OPTICS:
OPTical **I**BS **C**oatings for **S**wiss research

UNIVERSITÉ DE NEUCHÂTEL

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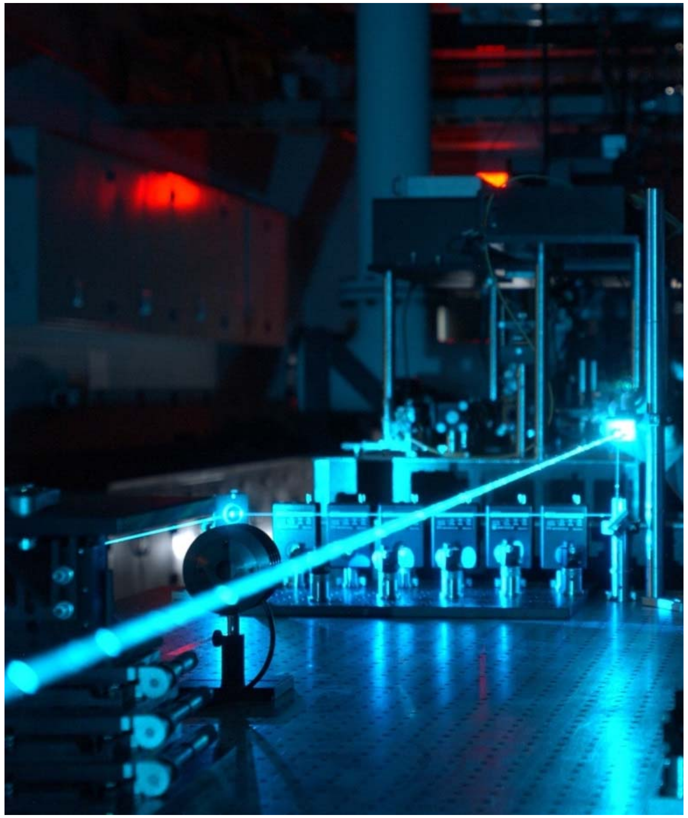
Time/Frequency Laboratory, Physics Institute, University of Neuchatel

Workshop on Optical Coatings for Laser Applications, June 11, 2015, Buchs

The Time/Frequency Laboratory at the University of Neuchâtel

Time, light, extreme precision

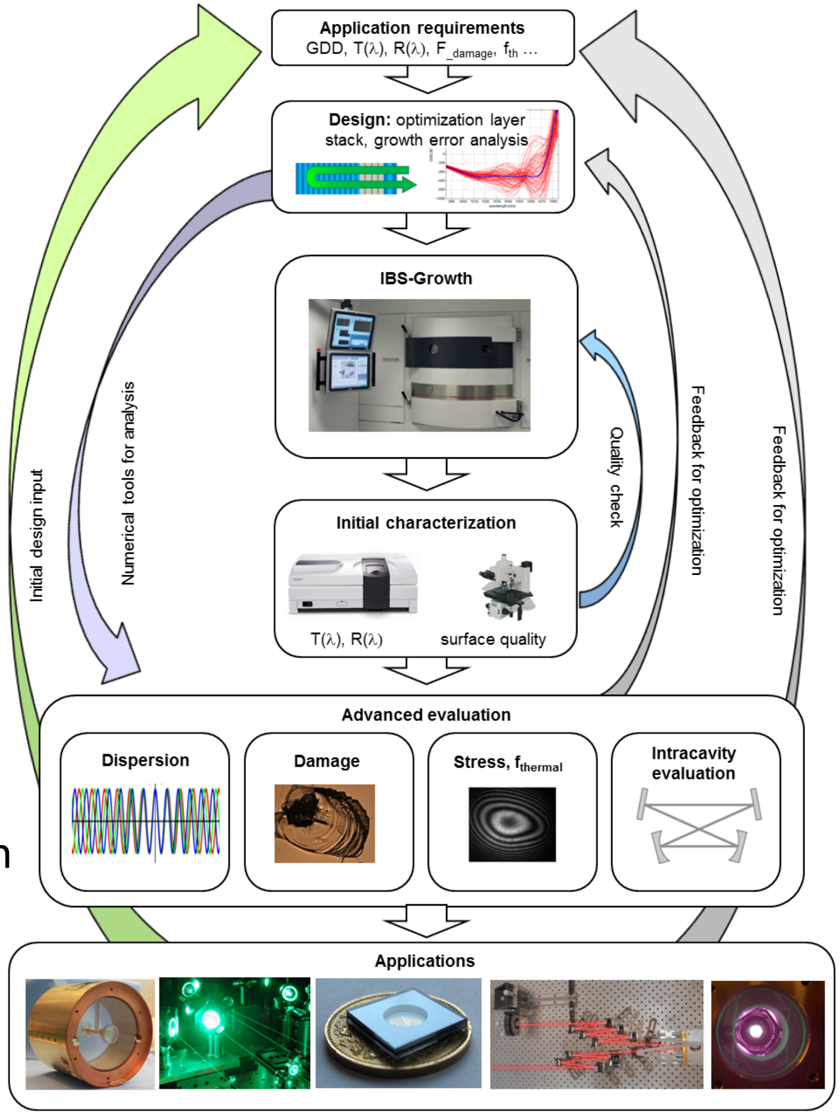


OPTICS: OPTical IBS Coatings for Swiss research

Target: develop new IBS solutions for research

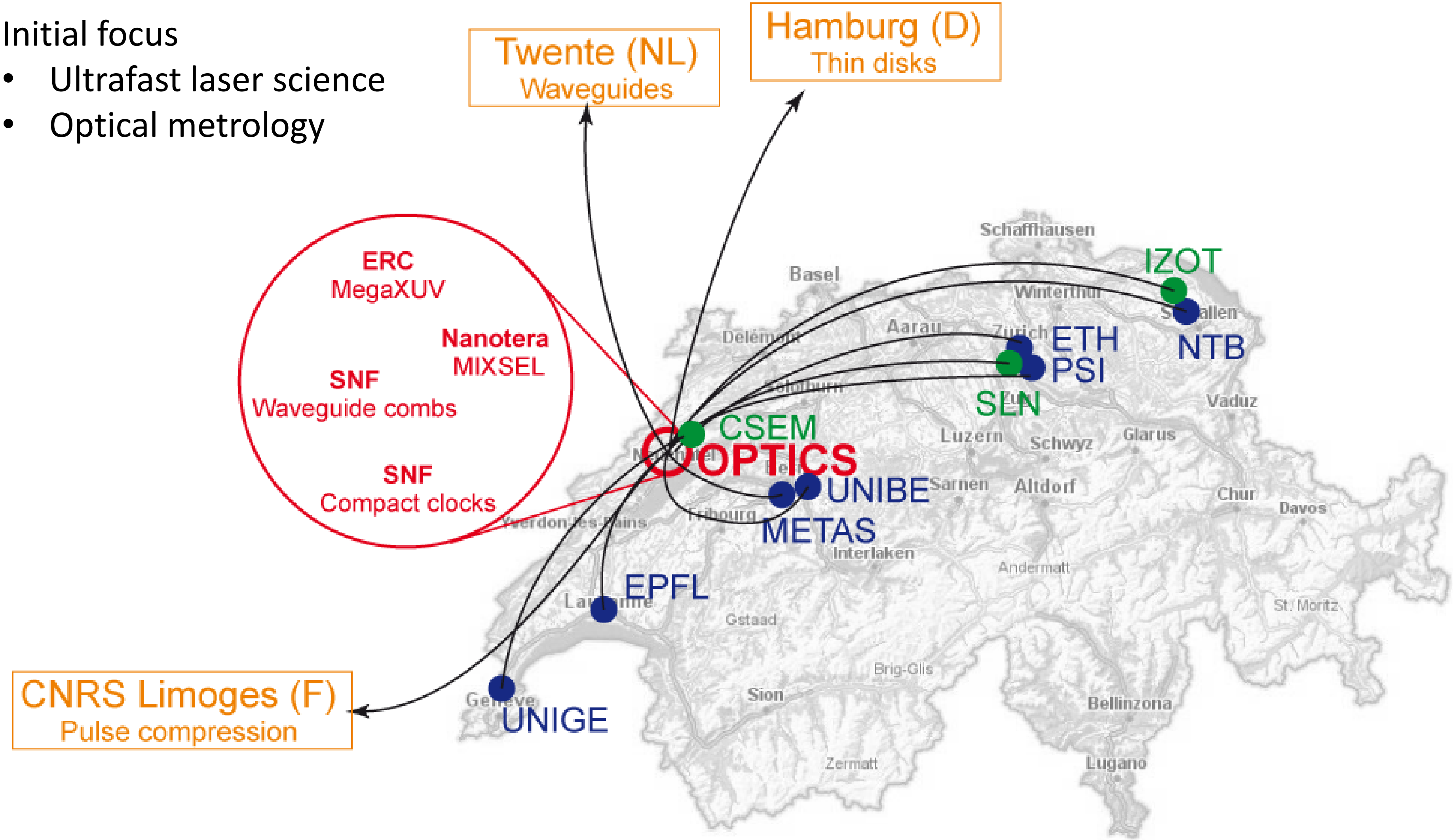
- IBS optimization with coating vendors
  - specific research solutions: low priority
  - time-consuming
  - expensive
  - growth parameters might vary

- OPTICS: provide fast development cycle
  - Analysis of application requirements
  - Optimized layer design
  - Growth on dedicated IBS machine
  - Full characterization
  - Immediate feedback to design & growth according to the needs of the application



OPTICS: OPTical IBS Coatings for Swiss research

Initial focus
- Ultrafast laser science
- Optical metrology



Overview

Introduction

Ultrafast lasers

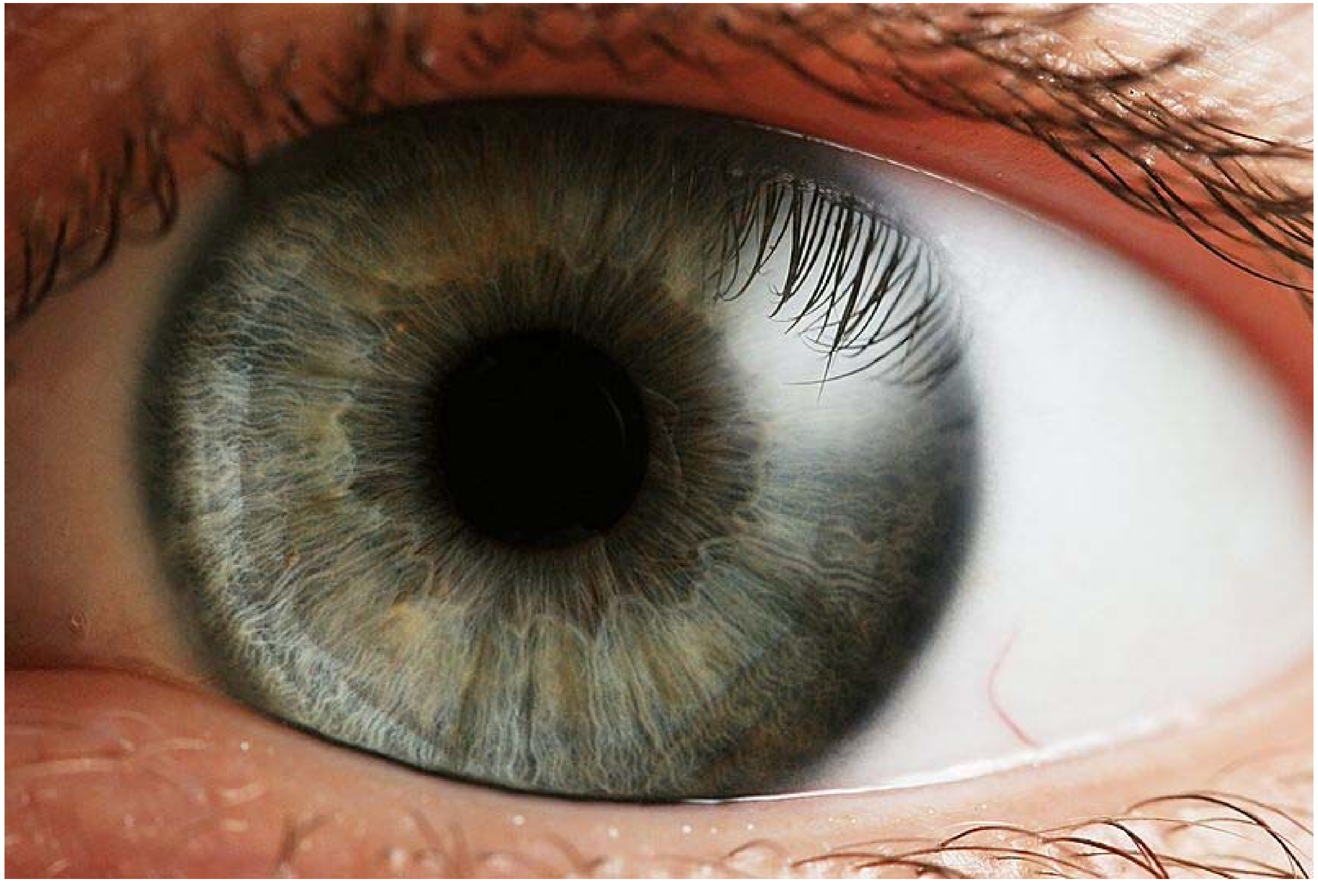
Ultrafast high power lasers and challenges for dielectric coatings

Analogies: MBE growth optimization at ETH

OPTICS: status and next steps

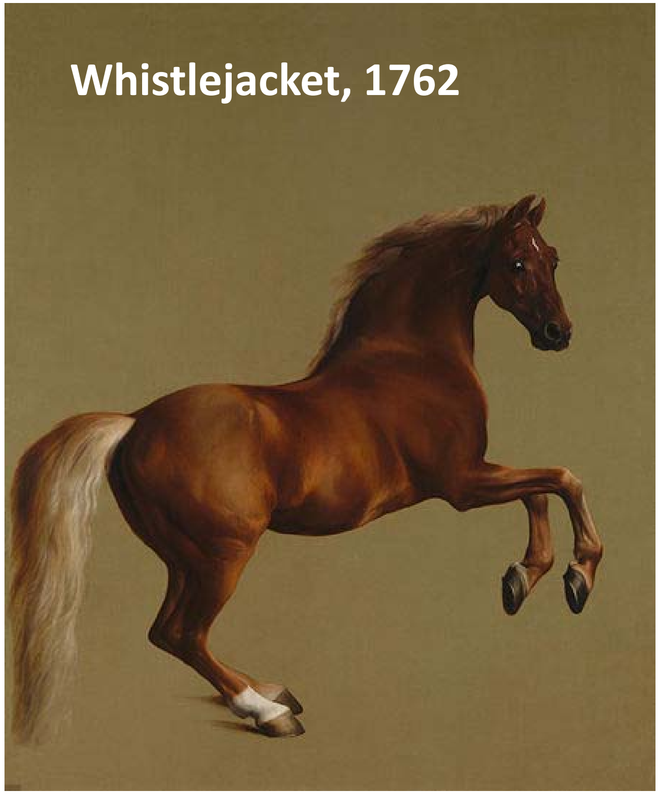
What is ULTRAFAST?

Resolving fast events



Cinema: time between images $\frac{1}{24\ \text{Hz}} = 42\ \text{ms}$

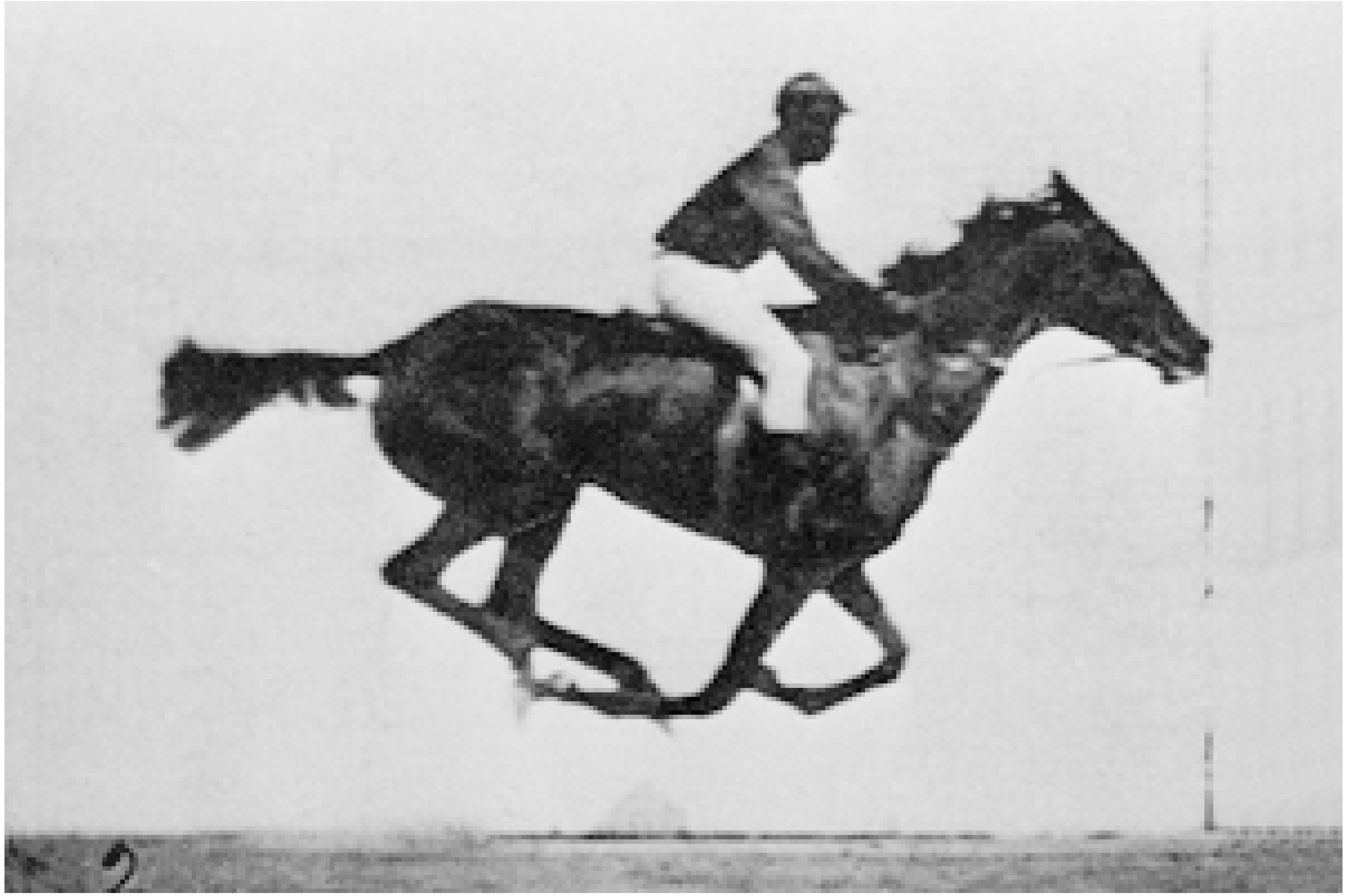
George Stubbs (1724-1806): English painter, best known for his paintings of horses.



www.wikipedia.org

Fast mechanical shutter photography

E. Muybridge in 1878:
understand horse gallop using fast photography in the ms-domain



Fast flash photography

Harold E. Edgerton (1903-1990):
understand fast processes using flash light (limited by duration of flashes to µs-domain)

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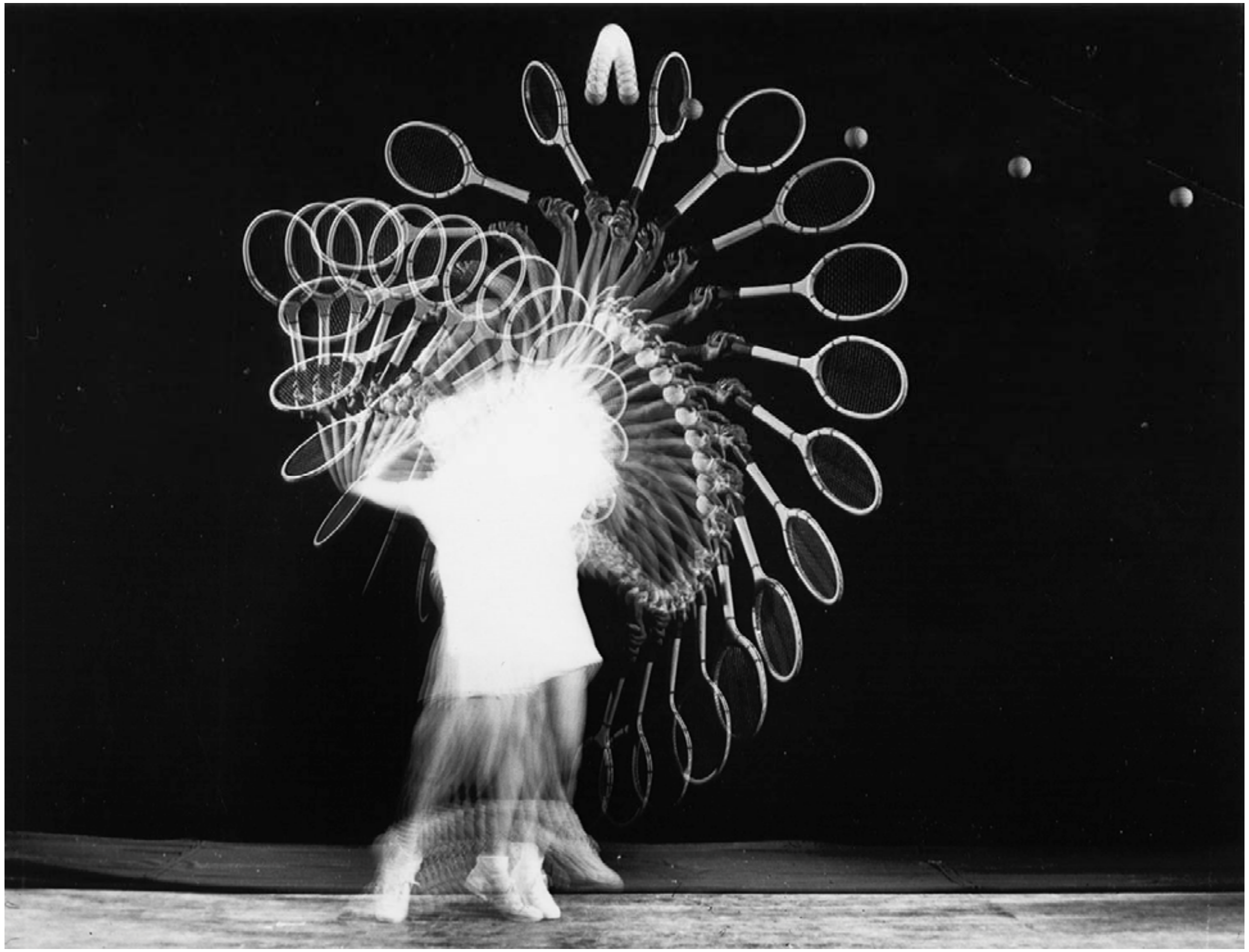

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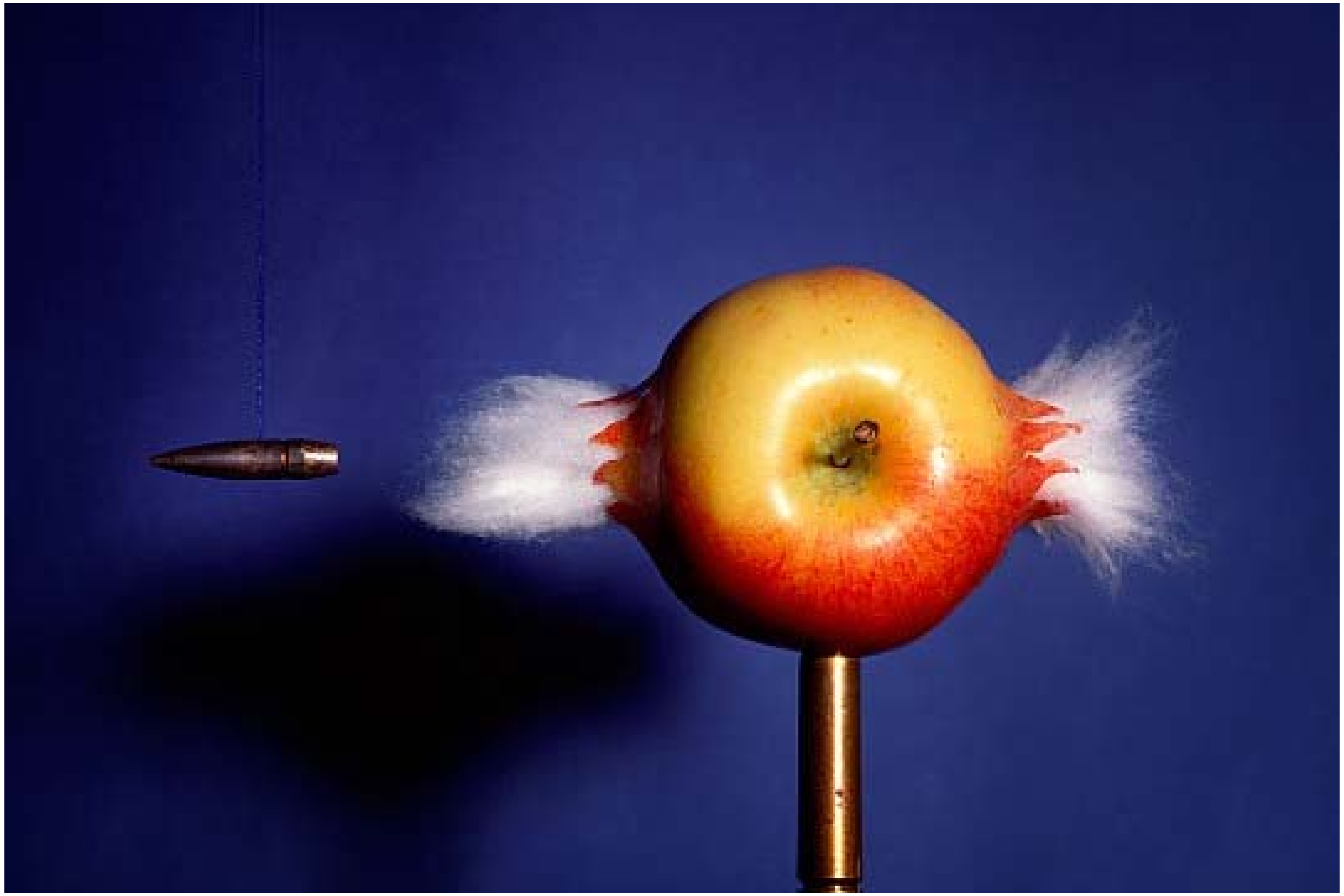

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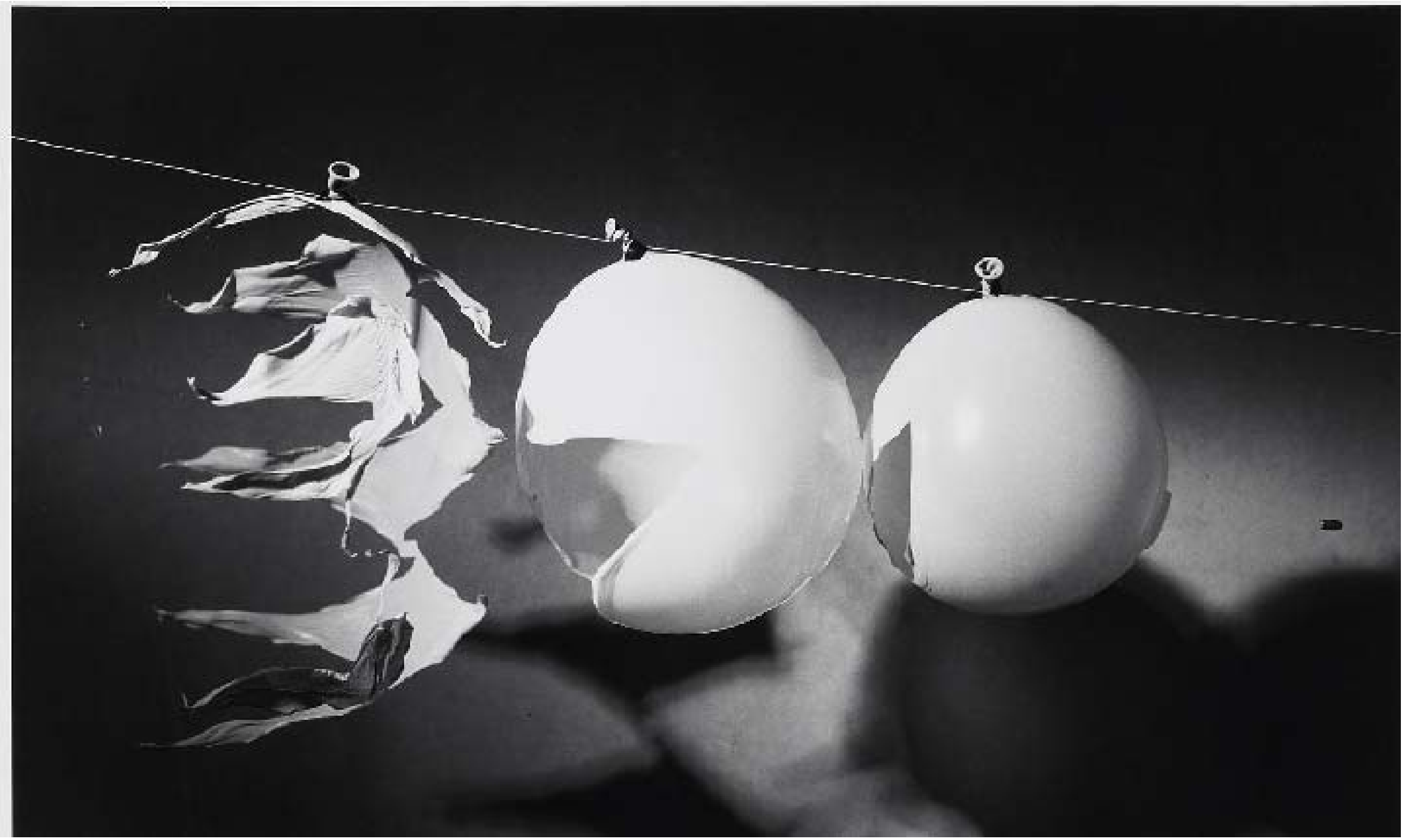
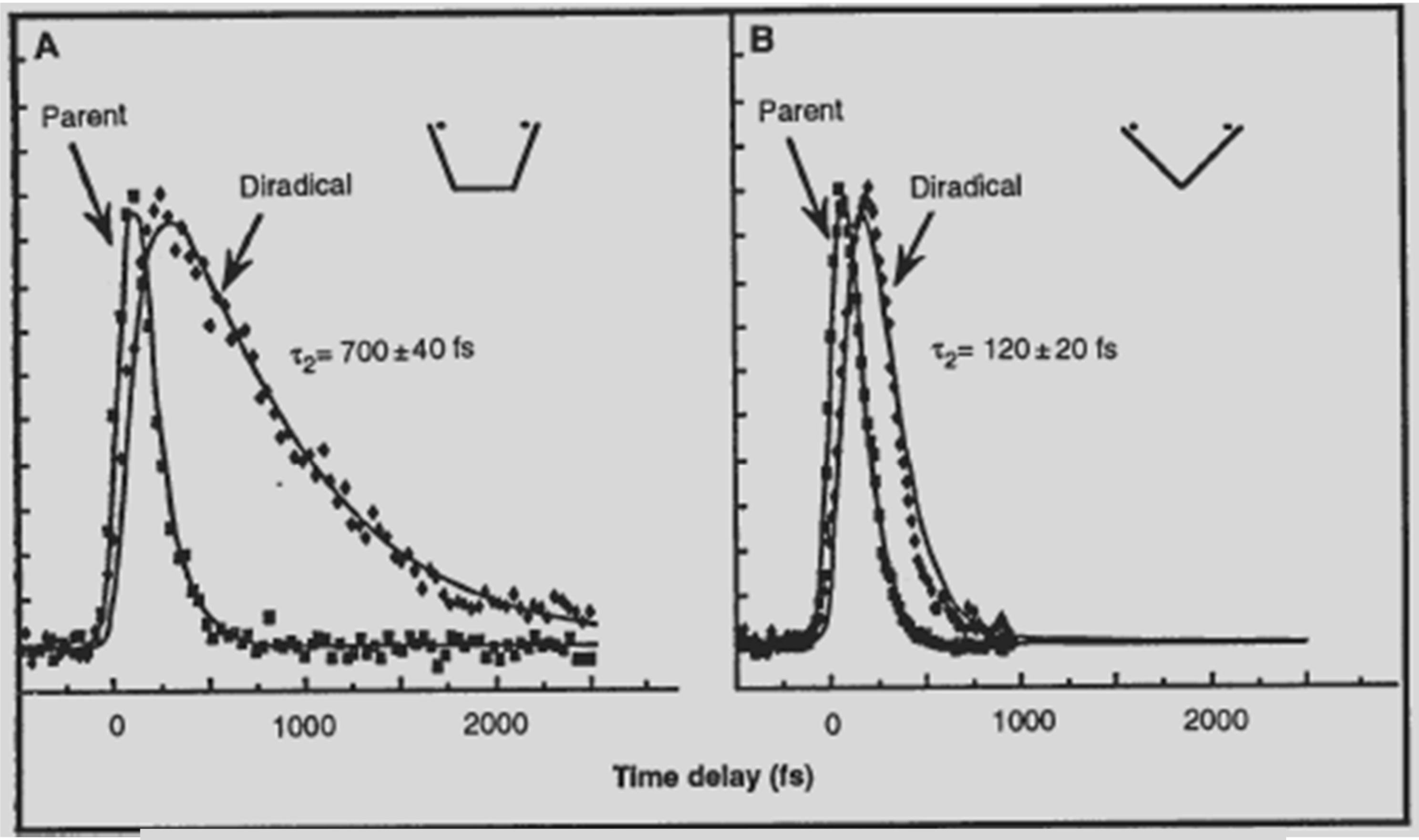


Femtochemistry by A. H. Zewail in 1994

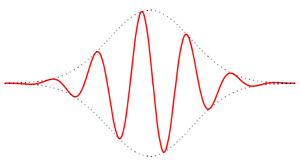
A. H. Zewail in 1994:
understand transition states in chemical reactions using fs-pulses



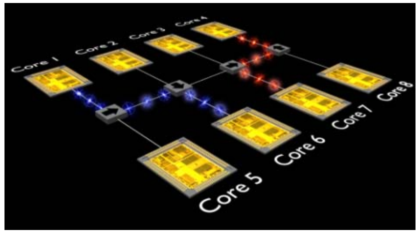
SCIENCE • VOL. 266 • 25 NOVEMBER 1994

Ultrafast laser pulses

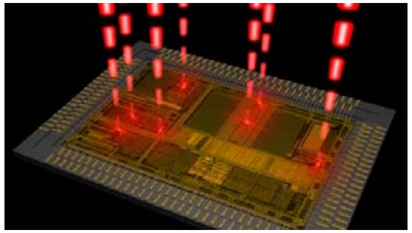
Access ultrashort time scales



⇨ Observe and use fast dynamics
- understand chemical reaction dynamics
- fast communication
- …



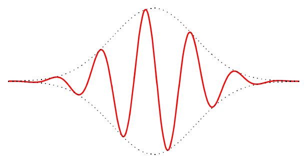
interconnects



optical clocking

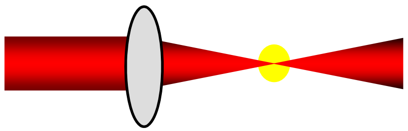
Ultrafast laser pulses

Access ultrashort time scales

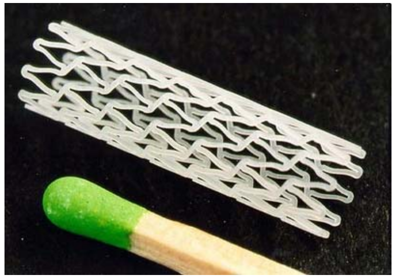


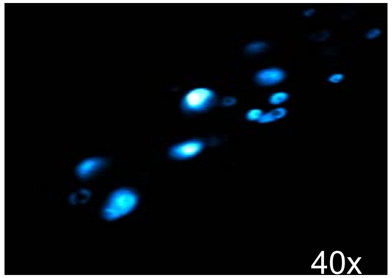
⇨ Observe and use fast dynamics
- understand chemical reaction dynamics
- fast communication
- …

Concentrate in time and space



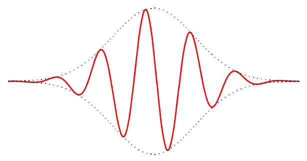
⇨ Achieve extremely high intensities
- material processing, eye surgery, …
- biomedical imaging, ….
- high field science, …





Ultrafast laser pulses

Access ultrashort time scales



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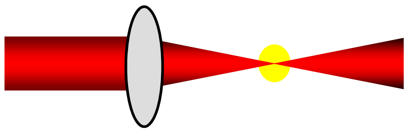
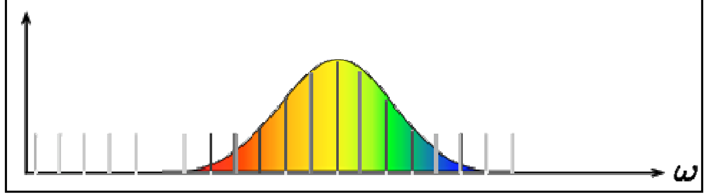
Concentrate in time and space



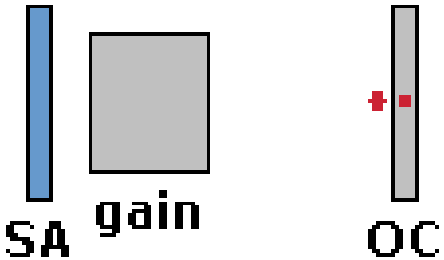
⇨ Achieve extremely high intensities
- material processing, eye surgery, …
- biomedical imaging, ….
- high field science, …

Broad optical spectrum

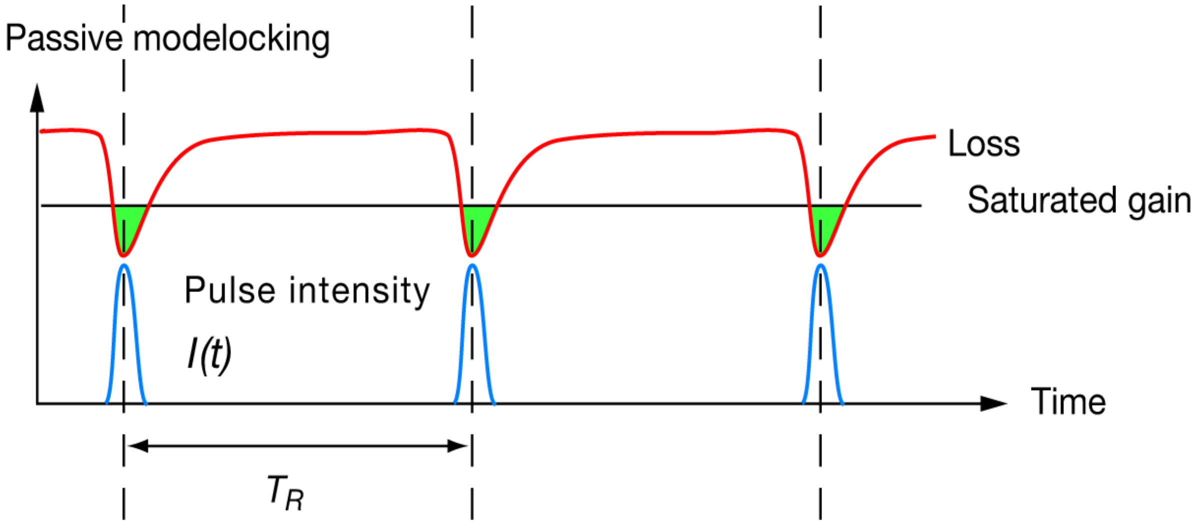


⇨ Generate ultrastable frequency combs
- high precision spectroscopy
- optical clocks
- …

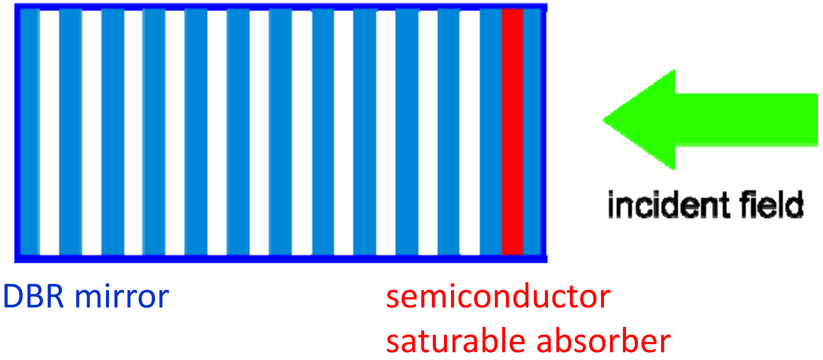
Generation of ultrashort pulses: passive modelocking

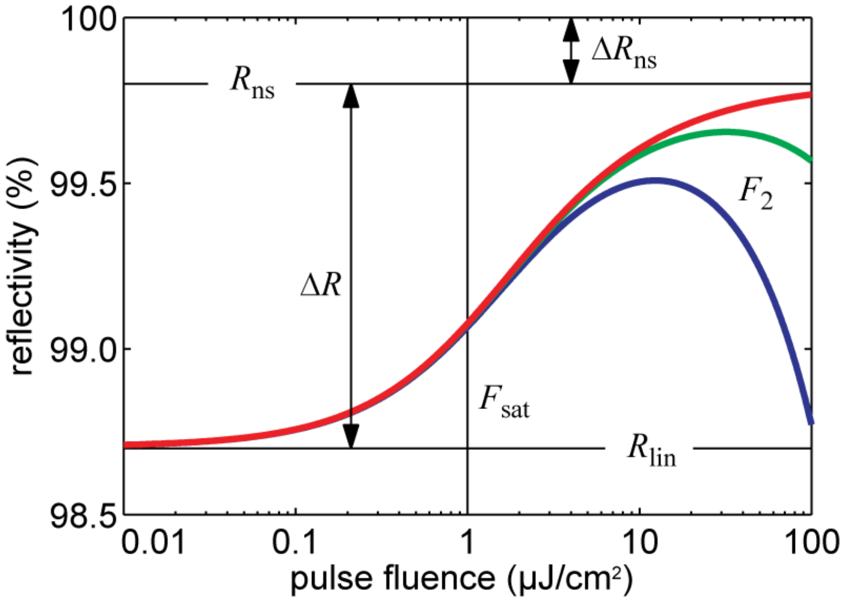


Animation: http://www.rp-photonics.com/mode_locking.html



SESAM (Semiconductor Saturable Absorber Mirror)





- Semiconductor absorber
  - typically QW or QD layer(s)
  - number of layers
  - growth temperature
  - material composition, …
- Integration in mirror structure
  - field strength in absorber
  - dispersion
  - reflectivity, OC, …

- Key parameters
  - saturation fluence F_{sat}
  - modulation depth ΔR
  - nonsaturable losses ΔR_{ns}
  - roll-over F_2
  - recovery time τ

U. Keller, et al., *IEEE J. Sel. Top. Quant.* **2**, 435 (1996)

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Applications for high power ultrafast sources

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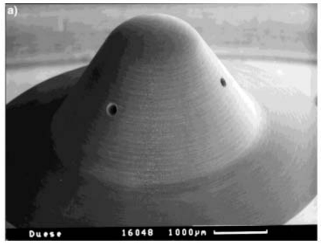
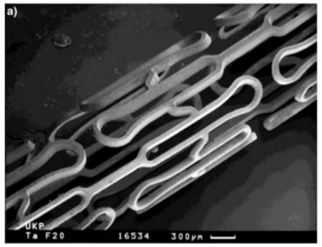
Industry: High-precision, high-speed micromachining



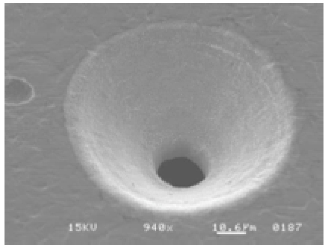
Fuel injection nozzles

Profeta et al., *Industrial Laser Solutions*, 2004



Stents

Nolte, et al., *Adv. Eng. Mater. 2*, 2000



Inkjet nozzles

Liu, et al., *Proc. SPIE*, Vol. 5713, 2005

Required

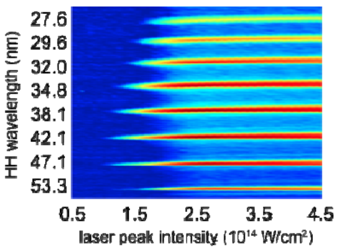
- High E_P > 10 µJ
- High P_{pk} > 10 MW

Wanted

- High f_{rep} (MHz)

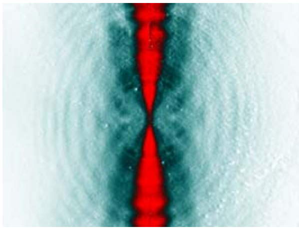
➡ **High average power**
$\boldsymbol{P_{av} = E_p \cdot f_{rep}}$

Science: Strong-field physics applications



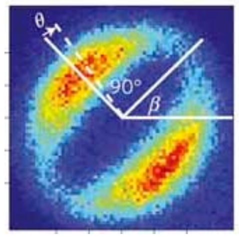
HHG

T. Auguste, et al., *PRA* **80**, 033817 (2009)



Spectroscopy

T. Südmeyer, et al., *Nat. Phot.* **2**, 599 (2008)



Attosecond science

A. Pfeiffer et al., *Nat. Phys.* **8**, 76 (2012)

Required

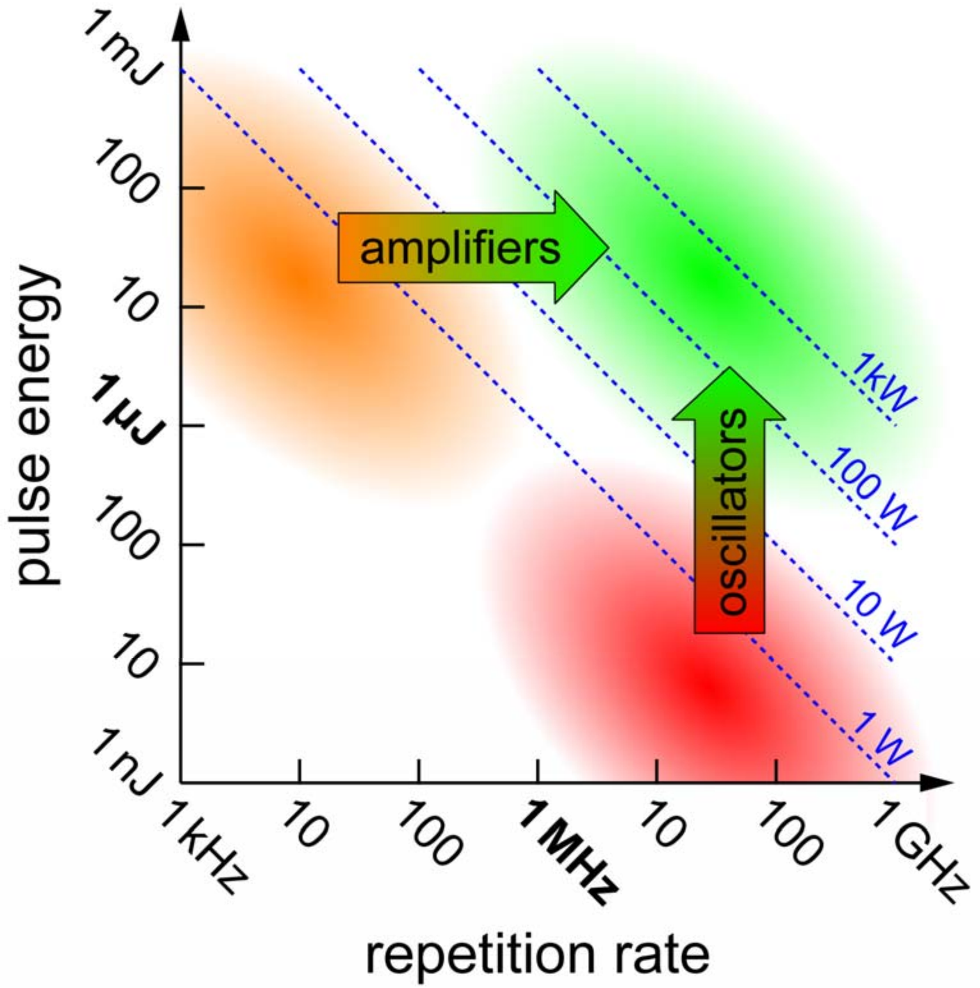
- High I_{peak} > 10^{14} W/cm^2
- Short pulses τ_p < 100 fs

Wanted

- High f_{rep} (MHz)

➡ **High average power**
$\boldsymbol{P_{av} = E_p \cdot f_{rep}}$

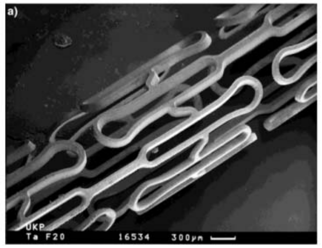
Frontier: average power and pulse energy



T. Südmeyer, et al., “Femtosecond laser oscillators for high-field science”, *Nature Photonics* **2**, 559 (2008)

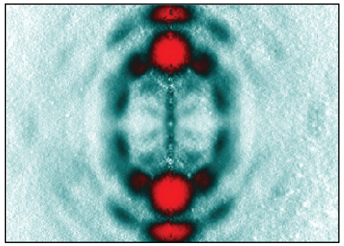
High energy <u>and</u> MHz

- **Industrial applications**
  - increase throughput,
  - reduce costs per item, …



Nolte, et al., *Adv. Eng. Mater. 2*, 2000

- **Scientific applications**
  - reduce measurement time,
  - increase signal-to-noise,
  - MHz XUV sources, …

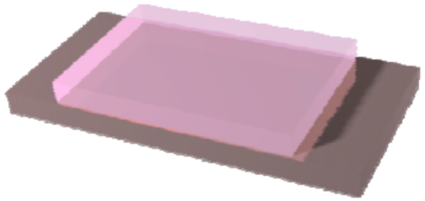


High average power ultrafast sources

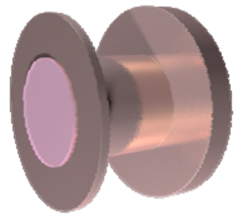
Key for high average power: heat removal

- Optimization of surface-to-volume ratio for efficient cooling

✓ Fiber



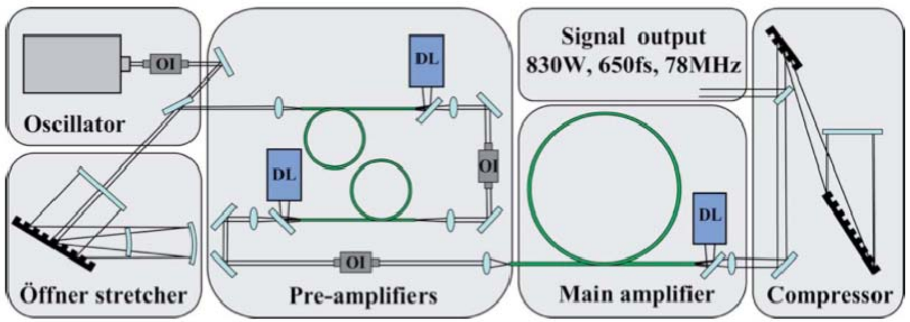
✓ Slab



✓ Thin disk

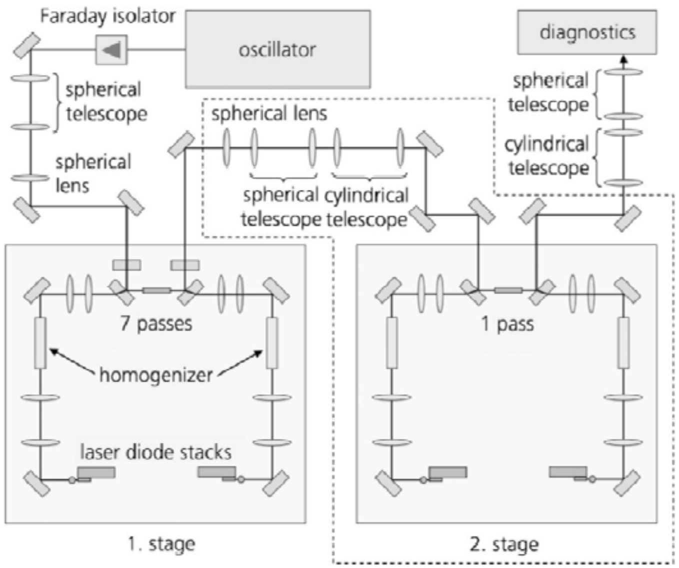
Key for ultrafast: reduce nonlinearities

- Operation at reduced peak intensity
- Reduced interaction volume



✓ Chirped pulse amplification (CPA) : 830 W, 640 fs

T. Eidam, et al., Optics Letters 35, 94-96 (2010)



✓ Innoslab : 1.1 kW, 615 fs

P. Russbueldt, et al., *Opt. Letters 35,* 4169-4171 (2010)

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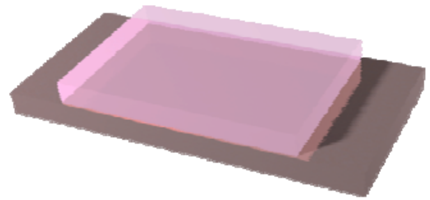

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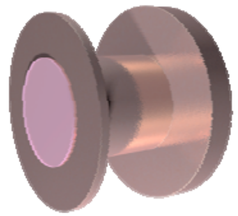

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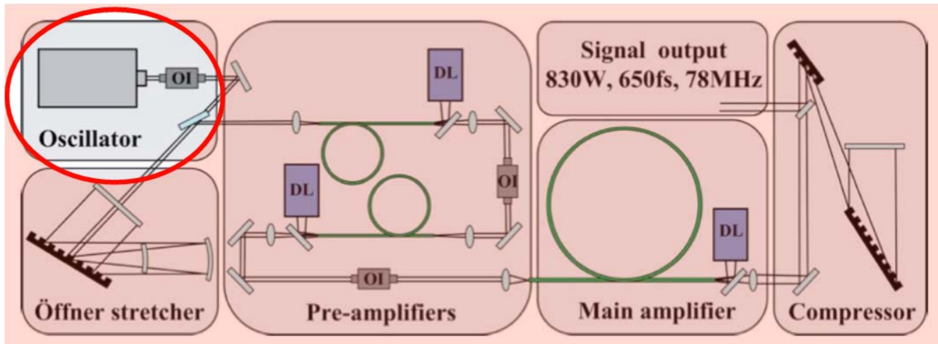

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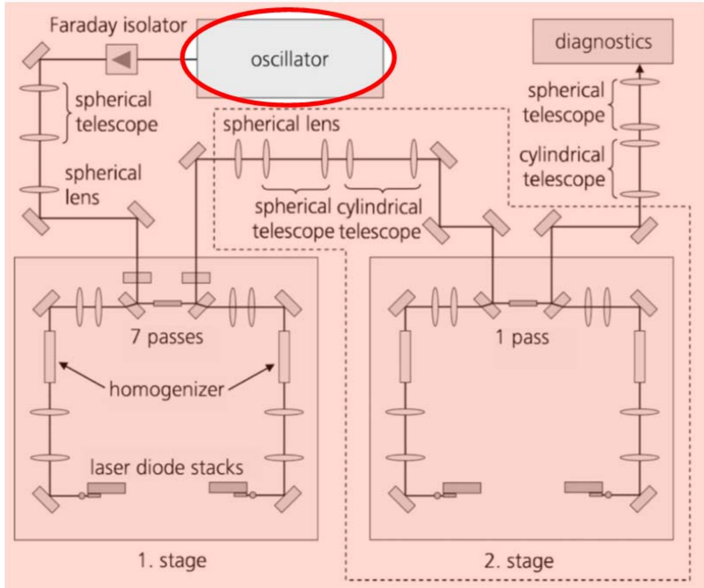

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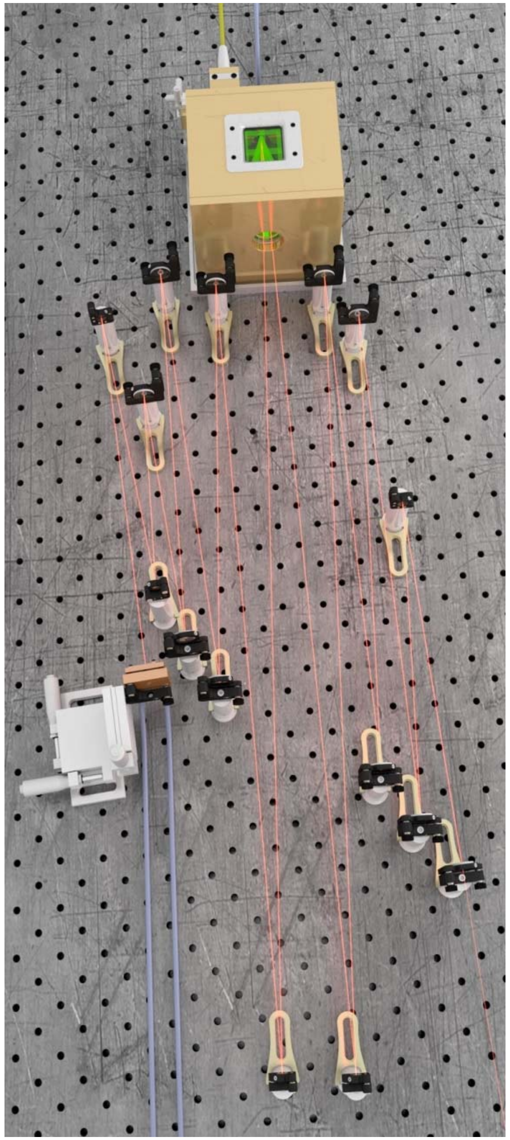
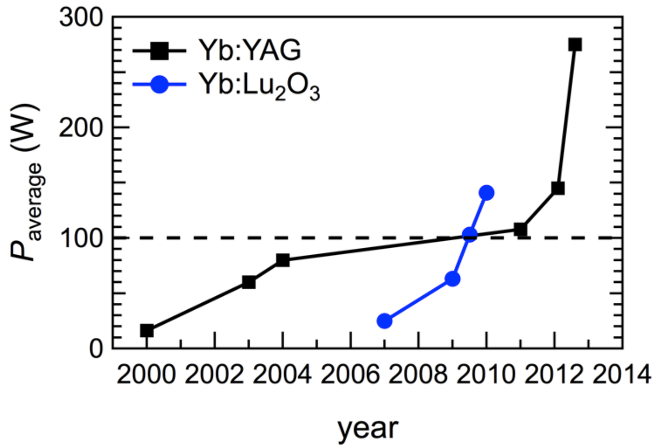
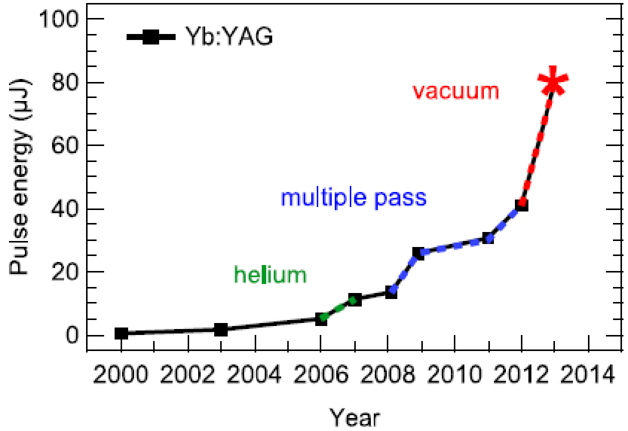
SESAM Modelocked Thin Disk Lasers



Highest average powers and highest energies of any ultrafast oscillator technology



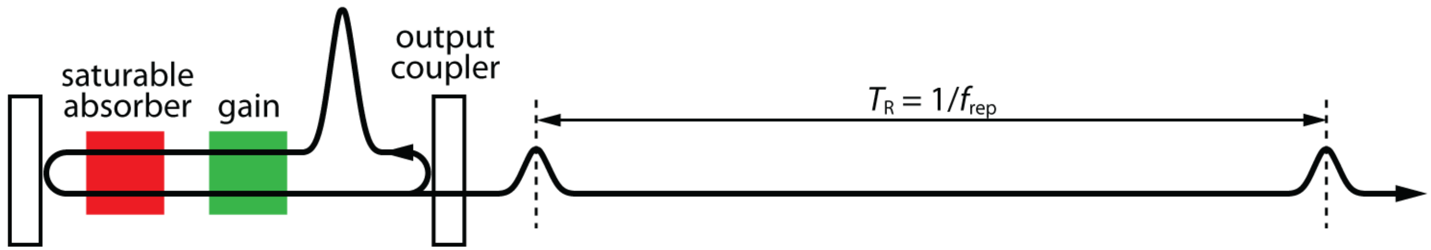
E_p = 17 µJ
P_{av} = 275 W
τ_p = 583 fs
f_{rep} = 16.3 MHz



E_p = 80 µJ
τ_p = 1.07 ps
f_{rep} = 3 MHz
P_{av} = 242 W

C.J. Saraceno, et al., *Optics Express* ***20***, 23535 (2012)

Challenges for high power operation

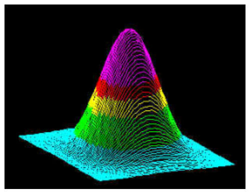


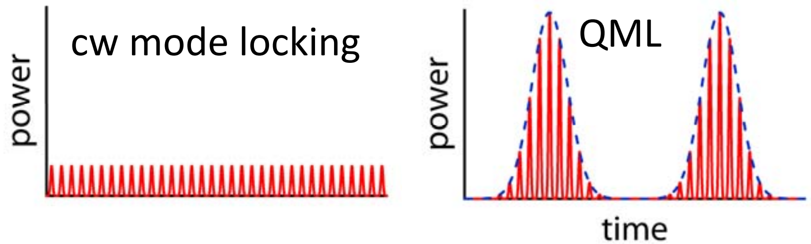
saturable absorber ➡ reduced losses for pulsed operation

$$E_P = P_{avg} \cdot T_R$$

Challenges

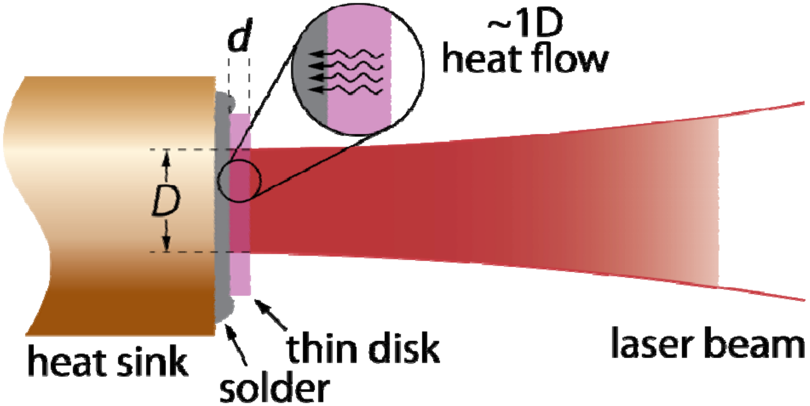
- TEM_{00} operation at high average power
  - efficient heat removal
  - suitable cavity design
  - suitable broadband gain material
  - **high damage threshold optics**
- Pulse formation
  - sustain high intracavity intensities
  - avoid mode locking instabilities

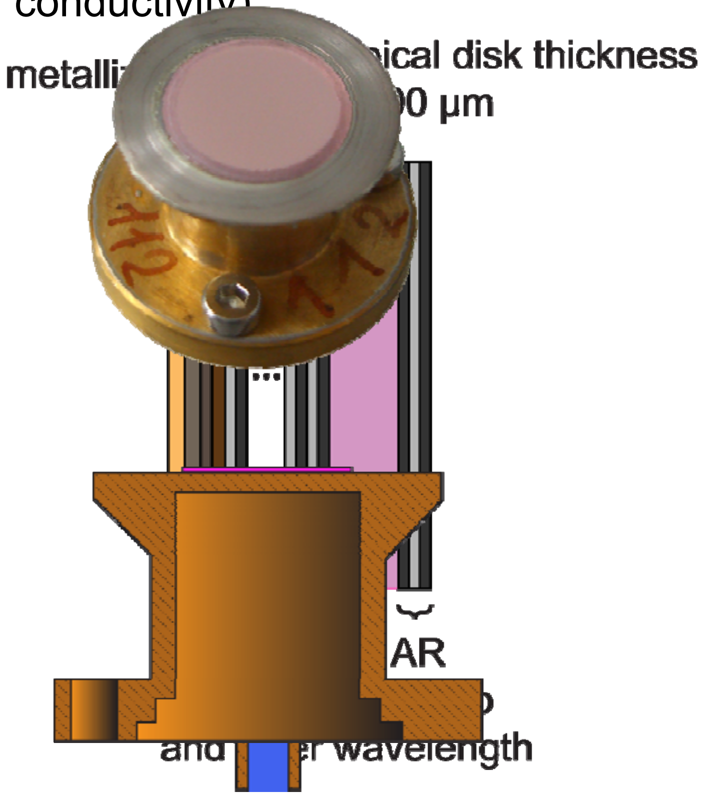




Challenge: Fundamental mode operation despite high thermal load

- Suitable gain material (good optical quality, high thermal conductivity)
- Suitable gain geometry (efficient heat removal)



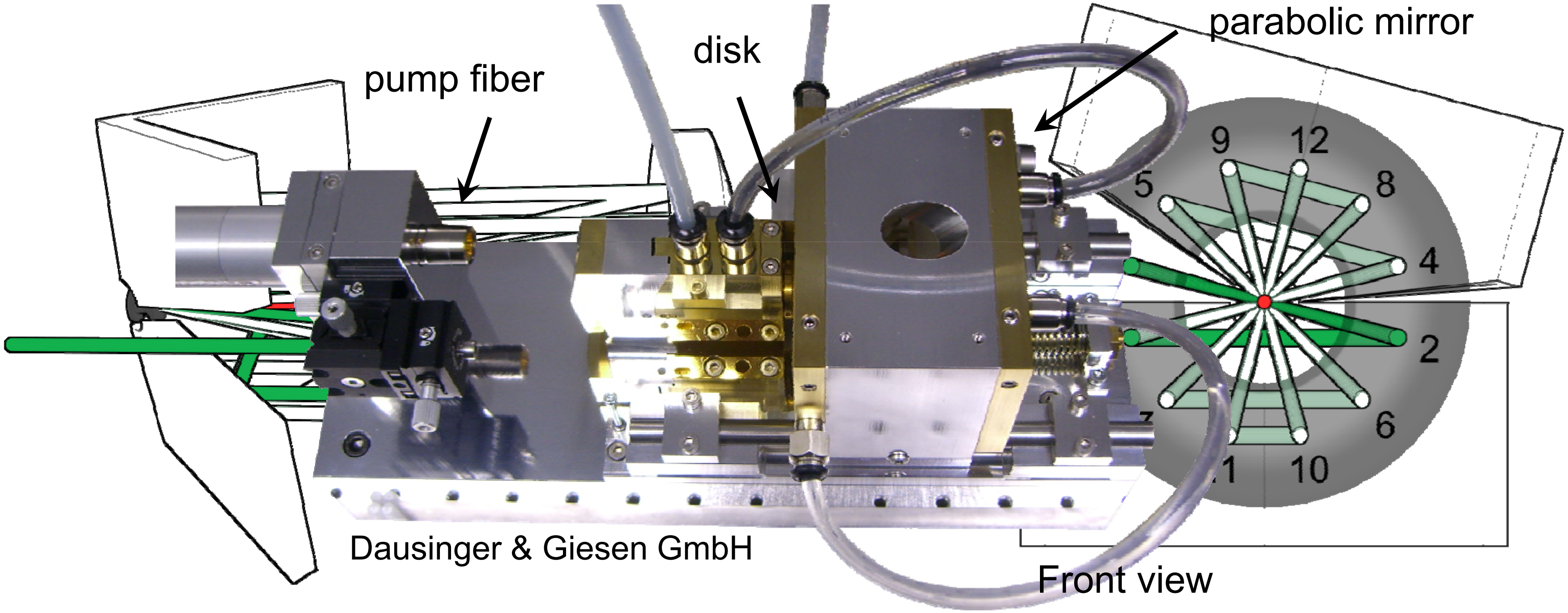


Thin disk laser

A. Giesen, et al., *Appl. Phys. B* **58**, 365 (1994)

- Efficient heat removal through back side
- Power scalable by increase of mode diameter *D* (constant intensities)
- 1D longitudinal heat flow → reduced thermal lensing

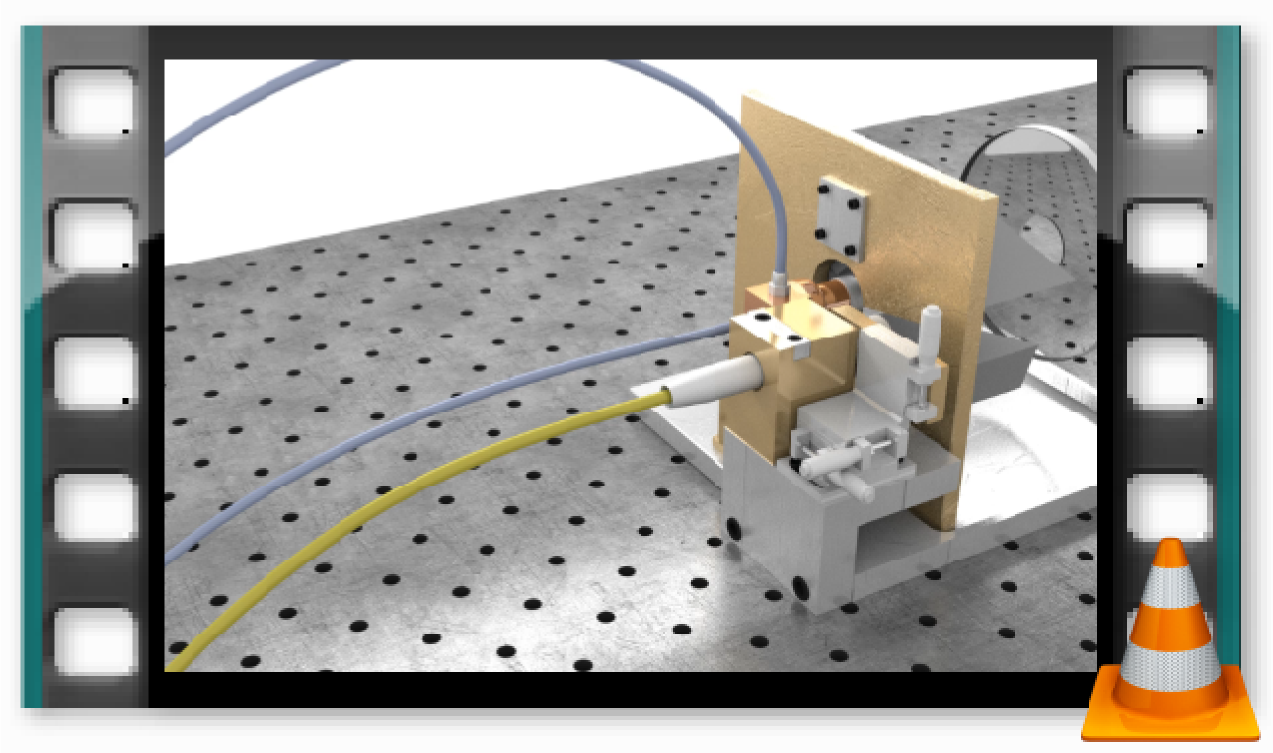
Multi-pass pumping scheme for efficient absorption



Pump module

- Typical single-pass absorption 8% - 15%
- Pump module with up to 32 passes available (here 24 passes)
- Typical over 98% of absorbed pump light
- Homogeneous pump light distribution
- Low demand on pump brightness (pump diameters of mm-cm)

Modelocked thin disk laser



Animation by Martin Hoffmann

High-power modelocking: challenges

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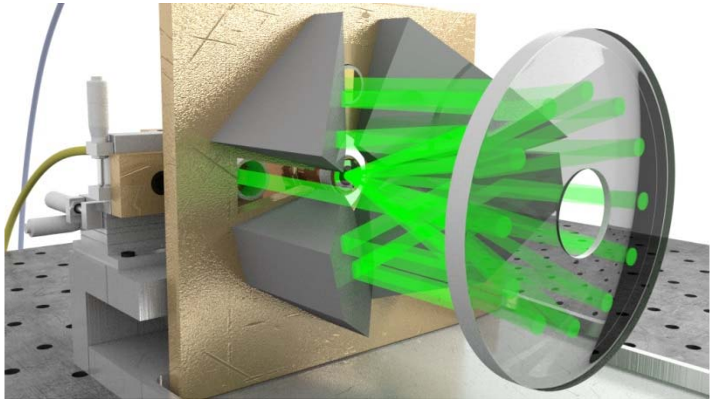
Challenge 1: TEM_{00} operation at high average power

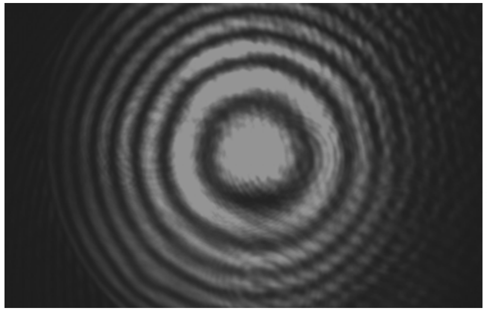
- efficient heat removal:
  - → material properties: thermo-mechanical and spectroscopic properties
  - → disk quality: thickness, diameter
  - → contacting
- suitable cavity design
- **optics with high damage threshold**

C. R. E. Baer, et al., *Optics Express* ***20****, 7054-7065* (2012)



Yb:YAG: the standard thin disk material

- large disks on diamond with excellent quality commercially available
- 500 W fundamental transverse mode (M^2<1.1) demonstrated[#1]
- 1.1 kW nearly fundamental mode (M^2<1.5) [#2]



✓ < 100 µm thick

✓ glued on water cooled diamond

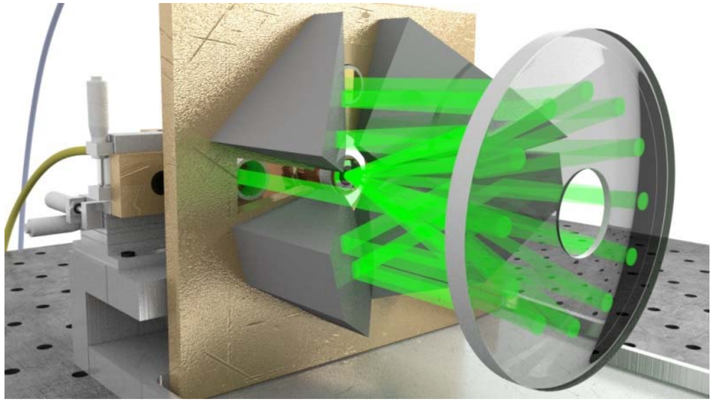
[#1] A.Killi, et al., *Proceedings of the SPIE, Volume 7193,* 2009

[#2] Peng, et. al., *Opt. Lett* 38, 10, pp. 1709-1711, 2013

High-power modelocking: challenges

Challenge 1: TEM_{00} operation at high average power

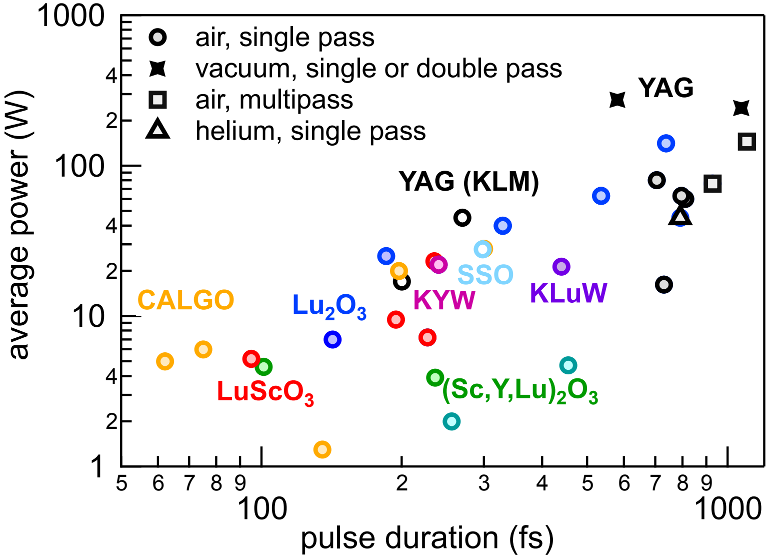
- efficient heat removal:
  - → material properties: thermo-mechanical and spectroscopic properties
  - → disk quality: thickness, diameter
  - → contacting
- suitable cavity design
- optics with high damage threshold



C. R. E. Baer, et al., *Optics Express* ***20**, 7054-7065* (2012)

Many other promising materials currently being investigated!

- Yb: CALGO
  - >70% slope efficiency
  - 62 fs pulses
- Yb doped sesquioxides (Uni Hamburg)
- Etc…
- **Typical disk production cycle: >1 year**



High-power modelocking: challenges

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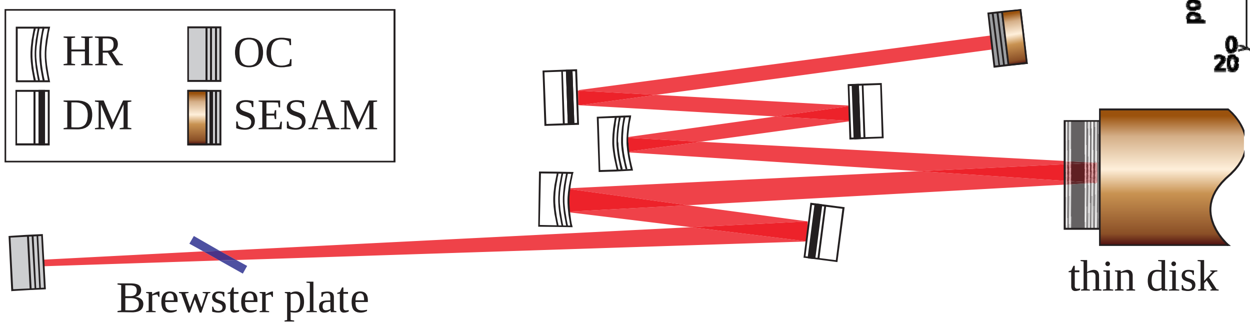
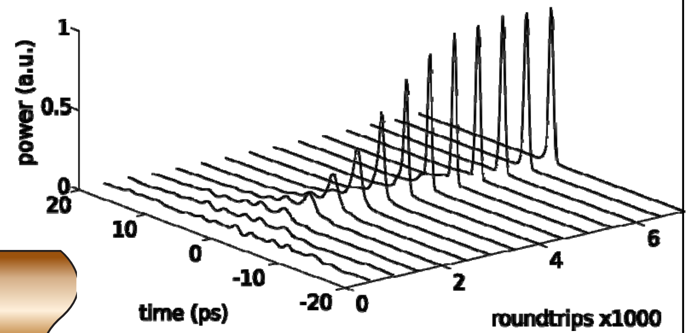
Challenge 2: Pulse formation at high intracavity peak power

Avoid excessive nonlinearities!



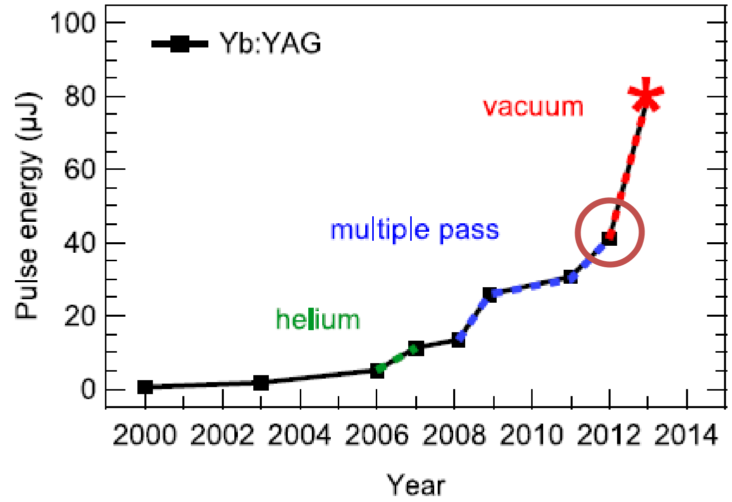


- → Soliton modelocking: balance **self-phase modulation** and **negative dispersion**
- → Thin-disk geometry: excellent for low nonlinearities
- → Avoid modelocking instabilities from excessive nonlinearities at very high intracavity levels
- → Origin of nonlinearities: mostly air in resonator
- → **Need dispersive optics: challenge at high power**

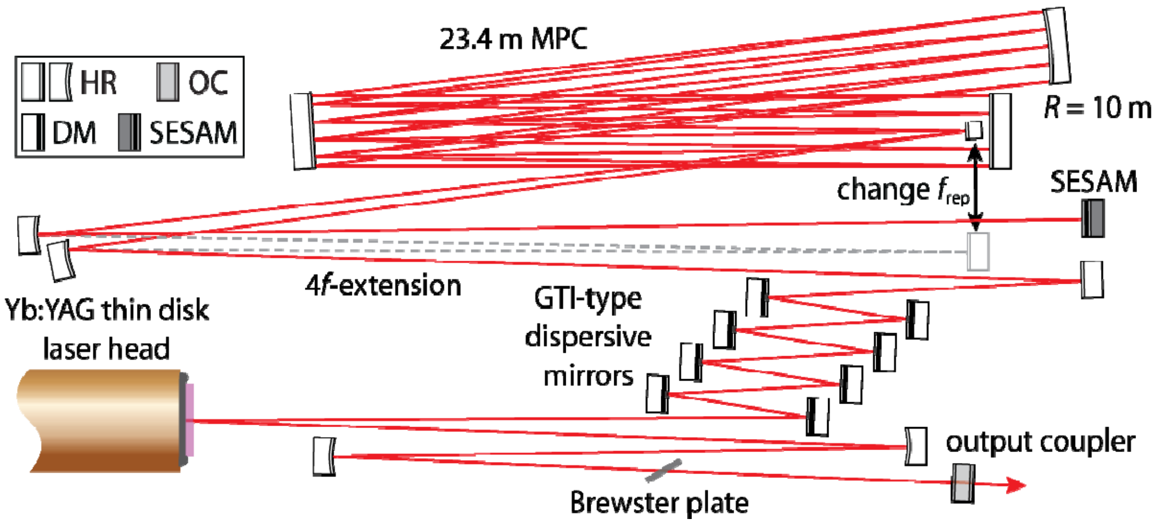
F. X. Kärtner and U. Keller, Opt. Lett. **20(1),** 16–18 (1995)
R. Paschotta and U. Keller, Appl. Phys. B **73(7),** 653–662 (2001)

Harnessing intracavity nonlinearities

Helium flooding 45 W, 11 µJ, 790 fs



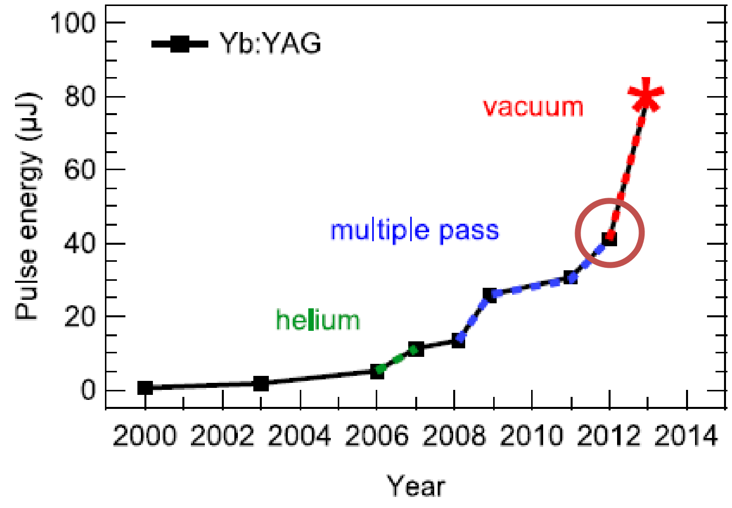
$n_{2,air} \approx 3.10^{-23}$ m²/W
$n_{2,He} \approx 8.10^{-26}$ m²/W (≈ **400 times lower)**



S. Marchese, et al., *Optics Express* ***16****, 6397-6409* (2008)

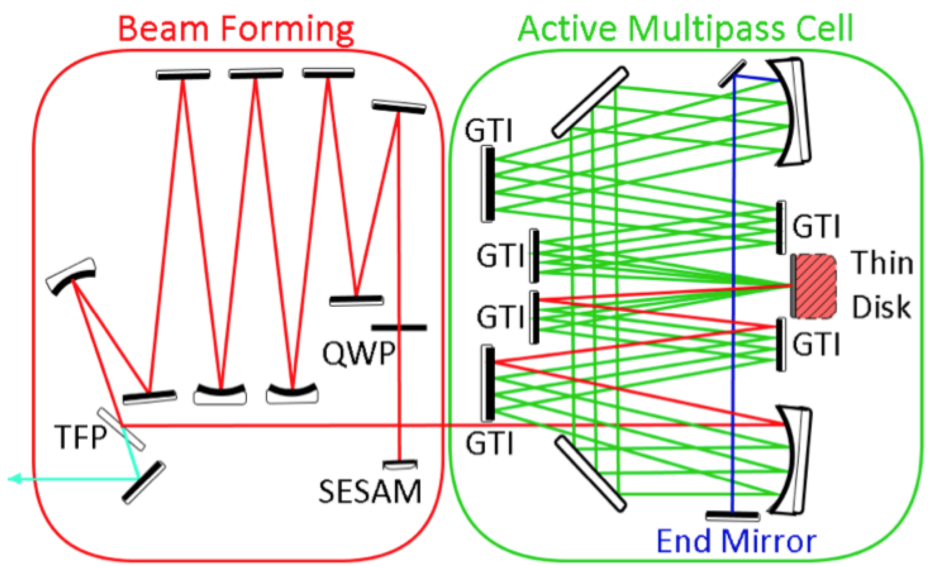
Harnessing intracavity nonlinearities

Helium flooding	45 W, 11 µJ, 790 fs
Multiple passes	145 W, 41 µJ, 1.1 ps



↑ number of passes ↑ gain per roundtrip

- ✓ efficient laser operation at lower OC rate
- ✓ for a given output power: reduced nonlinearities



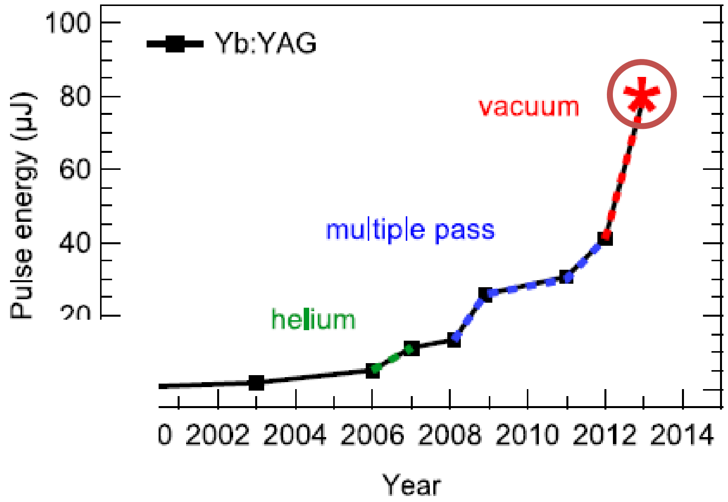
D. Bauer, et al., *Optics Express* ***20***, *9698-9704* (2012)

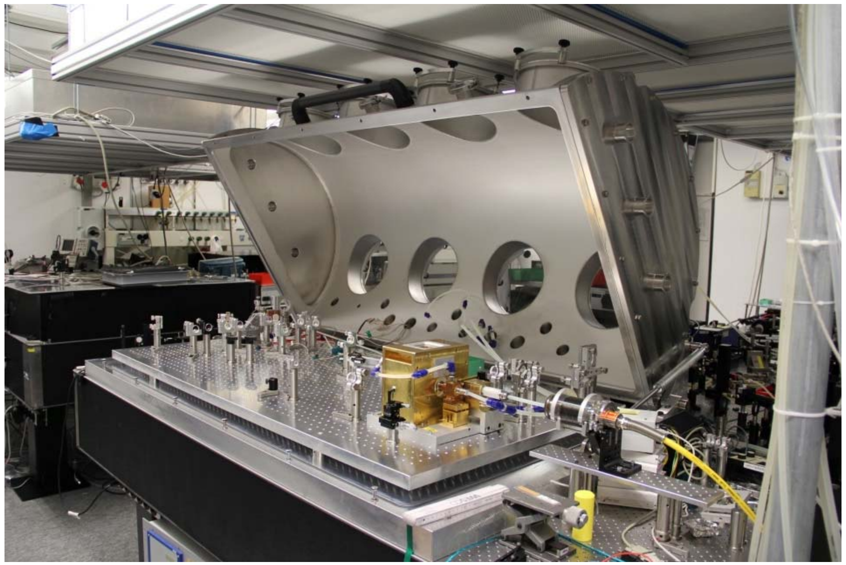
Harnessing intracavity nonlinearities

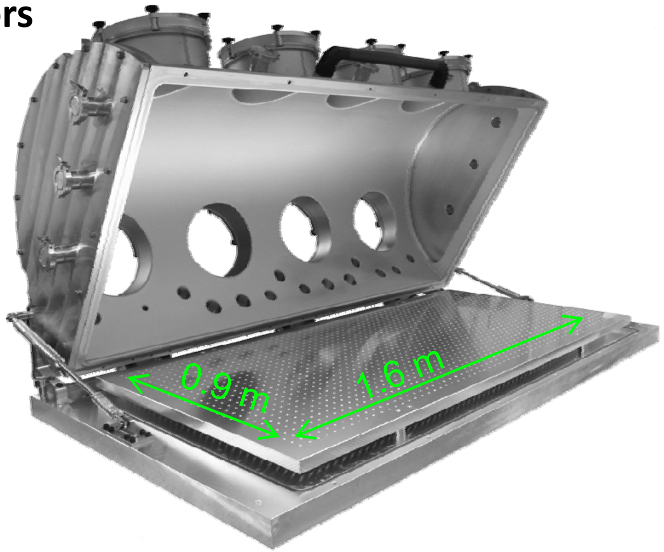
Helium flooding	45 W, 11 µJ, 790 fs
Multiple passes	145 W, 41 µJ, 1.1 ps
Vacuum	275 W, 17 µJ, 580 fs
Vacuum	**240 W, 80 µJ, 1.07 ps**

- ✓ minimum nonlinearity:
  higher intracavity peak power can be tolerated
- ✓ easy adjustment of SPM by adjusting pressure

Current limit: damage / thermal effects in dispersive mirrors

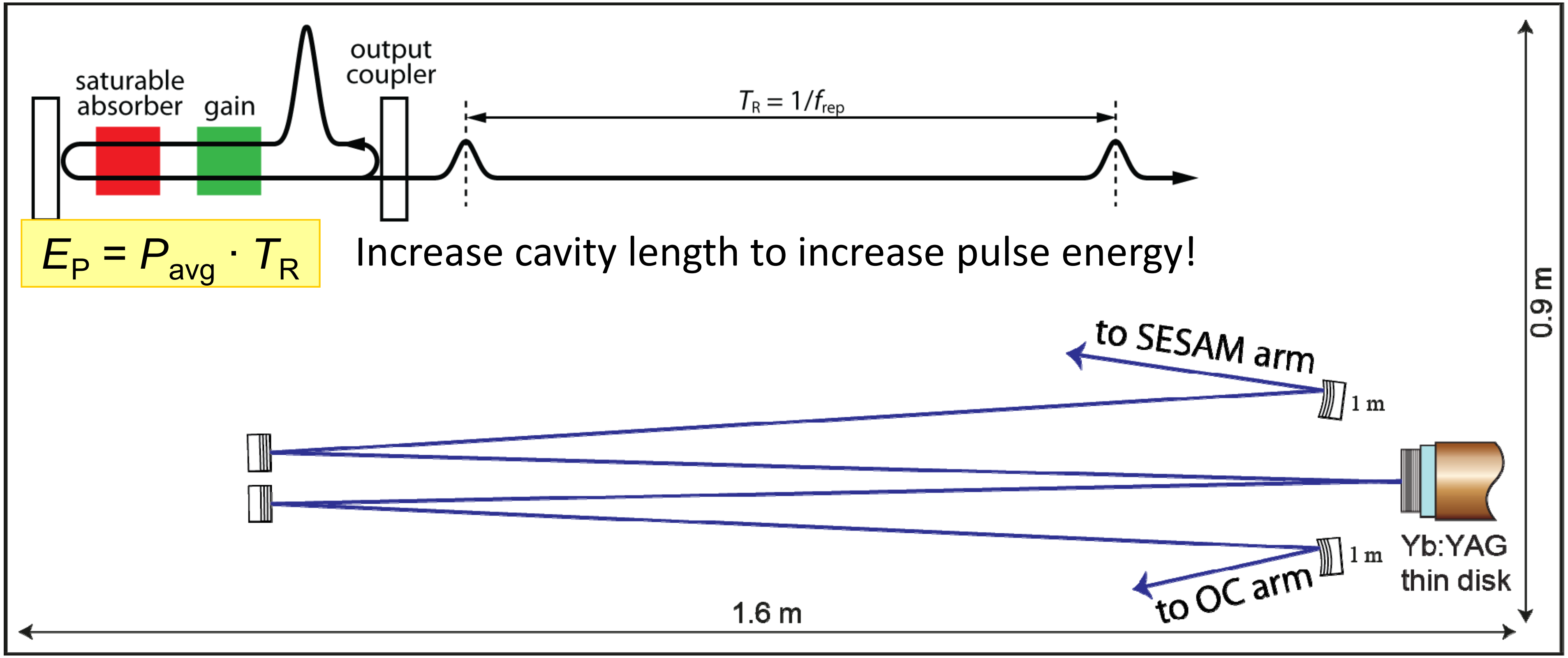






C.J. Saraceno, et al., *Optics Express* ***20***, 23535 (2012)

Energy scaling



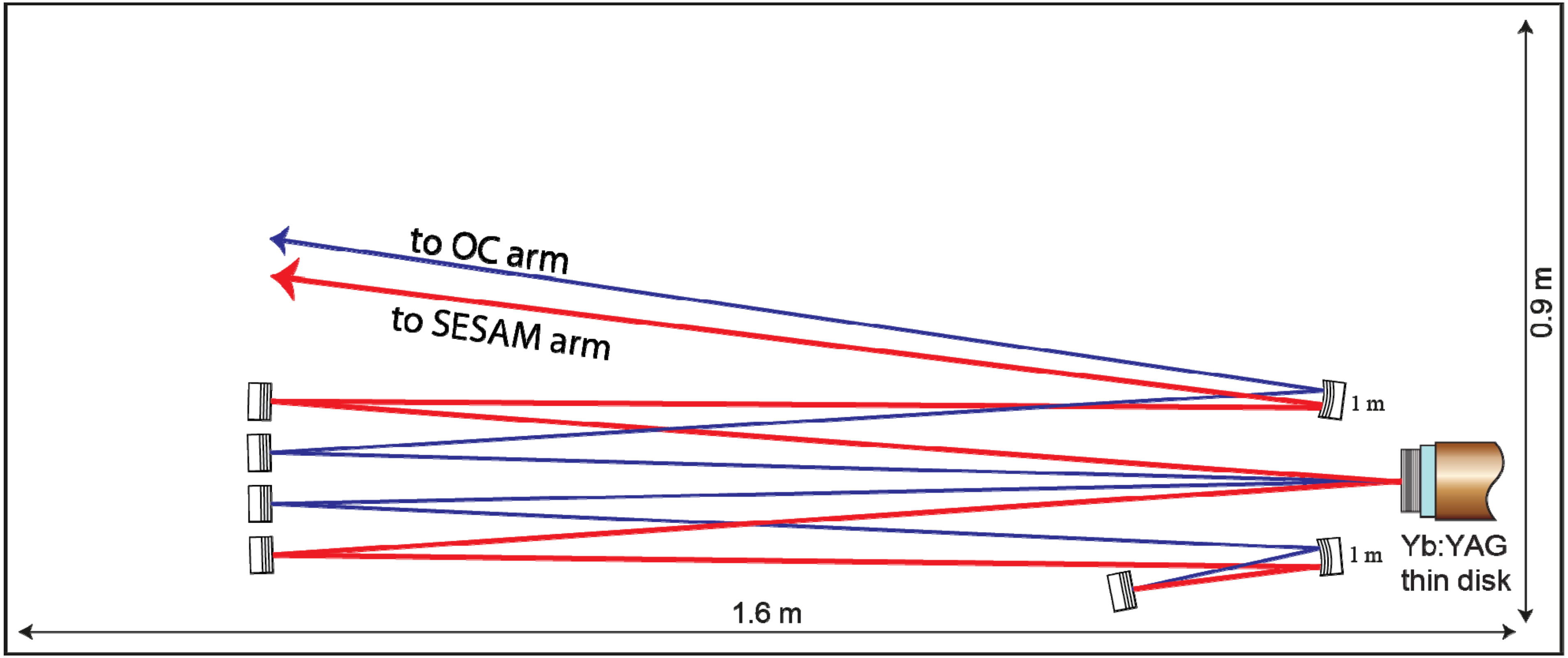
$E_P = P_{avg} \cdot T_R$

Increase cavity length to increase pulse energy!

First design (275 W modelocked laser):

- **17 MHz cavity with one double-pass through the disk**
- OC rate used for modelocking experiments: 11%
- Problems with thermal effects in dispersive mirrors

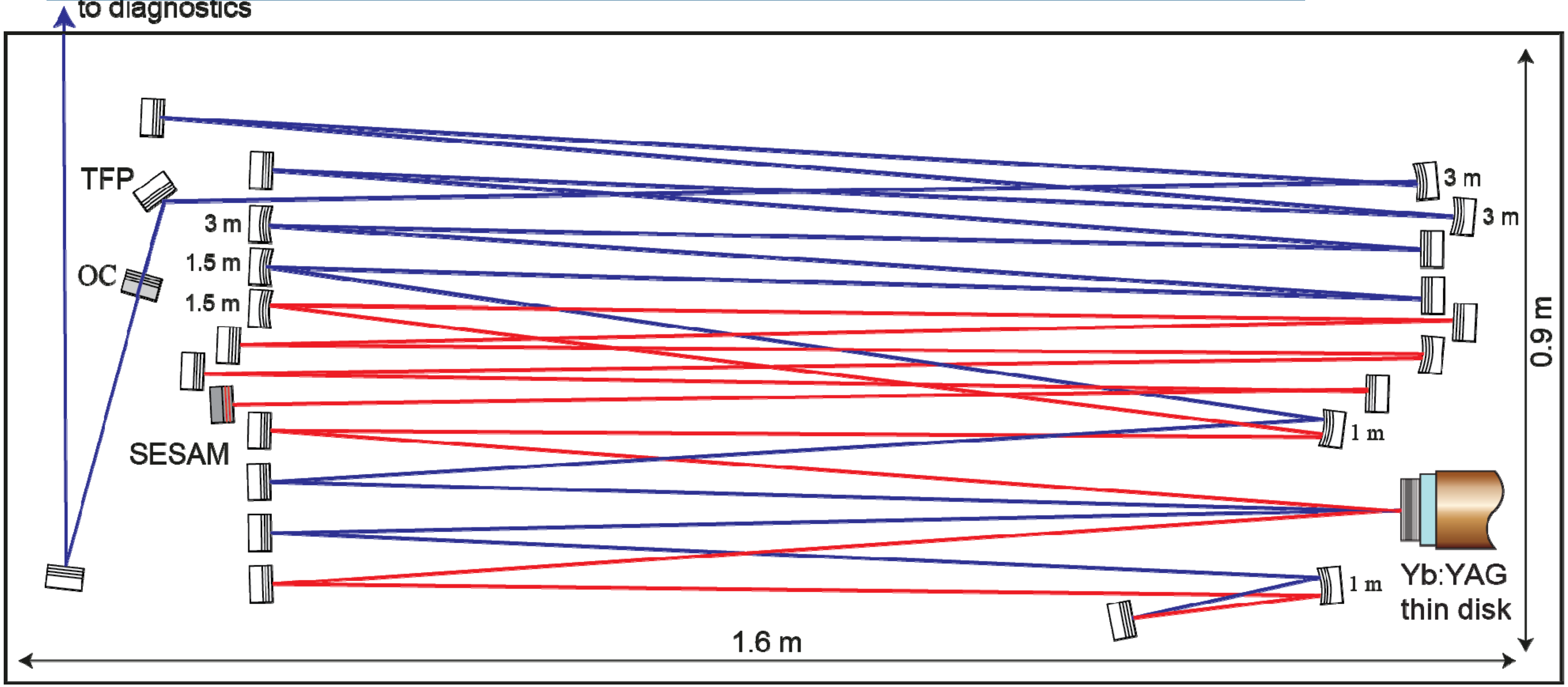
Energy scaling



New cavity:

✓ **Two double-passes through the disk:** higher gain, efficient operation with higher T_{oc}
→ reduced intracavity power for lower thermal effects

Energy scaling

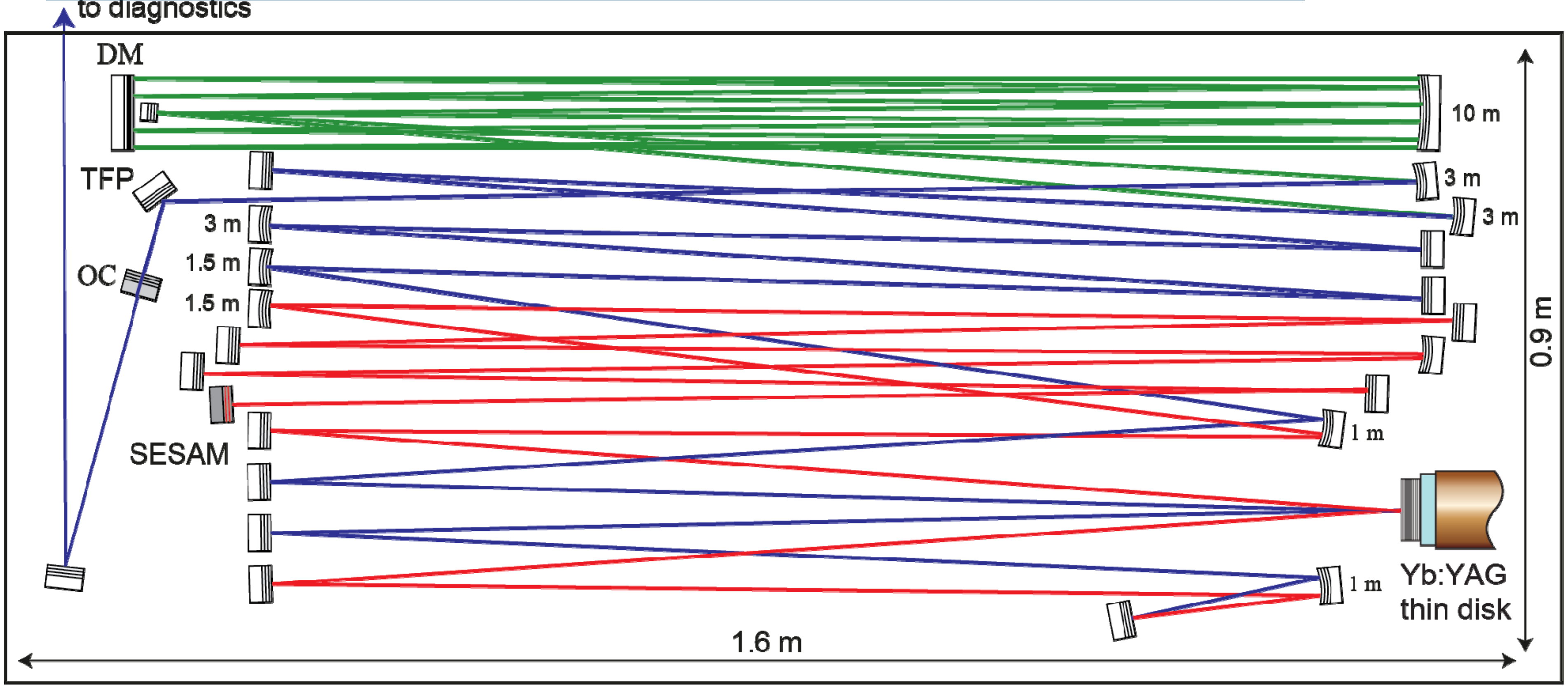


New cavity:

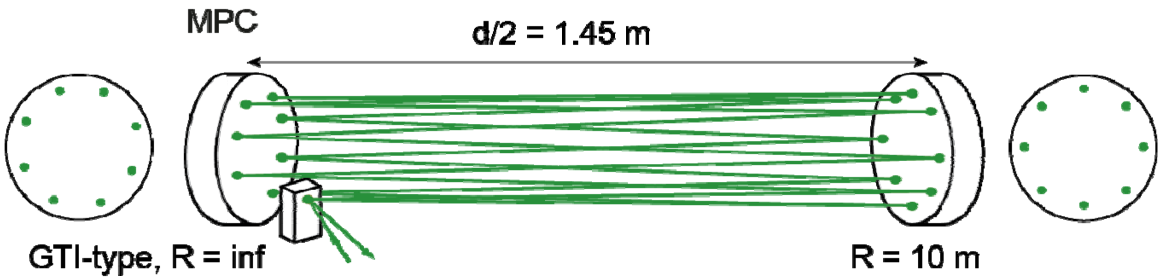
- ✓ **Two double-passes through the disk**
- ✓ **Beam shaping**
- ✓ **Thin-film polarizer for polarization selection**

➡

f_{rep} = 5.8 MHz
T_{oc} = 25 %



Cavity extension with Heriott-type Multi-Pass Cavity (MPC):

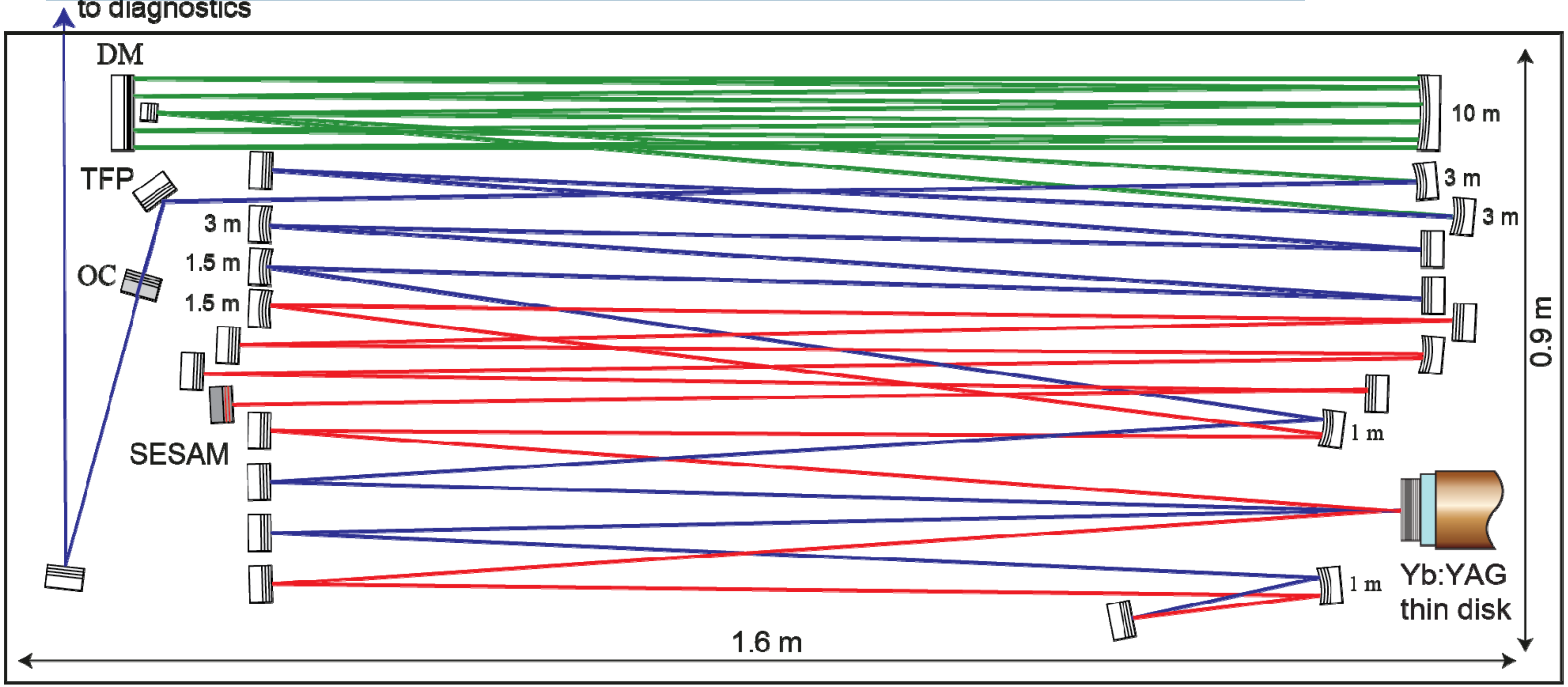


MPC-length

$$D = n \cdot d = 23.4 \text{ m}$$

D. Herriott, et al., *Appl. Opt.* **3**, 523 (1964)

Energy scaling



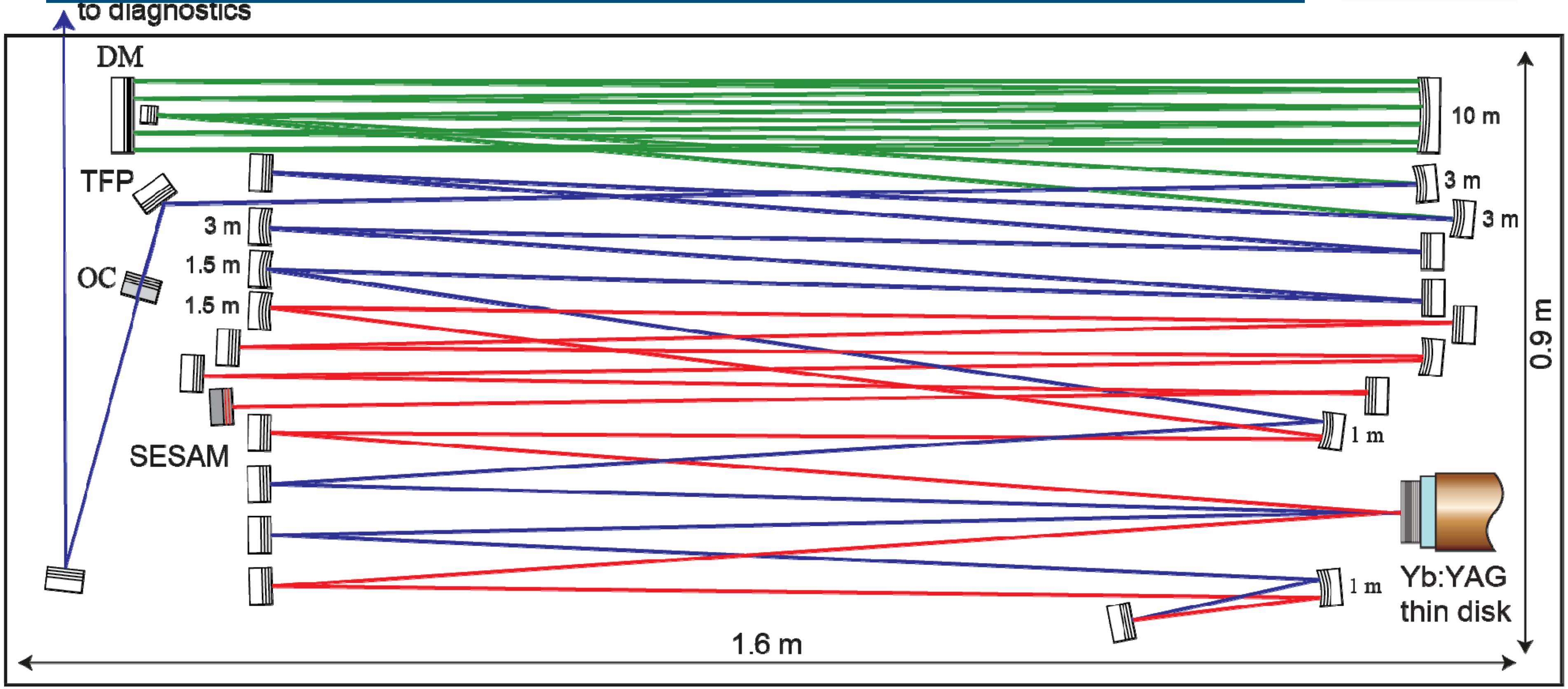
New cavity:

- ✓ **Two double-passes through the disk**
- ✓ **Thin-film polarizer for polarization selection**
- ✓ **Herriott-type multipass cell (10 m mirror)**

➡

- ✓ f_{rep} = 3 MHz
- ✓ T_{oc} = 25 %
- ✓ 300 W single fundamental mode

Energy scaling

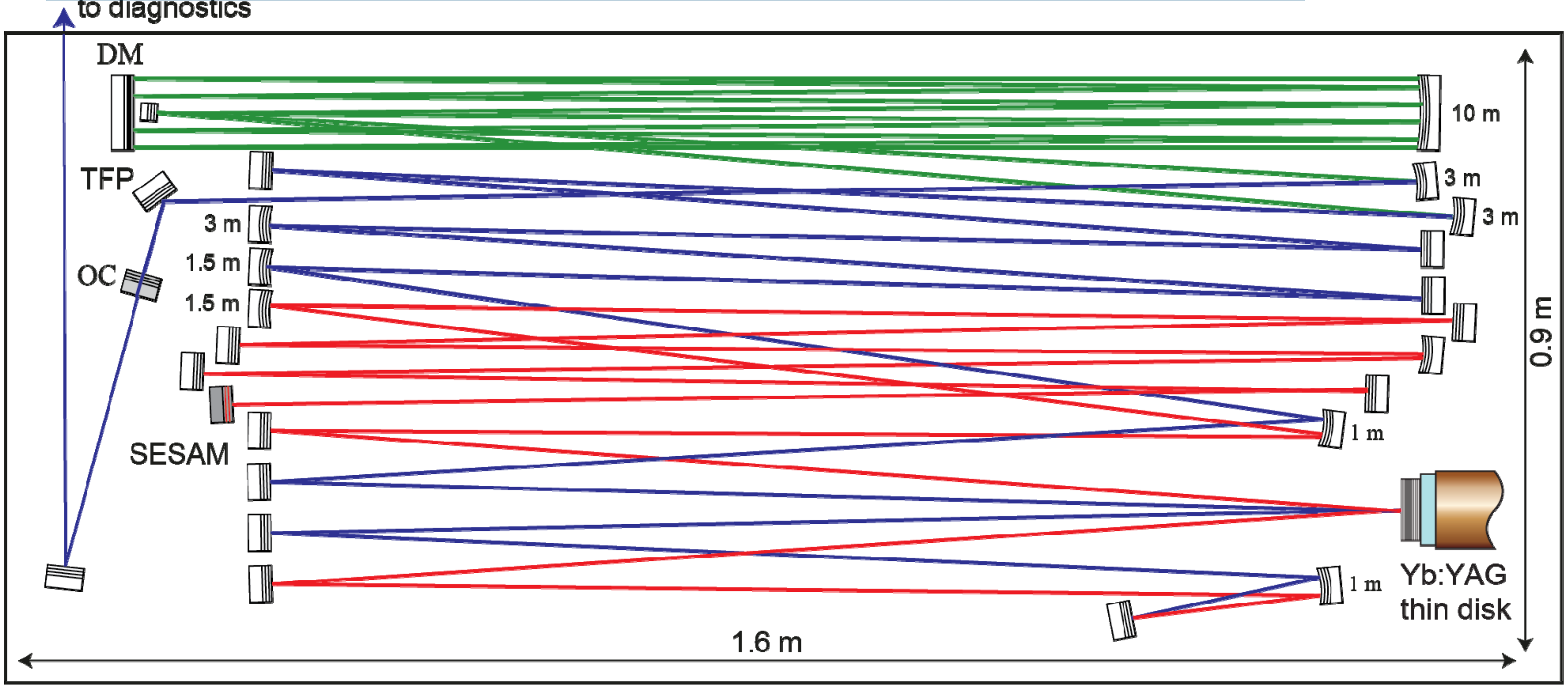


Soliton modelocking:

Self-phase modulation (remaining atmosphere at ≈1 mbar)
390 µrad/MW

Negative dispersion (GTI-type mirrors)
GDD = -28000 fs^2 per roundtrip

Energy scaling

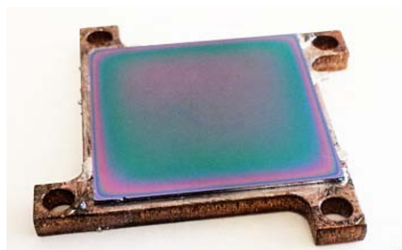


SESAM with multiple QW and dielectric topcoating for high damage threshold[#1]

- F_{sat} = 120 µJ/cm²
- ΔR = 1.1 %
- ΔR_{ns} = 0.1 %

FIRST

Center for Micro- and Nanoscience



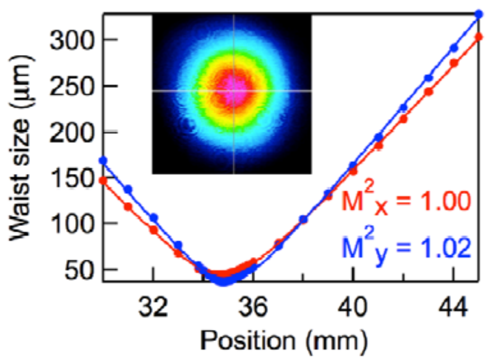
[#1] C.J. Saraceno, et al., *IEEE JSTQE,* vol 18, no.1, pp 29-41 (2012)

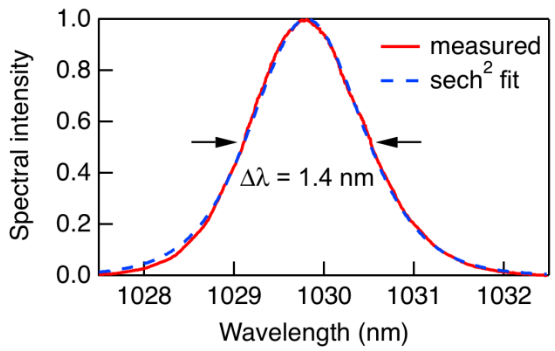
Results

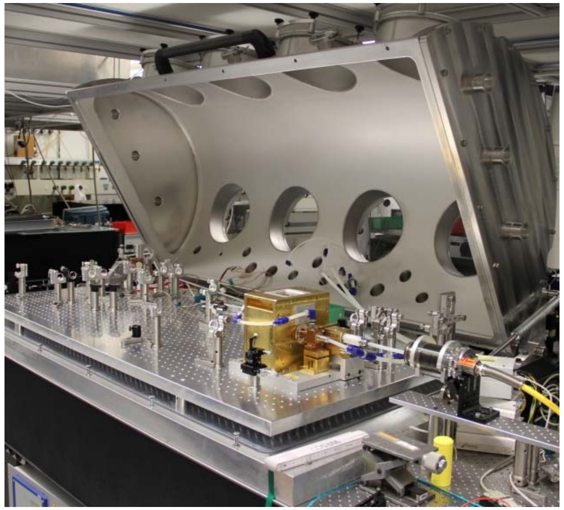
P_{avg}	= **242 W**	τ_p	= 1070 fs
P_{pump}	= 790 W	η_{opt}	= 30 %
f_{rep}	= 3.03 MHz	M^2	< 1.05
E_p	= **80 µJ**	$\tau_p \cdot \Delta\nu$	= 0.39
P_{pk}	= **66 MW**	(ideal: 0.315)	

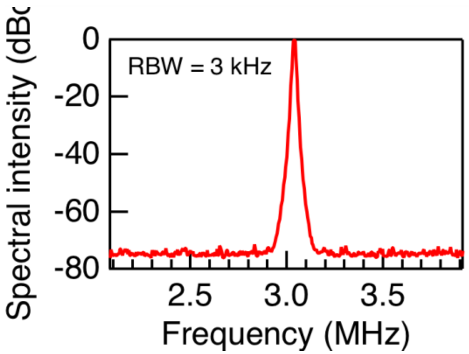
→ Highest pulse energy from any ultrafast oscillator

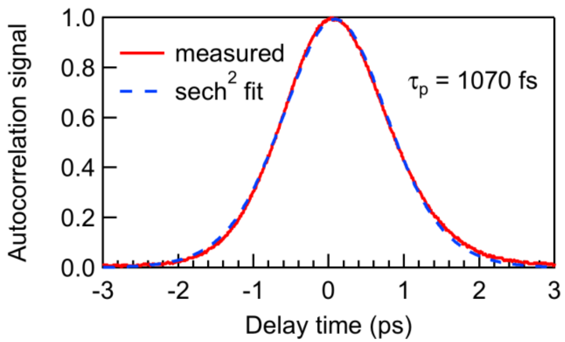
→ **Challenge: need better dispersive mirrors**





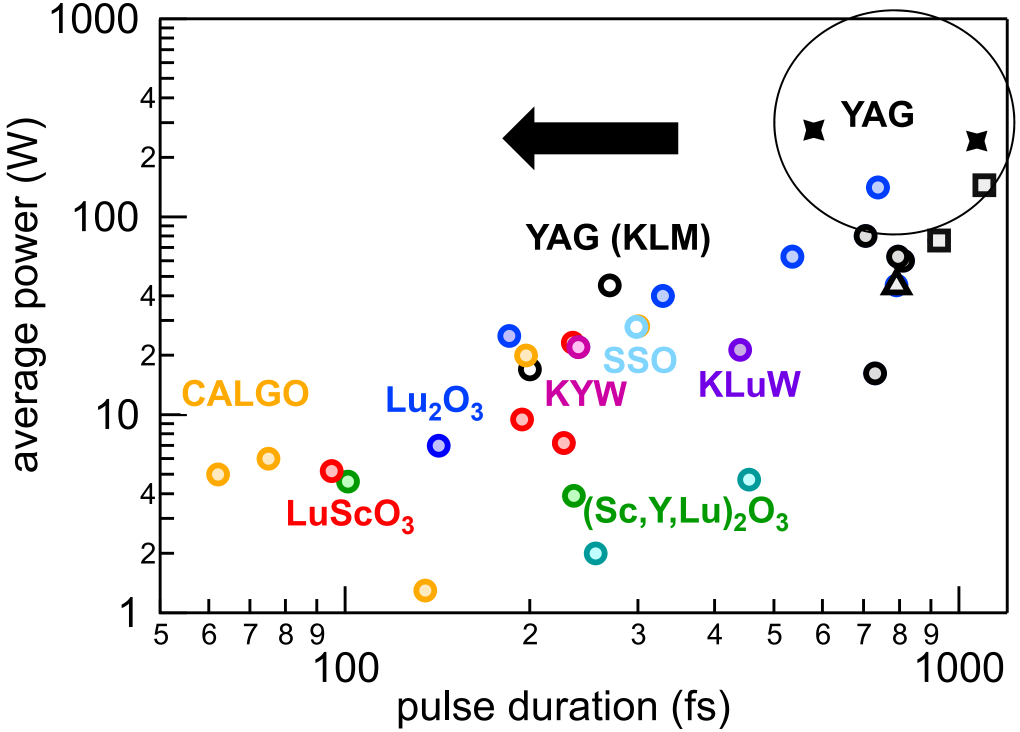






C. Saraceno, F. Emaury, C. Schriber, M. Hoffmann, M. Golling, T. Südmeyer, U. Keller, Optics Letters, 39, 9 (2014)

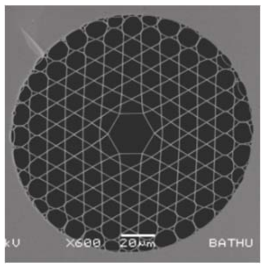
Pulse compression



	Yb:YAG	Yb:YAG
P_{av}	275 W	242 W
τ_p	583 fs	1.07 ps
E_p	17 µJ	80 µJ
P_p	25 MW	66 MW

For most targeted scientific applications

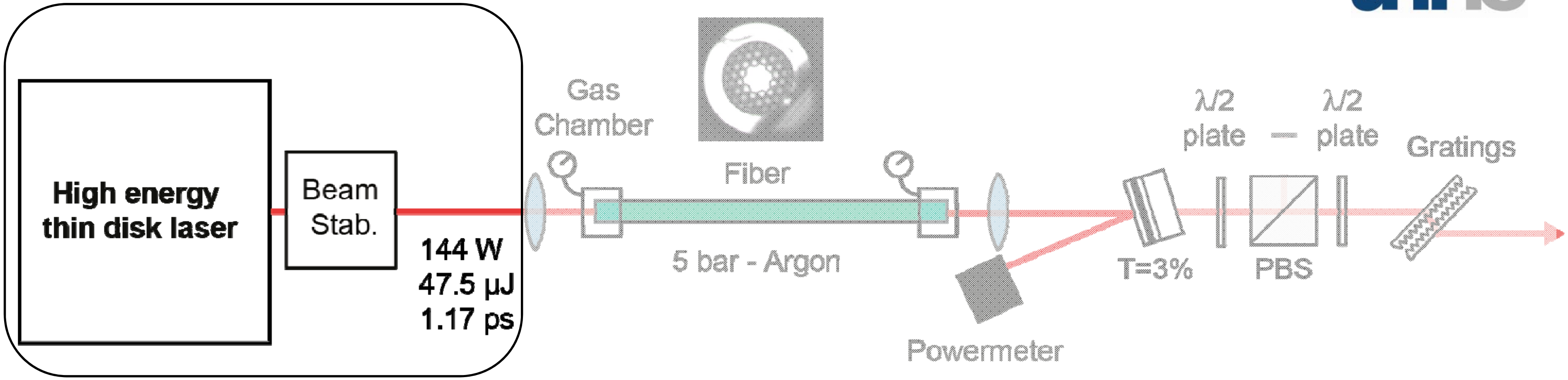
→ **Shorter pulses < 100 fs are required**



Compression in gas-filled HC-PCF

- ✓ Compression of few µJ level pulses to sub-50 fs at 4 MHz
  F. Emaury et al, *Optics Express* **21**, 4986 (2013)
- ✓ Compression/transmission of mJ level pulses at 1 kHz
  C. Fourcade Dutin et al, *Postdeadline Paper CTh5C.7 CLEO US* 2013
- ✓ **Compression of 40 µJ level pulses at 3 MHz (100 W)**

Pulse compression



Available at fiber launch:

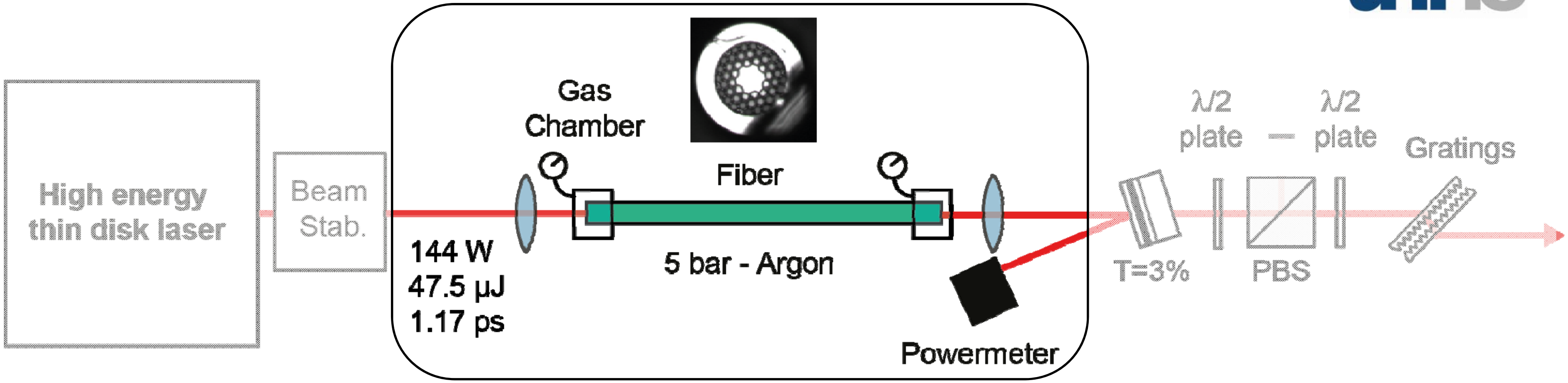
P_{av} = 150 W

E_p = 50 µJ

f_{rep} = 3 MHz

τ_p = 1.1 ps

Pulse compression



Available at fiber launch:

P_{av} = 150 W

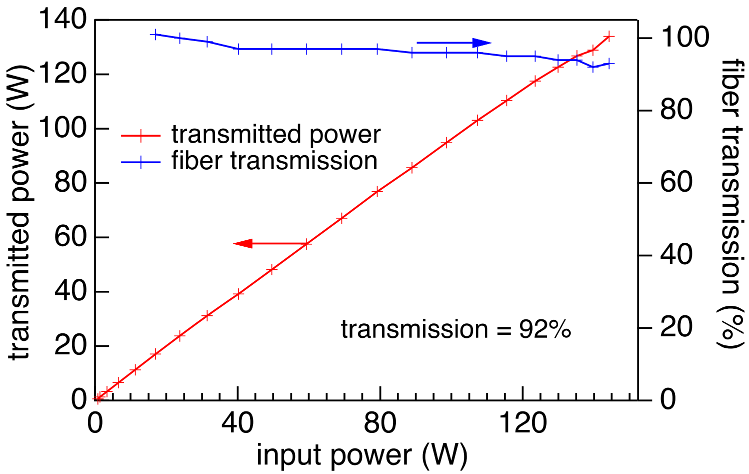
E_p = 50 µJ

f_{rep} = 3 MHz

τ_p = 1.1 ps

Fiber:

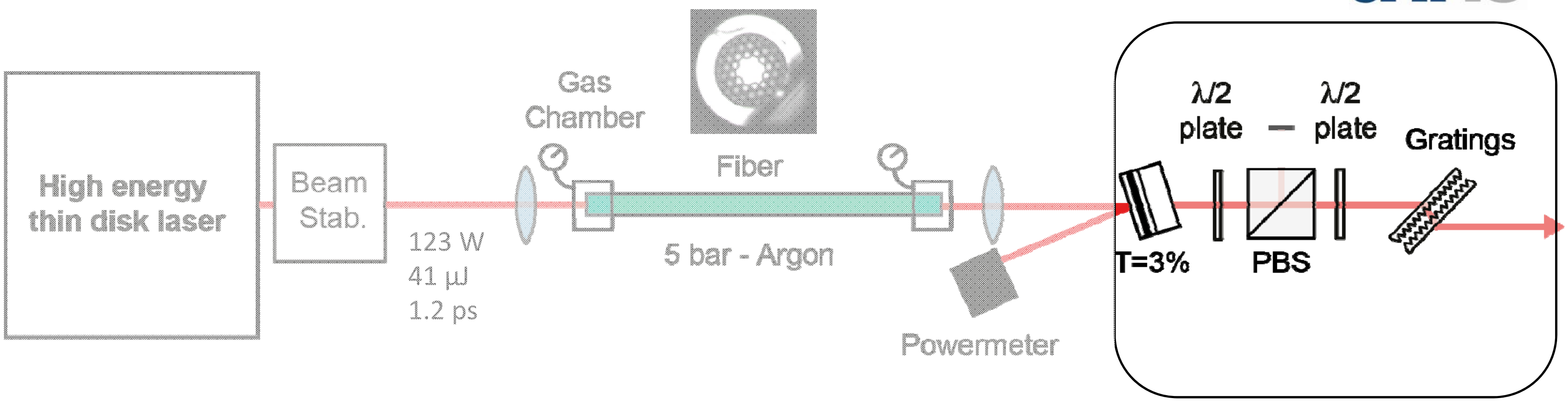
- Kagome-type HC-PCF 7-cell hypocycloid core
- MFD ≈ 30 µm
- Ar-filled: 5 bar
- Length = 67 cm

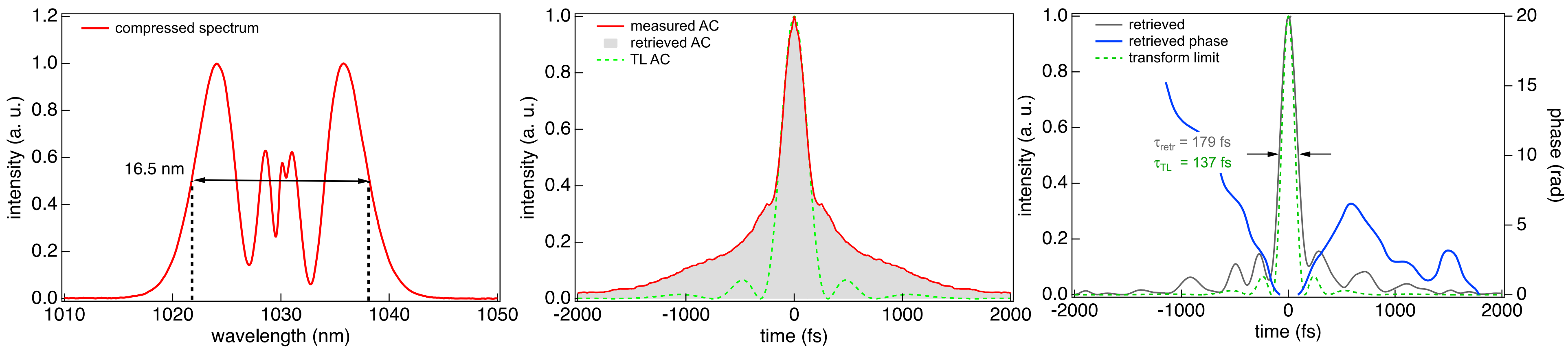


✓ Transmission 92% at maximum power

✓ 134 W out for 144 W launched: highest value through Kagome

Pulse compression



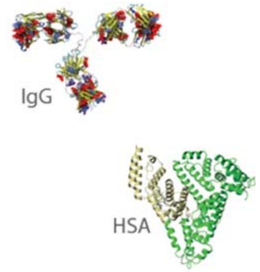


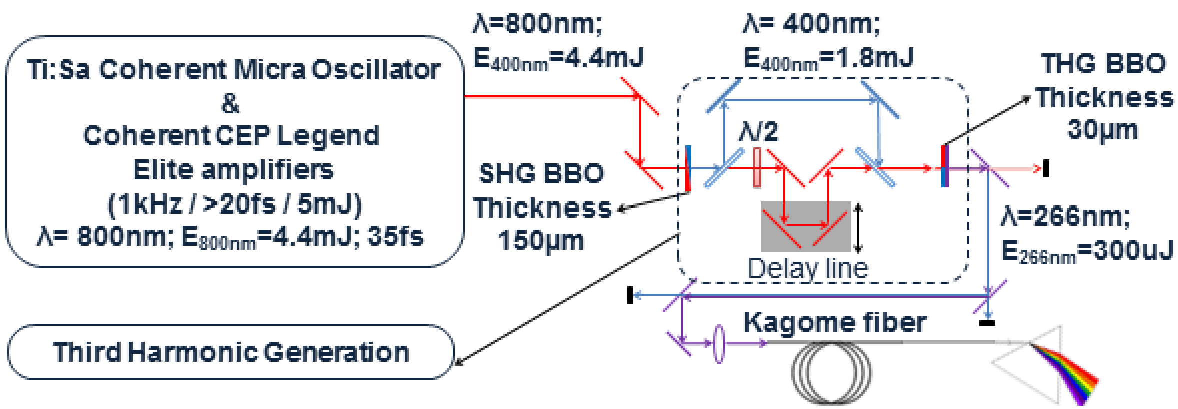
- ✓ Compression with 80% total power efficiency
- ✓ Output: 100 W compressed to sub-200 fs

Shorter pulses: need optimized dispersive mirrors for compression

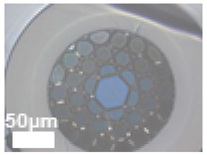
Beam transmission and spectral broadening of deep-UV fs pulses in Kagome-type hollow-core photonic crystal fibers

Target: ultrashort deep UV pulses
for time resolved optical and photo-electron spectroscopy





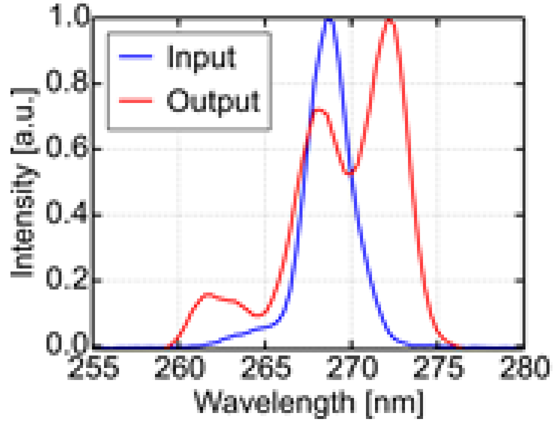
UV Kagome HC PC Fiber



Picture of the front end face of the fiber.

No	Core diameter in/out (µm)	Outer diameter (µm)	UV test Loss (dB/m @ 355nm)
1	44/52	400	0.654
2	21/25	140	1.703

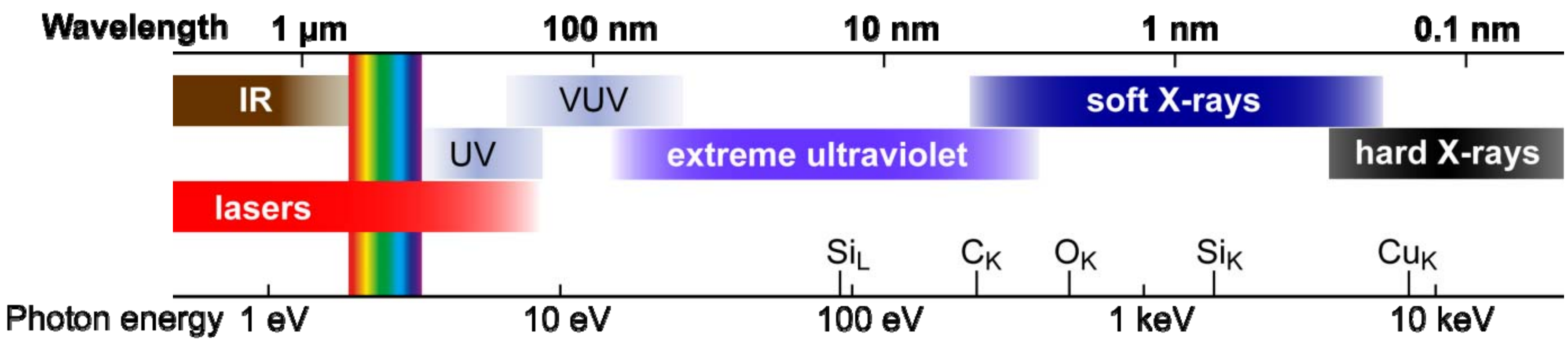
Picture of the illuminated fiber;
red: stripped cladding, white/green: coating.



Compression of broadened pulses: **need dispersive mirrors in DUV**

How to generate coherent XUV light?

- Observe smaller features
- Write smaller patterns
- Understand dynamics in nanostructures
- Elemental sensitivity (core level e^-)
- Frequency combs in the VUV/XUV



How to generate coherent XUV light?

- Observe smaller features
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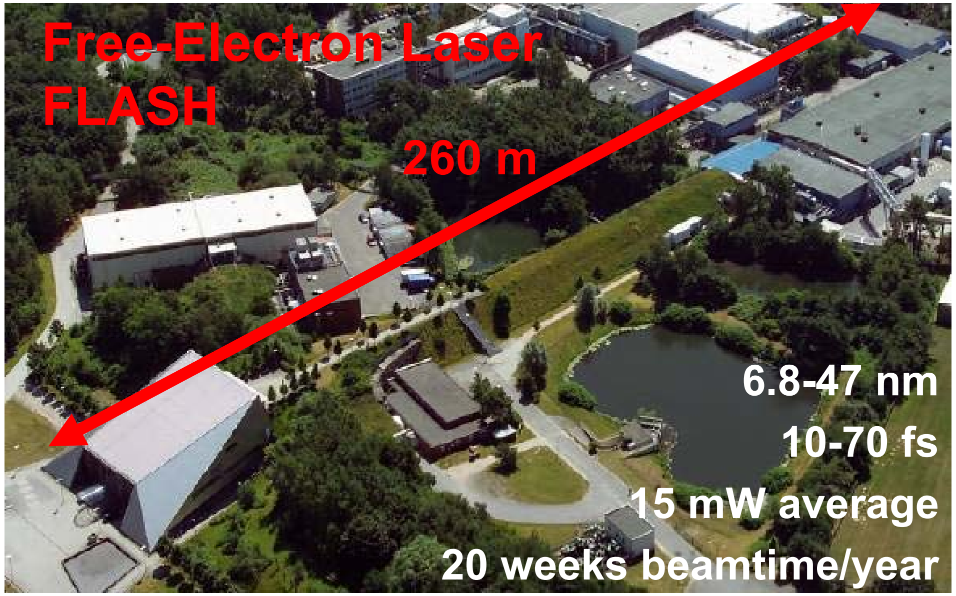
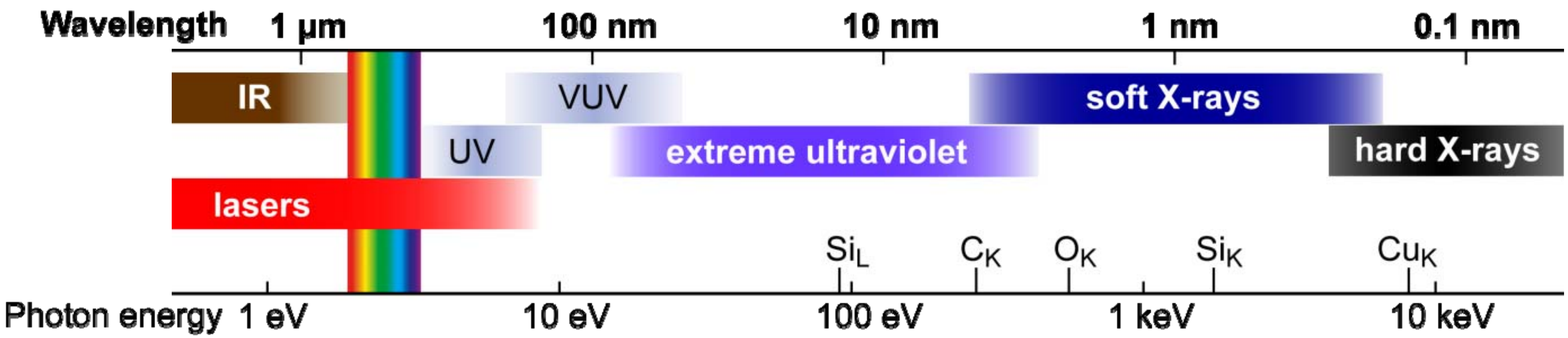
- Understand dynamics in nanostructures
- Elemental sensitivity (core level e$^-$)
- Frequency combs in the VUV/XUV

Accelerator-based light sources

- extremely bright, widely tunable
- but: large, expensive, limited access

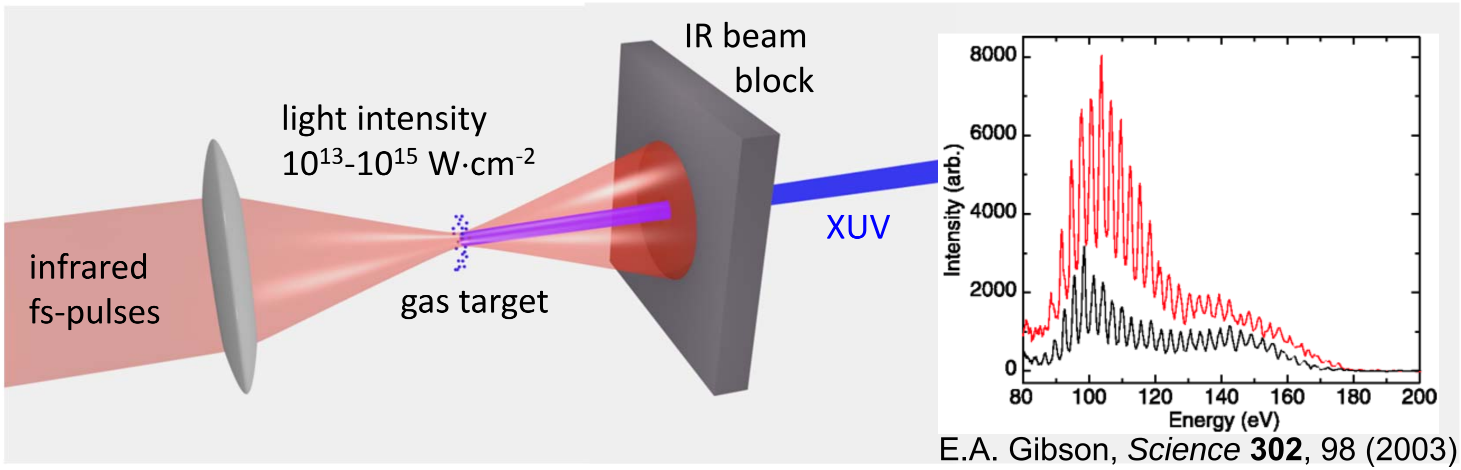




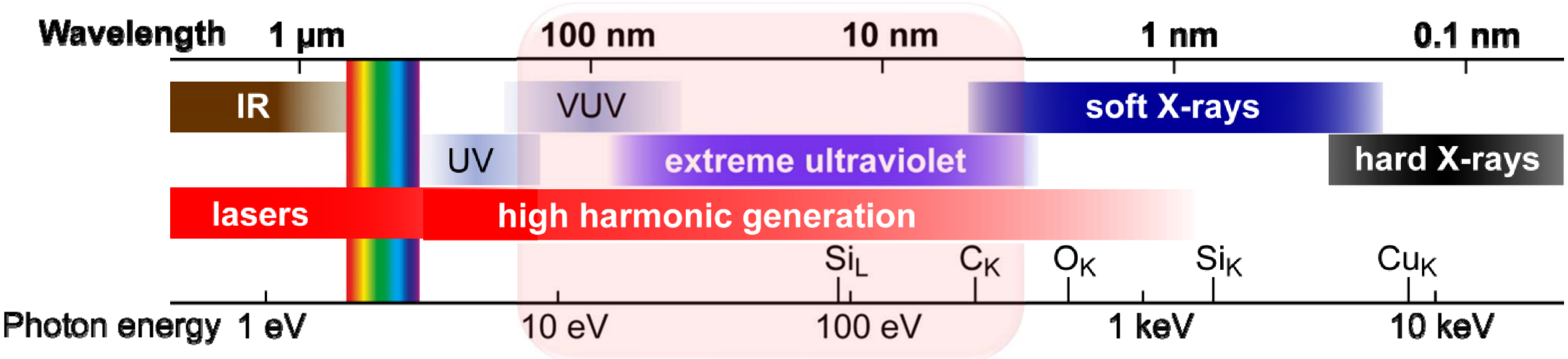
HHG: bringing coherent XUV light to the lab

Extreme nonlinear up-conversion of IR fs-pulses in gas target

- broad range of coherent UV-XUV radiation
- attosecond duration



E.A. Gibson, *Science* **302**, 98 (2003)



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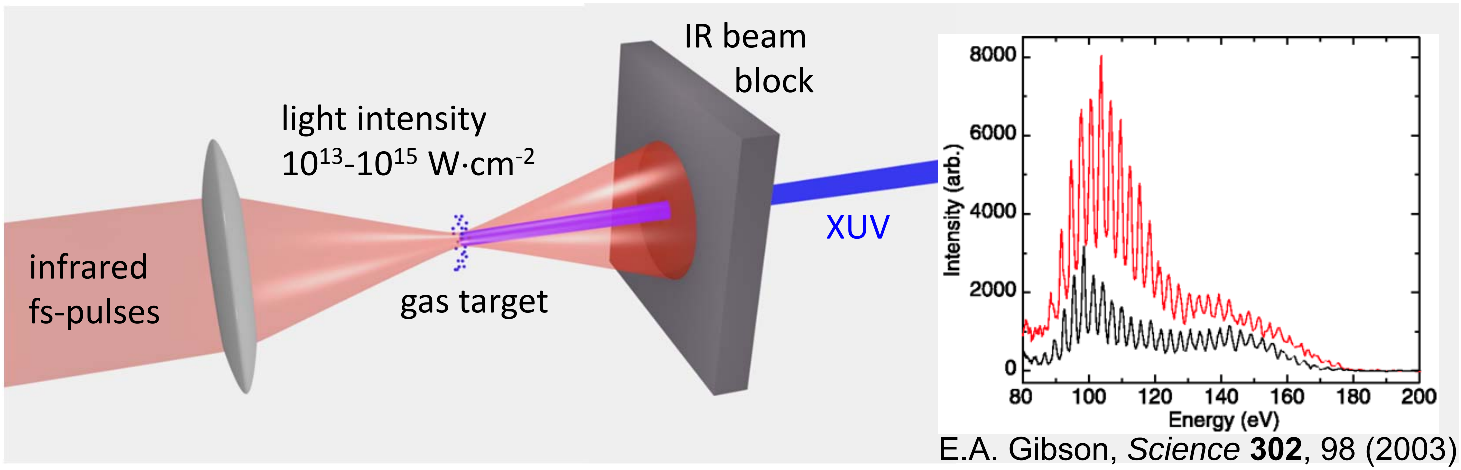
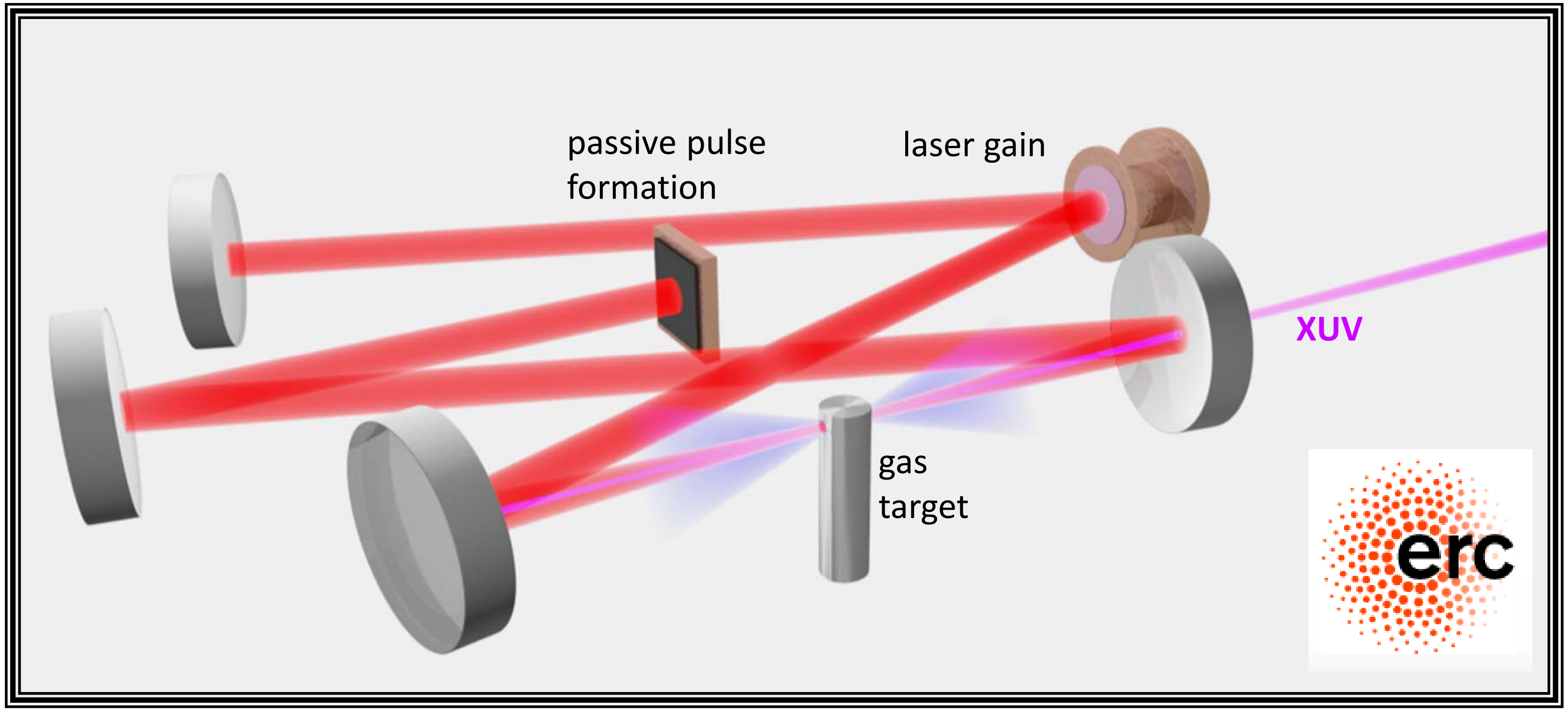


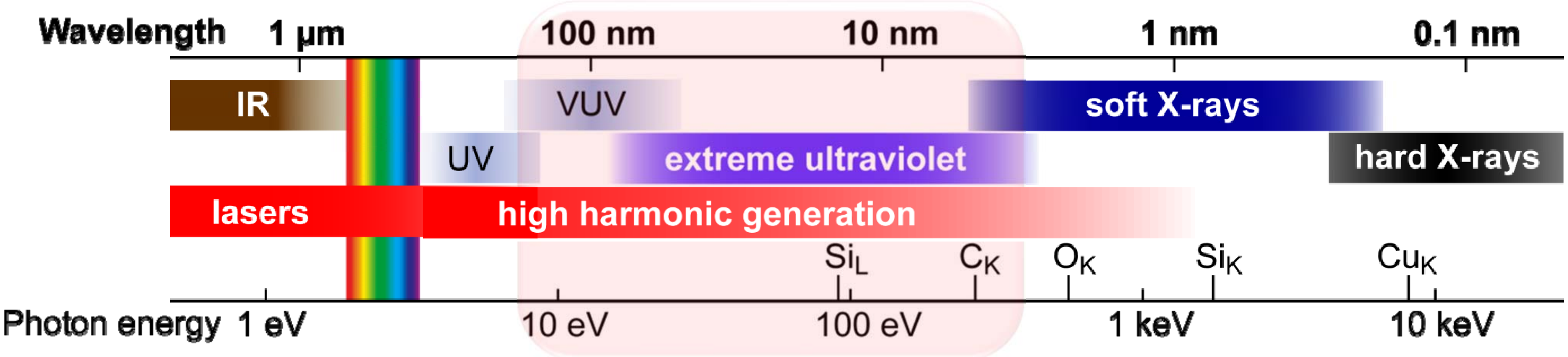
E.A. Gibson, *Science* **302**, 98 (2003)

Limitations

- conversion efficiency 10^{-8} to 10^{-6} ⇨ **flux too low for many applications**
- typical fs-amplifier: 10 W, 1 kHz ⇨ **kHz repetition rate: no frequency combs, limited usefulness**

ERC MegaXUV: intra-laser high harmonic generation





Minimum pulse duration of Yb-doped bulk lasers and TDLs

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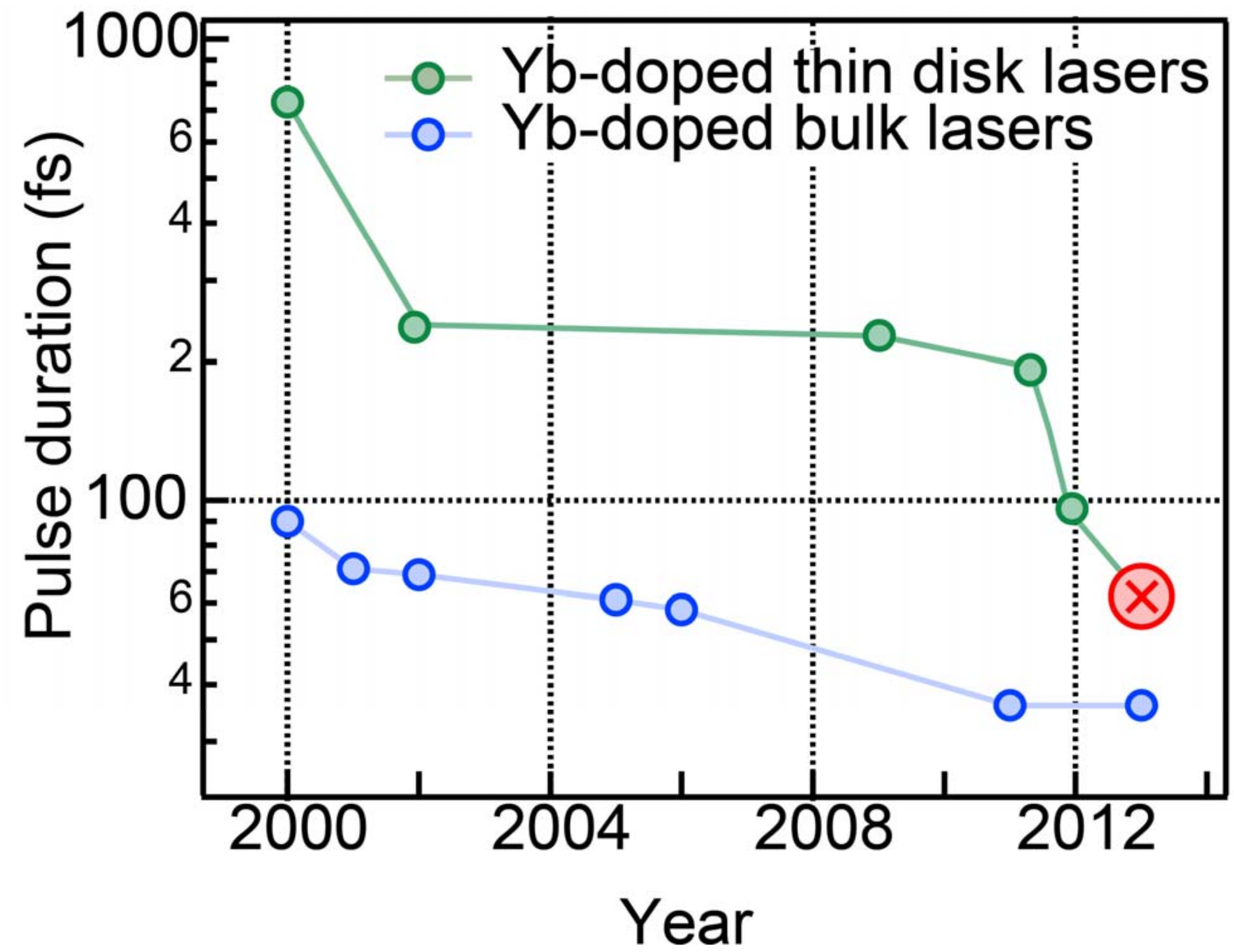
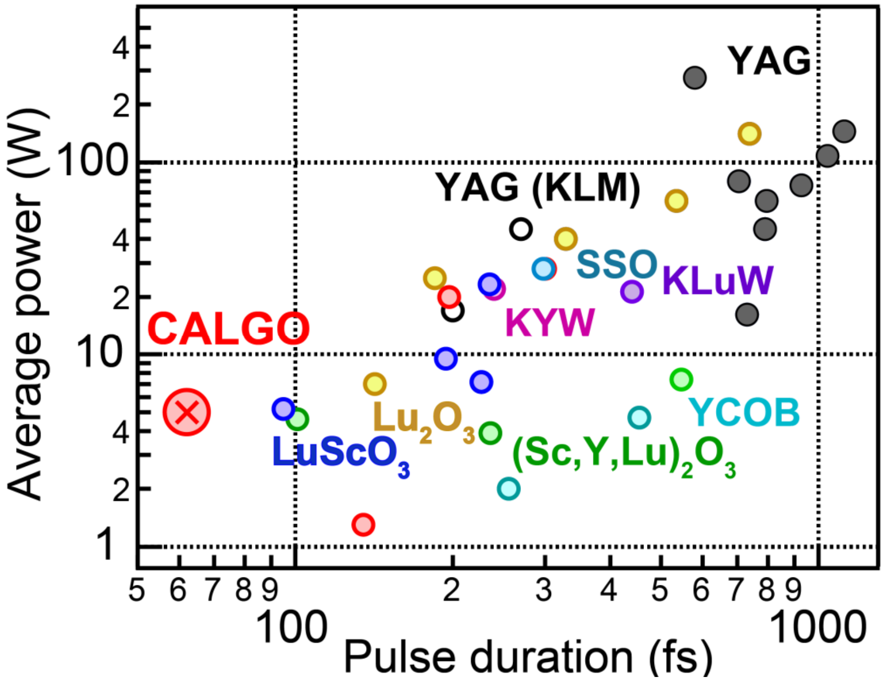
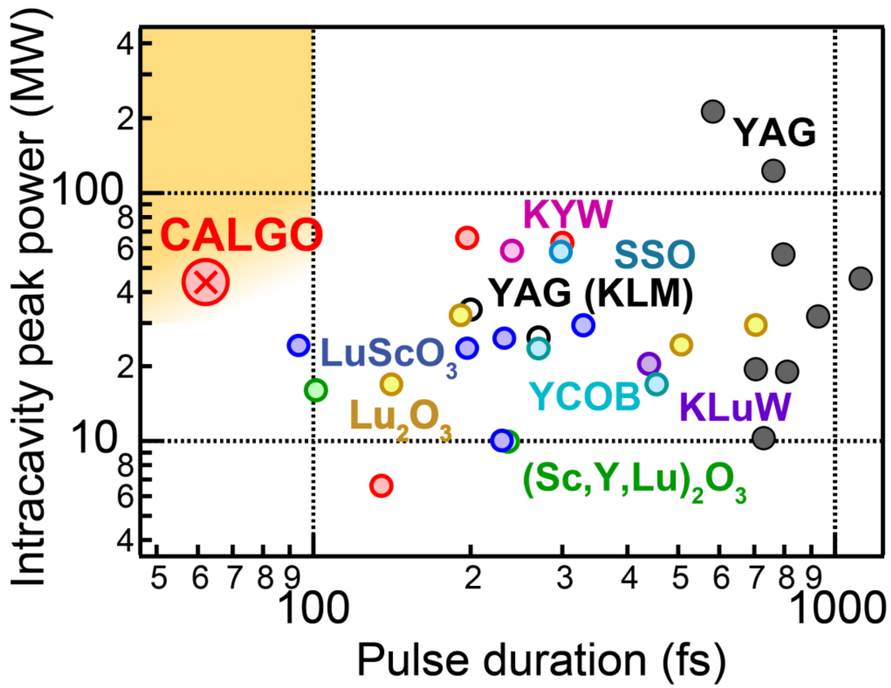


Average power and intracavity peak power of ultrafast TDLs





- Ultrafast TDL are highly suitable for intra-laser nonlinear optics at extreme intensities
- Expect GW intracavity peak powers and mJ intracavity pulse energies
- **Need optimized dielectric coatings that can stand these extreme intensities**

Overview

Introduction

Ultrafast lasers

Ultrafast high power lasers and challenges for dielectric coatings

Analogies: MBE growth optimization at ETH

OPTICS: status and next steps

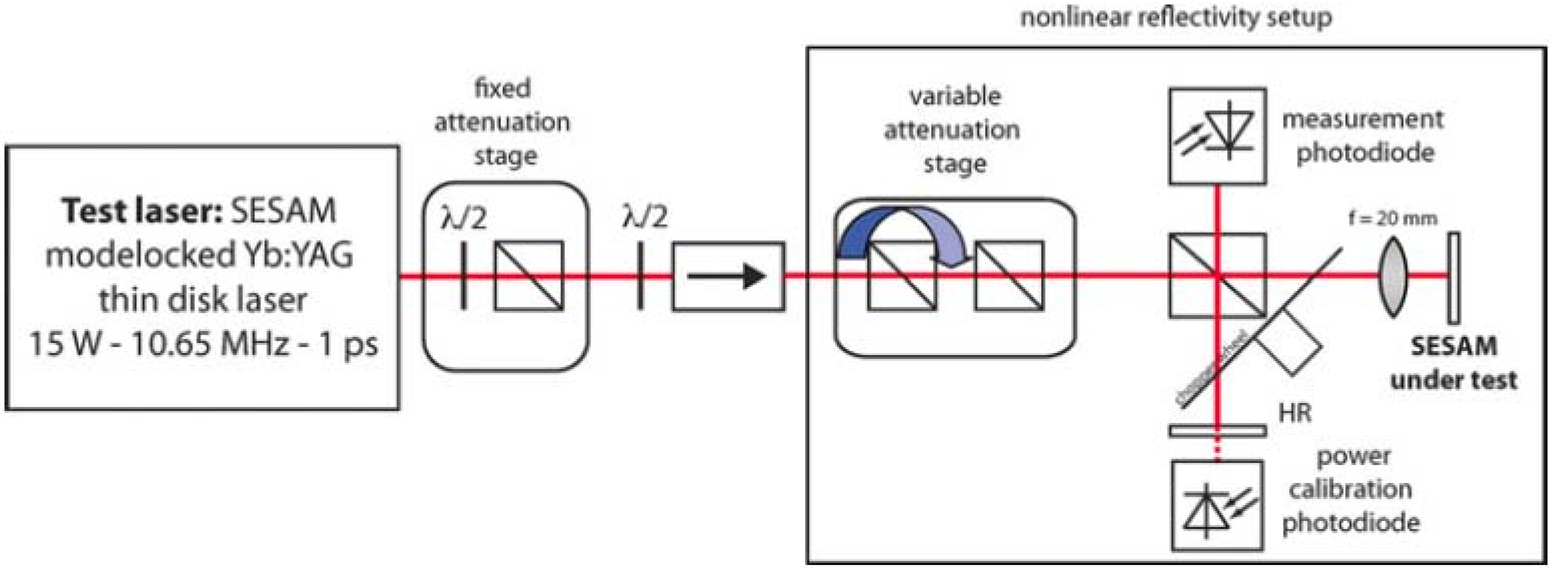
IEEE JOURNAL OF SELECTED TOPICS IN QUANTUM ELECTRONICS, VOL. 18, NO. 1, JANUARY/FEBRUARY 2012

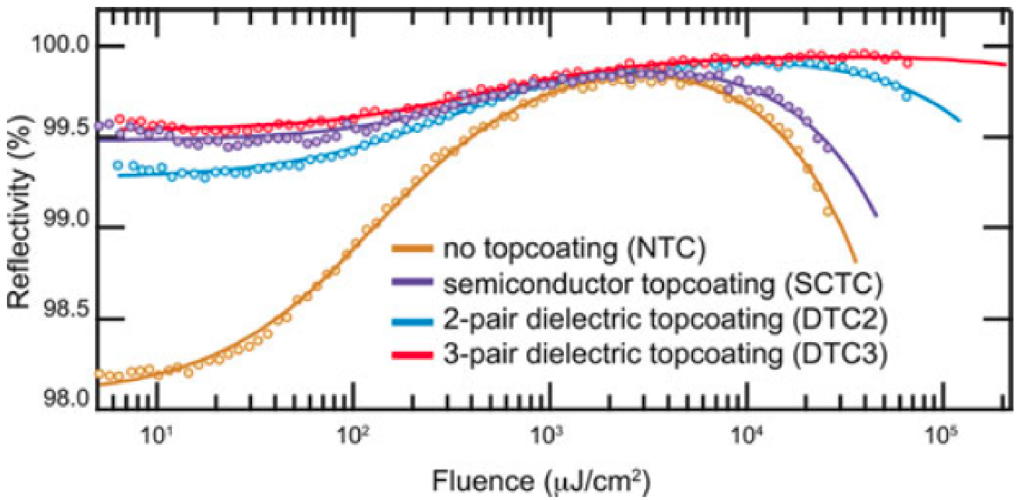
SESAMs for High-Power Oscillators: Design Guidelines and Damage Thresholds

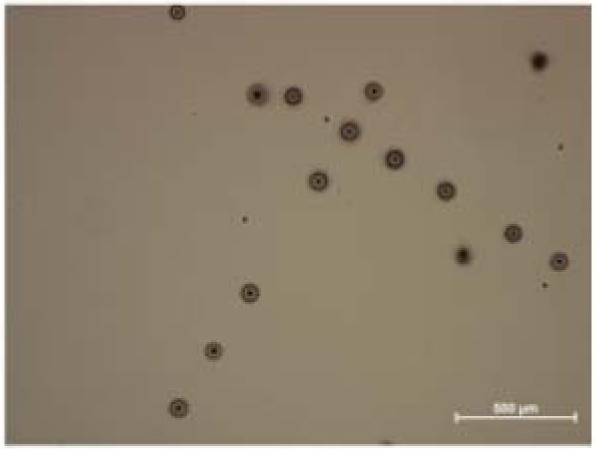
Clara J. Saraceno, Cinia Schriber, Mario Mangold, Martin Hoffmann, Oliver H. Heckl, Cyrill R. E. Baer, Matthias Golling, Thomas Südmeyer, and Ursula Keller

Symbol	**Yb:YAG [15]**	**Yb:YAG [7]**	**$Yb:Lu_2O_3$ [6]**
Average output power	45 W	76 W	**140 W**
Repetition rate	4 MHz	2.93 MHz	60 MHz
Intra-cavity average power	450 W	97.4 W	**1.49 kW**
Intra-cavity peak power	125.7 MW	31.5 MW	29.8 MW
Output pulse energy	11.3 µJ	**25.9 µJ**	2.35 µJ
Intra-cavity pulse energy	**113 µJ**	33.2 µJ	25 µJ
Fluence on SESAM	**≈ 5-7 mJ/cm²**	≈ 4 mJ/cm²	≈ 2 mJ/cm²
Average intensity on SESAM	≈ 2.9 kW/cm²	≈ 1.5 kW/cm²	**≈ 12 kW/cm²**
Peak intensity on SESAM	**≈ 16.5 GW/cm²**	≈ 9.9 GW/cm²	≈ 4.8 GW/cm²
Saturation fluence F_{sat} of SESAM	**112.2 µJ/cm²**	61 µJ/cm²	61 µJ/cm²
Saturation parameter S	≈ 50-60	**≈ 65**	≈ 33

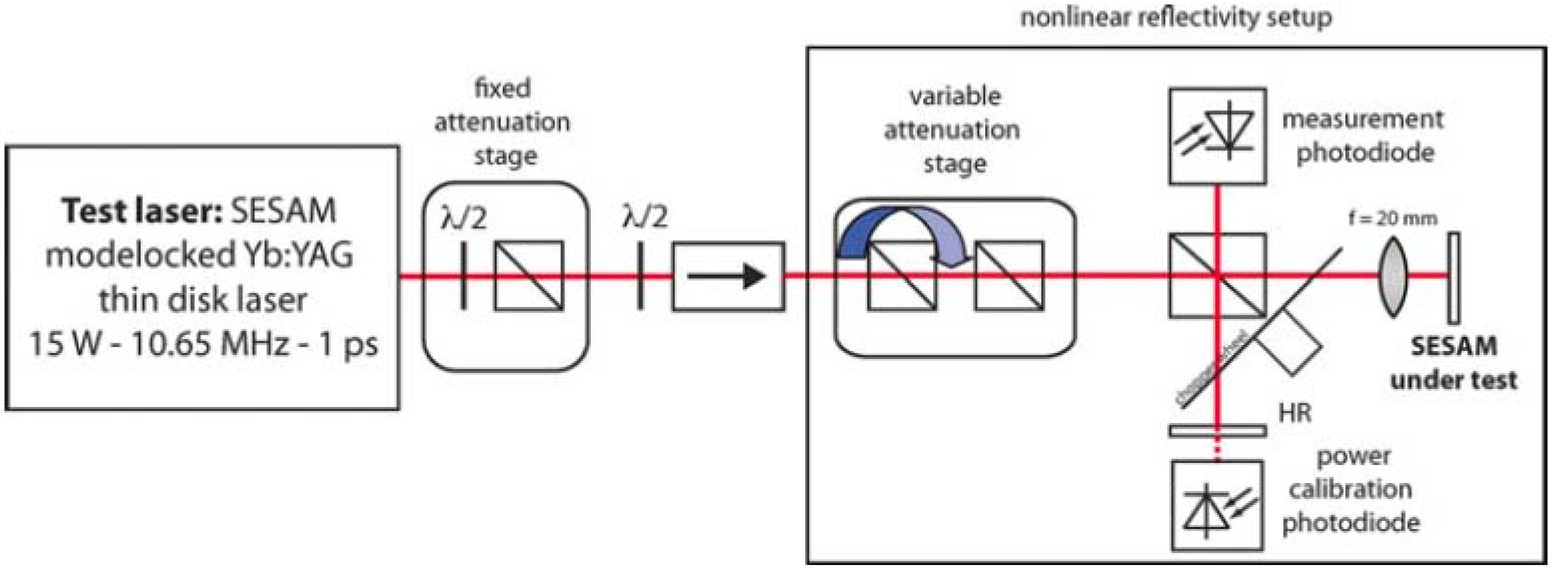
Optimization of SESAMs

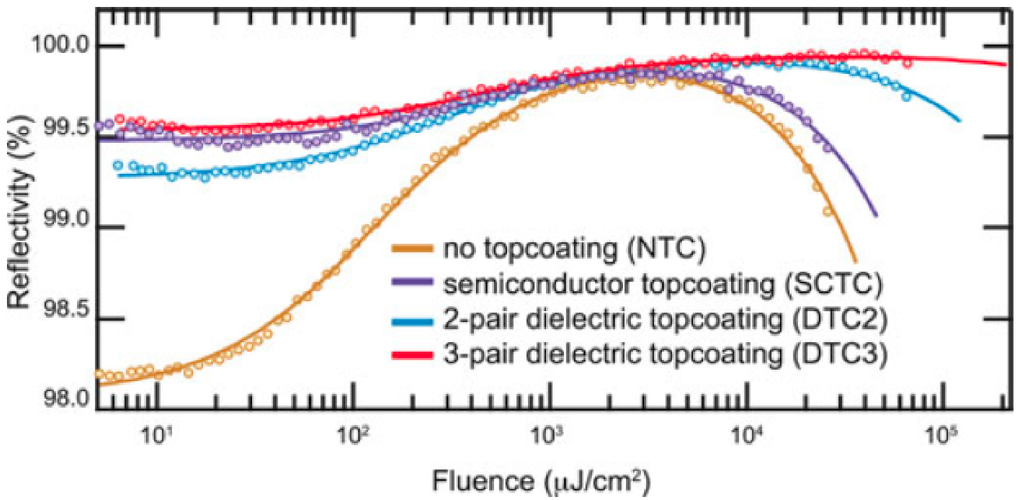


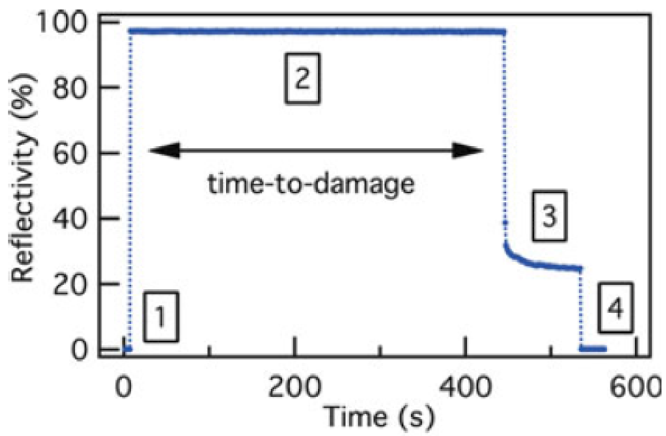




Optimization of SESAMs







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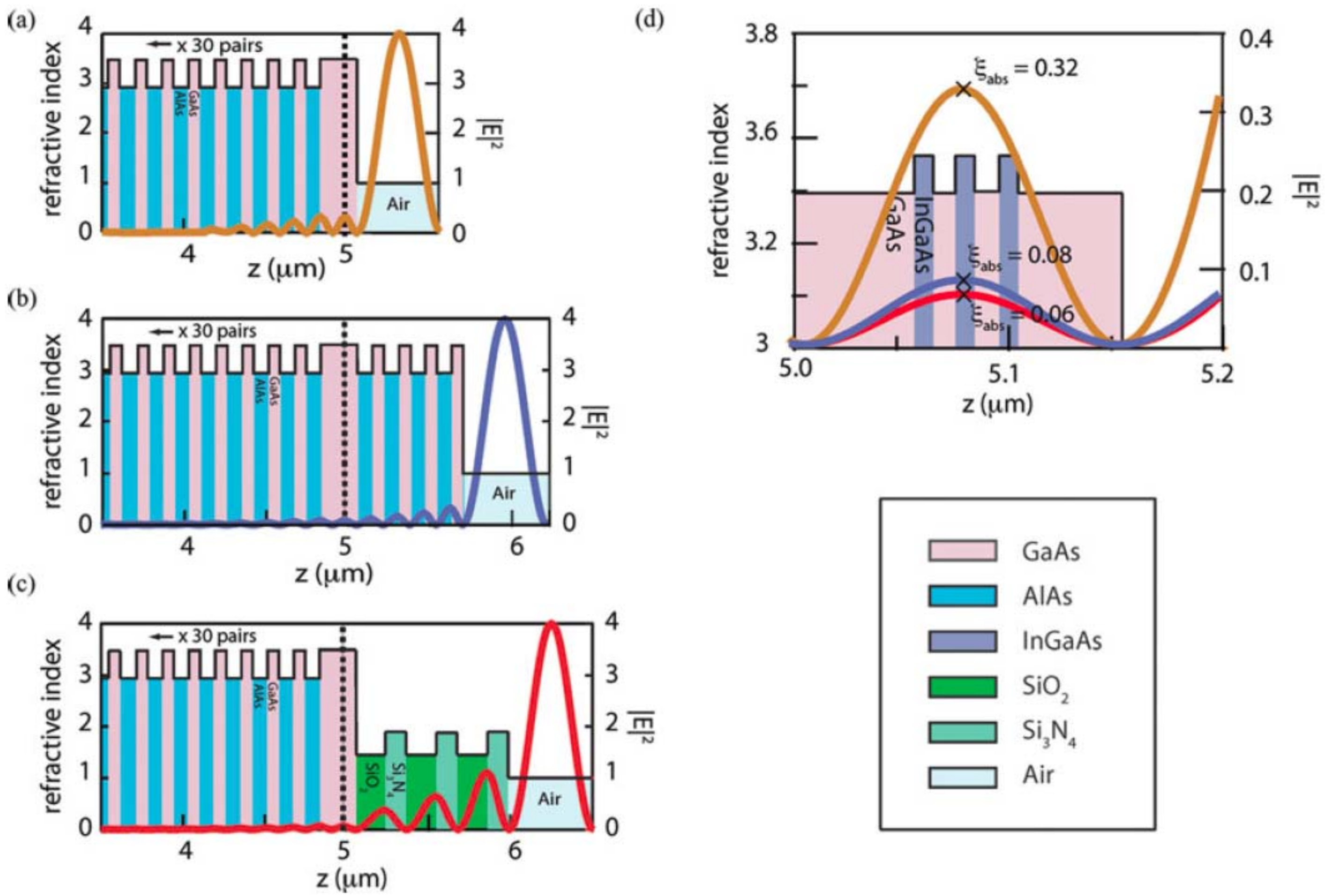
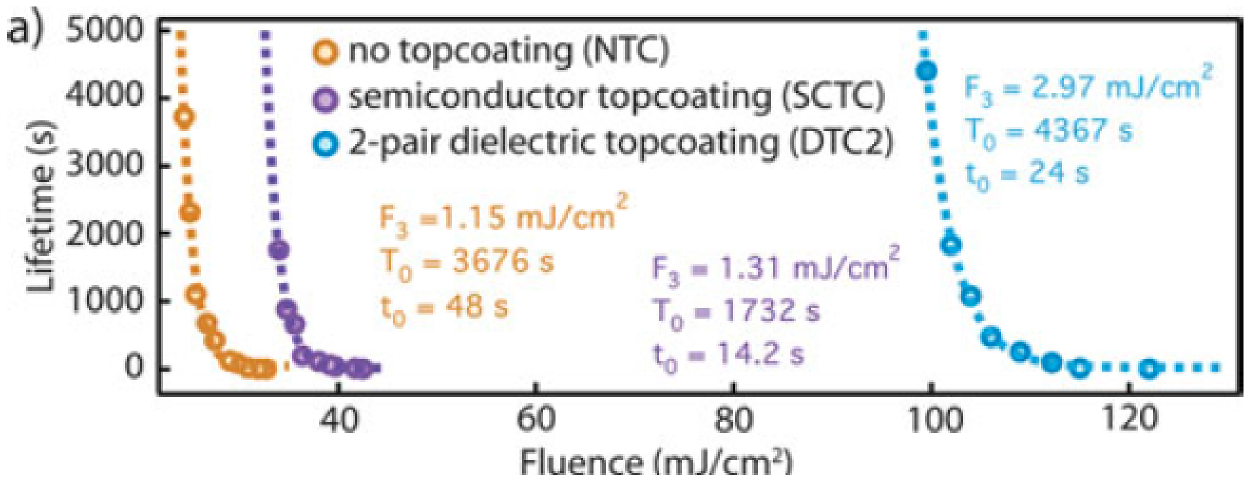
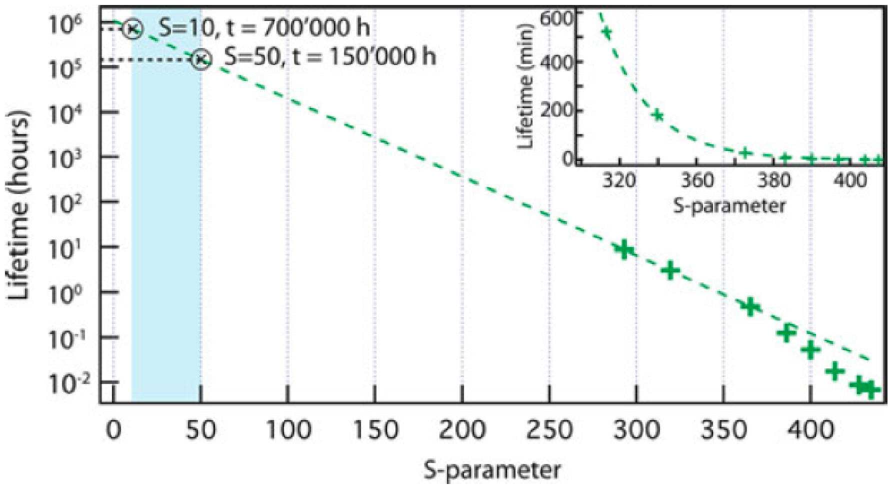


Optimization of SESAMs





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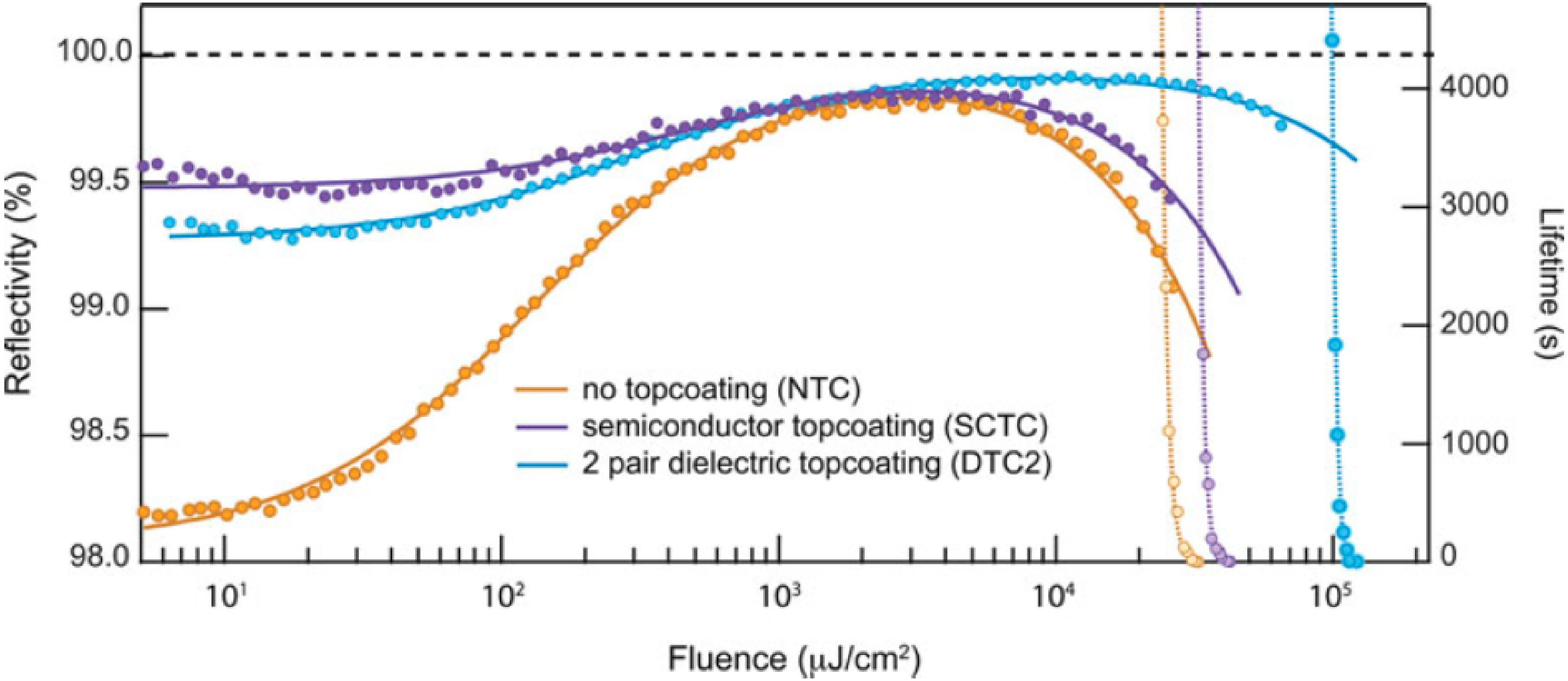

Experimental verification of soliton-like pulse-shaping mechanisms in passively mode-locked VECSELs

Martin Hoffmann*, Oliver D. Sieber, Deran J. H. C. Maas, Valentin J. Wittwer, Matthias Golling, Thomas Südmeyer, and Ursula Keller

#125661 - $15.00 USD Received 18 Mar 2010; revised 22 Apr 2010; accepted 25 Apr 2010; published 29 Apr 2010

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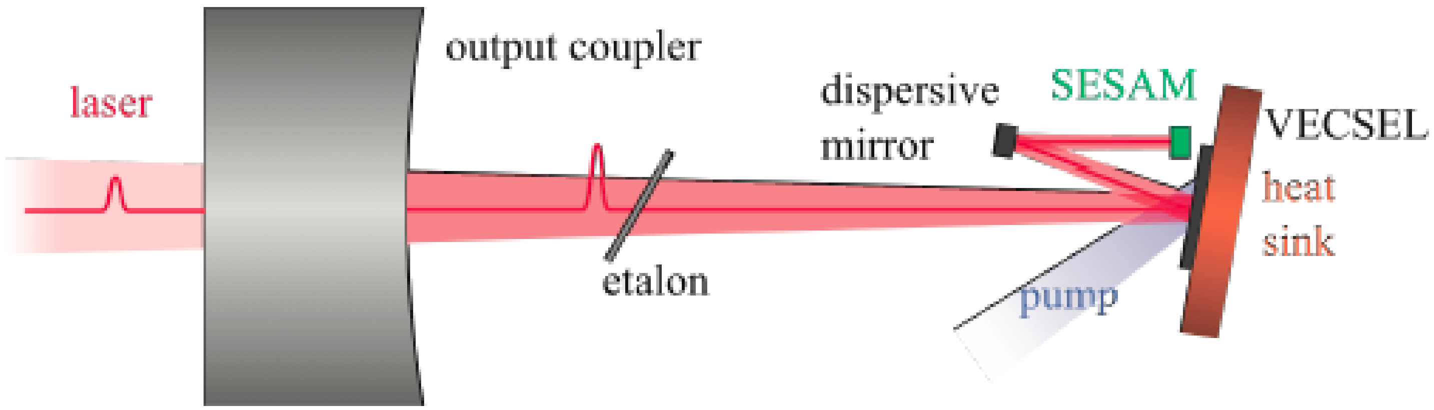
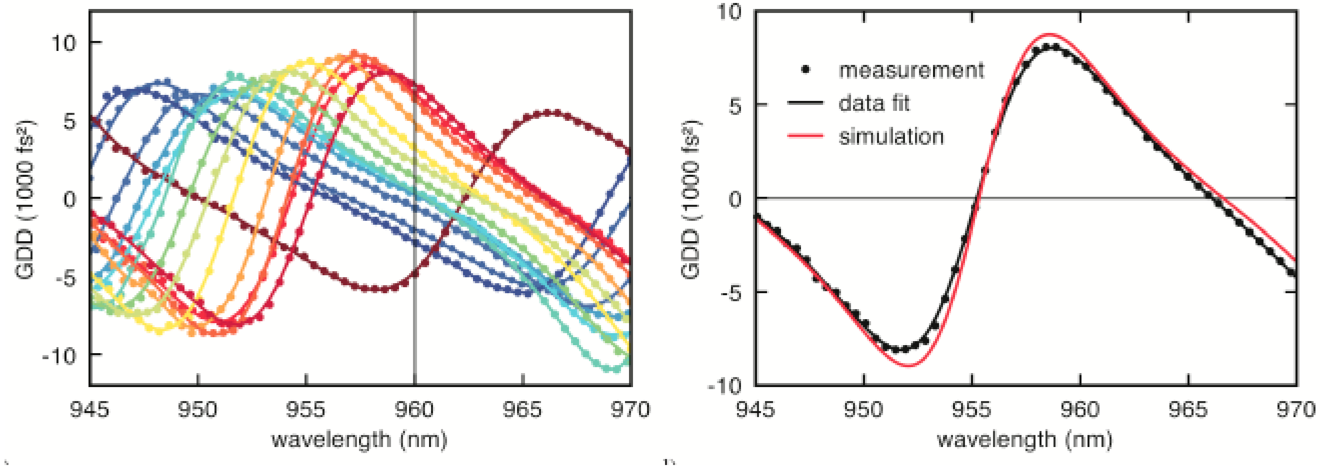
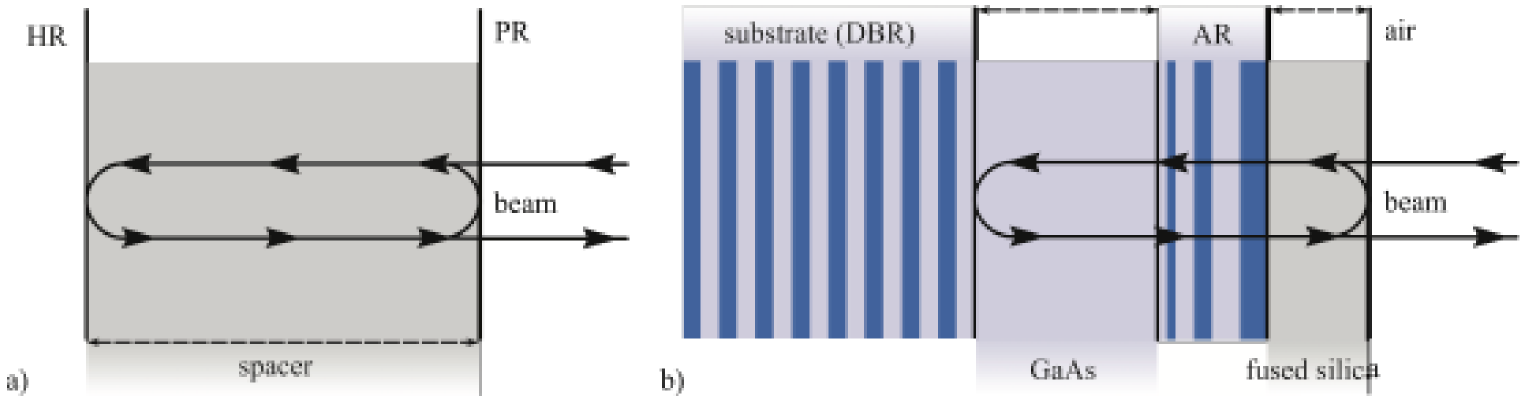


Optimization of VECSELs





Optimization of VECSELs

Femtosecond high-power quantum dot vertical external cavity surface emitting laser

Martin Hoffmann,[1,*] Oliver D. Sieber,[1] Valentin J. Wittwer,[1] Igor L. Krestnikov,[2] Daniil A. Livshits,[2] Yohan Barbarin,[1] Thomas Südmeyer,[1] and Ursula Keller[1]

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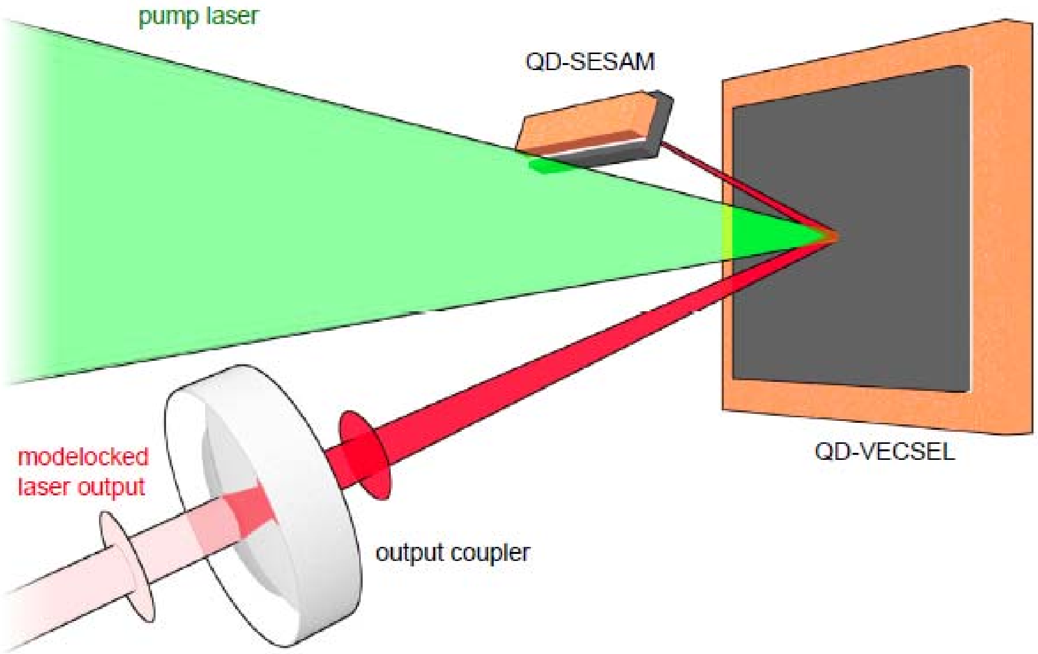
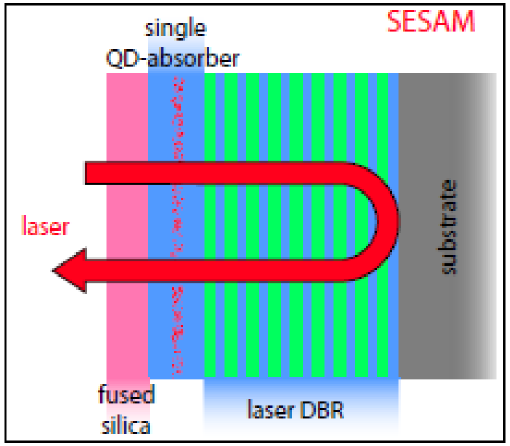
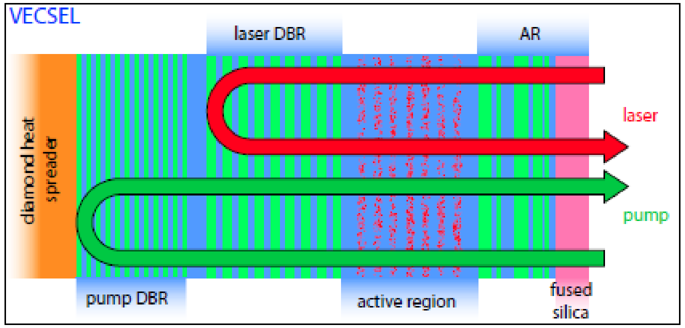
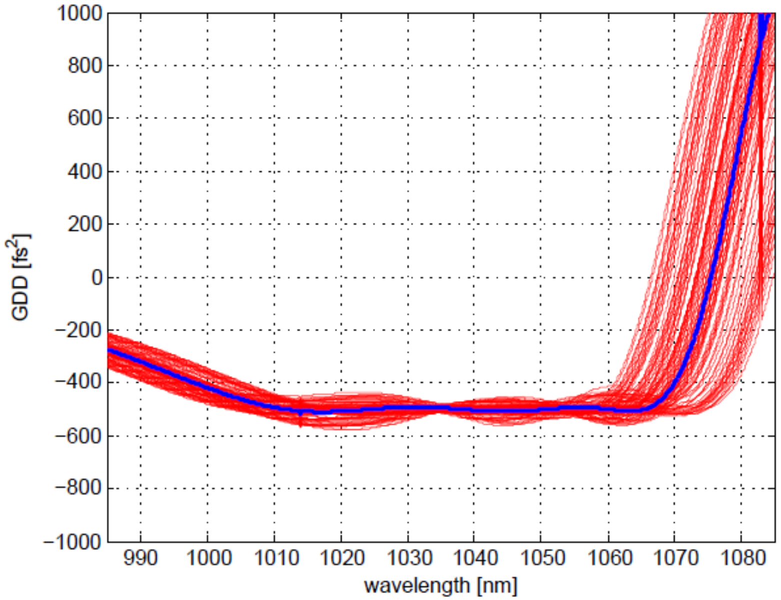
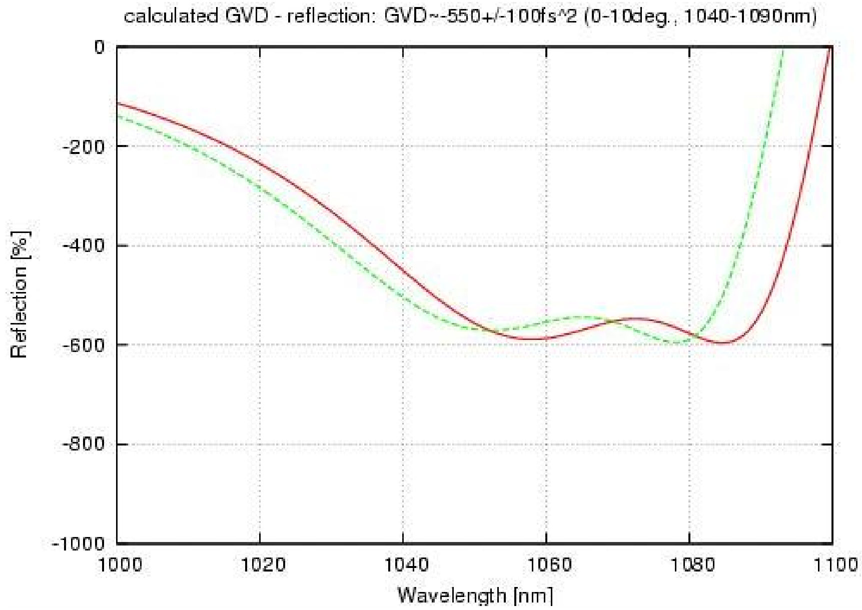






GTI mirror designs





GDD of a dispersive mirror designed using Monte-Carlo optimizations

- Red curves: 1% error in the material calibration
- Covers >50 nm spectral width without significant variation
- Similar designs applied to MBE growth of VECSELs resulted in new records in the femtosecond regime

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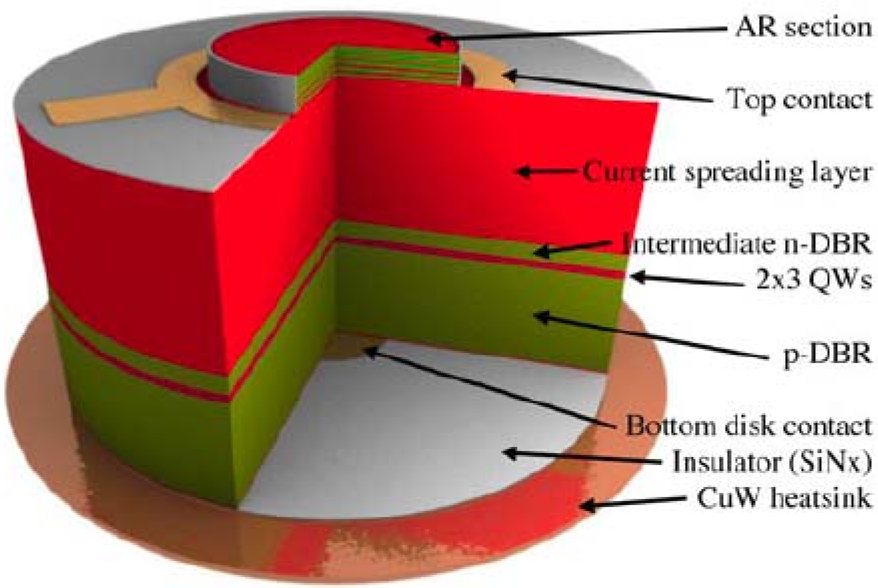
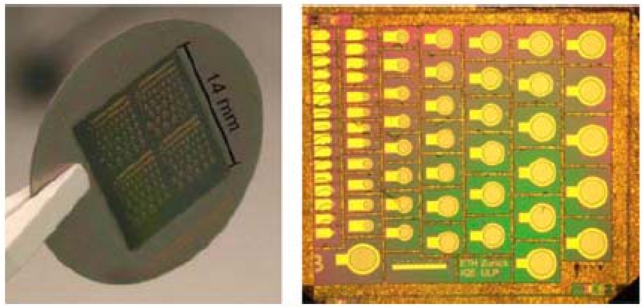
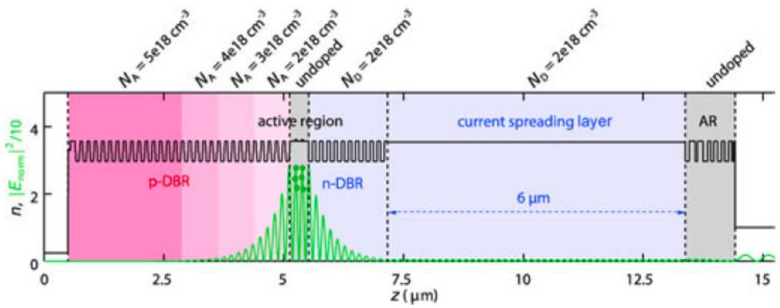
Electrically Pumped Vertical External Cavity Surface Emitting Lasers Suitable for Passive Modelocking

Yohan Barbarin, *Member, IEEE*, Martin Hoffmann, Wolfgang P. Pallmann, Imad Dahhan, Philipp Kreuter, Michael Miller, Johannes Baier, Holger Moench, Matthias Golling, Thomas Südmeyer, Bernd Witzigmann, *Member, IEEE*, and Ursula Keller







Overview

Introduction

Ultrafast lasers

Ultrafast high power lasers and challenges for dielectric coatings

Analogies: MBE growth optimization at ETH

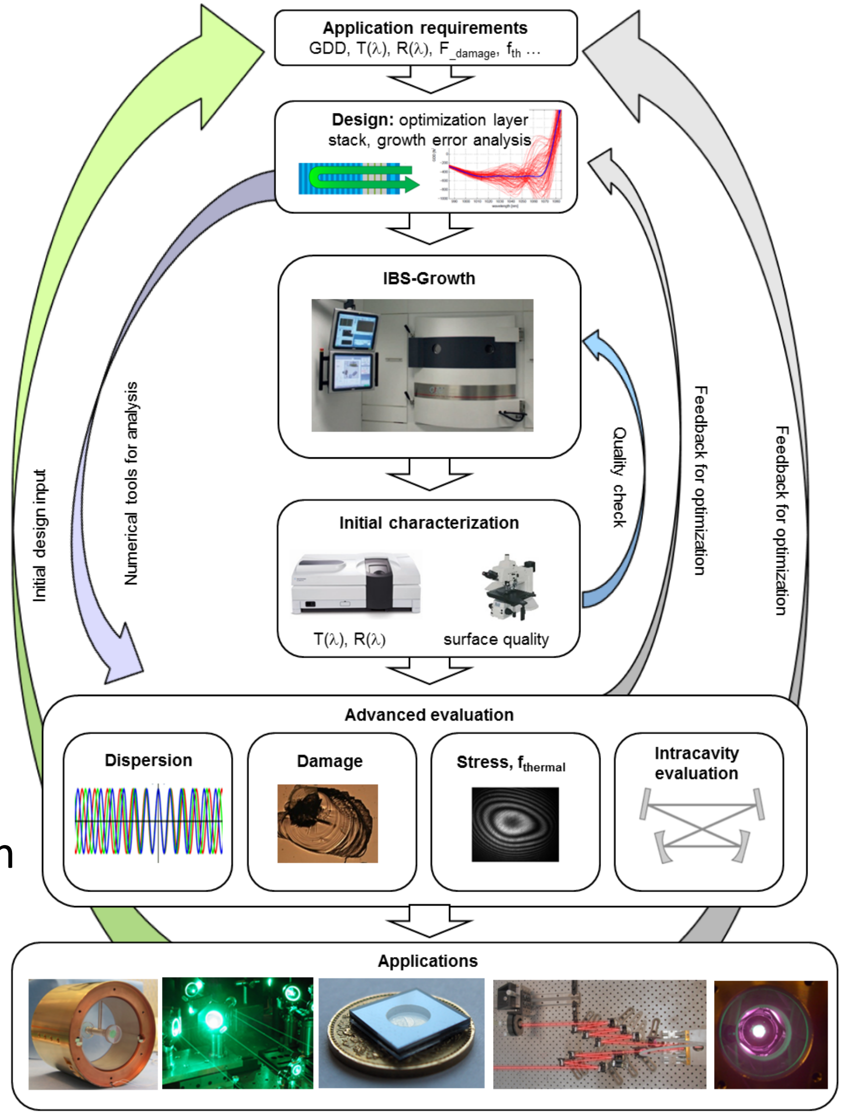
OPTICS: status and next steps

OPTICS: OPTical IBS Coatings for Swiss research

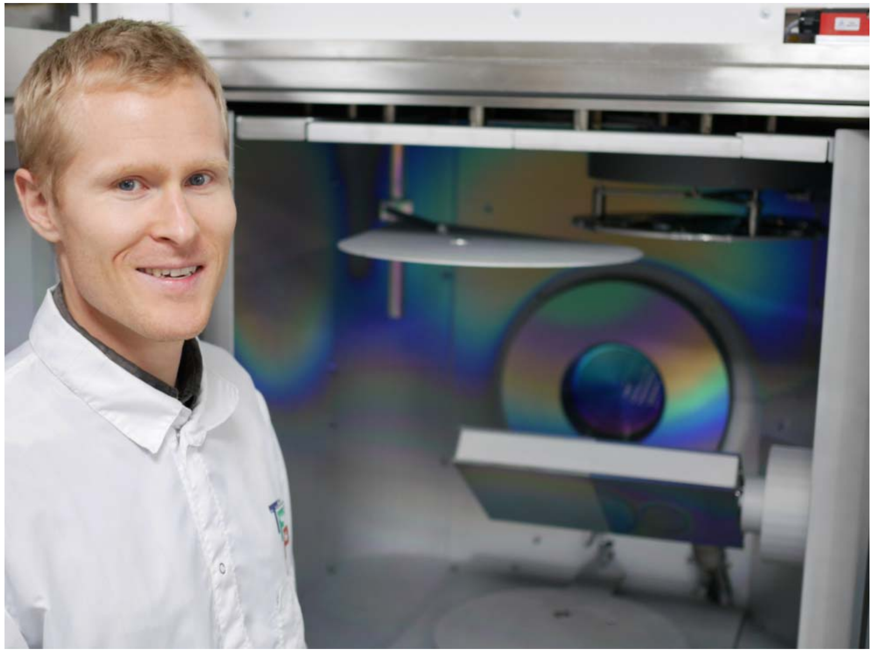
Target: develop new IBS solutions for research

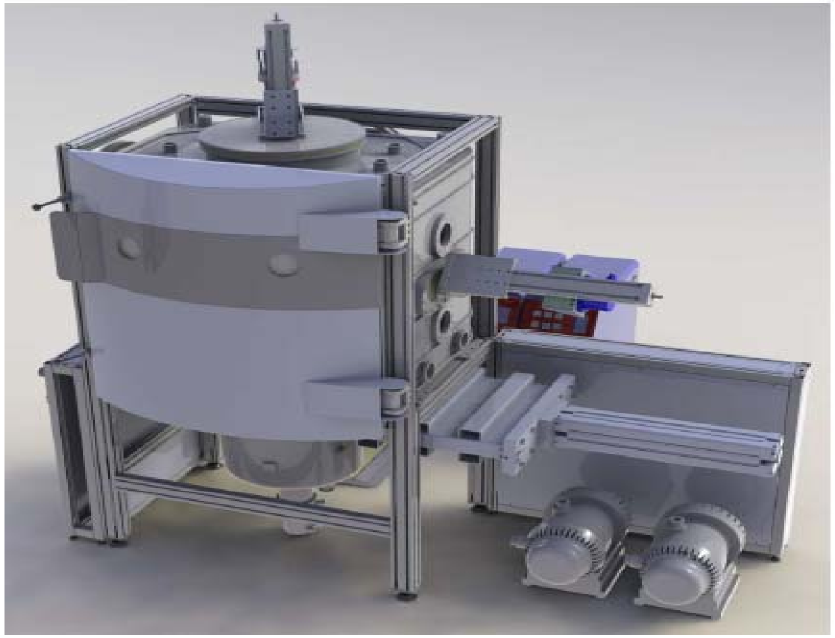
- IBS optimization with coating vendors
  - specific research solutions: low priority
  - time-consuming
  - expensive
  - growth parameters might vary

- OPTICS: provide fast development cycle
  - Analysis of application requirements
  - Optimized layer design
  - Growth on dedicated IBS machine
  - Full characterization
  - Immediate feedback to design & growth according to the needs of the application



Status





Acquired CEC Navigator 1100 from Cutting Edge Coatings (spin-off LZH)

- Ion Source Upgrade, assist source system
- Load-lock chamber, substrate heating, …
- Monitor glass changer
- Material mixtures ($n_{low} \leq n_{coating} \leq n_{high}$)
- Machine fully installed and currently in process of calibration

Next targets

Next targets

- HR mirrors with high damage threshold for MHz fs high power operation
- Optimized dispersive mirrors at 1 µm with high damage threshold
- DUV dispersive mirrors
- Output couplers for VUV/XUV
- …

Acknowledgments

FNSNF

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

erc

must
Molecular Ultrafast Science and Technology
National Center of Competence in Research

ETH ZÜRICH

unine

UniNE LTF group

ETH ULP group of Prof. Ursula Keller