High power ultrafast lasers

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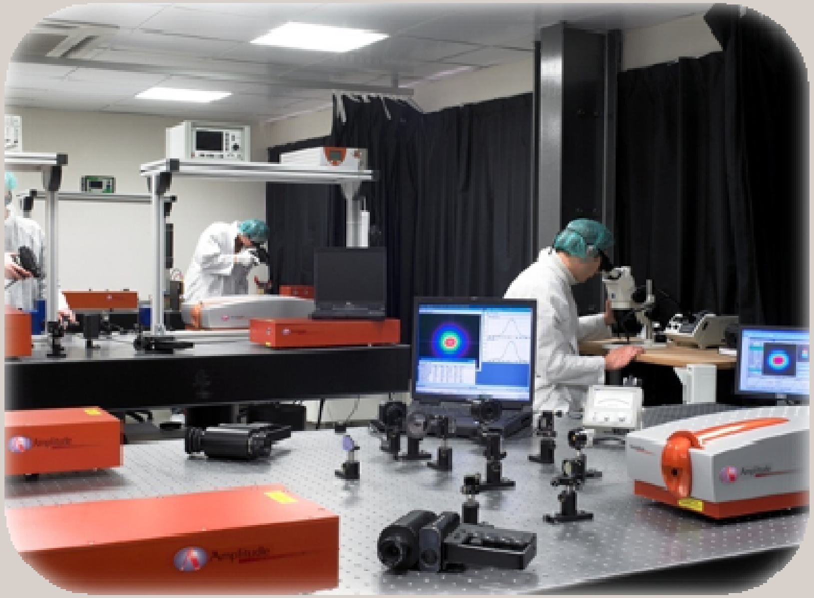
High Brightness Laser sources
Burgdorf, November 26, 2009

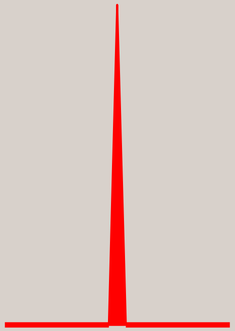
Company

- Pioneer in Ytterbium ultrafast lasers
- High quality manufacturing
- Intense and active R&D



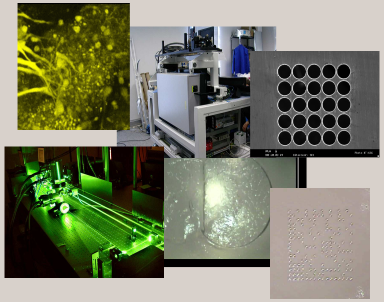
- Located in Bordeaux and Paris
- US offices in Boston and San Diego
- Worldwide offices and agents

Why ultrafast lasers ?

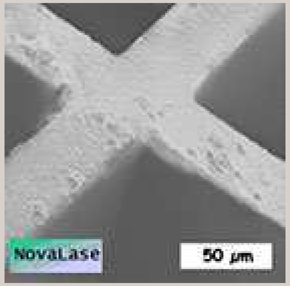


$$P = E / t$$

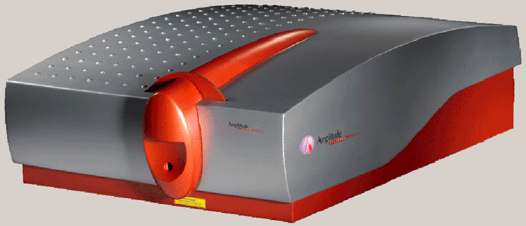
High power: Applications



Short duration: Quality and precision



Low energy: Compact lasers



Process development

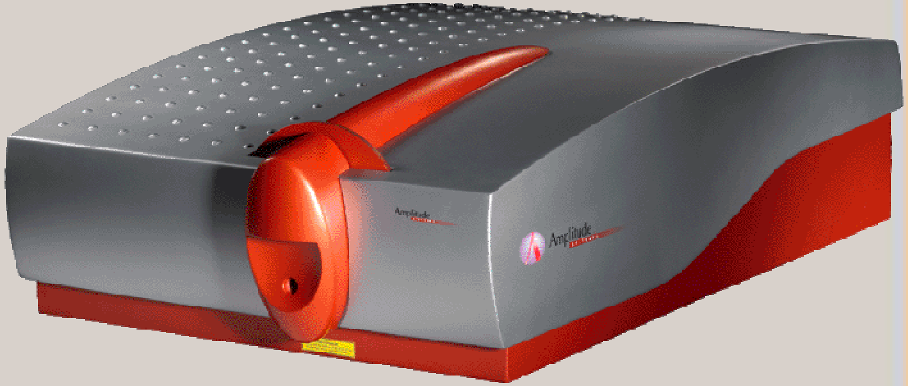
- Required laser parameters may vary by orders of magnitude:
  - Pulse duration from 100 fs to 10 ps
  - Repetition rate from single shot to MHz
  - Pulse energy from µJ to mJ

- Process development requires a flexible laser source.

Femtosecond amplifier s-Pulse HP

A flexible, user-friendly laser for material processing

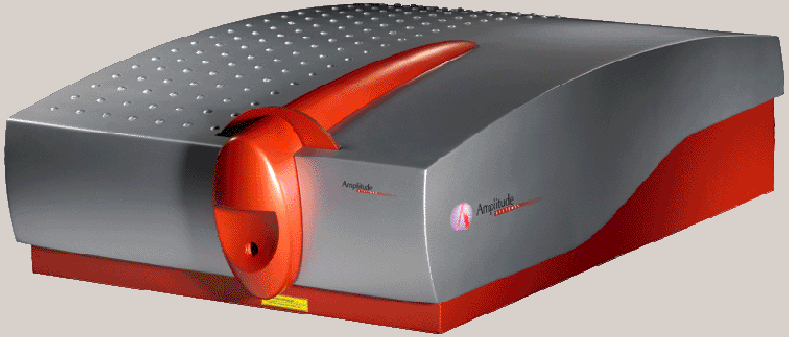
- High performance
  - High speed: ~0-300 kHz
  - High pulse energy: 1 mJ
  - Short pulse duration: 500 fs
  - Small footprint 50x75 cm



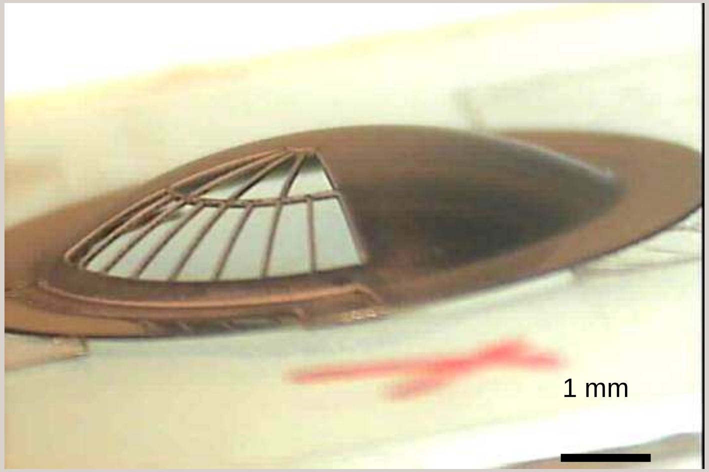
- User control of key parameters
  - Full computer control
  - Pulse duration from femtosecond to picosecond
  - Repetition rate from 0 to 300 kHz
  - Pulse energy from 0 to 1 mJ
  - Internal or external trigger

Dedicated ultrafast lasers

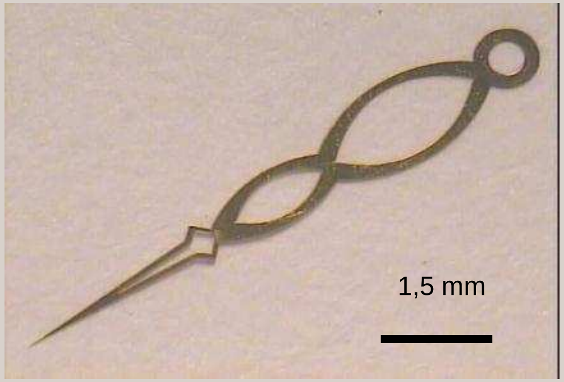
Product	**s-Pulse**	**s-pulse HR**	**s-Pulse PS**	**s-Pulse HP**
Pulse energy	> 100 µJ	> 10 µJ	> 50 µJ	> 1 mJ
Repetition rate	1-10 kHz	100 kHz	300 kHz	1-300 kHz
Pulse duration	< 400 fs	< 400 fs	< 3ps	< 500 fs
Footprint (cm)	50x75	50x75	50x75	50x75



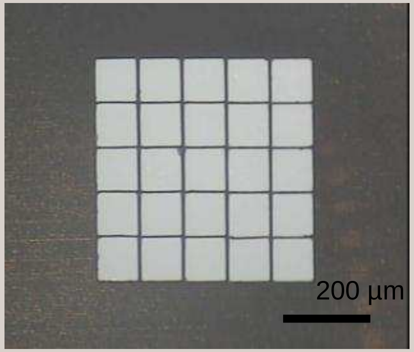
Micromachining examples



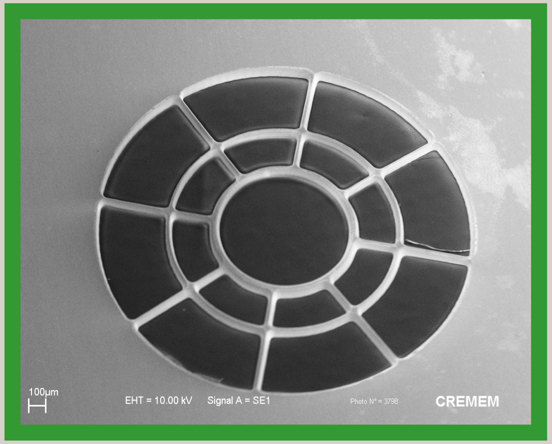
Metal - thickness.50µm
Bars width 90µm



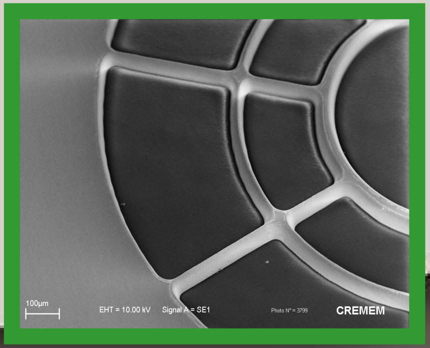
Gold - thickness.25µm



Platin - thickness.10µm
Bars width 10µm



Tungsten - thickness. 100µm
Bars : 100µm

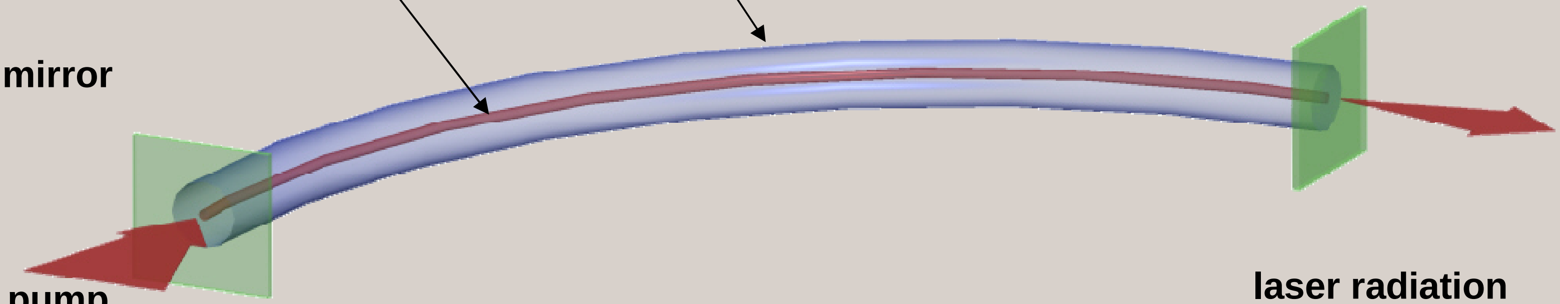


Ultrafast fiber lasers

- High average power cw and ns fiber lasers have gained wide acceptance in the industry

- What about ultrafast fiber lasers?
  - What are their limitations?
  - Can we overcome these limitations?

High power fiber lasers



cladding

active core

mirror

mirror

pump
light

laser radiation

Average power	☺	High exchange area
Beam quality	☺	Guided optics
Pulse energy	☹	**Non linear effects**

Development strategy

$$NL \propto \frac{L}{A_{eff}} I$$

Classic approach: minimize non linear effects

Development strategy

Non linear effects can be used to improve laser performance

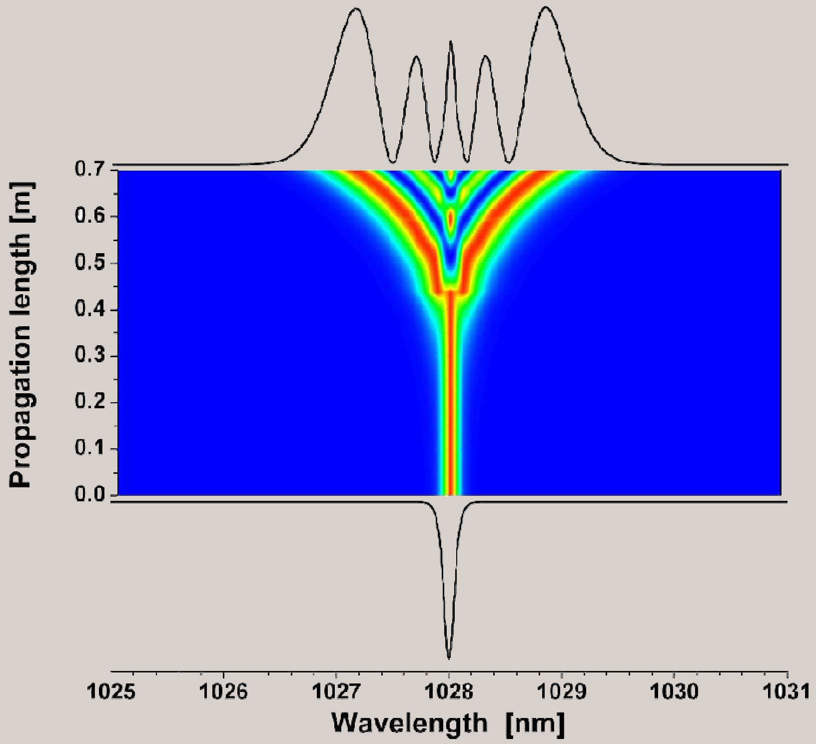
- **Spectral compression**
  Non linearity reduces pulse spectral width

- **Parabolic amplification**
  Non linearity reduces pulse duration

- **Chirped pulse amplification**
  Non linearity improves pulse quality

Spectral compression

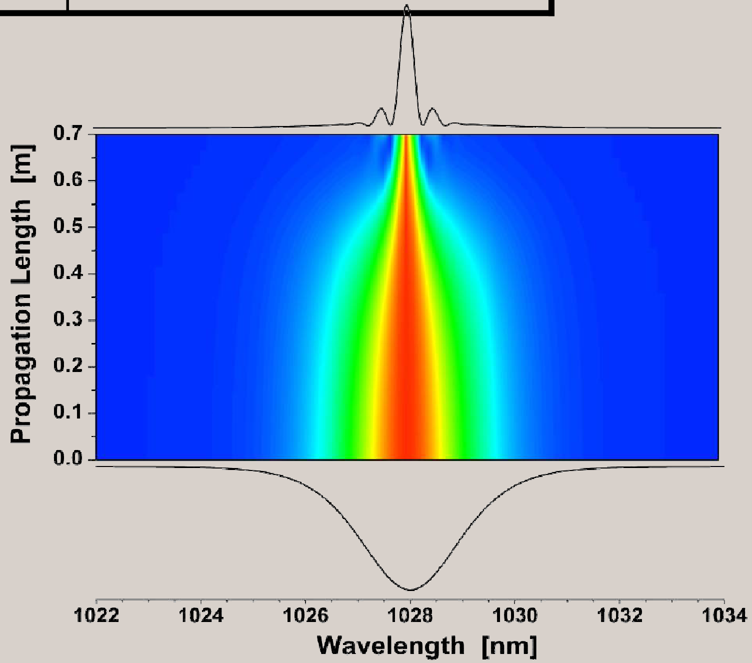
- Goal: picosecond laser with narrow spectral width for efficient frequency conversion
- Direct amplification of picosecond pulses lead to spectral broadening



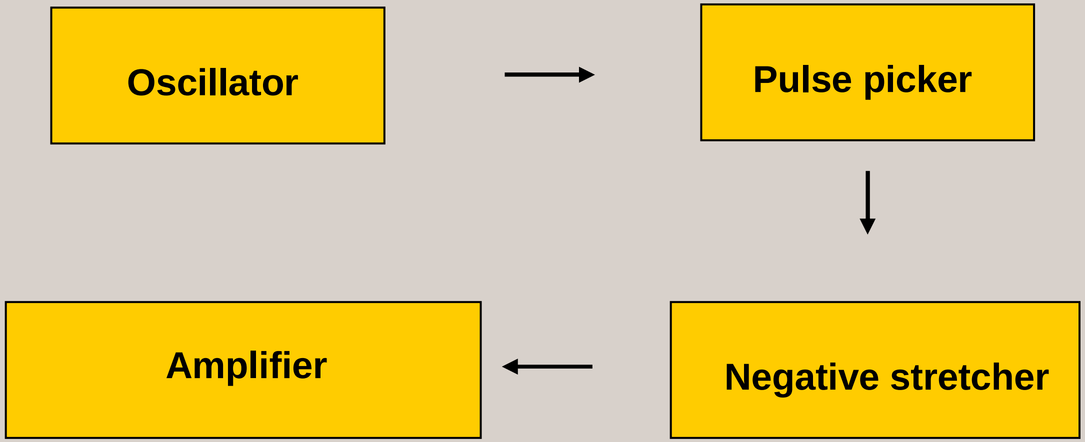
Spectral compression

	Oscillator	Stretcher	Amplifier
Duration	femtosecond	picosecond	picosecond
Spectrum	broad	broad	narrow

Self phase modulation compensate for initial negative pulse stretching



Experimental results



Oscillator

Pulse picker

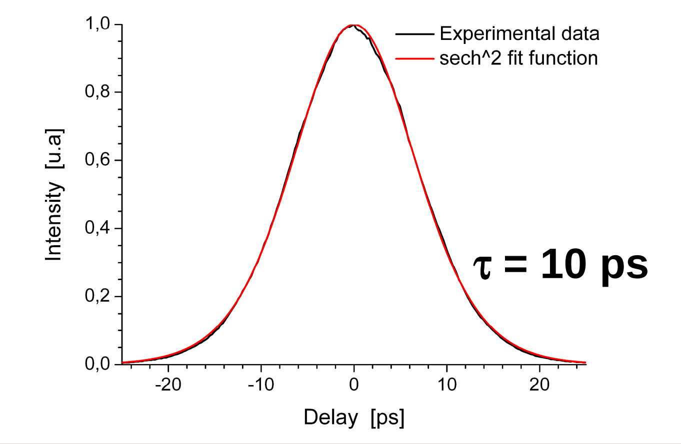
Negative stretcher

Amplifier

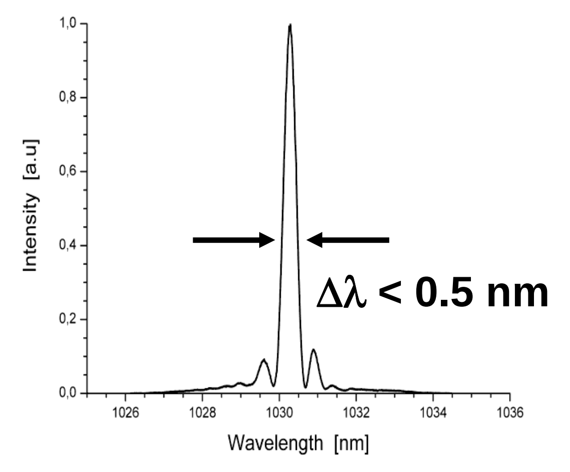
30W, 10 µJ, 10 ps

"High-power picosecond fiber amplifier based on nonlinear spectral compression",
Opt. Lett. **30**, 7, 2005

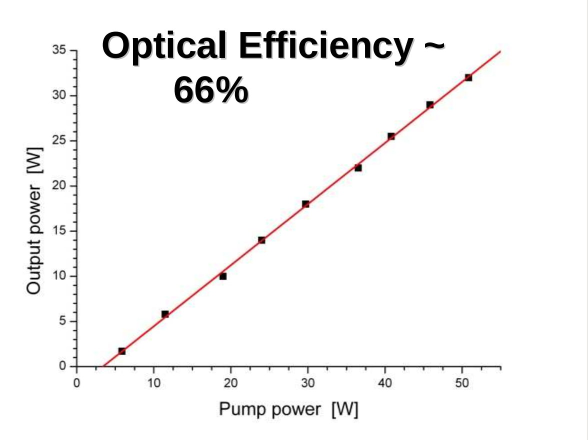
Experimental results



τ = 10 ps



$\Delta\lambda < 0.5$ nm

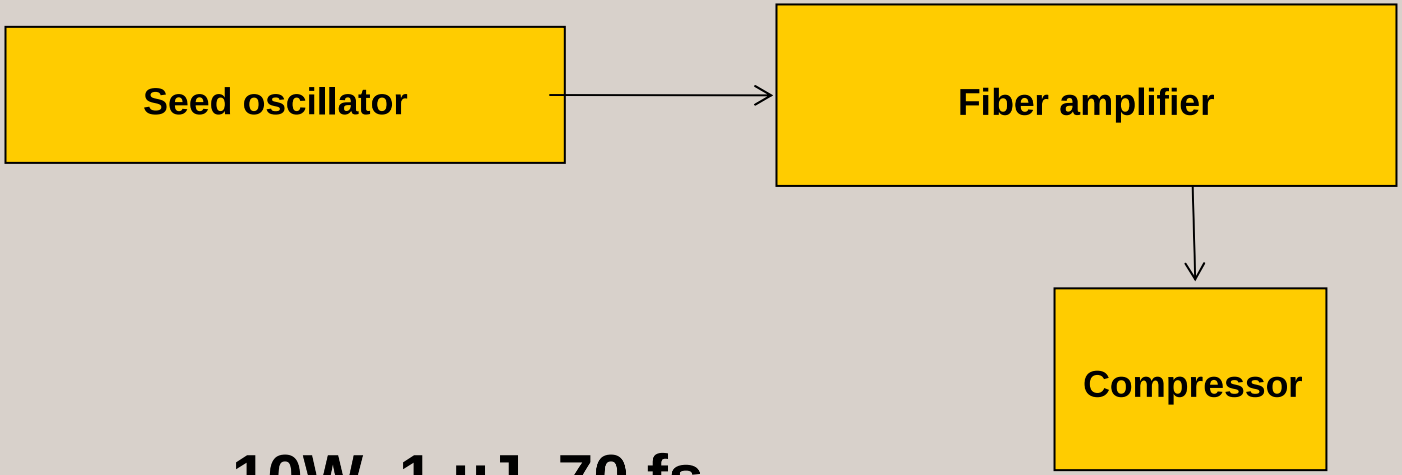


Optical Efficiency ~ 66%

30W, 10 µJ, 10 ps

"High-power picosecond fiber amplifier based on nonlinear spectral compression", Opt. Lett. **30**, 7, 2005

Parabolic amplification



Seed oscillator

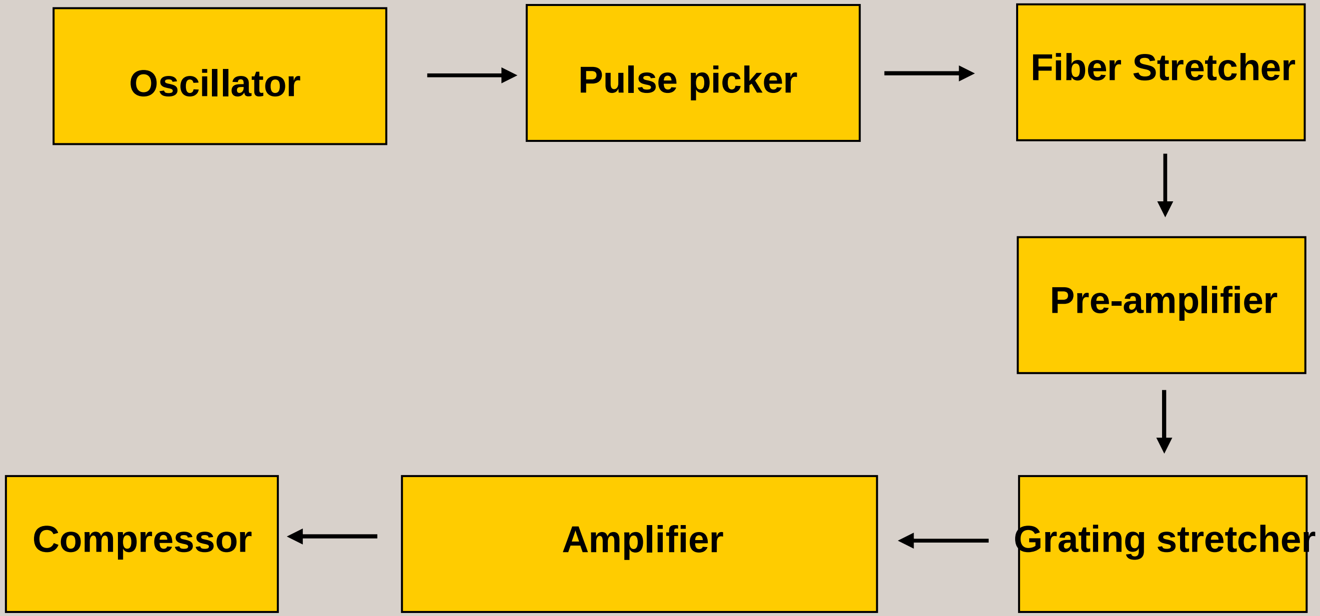
Fiber amplifier

Compressor

10W, 1 µJ, 70 fs

"Generation of 63 fs 4.1 MW peak power pulses from a parabolic fiber amplifier operated beyond the gain bandwidth limit",
Opt. Lett. **32**, 17, 2007

Nonlinear chirped pulse amplification



Oscillator → Pulse picker → Fiber Stretcher

↓

Pre-amplifier

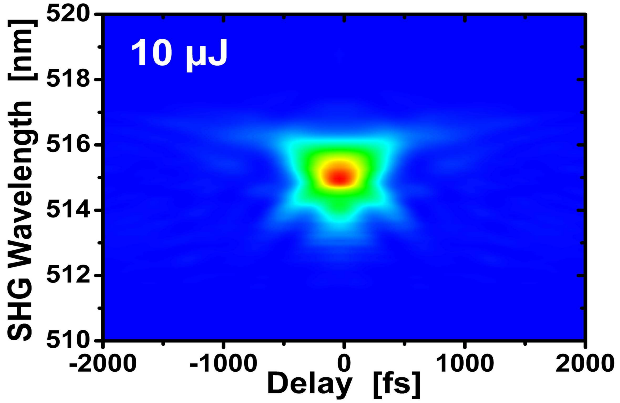
↓

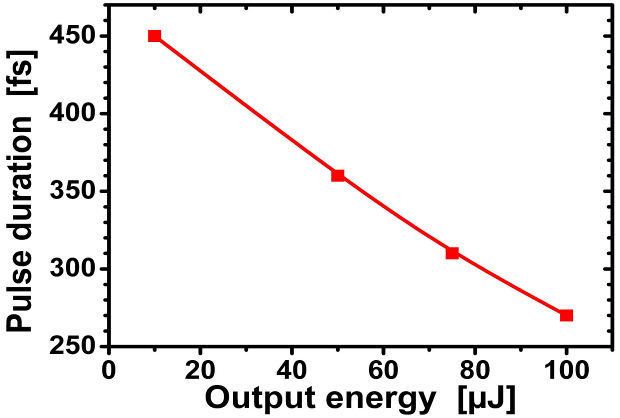
Grating stretcher → Amplifier → Compressor

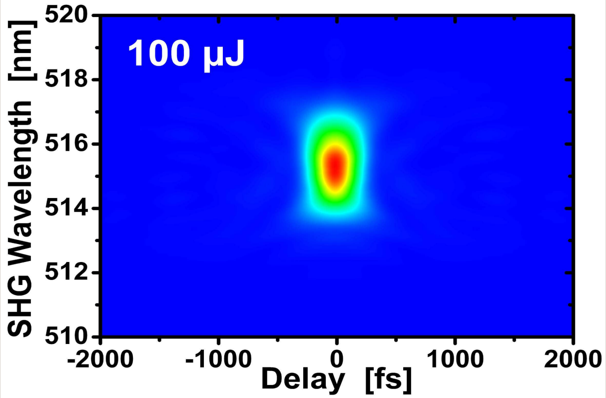
Non linear compensation between fiber stretcher, mismatched gratings and fiber amplifiers

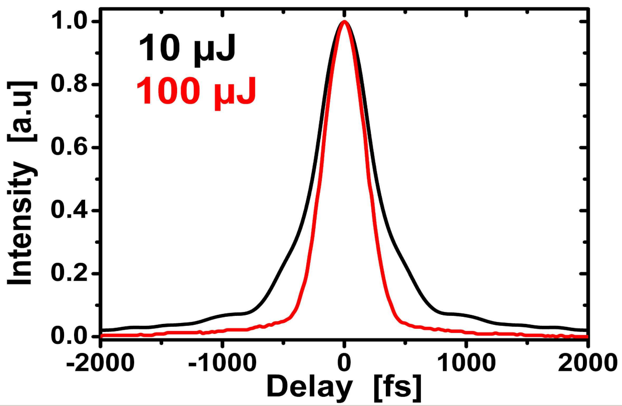
Non linear optimisation

- Adjust compressor gratings separation and stretcher grating angle to compensate for non linear effects in fiber

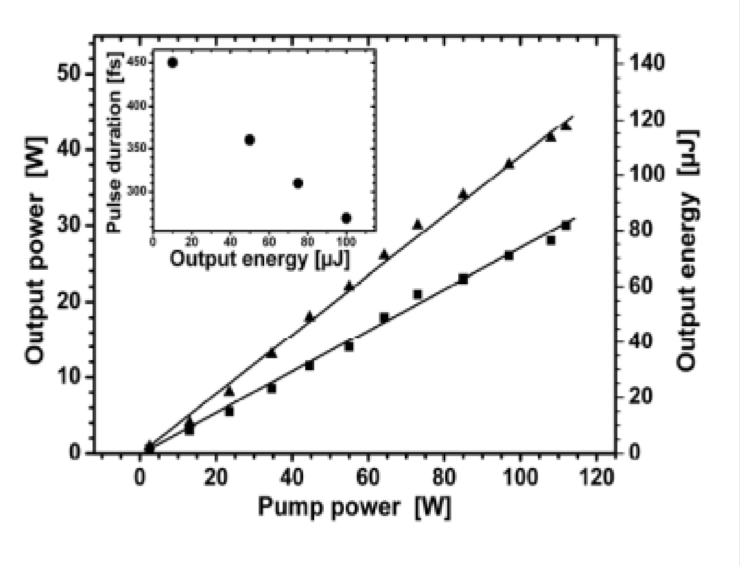


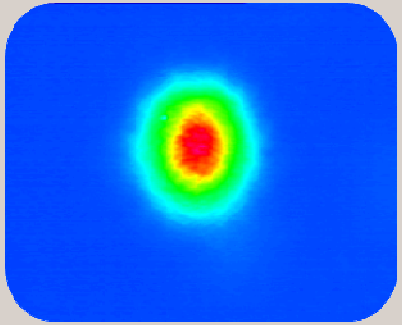




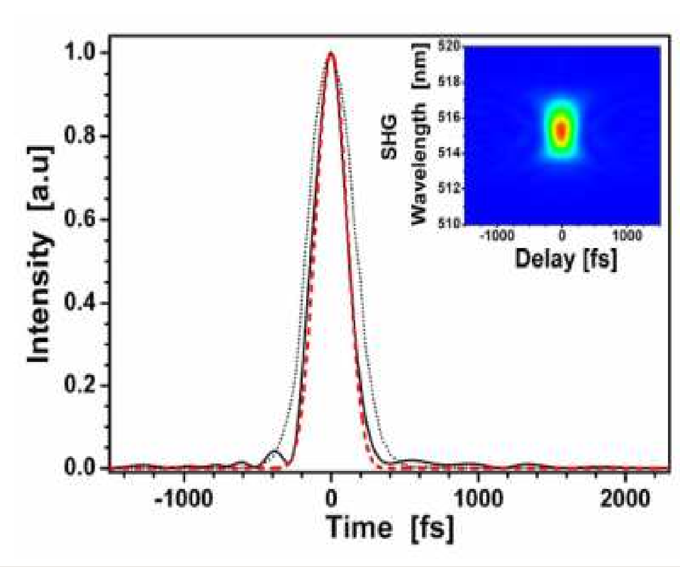


Experimental results





30W, 100 µJ, 290 fs



"100 µJ, 340 MW transform-limited pulses from a non-linear fibre chirped pulse amplifier using mismatched grating stretcher/compressor", Opt. Lett. **33**, 13 (2008)

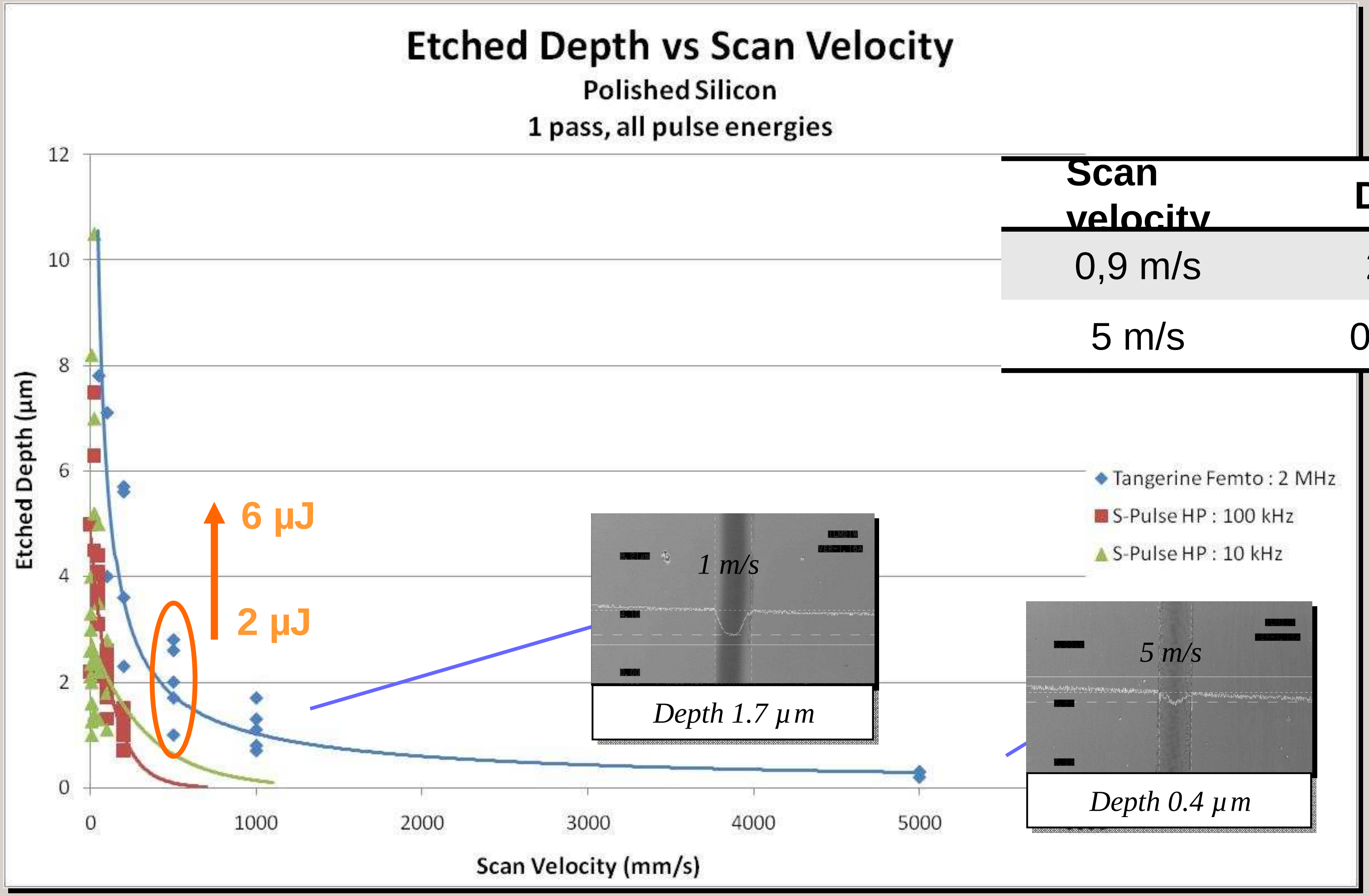
State of the art

Presentation #	Tangerine fs	Tangerine ps	Tangerine sp	Satsuma
Average power	20 W	20W	15 W	5 W
Pulse energy	50 µJ	10 µJ	500 nJ	10 µJ
Pulse duration	700 fs	10 ps	<100 fs	< 300 fs
Repetition rate	2 MHz	2 MHz	30 MHz	1 MHz

Outline

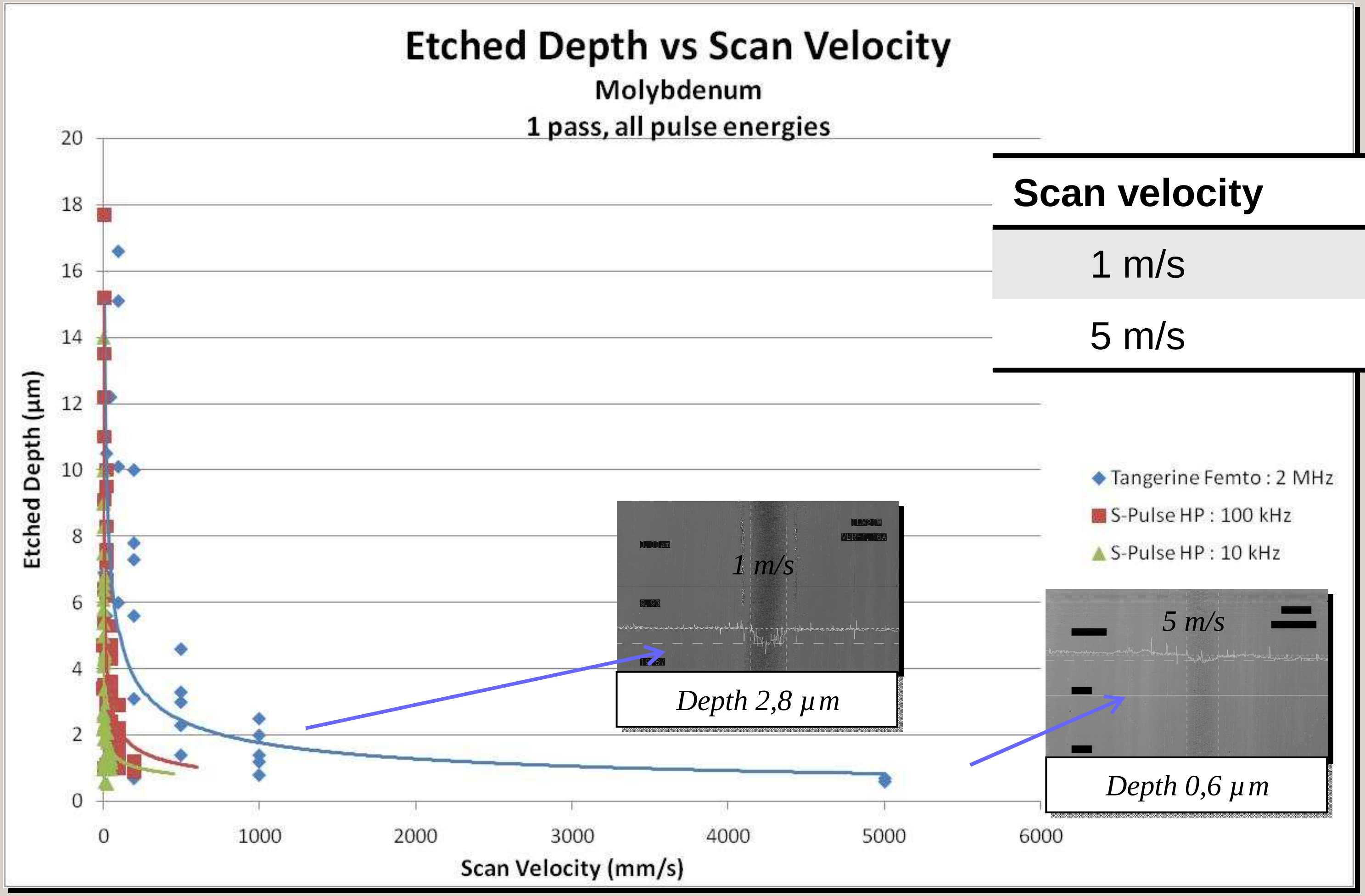
- Introduction
- Process development
- Industrial productivity
- **High speed engraving of metal and silicon**

Etch depth vs. Scan velocity For Silicon target



Scan velocity	Depth
0,9 m/s	2 µm
5 m/s	0.4 µm

Etch depth vs. Scan velocity
For Molybdenum target



Scan velocity	Depth
1 m/s	2 µm
5 m/s	0.6 µm

Pico- and femtosecond comparison

- Pulse energy 3µJ @2MHz, spot diameter 40 µm
- Molybdenum target
- Pulse duration 10ps and 500fs

Pulse duration	Energy	Peak power	Peak power density (spot 40µm)	Ablation rate
10 ps	3 µJ	0.3 MW	24 GW/cm²	0.03 mm³/min 0.2 nm/pulse
500 fs	3 µJ	6 MW	480 GW/cm²	0.87 mm³/min 6 nm/pulse

x20

x30

- In these conditions, fs regime is much more efficient than ps regime.

- To achieve the same removal rate, ps operation required a higher fluence, hence a higher average power

Conclusion

- Development of advanced process in ultrafast micromachining requires an extremely flexible laser system

- Industrial productivity requires high average power ultrafast lasers

- High speed engraving is demonstrated with a high average power fiber laser. In this specific experiment, femtosecond pulse duration is much more efficient than picosecond.

- Continuous advances in process development are required to take full advantage of available average laser power.

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