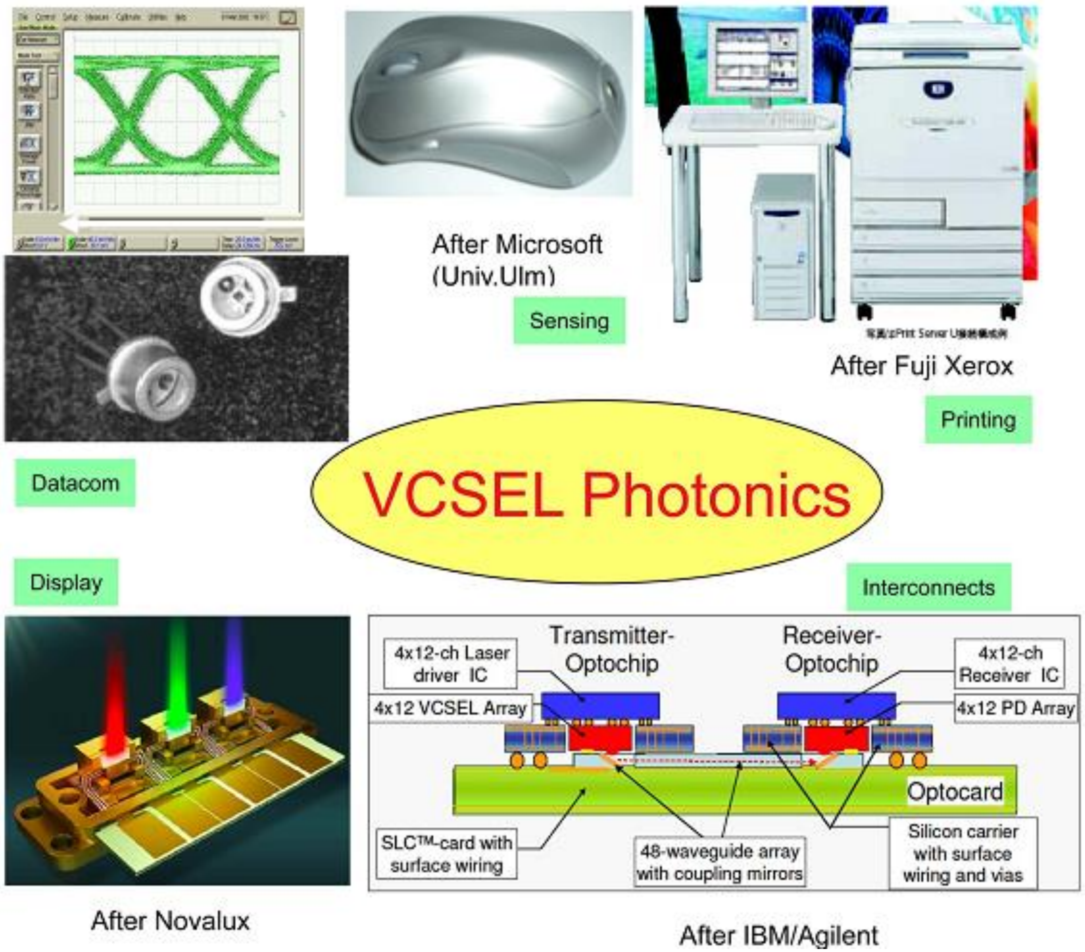
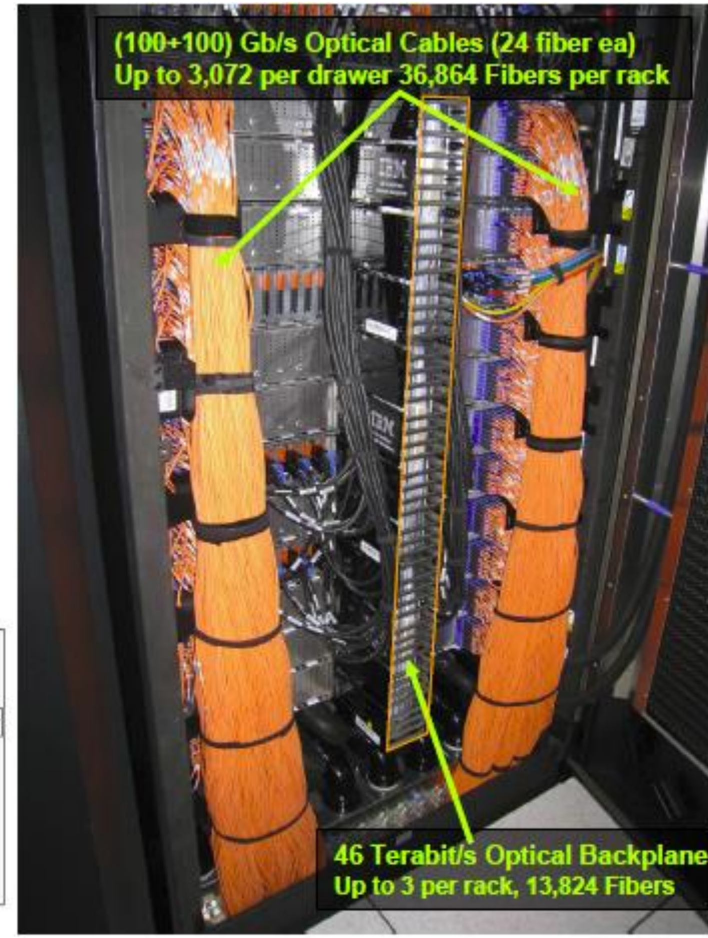
Tribute to
Prof. Larry Coldren

Connie Chang-Hasnain
EECS Dept.
UC Berkeley

UCSB
3/16/2018

VCSELs

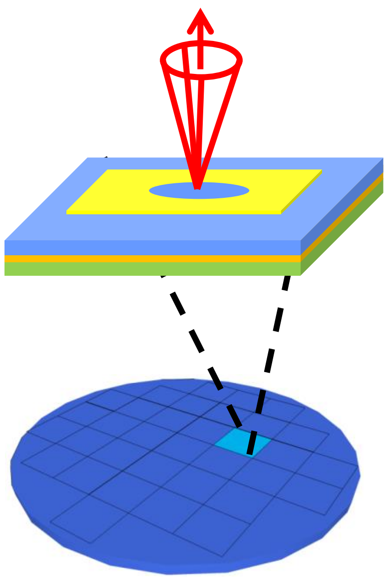




Kenichi Iga, *Proceedings of the IEEE* (2013).

Vertical-Cavity Surface-Emitting Laser (VCSEL)

- **Advantages**
  - Excellent fiber coupling
  - Low power consumption
  - Wafer-scale testing, Low-cost fabrication
  - **Single longitudinal mode**
  - **2D Array fabrication**



New Applications in 3D Sensing

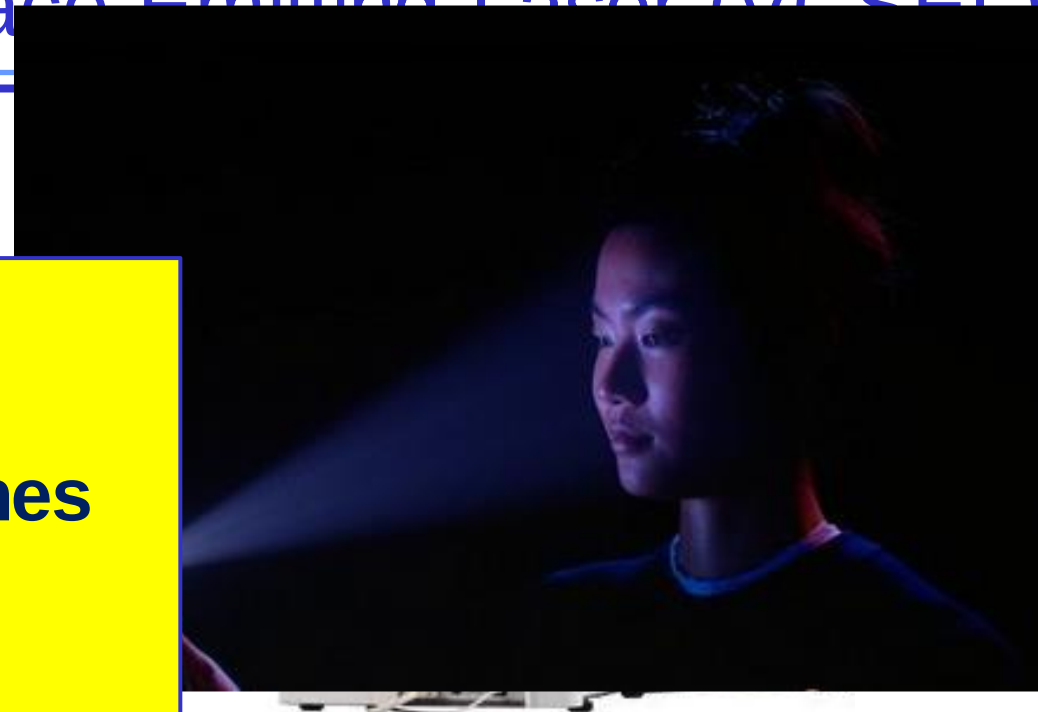
Optical Coherent Tomography

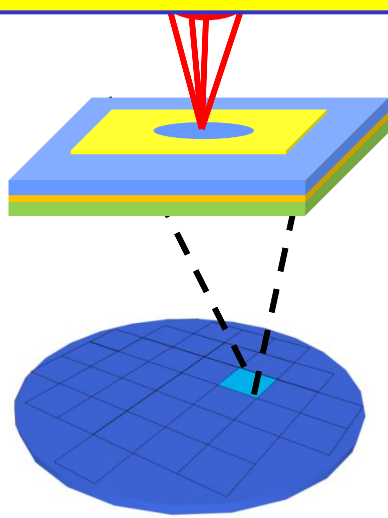
3D sensing

Vertical-Cavity Surface Emitting Laser (VCSEL)

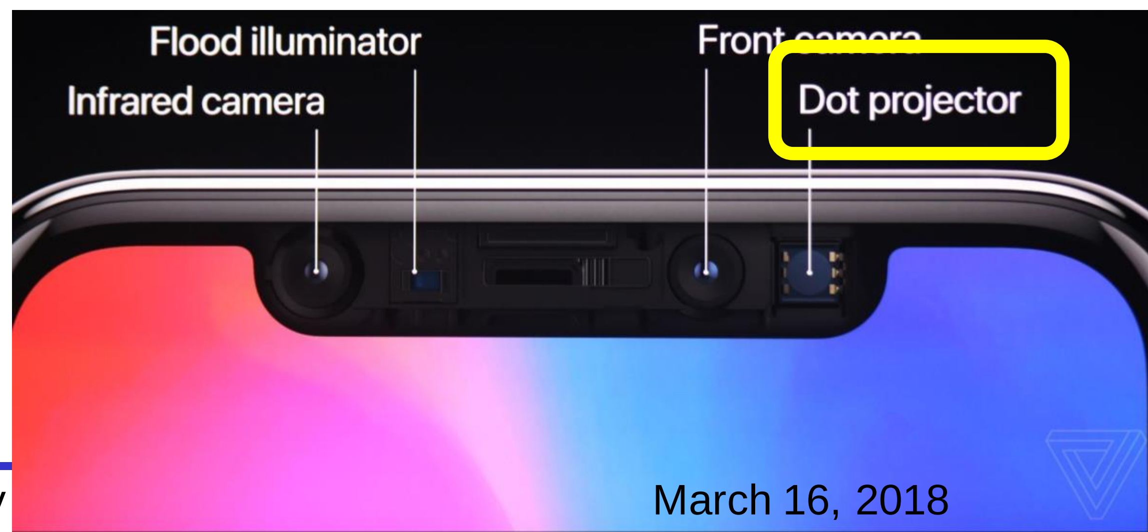
- **Advantages**
  - Excellent fiber coupling

Rapidly growing to B$/year market for 3D sensing in smart phones and facial recognition applications.





3D sensing

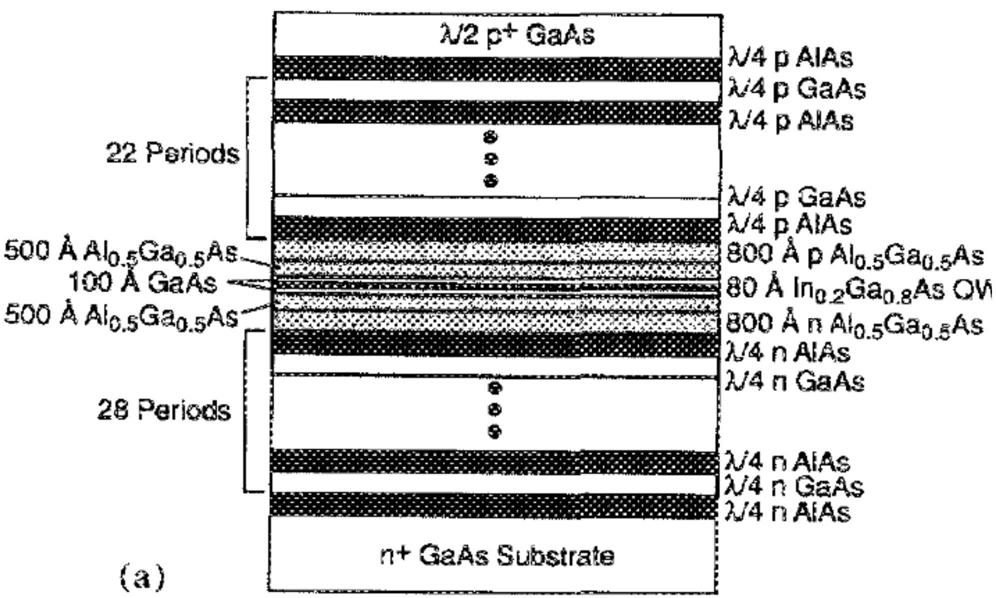


Submilliamp threshold vertical-cavity laser diodes

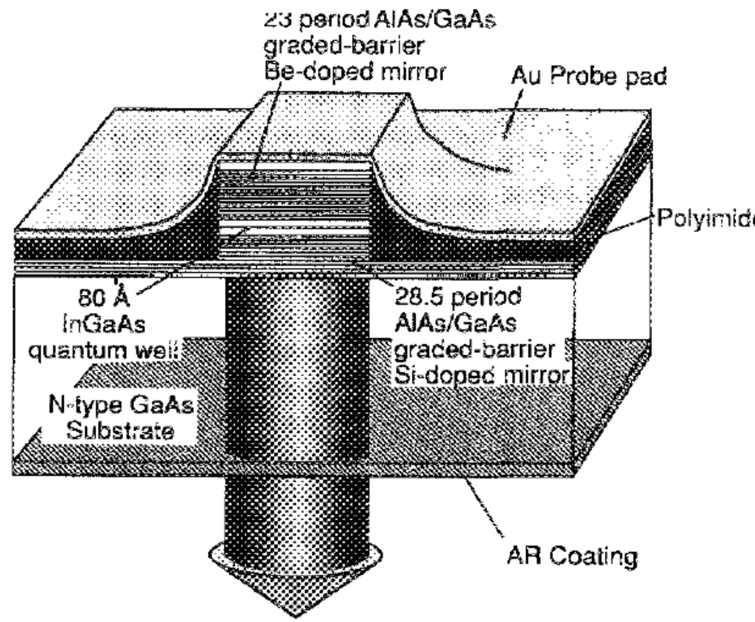
Randall S. Geels and Larry A. Coldren
Department of Electrical and Computer Engineering, University of California, Santa Barbara, California 93106

(Received 18 June 1990; accepted for publication 8 August 1990)

We report for the first time room-temperature, continuous-wave operation of individual vertical-cavity laser diodes with submilliampere threshold currents. A single quantum well active region emitting at 979 nm surrounded by GaAs/AlAs Bragg reflector mirrors was used. Threshold currents were as low as 0.7 mA. A record low linewidth-power product of 5 MHz mW and a linewidth as narrow as 85 MHz was measured. High yield and good uniformity were demonstrated.



(a)

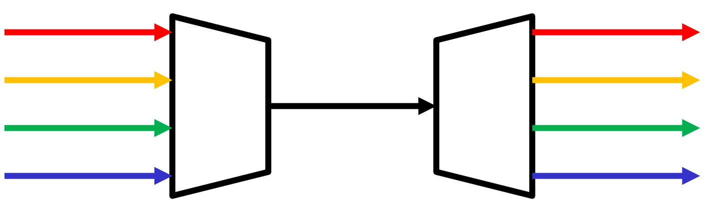


(b)

Tunable VCSEL Applications

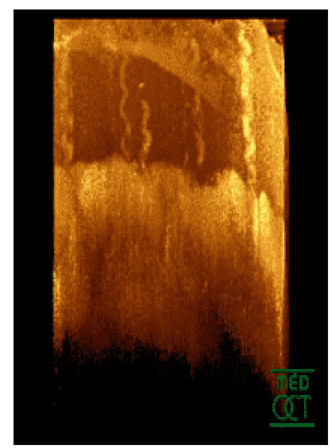
Optical Communications

- Wavelength Division Multiplexing (WDM)
- Dense WDM (DWDM)
  - O-band: 1260 nm-1360 nm
  - S-band: 1450 nm-1530 nm
  - C-band: 1530 nm-1565 nm
  - L-band: 1565 nm-1625 nm
- Shortwave WDM (SWDM4)
  - 850 nm - 940 nm
- Coarse WDM (CWDM)
  - 20 nm per channel



Optical Coherence Tomography

- Depth Resolution $\delta z = \frac{2 \ln 2}{\pi} \frac{\lambda^2}{\Delta\lambda}$
  - 50 nm+ for 10 µm resolution
  - 100 nm+ for 5 µm resolution
- Field of View ∝ sweep rate
  - *In vivo* Optical Coherence Tomography

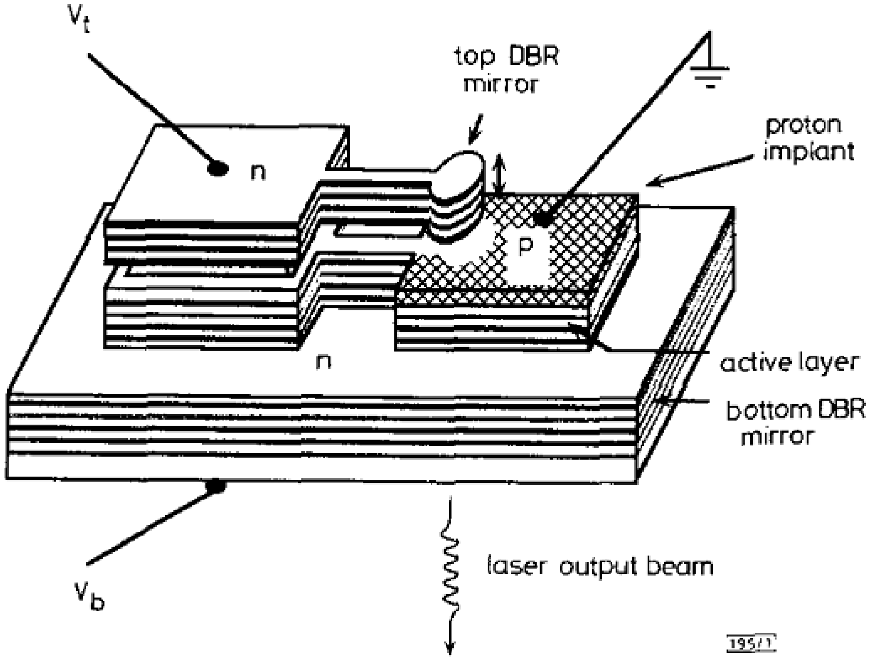


medOCT group, Center of biomedical Engineering and Physics, Medical University Vienna, Austria

Electrostatic Tuning of MEMS-VCSEL

First MEMS Tunable VCSEL

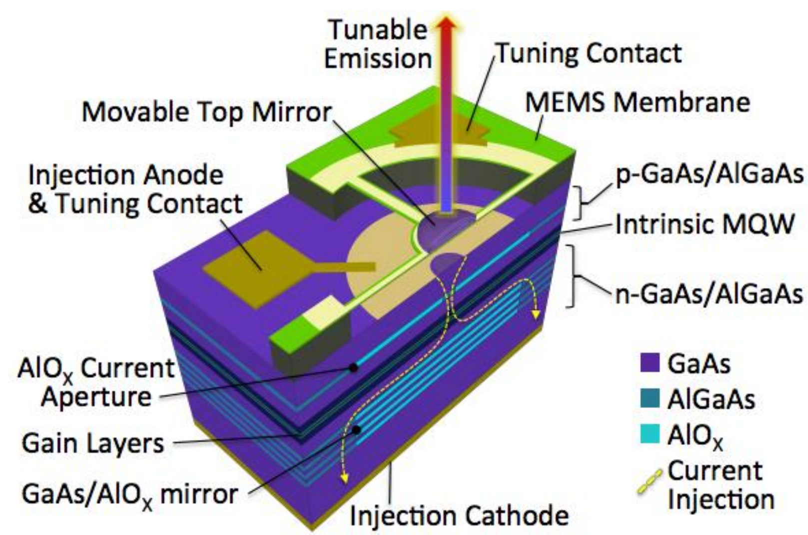
- **940-nm VCSEL; suspended cantilever GaAs/AlGaAs DBR**
- **Electrostatic tuning ~32 nm, 300 kHz**



Chang-Hasnain group, LEOS Conference, post-deadline, 1994; M.S. Wu, *Electron. Lett.* 1995.

Praevium/Thorlabs

- Electrically pumped 1060 nm VCSEL wiht 63.8 nm sweep
  - I_{th}~0.5 mA, P_{out} ~0.4 mW
  - 150 kHz sweep rate
- OCT applications



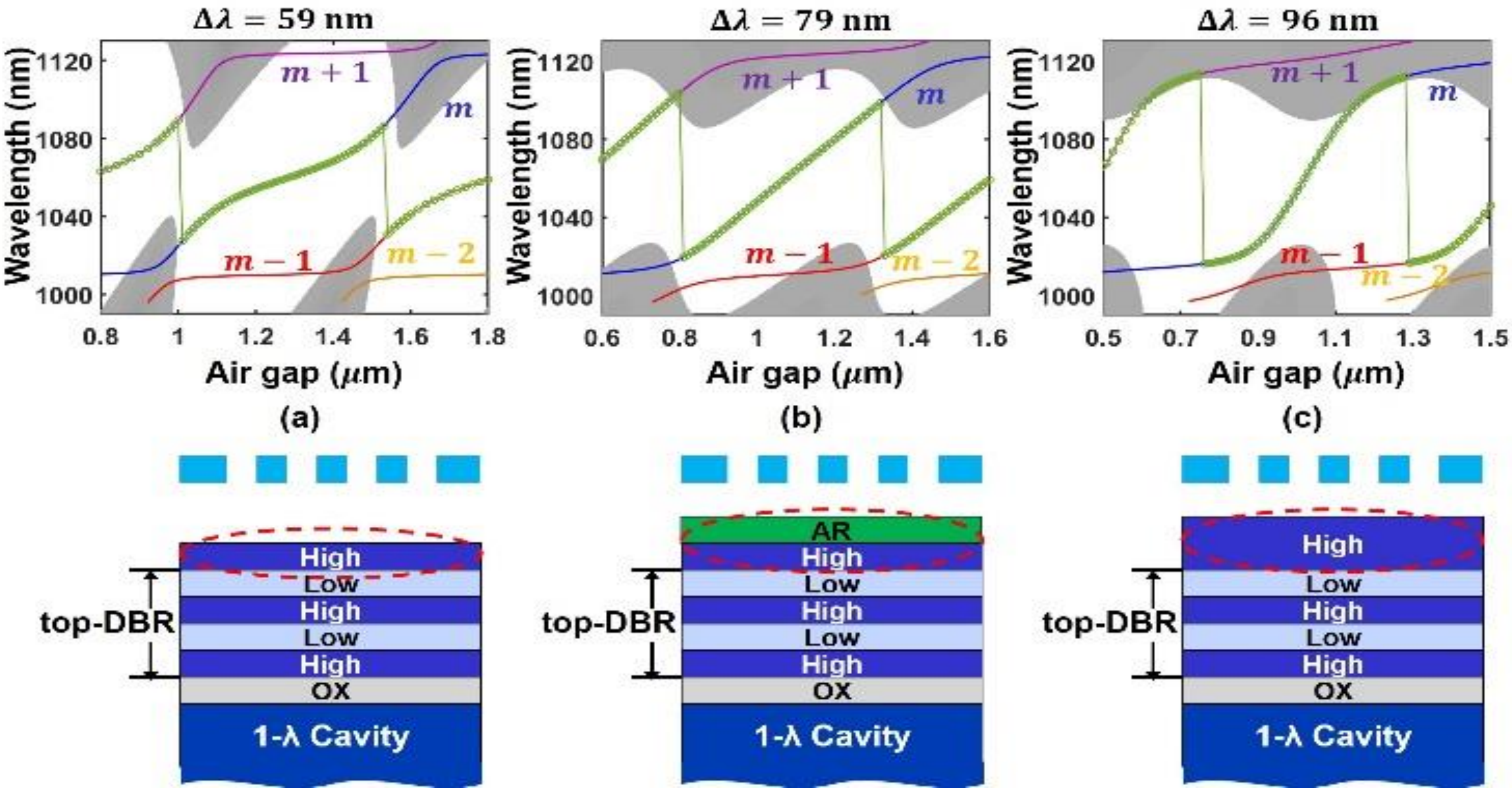
D. D. John, et. al, J. of Lightwave Technol. (2015).

New Design – Tale of Two Cavities

Semiconductor Cavity Dominant (SCD)

Extended Cavity (EC)

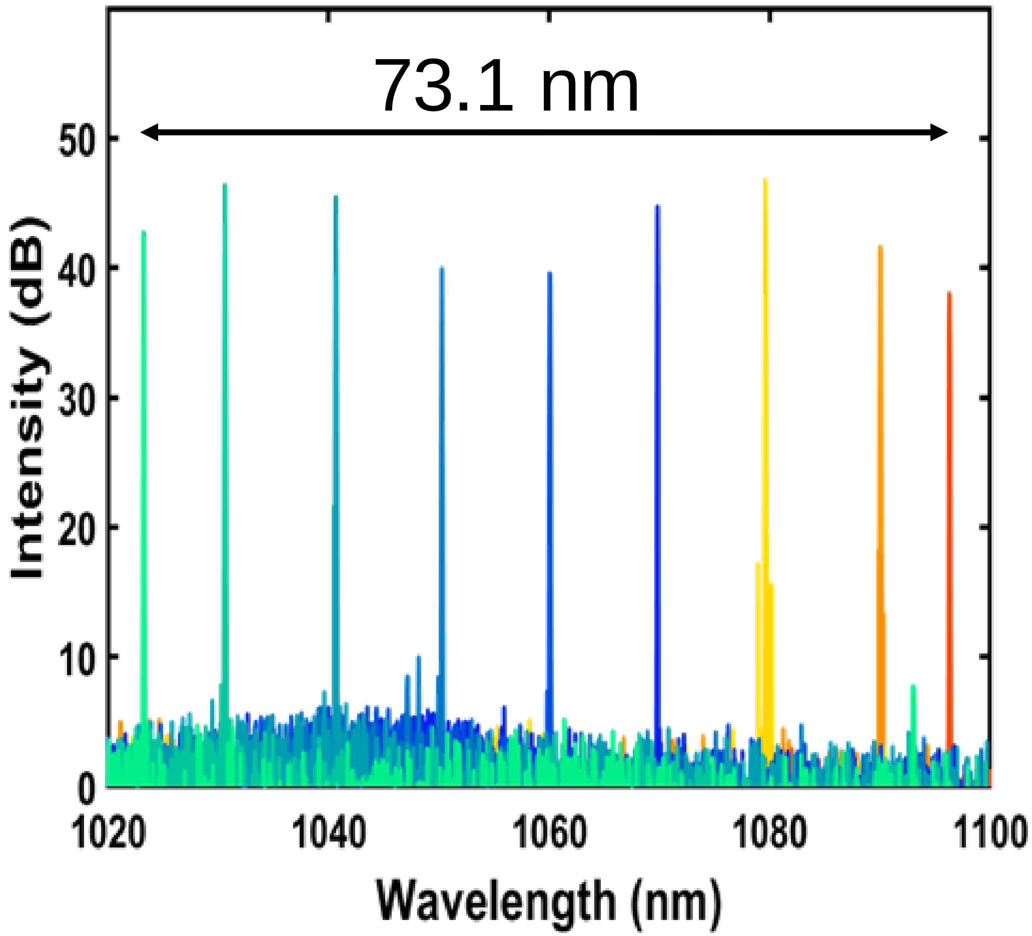
Air Cavity Dominant (ACD)

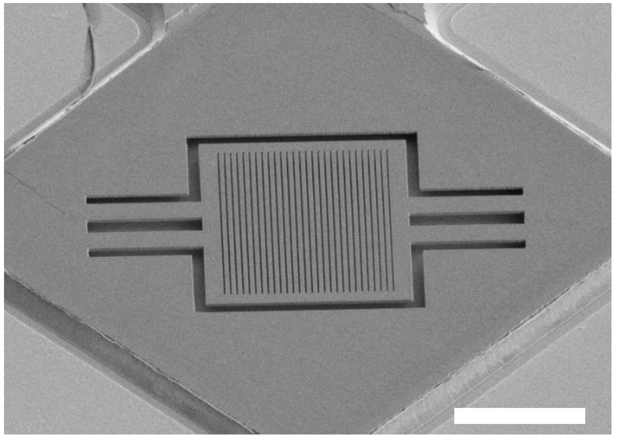


Qiao, Cook, Li, Chang-Hasnain, IEEE JSTQE. **23**, 1700516 (2017).

Record Tuning Ratio @ 1060 nm

- Static tuning range spans 1023.2 nm to 1096.3 nm
- Fractional tuning range $\Delta\lambda/\lambda$ = **6.9%**



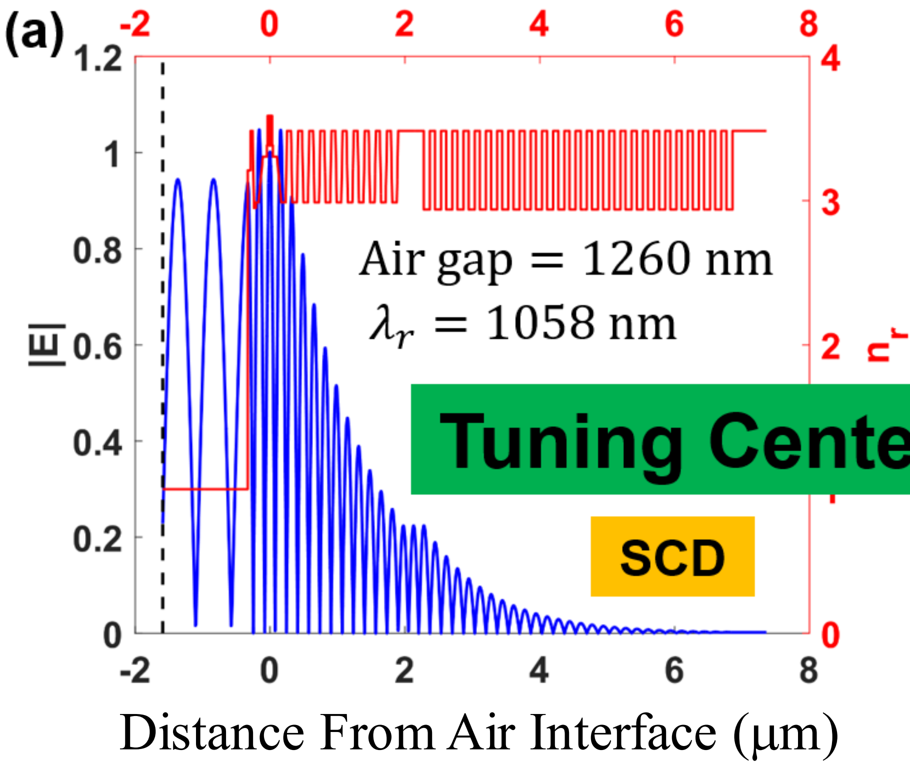


Qiao, Cook, Li, Chang-Hasnain, IEEE JSTQE. **23**, 1700516 (2017).

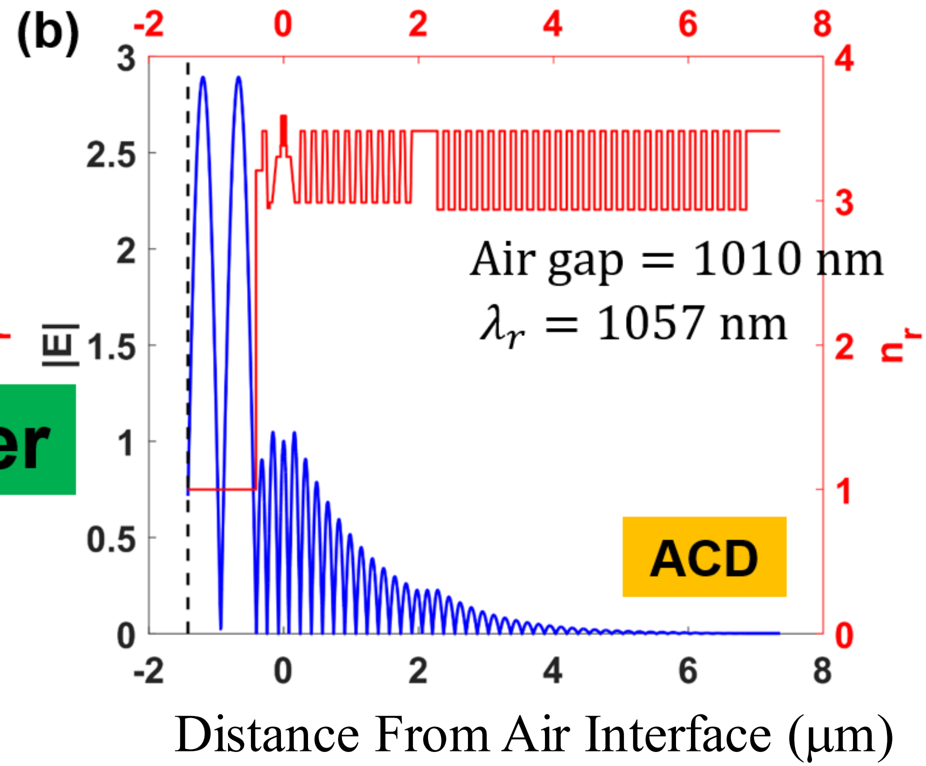
Conventional Wisdom: ***Don't Do it!***

SCD VCSEL with an Airgap

ACD VCSEL with an Airgap

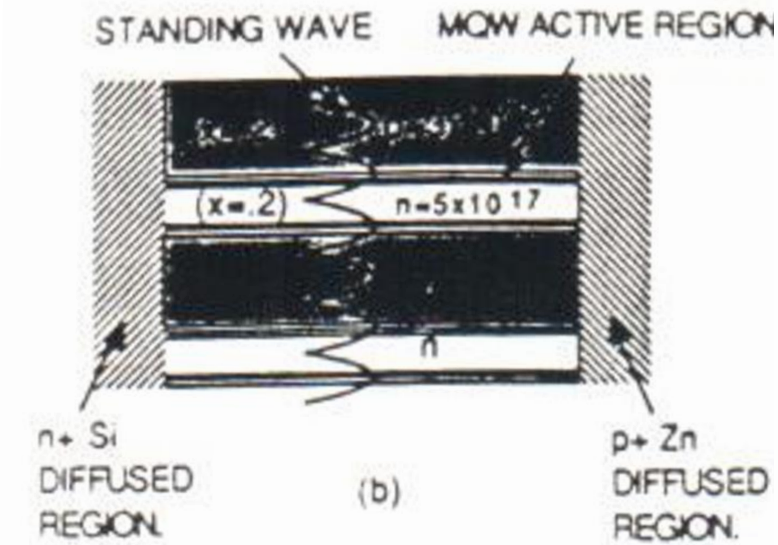


Tuning Center



Qiao, Cook, Li, Chang-Hasnain,
IEEE JSTQE. **23**, 1700516 (2017).

Resonant Cavity and Optical Confinement



Conference on Lasers and Electro-Optics, Anaheim, CA

Wednesday **AFTERNOON**

27 April 1988 **WM**

PACIFIC BALLROOM A/B

1:00 PM **Poster Session: 2**

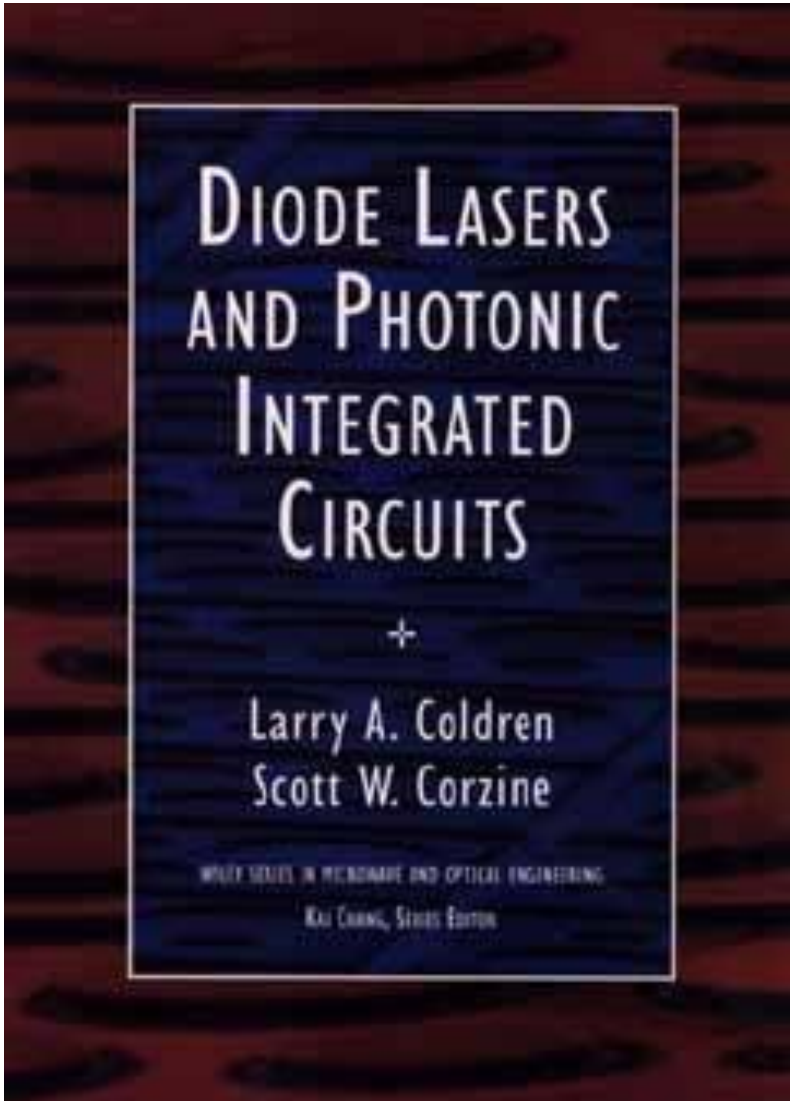
SEMICONDUCTOR DIODE LASERS

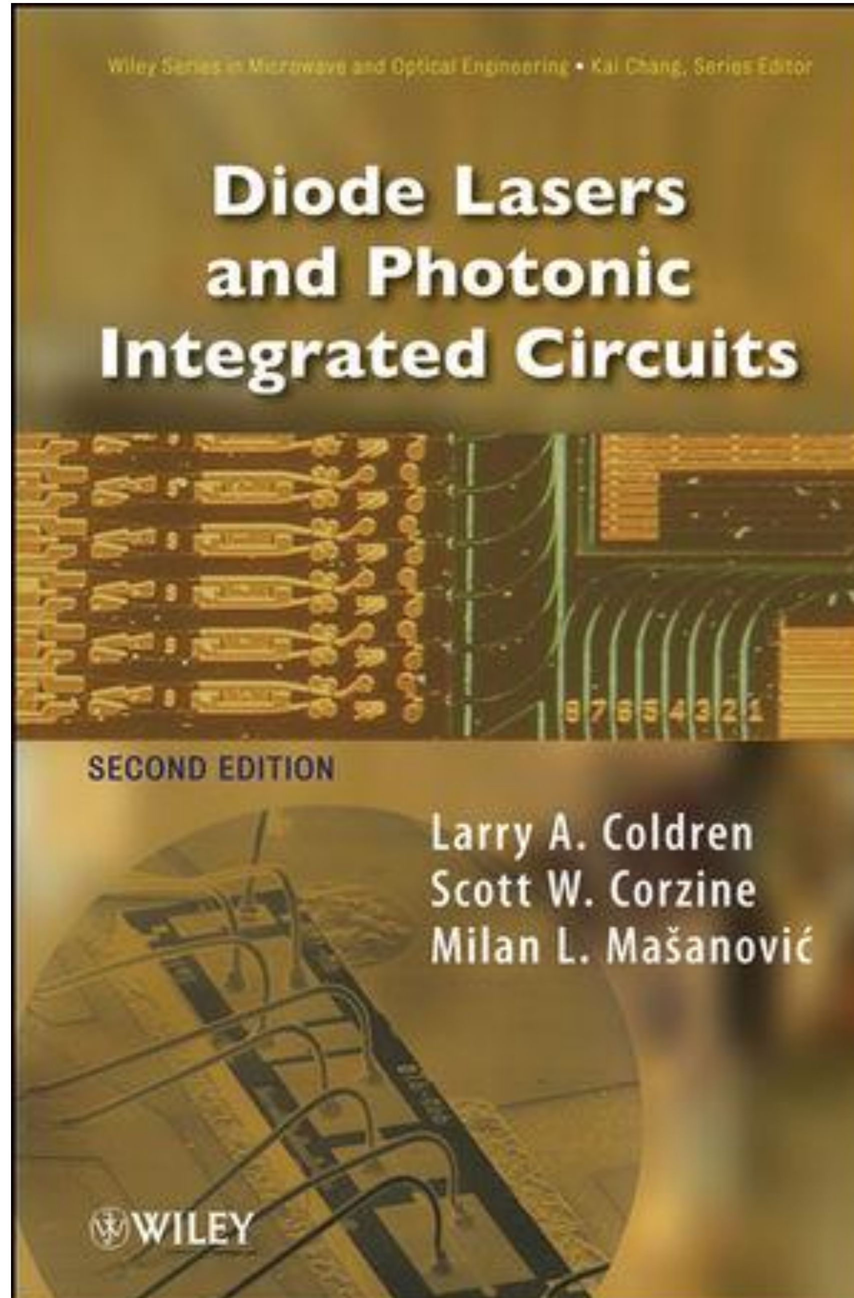
WM1 Analysis and design of a novel parallel-driven MQW-DBR surface-emitting diode laser

R. GEELS, R. H. YAN, J. W. SCOTT, S. W. CORZINE, R. J. SIMES, LARRY A. COLDREN, UC–Santa Barbara, Electrical & Computer Engineering Dept., Santa Barbara, CA 93106.

Several significant features of our design are indicated in Fig. 1(b). The MQW-undoped active regions are placed at maxima of the cavity standing-wave pattern, and the lossy highly doped regions are centered on standing-wave nulls. This, together with the fact that the entire lateral mode width crosses the MQW active regions, results in a much higher net confinement factor (~0.2) than in

The BOOK


DIODE LASERS
AND PHOTONIC
INTEGRATED
CIRCUITS
Larry A. Coldren
Scott W. Corzine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Wide, Continuously Swept VCSEL Using a Novel Air-Cavity-Dominant Design

Pengfei Qiao[1], Kevin T. Cook[1], Jipeng Qi[1], Larry A. Coldren[2] and Connie J. Chang-Hasnain[1]
1: EECS Department and Tsinghua-Berkeley Shenzhen Institute, University of California, Berkeley, CA 94720, USA
2: Department of Electrical and Computer Engineering, University of California, Santa Barbara, CA 93117, USA
Email address: cch@berkeley.edu

Abstract: We report electrically-pumped MEMS-VCSELs with a record 70 nm continuous wavelength sweep at 1057-nm with 600 kHz rate using a novel air-cavity-dominant design. Such devices are promising for swept-source OCT and 3D sensing applications.

OCIS codes: (140.7260) Vertical cavity surface emitting lasers; (050.6624) Subwavelength structures; (230.4685) Optical microelectromechanical devices; (260.2110) Electromagnetic optics; (140.3600) Lasers, tunable.

OFC 2018

Research Article

optica

Air Cavity Dominant VCSELs with a Wide Wavelength Sweep

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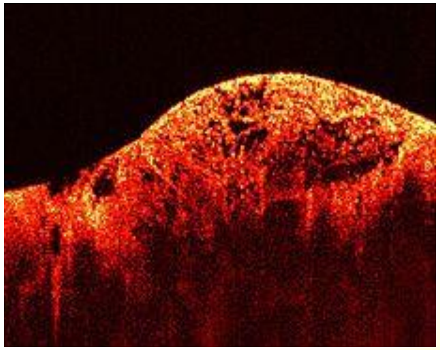
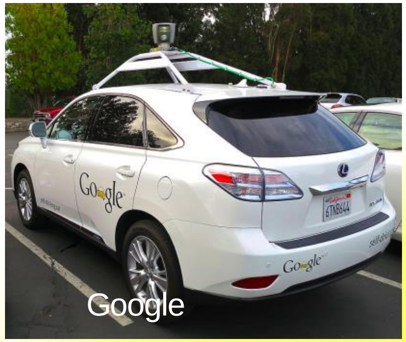
[1]*Department of Electrical Engineering and Computer Sciences and Tsinghua-Berkeley Shenzhen Institute, University of California at Berkeley, Berkeley, CA 94720, USA*
[2]*Departments of Electrical and Computer Engineering and Materials, University of California at Santa Barbara, Santa Barbara, CA 93106, USA*
**Corresponding author: cch@berkeley.edu*

VCSEL30, December 17-18, 2007, Tokyo, Japan

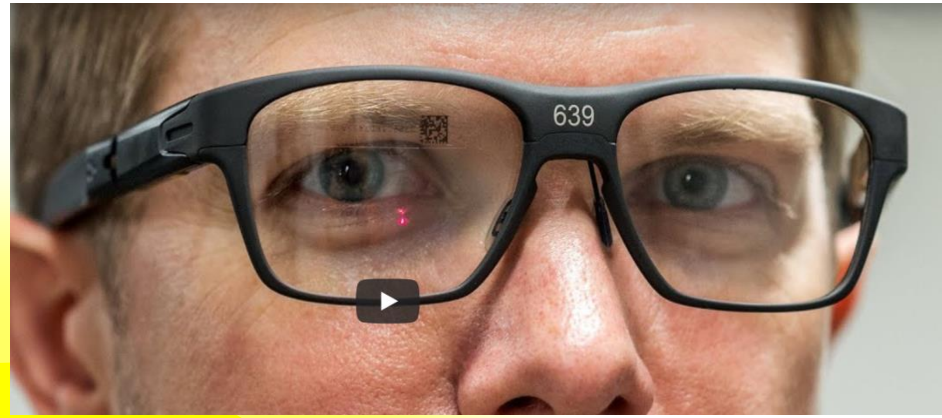
VCSEL35, December 11, 2011, Tokyo, Japan



Tomography



Ranging



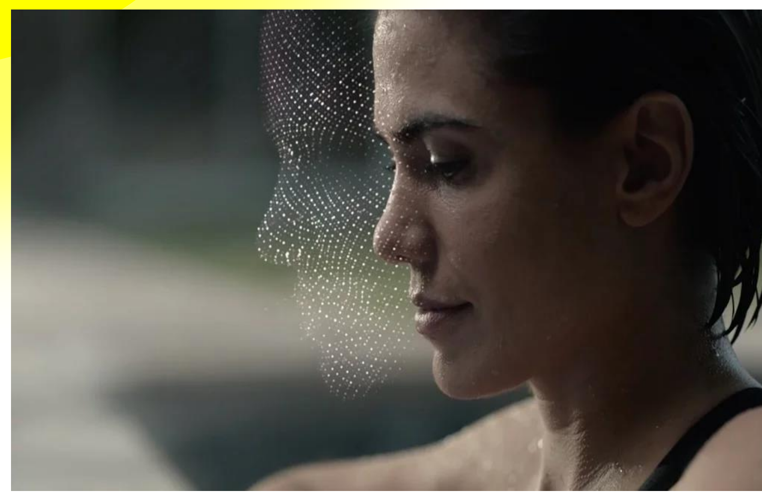
OCT & LIDAR

AR & VR

VCSEL40

3D Sensing

Communications



Congratulations!