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MIXSEL2 RTD 2013

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Dual-comb MIXSEL

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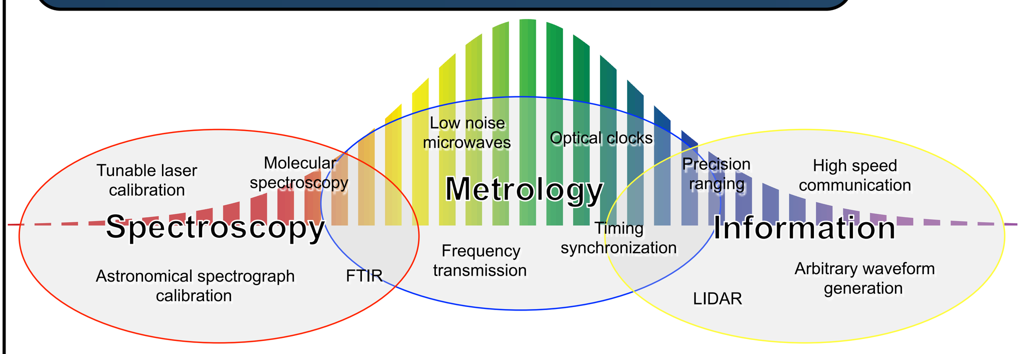
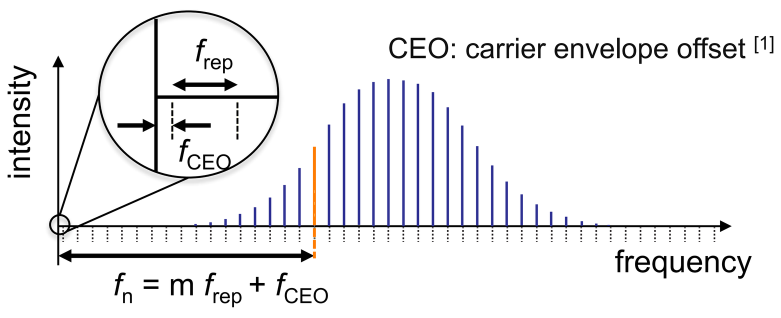
Motivation

applications of optical frequency combs



☆ down-convert optical signals (THz) into the microwave range (MHz/GHz)



high repetition rate frequency combs

- ☆ easier access to the individual comb lines
  - ➠ mandatory for many applications
- ☆ higher power per comb mode
  - ➠ improves signal-to-noise
- ☆ more compact laser systems
  - ➠ robustness and reliability

dual-comb applications

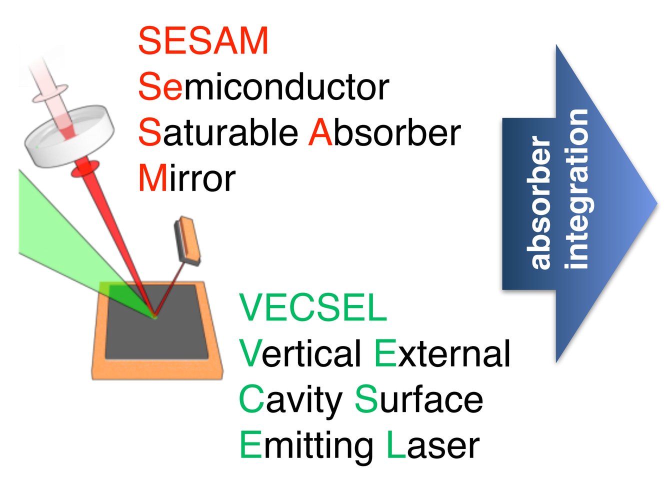
- dual-comb spectroscopy [2]
- ASOPS [3]
- pump-probe
- fiber Bragg grating [4] sensing

need for compact, cost-efficient, GHz dual-comb source

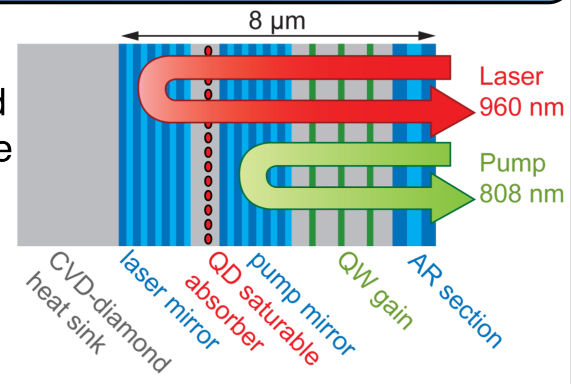
[1] H. R. Telle, G. Steinmeyer, A. E. Dunlop, J. Stenger, D. H. Sutter, and U. Keller, Appl. Phys. B **69**, 327-332 (1999)
[2] S. Schiller, Opt. Lett. **27** (9), 766–768 (2002)
[3] A. Bartels, R. Cerna, C. Kistner, A. Thoma, F. Hudert, C. Janke, and T. Dekorsy, Rev. Sci. Instrum. **78**, 035107 (2007)
[4] K. O. Hill, Y. Fujii, D. C. Johnson, and B. S. Kawasaki, Appl. Phys. Lett. **32**, 647 (1978)

MIXSEL concept

integration concept



MIXSEL
Modelocked Integrated eXternal-cavity Surface Emitting Laser



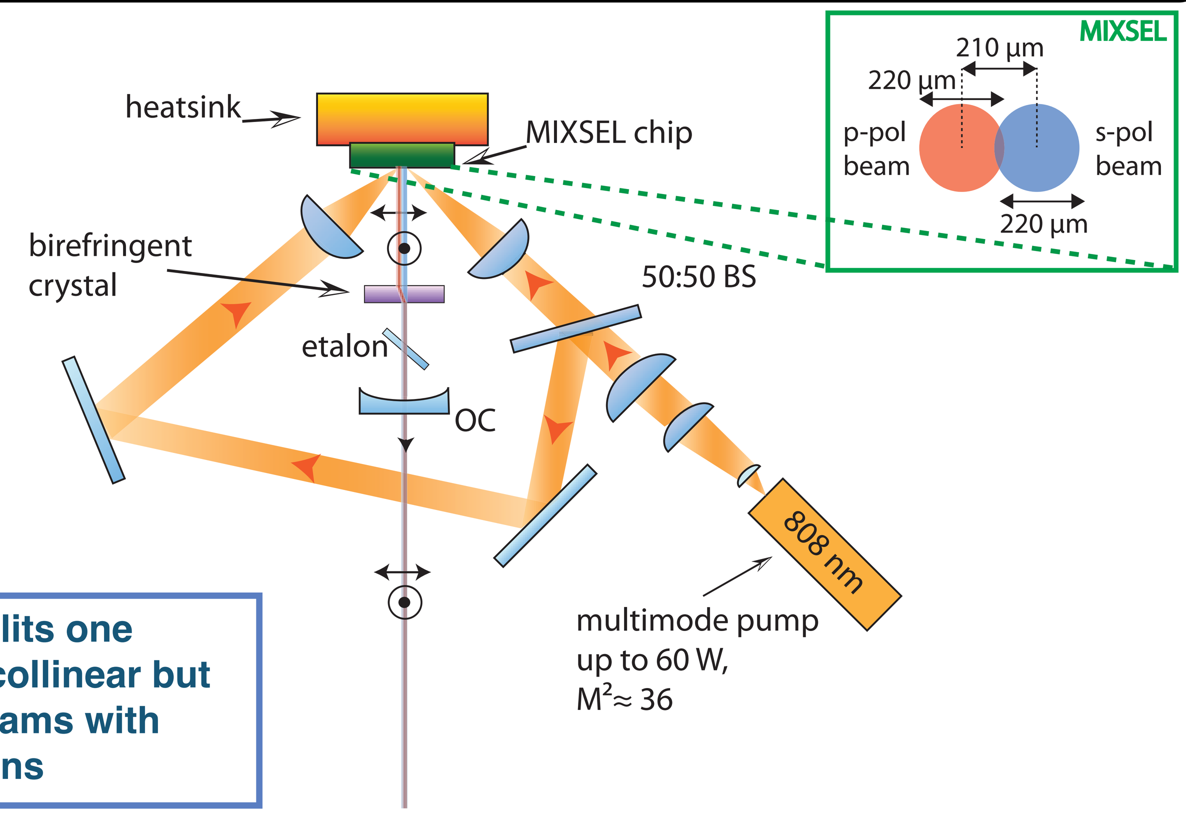
- ➠ very compact cavity
- ➠ simple pulse repetition rate scaling possible (5-100 GHz with single chip [1])
- ➠ very low noise performance [2]

[1] M. Mangold, C. A. Zaugg, S. M. Link, M. Golling, B. W. Tilma, and U. Keller, Optics Express **22**, No. 5, pp. 6099-6107, 2014
[2] M. Mangold, S. M. Link, A. Klenner, C. A. Zaugg, M. Golling, B. W. Tilma, and U. Keller, Photonics Journal, IEEE **6**, 1-9 (2014)

Laser setup

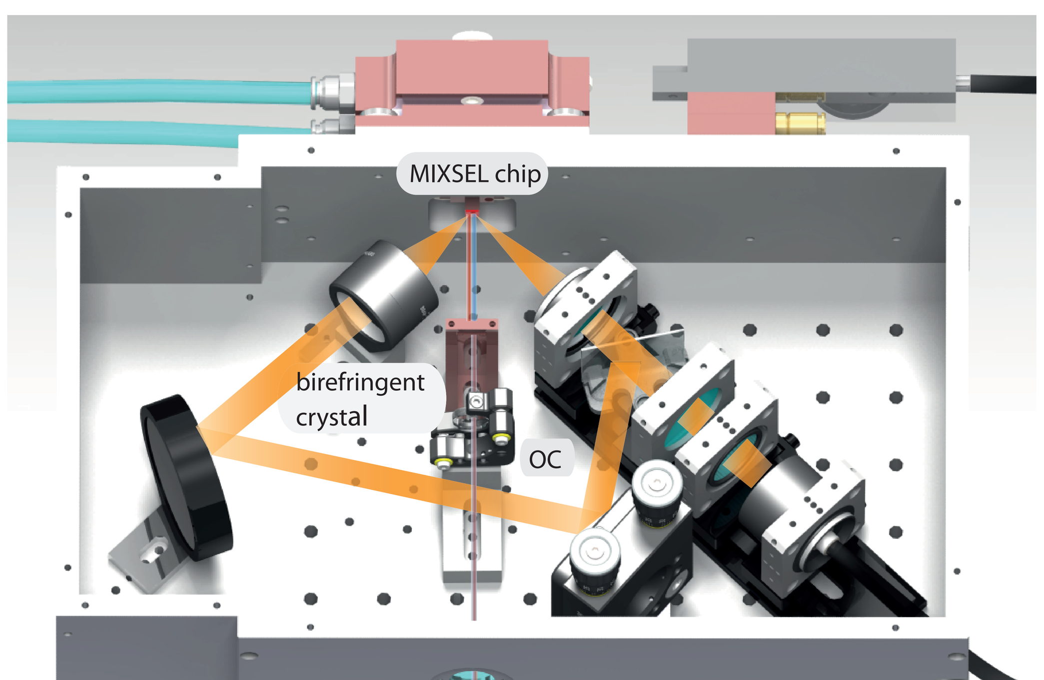
straight linear cavity

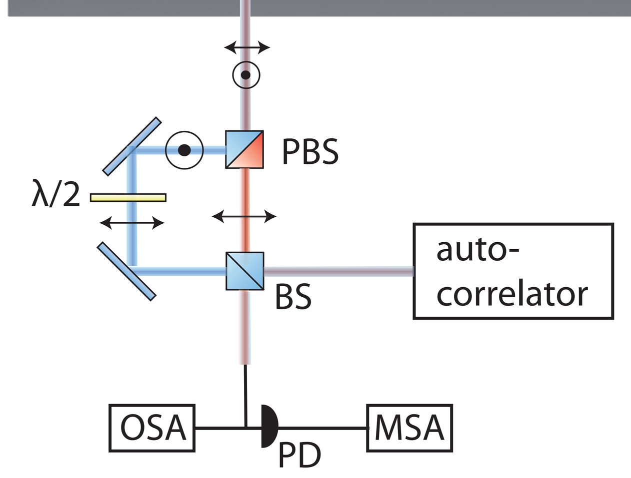
- MIXSEL chip [1]
  - ➠ gain: 7 InGaAs QW
  - ➠ absorber: 1 InAs QD layer
- fused silica etalon
- output coupler (OC) (T=0.5 %)
- birefringent crystal ($CaCO_3$, 2 mm)



birefringent crystal splits one cavity beam into two collinear but spatially separated beams with orthogonal polarizations

stable and closed laser housing





stable and compact housing

- closed aluminium housing
  - ➠ prevent airflow
- fixed mounted optics
  - ➠ minimize mechanical vibrations
- water cooling
- temperature stabilized to 15 °C (Peltier element)

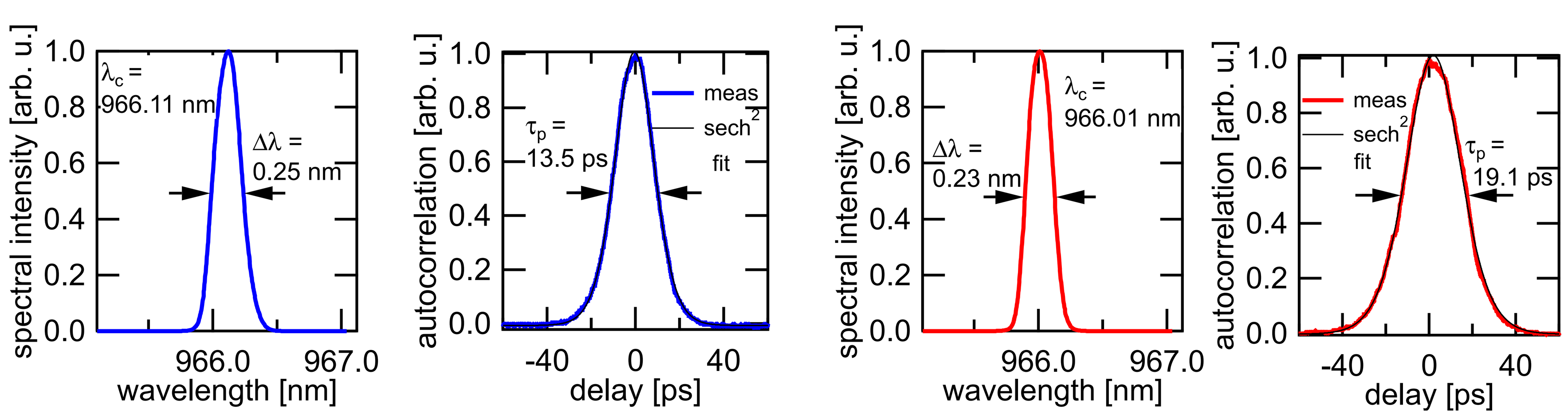
external pump diode

- laser diode (808 nm, 60 W max)
- fiber coupled (Ø 100 µm, 0.22 NA)
- 45° angle of incidence
- 50:50 split or elliptical spot

two fundamentally modelocked pulse trains with slightly different pulse repetition rates from a single MIXSEL chip

Dual-comb results

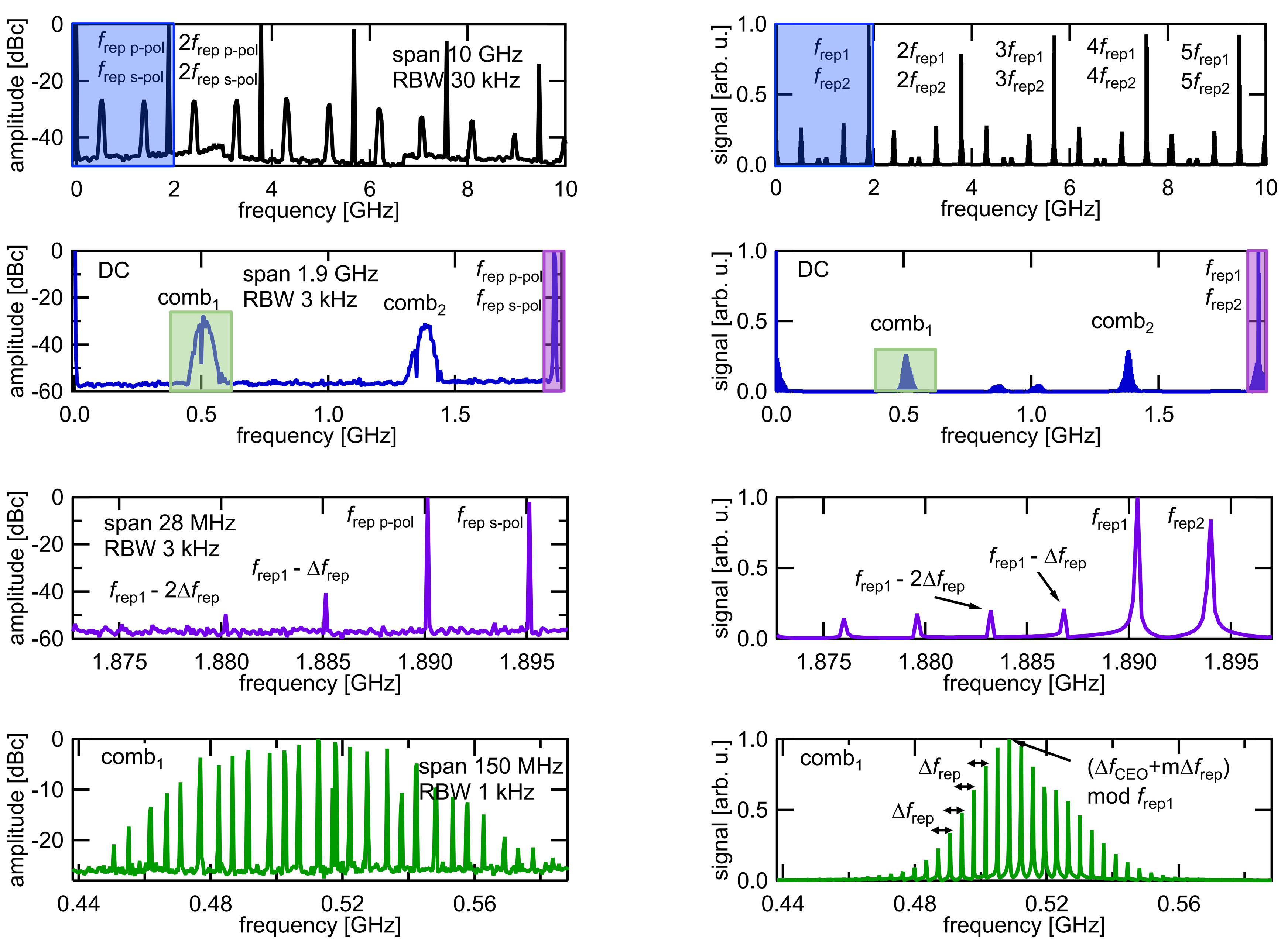
modelocking performance



pulse duration	output power	center wavelength	pulse duration	output power	center wavelength
13.5 ps	78 mW	966.11 nm	19.1 ps	70 mW	966.01 nm

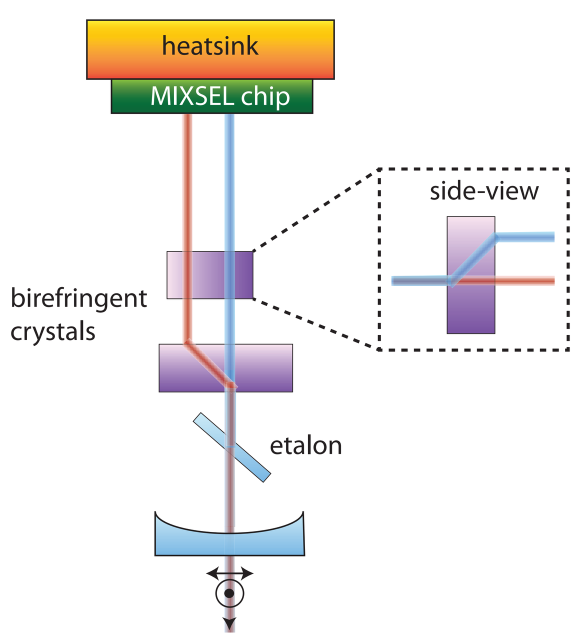
microwave spectrum

$f_{rep\ p\text{-}pol}$ = 1.890 GHz $f_{rep\ s\text{-}pol}$ = 1.895 GHz Δf_{rep} = 5 MHz



microwave comb resulting from interference between the two optical combs, providing a direct link between the terahertz optical frequencies and the electronically accessible microwave regime

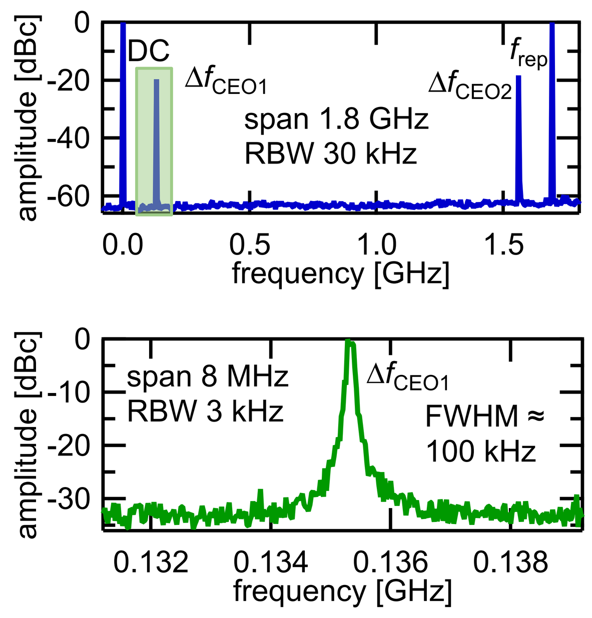
Relative CEO detection



$f_{rep\ p\text{-}pol} = f_{rep\ s\text{-}pol}$ = 1.692 GHz Δf_{rep} = 0 Hz

insert second birefringent crystal

- ➠ still two spots on MIXSEL chip
- ➠ same optical path length for both beams
- ➠ same pulse repetition frequency



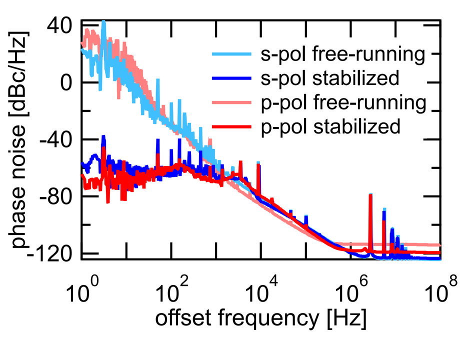
direct access to the relative CEO frequency of a semiconductor disk laser (SDL)

Swiss patent application 01498/14, filed October 2014

Conclusion and outlook

conclusion

- ☆ compact way of generating two modelocked beams
- ☆ utilizing key advantage of MIXSEL of having a straight linear cavity
- ☆ simple link between terahertz optical frequencies and microwave regime
- ☆ direct access to relative CEO of an SDL



outlook

- ☆ stabilization of pulse repetition frequencies and relative CEO frequency
- ☆ shorter pulses from MIXSEL

More details on the results of this poster can be found in the paper:
S. M. Link, A. Klenner, M. Mangold, C. A. Zaugg, M. Golling, B. W. Tilma, U. Keller, "Dual-comb modelocked lasers", Optics Express **23**, No. 5, pp. 5521-5531, 2015