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MIXSEL2 RTD 2013

FNSNF

Sub-200 fs-MIXSEL

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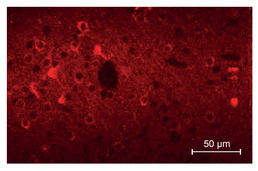
Motivation

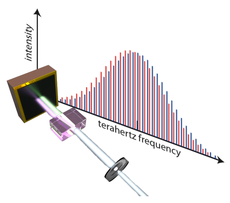
Potential applications of ultrafast **semiconductor disk lasers** (SDL)

metrology



biomedical imaging

natural user interface

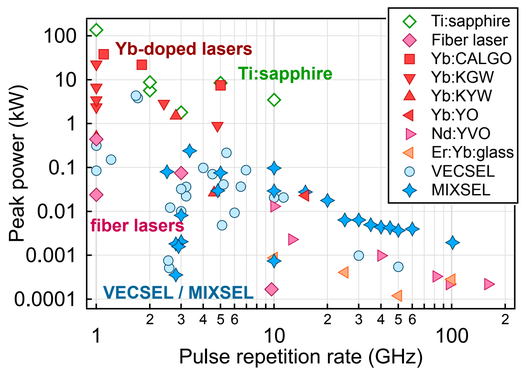


spectroscopy and frequency combs

first CEO-frequency detection of a SESAM-modelocked VECSEL [1]

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

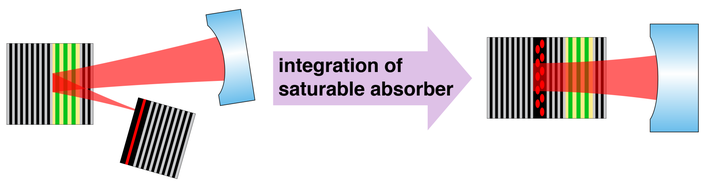
Enabling key technology for applications at 1-100 GHz repetition rate



[1] C.A. Zaugg *et. al.*, Optics Express (2014) Vol. 22, 16445-16455

MIXSEL concept

- Semiconductor based
- Integrated saturable absorber
- Potential for monolithic design
- Low noise operation
- Straight cavity for simplified repetition rate scalability

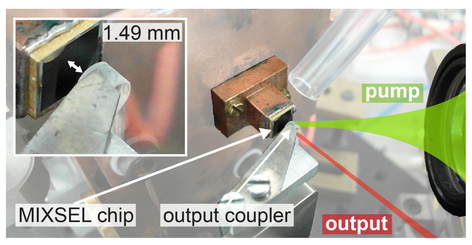


VECSEL	+	SESAM	=	MIXSEL
Vertical External Cavity Surface Emitting Laser		SEmiconductor Saturable Absorber Mirror		Modelocked Integrated External-Cavity Surface Emitting Laser

modelocking results

28.1 ps	6.4 W	2.5 GHz
pulse duration	output power	repetition rate
230 fs	132 mW	3.9 GHz

- **Highest output power of a modelocked semiconductor laser** [2]
- **Shortest pulse duration from a MIXSEL**
- **Femtosecond operation at 100 GHz: highest repetition rate of any fundamental mode locked SDL** [3]



[2] B. Rudin, et al., Opt. Exp. (2010) vol. 18, pp. 27582
[3] M. Mangold et al., Optics Express, vol. 22, No. 5, pp. 6099-6107, 2014

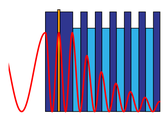
MOVPE MIXSEL

- **Easier access to strain compensation**
- **More uniform structure for better performances**
- **Industry-oriented large scale MIXSEL production**

Need to optimize low temperature grown saturable absorbers from MOVPE

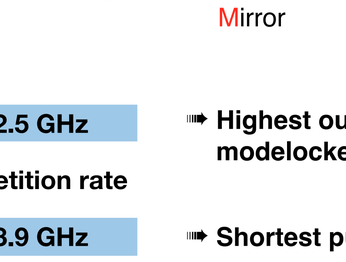
MOVPE absorber characterisation

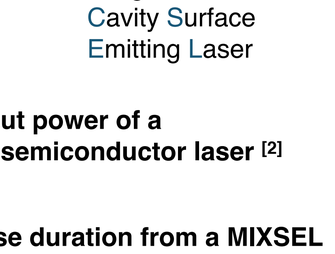
Single quantum-well (QW) absorber



The optimum absorber for a MIXSEL has:

- ✗ Low saturation fluence (< 5 $\mu J/cm^2$)
- ✓ Low non saturable losses (< 0.4%)
- ✓ Fast recovery time (< 5 ps)





11 ps	2.6 ps	301 mW
recovery time	pulse duration	output power
2.5 ps	980 fs	77 mW

We demonstrated the first generation of MOVPE MIXSELs:

- Pulse duration was shortened by a faster absorber.
- At this point still a trade-off between faster absorber and low non-saturable losses.
- Lower F_{sat} will allow sub-300-fs operation from MOVPE MIXSELs

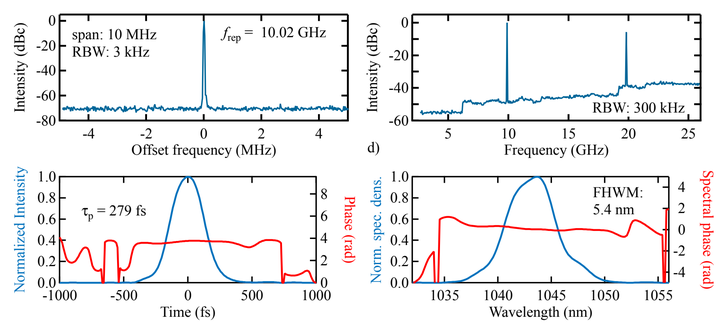
Recent results

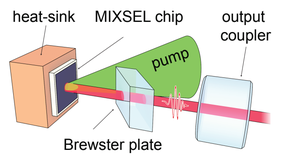
Pulse duration:	**279 fs**
Average output power:	**310 mW**
Opt. to opt. efficiency	**1.34%**
Repetition rate:	**10 GHz**
Center wavelength:	**1043 nm**

- **Highest average power of fs-MIXSEL**
- **High peak power:**

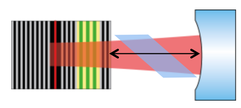
P_{peak} **= 97 W**

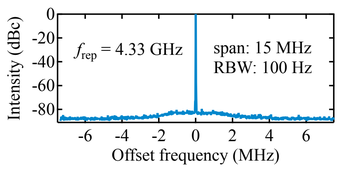
[4]

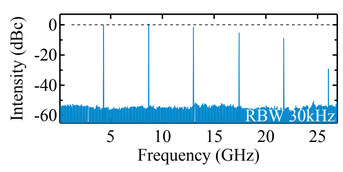


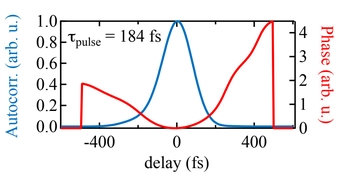


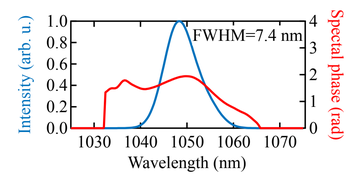
Sub-200-fs MIXSEL











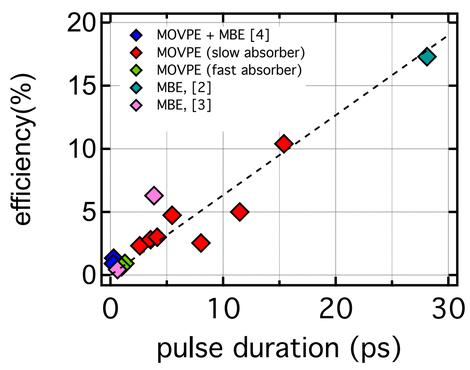
Pulse duration:	**184 fs**
Average output power:	**115 mW**
Opt. to opt. efficiency	**0.7%**
Repetition rate:	**4.33 GHz**
Center wavelength:	**1048 nm**

- **Shortest pulse duration of a MIXSEL**
- **High peak power:**

P_{peak} **= 130 W**

[4] M. Mangold et al., Optics Express (2015) Vol. 23, 22043-22059

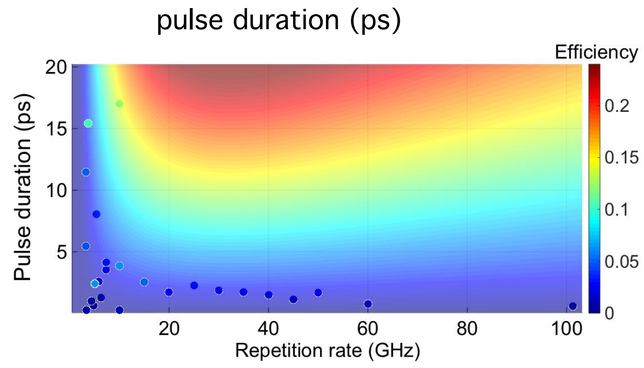
Challenges for performance scaling



- **Increase the optical-to-optical efficiency in fs-operation**

Carriers pumped into the gain QWs create a reservoir. A fs-pulse is not using all the carriers for stimulated emission. The remaining part decays spontaneously affecting the efficiency.

- **For fs-MIXSELs the efficiency is typically ≈1%**
- **Repetition rate has an influence on the efficiency**



MIXSEL data points fitted to a model for efficiency simulation

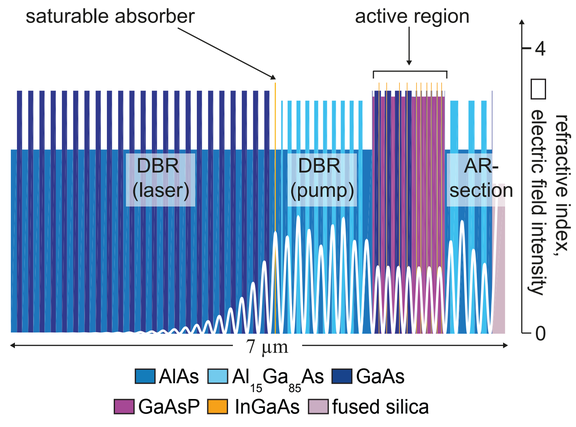
To enhance the efficiency:

- Increase the carrier lifetime in the gain QWs
- Use quantum dots with longer life times as gain medium
- Bandgap engineering

- **Reduce losses induced by two-photon absorption (TPA)**

At high power two photon absorption (TPA) becomes stronger and transparent layers become absorptive

- **TPA prevents further power scaling**
- **TPA losses are higher at short pulse duration**



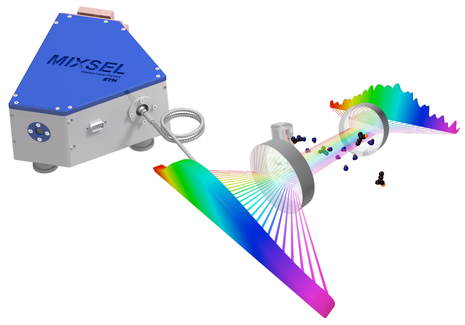
✗ Where the electric field is more intense (i.e. pump DBR, AR section) TPA is increased

➠ Design full dielectric AR section and reduce the electric field in the pump DBR

✗ Low bandgap materials (i.e. GaAs, GaAsP, $Al_{15}Ga_{85}As$) contribute more to TPA

➠ Use large bandgap materials (i.e. AlAsP) for strain compensation instead of GaAsP

Outlook



next steps: **sub-200-fs pulses with > 1 kW peak power from a MIXSEL**

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

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