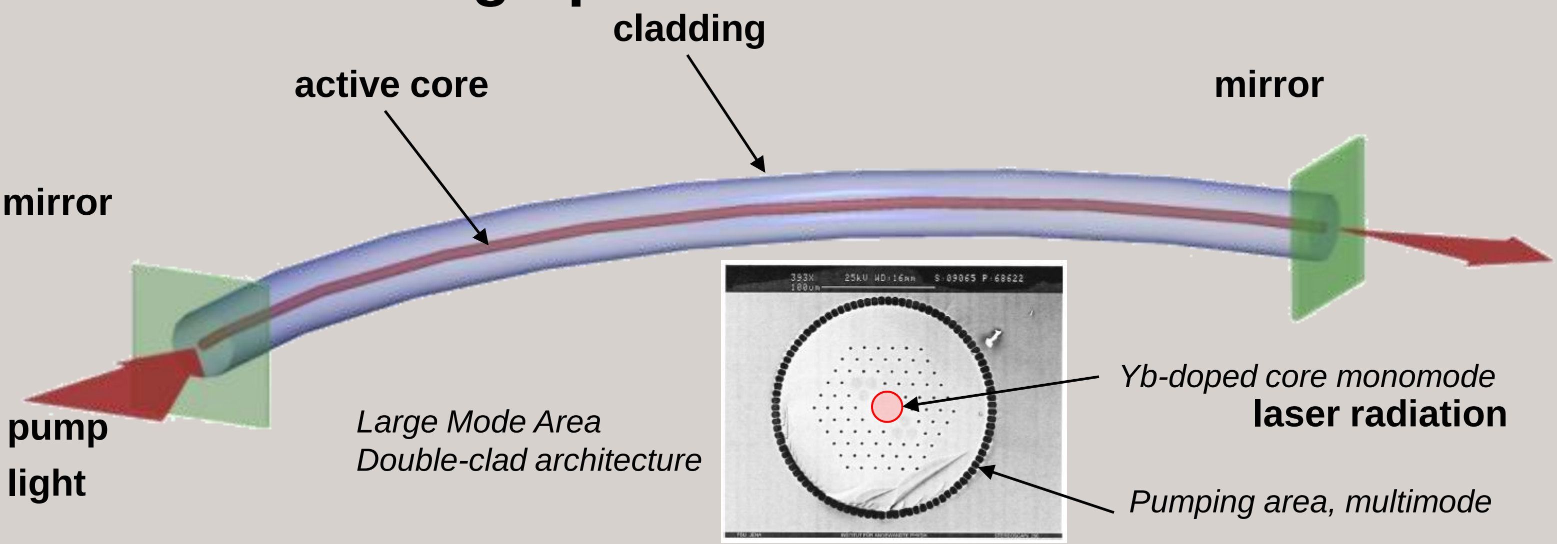
- regenerative amplifiers using crystals (thermal limitations)
- single stage amplifiers using fibers (nonlinearity limitations)

→ Use of **hybrid architecture** to exploit benefits of both fiber and crystal technology

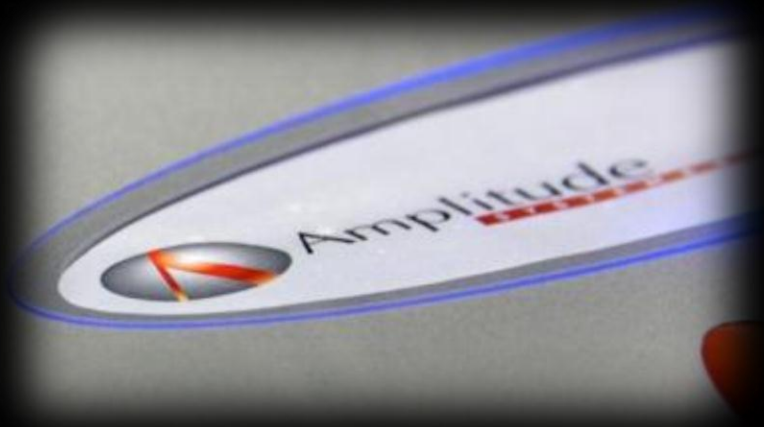
Crystal based solid state lasers

		Oscillator	Amplifier
Pulse energy	☺	20 to 500nJ	Up to 2mJ
Stability, reliability	☺	Vibration >5G Thermal test: 15°C – 35°C Long term stability (12h): <0.5% RMS	
Average power	☹	1 to 5 W	Up to 8W

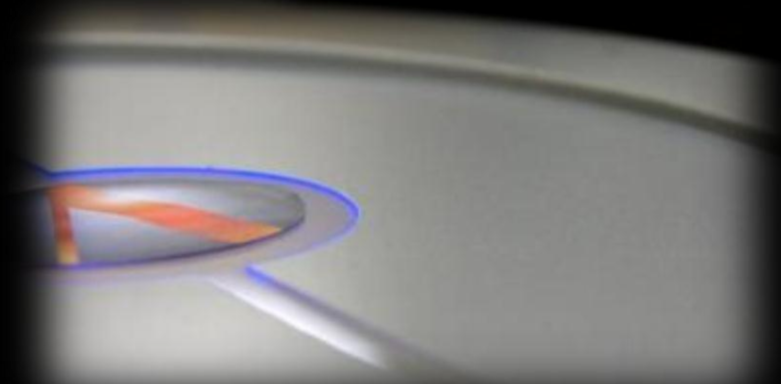
High power fiber lasers



Average power	☺	High exchange area: >20W femtosecond laser
Stability, reliability	☺	Vibration >5G Thermal test: 15°C – 35°C Long term stability (12h): <0.5% RMS
Pulse energy	☹	Non linear effects: 20µJ for PCF 300µJ for rod type fiber



Products



Production

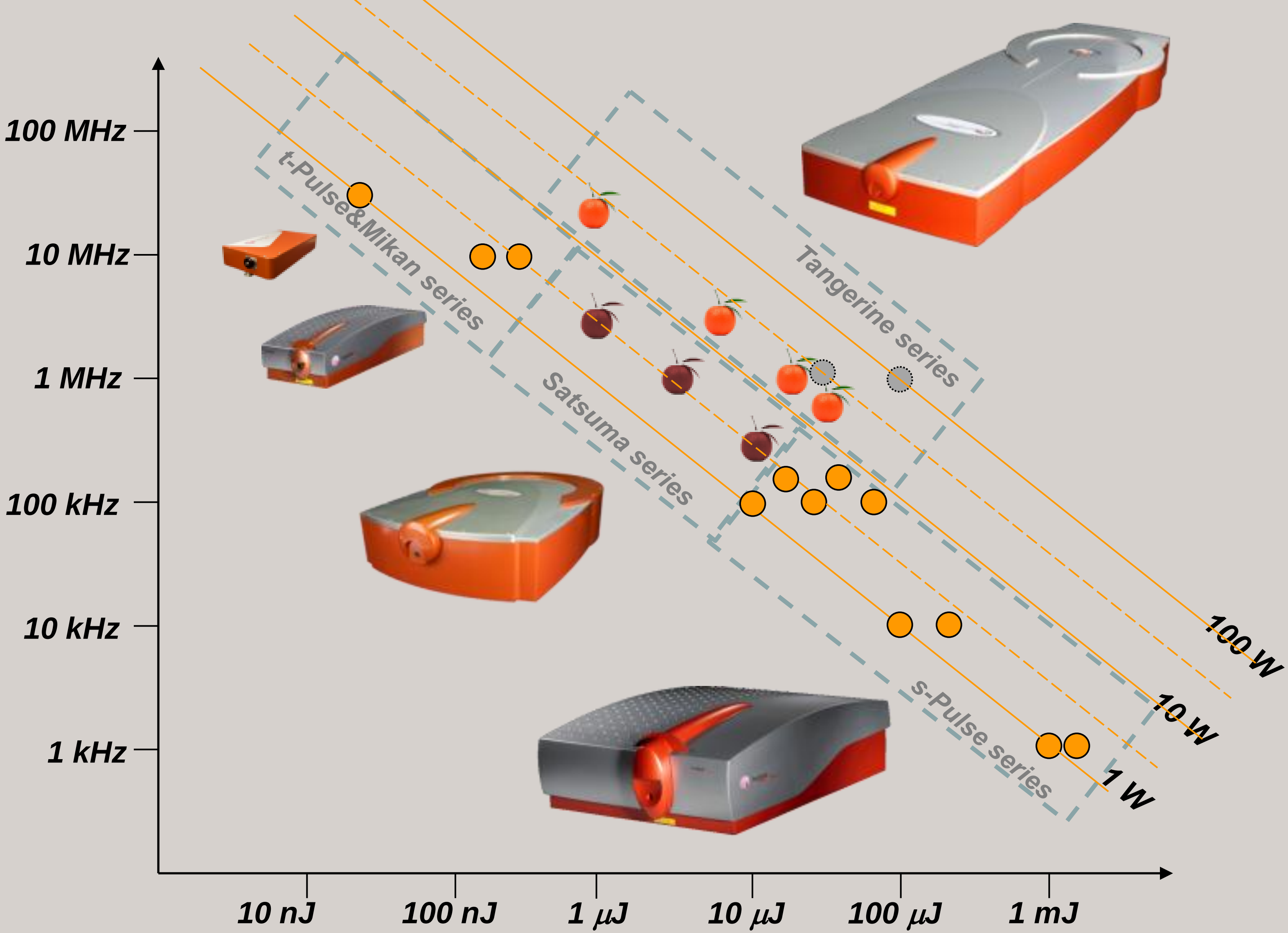
- Clean room production:
    - From mechanical assembly to quality control
- High production capacity
- Vibration and temperature cycling

Mechanical assembly

Laser quality control

Oscillator alignment workstations

Product range



Amplitude SYSTEMES

t-Pulse series

• Up to 5W

• Up to 500nJ energy per pulse

• Industry ready

• 10MHz and 50MHz repetition rate

Ultrafast oscillator series

Applications:

•Glass marking & engraving

•Biology : Multiphoton excitation

•Multi-photon polymerisation

•Lab-On-Chip direct writing

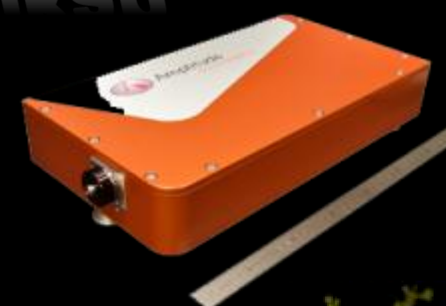
•Picosecond acoustics…

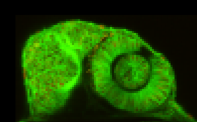
Mikan

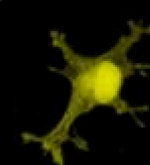
• >1W

• Ultra compact

• Air-cooled



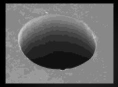




Air-cooled Ultrafast oscillator

s-Pulse series

- Up to 8W
- Up to 2mJ energy per pulse
- Industry ready
- Up to 300kHz repetition rate



Ultrafast amplifier series

Applications:

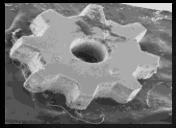
•Micro-machining

•Glass marking & engraving

•Chemical & material analysis

Satsuma series

- Up to 10W & 20µJ
- Ultra compact
- Industry ready
- Up to 5MHz repetition rate



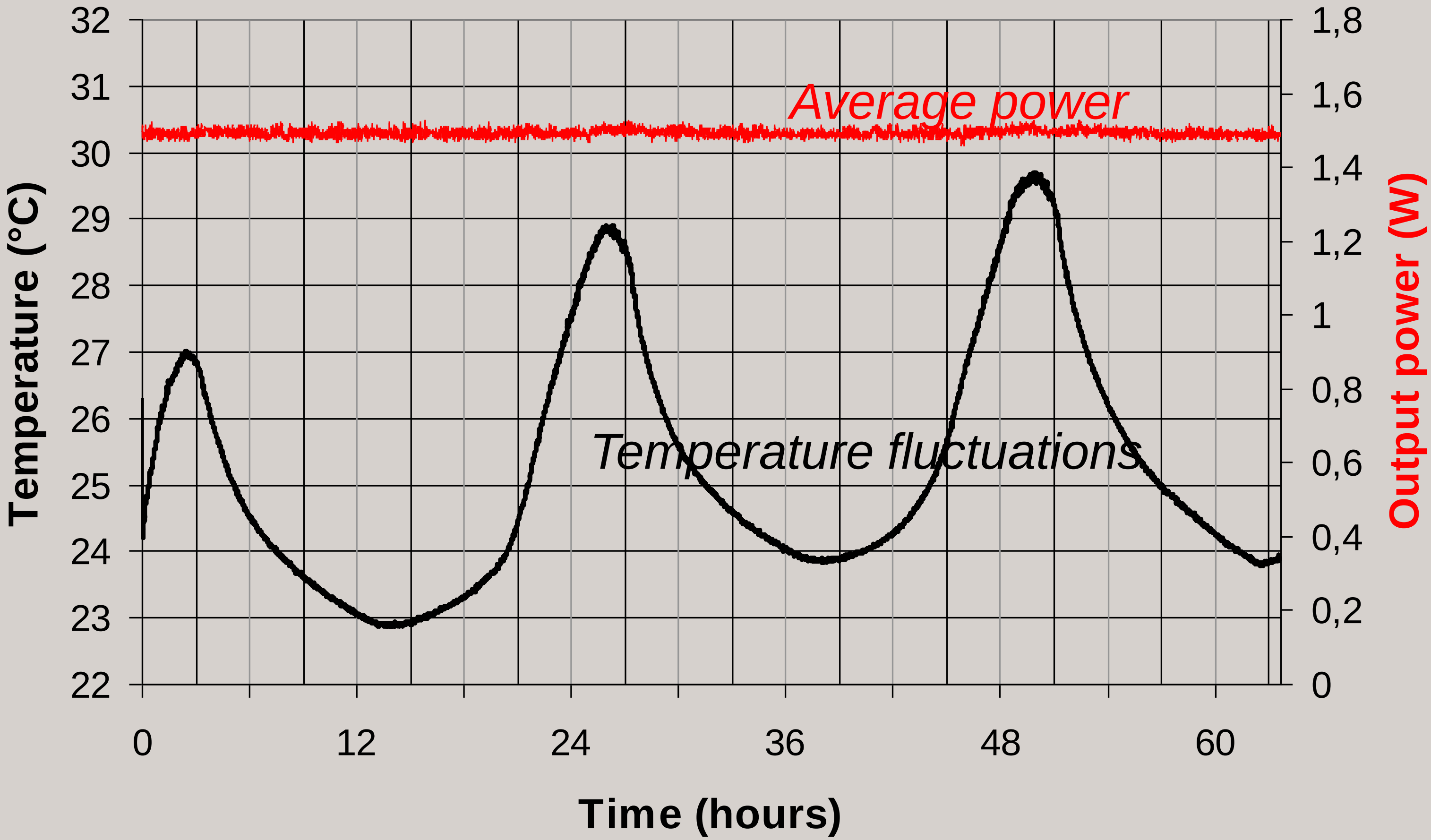
Ultrafast fiber amplifier series

Tangerine series

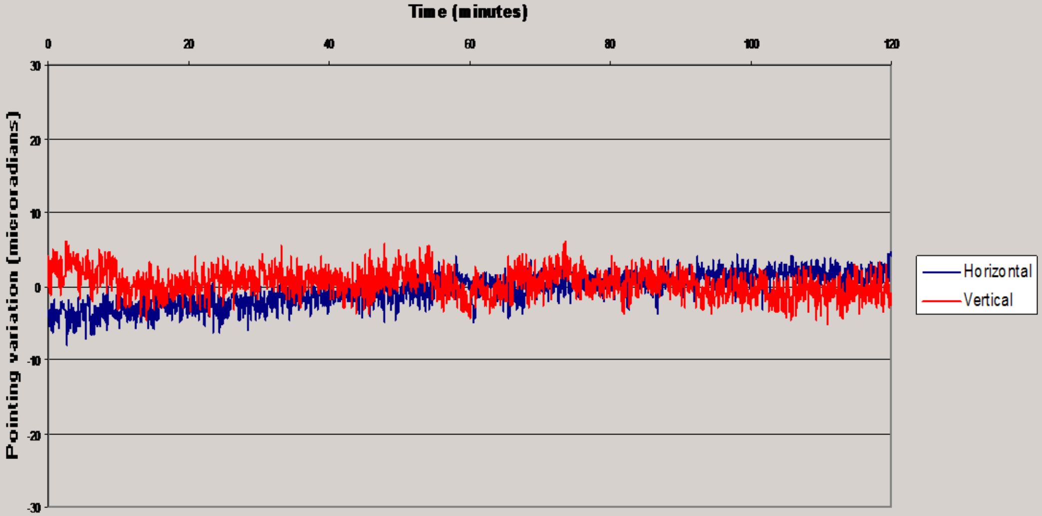
- Up to 20W & 100µJ
- Pulse duration <100fs up to 10ps
- Industry ready
- Up to 2MHz repetition rate

Ultrafast fiber amplifier series

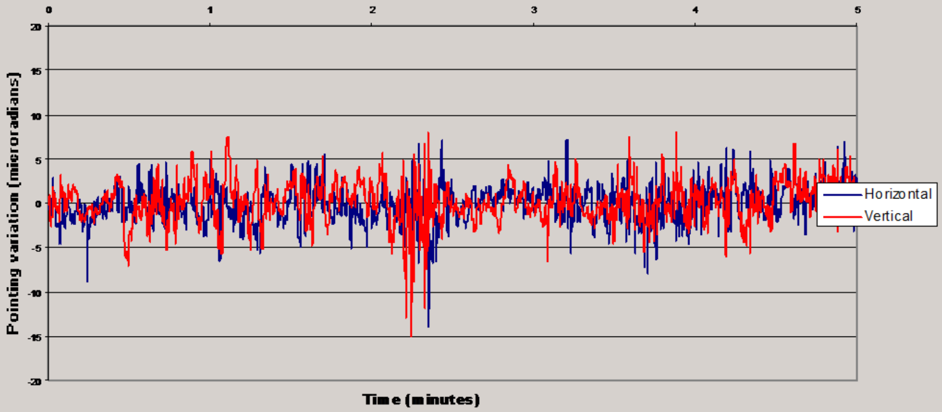
Sensitivity to environment



Pointing stability



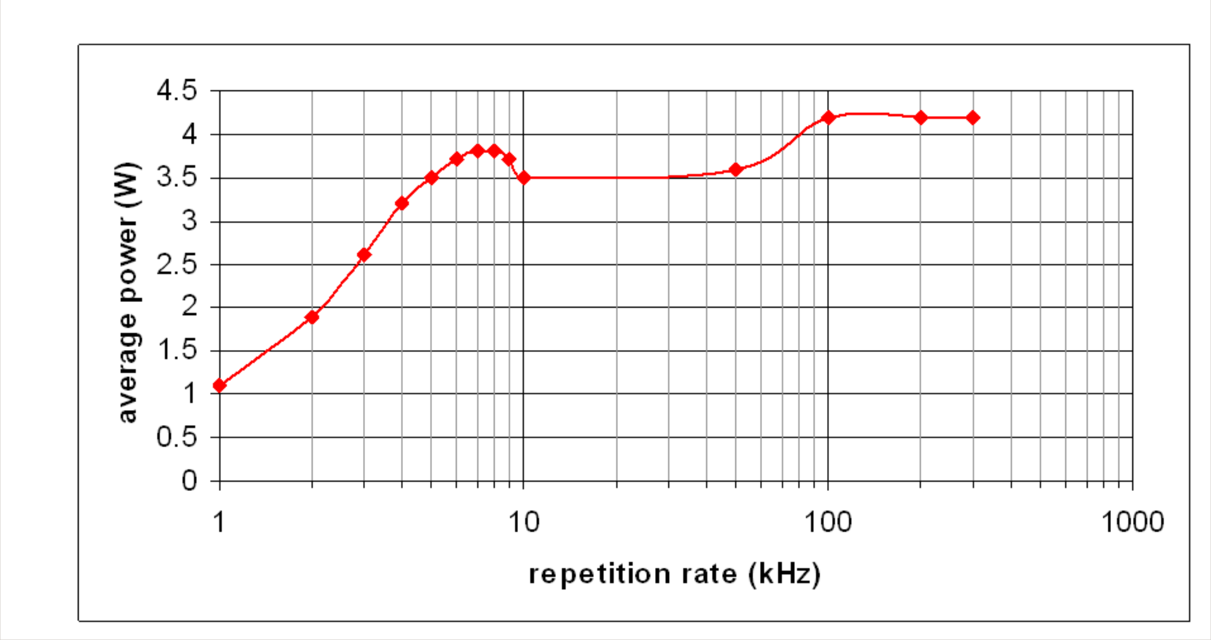
Pointing stability long-term : < 10µrad rms over 2 heures (divergence 700µrad)



Pointing stability short-term : approx. 2 µrad rms over 5 mn

Energy performances

Example : s-Pulse HP



CW pumping allows any rep rate
No need for compressor readjustment

Versatile source : well adapted for ablation process optimisation

Amplitude SYSTEMES

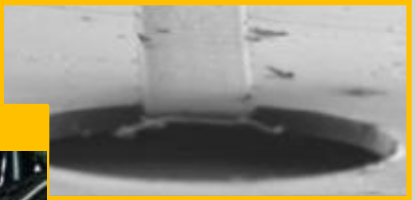
Applications

MEDICAL DEVICE MFG

IMAGING

EYE SURGERY

INSTRUMENTATION



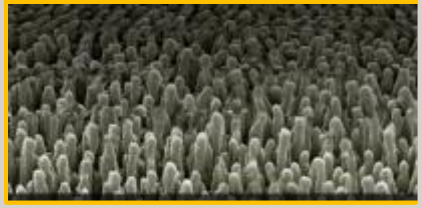
MICRO-MACHINING

SCIENTIFIC RESEARCH

PHARMA

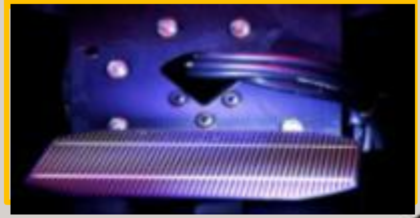
DISPLAY

NANOTECHNOLOGY



SEMICONDUCTOR

PHOTOVOLTAIC



Strong R&D activity

Motivations :

- Shorter pulses for specific materials ablation
- Higher power for higher process speed
- Higher intensity for new applications

Recent results :

- Sub-100fs post-compression (60fs 300µJ @ 5kHz)
- High energy femtosecond fiber laser (60W 600µJ 300fs)
- Thin disk Yb:YAG picosecond laser source (20W 500µJ <1ps)
- Thin disk laser based on Yb:Calgo
- High average power cryocooled Yb:CaF_2 laser
- Femtosecond Yb:CaF_2 lasers

Postcompression

Post-compression in LMA fiber / gas capillary:

1. Spectral broadening by SPM in fused silica / gas (nitrogen)
2. Monomode guiding
3. Dispersion compensation (dispersive mirrors)

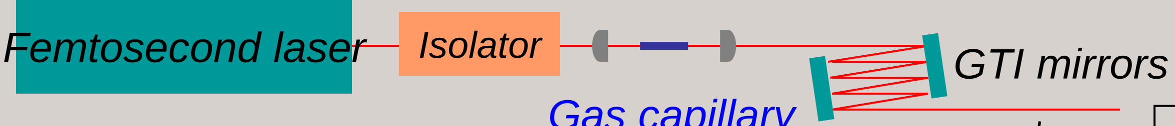
Allows to achieve sub-100fs pulse duration with

- >50% overall transmission
- Compact architecture

Low energy *500nJ 400fs*
P = 1,2MW

LMA fiber
l~1-3 cm

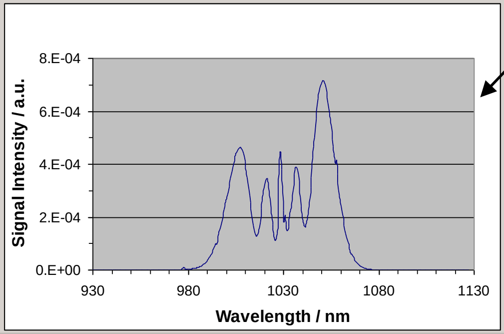
250nJ 40fs
P > 5MW !

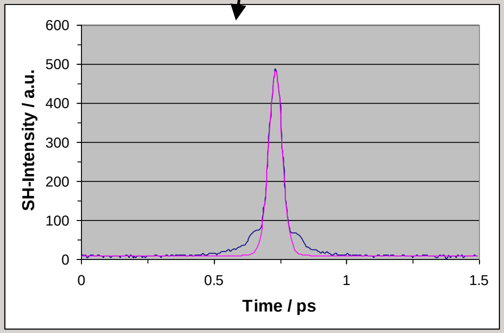


High energy *600µJ 500fs 5kHz*
P = 1,2GW

Gas capillary
l~15 cm

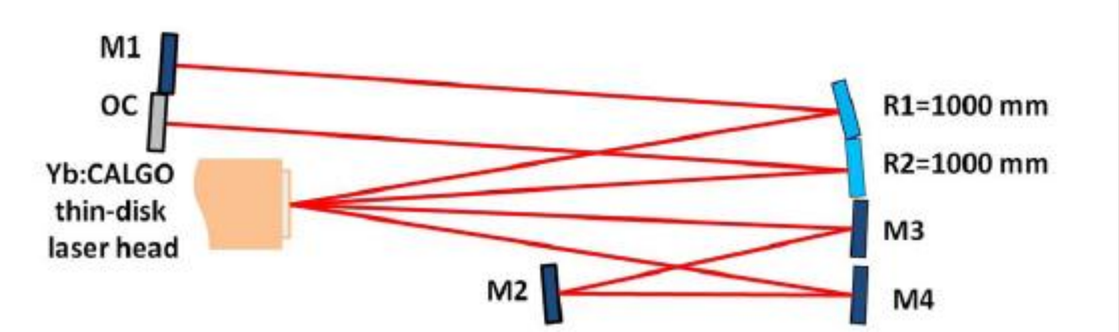
300µJ 60fs
P > 5GW !



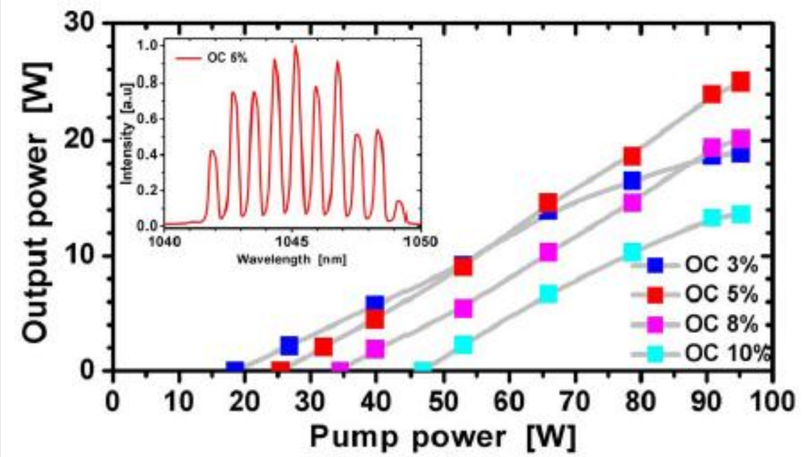


Thin disk Yb:Calgo

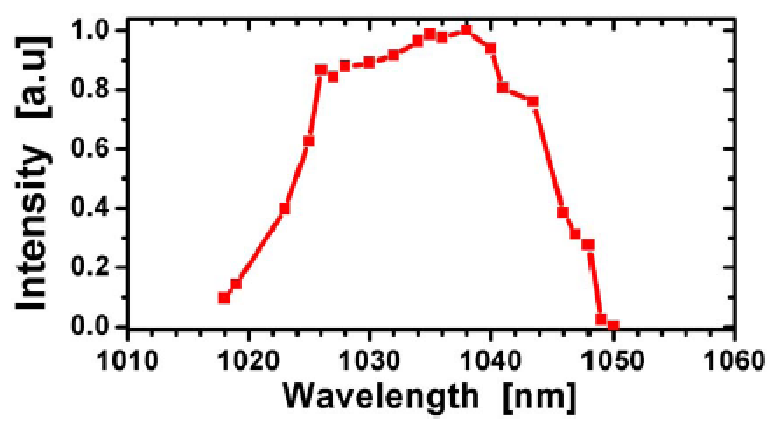
Experimental setup



Power performances



CW tunability



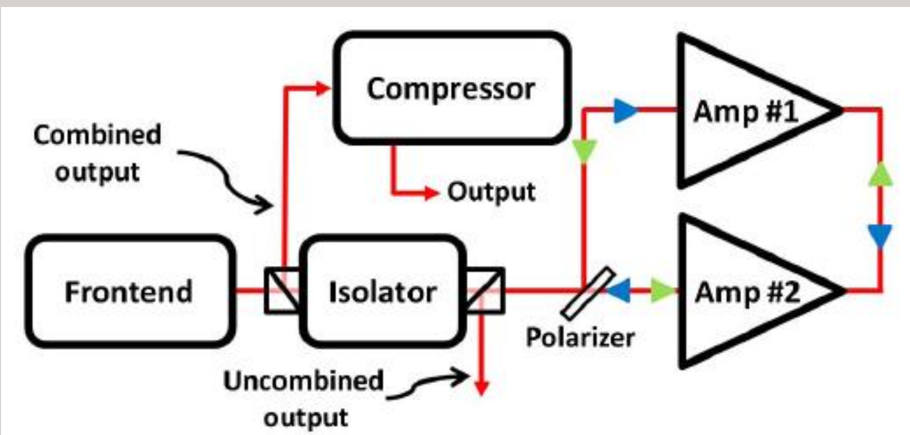
Coherent combining

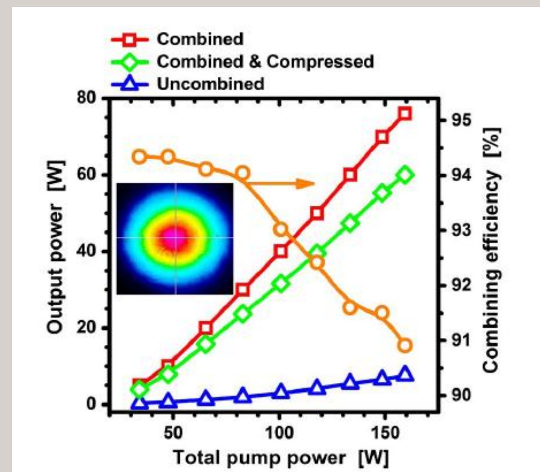
1460 OPTICS LETTERS / Vol. 37, No. 9 / May 1, 2012

Passive coherent combination of two ultrafast rod type fiber chirped pulse amplifiers

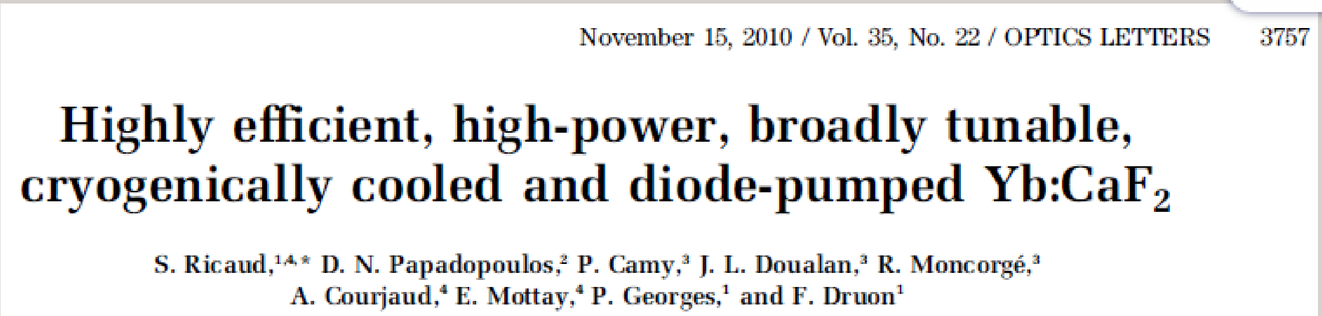
Y. Zaouter,[1,*] L. Daniault,[2] M. Hanna,[2] D. N. Papadopoulos,[3] F. Morin,[1] C. Hönninger,[1] F. Druon,[2] E. Mottay,[1] and P. Georges[2]

Up to 650µJ 300fs at 100kHz
Using 2 rod-type fibers, >90% combining efficiency
Fully passive architecture : high robustness





Cryo-cooled Yb:CaF_2


November 15, 2010 / Vol. 35, No. 22 / OPTICS LETTERS 3757

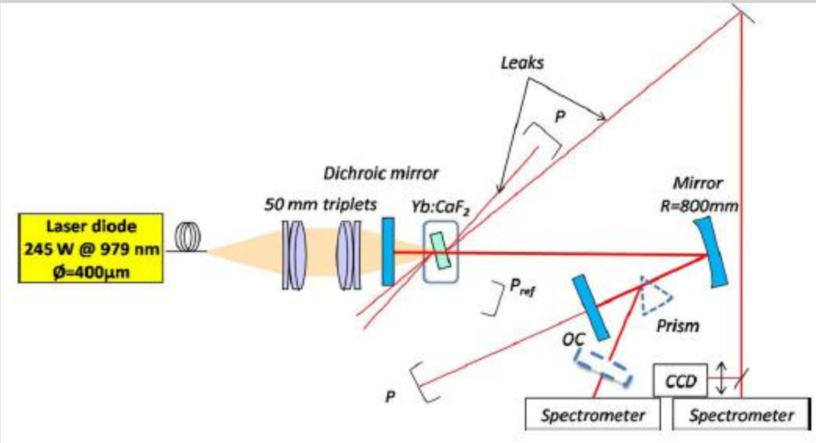
Highly efficient, high-power, broadly tunable, cryogenically cooled and diode-pumped Yb:CaF_2

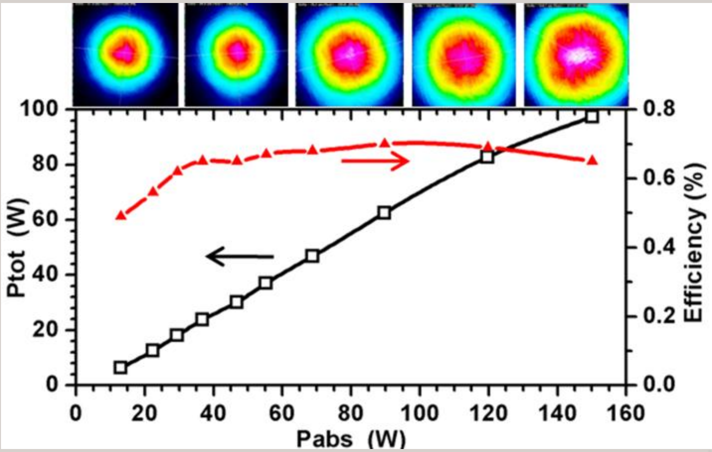
S. Ricaud,[1,4,*] D. N. Papadopoulos,[2] P. Camy,[3] J. L. Doualan,[3] R. Moncorgé,[3] A. Courjaud,[4] E. Mottay,[4] P. Georges,[1] and F. Druon[1]

Demonstration of 97W pumped with 245W

Collaboration between LCFIO, CIMAP and Amplitude Systemes

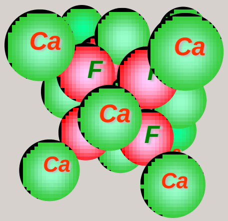
Moderate thermal lensing

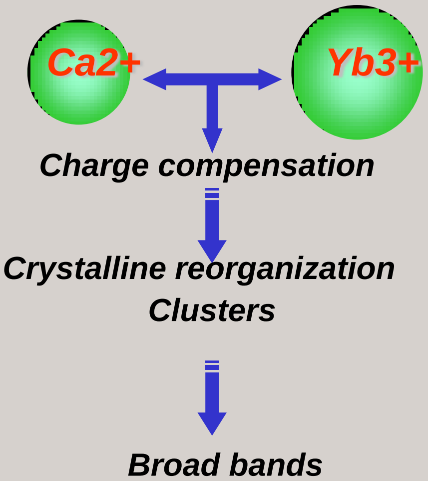


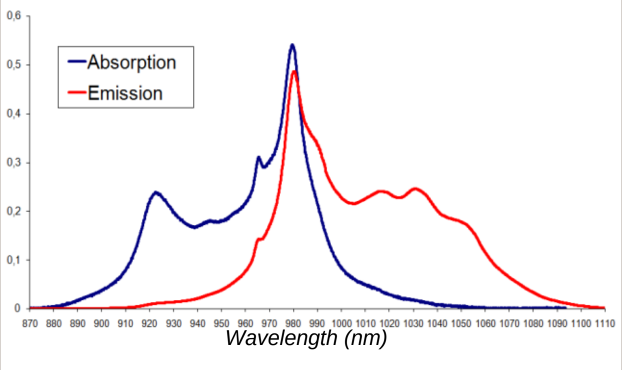


Yb:CaF_2 : broadband material

Multisite





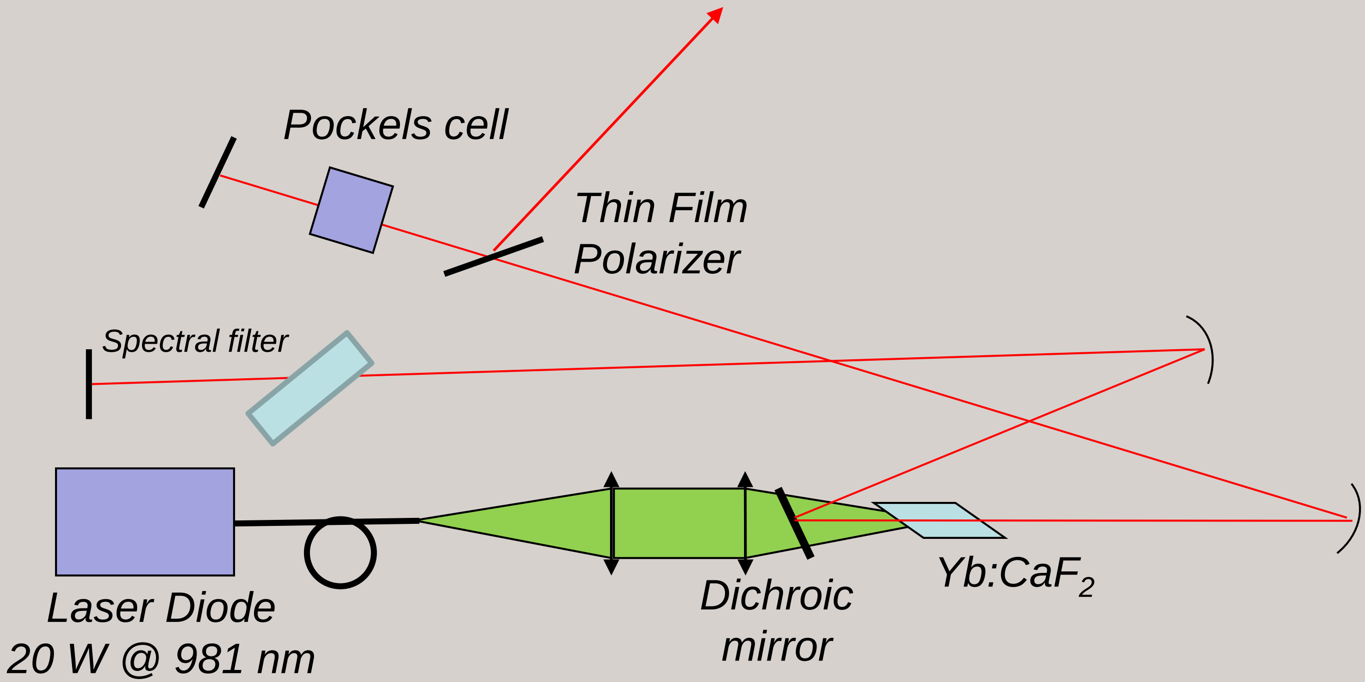


Experimental demonstrations (room temperature):

- Tunability CW : 1018 – 1072 nm
  *Lucca et al, Opt Lett, **29**, 1879 (2004)*
- Femtosecond oscillator : 150 fs @ 1043 nm
  *Lucca et al, Opt Lett, **29**, 2767 (2004)*
- High energy amplification : 190 mJ 190 fs @1Hz
  Siebold et al, Opt Lett, 33, 2770 (2008)
- High rep rate CPA laser: 0,7 mJ 180 fs @100-10kHz
  Ricaud et al, Opt Lett, 35, 2415 (2010)

Interest for higher intensities **and** high repetition rate

Experimental setup



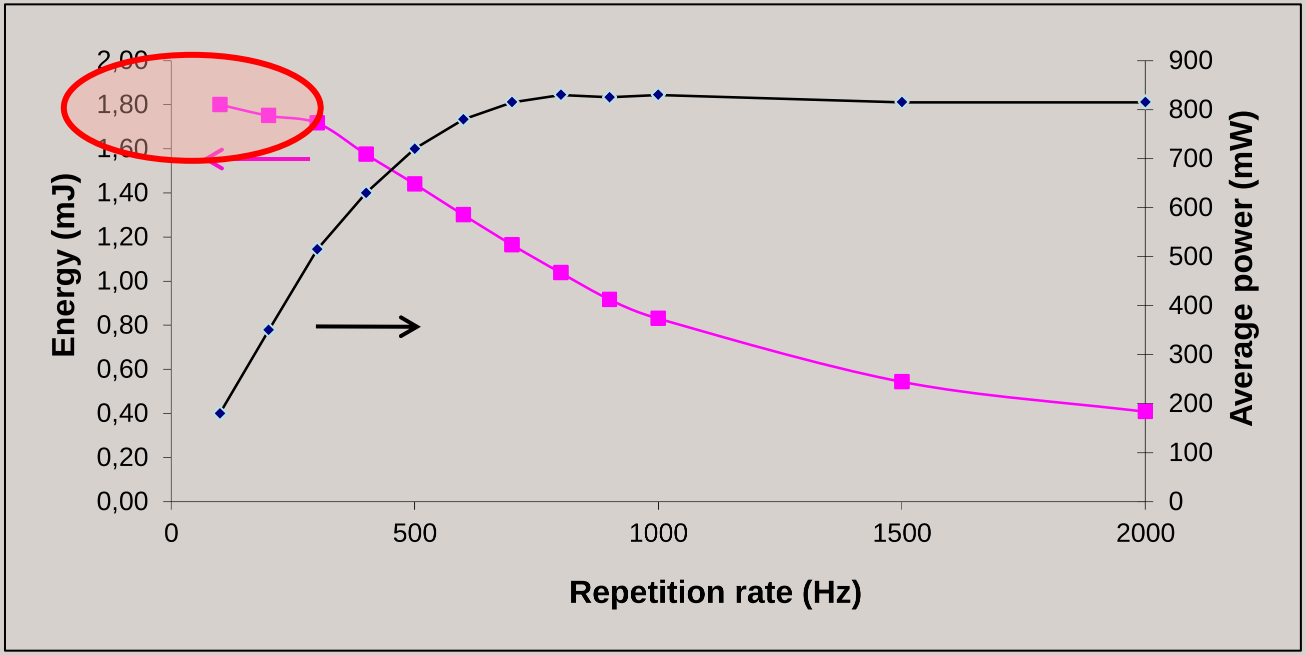
Zero-line pumping for lower heat deposition

Yb:CaF_2 : 2,5 to 4,5% doping concentration, 3 to 5mm thickness

Conductively cooled on a water cooled baseplate

Energy vs repetition rate

Typical performances : Energy vs repetition rate



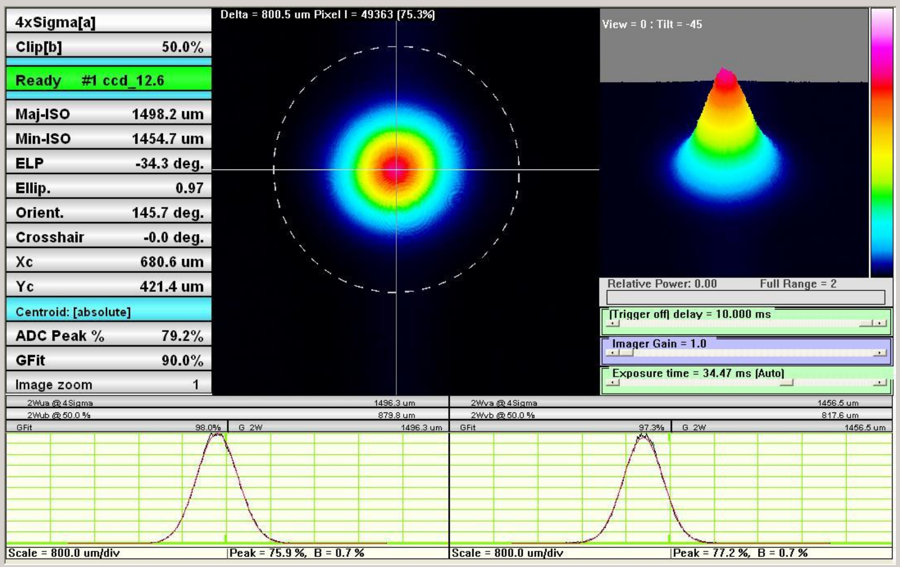
Pulse duration : 10ns (roundtrip time)

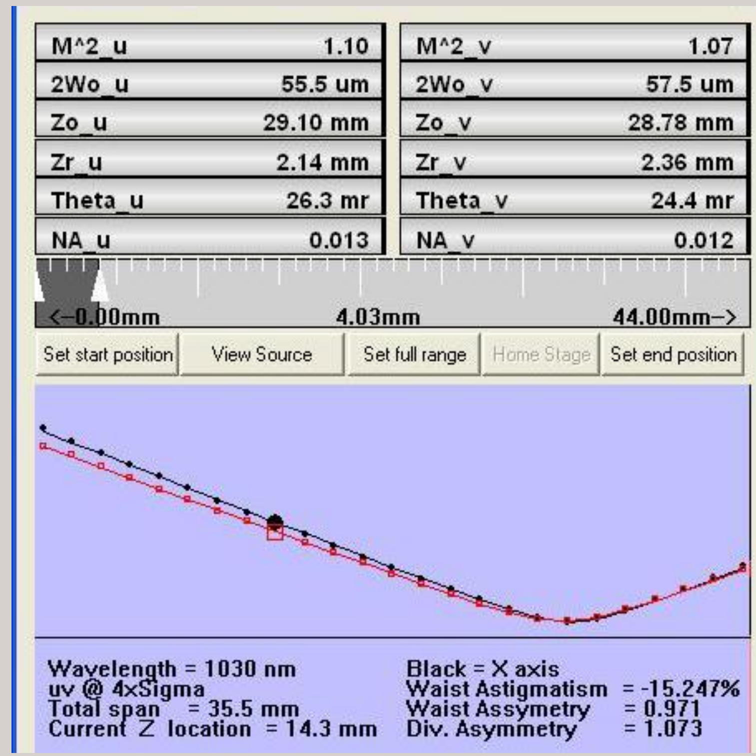
High extracted energy for moderate pump power (<10W)

Optimum repetition rate ~ 300 Hz

Beam quality

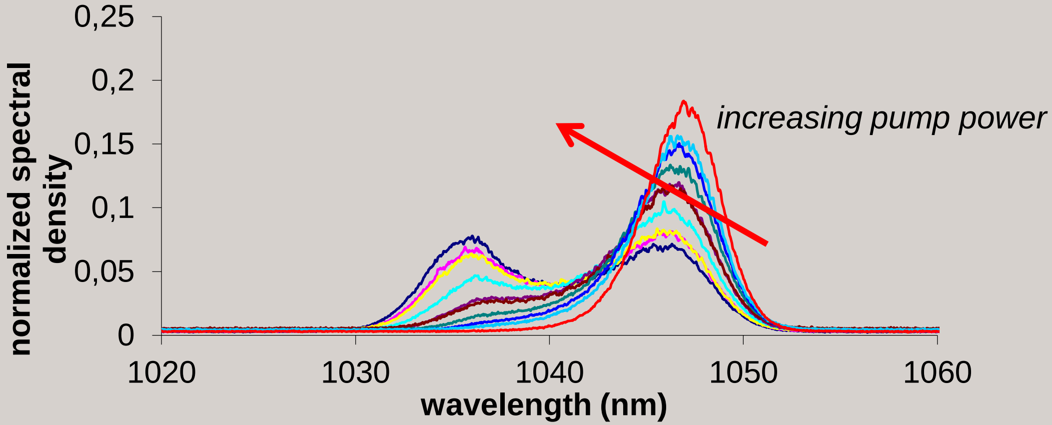
Excellent beam quality : M^2=1.10 x 1.07



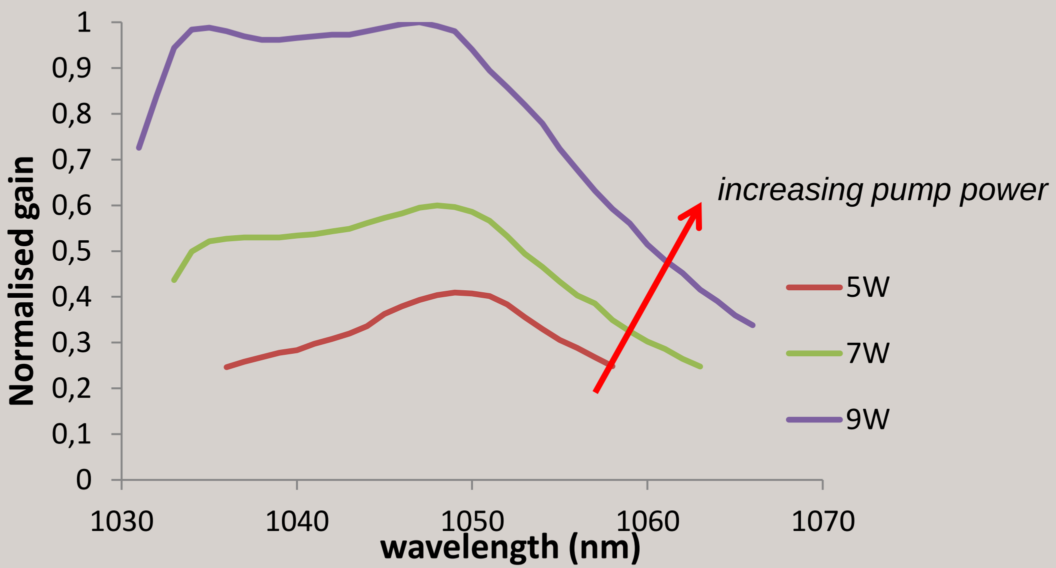


Spectral investigations

Qswitched output spectrum depends on pumping conditions



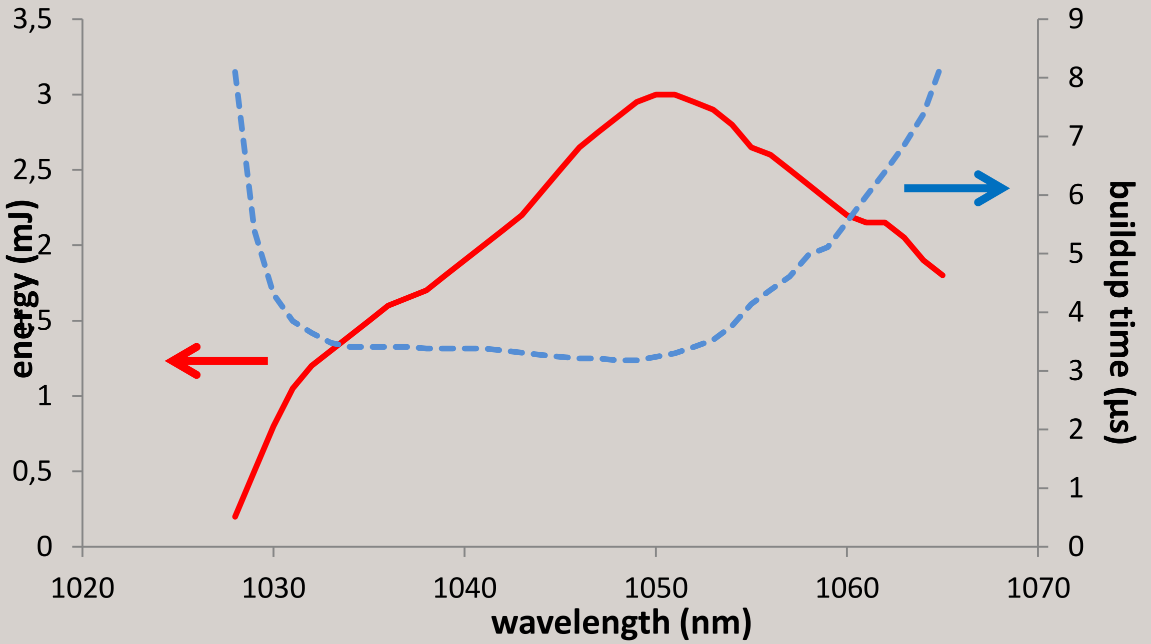
Spectral gain measurement confirms broadband spectral gain



Tunability

Up to 3mJ extracted at 100Hz for 10W pumping

Tunable between 1030 and 1065nm, max @1050nm!

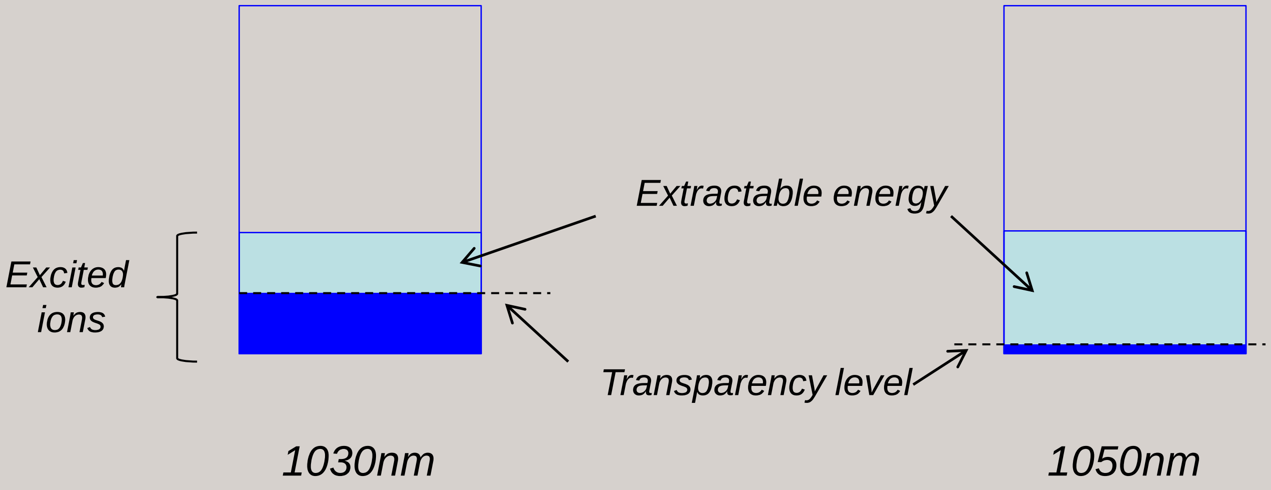


Discussion

Optimum of energy at 1050nm

➡ trade-off between gain and extractable energy

Specific to Quasi Three Level nature



Femtosecond regime

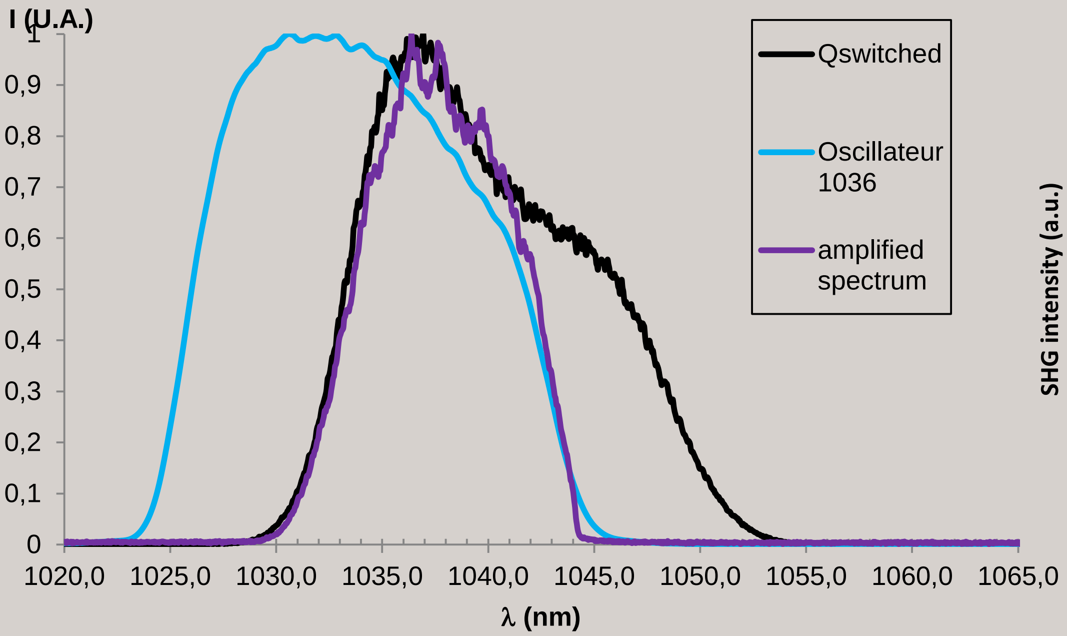
Improved design for 5mJ regenerative amplification (17W CW pump power)

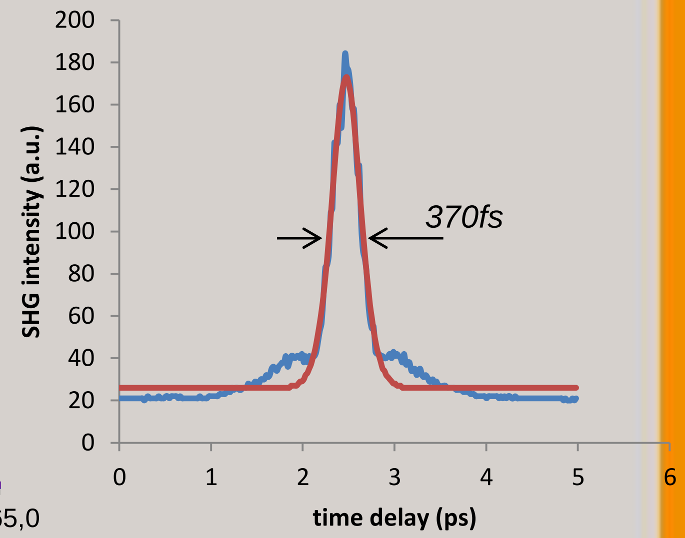
Seeded by fiber oscillators
- Compacity and integrability
- Investigate 2 different spectral ranges : 1034nm and 1053nm

Diffraction grating stretcher & compressor :
- Flexible and compact architecture
- ~300ps stretched pulses

Injection at 1034nm

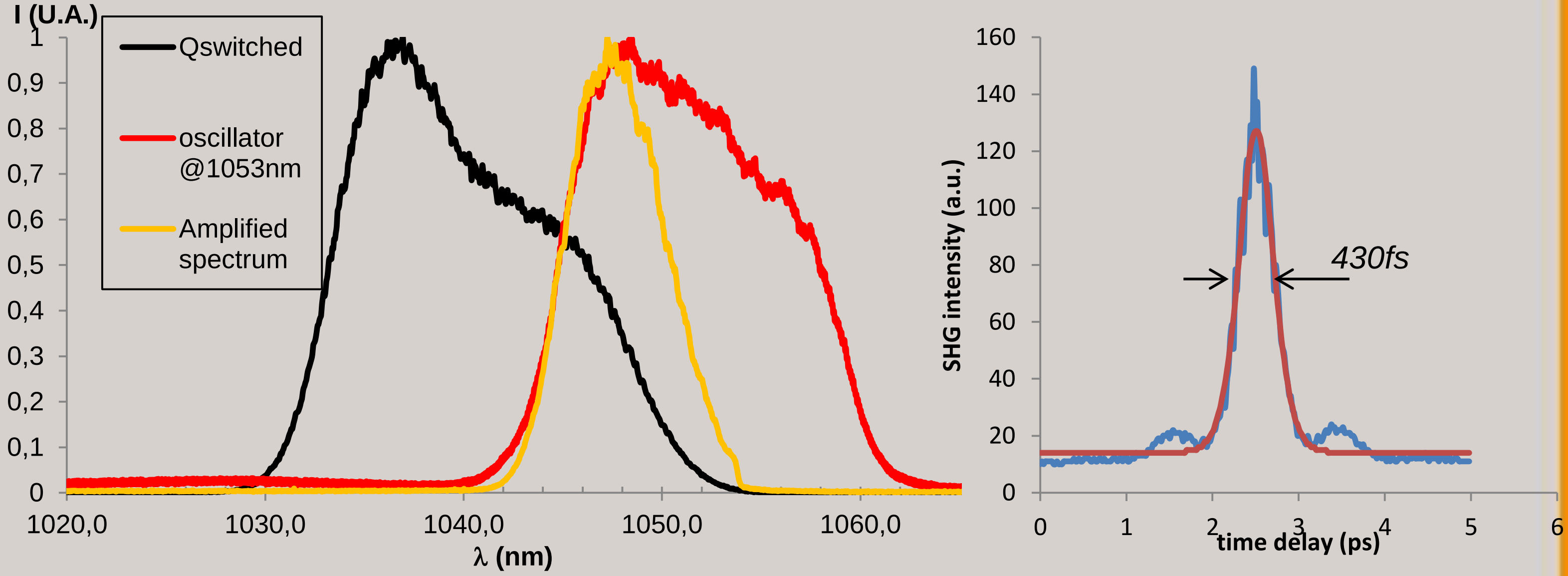
Oscillator #1 : injection with λ_0 = 1034nm
Amplification @ 1038nm , with 8,8nm bandwidth
2,5mJ recompressed energy (3,6mJ before compression) @100Hz
Recompressed pulses : 250fs





Injection at 1053nm

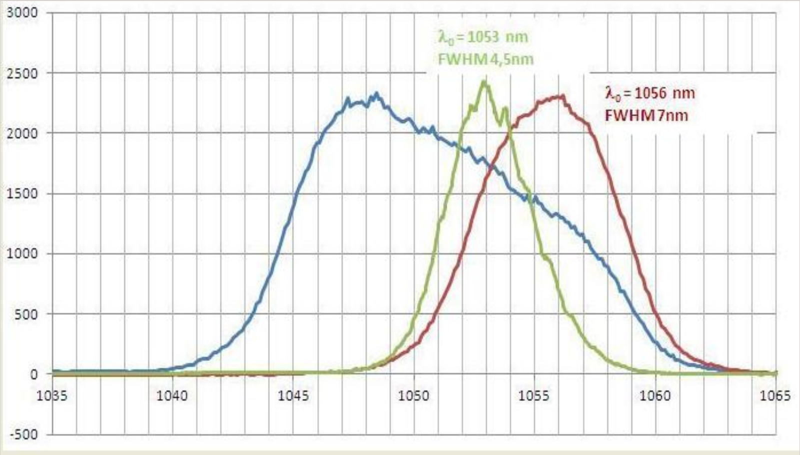
Oscillator #2 : injection with λ_0 = 1053nm
Amplification @ 1048nm , with 6nm bandwidth
3,2mJ recompressed energy (4,8mJ before compression) @100Hz
Recompressed pulses : 320fs



Extension to 1053nm

Interest for damage threshold tests in the femtosecond regime
1053nm required for specific components (gratings, filters…)
100Hz allows long term testing

Use the same oscillator centered at 1053nm
Use spectral shaping before amplification



2mJ compressed energy @1053nm @100Hz
Recompressed pulses : 600fs for 3,5nm bandwidth

Conclusion & Outlook

Broadly tunable ns laser from 1030-1065nm at millijoule level

→ *good seeder for high energy lasers*

10GW class femtosecond lasers at 10-300Hz

→ *enlarging the laser portfolio*

2mJ 600fs achieved @1053nm

→ *for Nd:glass laser components qualification*

Outlook :

Improve the thermal management for higher average power

Thank you for your attention !

ISO 9001
BUREAU VERITAS
Certification

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