A Picosecond Passively Mode-locked Vertical (Extended Cavity) Surface Emitting Diode Laser

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Introduction and Motivation

Some History:
- edge emitting diode lasers modelocked both passively and actively (e.g. NEC ‘hybrid’ modelocked laser, $\tau_p \sim 2$ psec)

But, modelocking on VCSELs offers benefits for on-chip geometry, ease of integration with micro/optoelectronics, and high density arrays

So far for VCSELs:
- active modelocking work in 1990’s (Bowers, Ebeling)
- optically pumped high-power passively modelocked extended cavity VCSELs (Keller)

Now:
- passively modelocked (extended cavity) VCSEL diode
- challenge: device design and implementation in a vertical diode; SESAM

Why: applications from chipscale all-optical processors to bioinstrumentation

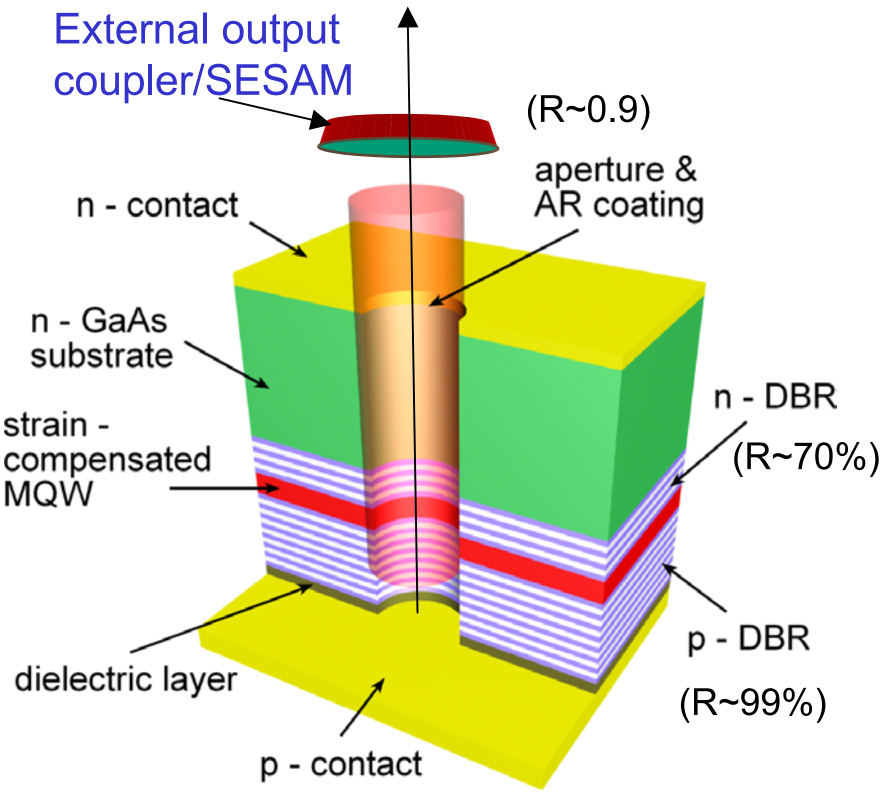
Challenge of Passively Modelocking a Diode VCSEL

1) Resonator configuration: saturation of absorption vs. gain
2) Compatibility with electrical transport
3) Design of the saturable absorber

Device base: A Large Aperture Extended Cavity VCSEL (Novalux Inc); λ~ 980 nm

- 3-mirror coupled-cavity configuration design for large aperture, high power operation; substrate part of resonator
- MOCVD grown GaInAs/GaAsP strain-compensated multiple QWs gain medium
- TEM_{00} mode size controlled by extended cavity and internal aperture (50- 150μm)
- Monolithic integration has been achieved

Device Idea:



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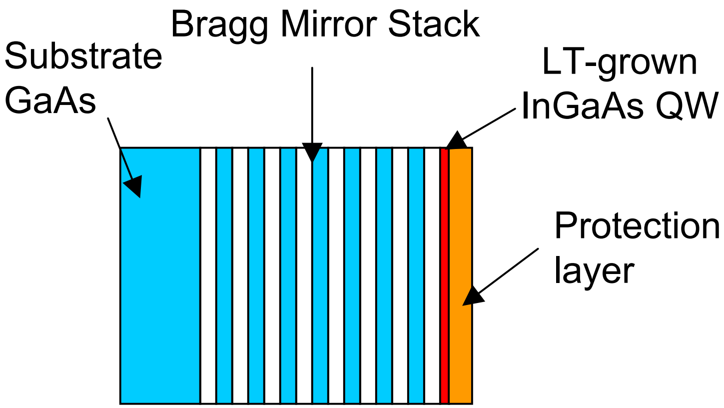
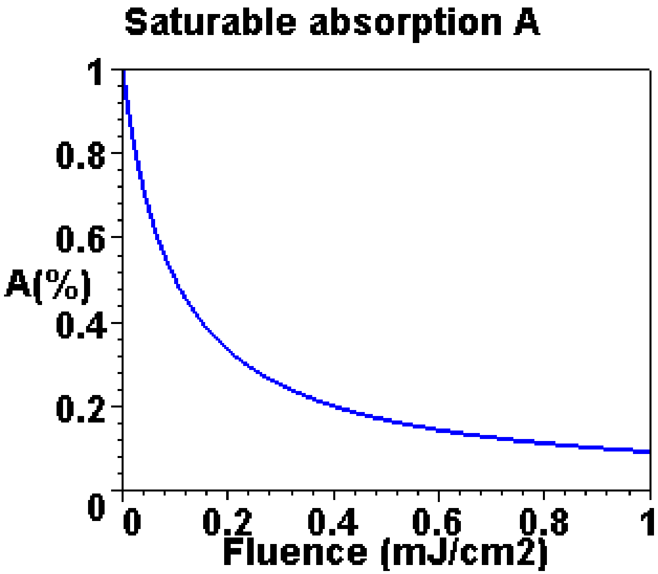
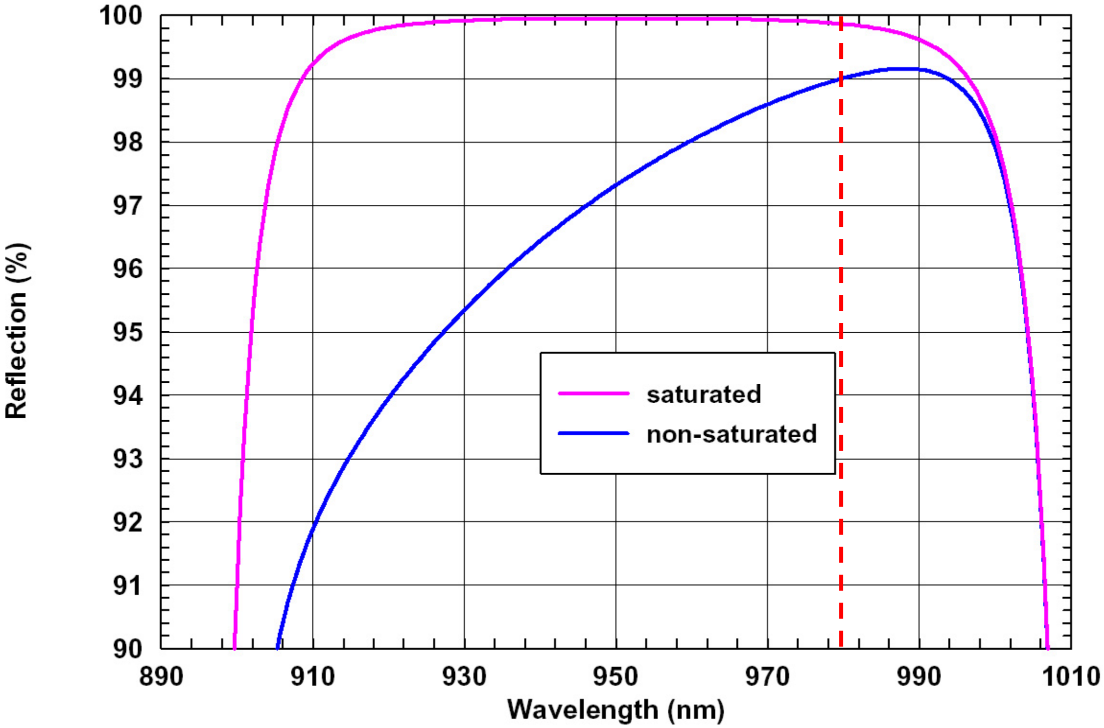
Semiconductor Saturable Absorber Mirror (SESAM)

(W.Richter, Weimar)

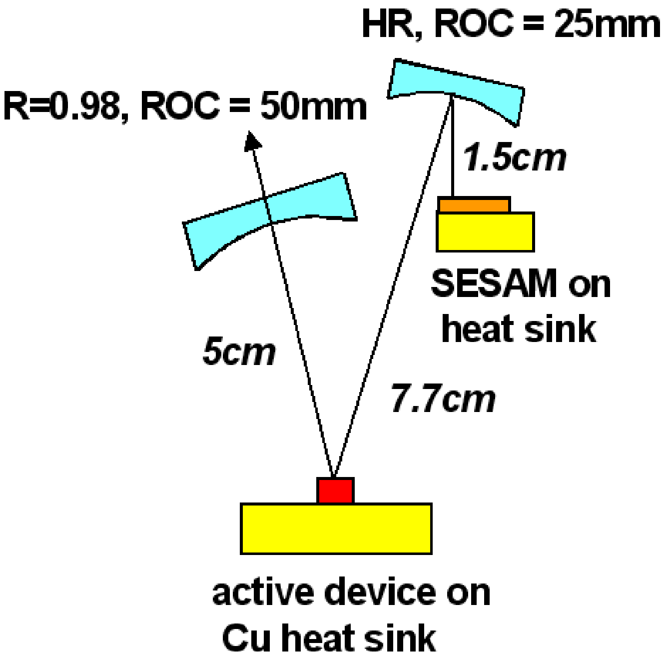
Saturable absorption	**1%**
Saturation fluence	**70μJ/cm²**
Relaxation time	**20ps**



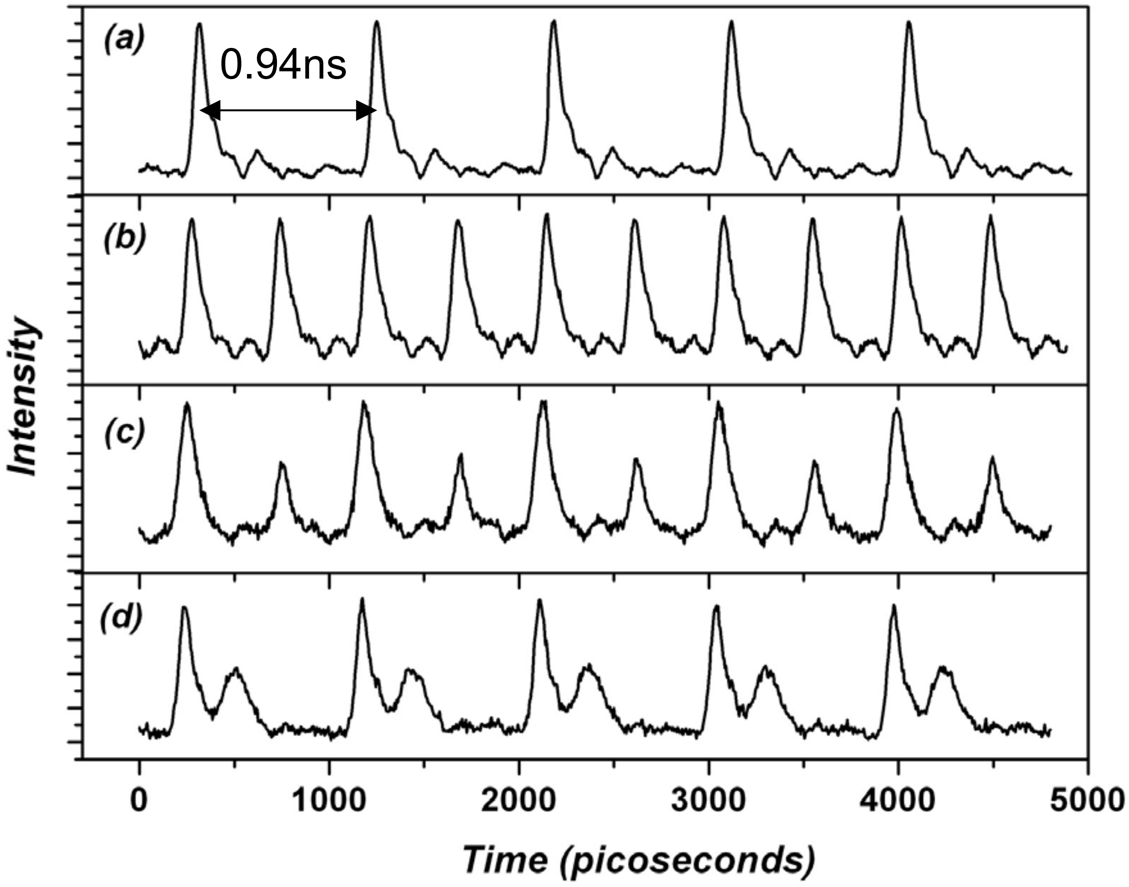




“Z-shape” Folded Cavity Configuration



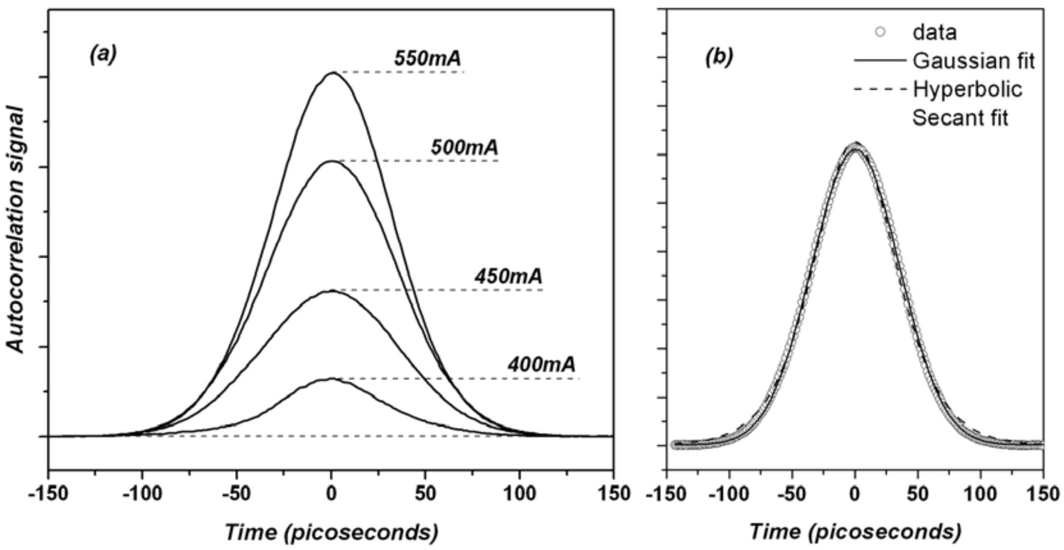
- stable mode-locking at any current level beyond threshold
- 40mW average output power with an OC R~96%
- ~1W peak power, 1.1GHz rep. rate
- ~20μm spot size on SESAM



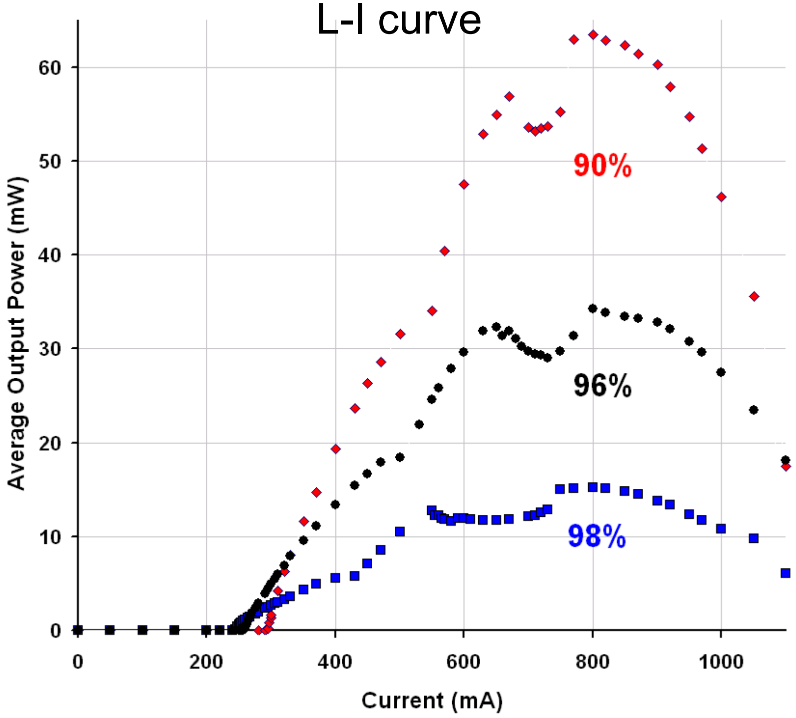
(photodiode output)

Pulse Width and L-I Measurements

Second-Harmonic Autocorrelation Measurement



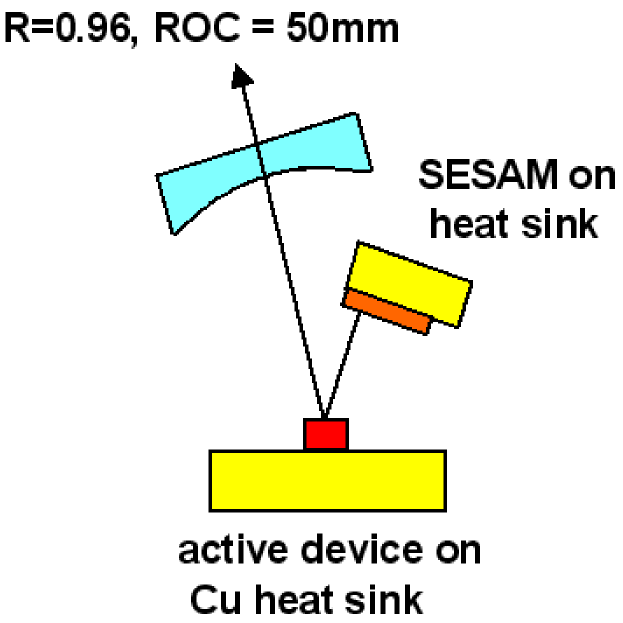
L-I curve

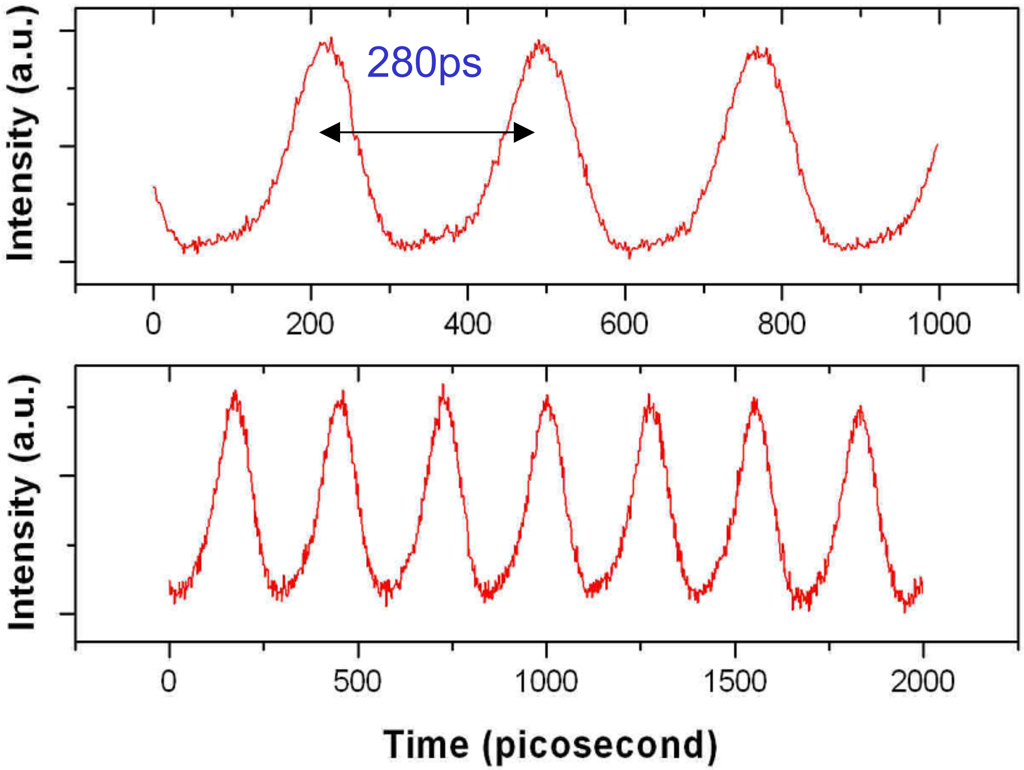


- Pulse width of 57ps @500mA (limited by “extra” n-DBR)
- Fast saturable absorber regime

- Power scalable for different reflectance of output coupler
- Mode-locking achieved for R_{oc} as low as 90%

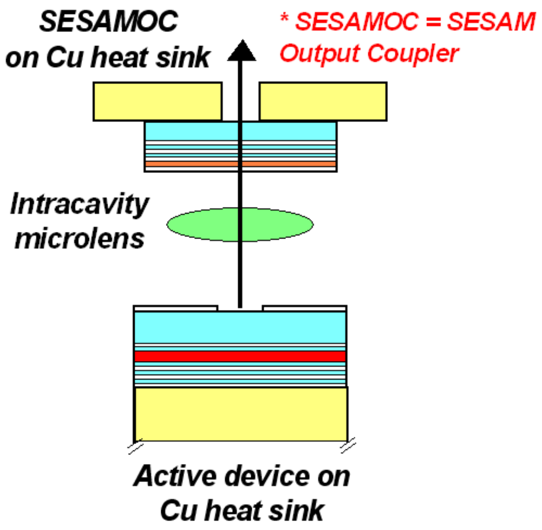
V-shape Folded Cavity Configuration





- Shorter cavity length gives higher rep. rate ~ 3.6 GHz
- Comparable pulse width ~ 60ps (limited by “extra DBR”)
- Less stable because of spot size on SESAM is larger

Linear Cavity Configuration

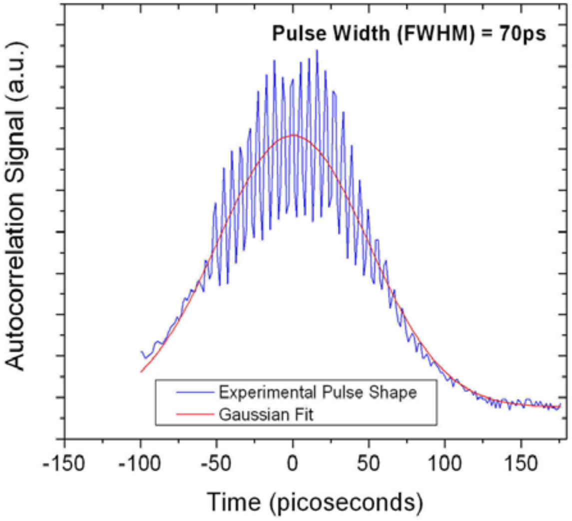


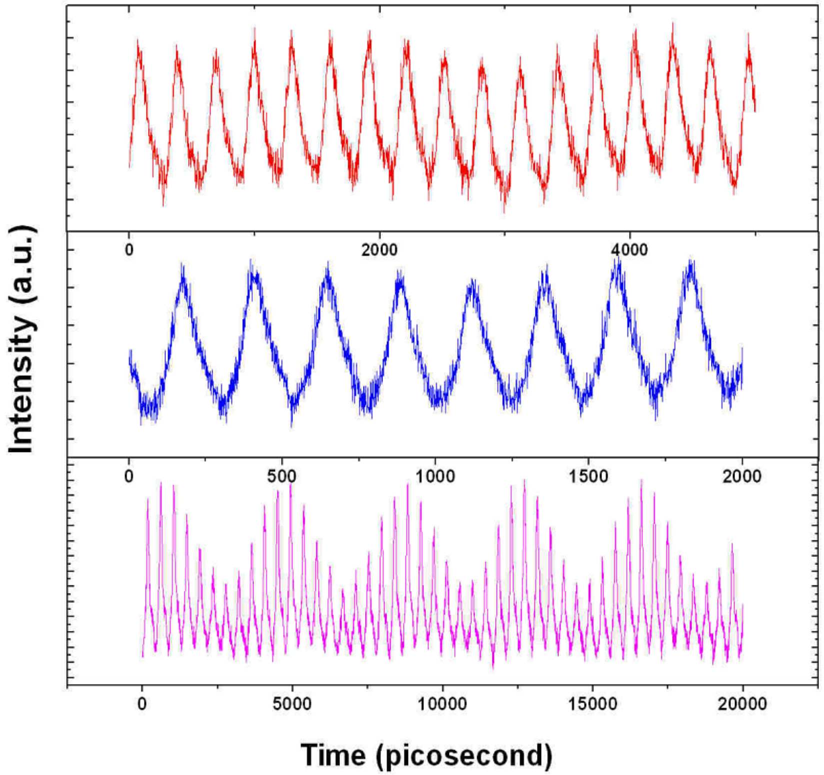
***SESAMOC* on Cu heat sink**

** SESAMOC = SESAM Output Coupler*

Intracavity microlens

Active device on Cu heat sink





f_{rep} = 3.3GHz

f_{rep} = 4.5GHz

Gain switching- and mode-locking

- Linear cavity design with “SESAMOC” and intracavity lens delivers compact package size
- Preliminary rep. rate ranging from 1GHz to 4.5GHz, potential of reaching multi-GHz regime (10-100 GHz)

SUMMARY

- Demonstrated stable multi-GHz rate picosecond pulse generation by passive mode-locking of an extended cavity VCSEL
- Peak powers >1 W and pulsewidths ~ 50 psec achieved in linear, “Z” and “V”-cavities
- Device design properly balances saturation of absorption (intracavity SESAM) and saturation of gain
- Considerably higher repetition rates (up to 100 GHz) and shorter pulses (~ psec)are possible by optimizing cavity design/parameters
- Goal: Monolithic integration of a passively modelocked VCSEL

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