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MIXSEL2 RTD 2013

FNSNF

Sub-300_fs-MIXSEL

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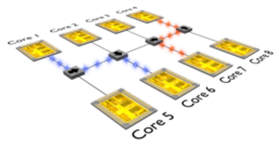
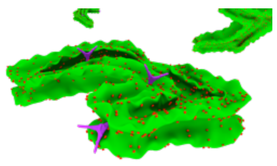
Motivation

Potential applications of ultrafast **semiconductor disk lasers** (SDL)

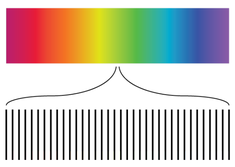


optical communication



biomedical imaging

natural user interface



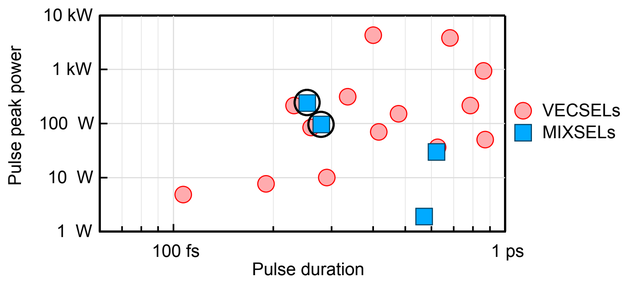
frequency combs

first Watt-level femtosecond VECSEL [1]

- 784-fs-pulses with >1 W output power in a 5.4 GHz V-cavity

first CEO-frequency detection of a SESAM-modelocked VECSEL [2]

- amplified and recompressed 238-fs pulses from a 100-mW VECSEL

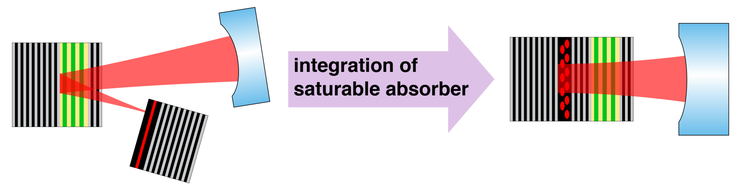


Black rings indicate new results here presented

[1] M. Hoffmann *et. al.*, Optics Express (2011) vol. 19, 8108-8116
[2] C.A. Zaugg *et. al.*, Opics Express (2014) Vol. 22, 16445-16455

MIXSEL concept

- semiconductor based
- integrated saturable absorber
- power scalable
- potential for monolithic design
- low noise operation



VECSEL + **SESAM** = **MIXSEL**

Vertical External Cavity Surface Emitting Laser

SEmiconductor Saturable Absorber Mirror

Modelocked Integrated External-Cavity Surface Emitting Laser

modelocking results

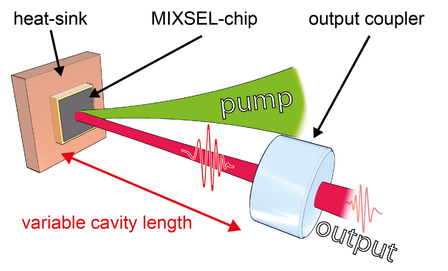
28.1 ps	6.4 W	2.5 GHz
pulse duration	output power	repetition rate
16.9 ps	2.4 W	10 GHz

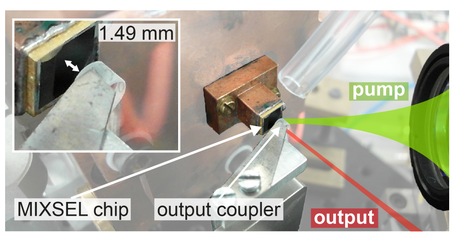
- **highest output power of a modelocked semiconductor laser** [4]
- **highest output power of a modelocked 10 GHz semiconductor laser**[5]

[4] B. Rudin, V. J. Wittwer, D. J. H. C. Maas, M. Hoffmann, O. D. Sieber, Y. Barbarin, M. Golling, T. Südmeyer, and U. Keller, Opt. Exp. (2010) vol. 18, pp. 27582
[5] V. J. Wittwer, M. Mangold, M. Hoffmann, O. D. Sieber, M. Golling, T. Südmeyer, U. Keller, Electronics Lett., vol. 48, No. 18, pp. 1144, 2012

Repetition rate scaling to 100 GHz[3]

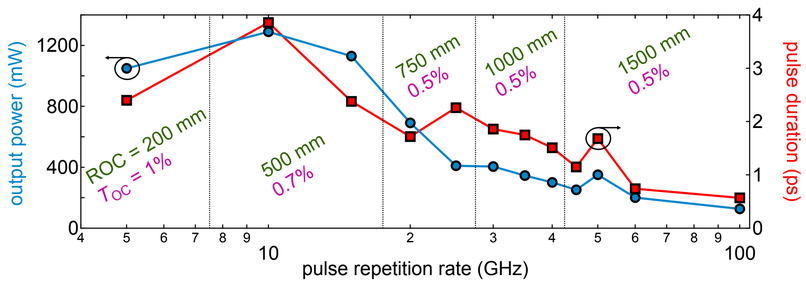
- **straight cavity for nearly arbitrarily high repetition rates**
- **negligible Q-switching instabilities for semiconductor gain materials**
- **integrated absorber: no cavity dependent mode-size difference on gain/absorber**





results of repetition rate scaling

- **sub-4-ps pulses and watt-level operation up to 15 GHz**
- **femtosecond operation at 60 GHz and 101 GHz**
- **excellent beam quality: $M^2 < 1.05$**
- **highest repetition rate of any fundamental mode locked SDL**

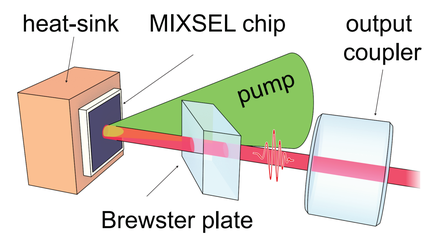


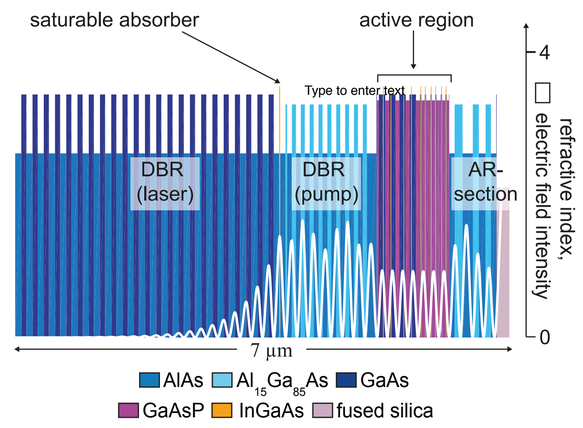
[3] M. Mangold, C. A. Zaugg, S. M. Link, M. Golling, B. W. Tilma, U. Keller, Optics Express, vol. 22, No. 5, pp. 6099-6107, 2014

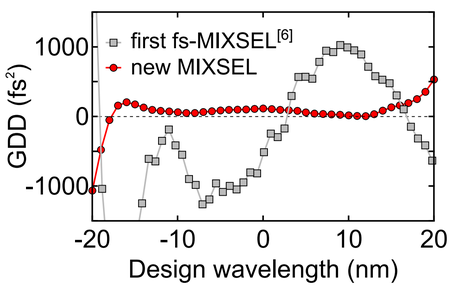
1040 nm - MIXSEL

Structural improvements

- **Strain compensated active region for lasing at 1040nm**
- **Optimized AR section for reduced and flat dispersion**
- **Intracavity Brewster plate for linearly polarized laser beam**



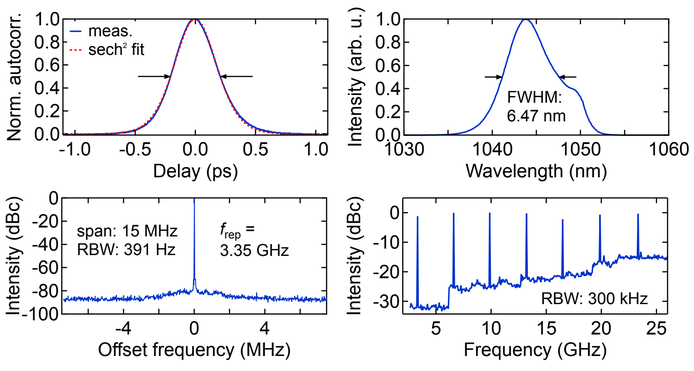




Regrown structure:

- AR coating and active region MOVPE grown
- DBRs and absorber MBE grown

Modelocking performance

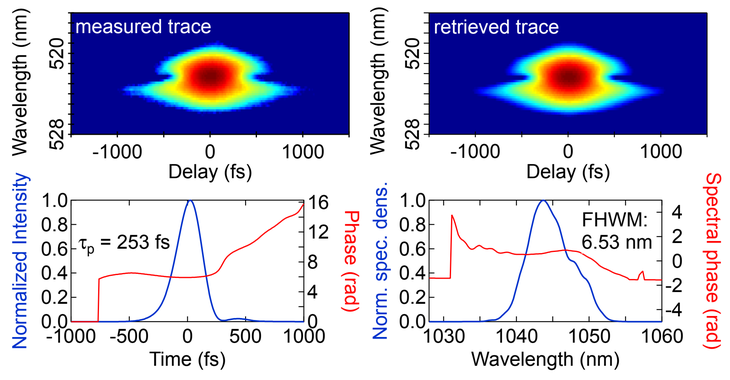


pulse duration	output power	repetition rate
253 fs	235 mW	3.35 GHz

- **Shortest pulse duration from a MIXSEL (<300 fs)**
- **Highest peak power from a MIXSEL (>240 W)**

State of the art diagnostics to confirm clean, fundamental modelocking:

- Frequency Resolved Optical Grating (FROG)
- Microwave spectrum with minimal resolution bandwidth and high SNR



[6] M. Mangold, V. J. Wittwer, C. A. Zaugg, S. M. Link, M. Golling, B. W. Tilma, and U. Keller, Opt. Express **21**, 24904-24911 (2013).

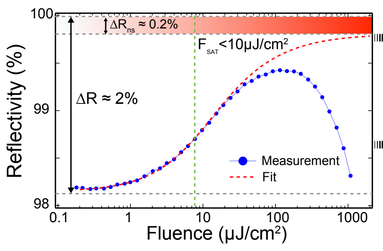
Towards an MOVPE grown MIXSEL

- **Single MIXSEL growth run**
- **More uniform structure for better performances**
- **Industry-oriented large scale MIXSEL production**

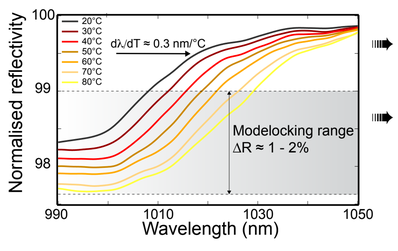
Need to optimize low temperature grown saturable absorbers from MOVPE

MOVPE absorber characterisation

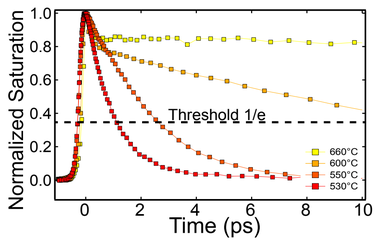
Single quantum-well absorber



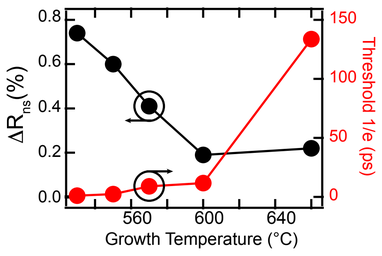
- Low saturation fluences (<10 $\mu J/cm^2$)
- Low non saturable losses (<0.5%)



- blue-shifted absorption
- operation near the band-edge

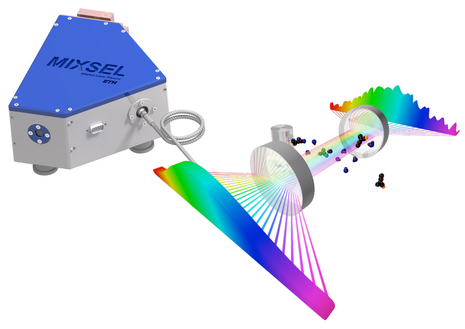


- Recovery time decreases with T_{growth}
- Fast absorbers: Threshold 1/e <10 ps for $T_{growth} < 600°C$.



- Non-saturable losses increase when T_{growth} decreases

Outlook



next steps: **sub-200-fs pulses with > 1W average output power from a MIXSEL**

ultimate goal: **fully stabilized frequency comb (repetition rate & CEO-frequency) from a compact, low cost MIXSEL**

FIRST Center for Micro- and Nanoscience