Energy efficient MBE-grown wafer fused 1310 nm VCSELs

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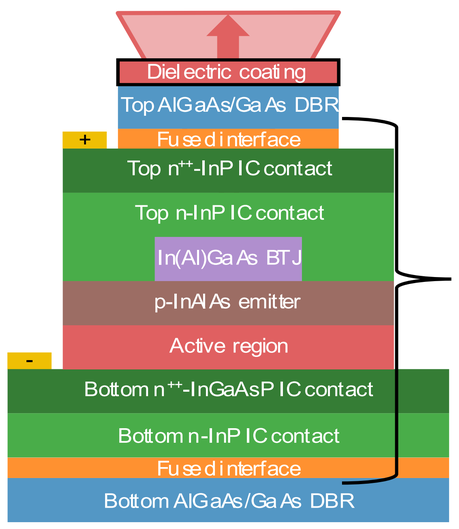
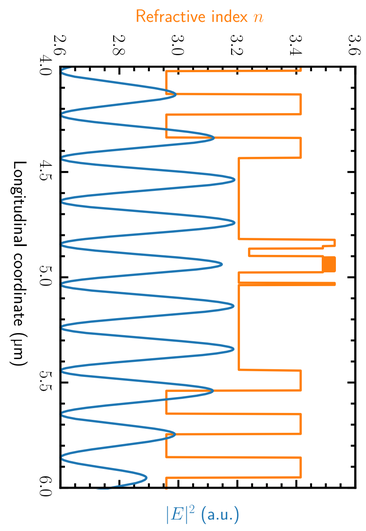
Motivation

- GaAs-based VCSELs presently dominate optical links in data centers, but cover only distances up to 1 km.
- 1310 nm InP-based VCSELs enable multi-km reach over zero-dispersion fiber, distances increasingly required as data center footprints grow.
- Data rates and energy consumption of InP-based VCSELs are presently insufficient.

Meta Hyperion (LA, 2030) compared to Manhattan

Our VCSELs



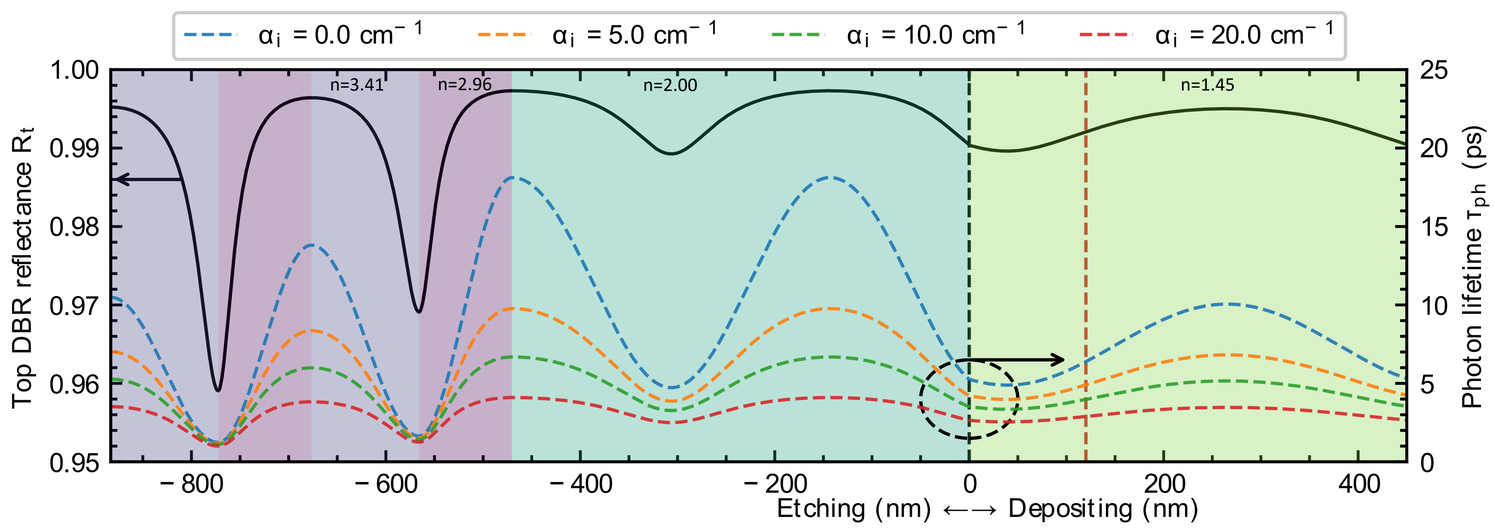


Photon Lifetime Tuning

- Dielectric coating (or partial etching) tunes the top DBRs reflectance R_t, and thus total cavity loss.
- Threshold gain condition: $\Gamma g_{th} = \alpha_i + \frac{1}{2L_{eff}} \ln\left(\frac{1}{R_t R_b}\right) = \frac{1}{v_{gr}\tau_{ph}}$.
- Total loss sets τ_p, giving control over VCSEL dynamics:
  - Relaxation resonance frequency: $f_R \propto \sqrt{1/\tau_{ph}}$
  - Damping factor: $\gamma \approx K f_R^2 + \gamma_0$
  - Small-signal response: $|H(f)|^2 = \frac{C f_R^4}{\left(f_R^2 - f^2\right)^2 + \left(\frac{f\gamma}{2\pi}\right)^2}$

- G. Larisch et al., IEEE Photon. Technol. Lett., 28 (2016).
- D. Bimberg et al., US patent 9,9791,58.

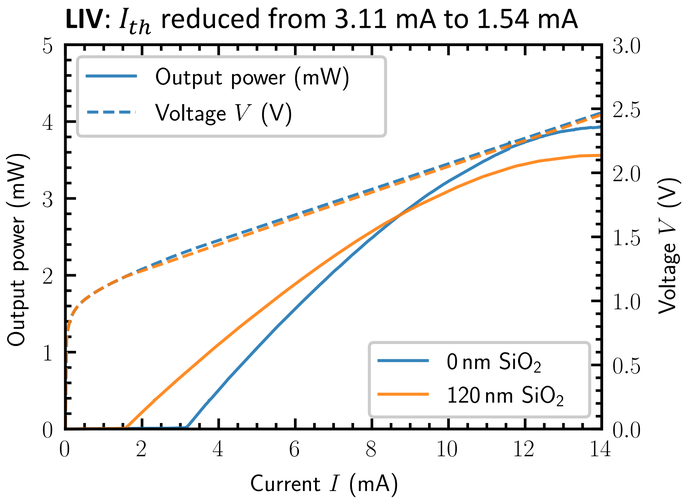
Simulation of the DBR reflectance R_t and resulting photon lifetime τ_{ph} via Transfer Matrix Method



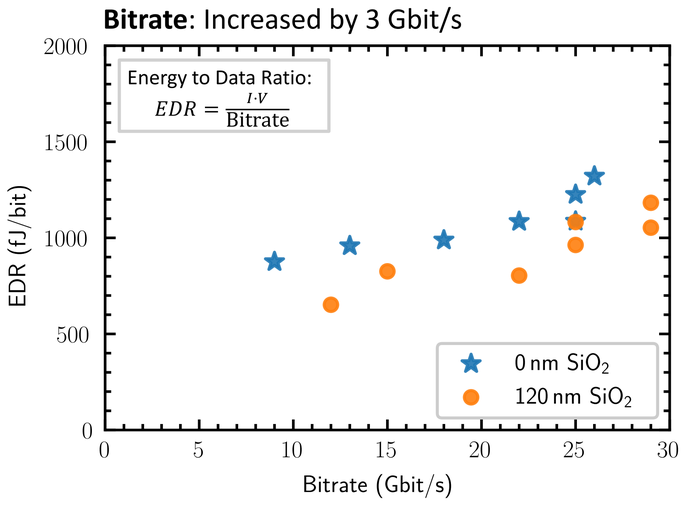
Experimental Results: a) Varying photon lifetime and using b) pre-emphasis strongly reduce energy consumption

a)

LIV: I_{th} reduced from 3.11 mA to 1.54 mA

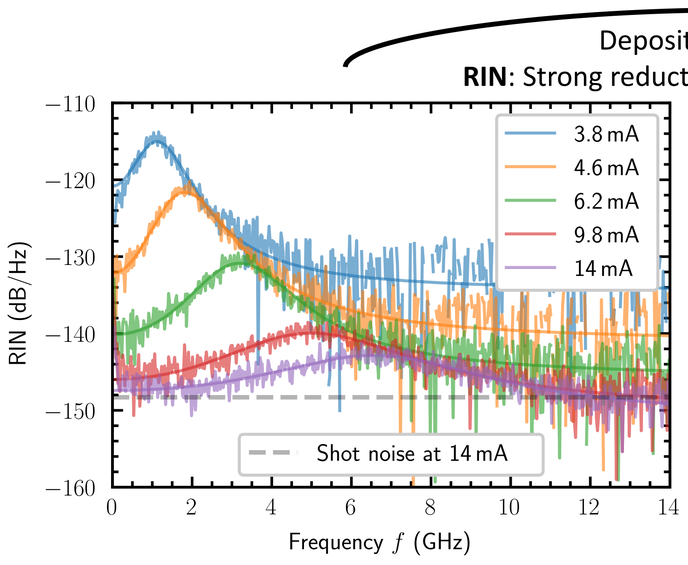


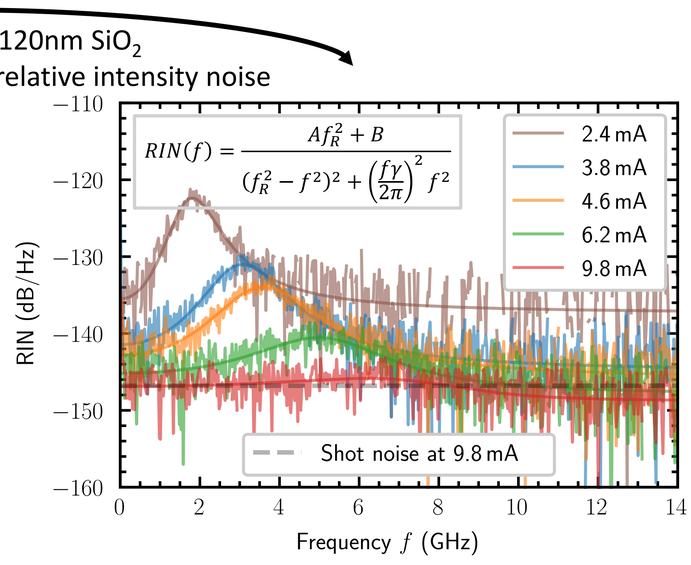
Energy per bit: Reduced from 875 fJ/bit to 650 fJ/bit
Bitrate: Increased by 3 Gbit/s



Deposition of 120nm SiO_2

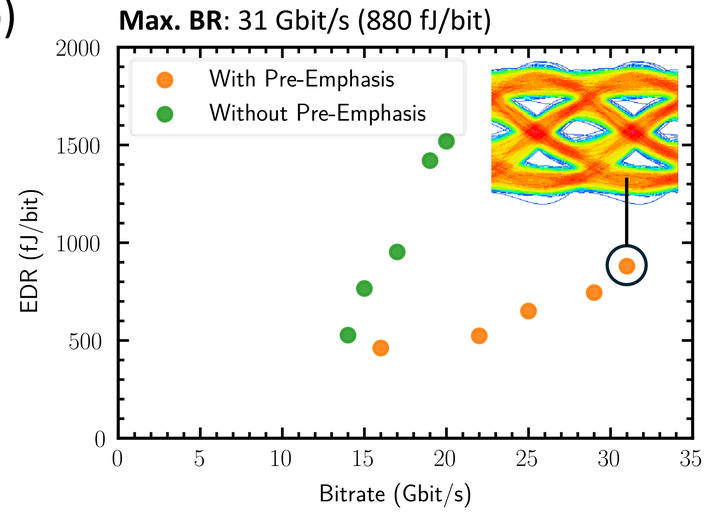
RIN: Strong reduction of relative intensity noise



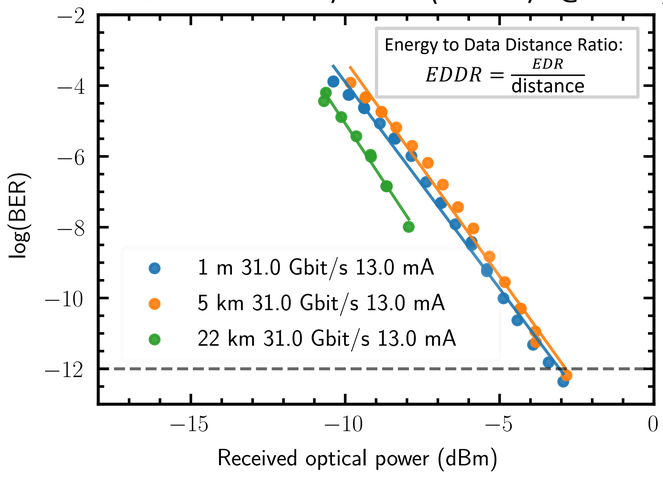


b)

Record-low EDR: 460 fJ/bit @ 16 Gbit/s
Max. BR: 31 Gbit/s (880 fJ/bit)



Error free over 22km @ 31 Gbit/s (40 fJ/bit·km)
Record EDDR: 21 fJ/bit·km (16 Gbit/s @ 22km)



Conclusion

- 1310 nm VCSELs with InP-based active regions, wafer-fused to high-thermal-conductivity AlGaAs/GaAs DBRs, achieve record-low energy per bit through post-fabrication tuning of the photon lifetime via dielectric coating of the top DBR. Together, these improvements yield lower threshold currents, higher modulation bandwidth, and greater energy efficiency.
- We demonstrate a record-low EDR of 460 fJ/bit and a maximum NRZ data rate of 31 Gbit/s using pre-emphasis, demonstrating this technology's potential for future energy-efficient, longer-distance optical interconnects.

Let's connect!

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