EE 232: Lightwave Devices
Lecture #1 – Introduction

Instructor: Seth A. Fortuna

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UNIVERSITY OF CALIFORNIA

Course information

- **Instructors:**
  - Dr. Seth A. Fortuna (fortuna@eecs)
    - **Office hours:** 390 Cory Hall Time TBD
  - GSI: Kevin Cook (kevin.cook@eecs)
- **Course website:** https://inst.eecs.berkeley.edu/~ee232/sp19/
- **Lectures:** TuTh 12:30PM – 2:00PM Cory 293
- **Discussion:** W 11:00AM – 12:00PM 3105 Etcheverry
- **Pre-requisites:**
  - **EE130** (required): semiconductor physics, pn junction, origin on energy bands, Fermi level.
  - **PHYS 137A** (recommended): introductory quantum mechanics.
  - **EE117** (recommended): Maxwell's equations, waveguides.

Course information (cont'd)

- **Textbook**:
  - S.L. Chuang, *Physics of Photonic Devices*, 2nd Edition, Wiley, 2009.
- **Other useful resources:**
  - P. Blood, *Quantum Confined Laser Devices*, Oxford University Press, 2015.
  - Coldren et al., *Diode Lasers and Photonic Integrated Circuits*, 2nd Edition, Wiley, 2012.
  - D.A.B. Miller, *Quantum Mechanics for Scientists and Engineers*, Cambridge University Press, 2008.
  - J.I. Pankove, *Optical Processes in Semiconductors*, Dover, 2010 (reprint).
  - S. Alexander, Optical Communication Receiver Design, SPIE, 1997.

Course overview

- **Grade breakdown**
  - Midterm (20%)
  - Final Exam (25%)
  - Final Project (25%)
  - Homework (20%)
  - Participation (10%)
- **Exams**:
  - All exams will be given during lecture period.
  - Final on last day of class.
- **Homework**:
  - Assigned in-class. Must be turned in at the beginning of lecture on the due date.

Discussion section

- Semester-long tutorial on photonic simulation using Lumerical software (https://www.lumerical.com/).
  - Each student will be given license to install software on personal computer. License dictates that software should only be used for this course. **Bring your laptop to discussion.**

- **Learning goals:**
  - Become familiar with simulation best-practices.
  - Visualize concepts learned in lecture.
  - Learn new material that we do not have to cover in lecture (in particular, passive components)
  - Software is required for final project.

Course schedule

- See syllabus for details

Final project

- 3-4 page paper in the format of a journal article on a topic of your choosing.
- The Final Project is intended as a comprehensive exercise of what you learned in this course. You will analyze an optoelectronic device of your choice, using the techniques and tools covered in this course. You will not need to invent a new device.
- You can analyze structures published in the literature and extend, elaborate upon, or improve upon the published result.

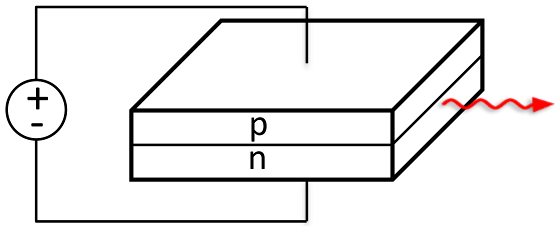
Demonstration of LASER

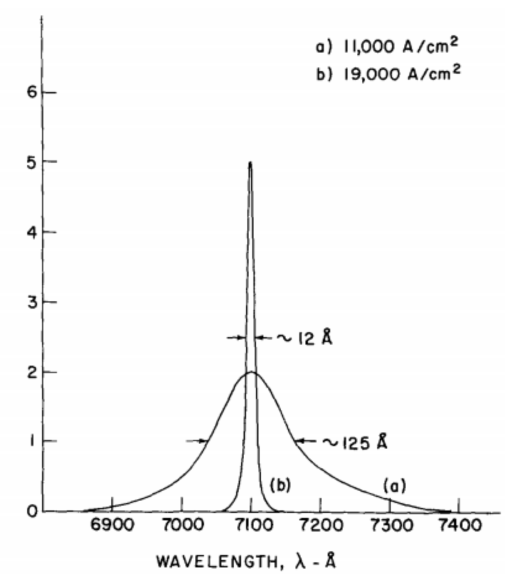
Theodore Maiman's Ruby Laser (1960)

T.H. Maiman, The Laser Inventor, Springer Biographies.

Demonstration of semiconductor LASER

- Four nearly simultaneous reports of semiconductor pn junction LASERs in Fall 1962.





[1] R. N. Hall, G. E. Fenner, J. D. Kingsley, T. J. Soltys, and R. O. Carlson, ''Coherent light emission from GaAs junctions,'' *Phys. Rev. Lett.*, vol. 9, pp. 366–368, Nov. 1, 1962. (Received Sept. 24, 1962.)

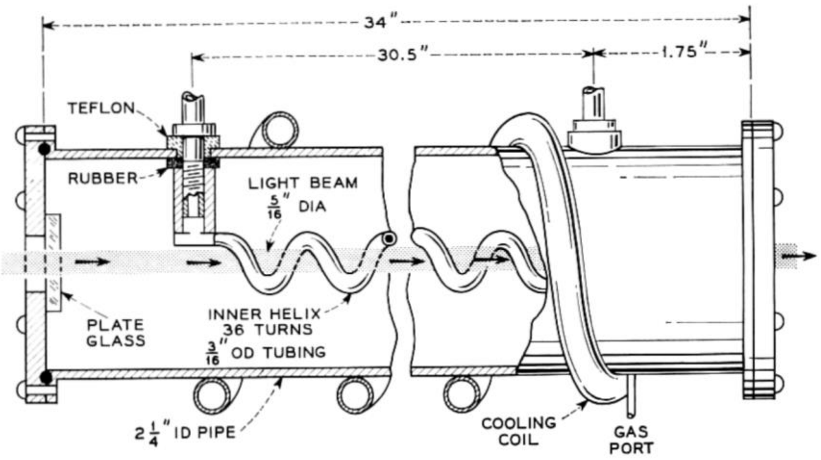
[2] M. I. Nathan, W. P. Dumke, G. Burns, F. H. Dill, Jr., and G. Lasher, ''Stimulated emission of radiation from GaAs p–n junctions,'' *Appl. Phys. Lett.*, vol. 1, pp. 62–64, Nov. 1, 1962. (Received Oct. 6, 1962.)

[3] N. Holonyak, Jr. and S. F. Bevacqua, ''Coherent (visible) light emission from Ga($As_{1-x}P_x$) junctions,'' *Appl. Phys. Lett.*, vol. 1, pp. 82–83, Dec. 15, 1962. (Received Oct. 17, 1962.)

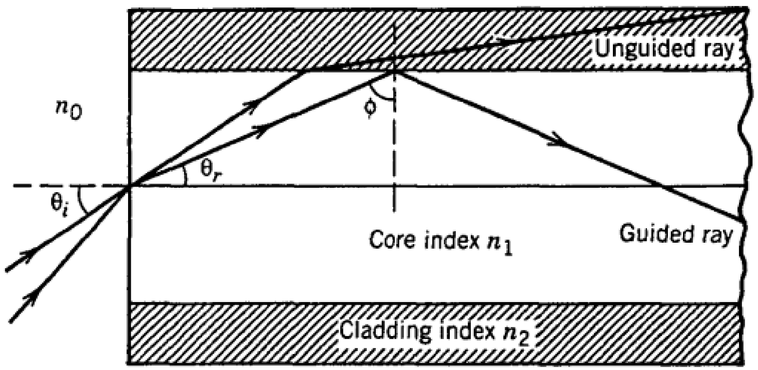
[4] T. M. Quist, R. H. Rediker, R. J. Keyes, W. E. Krag, B. Lax, A. L. McWhorter, and H. J. Zeiger, ''Semiconductor maser of GaAs,'' *Appl. Phys. Lett.*, vol. 1, pp. 91–92, Dec. 1, 1962. (Received Oct. 23, 1962, in final form Nov. 5, 1962.)

Guiding of light

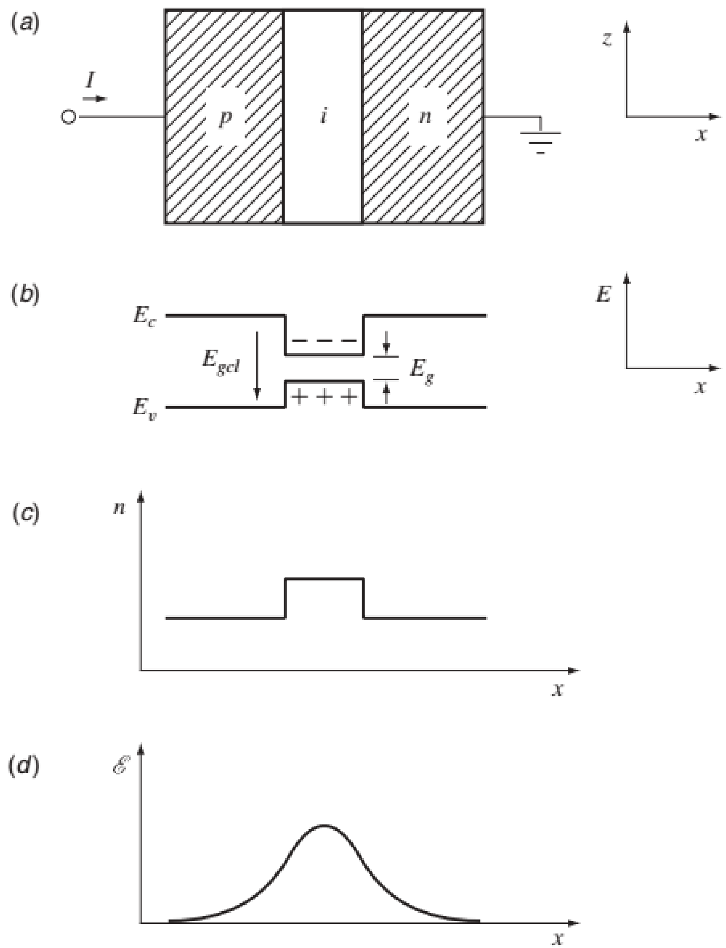
- **Gas lens system**
  - Berreman, "A Lens or Light Guide Using Convectively Distorted Thermal Gradients in Gases". Bell System Technical Journal (1964).



- **Fiber optic cable**
  - Kao et al. "Dielectric-fibre surface waveguides for optical frequencies" (1966)
  - Losses reduced below 20 dB/km (Corning, 1970)
  - Charles Kao Nobel Prize 2009



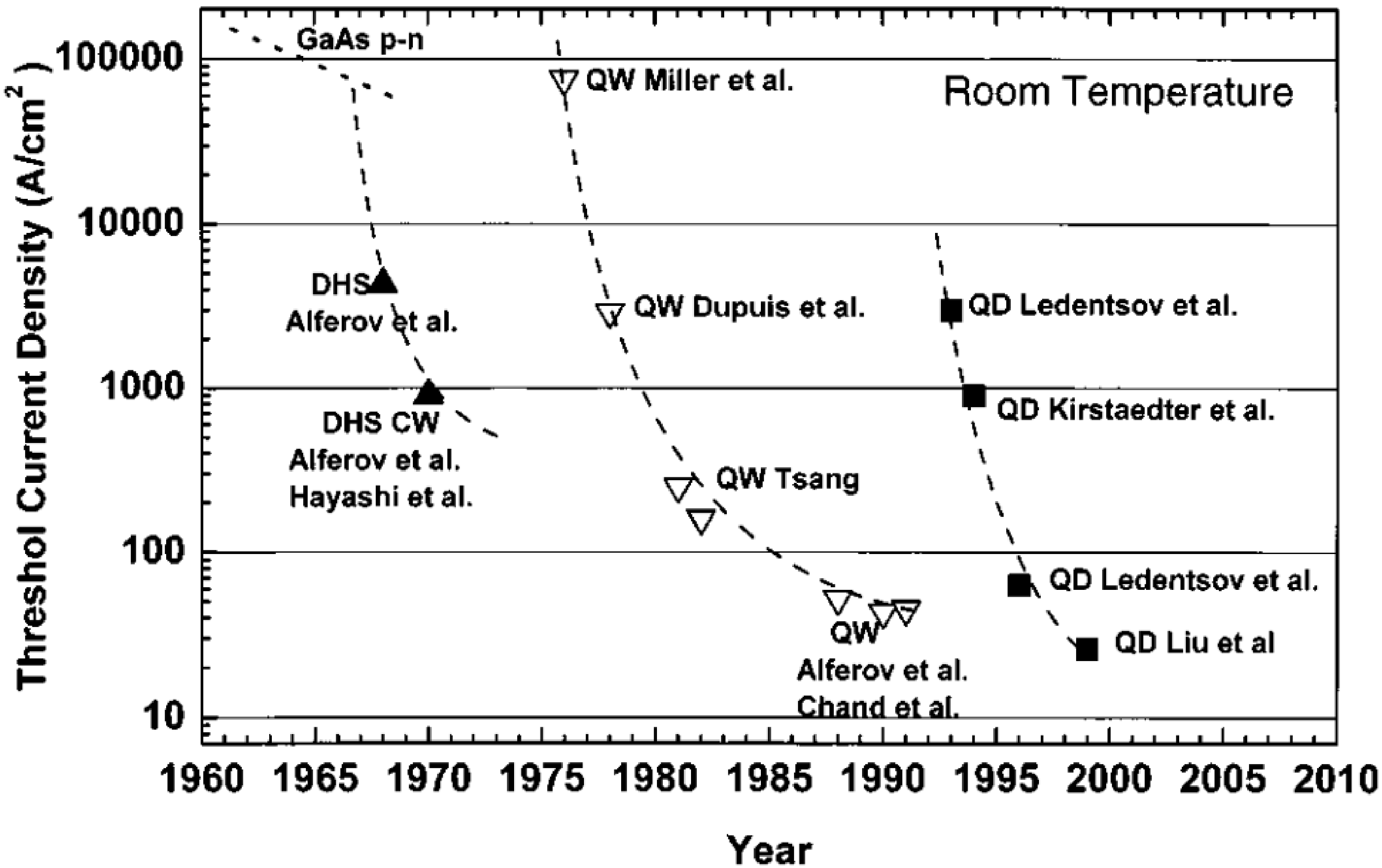
Efficient semiconductor lasers



- **Heterojunction lasers**
  - Improved carrier and light confinement
  - Hayashi et al., “Junction Lasers Which Operate Continuously at Room Temperature” 1970
  - Nobel Prize in 2000 for Herbert Kroemer and Zhores Alferov for semiconductor heterostructures

Coldren et al. Diode Lasers and Photonic Integrated Circuits.

Quantum-confined lasers



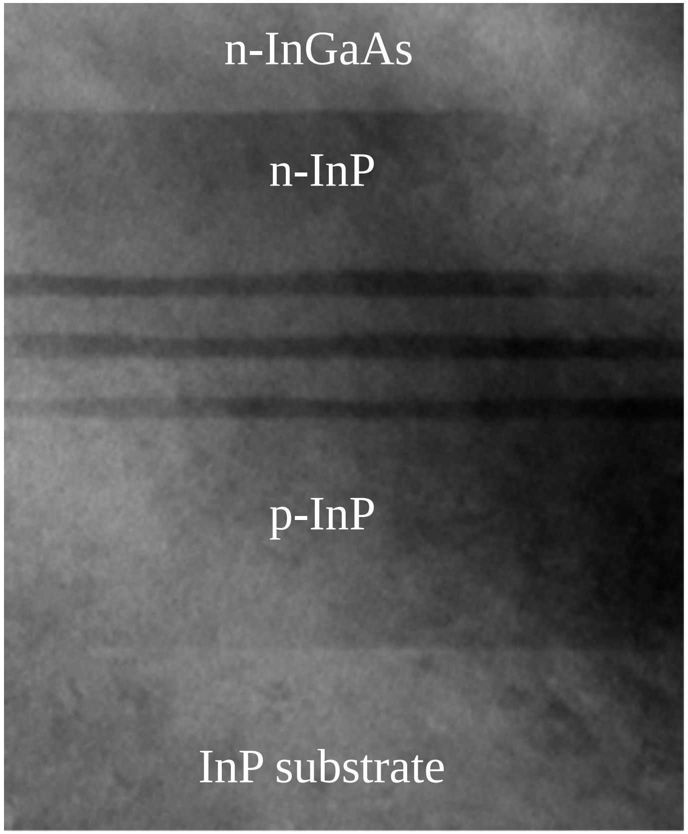
N. N. Ledentsov *et al.*, "Quantum-dot heterostructure lasers," in *IEEE Journal of Selected Topics in Quantum Electronics*, vol. 6, no. 3, pp. 439-451, May-June 2000.

Growth of compound semiconductors

Modern commercial MOCVD reactor

MOCVD: Metal-organic chemical vapor deposition

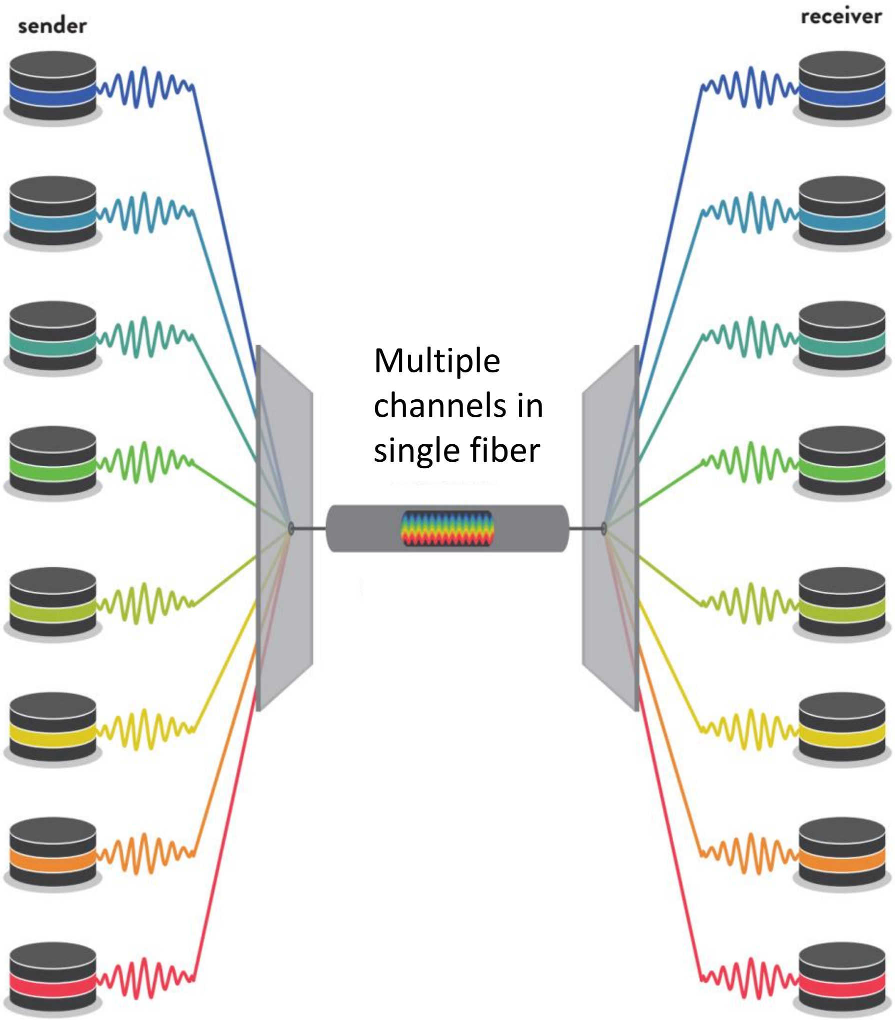
Multiple quantum well III-V LED Cross-section



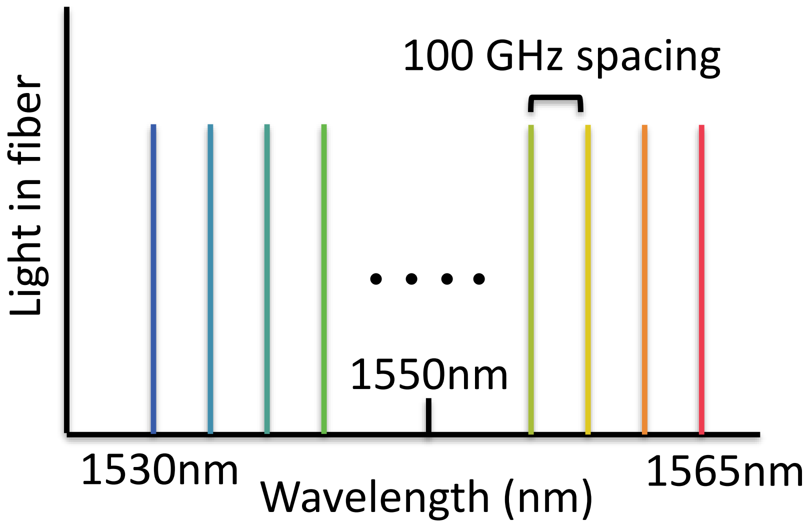
InGaAs/ InP quantum wells

Christopher Heidelberger (MIT)

Light-based telecommunication



Wavelength division multiplexing (WDM)

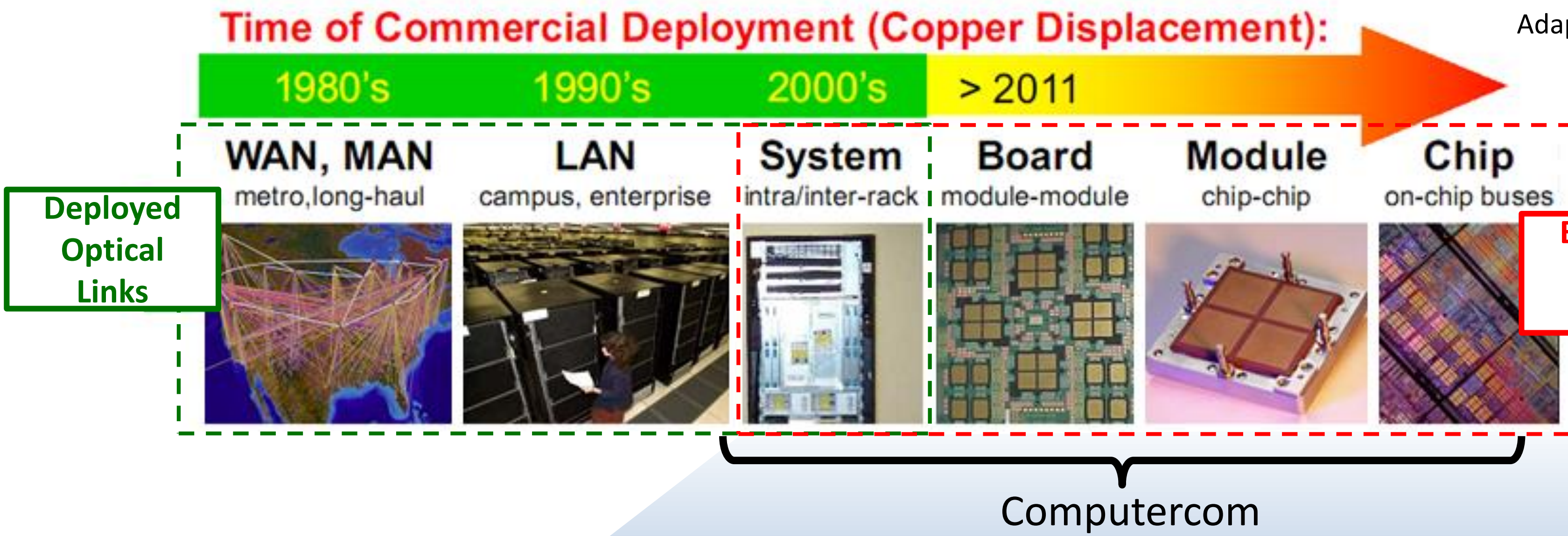


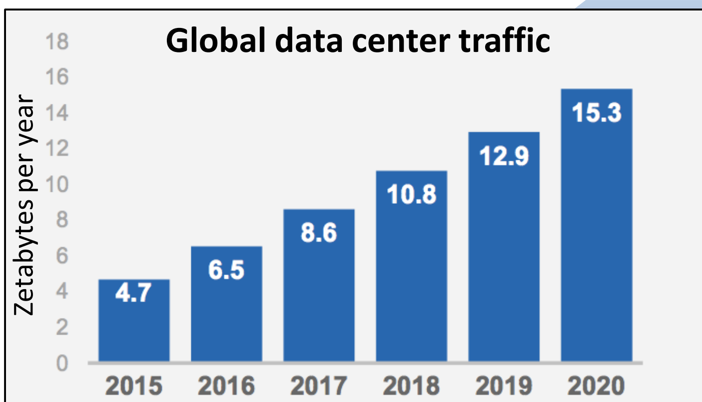
Common laser line spacing
for Dense-WDM in the "C-band"
centered near 1550nm wavelength

Photonics: Technical Applications of Light. SPIE.

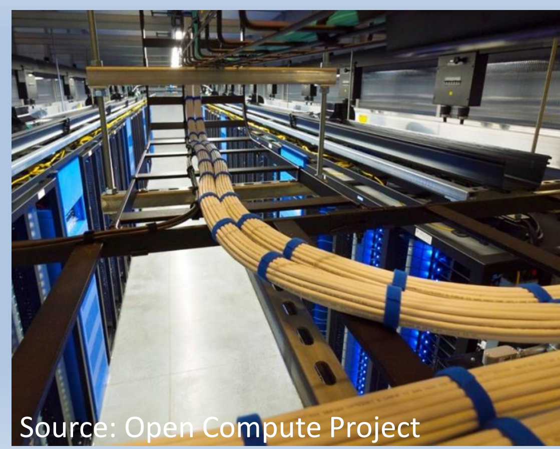
Emergence of large-scale data centers

Adapted from IBM





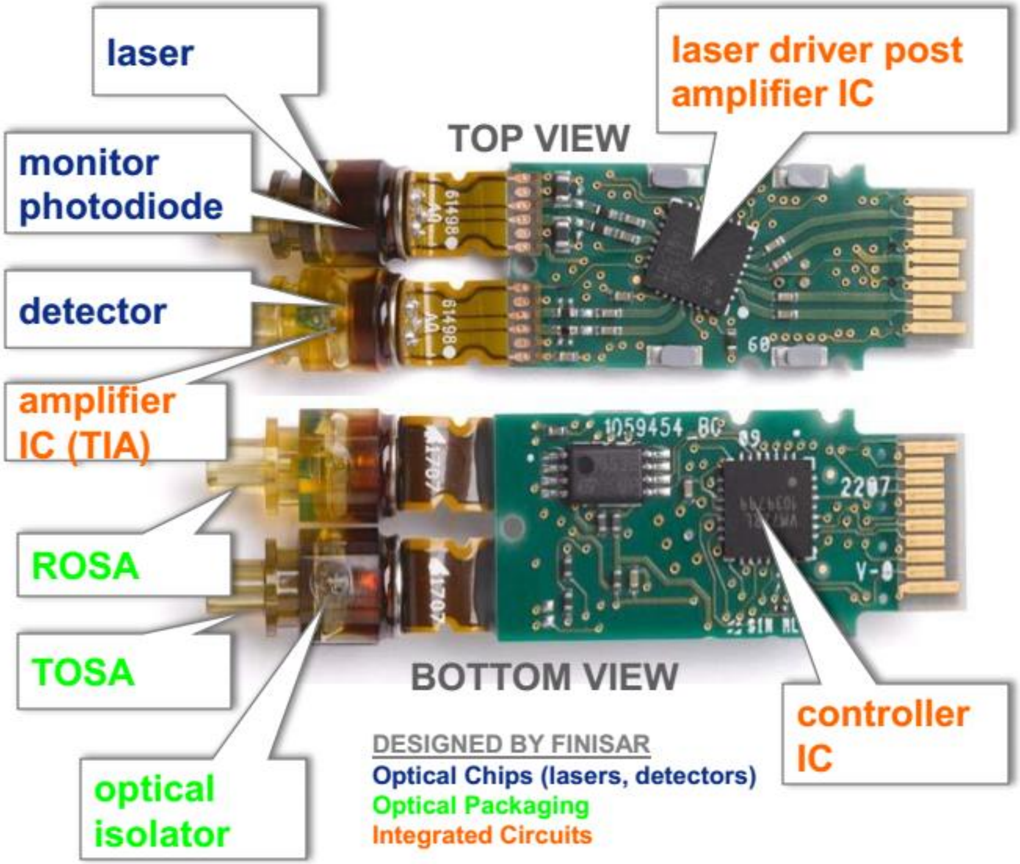
Source: Cisco



Source: Open Compute Project

Source: Facebook

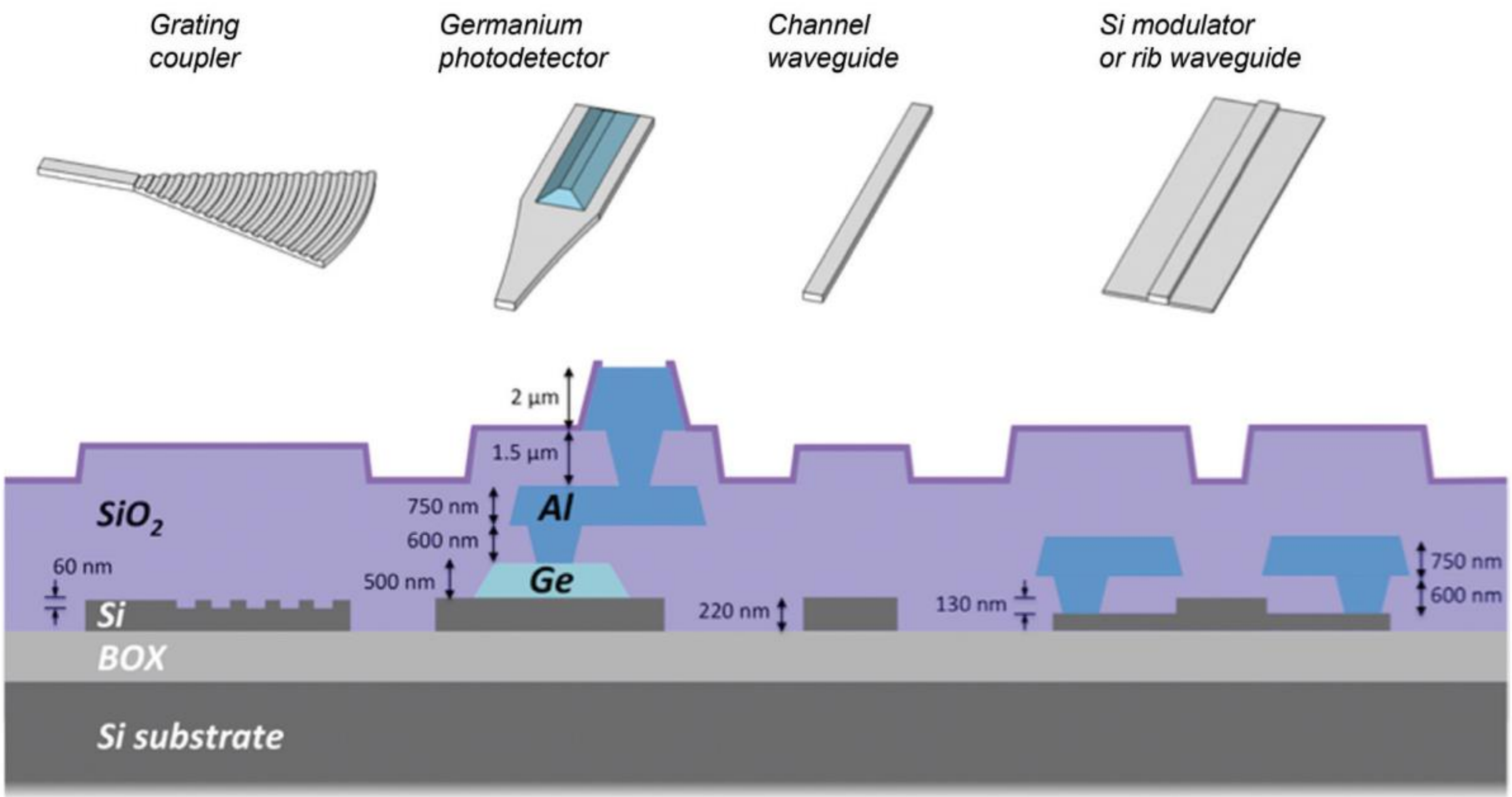
Short-reach optical transceiver



Source: Finisar

Silicon photonics

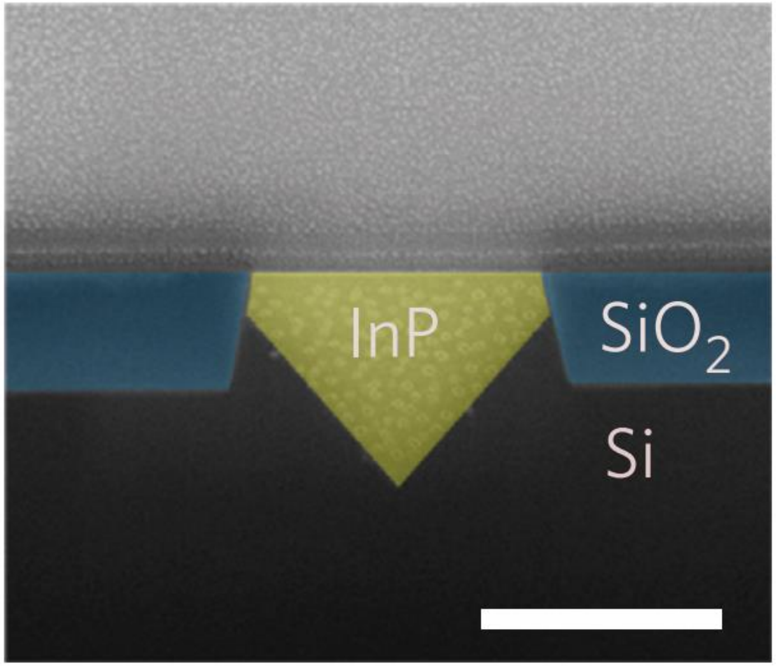
- Economy of scale with silicon-based manufacturing



Novack et al. Nanophotonics 2014; 3(4-5): 205–214

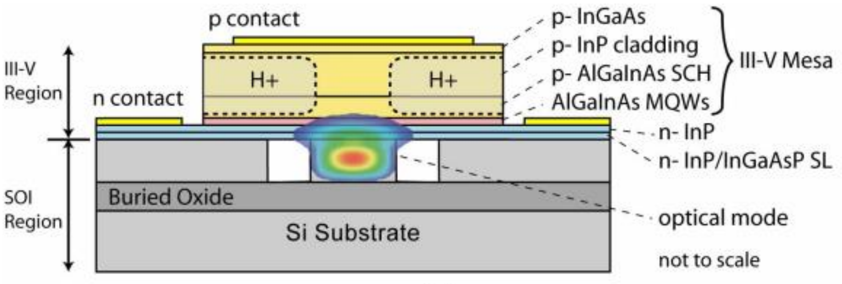
III-V / Silicon integration

Direct growth of III-V on silicon



Wang et al. *Nature Photonics,* volume 9, pages 837–842 (2015)

Heterogenous (hybrid) approach



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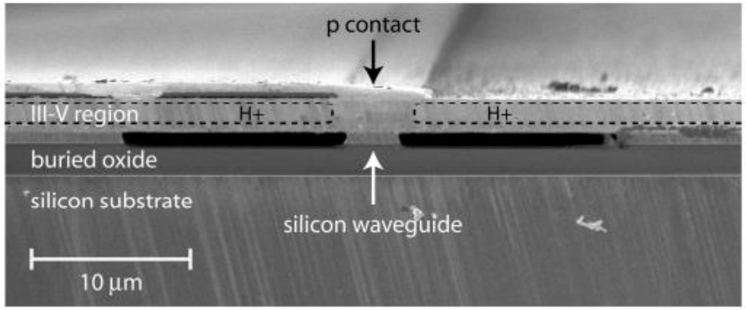
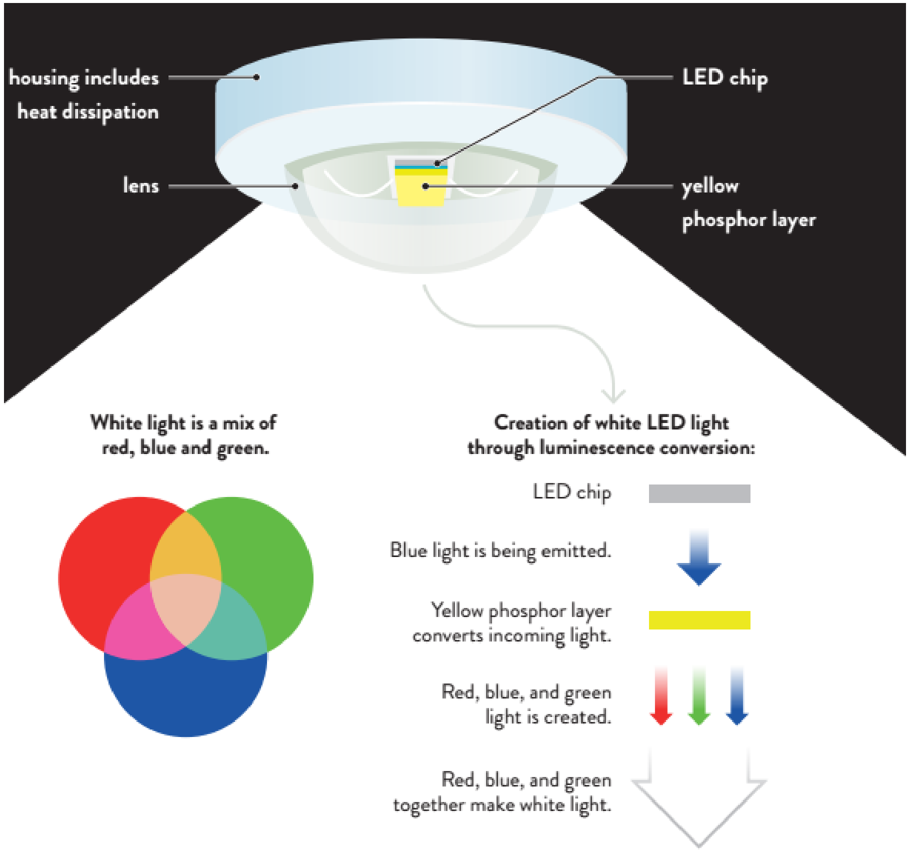
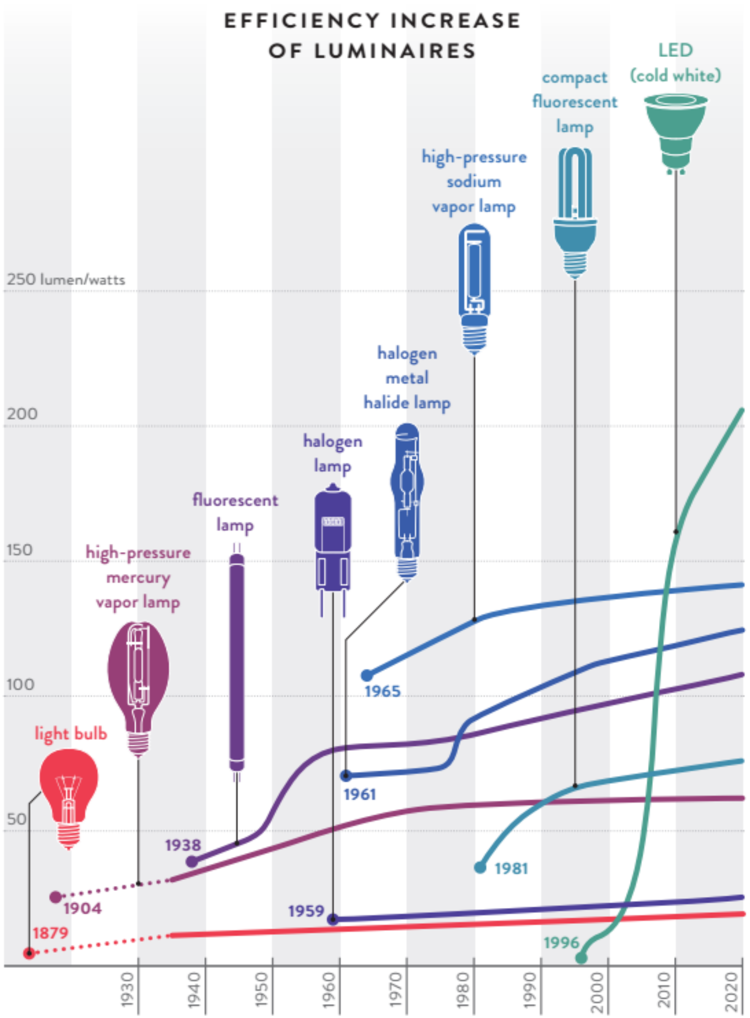


Fang et al., "Electrically pumped hybrid AlGaInAs-silicon evanescent laser," Opt. Express **14**, 9203-9210 (2006)

Solid-state lighting



Photonics: Technical Applications of Light. SPIE.



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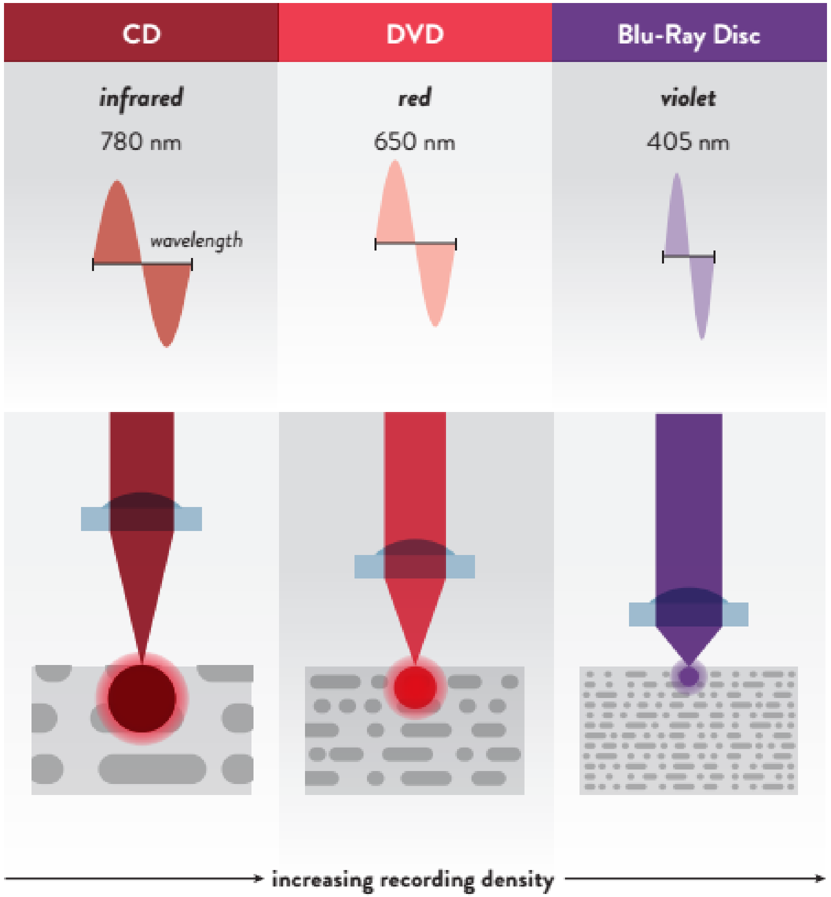
Data storage

Optical data storage



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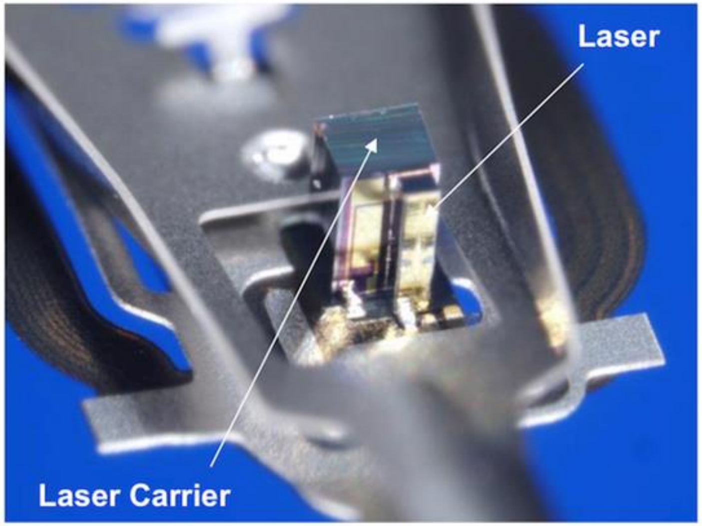
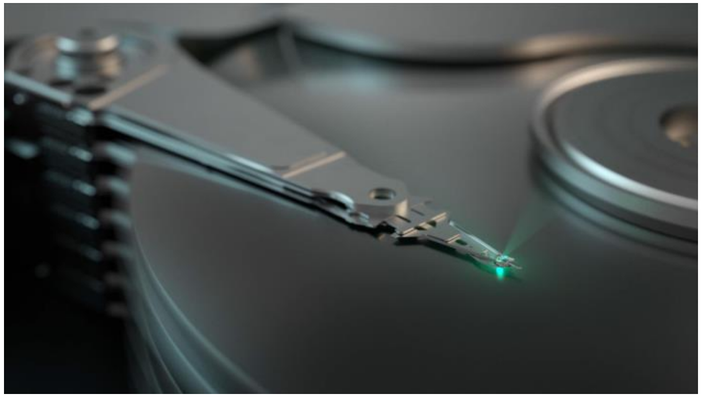
Magnetic data storage

Heat-assisted magnetic recording (HAMR)

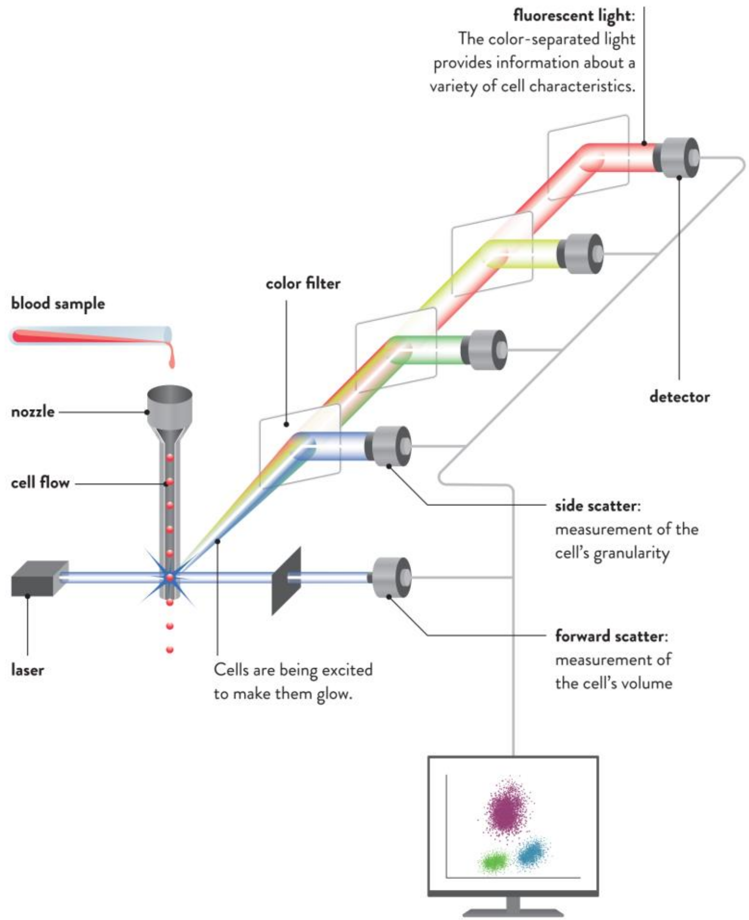




Source: Seagate

Bio-medical

Cell counting and sorting



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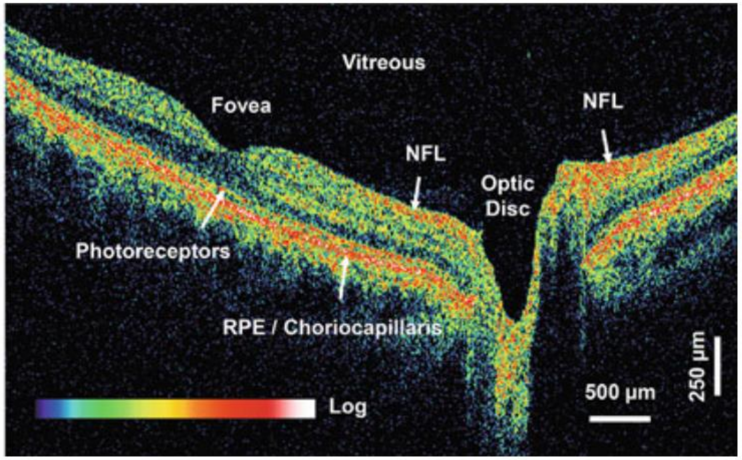
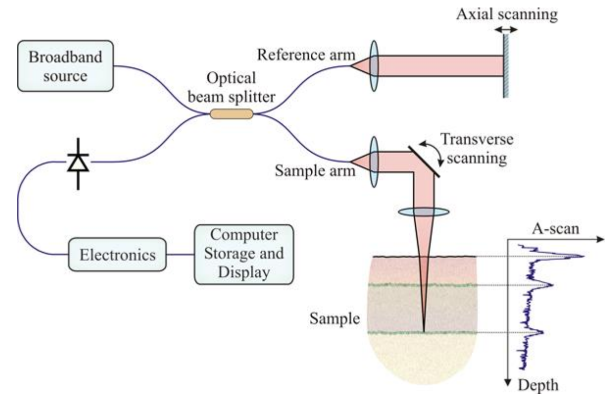
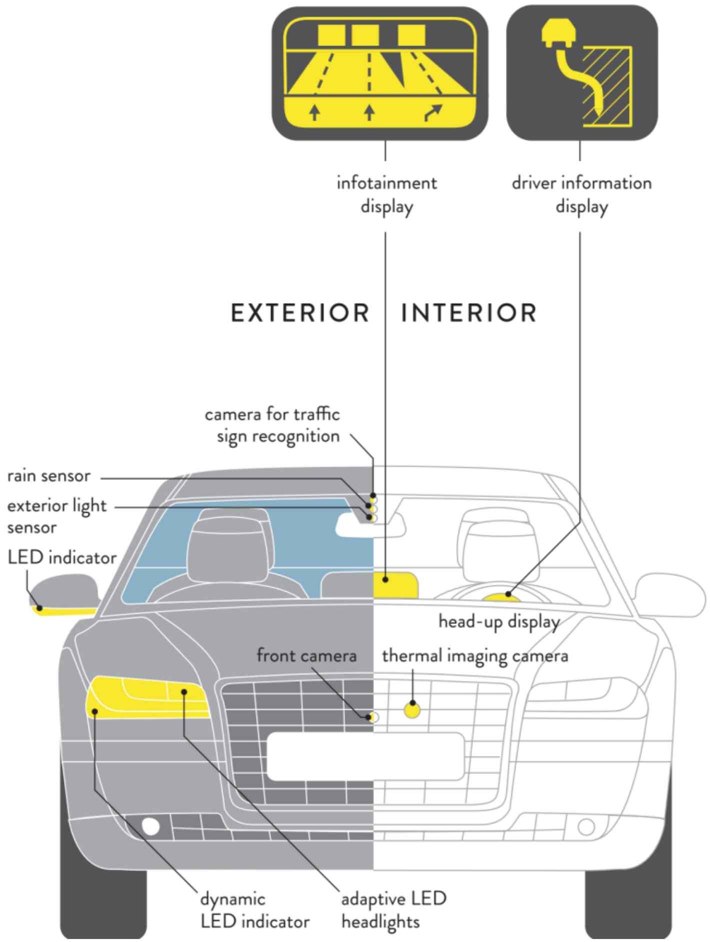
Optical coherence tomography (OCT)





Sources: (Top) Optical Coherence Tomography. Springer Reference. 2015.
(Bottom) http://obel.ee.uwa.edu.au/research/fundamentals/introduction-oct/

Automotive



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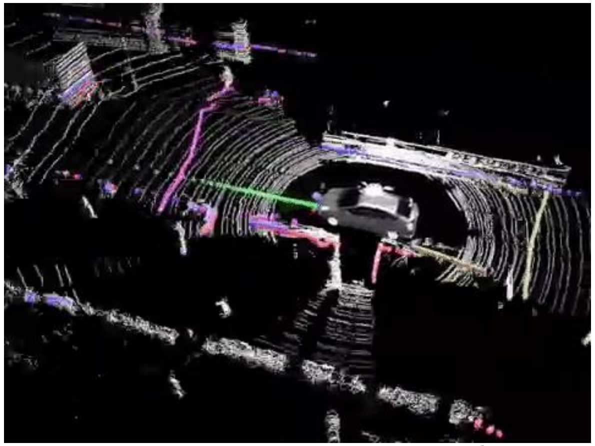
Self-driving vehicles

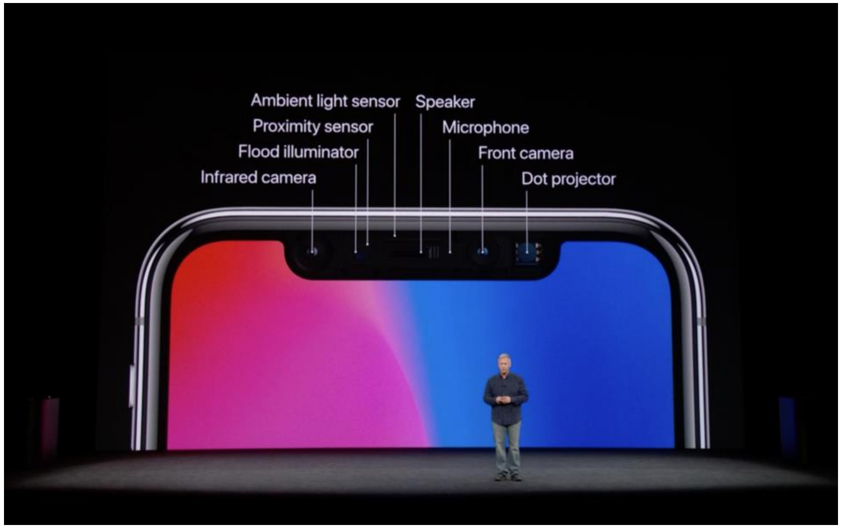


youtube.com

3D Imaging (LIDAR)

theverge.com

Consumer electronics



source: theverge.com

BUSINESS NEWS

Finisar buys wafer fab to ramp VCSEL arrays for 3D sensing

08 Dec 2017

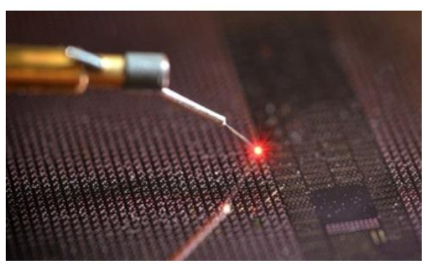
700,000 square-foot facility in Sherman, Texas, will host 6-inch VCSEL wafer production, with CEO Jerry Rawls expecting 'gigantic' future demand.

Optoelectronics company **Finisar** is to expand its VCSEL production capacity dramatically next year, with more than $100 million of investment earmarked for a 6-inch wafer production fab in Sherman, Texas.

The facility, a short drive from the company's existing VCSEL wafer fab in the Dallas suburb of Allen, has been acquired to address what Finisar's CEO Jerry Rawls anticipates will be "gigantic" demand for VCSEL arrays in 3D sensing applications.

At the moment Apple's new iPhone X is the driving that demand, with speculation that Finisar and Lumentum are among the suppliers of one of the key components behind Apple's "Face ID" security technology.

Announcing Finisar's latest quarterly results Rawls said: "During the second [fiscal] quarter, we began shipping production



VCSELs: in demand

Optical parts maker II-VI eyes 5G, driverless cars with Finisar buy

Akanksha Rana, Uday Sampath Kumar

3 MIN READ

(Reuters) - Laser and optical parts maker II-VI Inc (IIVI.O) said on Friday it would buy Apple Inc supplier Finisar Corp (FNSR.O) for about $3.2 billion, to grab a bigger slice of 5G investments and sell more sensors for iPhones and driverless cars.

II-VI will pay Finisar shareholders $26 per share, in cash and stock, a premium of 37.7 percent to Finisar's closing share price on Thursday.