Sub-100-fs SESAM modelocked VECSEL

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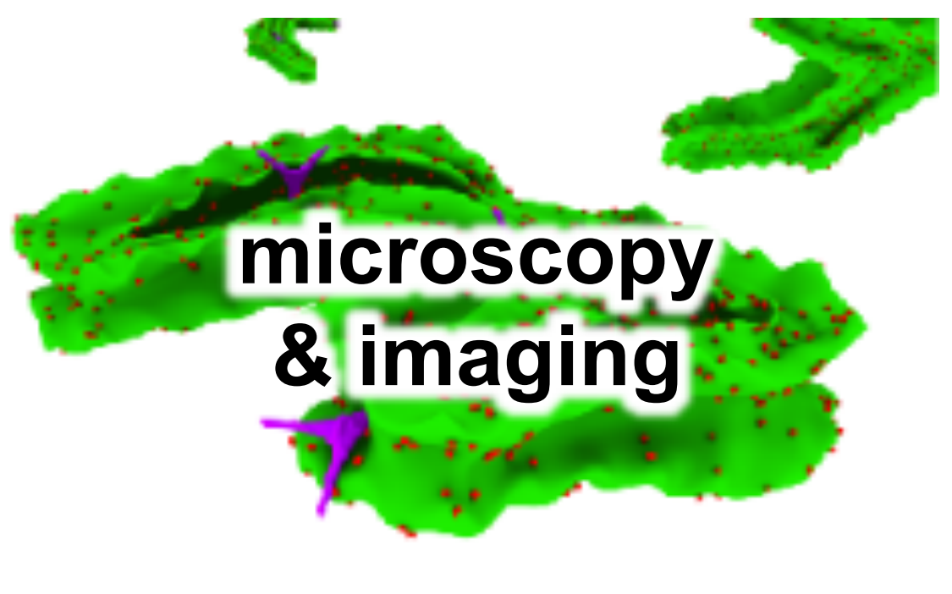
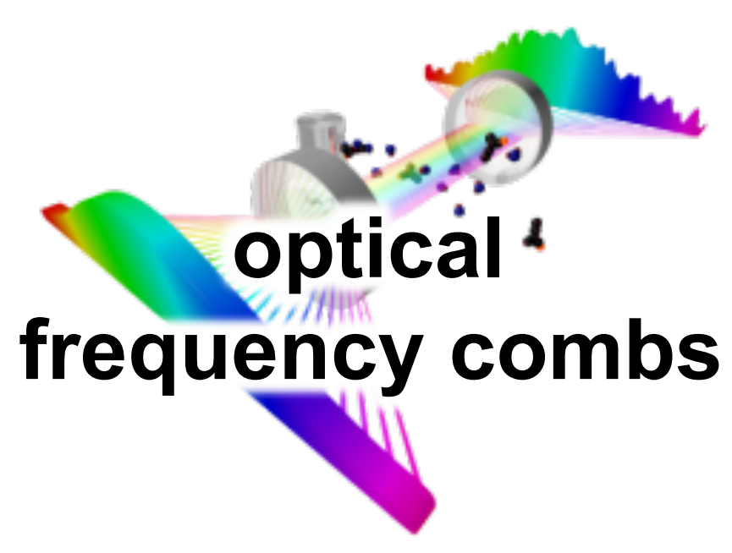
Motivation

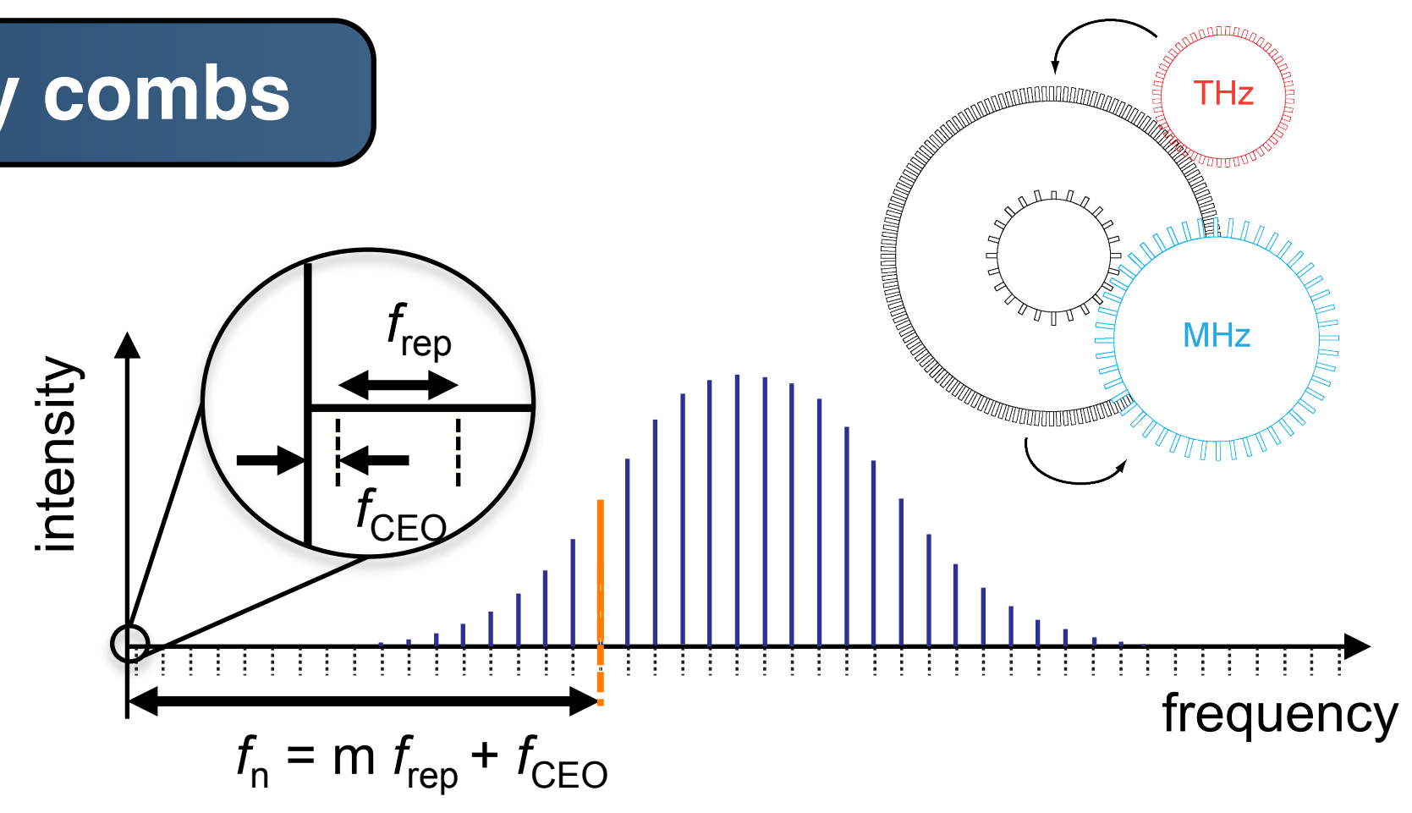
Applications of ultrafast semiconductor disk lasers (SDL)

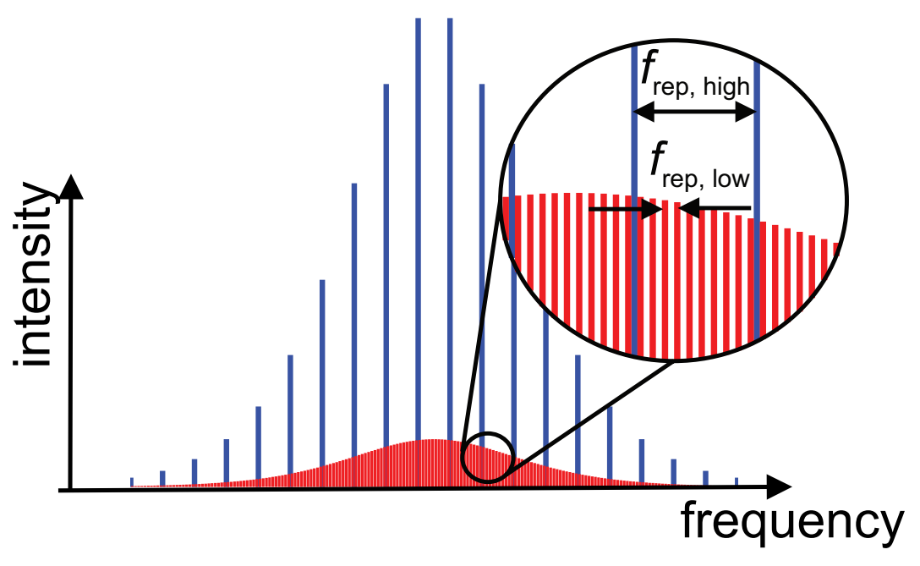




Our Goal: Self-referenceable frequency combs

- Down-convert optical signals (THz) into the microwave range (MHz/GHz)
- Need to stabilise:
  - Repetition rate
  - Carrier envelope offset frequency (f_{CEO}) [1]
- Benefits from GHz repetition rates:
  - Wider line spacing: better access
  - High power per comb line
  - Compact systems



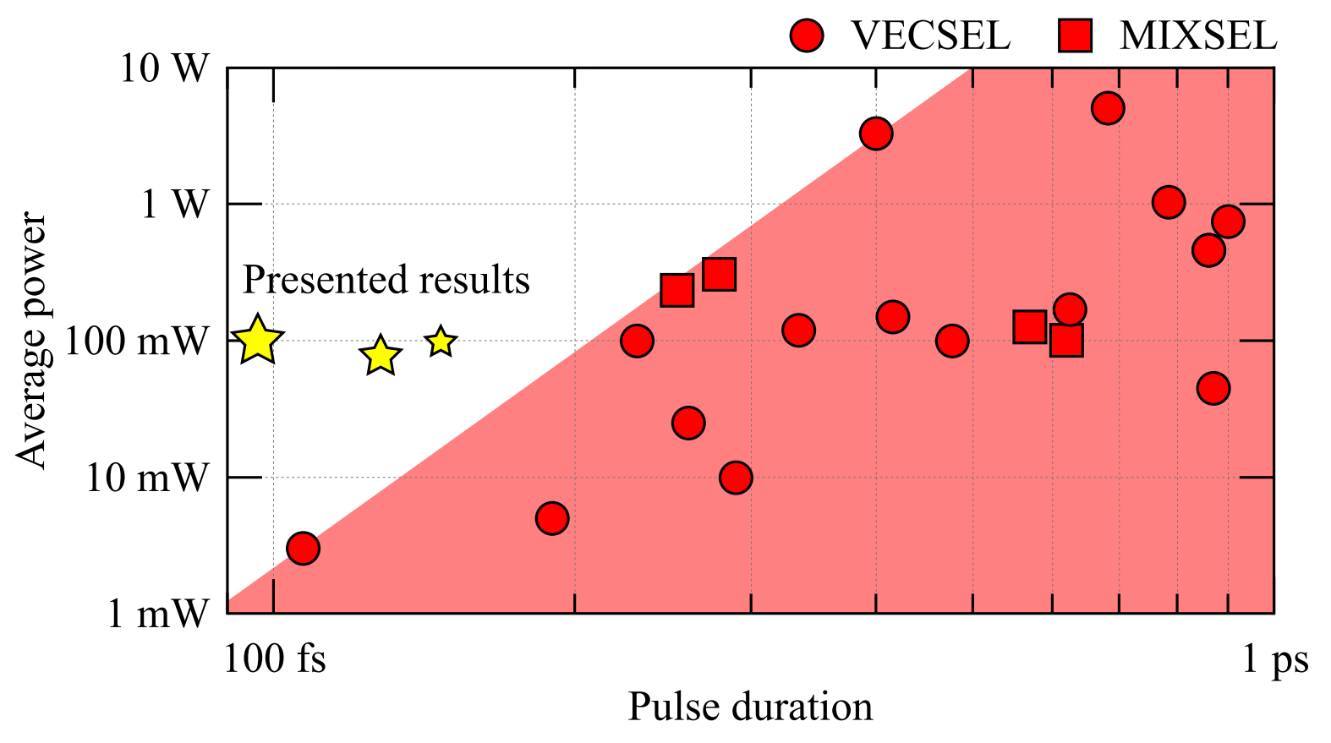


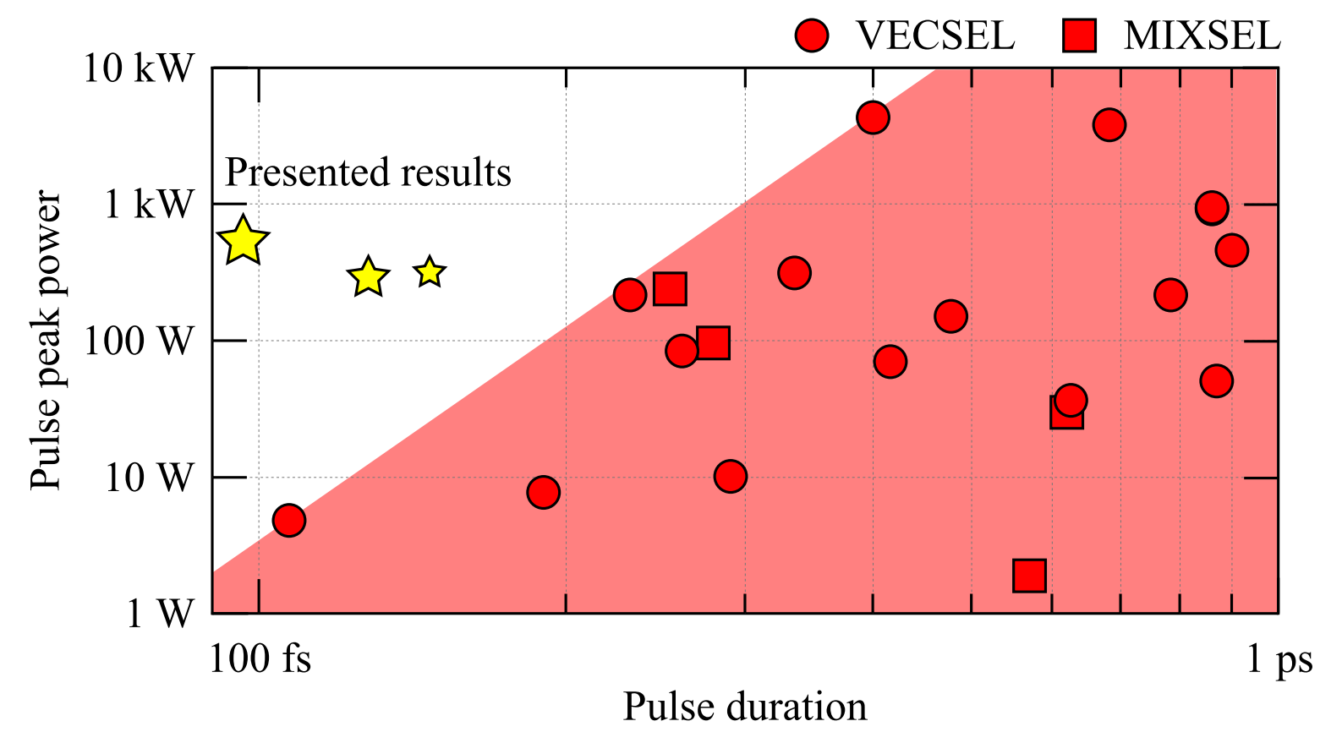
[1] H. R. Telle, G. Steinmeyer, A. E. Dunlop, J. Stenger, D. H. Sutter, and U. Keller, Appl. Phys. B **69**, 327-332 (1999)

SESAM modelocked VECSEL

Overview

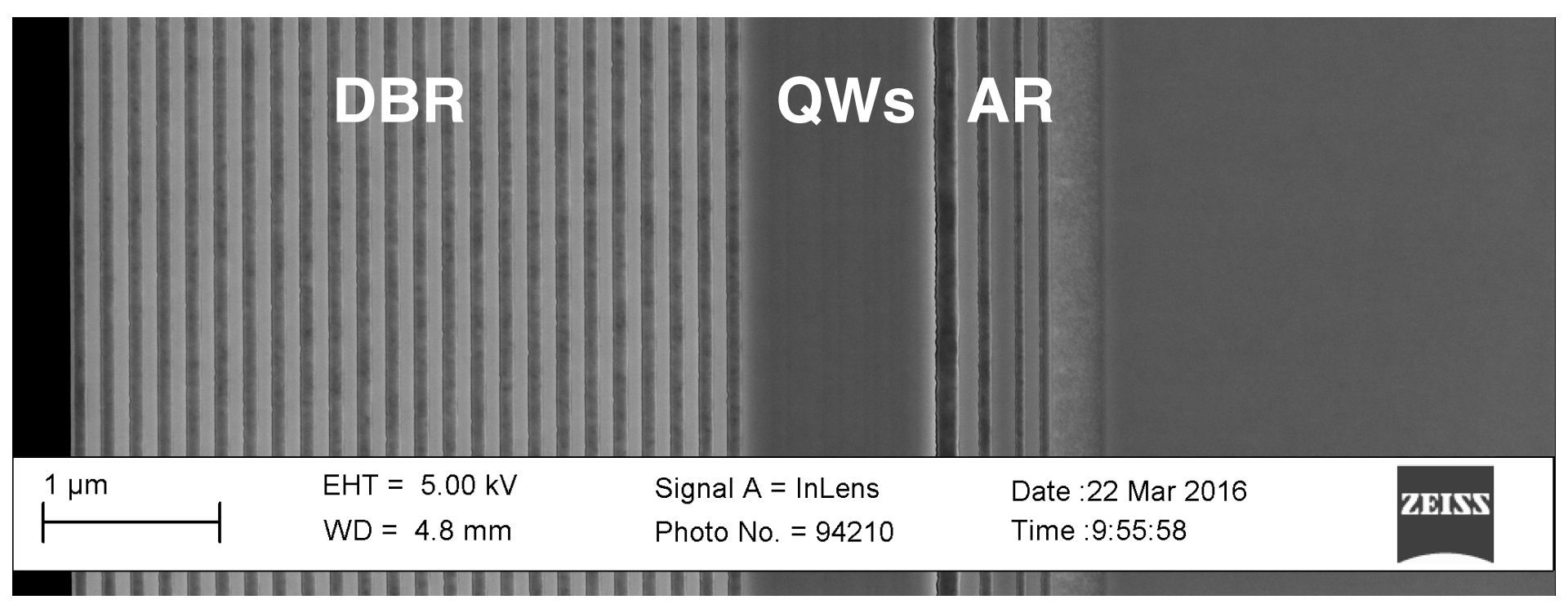
- Overview of the state-of-the-art semiconductor disk lasers in the 1-μm wavelength range
- Trade-off between pulse duration and power





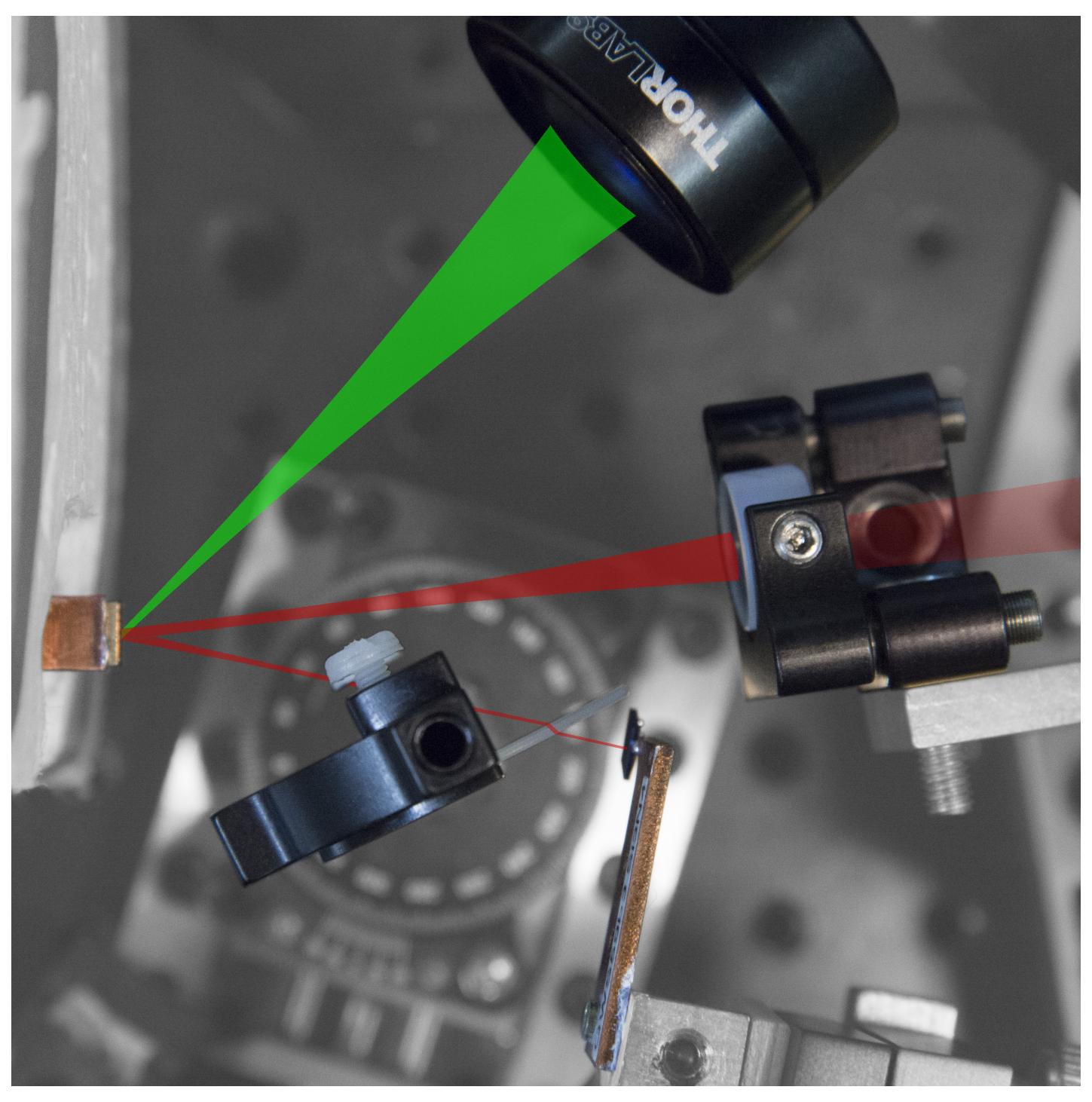
VECSEL

- **V**ertical **e**xternal-**c**avity **s**urface-**e**mitting **l**aser
- Distributed Bragg reflector AlAs/GaAs-pairs grown on GaAs substrate for laser reflection
- Active region: Laser light amplification in quantum wells (QW)
- Antireflection-coating: Minimizing pump reflection and optimizing group delay dispersion



SESAM

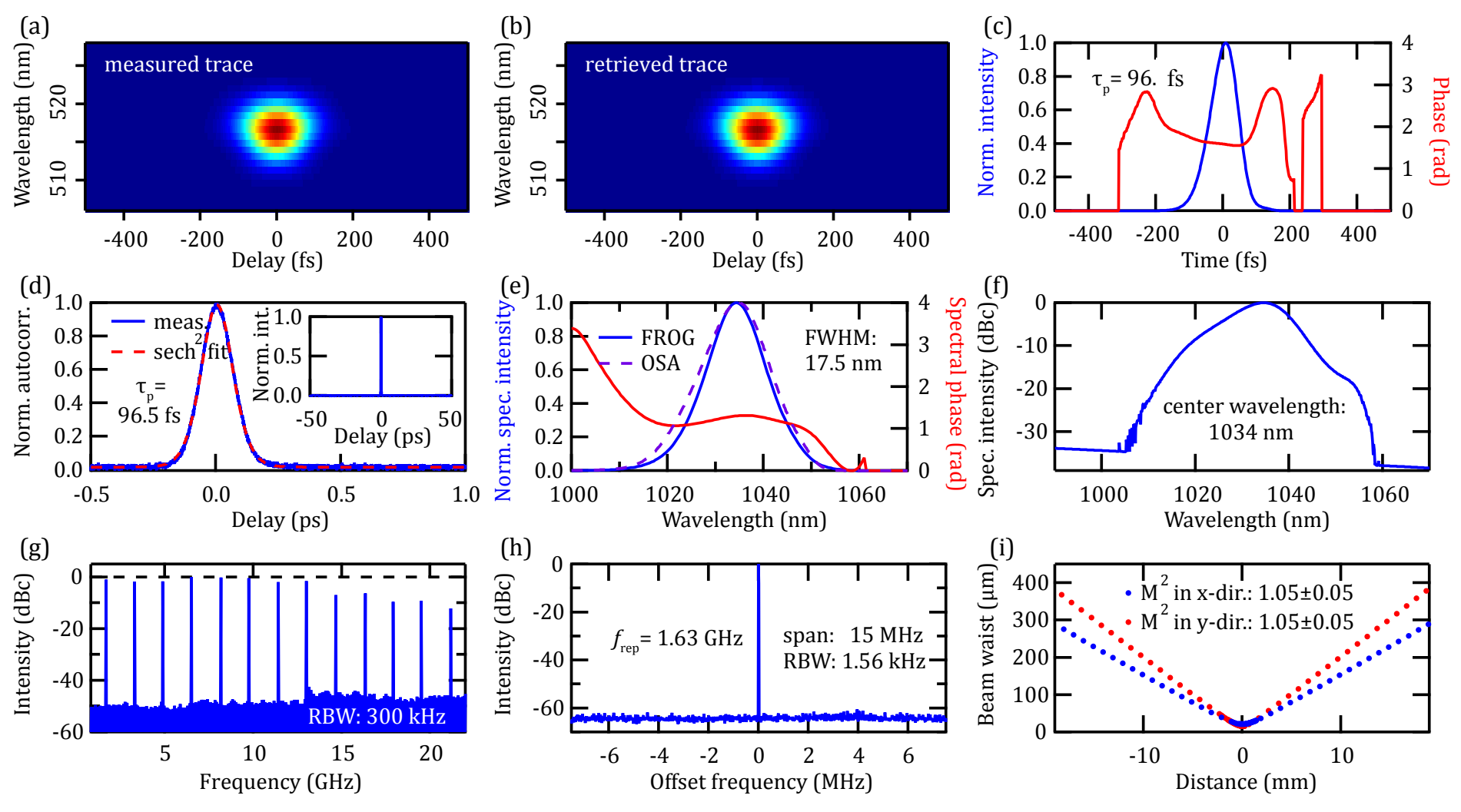
- **S**emiconductor **s**aturable **a**bsorber **m**irror
- Induce self-starting modelocking operation with quasi-solitons



Modelocking result

- **Shortest pulses** from any fundamentally modelocked semiconductor disk laser

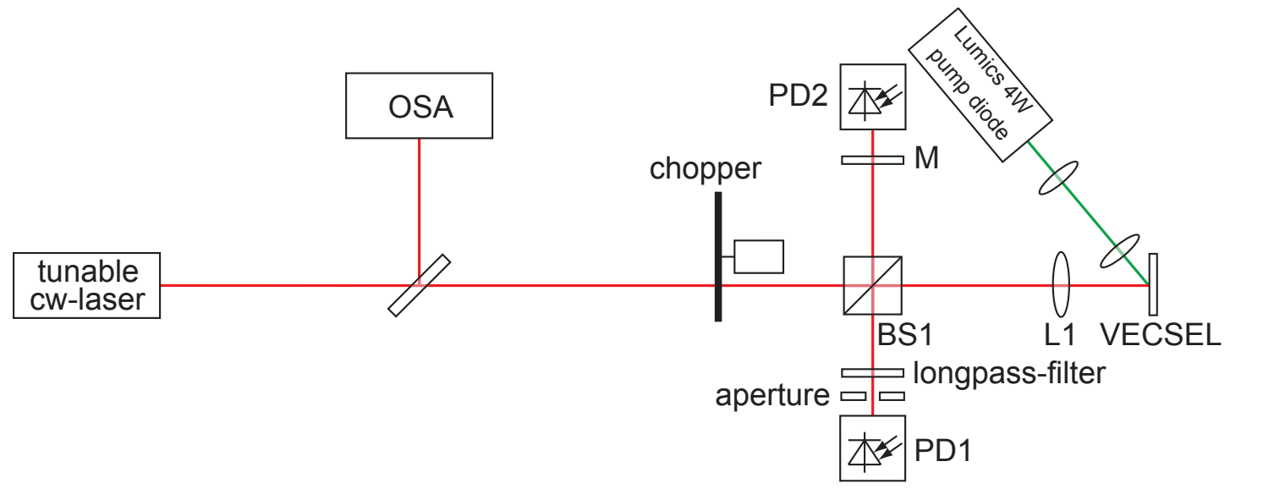
pulse duration	repetition rate	average power
96 fs	1.63 GHz	100 mW
center wavelength	**spectrum FWHM**	**peak power**
1034 nm	17.5 nm	560 W

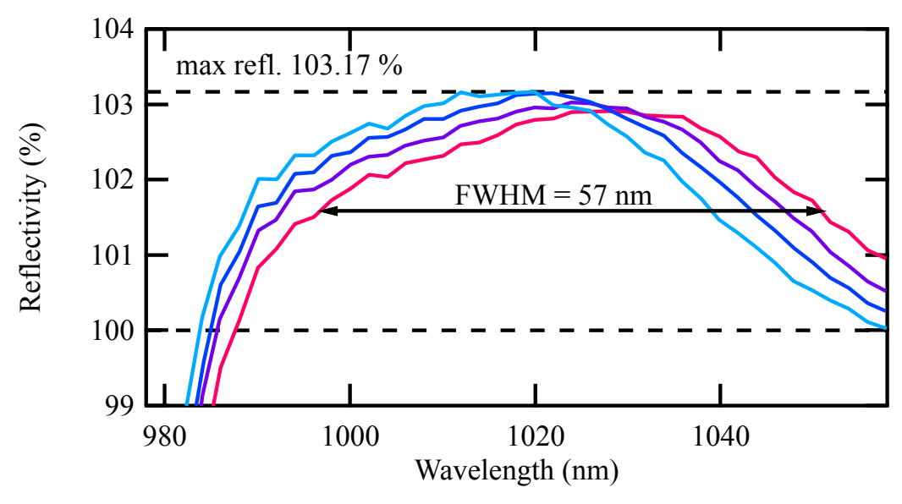


VECSEL gain characterisation

Spectral characterisation

- Spectrally resolved reflectivity measurement of a pumped VECSEL





Comparison with previous VECSEL reveals as expected:

- **Increased gain bandwidth**
- Reduces small signal gain

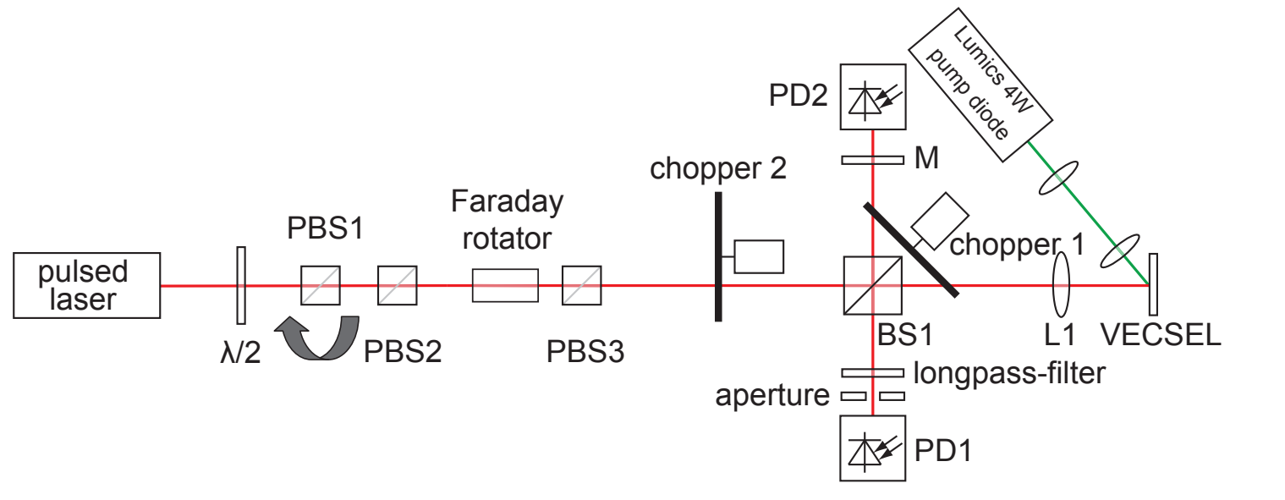
but unforeseen:

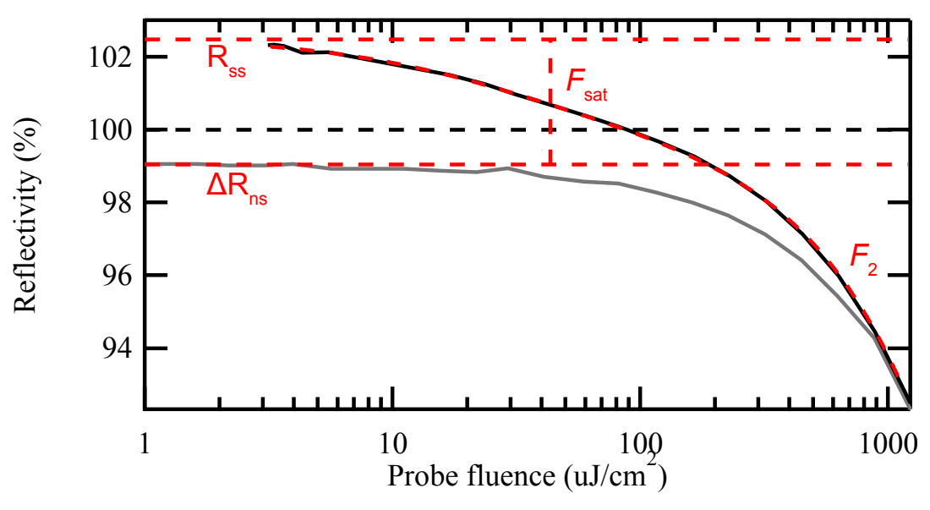
- Unchanged saturation fluence

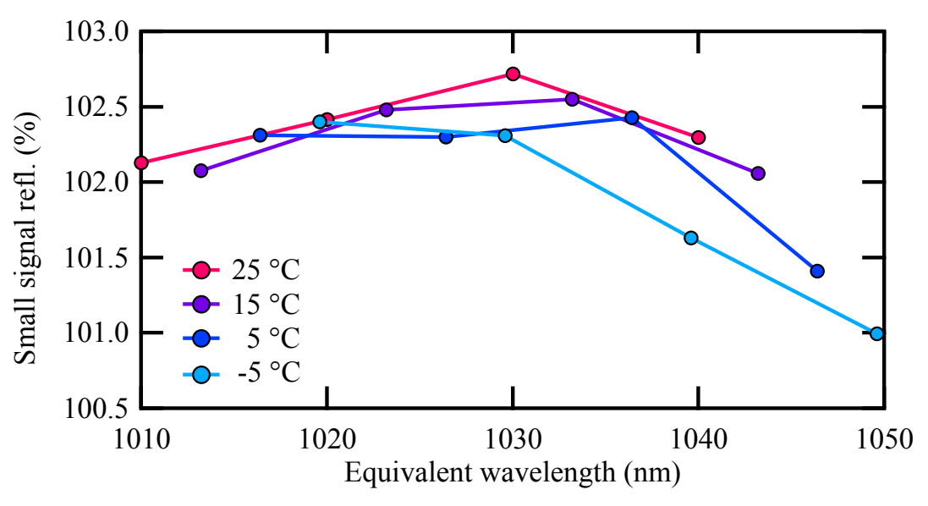
	previous [2]	new
growth method	MBE	MOVPE
active region	7 QWs/QDs	10 SCQWs
FE	1.14/1.25	0.52
λ_c	960 nm	1030 nm
F_{sat}	32 - 54 µm/cm²	30 - 51 µm/cm²
g_{ss}	3.6 - 5.3 %	2.8 - 3.2 %
g_{FWHM}	26 - 30 nm	50 - 57 nm
F_2	20 - 25 mJ/cm²	17 mJ/cm²

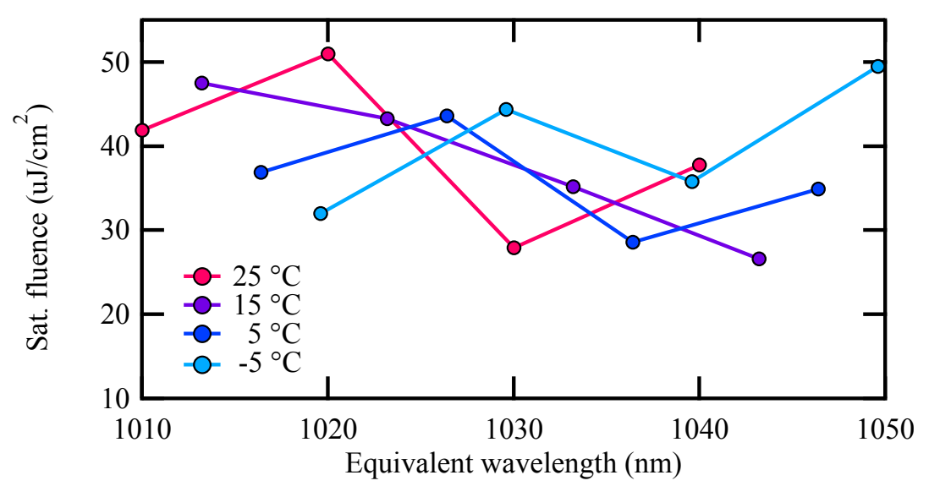
Saturation characterisation

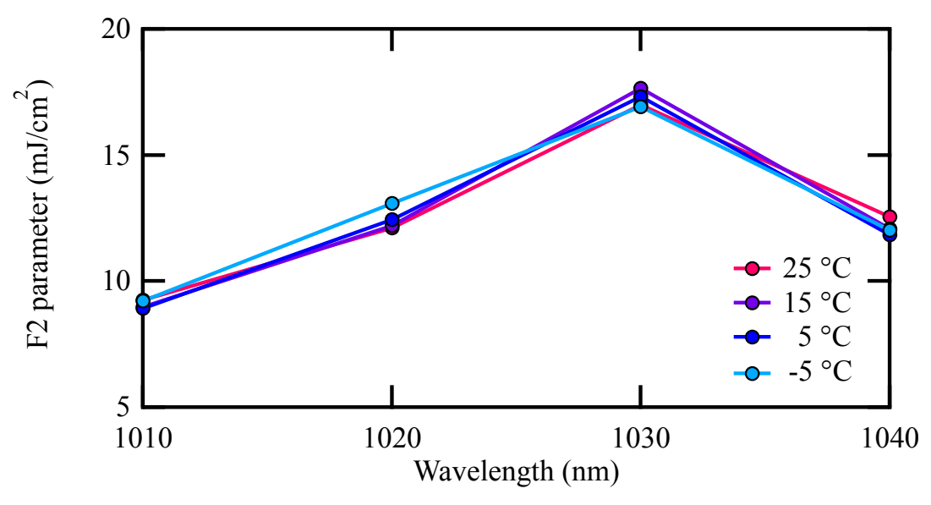
- Fluence depending reflectivity measurement of a pumped VECSEL









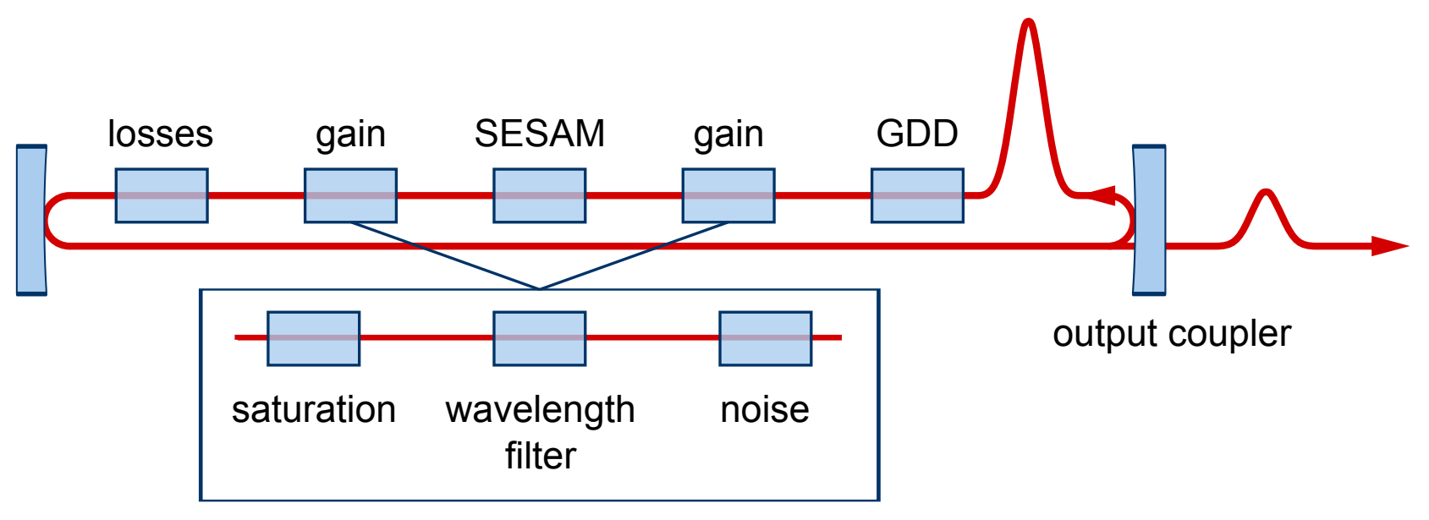


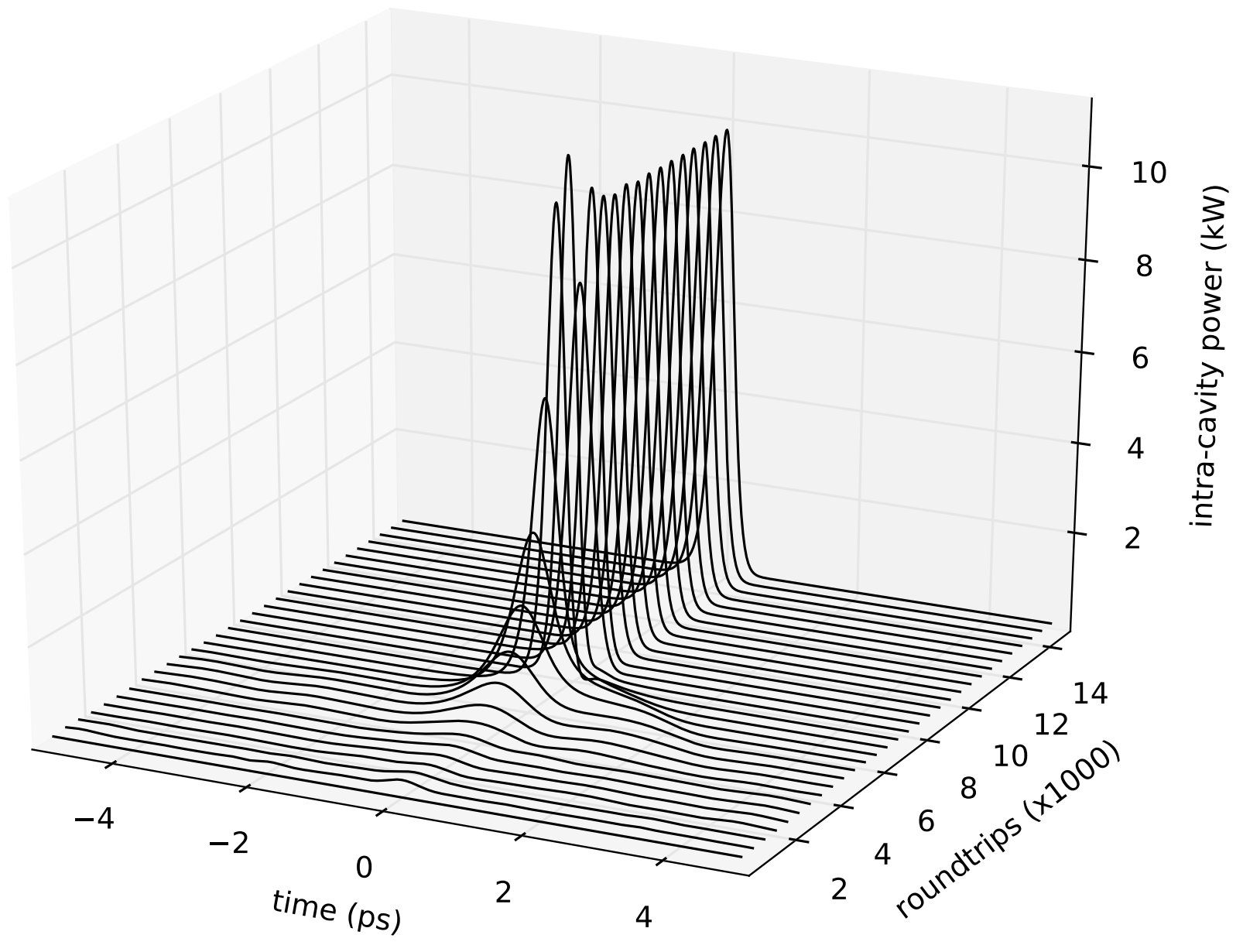
[2] M. Mangold, V. J. Wittwer, O. D. Sieber, M. Hoffmann, I. L. Krestnikov, D. A. Livshits, M. Golling, T. Südmeyer, and U. Keller, Opt. Express **20**, 4136-4148 (2012).

Numerical pulse formation simulation

Simulation model [3]

- Based on macroscopic measurable parameters

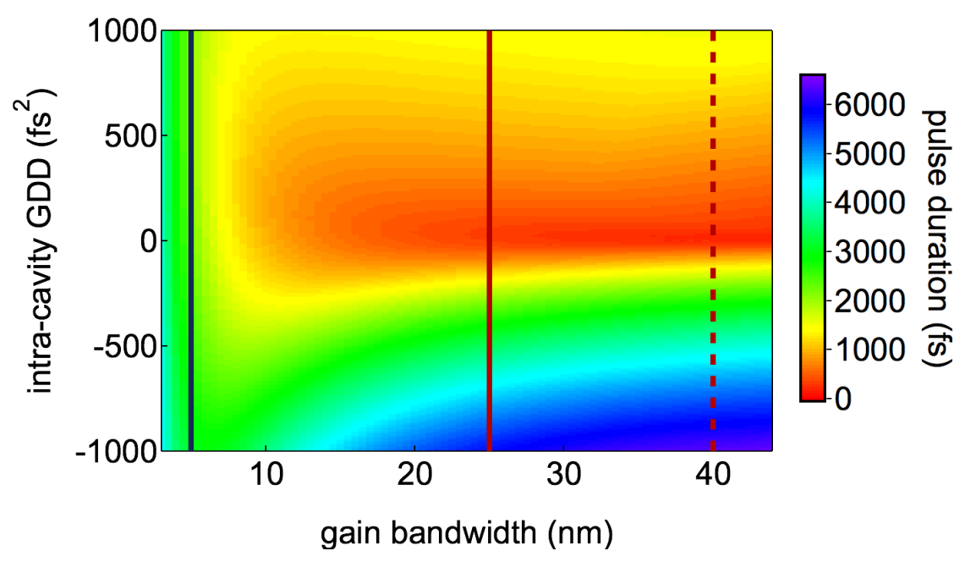


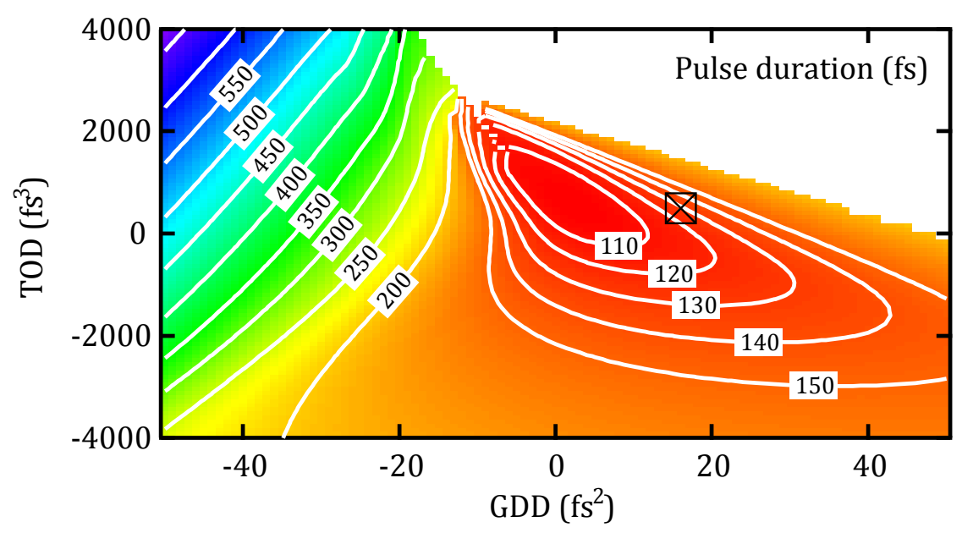


Results

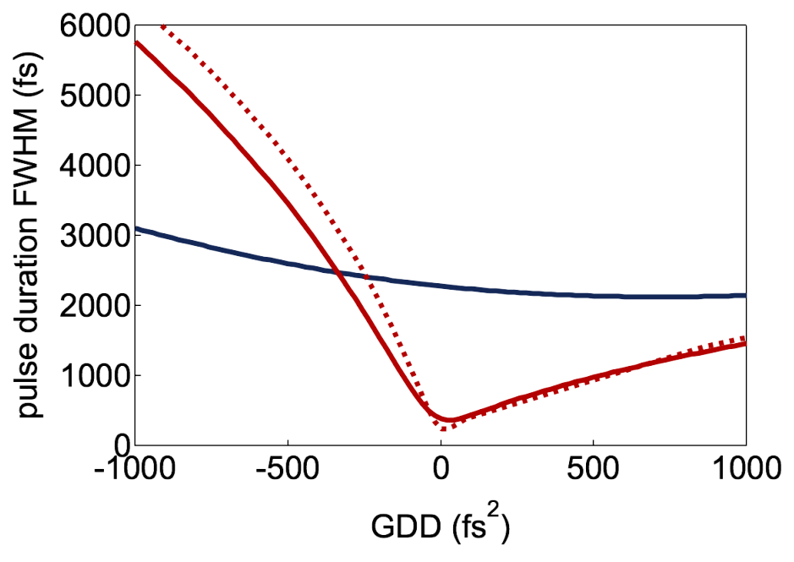
Goals for short pulses:

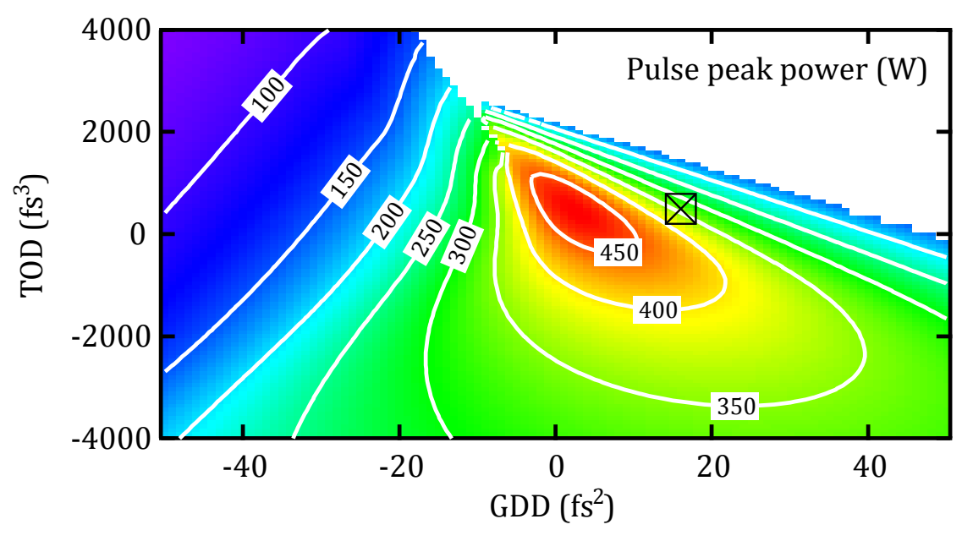
- Broadband gain
- Near zero and flat group delay dispersion
- High gain saturation fluency





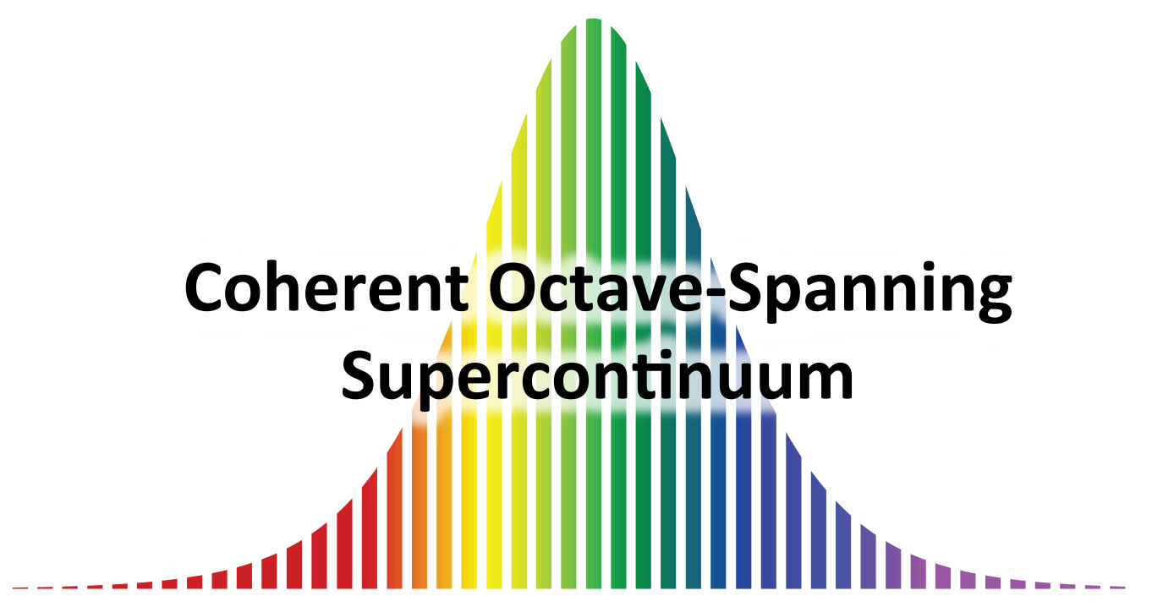
- Increased gain bandwidths require stricter demands on the cavity dispersion





[3] O. D. Sieber, M. Hoffmann, V. J. Wittwer, M. Mangold, M. Golling, B. W. Tilma, T. Südmeyer, and U. Keller, Applied Physics B **113**,

Outlook



Next step: Increasing the output power for direct supercontinuum generation

Ultimate goal: Fully stabilized (repetition rate & CEO-frequency) frequency comb from a compact, low cost SDL

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