EE 232 Lightwave Devices
Lecture 1: Introduction

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Common Optoelectronic Components
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".

Charles H. Townes, Nicolay G. Basov, Aleksandr M. Prokhorov
Demonstration of LASER

Theodore Maiman’s Ruby Laser (1960)

Demonstration of semiconductor LASER

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


Guiding of light

- **Gas lens system**

- **Fiber optic cable**
  - 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

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

Growth of compound semiconductors

Modern commercial MOCVD reactor

Multiple quantum well III-V LED Cross-section

n-InGaAs

n-InP

p-InP

InP substrate

source: azo.com

InGaAs/InP quantum wells

Christopher Heidelberger (MIT)

MOCVD: Metal-organic chemical vapor deposition
Light-based telecommunication

Wavelength division multiplexing (WDM)

- 100 GHz spacing
- Common laser line spacing for Dense-WDM in the “C-band” centered near 1550nm wavelength

Photonics: Technical Applications of Light. SPIE.
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

Time of Commercial Deployment (Copper Displacement):
- 1980's
- 1990's
- 2000's
- > 2011

WAN, MAN
- metro, long-haul

LAN
- campus, enterprise

System
- intra/inter-rack

Board
- module-module

Module
- chip-chip

Chip
- on-chip buses

Deployed Optical Links

Emerging Optical Links

Global data center traffic

Zetabytes per year

4.7 6.5 8.6 10.8 12.9 15.3

Source: Cisco

Source: Open Compute Project

Source: Facebook

Adapted from IBM

Computercom
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

Heterogenous (hybrid) approach


Solid-state lighting

Photonics: Technical Applications of Light. SPIE.
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: Toshiba (Technorainbow)

Outdoor lighting scenarios

Source: Toshiba (Technorainbow)

Source: Wustlich Design AG

Furniture Lighting

Source: http://www.northamericanlighting.com

Architectural lighting
Data storage

Optical data storage

<table>
<thead>
<tr>
<th>CD</th>
<th>DVD</th>
<th>Blu-Ray Disc</th>
</tr>
</thead>
<tbody>
<tr>
<td>infrared</td>
<td>red</td>
<td>violet</td>
</tr>
<tr>
<td>780 nm</td>
<td>650 nm</td>
<td>405 nm</td>
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Magnetic data storage
Heat-assisted magnetic recording (HAMR)

Laser
Laser Carrier

Increasing recording density

Source: Seagate

Photonics: Technical Applications of Light. SPIE.
Bio-medical

Cell counting and sorting

Optical coherence tomography (OCT)


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Automotive

Self-driving vehicles

3D Imaging (LIDAR)

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Consumer electronics

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

Alanaha Rana, Uday Sampath Kumar

(Reuters) - Laser and optical parts maker II-VI Inc (IIVLO) 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)

Top Mirror (99.0% Reflective)
Laser Cavity (Length = $\lambda!!$)
Bottom Mirror (99.9% Reflective)

Oxide Layers
Gain Region

(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)

Single Shot

Typical peak power ~ 10W
Pulse duration ~ ns

*Figure 1 Picture of typical 2D high power VCSEL array*