nano-tera.ch
swiss scientific initiative in health / security / environment systems

MIXSEL RTD 2009

FNSNF

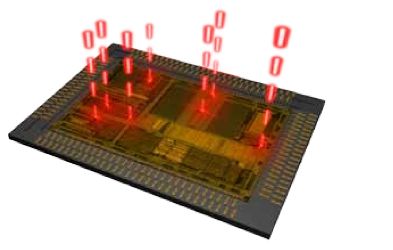
Electrically Pumped VECSELs and MIXSELs

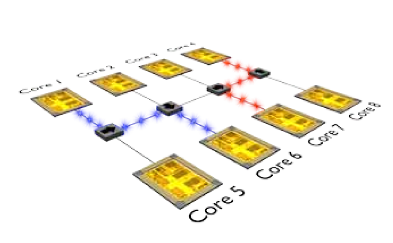
W. P. Pallmann[1], C. A. Zaugg[1], I. Dahhan[2], B. Witzigmann[2], M. Golling[1], B. W. Tilma[1] and U. Keller[1]

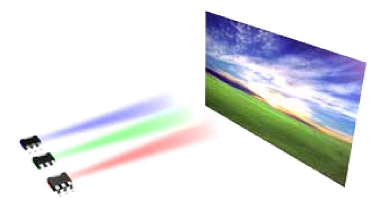
[1]Ultrafast Laser Physics Lab, ETH Zurich, [2]Computational Electronics and Photonics Group, University of Kassel

ETH Eidgenössische Technische Hochschule Zürich Swiss Federal Institute of Technology Zurich

motivation for pulsed semiconductor lasers


multi-core clocking


optical interconnects


RGB projection

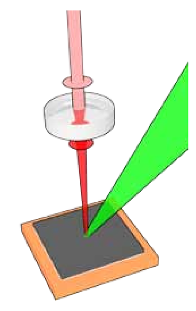
➡ SESAM[1]-modelocked VECSELs[2] ideally suited for pulse generation in GHz regime

[1] SESAM: Semiconductor Saturable Absorber Mirror (U. Keller, et al., IEEE J. Sel. Top. Quantum Electron. **2**, 435-453 (1996))
[2] VECSEL: Vertical External Cavity Surface Emitting Laser (M. Kuznetsov, et al., IEEE Photon. Technol. Lett. **9**, 1063-1065 (1997))

approach: electrical pumping

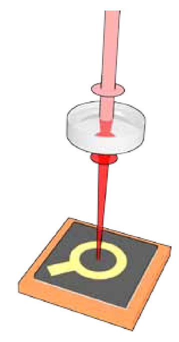
achieved with optically pumped VECSELs:

- 5.1 W in 682 fs pulses [1]
- sub-100-fs pulses [2]
- but: bulky pump optics



electrically pumped VECSELs:

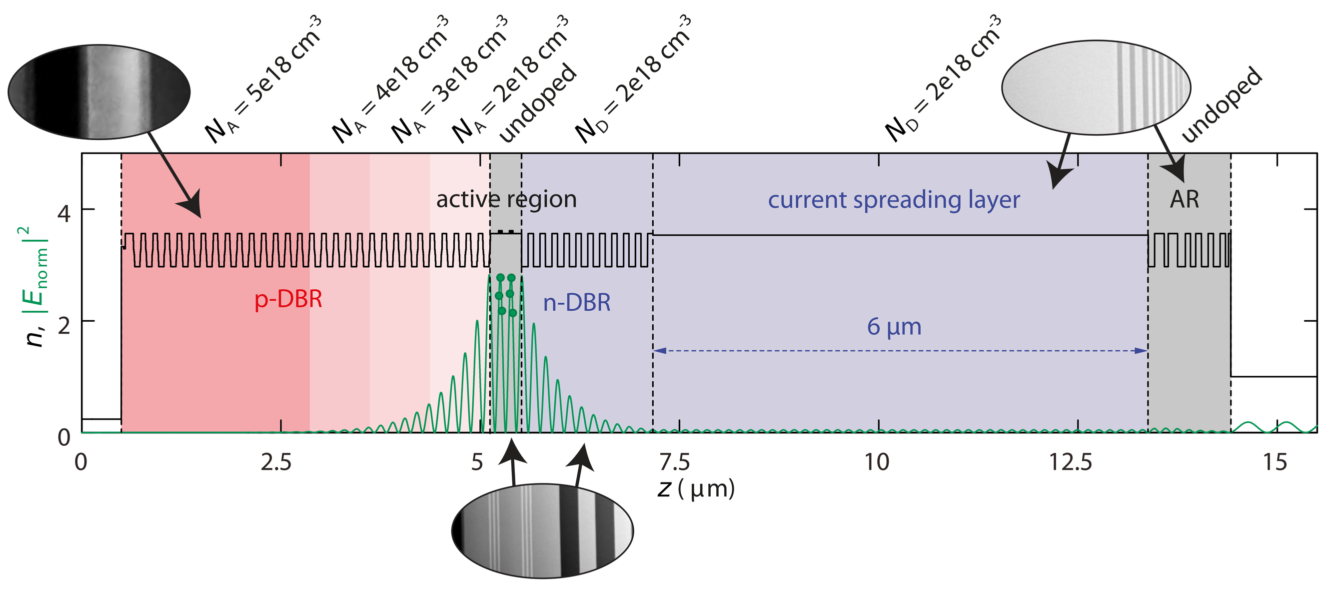
- compact, reliable, cost-efficient
- high power
- excellent beam quality
- multi-GHz repetition rate



[1] M. Scheller, T. L. Wang, B. Kunert, W. Stolz, S. W. Koch, J. V. Moloney, Elect. Lett. **48**, 588-589 (2012)
[2] A. Quarterman, K.G. Wilcox, V. Apostolopoulos, Z. Mihoubi, S. Elsmere, I. Farrer, D.A. Ritchie, A. Tropper, Nat. Phot. **3**, 729-731 (2009)

design of the electrically pumped VECSEL

gain structure



refractive index profile, normalized electrical field distribution and doping profile of the initial EP VECSEL* gain structure with TEM insets

* EP VECSEL: Electrically Pumped Vertical External Cavity Surface Emitting Laser

EMEZ Electron Microscopy ETH Zurich

design [3]

optical-electrical trade off
optimized doping profile
p-DBR with compositional or digital alloy grading
intermediate n-DBR for increased gain

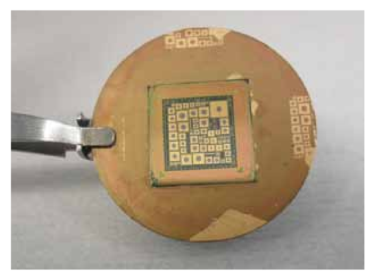
power scalability
substrate removal
large apertures possible
high power achievable

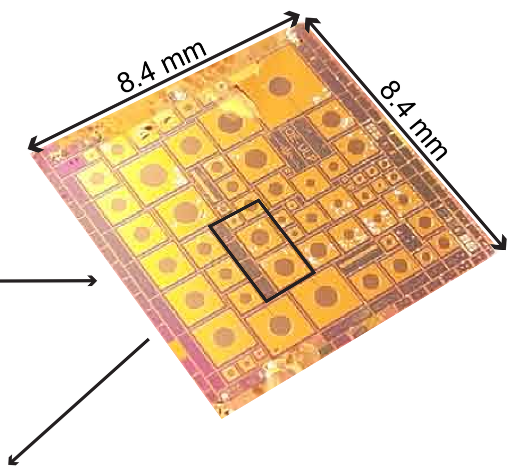
suitable for modelocking
optimized AR section
6 µm current spreading layer
confined current injection: good beam profile

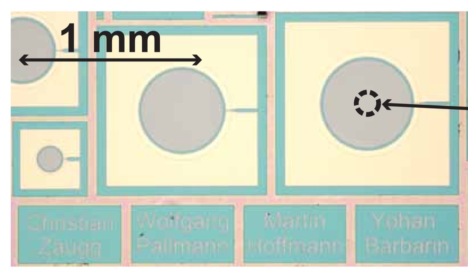
[3] P. Kreuter, B. Witzigmann, D. J. H. C. Maas, Y. Barbarin, T. Südmeyer, U. Keller, Appl. Phys. B **91**, 257-264 (2008)

realized lasers

63 lasers with different sizes on CuW wafer

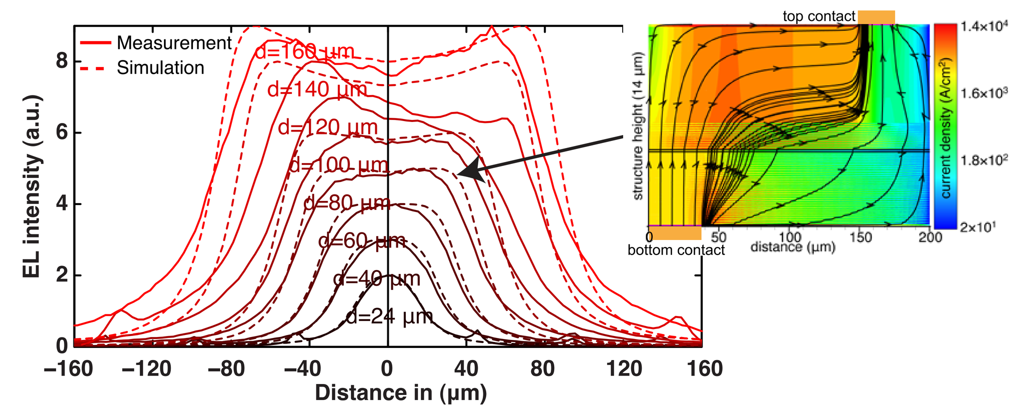




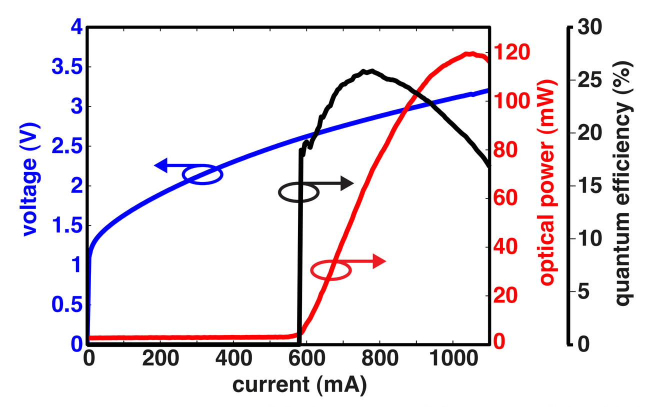


bottom contact diameter (BCD): 140 µm

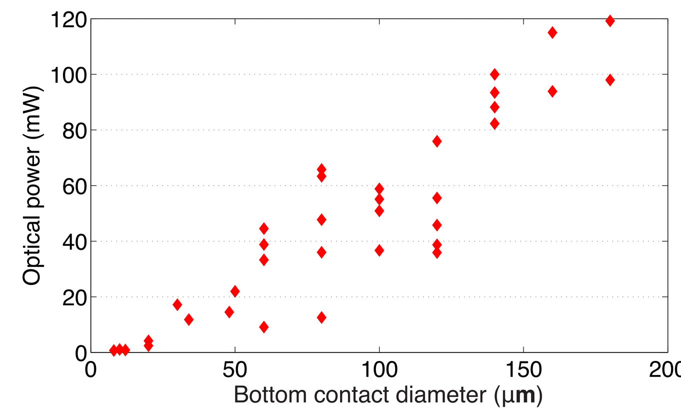
experimental results of the first generation lasers



electroluminescence profiles of EP VECSELs with different back contact diameters at high current injection



L-I-V curve and quantum efficiency of laser with 180 µm BCD in a straight cavity with OC with 10% transmission, heat sink at 3°C

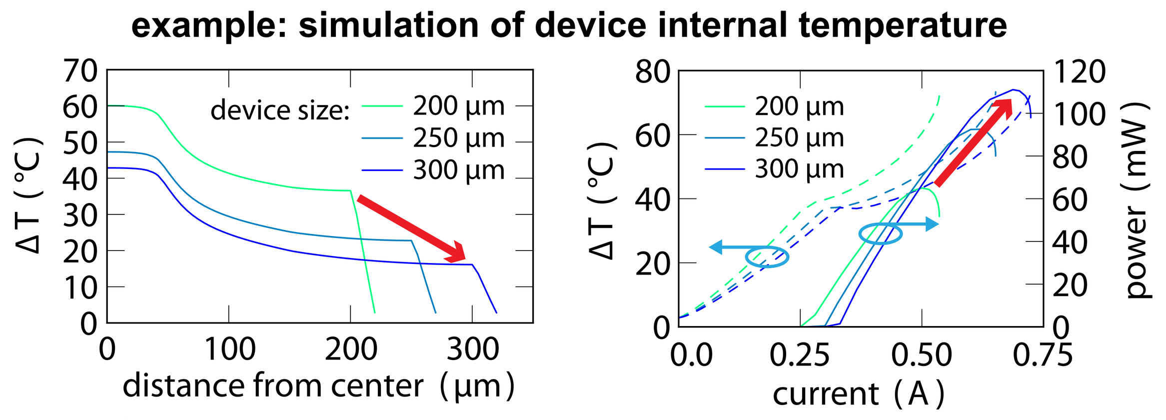


output power of lasers with different BCDs measured with OC with 10% transmission, heat sink at 3°C

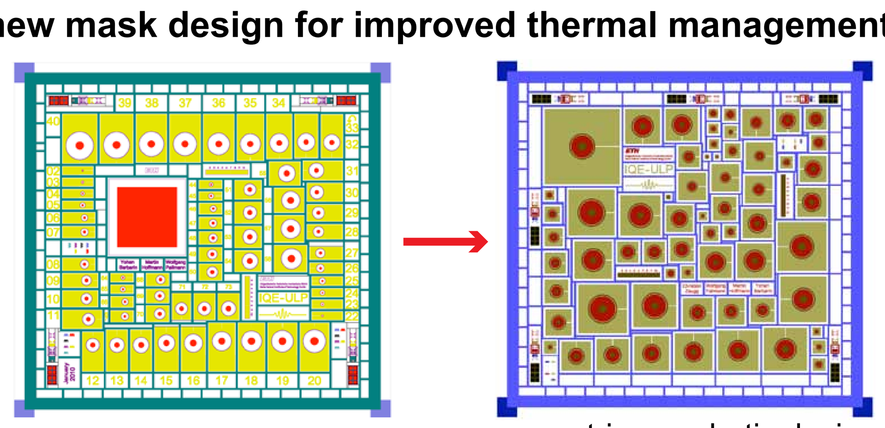
Y. Barbarin, M. Hoffmann, W. P. Pallmann, I. Dahhan, P. Kreuter, M. Miller, J. Baier, H. Moench, M. Golling, T. Südmeyer, B. Witzigmann, U. Keller, IEEE J. Selected Topics in Quantum Electronics (JSTQE), vol. 17, No. 6, pp. 1779-1786, (2011)

optimization using numerical methods

example: simulation of device internal temperature



new mask design for improved thermal management

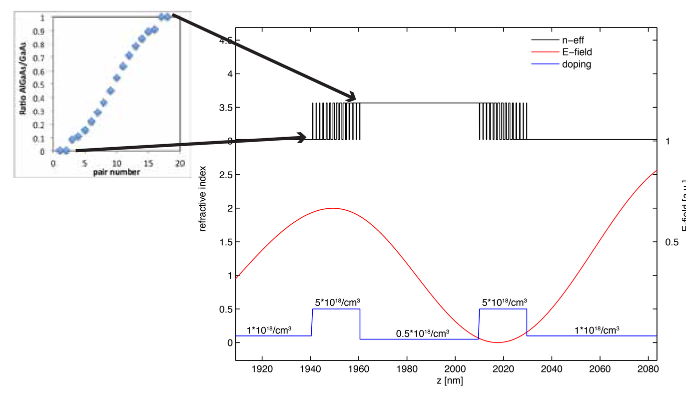


small, asymmetric devices

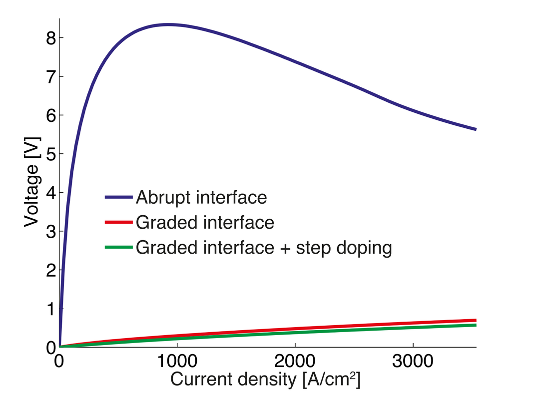
symmetric, quadratic devices with larger heat transfer area

➡ increase in output power by scaling the heat transfer area

p-DBR optimization

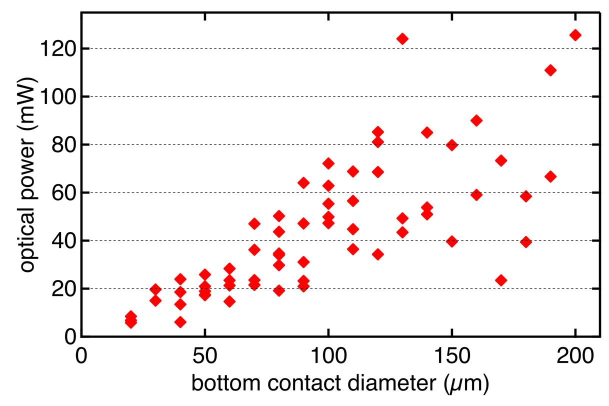


bi-parabolic digital graded interface from GaAs to $Al_{90}Ga_{10}As$ realized with MBE



I-V curve of 15 pair p-DBRs with abrupt and digital alloy interfaces

experimental results of the improved lasers

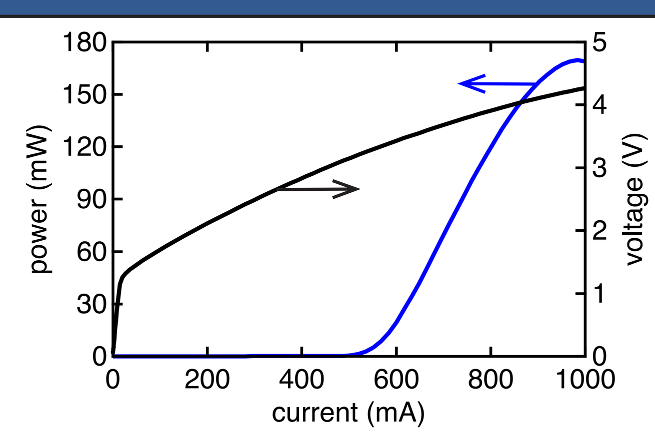


output power of lasers with different BCDs measured with OC with 5.5% transmission, heat sink at 3°C

improvements
digital alloy p-DBR
larger heat transfer area
improved doping levels

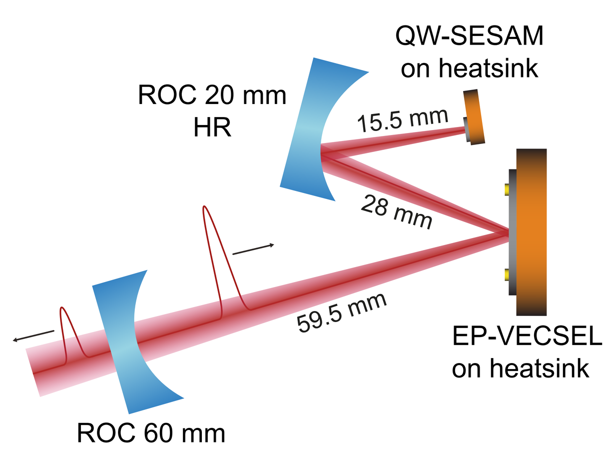
result
improved performance for lower n-DBR reflectivity (81 % instead of 92.5 %)

➡ better for beam quality and modelocking experiments



L-I-V curve of laser with 200 µm BCD measured with OC with 5.5% transmission, heat sink at - 20°C

modelocking experiments



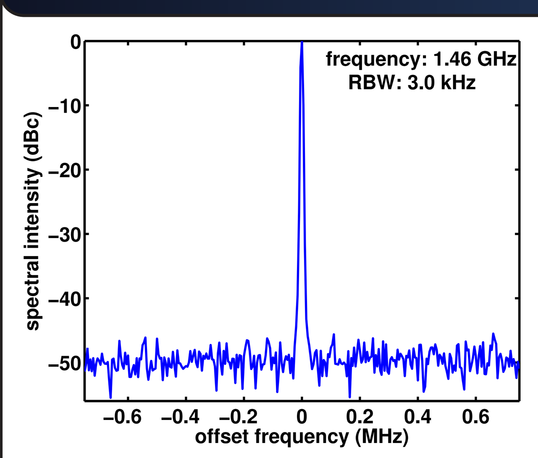
cavity setup:

z-shaped cavity with 70 µm diameter spot on EP-VECSEL and ≈ 40 µm spot on SESAM

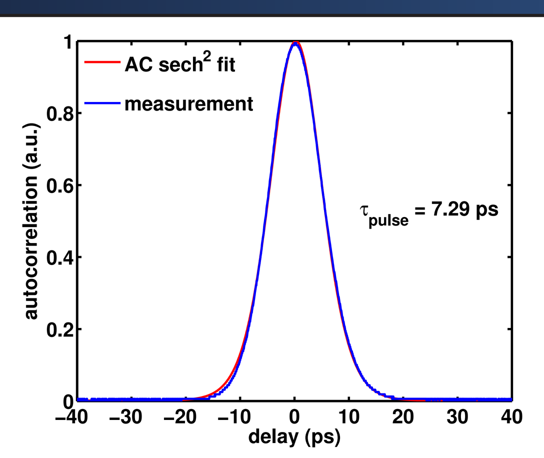
both VECSEL and SESAM on temperature-stabilized heat sink

low saturation-fluence quantum-well SESAM (F_{sat} ≈ 5 µJ/cm^2)

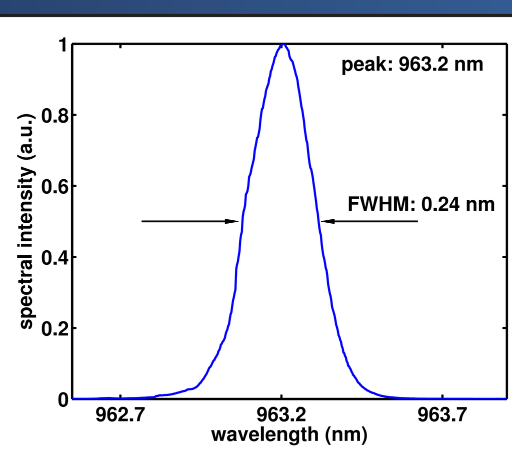
modelocking experiments: results



microwave spectrum



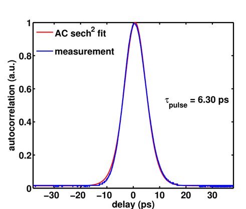
intensity autocorrelation and sech^2-fit



optical spectrum

average output power:	13.1 mW
pulse duration:	**7.3 ps**
peak power:	**1.08 W**
pump current:	266 mA
VECSEL / SESAM temp.:	-20.7°C / 35.5°C
time-bandwidth-product:	0.56 (≈ 1.7 x sech^2)

with lower power: **6.3 ps** (6.2 mW)



➡ **shortest pulses and highest peak power from an EP VECSEL so far**

outlook

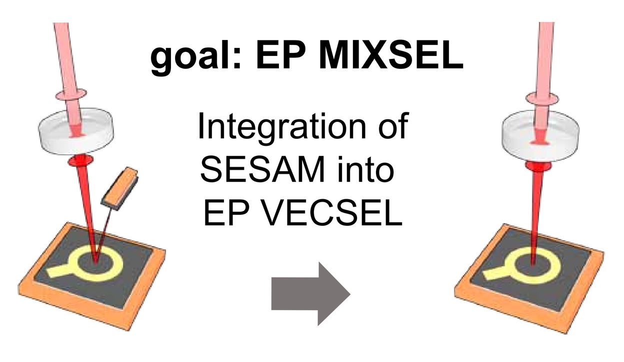
near future:

further increase single-mode power with optimized heatsink

further optimize electrical properties of devices

goal: EP MIXSEL

Integration of SESAM into EP VECSEL



➡ **ultracompact device with: GHz repetition rate, high power, excellent beam quality**

our work is supported by: nano-tera.ch FIRST Center for Micro- and Nanoscience

Ultrafast Laser Physics — Institute for Quantum Electronics