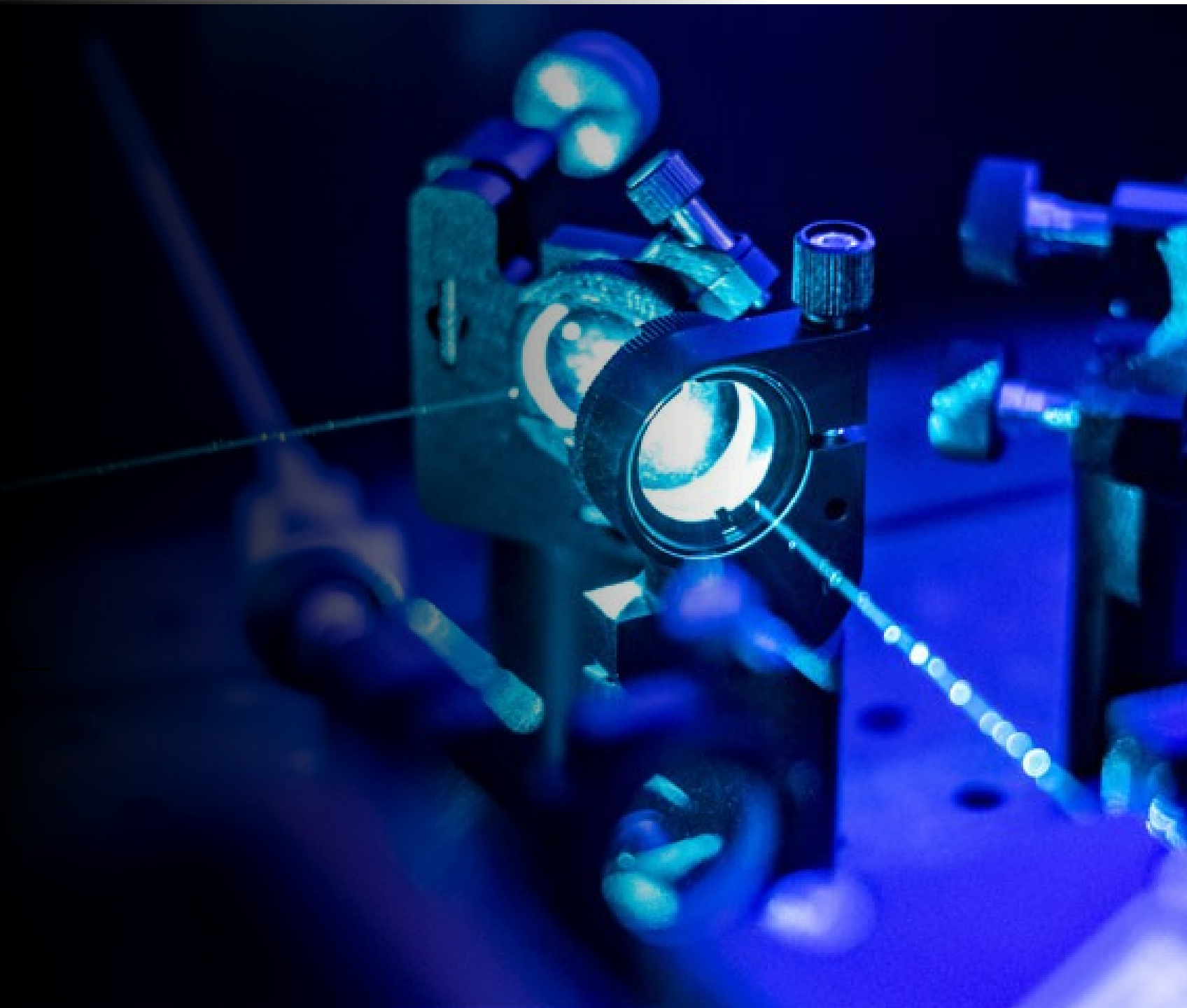




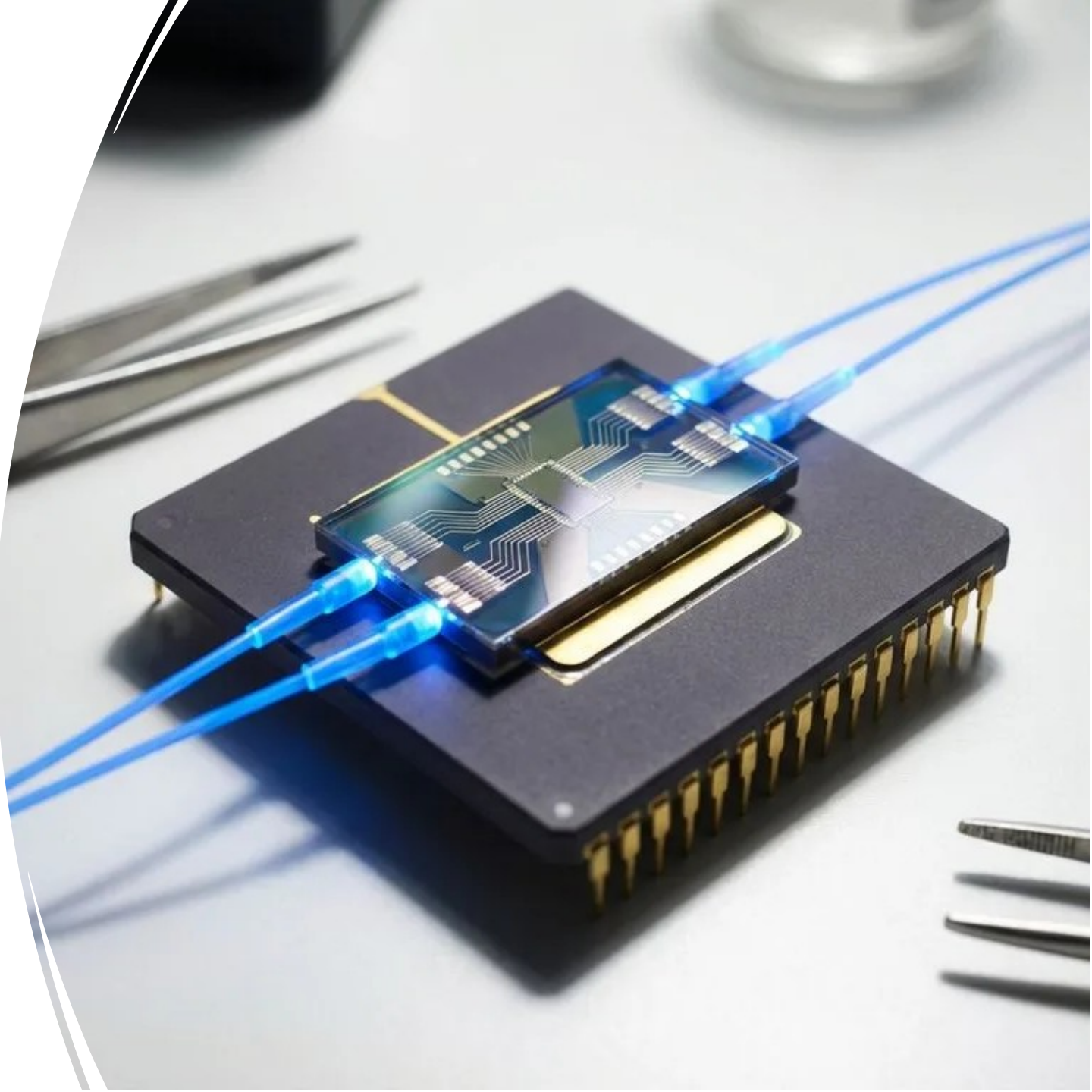
Optoelectronics Technologies

John Spina



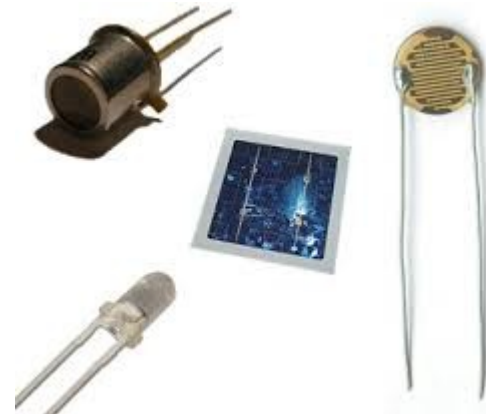
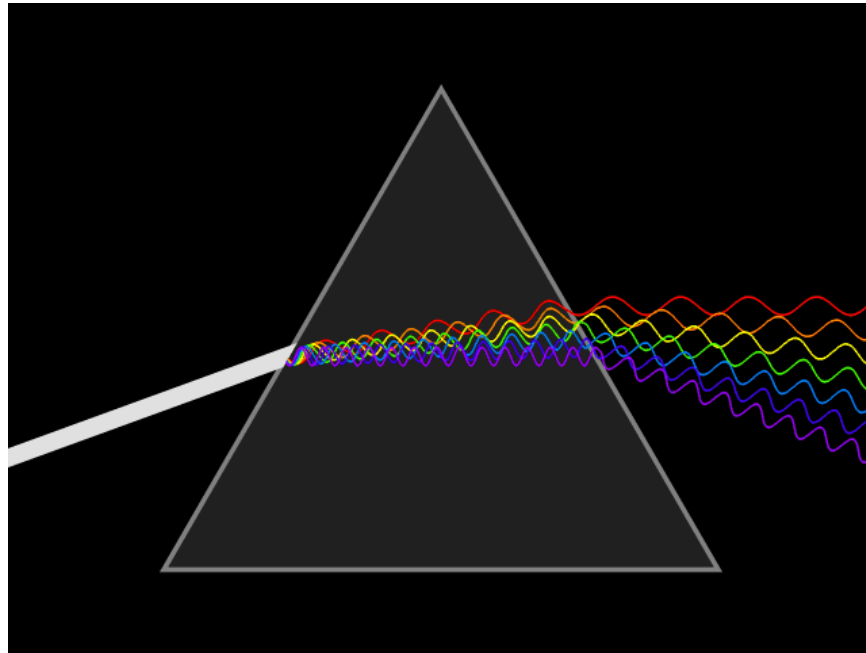
Agenda

- Fundamentals of Light
- Different Optical Technologies and How They Work
- Why to Use Optoelectronic devices
- Applications of Optoelectronic devices



What are Optoelectronics

- Optics is the study of light and how it interacts with different materials
- Photonics refer to the study of how to use photons
- Optoelectronics refers to electronic based and related devices that use photonic principles

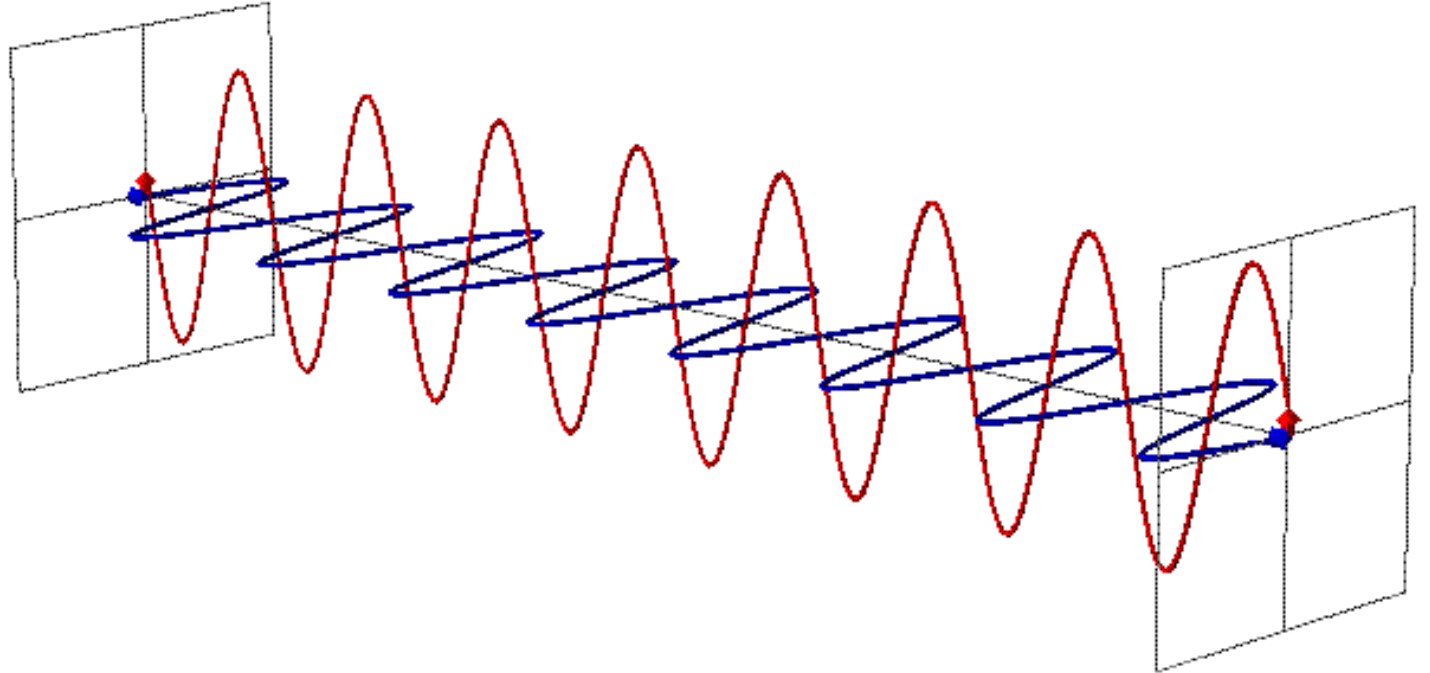


Fundamentals of Light



What is Light?

- Wave but also particle
- Photon model is better to use when dealing with energy
- Wave model is better to use when dealing with travelling light
 - Contains an E-Field and a perpendicular B-Field
- Photon
 - A particle representation of light that contains an energy with a correlated wavelength

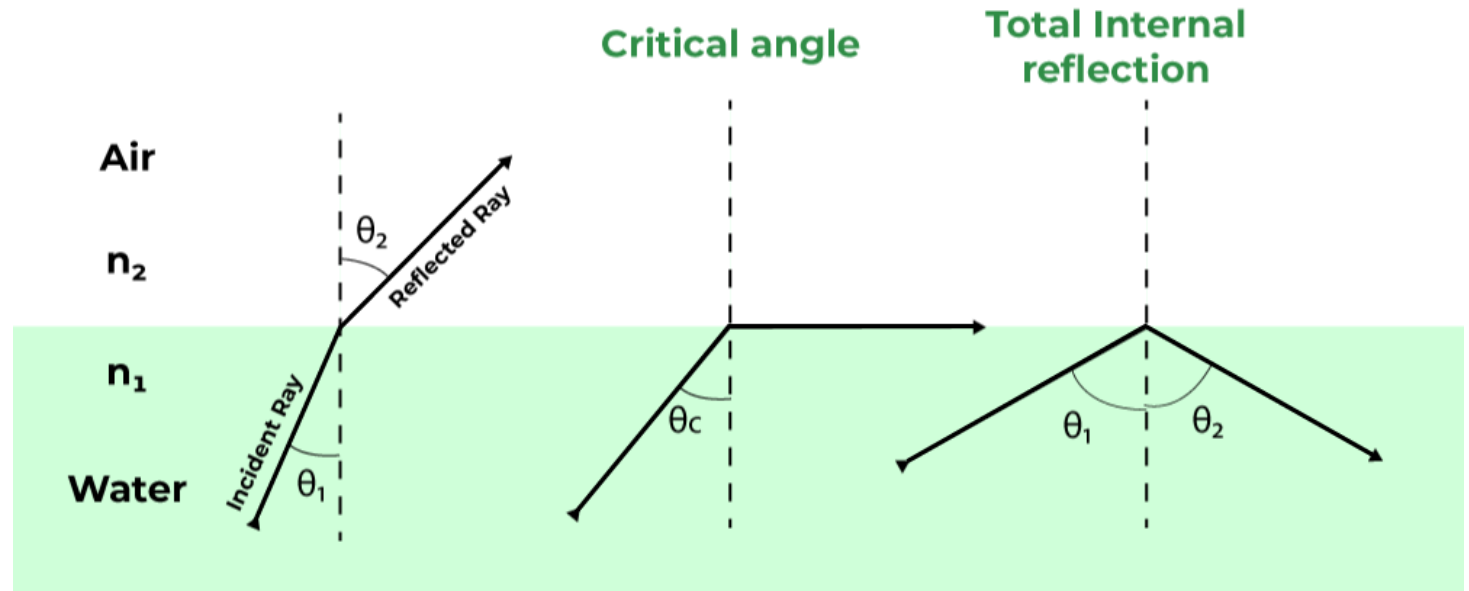


Important Terms to know

- Intensity
 - Defined as Power over an area
- Polarization
 - The Electromagnetic field is aligned in a specific direction (we'll assume most of the light is polarized)
- Refractive Index
 - Property of a material that determines how quickly and easily light should move inside the material
 - Harder for light to escape from high index to low index

Total Internal Reflection

- When two materials are at a junction with different refractive indexes, some light will go into the new medium and some will reflect
- At a critical angle, all the light will reflect, and none will be transmitted
- Useful in many optical technologies to capture light

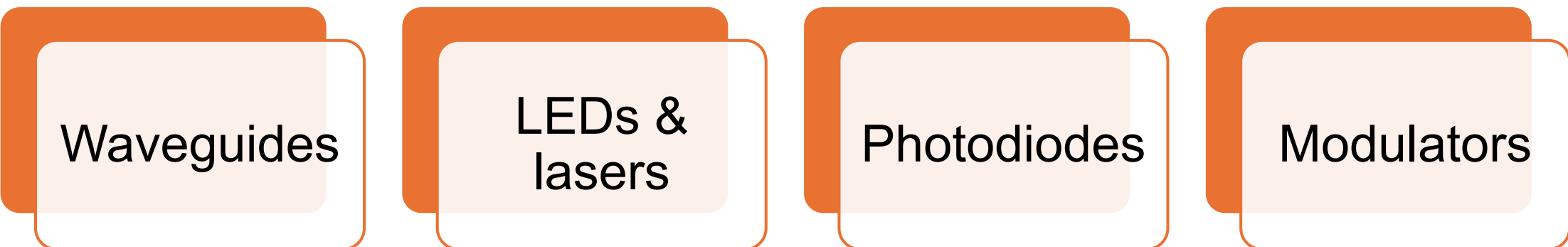


$$\theta_c = \arcsin\left(\frac{n_2}{n_1}\right)$$

Where $n_1 > n_2$

The Optoelectronics Technologies

Different Types of Devices



Waveguides

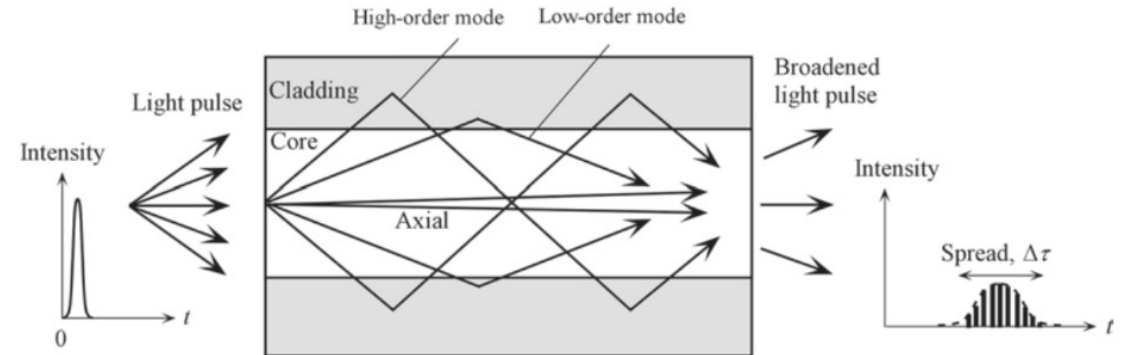
LEDs &
lasers

Photodiodes

Modulators

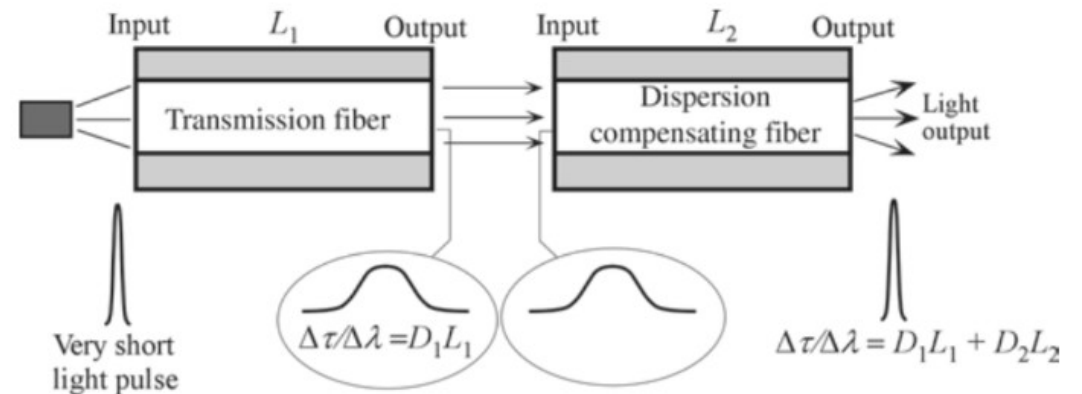
Waveguides

- Guides light into going a specific direction
 - Likes the “wires” of the photonics world
- Consist of an inner core material surrounded by outside cladding to keep light inside the fiber
- Often supports multiple “modes”, or angles that a frequency can be set at and still travel forward



Waveguide Dispersion

- Signals and become distorted over time due to refractive index
- Solution is to use different material to reverse this distortion
 - Typically Silica (SiO)





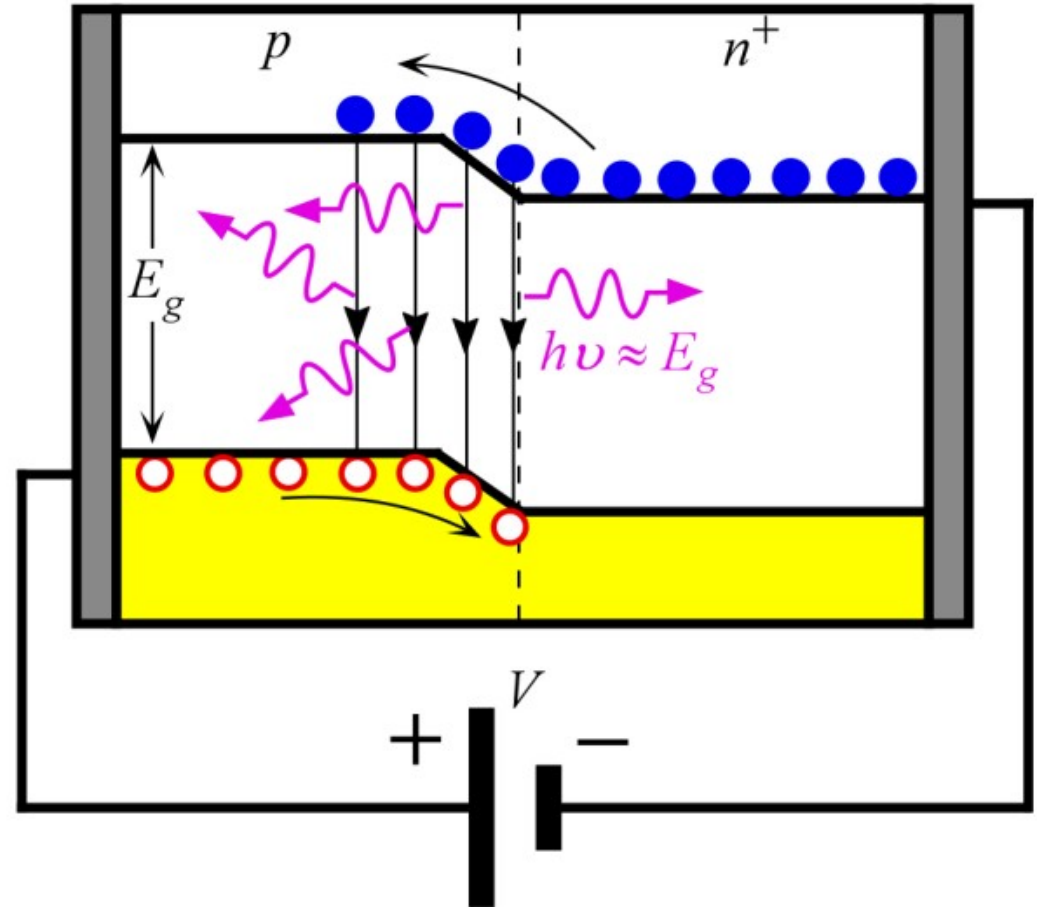
LEDs

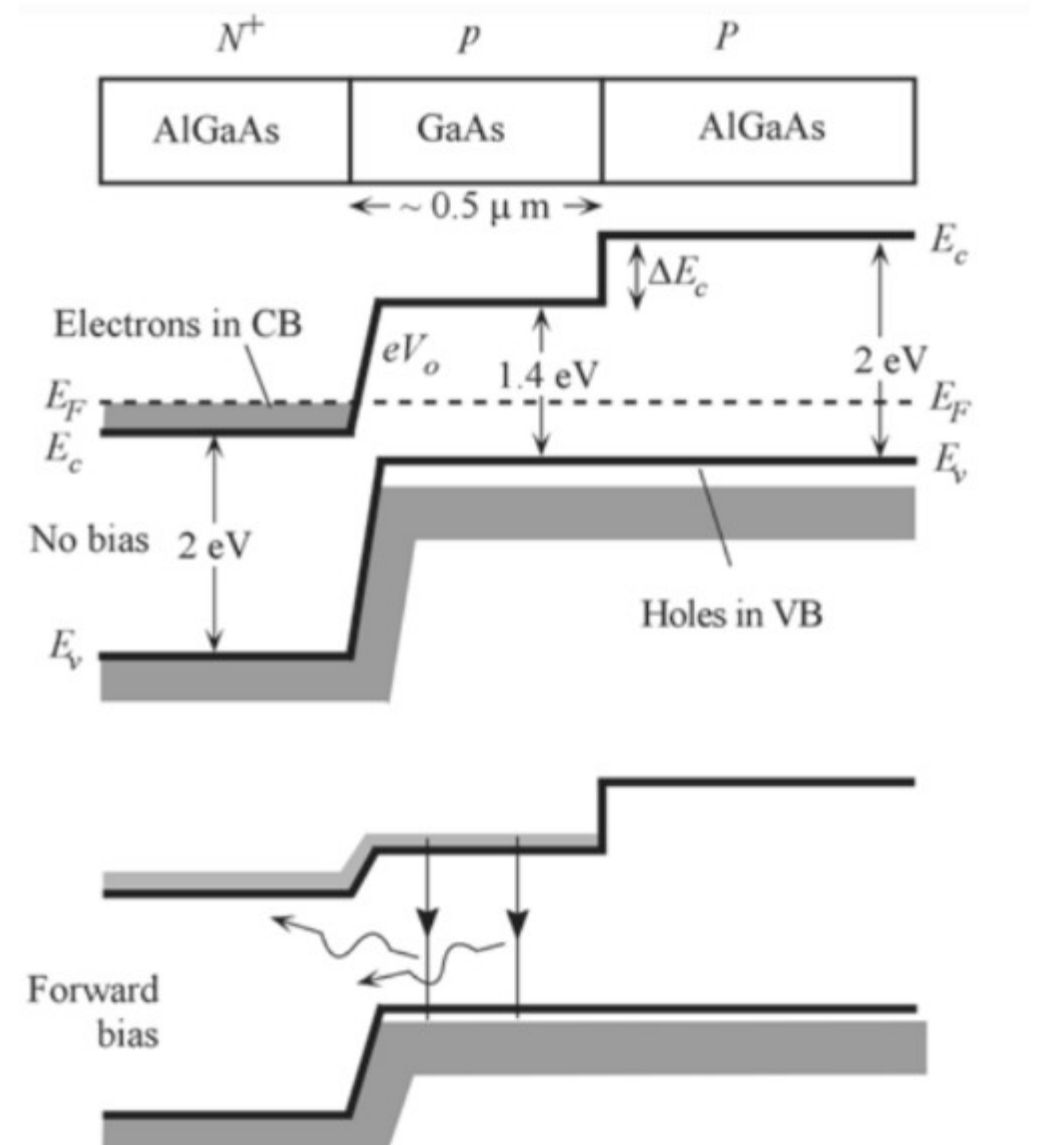
- Simplest design light emission with electronics (Next to destroying something)
- Low intensity
- Non coherent light
- Current efficient



LEDs

- Applied voltage allows electrons to recombine with holes at the junction and p side
- This recombination emits a photon
- Frequency is based on materials band-gap energy

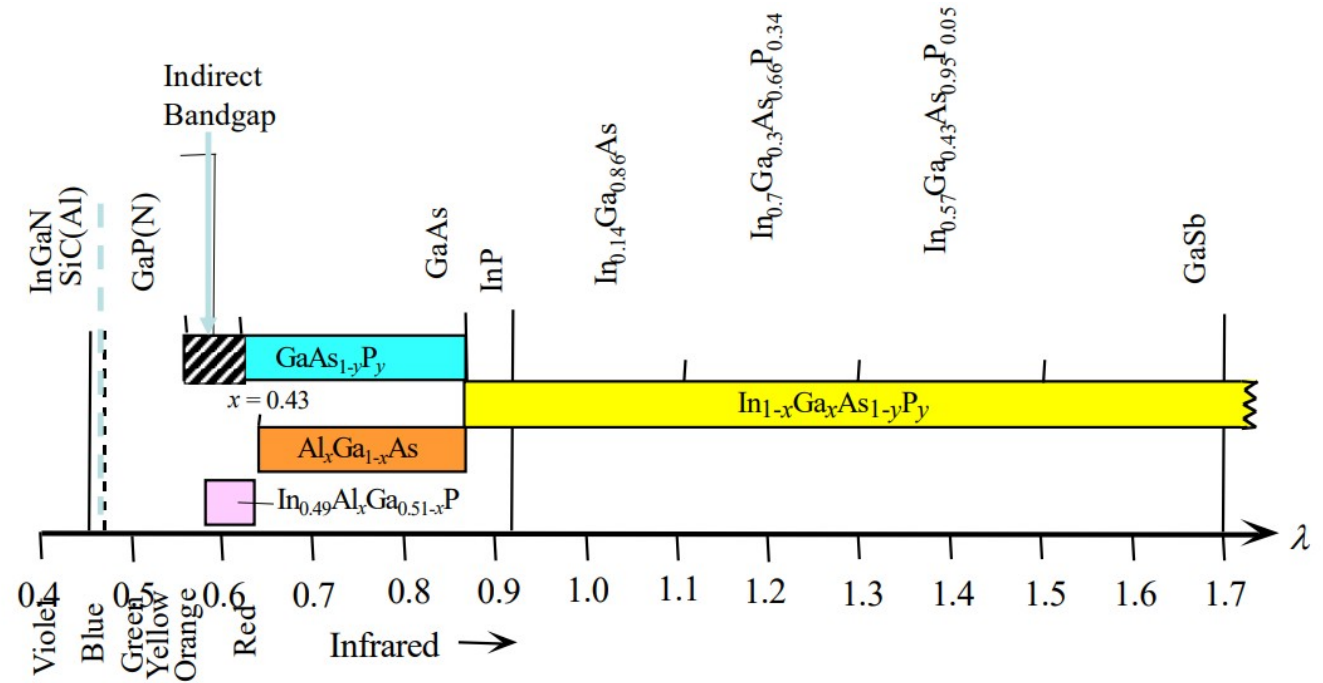




Semiconductor Color Correlation

- Notable materials:
- GaAs: 1.24eV (Red)
- GaP: 2.25eV (Green)
- InGaN: 2.80eV (Blue)

$$E_g = h\nu$$



Dashed and hatched lines are indirect bandgap materials

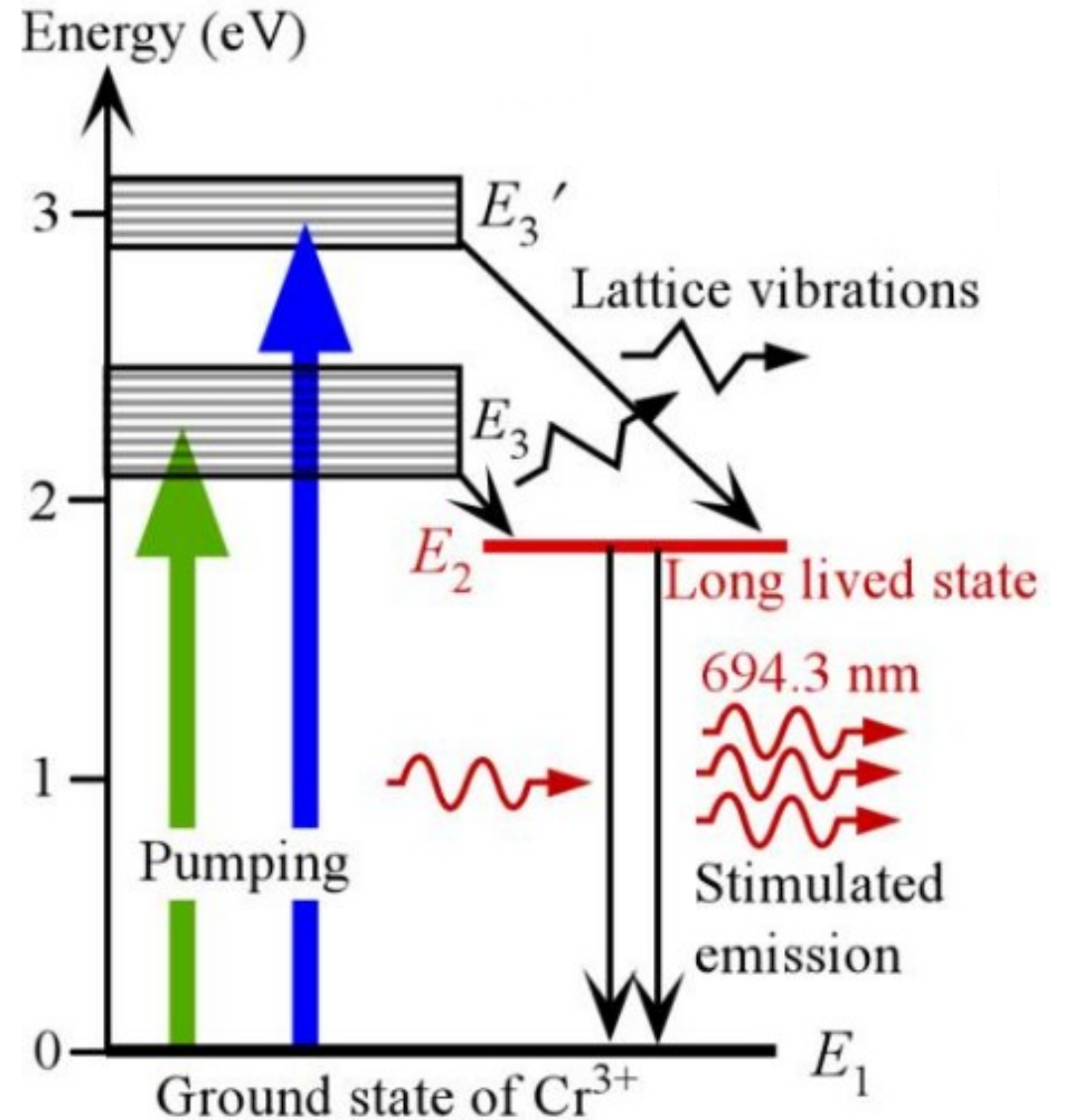
LASERs

- **L**ight **A**mplification by **S**timulated **E**mission of **R**adiation
- Complex design
- High intensity
- Coherent beam due to optical cavity



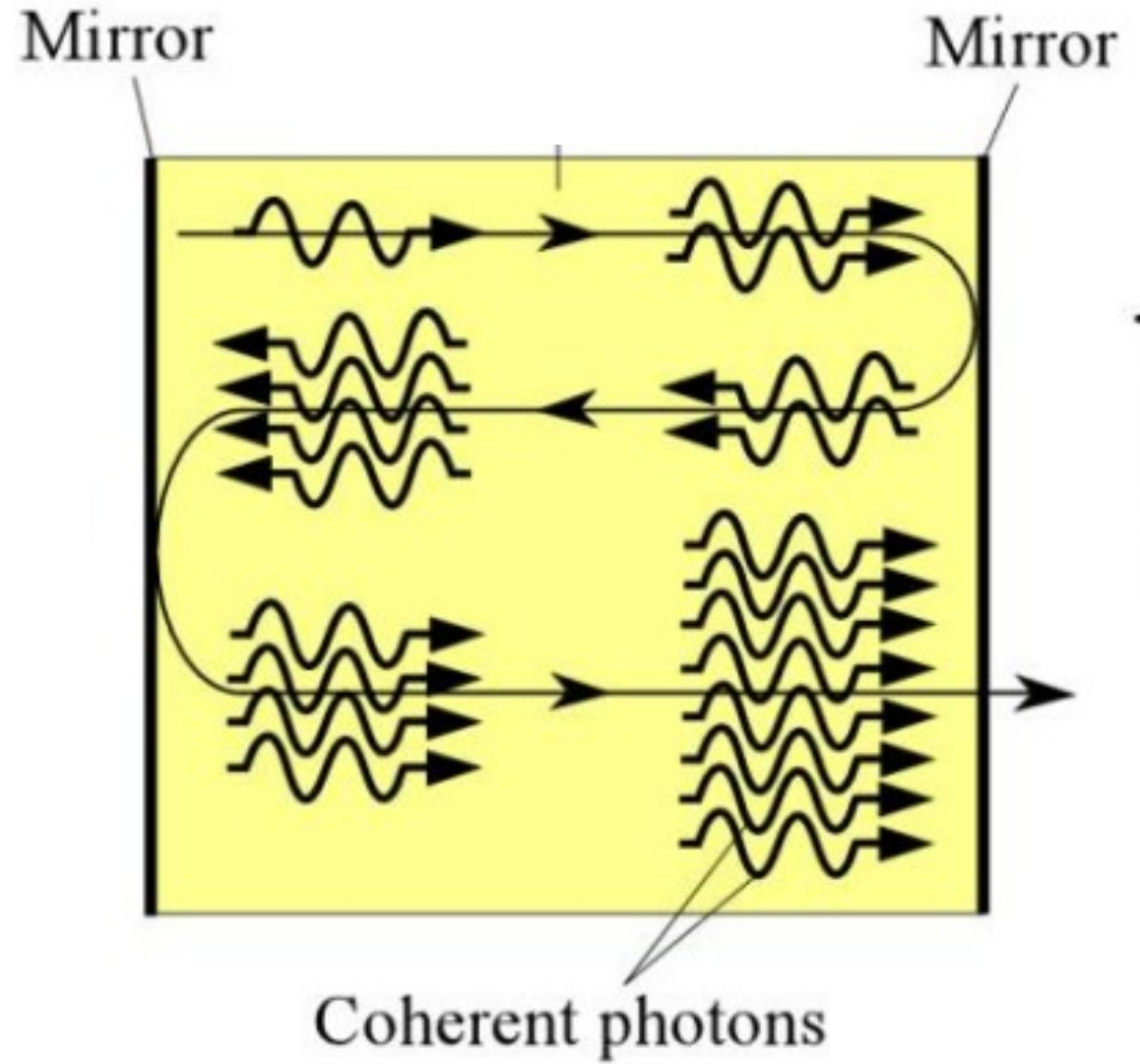
Lasers

- electrons gets pumped to a high energy level and falls to a slightly lower level
- 3 Levels are necessary to avoid reabsorption and allow again
- Incoming photons stimulates the electrons at that level to emit more photons



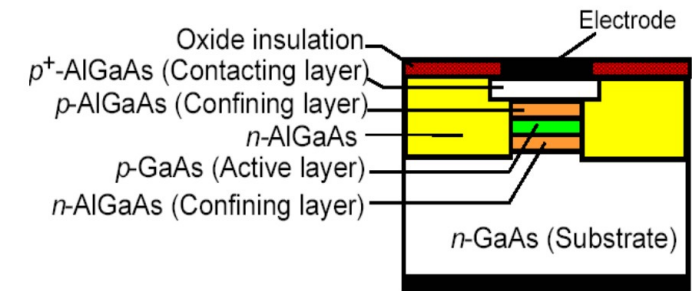
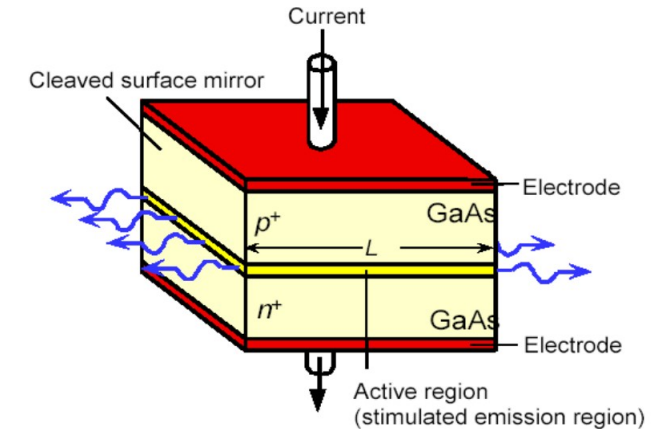
Lasers

- The light is generated in an optical cavity
- Photons build up in cavity, generating even more photons
- Out of phase and frequency are reabsorbed, making coherent light
- The Reflectance of the mirrors are nearly 100%



Laser Diodes

- In laser diodes pumping is achieved via injection of carriers due to induced current
- Semiconductors have a high reflective index and thus good reflectors
- For similar reasons to LEDs, heterogenous structures provide more benefits



LEDs vs Laser Diodes

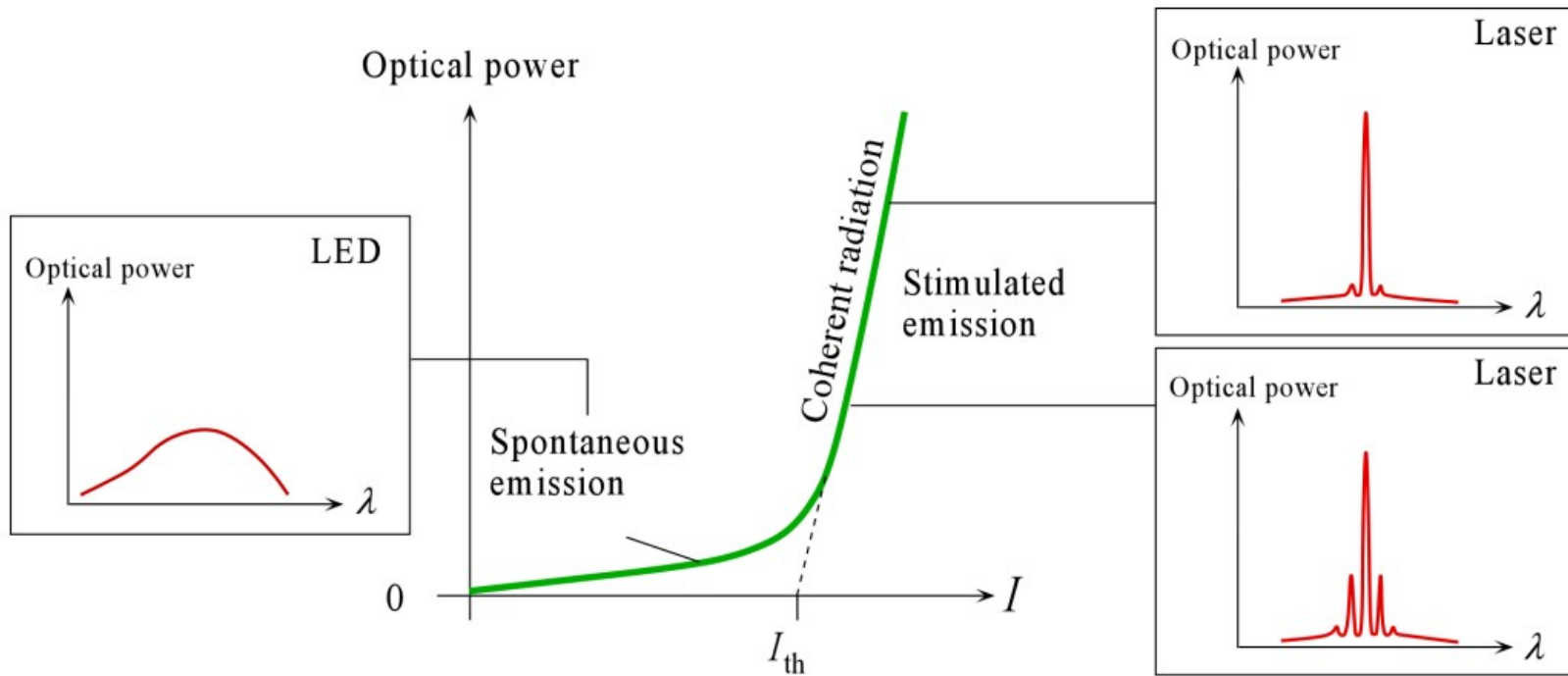
LEDs

- Simple design
- Low output intensity
- Non-coherent light
- Scattered beam
- Low input current
- Wider frequency spectrum

Laser Diodes

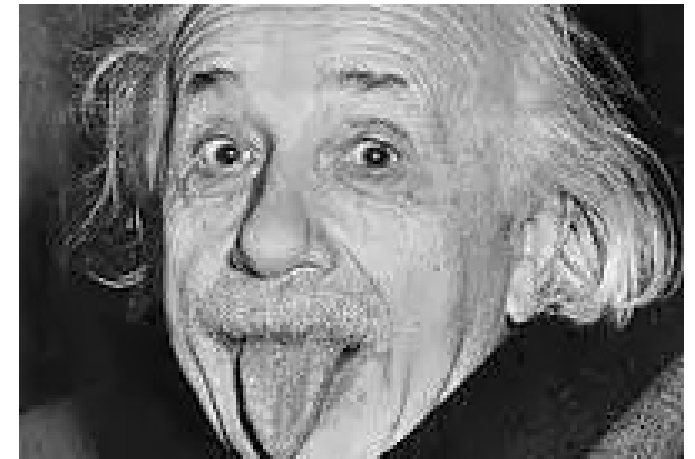
- Complex Design
- High output intensity
- Coherent light
- Directed beam
- High input current
- Narrower frequency spectrum

LEDs vs Lasers



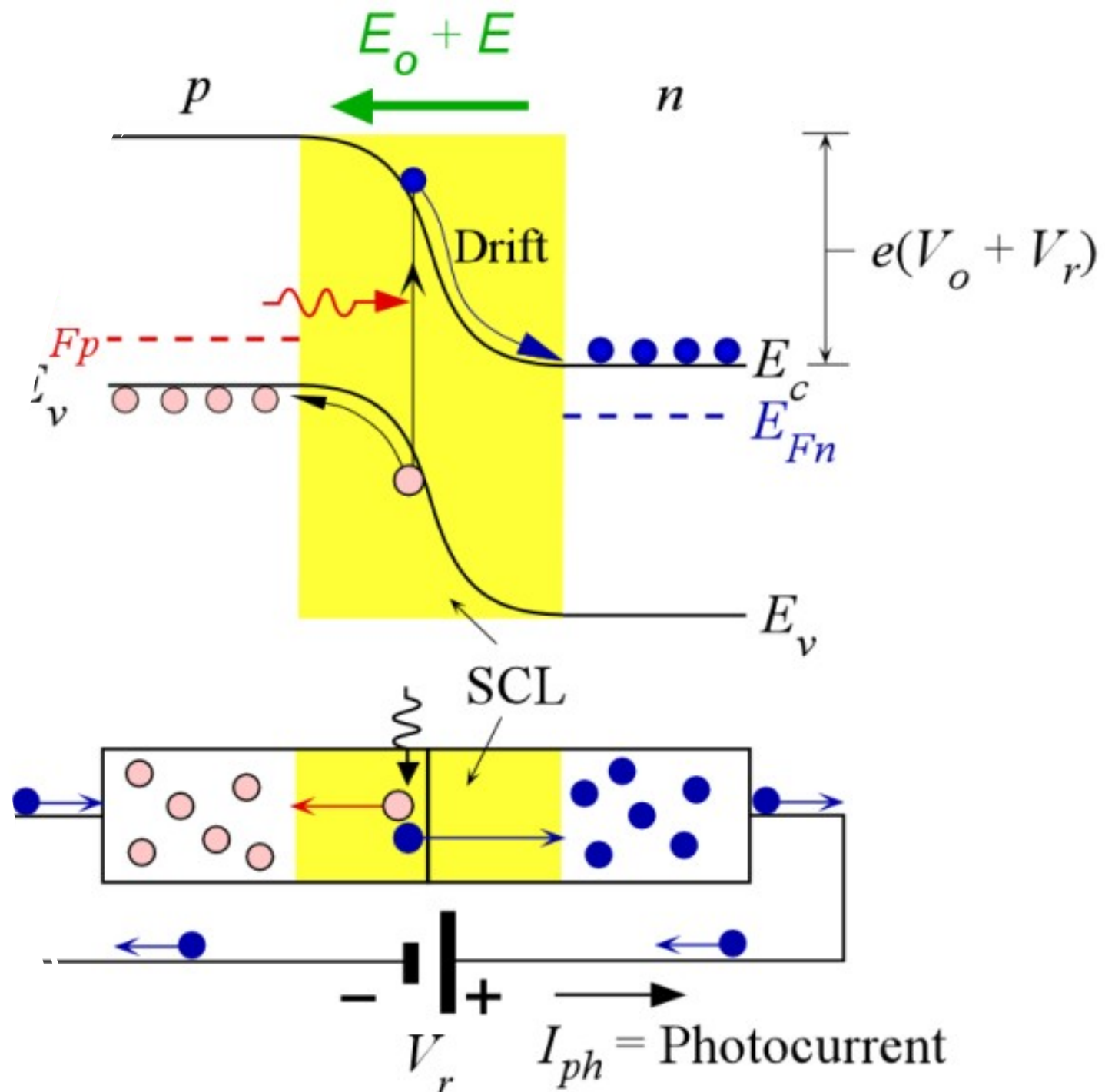
Photodiodes

- Take in light and converts it into current
- Photodiodes can act as (bad) LEDs
- This is possible due to the photoelectric effect
 - Photon hits a material and ionizes electron



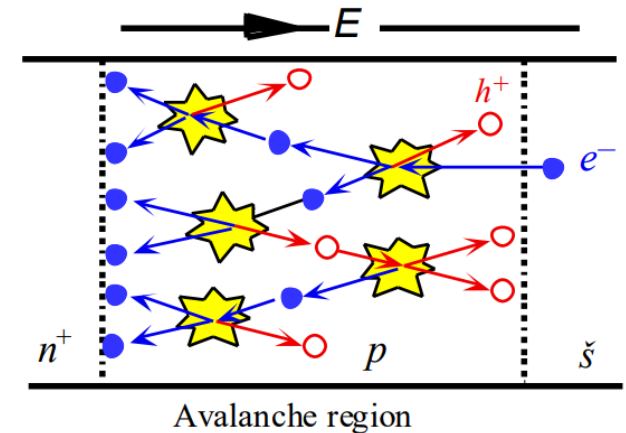
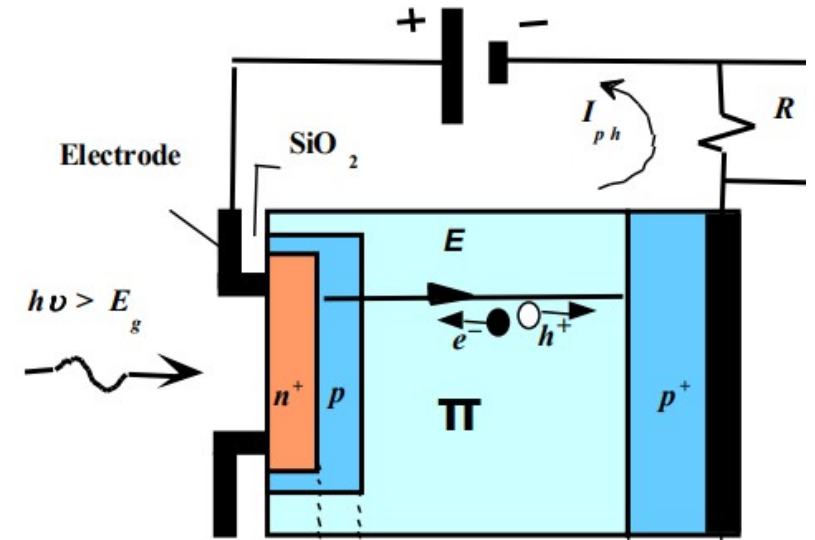
Photodiodes

- Photodiode is placed in reverse bias, creating a large energy difference between p and n sides
- Photons ionize material, creating free electron and hole
 - Due to large energy difference, the carriers drift to respective sides, creating current



Avalanche Photodiode

- The photons are mainly absorbed in the π -region, which is very lightly doped ($< 10^{14} \text{ cm}^{-3}$)
- p region acts as the avalanche region, which electrons are multiplied

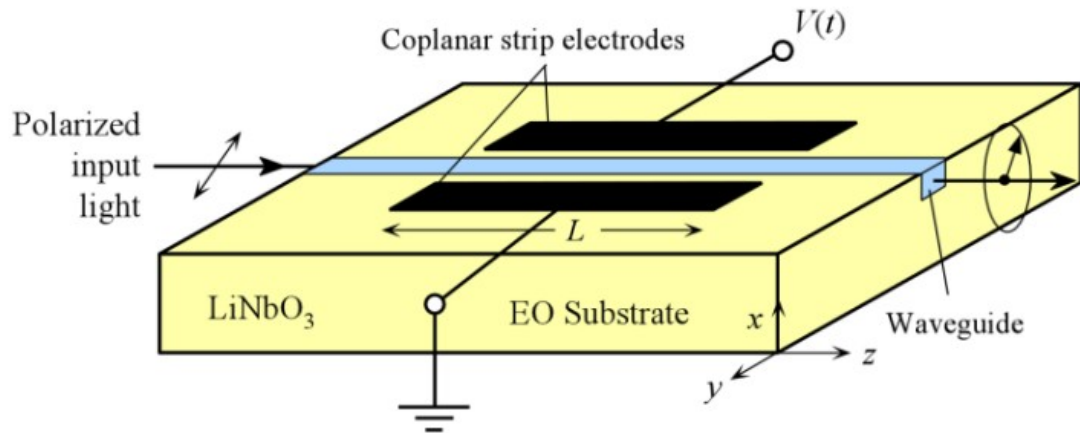


Photodiode materials

Photodiode	λ_{range}	λ_{peak}	R at λ_{peak}	Gain	I_d For 1 mm ²	Features
GaP <i>pin</i>	nm 150–550	nm 450	A/W 0.1	<1	1 nm	UV detection ^a
GaAsP <i>pn</i>	150–750	500–720	0.2–0.4	<1	0.005–0.1 nA	UV to visible, covering the human eye, low I_d .
GaAs <i>pin</i>	570–870	850	0.5–0.5	<1	0.1–1 nA	High speed and low I_d
Si <i>pn</i>	200–1100	600–900	0.5–0.6	<1	0.005–0.1 nA	Inexpensive, general purpose, low I_d
Si <i>pin</i>	300–1100	800–1000	0.5–0.6	<1	0.1–1 nA	Faster than <i>pn</i>
Si APD	400–1100	800–900	0.4–0.6 ^b	10–10 ³	1–10 nA ^c	High gains and fast
Ge <i>pin</i>	700–1800	1500–1580	0.4–0.7	<1	0.1–1 μ A	IR detection, fast.
Ge APD	700–1700	1500–1580	0.4–0.8 ^b	10–20	1–10 μ A ^c	IR detection, fast
InGaAs <i>pin</i>	800–1700	1500–1600	0.7–1	<1	1–50 nA	Telecom, high speed, low I_d
InGaAs APD	800–1700	1500–1600	0.7–0.95 ^b	10–20	0.05–10 μ A ^c	Telecom, high speed and gain.
InAs <i>pn</i>	2–3.6 μ m	3.0–3.5 μ m	1–1.5	<1	>100 μ A	Photovoltaic mode. Normally cooled
InSb <i>pn</i>	4–5.5 μ m	5 μ m	3	<1	Large	Photovoltaic mode. Normally cooled

Optical Phase Modulator

- Electro-Optic Effect
 - Different materials change their refractive index in the presence of an electric field
- A voltage signal can be used to encode a message onto a beam
 - Like phase modulated radio!



Induced phase change

$$\Delta\phi = \Gamma \frac{2\pi}{\lambda} n_o^3 r_{22} \frac{L}{d} V$$

Spatial overlap efficiency = 0.5 – 0.7

Pockels coefficient
Different for different crystal orientations

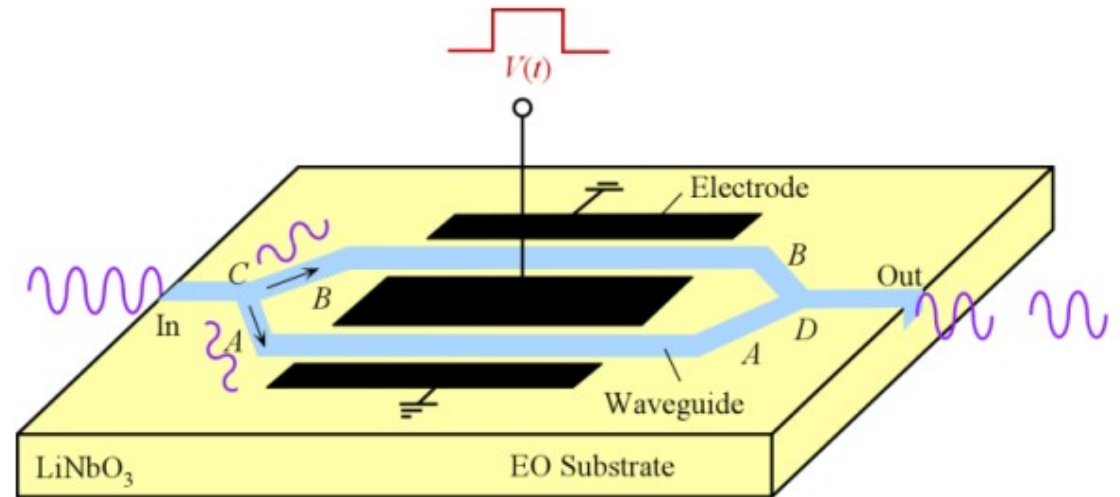
Length of electrodes

Applied voltage

Electrode separation

Mach-Zehnder Modulator

- Takes advantage of out of phase photons to cancel out
- Clear use in transmitting binary data





Why to Use Optoelectronics



Benefits of Optoelectronics

- Allows for multiplexing of multiple channels by using different colors
 - Don't have to deal with different interfering signals or characteristic impedance
- Allows for transfer of much more data via a single fiber strand

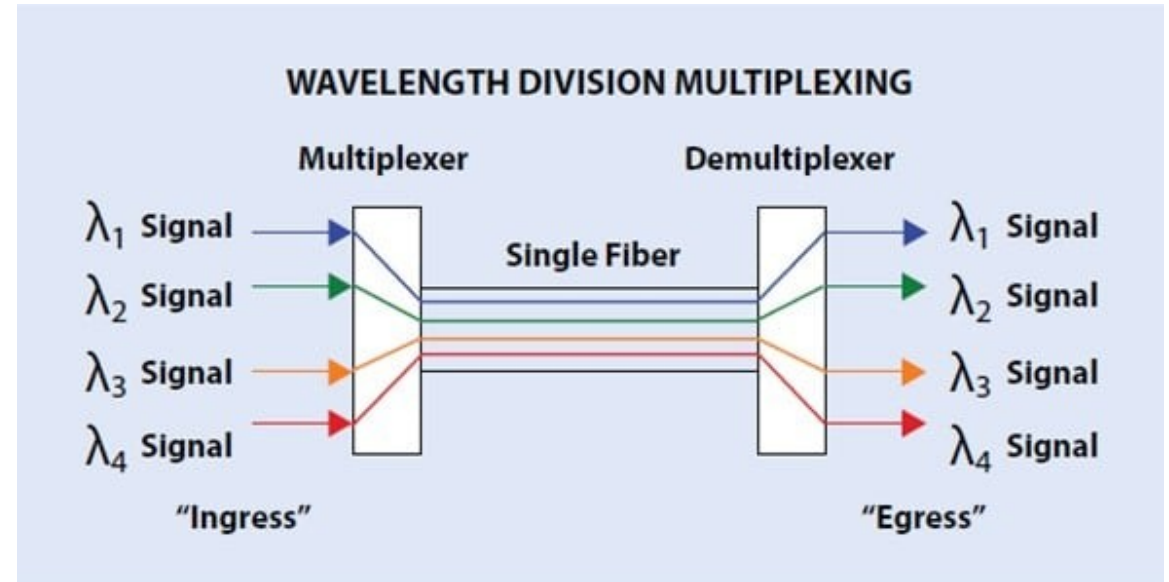


Figure 1: Basic WDM Technology Diagram

Benefits of Optoelectronics

- No electromagnetic interference
 - Photons do not create any extra E&M interference
 - This allows designs to be smaller
 - Relevant in small traces
- Low power losses
 - Allows cables to be much smaller compared to electrical counterpart at long distance

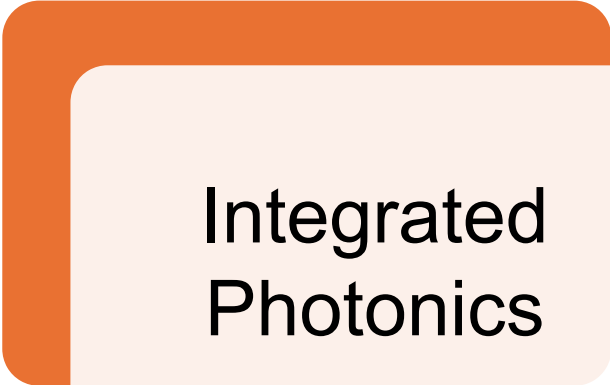
Applications of Optoelectronic Devices



How are Optoelectronic Devices Being Used?



Fiber-Optic
Communication



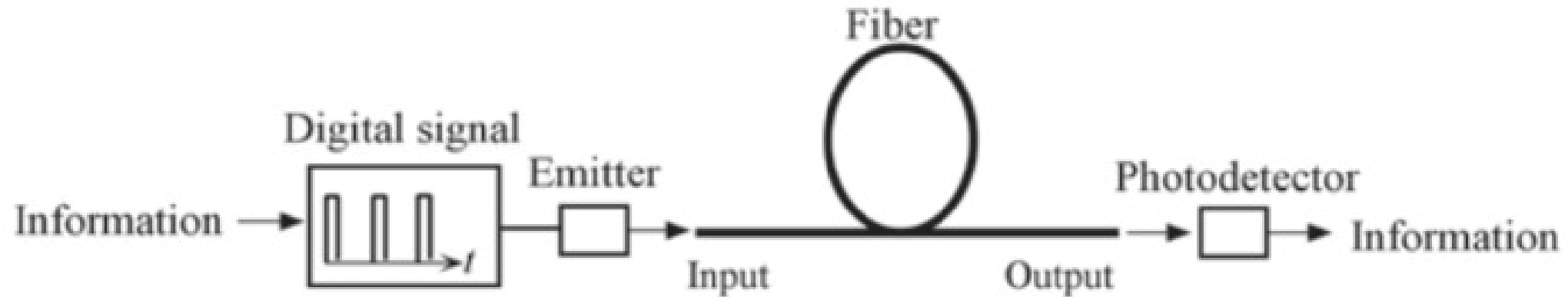
Integrated
Photonics



LiDAR

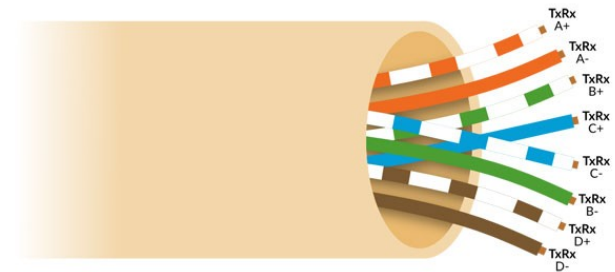
Fiber-Optic Communication

- Information is encoded by a laser onto a fiber-optic waveguide over a long distance and detected via a photodiode
- Losses over distance are much lower compared to copper
 - Fiber-optic: 0.0002 – 0.003 dB/m
 - Copper: 0.2 – 40 dB/m
- Fiber-optic is more expensive up front



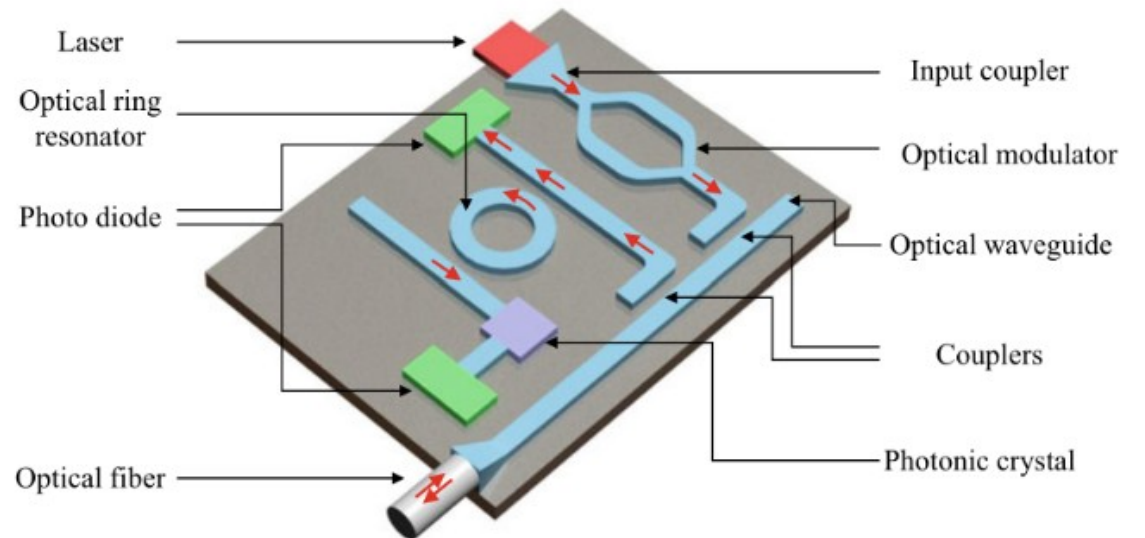
Fiber-Optic Communication

- Optic fibers are much smaller compared to copper cables
 - Fiber-Optic: 250 microns thick
 - Copper: 8 mm thick
- Smaller size allows fiber cables to contain more strands compared to ethernet



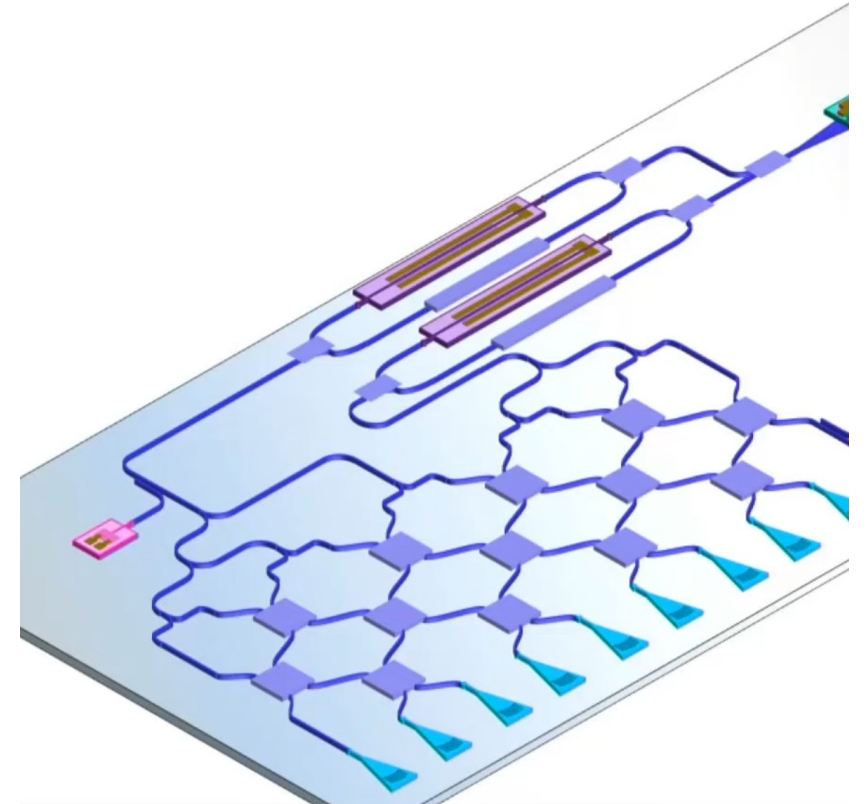
Integrated Photonics

- Waveguides and modulators can be used within chips to perform calculations
- Optical modulator can be used to “program” functions using light
 - By altering phase and amplitude



Programmable Photonics Chips

- The mesh of Mach-Zehnder Interferometers manipulate can be programmed to perform a specific operation
- Perfect for performing matrix operations at light speed
 - Interference patterns represent elements in matrix multiplication
 - Parallel computing
 - Used in neuromorphic computing



LiDAR

- Very similar to Radar, but uses light instead of radio waves
- Light is shot out from lasers thousand times a second, and photodiodes are used to detect when they bounce back
- Math is used to find the distance from the source and target based off return time



Conclusion

- Many optoelectronics take advantage of photon emission and absorption in bandgaps to generate and read light
- Optoelectronics provide more efficient and low power solutions to popular issues, although with added complexity and up-front costs



Thank you for Listening