Quasi-single mode VCSELs for longer-reach multimode fiber optical interconnects

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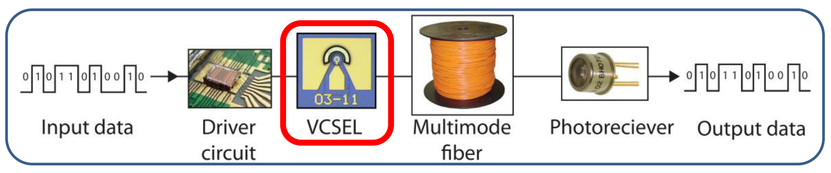
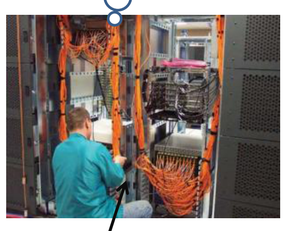
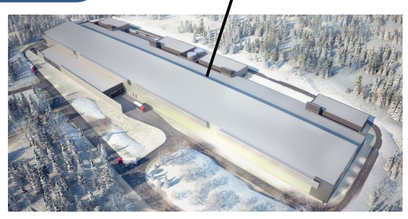
Motivation

Longer-reach (>300 m) optical interconnects are needed as datacenters grow ever larger. Today the reach of 850 nm VCSEL-based optical interconnects is mainly limited by fiber dispersion. By reducing the spectral width of the VCSEL, the effects of fiber dispersion may be reduced, effectively increasing the error-free transmission distance.







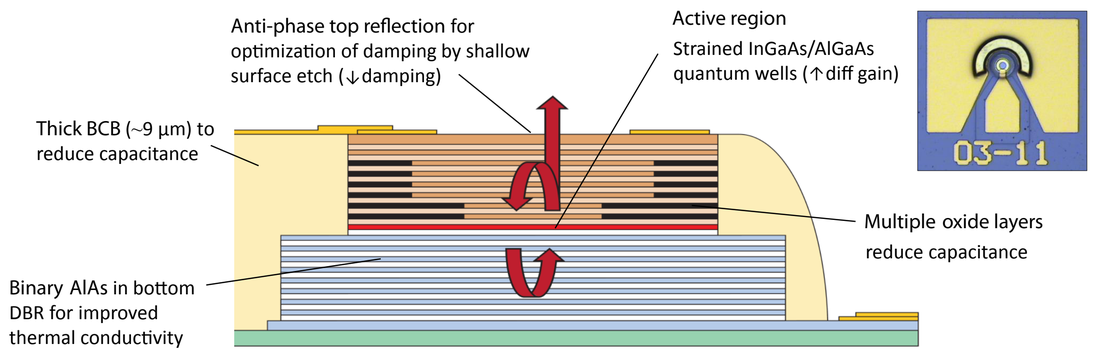
Example: Facebook datacenter in Luleå, Sweden

- 3 buildings with 28 000 m^2 each (300 x 100 m)
- Need high-speed interconnects > 300 m
- Google: need 1-2 km interconnects

Vertical-cavity surface-emitting lasers (VCSELs)

High-speed AlGaAs-based VCSELs emitting at 850 nm

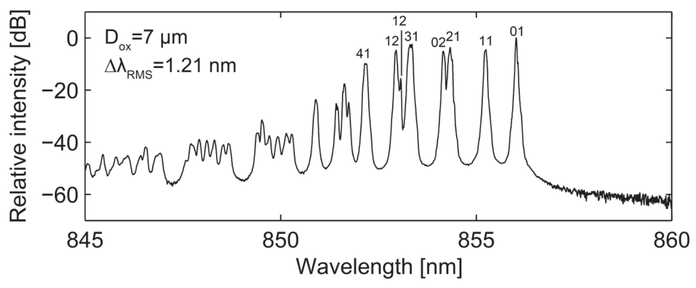
- Gain region sandwiched between two distributed Bragg reflectors (DBRs)
- Top emitting → easy on-wafer testing (low-cost manufacturing)
- Small volume device → low power consumption, fast direct modulation
- Main applications: Optical interconnects, computer mice, sensing



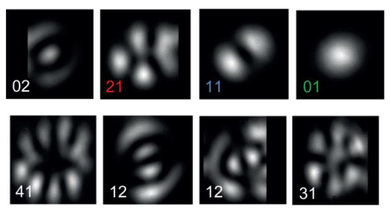
A. Larsson., "*Advances in VCSELs for communication and sensing*", IEEE J. Sel. Top. Quantum Electron. 17 (6), 2011

VCSEL spectral properties

- Short cavity → single longitudinal mode
- Relatively large transverse dimensions → multiple transverse modes
- Large spectral width ($\Delta\lambda_{RMS}$) distorts signal by chromatic and modal fiber dispersion
- Dispersion limits performance at >300 m and >10 Gbit/s
  or >100 m and >30 Gbit/s
- Lower spectral width required for future >30 Gbit/s interconnects



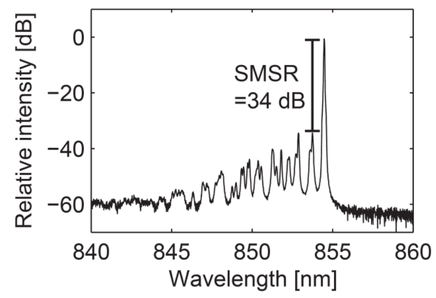
$$\Delta\lambda_{RMS} = \sqrt{\sum_{i=1}^{n} \frac{P_i}{P_{tot}} (\lambda_i - \langle\lambda\rangle)^2}$$



Quasi-single mode VCSELs

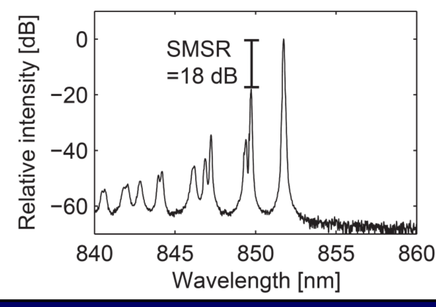
Single mode VCSELs

- > 30 dB side-mode suppression ratio (SMSR)
- Required for many sensing applications



Quasi-single mode VCSELs

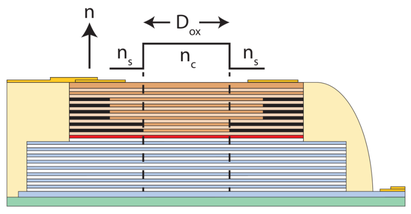
- Almost single mode
- SMSR ~ 15-20 dB
- Compromise between desired properties
  - SMSR, $\Delta\lambda_{RMS}$
  - Output power
  - Dynamics

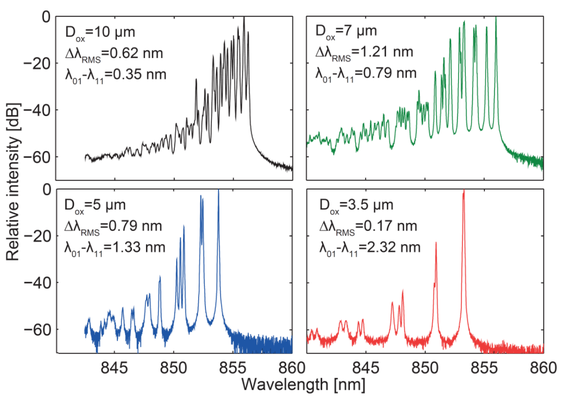


Small oxide aperture VCSEL

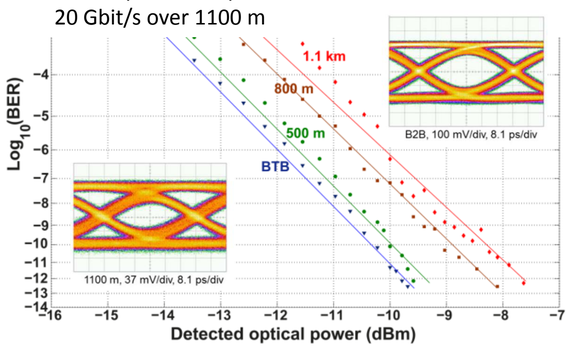
Decreasing the size of the oxide aperture will eventually make the VCSEL waveguide single mode

- Similar to a single mode optical fiber
- Fewer guided modes and larger mode spacing
- Need single mode or quasi-single mode for low $\Delta\lambda_{RMS}$
- Oxide aperture ~3 µm





Oxide aperture ~3 µm
20 Gbit/s over 1100 m

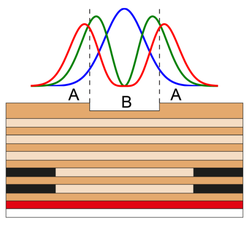


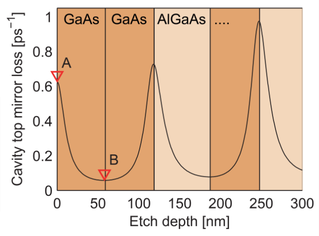
R. Safaisini et al., "*High-Speed 850 nm Quasi-Single-Mode VCSELs for Extended-Reach Optical Interconnects*", J. Opt. Commun. Netw. 5 (7), 2013

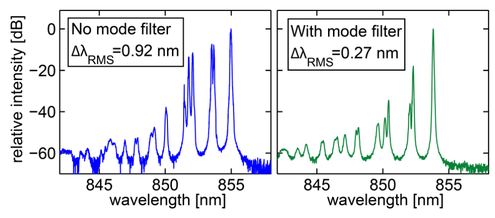
Surface mode filter VCSEL

An anti-phase layer is added to the top DBR, increasing top mirror loss (increasing the required threshold gain). By shallow etching in the center, the threshold is lowered for the best confined fundamental mode, promoting single or quasi-single mode emission.

- Spectral width reduced by >70 % for 5 µm oxide aperture
- Large increase in error-free transmission distance





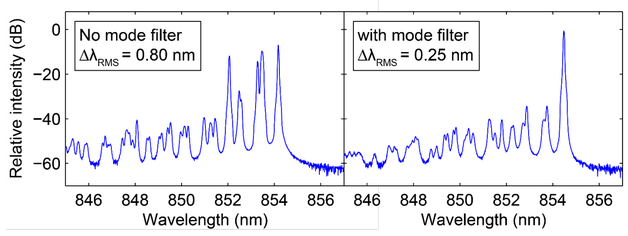


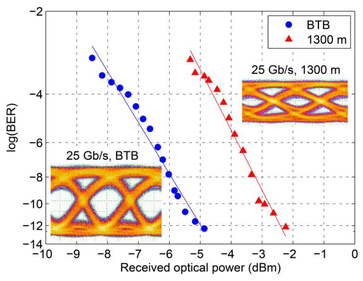
	No mode filter	Mode filter
1 m		
100 m		
300 m		
500 m		

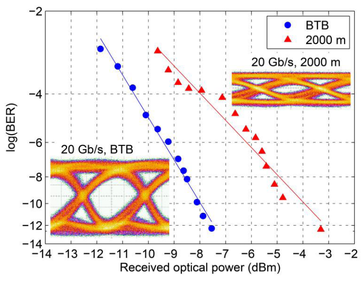
E. Haglund et al., "*25 Gbit/s transmission over 500 m multimode fiber using 850 nm VCSEL with integrated mode filter*", Electron. Lett. 48 (9), 2012

- Single-mode emission from 7 µm oxide aperture VCSEL
- Error-free transmission up to
  - 25 Gbit/s over 1300 m
  - 20 Gbit/s over 2000 m

<u>Record-high bit-rate-distance product</u> for directly modulated 850 nm VCSEL multimode fiber links 40 Gbit·km/s (previous 28.2 Gbit·km/s)







R. Safaisini et al., "*20 Gbit/s data transmission over 2 km multimode fibre using 850 nm mode filter VCSELs*", Electron. Lett. 50 (1), 2014

Conclusion & acknowledgements

- Significant increase of error-free transmission distance by single mode or quasi-single mode VCSELs
- Mode filter VCSELs
  - Up to 7 µm oxide aperture VCSELs single mode
  - Requires extra processing step
- Small oxide aperture
  - Requires small ~3 µm oxide aperture

Epitaxial material from: IQE Europe

Financial support from: VISIT EU FP7 Project 224211; LASTECH Swedish Foundation for Strategic Research

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