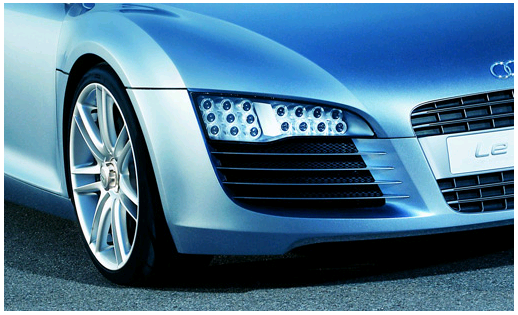
EE 232 Lightwave Devices
Lecture 1: Introduction

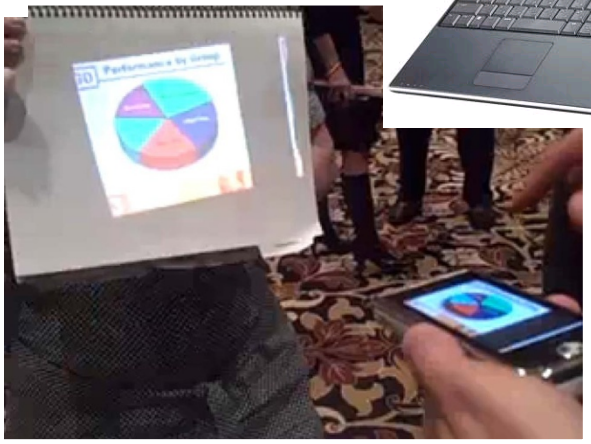
Instructor: Ming C. Wu

University of California, Berkeley
Electrical Engineering and Computer Sciences Dept.

Acknowledgment: some lecture materials are provided by Seth Fortuna

Common Optoelectronic Components





The Nobel Prize in Physics 1964

Charles H. Townes, **Nicolay G. Basov,** **Aleksandr M. Prokhorov**

The Nobel Prize in Physics 1964 was awarded *"for fundamental work in the field of quantum electronics, which has led to the construction of oscillators and amplifiers based on the maser-laser principle"*.

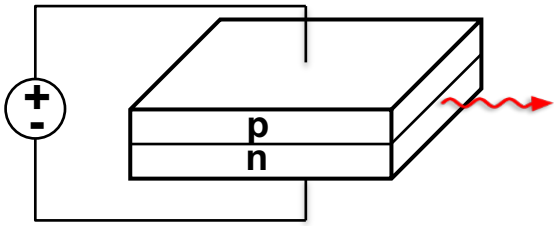
Demonstration of LASER

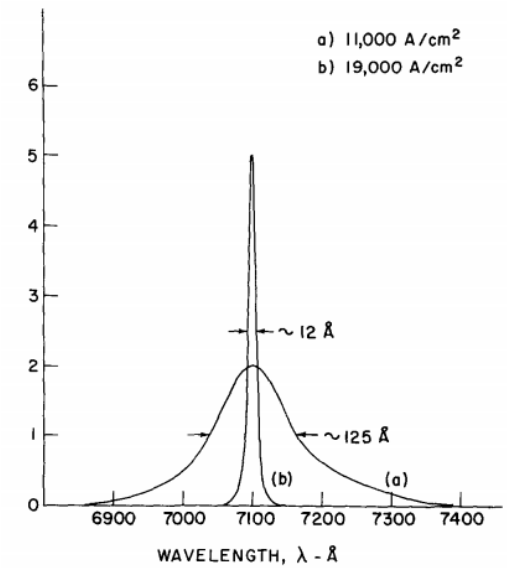
Theodore Maiman's Ruby Laser (1960)

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.)

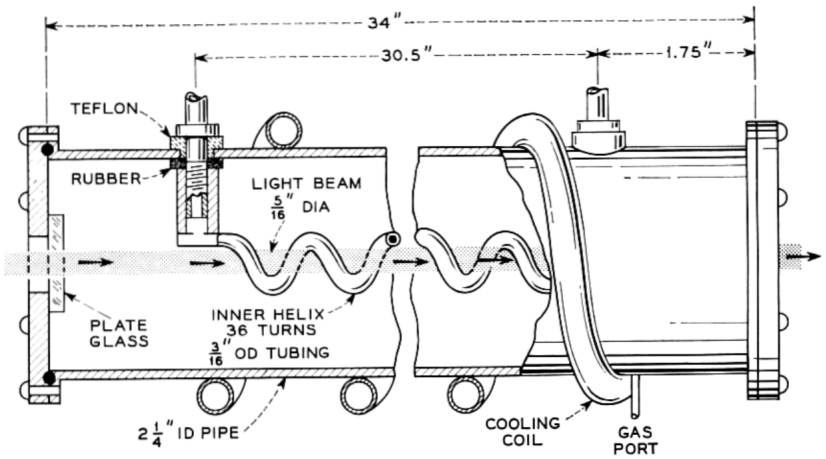
[2] M. I. Nathan, W. P. Dumke, G. Burns, F. H. Dill, Jr., and G. Lasher, "Stimulated emission of radiation from GaAs p–n junctions," *Appl. Phys. Lett.*, vol. 1, pp. 62–64, Nov. 1, 1962. (Received Oct. 6, 1962.)

[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.)

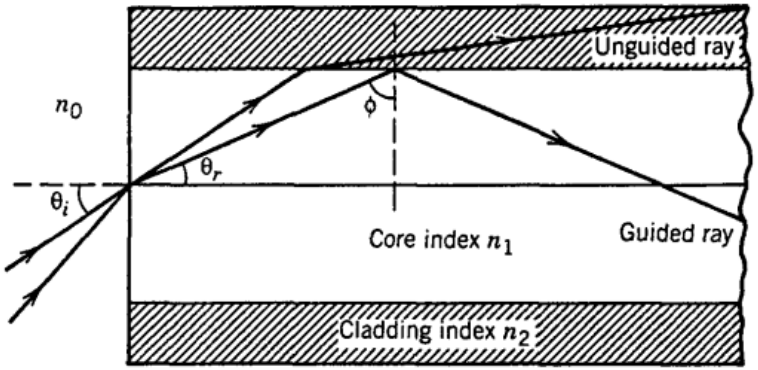
[4] T. M. Quist, R. H. Rediker, R. J. Keyes, W. E. Krag, B. Lax, A. L. McWhorter, and H. J. Zeiger, "Semiconductor maser of GaAs," *Appl. Phys. Lett.*, vol. 1, pp. 91–92, Dec. 1, 1962. (Received Oct. 23, 1962, in final form Nov. 5, 1962.)

Guiding of light

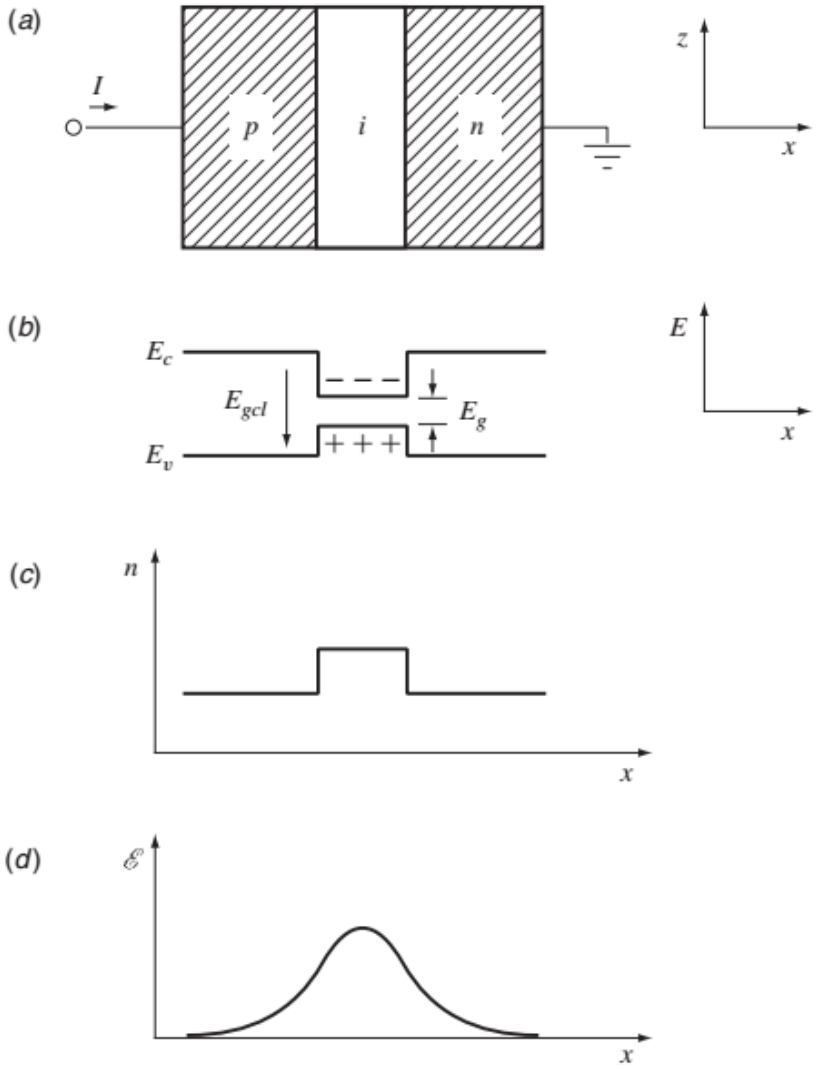
- **Gas lens system**
  - Berreman, “A Lens or Light Guide Using Convectively Distorted Thermal Gradients in Gases”. Bell System Technical Journal (1964).



- **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



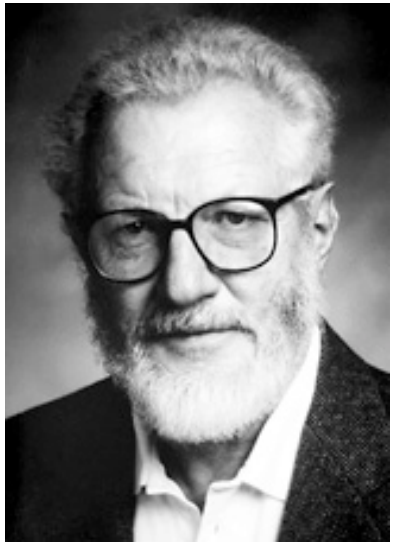
Efficient semiconductor lasers

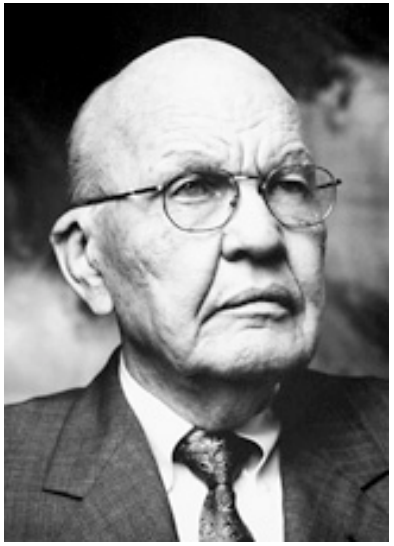


- Heterojunction lasers
  - Improved carrier and light confinement
  - Hayashi et al., “Junction Lasers Which Operate Continuously at Room Temperature” 1970
  - Nobel Prize in 2000 for Herbert Kroemer and Zhores Alferov for semiconductor heterostructures

Coldren et al. Diode Lasers and Photonic Integrated Circuits.

The Nobel Prize in Physics 2000

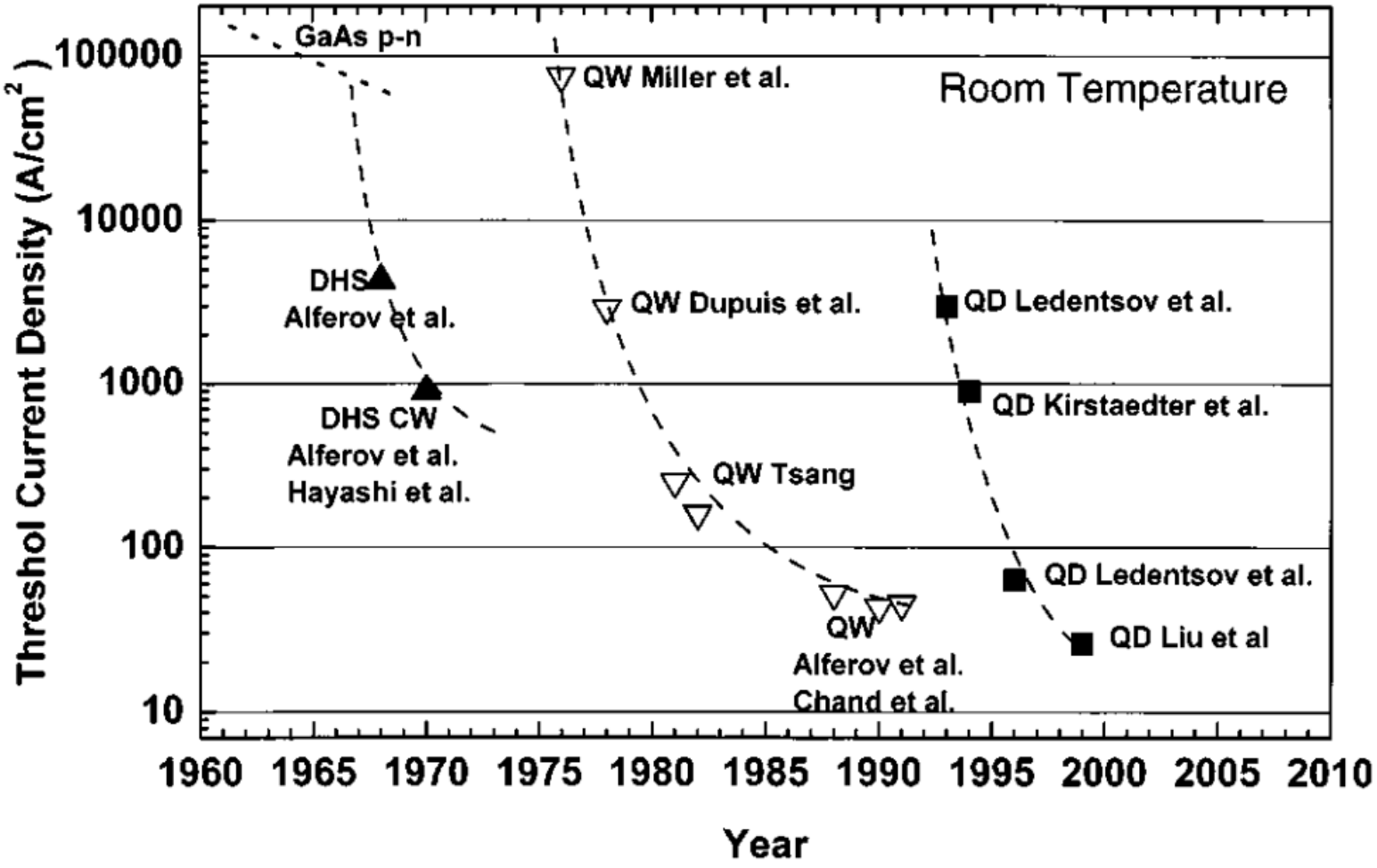




Zhores I. Alferov, **Herbert Kroemer,** **Jack S. Kilby**

The Nobel Prize in Physics 2000 was awarded *"for basic work on information and communication technology"* with one half jointly to Zhores I. Alferov and Herbert Kroemer *"for developing semiconductor heterostructures used in high-speed- and opto-electronics"* and the other half to Jack S. Kilby *"for his part in the invention of the integrated circuit"*.

Quantum-confined lasers



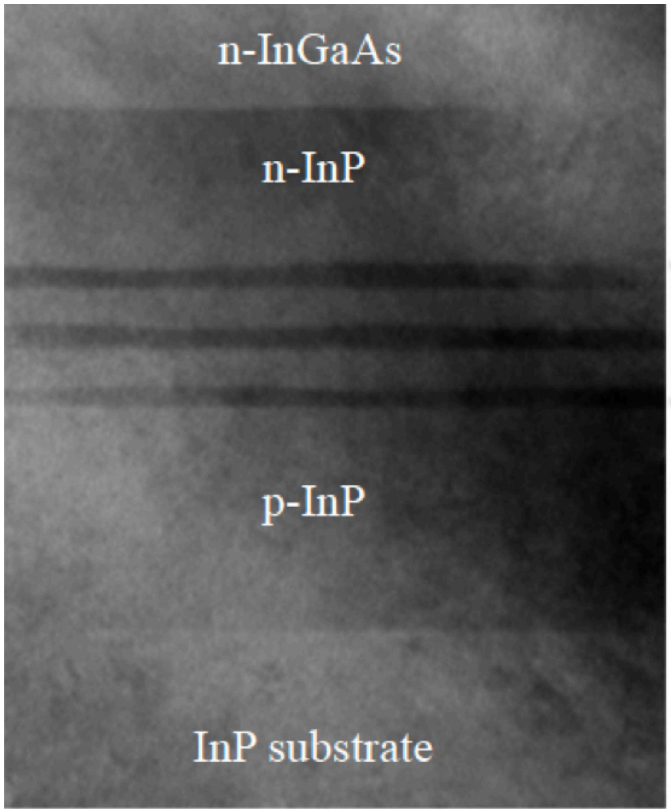
N. N. Ledentsov *et al*., "Quantum-dot heterostructure lasers," in *IEEE Journal of Selected Topics in Quantum Electronics*, vol. 6, no. 3, pp. 439-451, May-June 2000.

Growth of compound semiconductors

Modern commercial MOCVD reactor

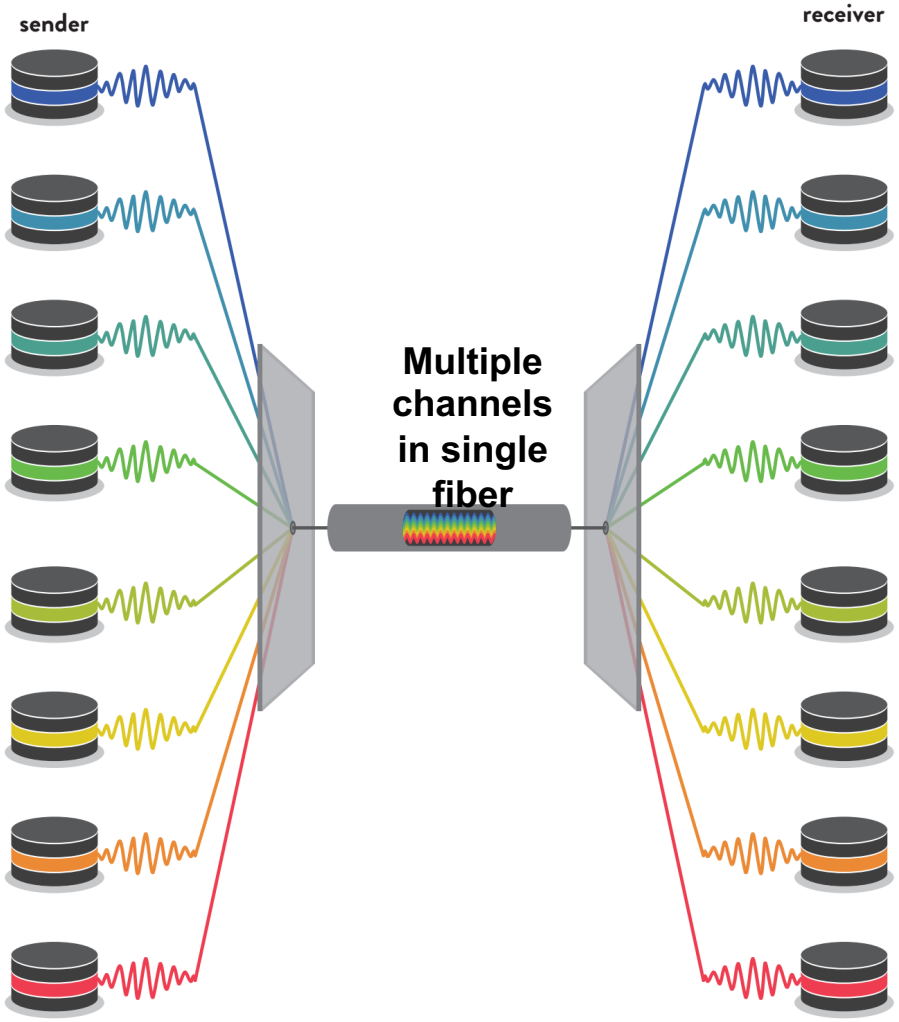
MOCVD: Metal-organic chemical vapor deposition

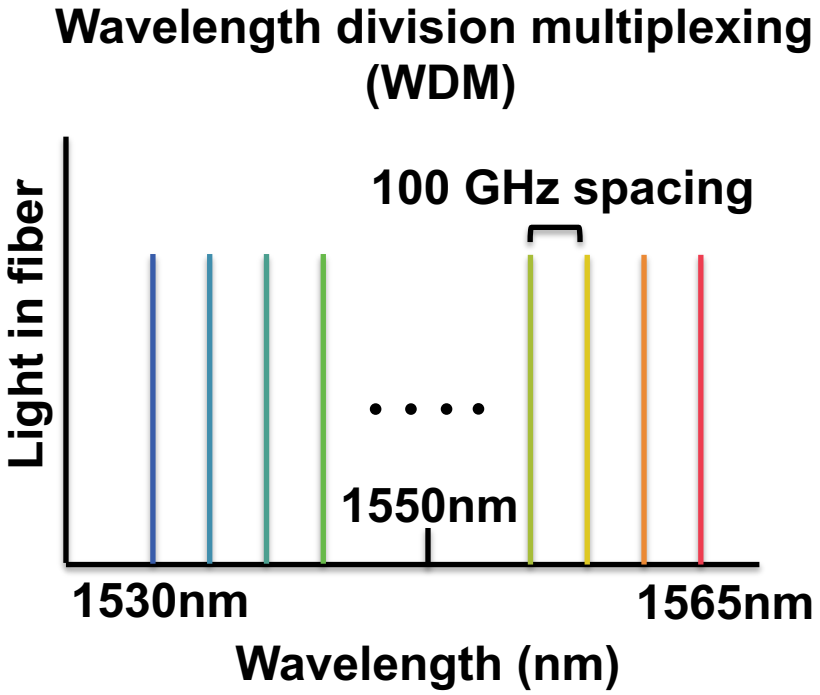
Multiple quantum well III-V LED Cross-section



Christopher Heidelberger (MIT)

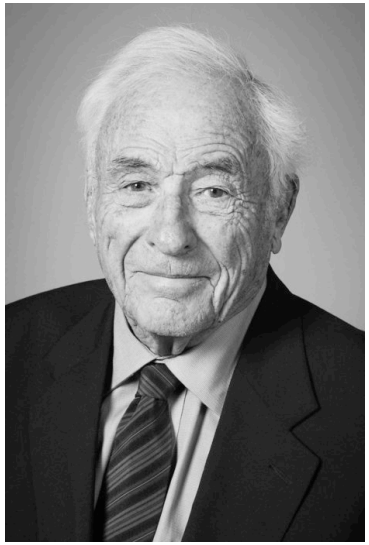
Light-based telecommunication





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

The Nobel Prize in Physics 2009



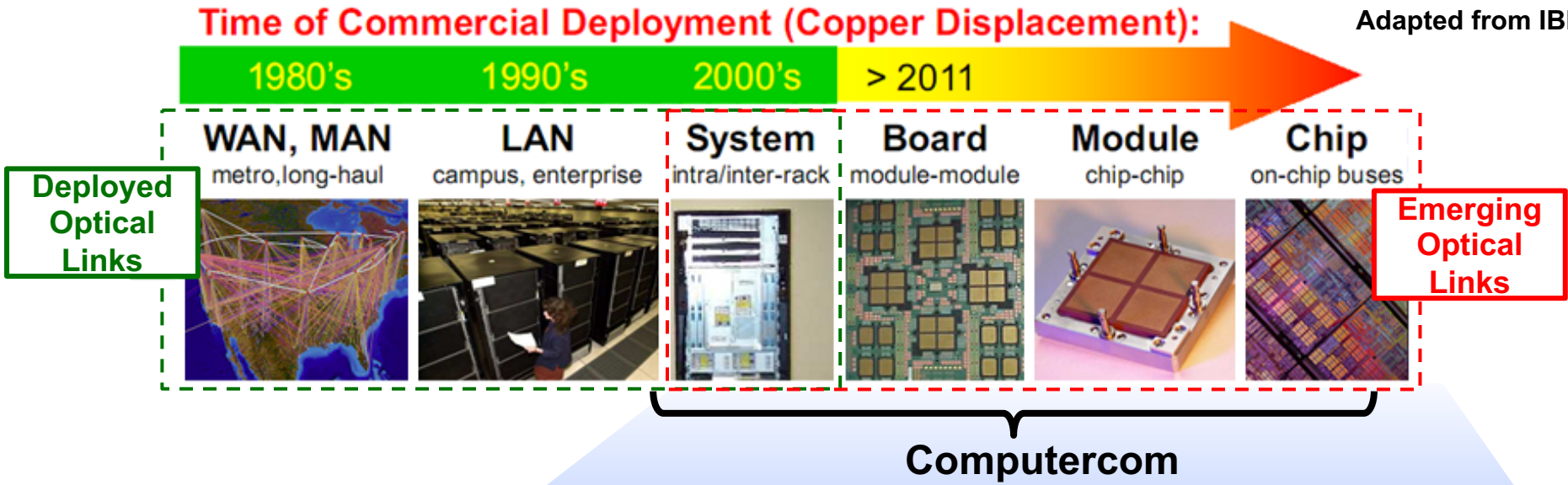
Charles K. Kao, **Willard S. Boyle,** **George E. Smith**

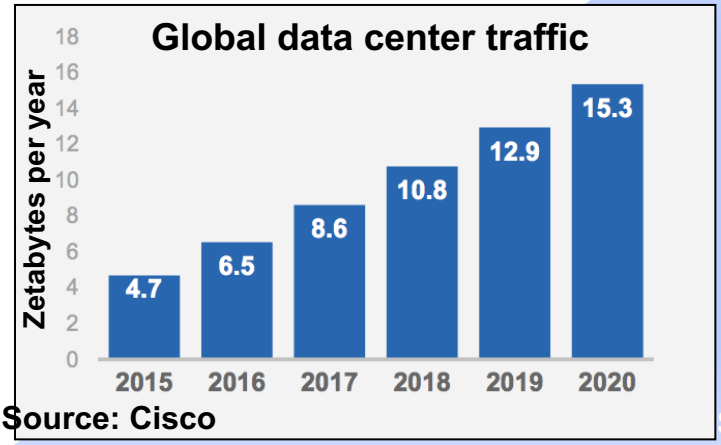
The Nobel Prize in Physics 2009 was awarded to

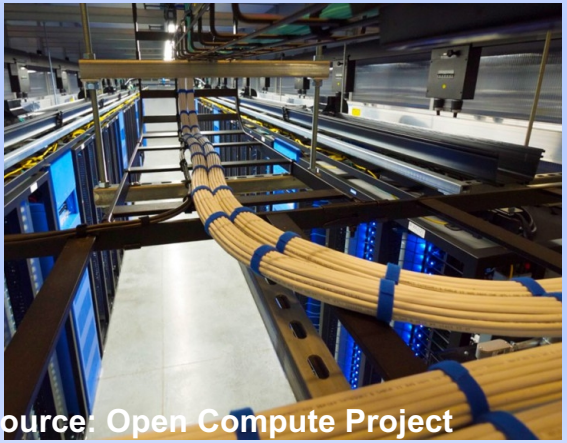
- **Charles K. Kao "for groundbreaking achievements concerning the transmission of light in fibers for optical communication"**
- **Willard S. Boyle and George E. Smith "for the invention of an imaging semiconductor circuit - the CCD sensor."**

(Corning has deployed 3 billion km's of fiber, = 21 round-trips from earth to sun)

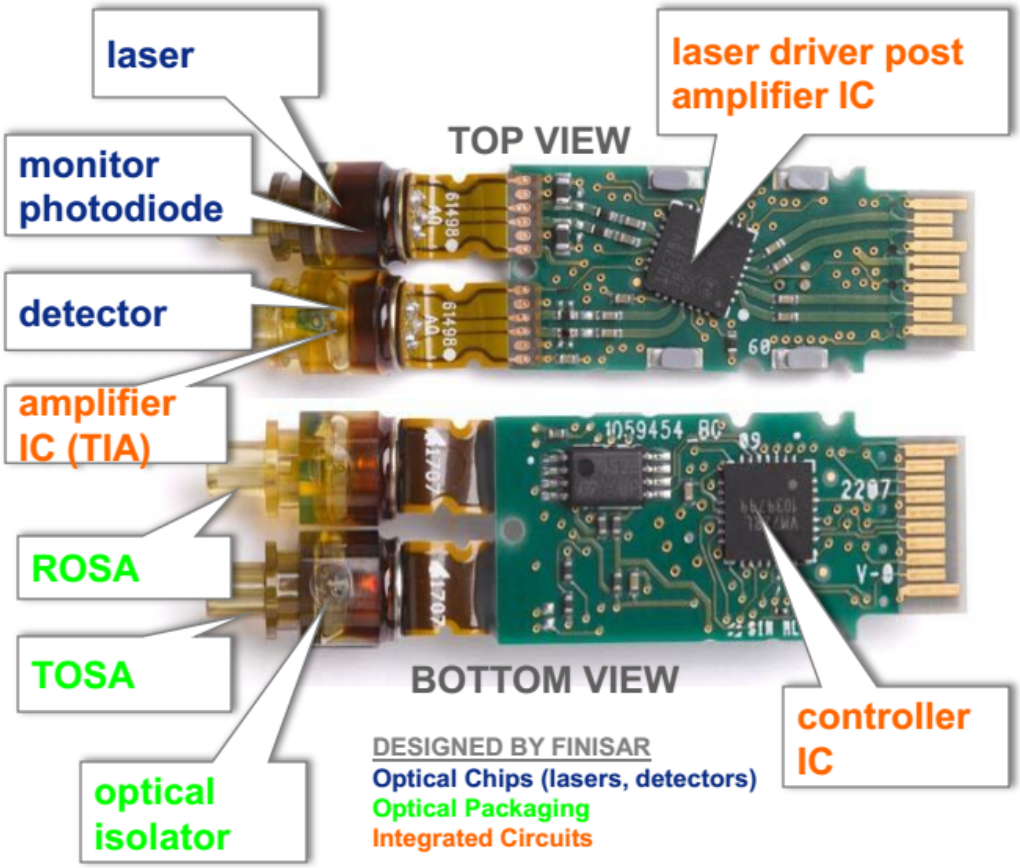
Emergence of large-scale data centers







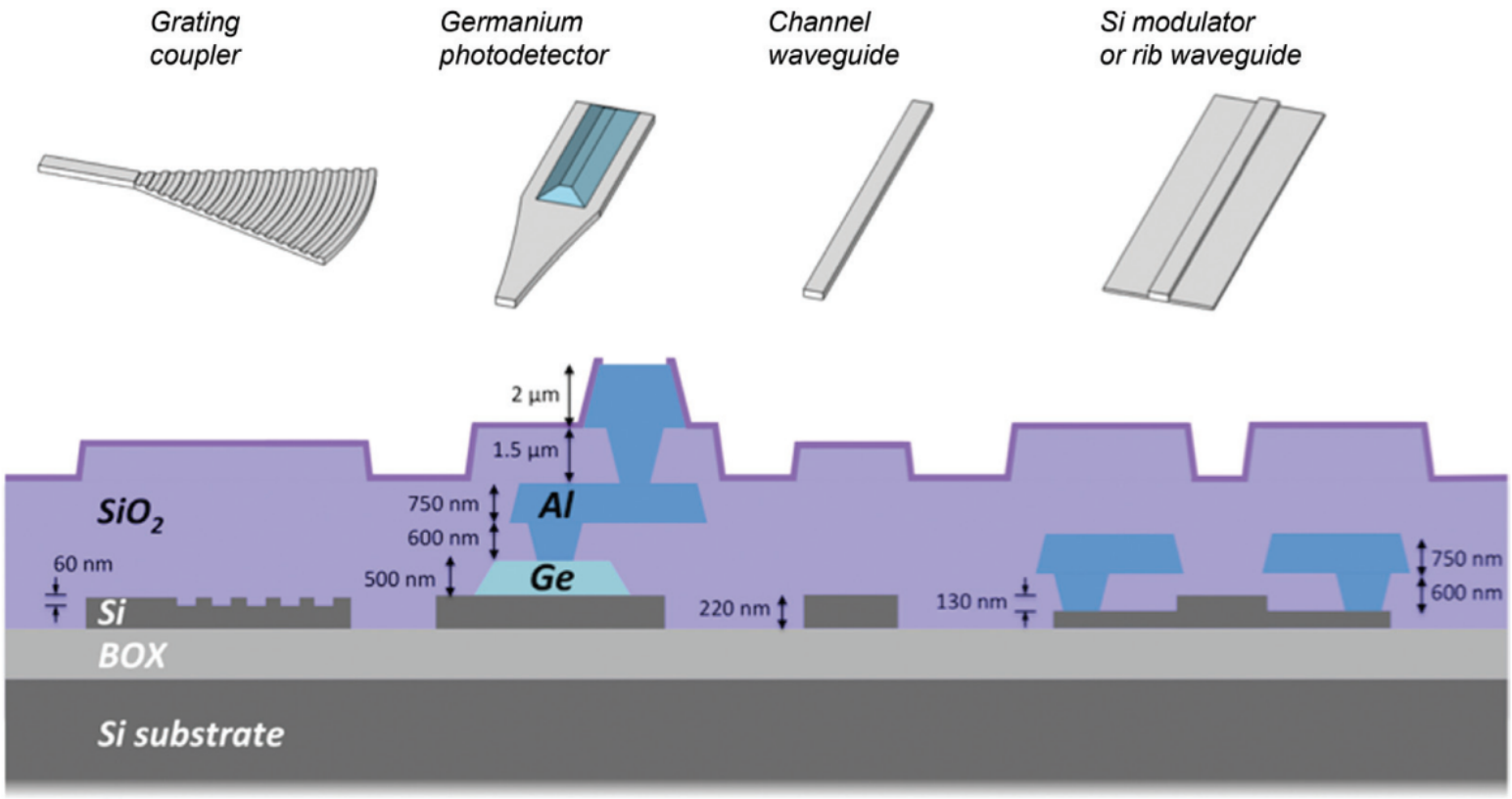
Short-reach optical transceiver



Source: Finisar

Silicon photonics

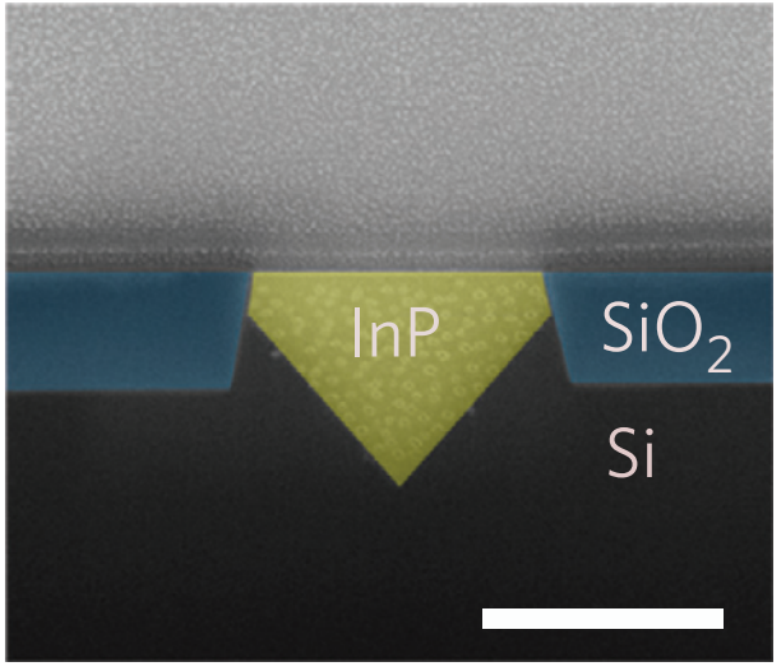
- Economy of scale with silicon-based manufacturing



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

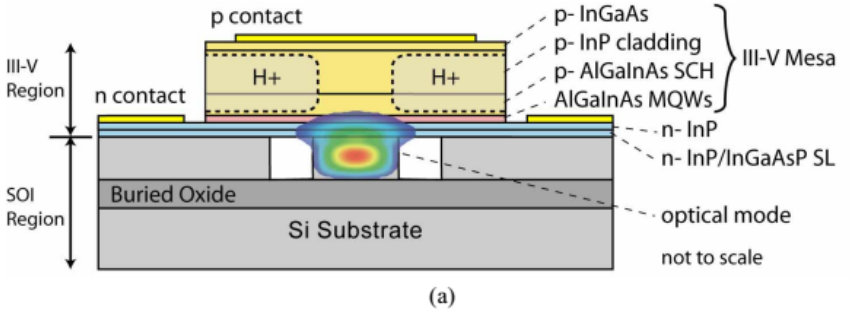
III-V / Silicon integration

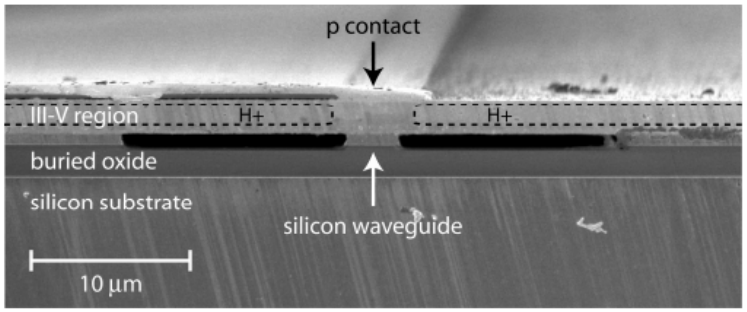
Direct growth of III-V on silicon



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

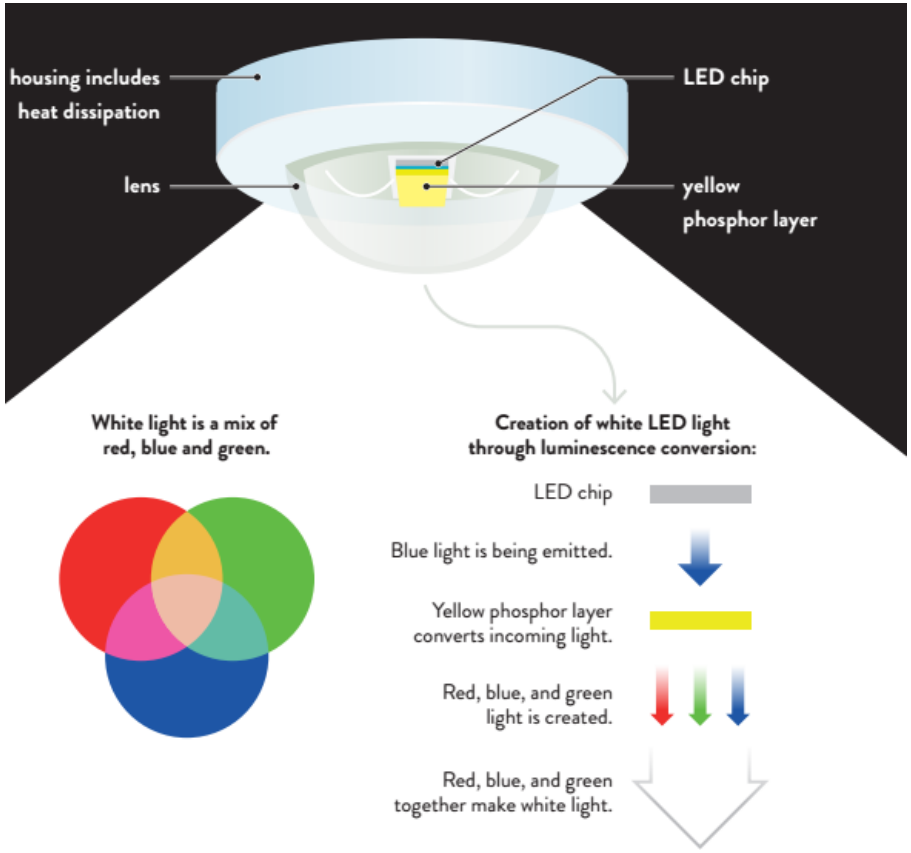
Heterogenous (hybrid) approach

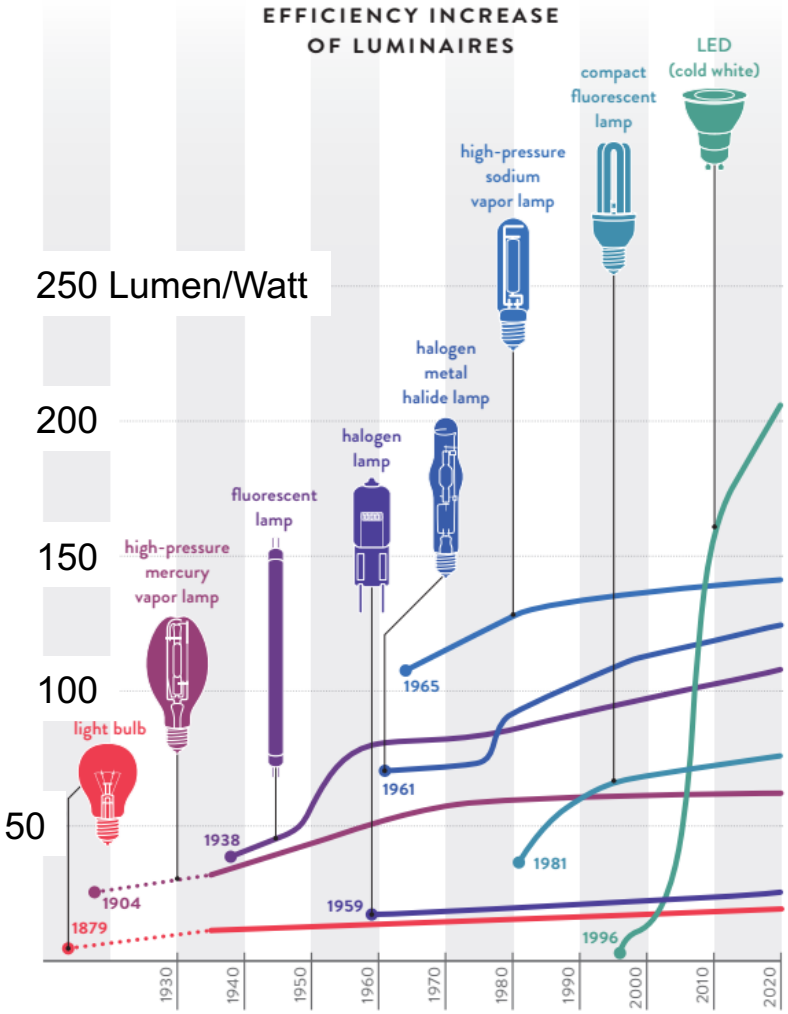




Fang et al., "Electrically pumped hybrid AlGaInAs-silicon evanescent laser," Opt. Express 14, 9203-9210 (2006)

Solid-state lighting





Photonics: Technical Applications of Light. SPIE.

The Nobel Prize in Physics 2014

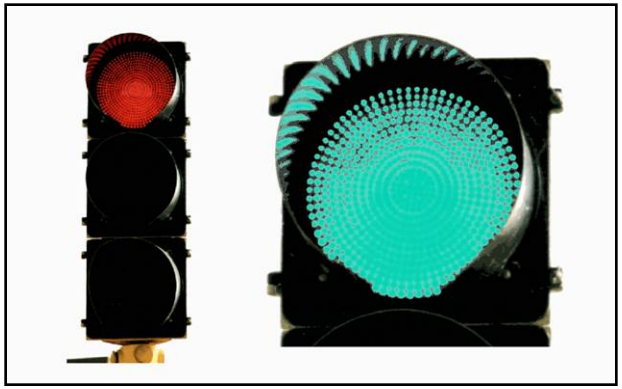
Isamu Akasaki

Hiroshi Amano

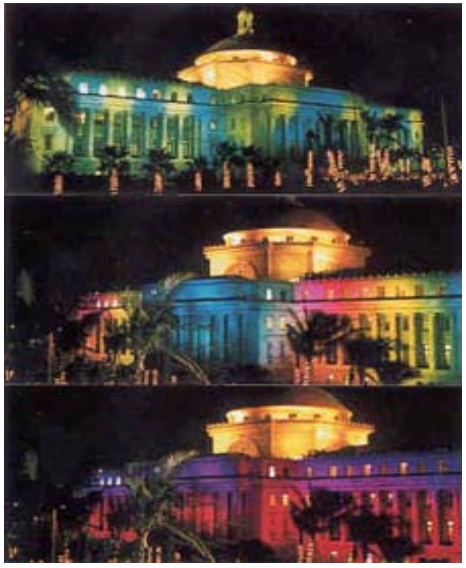
Shuji Nakamura

The Nobel Prize in Physics 2014 was awarded jointly to Isamu Akasaki, Hiroshi Amano and Shuji Nakamura *"for the invention of efficient blue light-emitting diodes which has enabled bright and energy-saving white light sources"*.

Applications of HBLEDs



Traffic Signals (inc white)



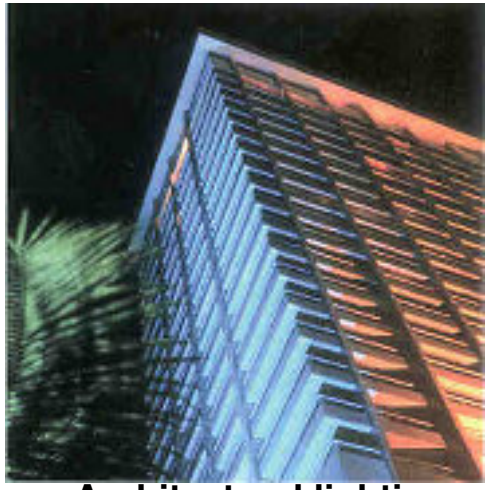
Source: http://www.northamericanlighting.com

Source: Toshiba (Technorainbow)

Outdoor lighting scenarios

Source: Wustlich Design AG

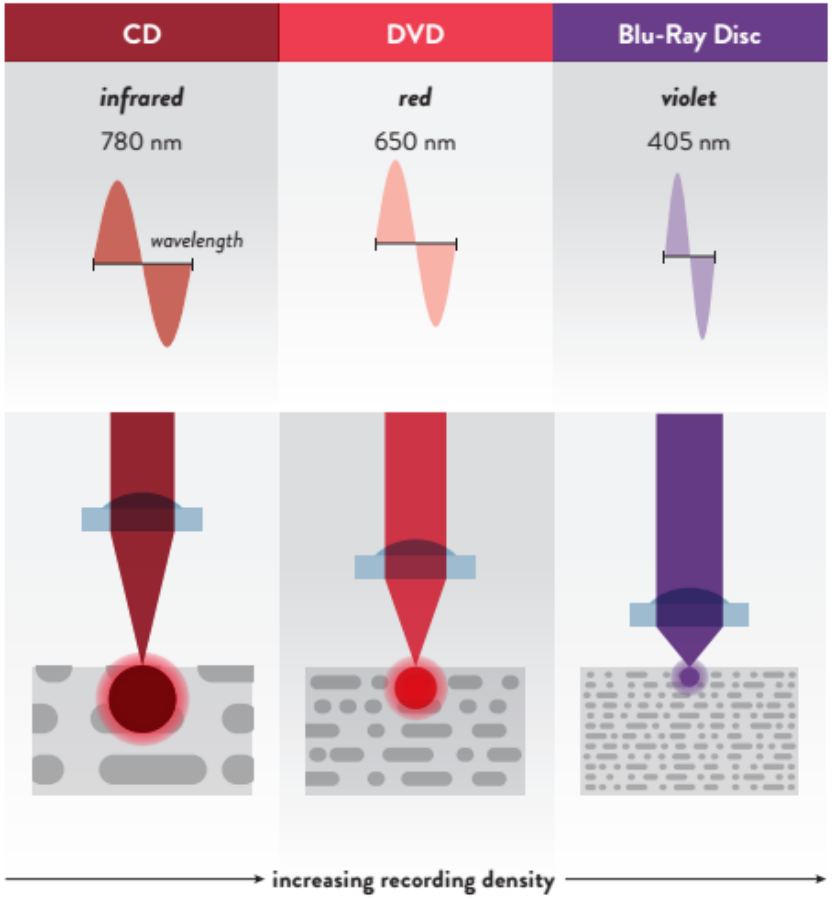
Furniture Lighting



Architectural lighting

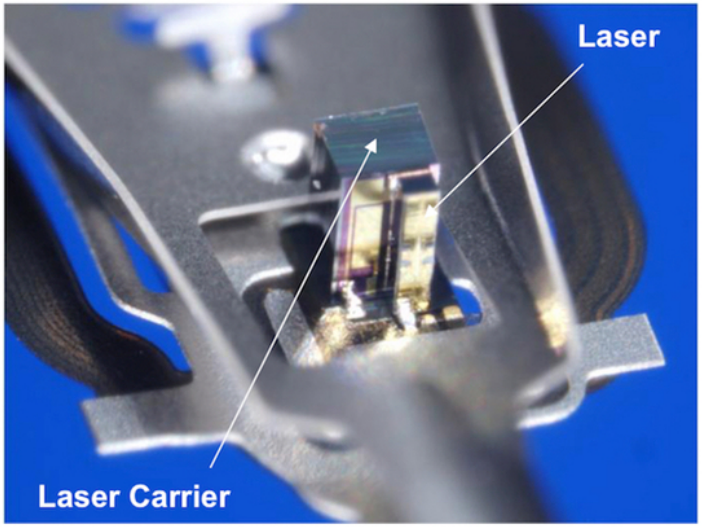
Data storage

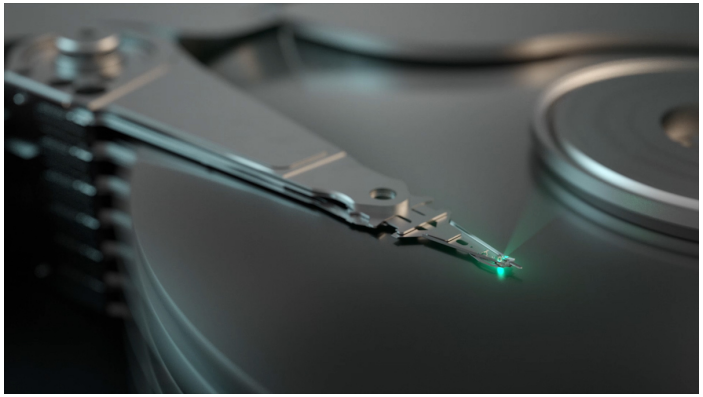
Optical data storage



Photonics: Technical Applications of Light. SPIE.

Magnetic data storage
Heat-assisted magnetic recording (HAMR)

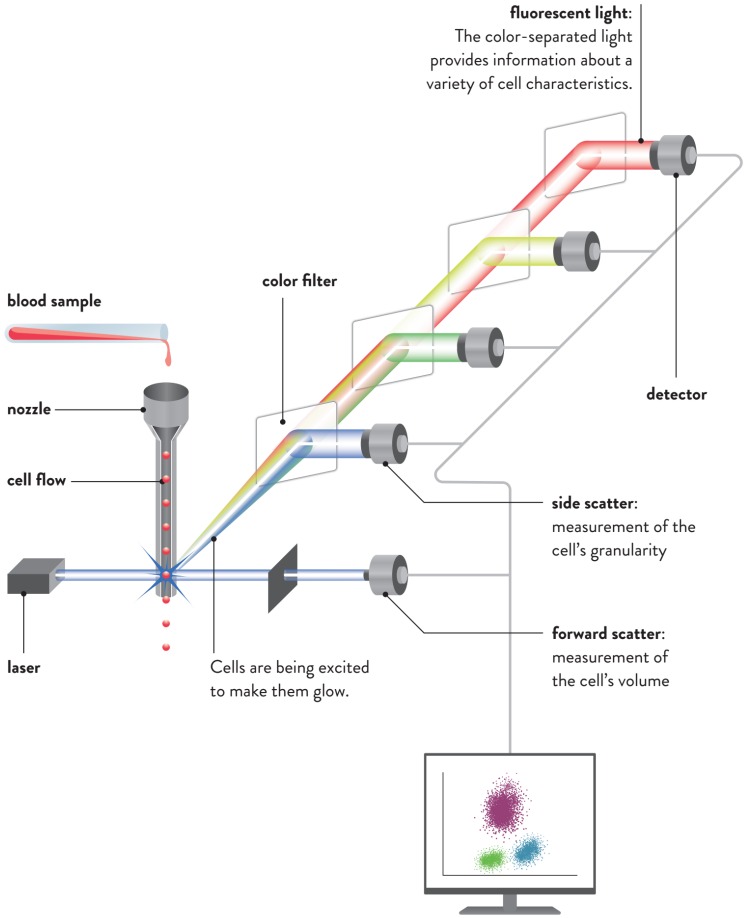




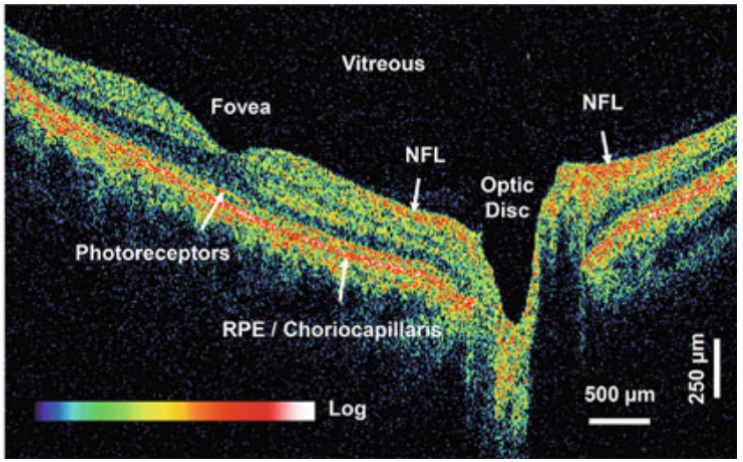
Source: Seagate

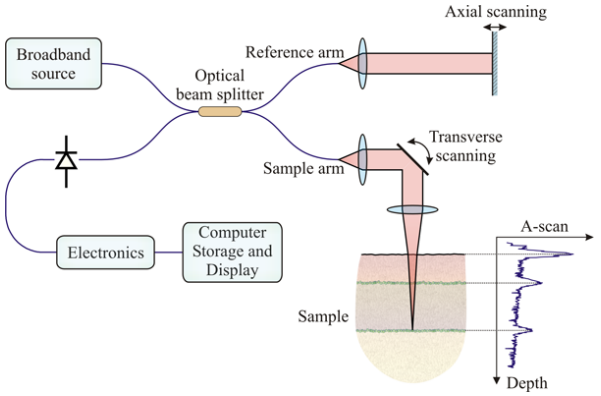
Bio-medical

Cell counting and sorting



Optical coherence tomography (OCT)

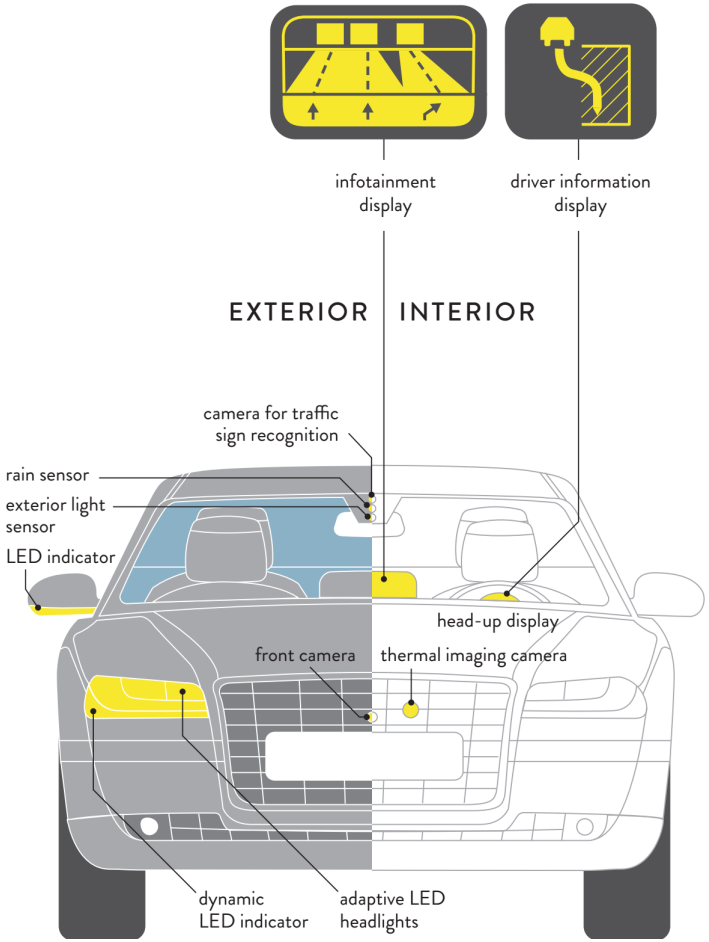




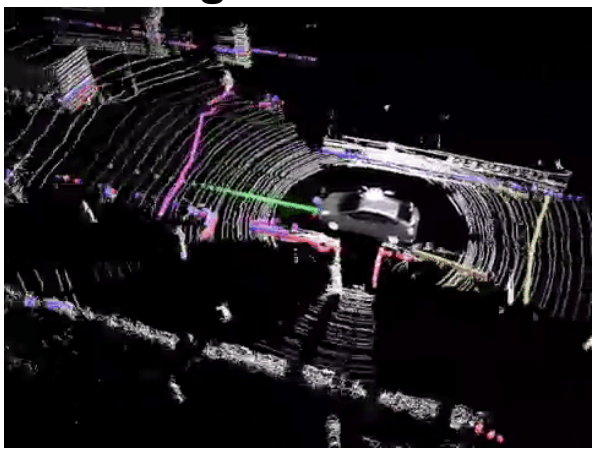
Photonics: Technical Applications of Light. SPIE.

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

Automotive



Self-driving vehicles



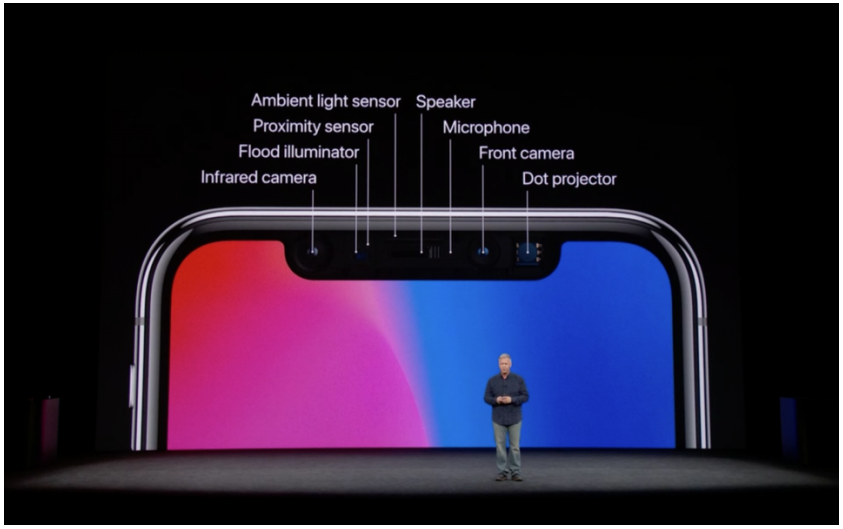
youtube.com

3D Imaging (LIDAR)

theverge.com

Photonics: Technical Applications of Light. SPIE.

Consumer electronics



BUSINESS NEWS

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

08 Dec 2017

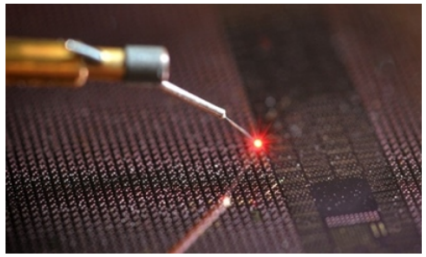
700,000 square-foot facility in Sherman, Texas, will host 6-inch VCSEL wafer production, with CEO Jerry Rawls expecting 'gigantic' future demand.

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

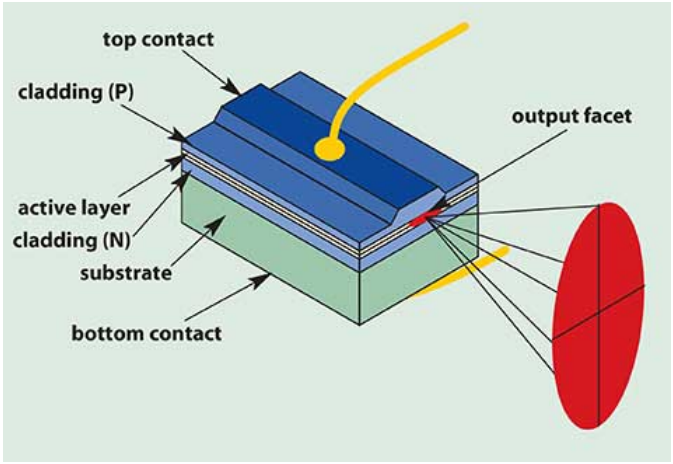
Akanksha Rana, Uday Sampath Kumar

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.

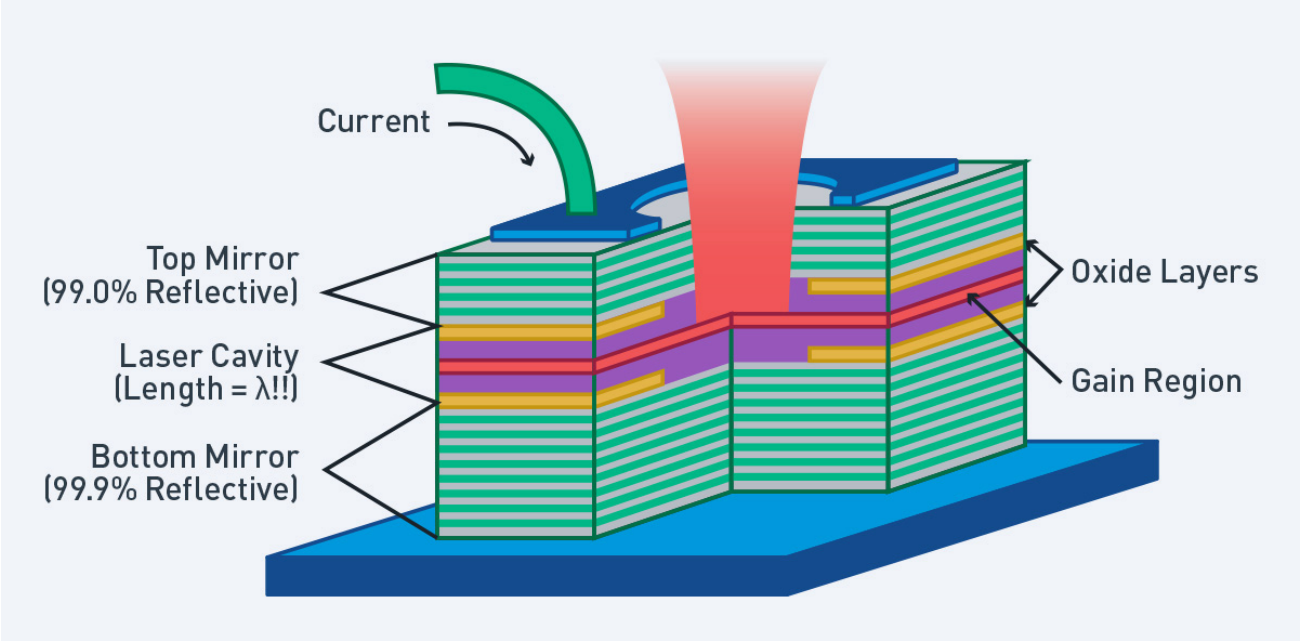
II-VI will pay Finisar shareholders $26 per share, in cash and stock, a premium of 37.7 percent to Finisar's closing share price on Thursday.

Semiconductor Lasers



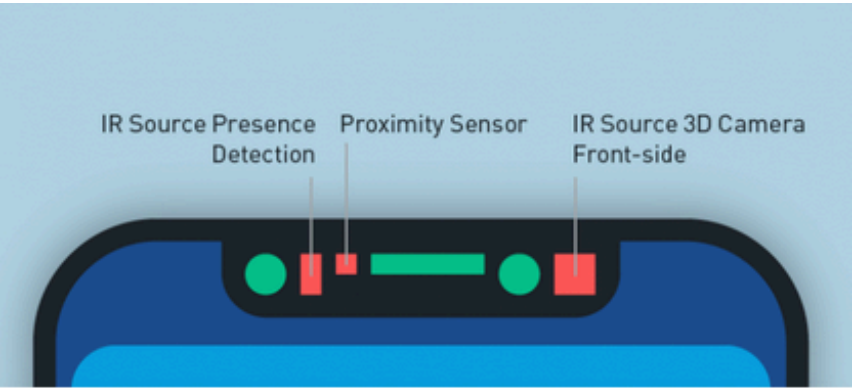
Edge-Emitting Lasers

Vertical Cavity Surface-Emitting Lasers (VCSEL)

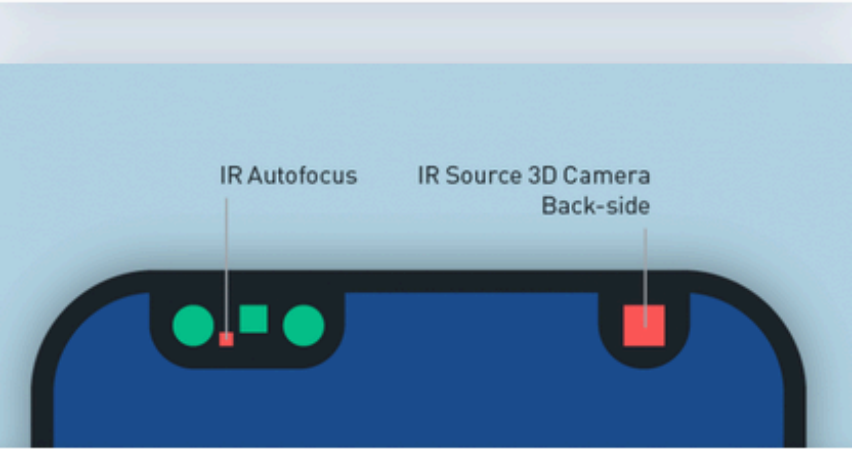


(Finisar)

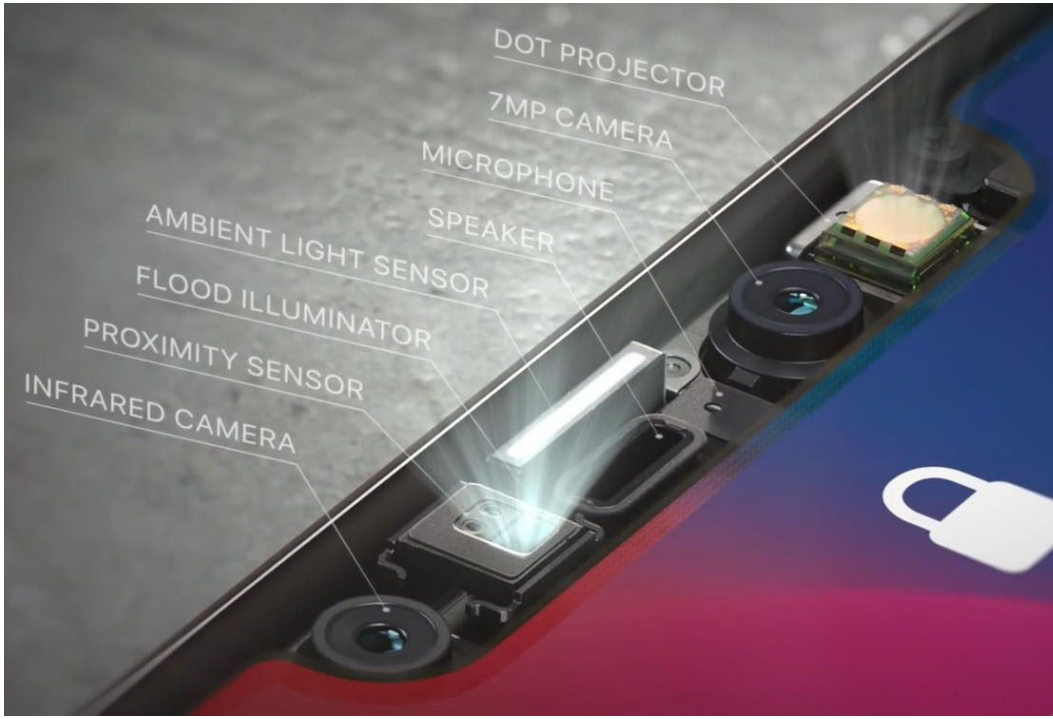
VCSELs in Smart Phones



VCSEL in the Front of a Smart Phone

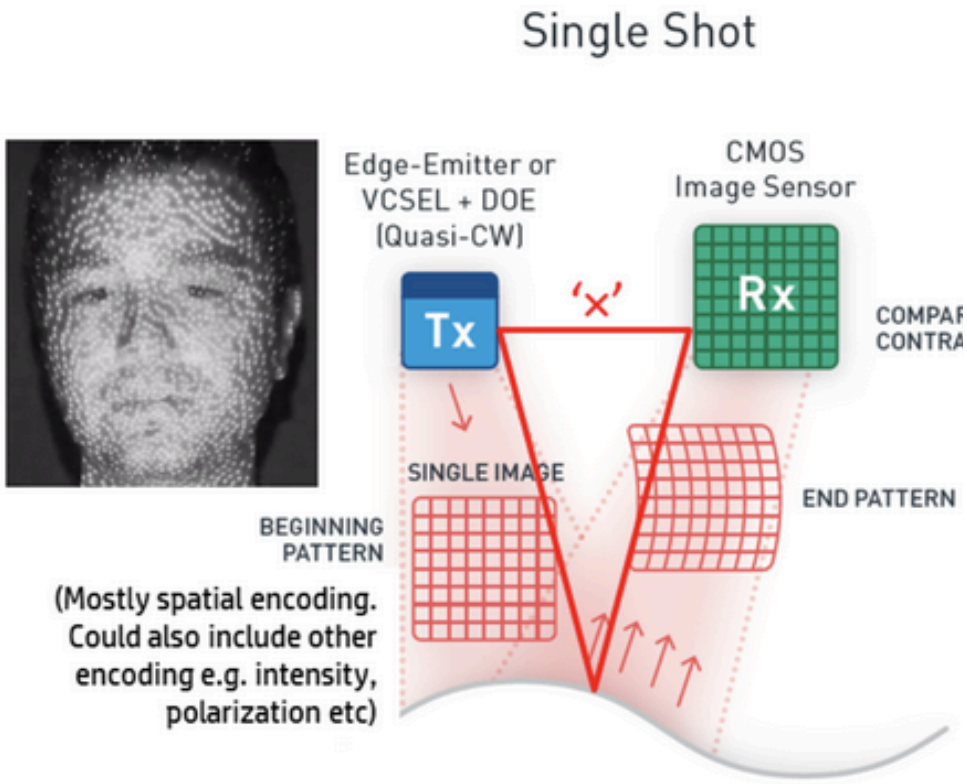


VCSEL in the Back of a Smart Phone



Structured Light 3D Camera

(Images from Finisar)



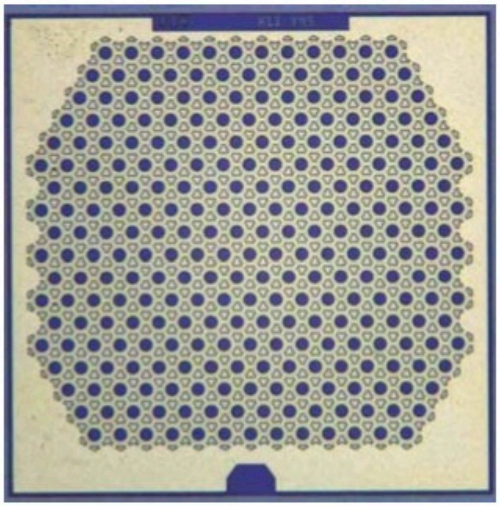


Figure 1 Picture of typical 2D high power VCSEL array

Typical peak power ~ 10W
Pulse duration ~ ns