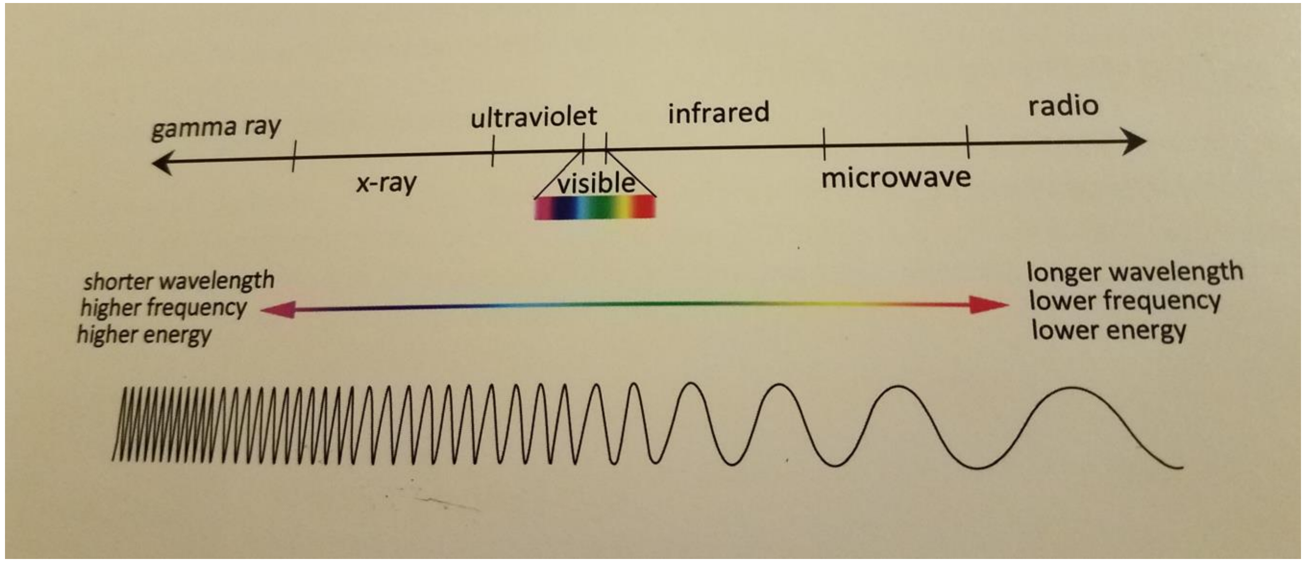
Light & Photonics

The United Nations proclaimed 2015 as the International Year of Light and Light Based Technologies

To raise global awareness of how light based technologies promote sustainable development and provide solutions to global challenges in energy, education, agriculture and health.

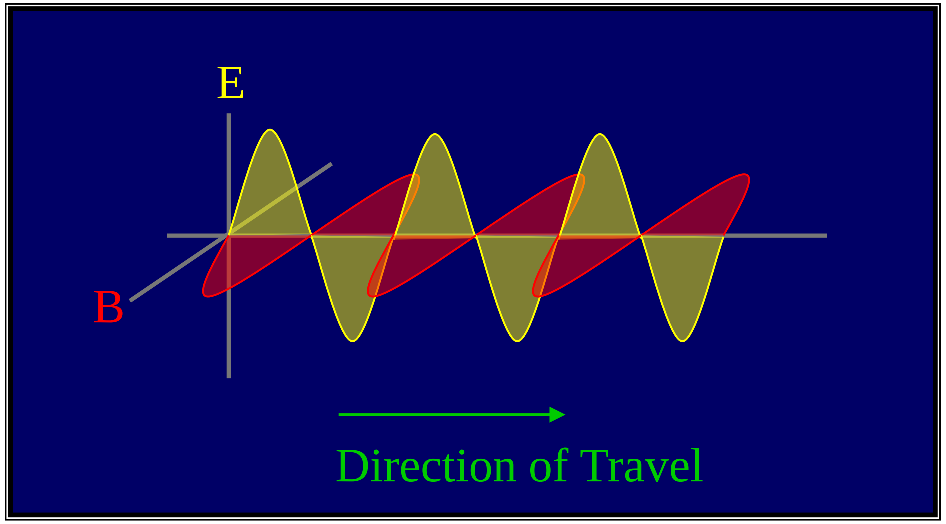
Light is a form of energy that can behave both as waves and as particles called photons. The various forms of light span the electromagnetic spectrum from x-rays to radio waves. Let's start with a **video** on **Introduction to Light**.

Only a small portion of this spectrum is visible to the human eye. Most recent technologies are based on parts of the spectrum we cannot actually see, so we do not think of them as light.



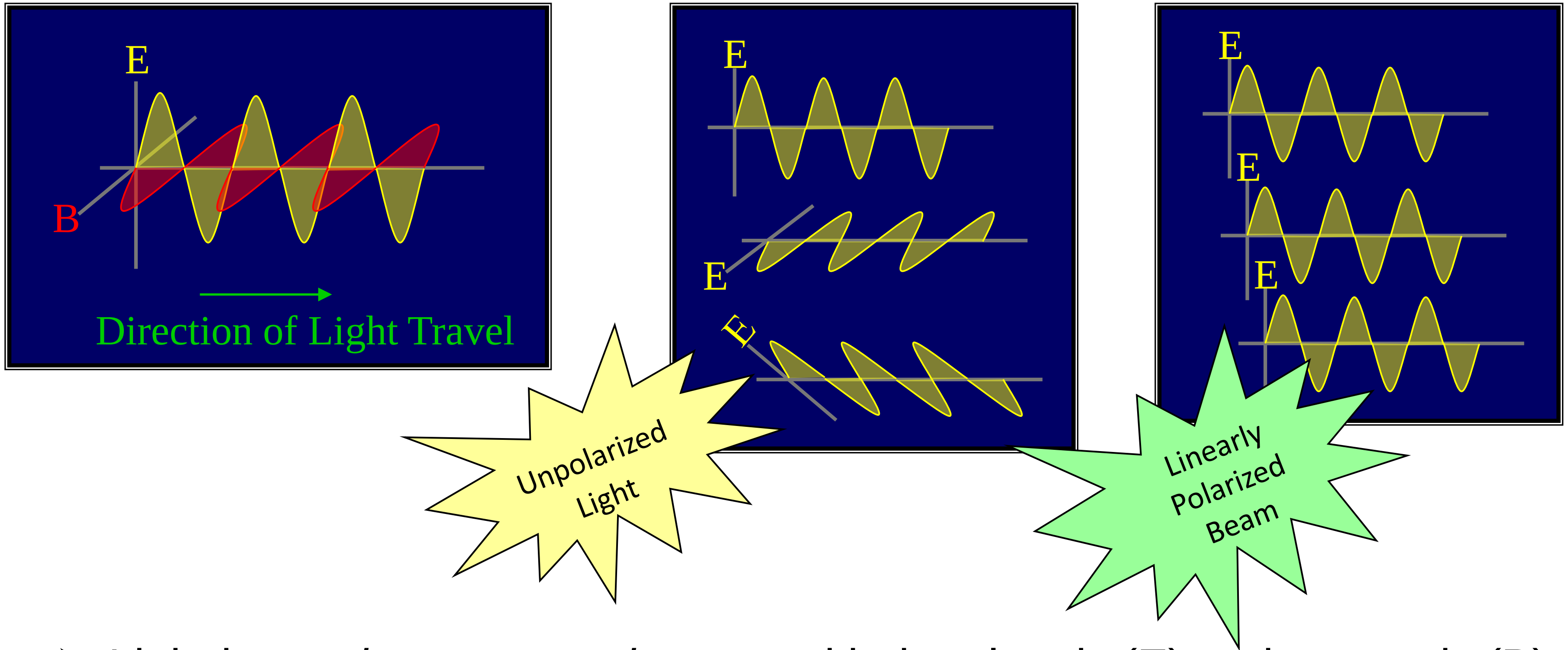
Let's start with a video on Introduction to light.

Light and Polarization



- Light is an *electromagnetic wave* because it requires two interdependent fields to propagate.
- Both electrical (**E**) and magnetic (**B**) waves must exist for light to propagate. **E** and **B** are perpendicular to each other and to the direction of motion. This is called a transverse wave.
- Wavelength and frequency and velocity are important attributes of light.
- The electric field has the greater effect on materials, and so we mostly ignore the effect of the magnetic field from this point on in Photonics.

Light and Polarization

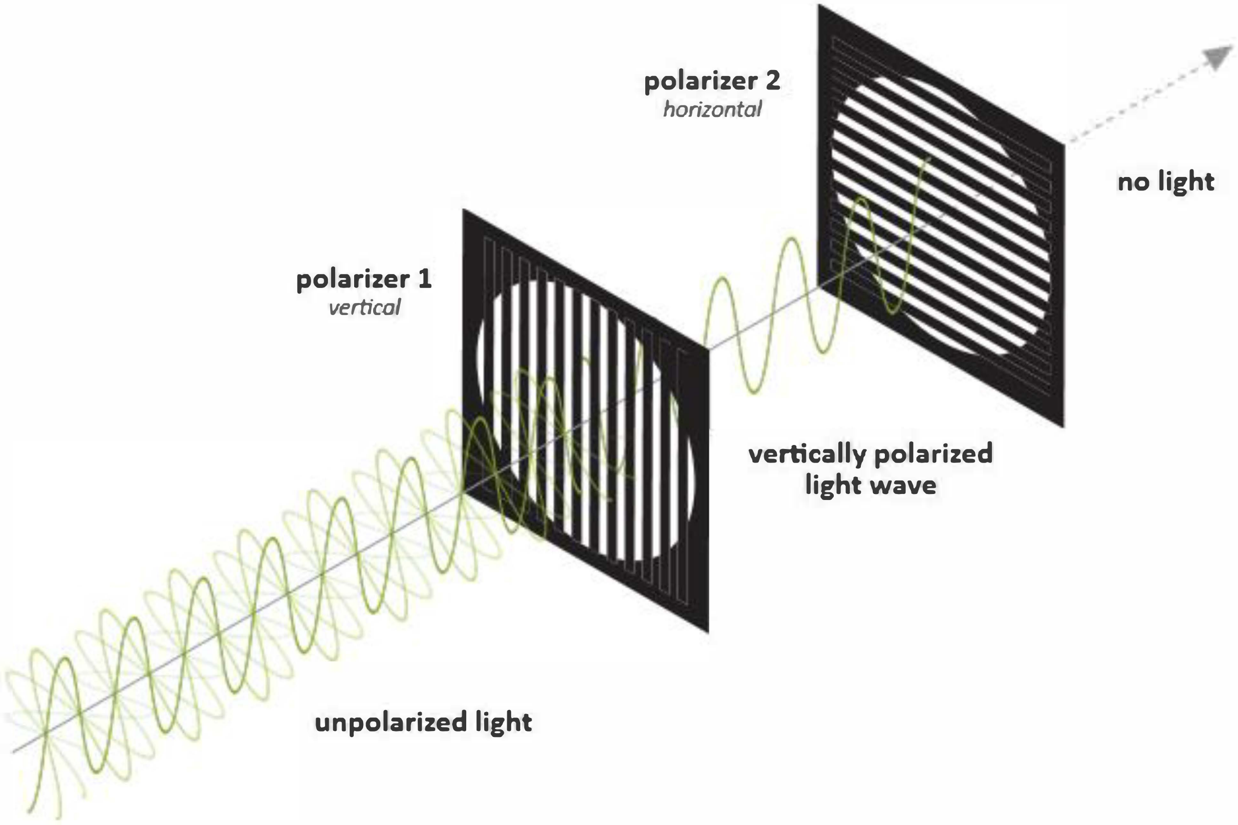


- Light is an *electromagnetic wave* with the electric (E) and magnetic (B) vectors orthogonal to each other.
- Wave theory is the simplest way to explain polarization of light
- In unpolarized light electric fields vary along many directions
- In polarized light electric fields of waves vary along the **same direction**

How polarizers block light

Most light sources, like light bulbs or the sun, produce light waves that are oriented in all different directions. Polarizers work by blocking certain orientations of light. Once light goes through a polarizer, it is *plane polarized*, meaning that all of the light waves passing through are parallel to each other.

When you look through two (or more) polarizers, the brightness depends on how the polarizers are aligned. So when you rotate the polarizers, the brightness changes. When two polarizers are aligned parallel to each other, the light that makes it through the first polarizer will make it through the second polarizer. Parallel polarizers like this let the most light through and look the brightest. Conversely, when two polarizers are perpendicular to each other, the light that makes it through the first polarizer is oriented perpendicular to the second polarizer, so it will be blocked. Polarizers that are fully perpendicular to each other are called *crossed polarizers*, let the least light through, and look the darkest.



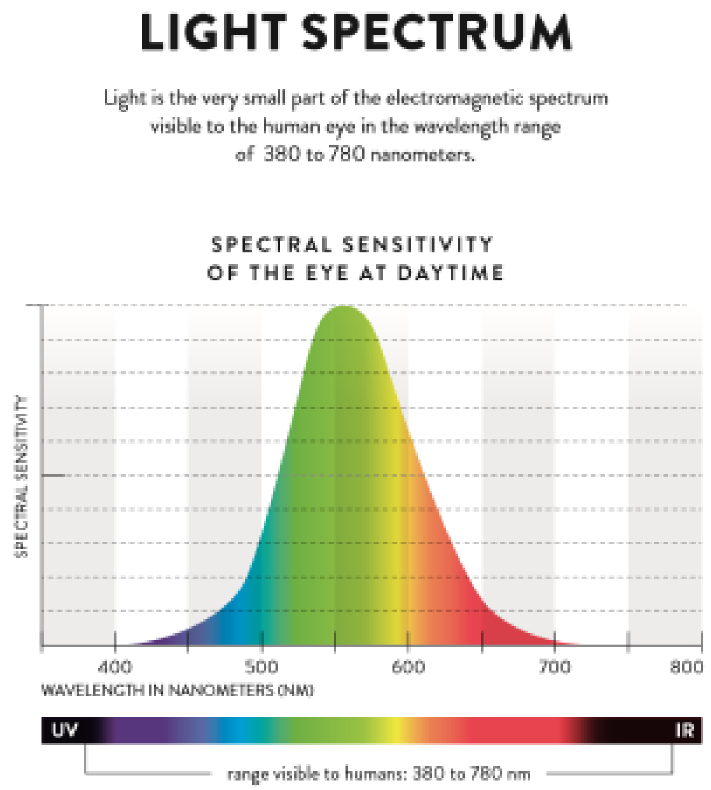
Light and Photonics

Basic Properties of light
- Transmission
- Reflection
- Refraction
- Absorption

Main attributes of light
- Wavelength
- Frequency
- Velocity

How do we see colors? …..

Photopic sensitivity

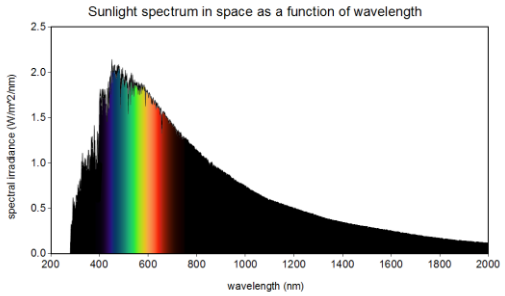


Introduction to Photonics TED talk https://www.youtube.com/watch?v=vYxjS0bGuCM.

Comparing Light Sources

Sunlight

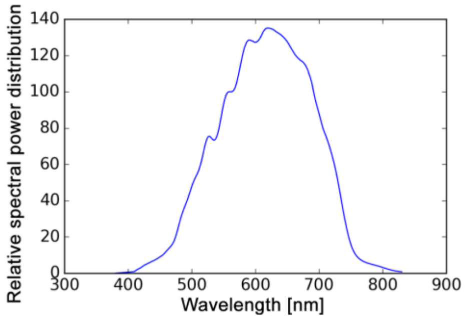
- Incoherent light
- Multiple wavelengths over a broad spectrum



Lightbulb

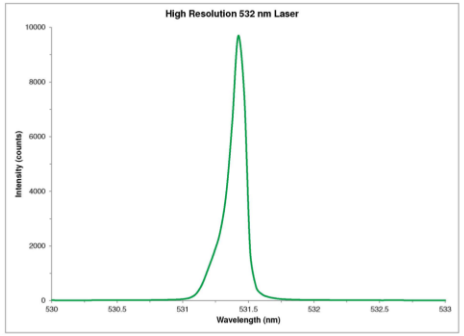
- Incoherent
- Multiple wavelengths, narrow

spectrum



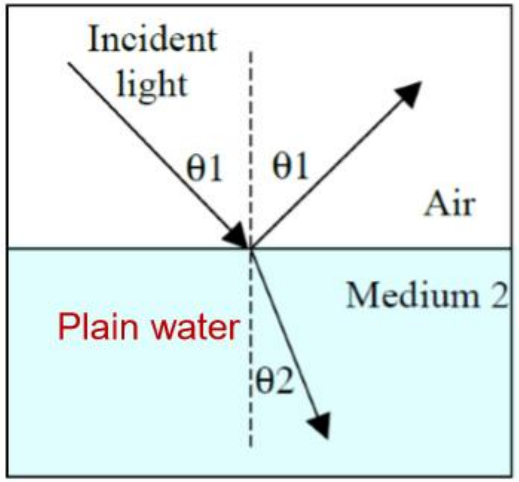
Laser

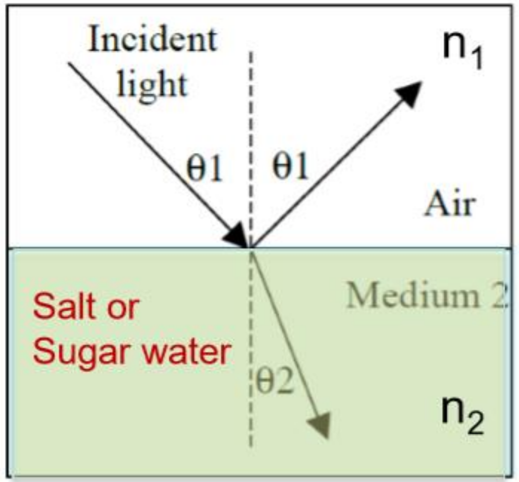
- Monochromatic- single wavelength
- Coherent light



shutterstock.com • 527918392

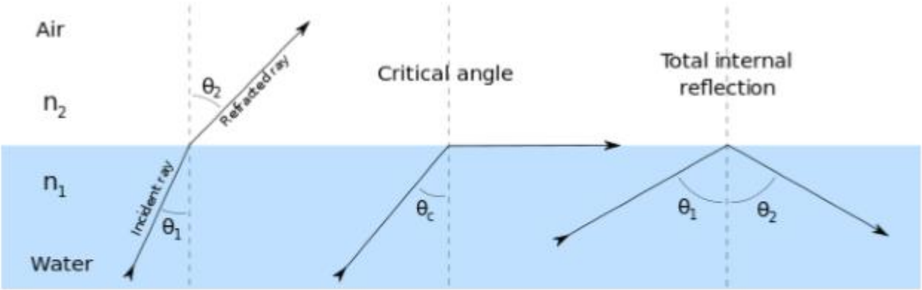
Manipulation of light using Refractive Index



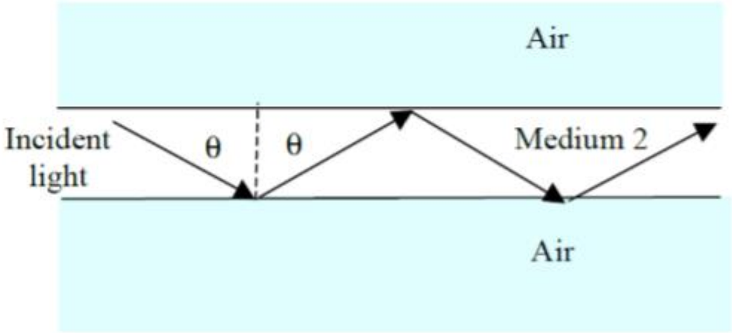


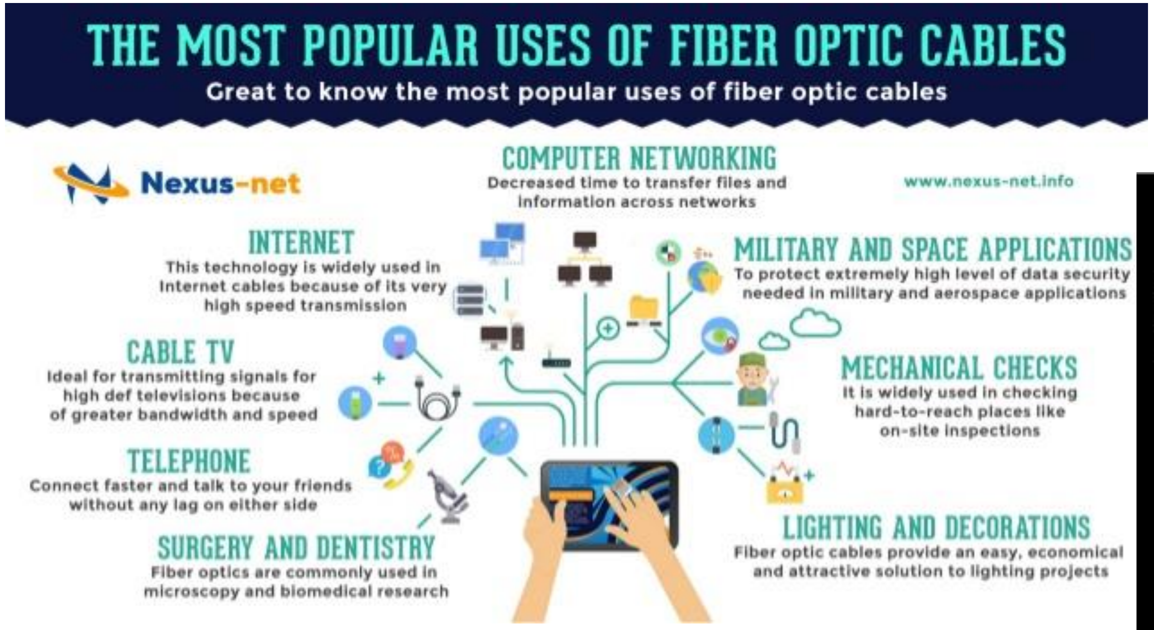
Snell's Law

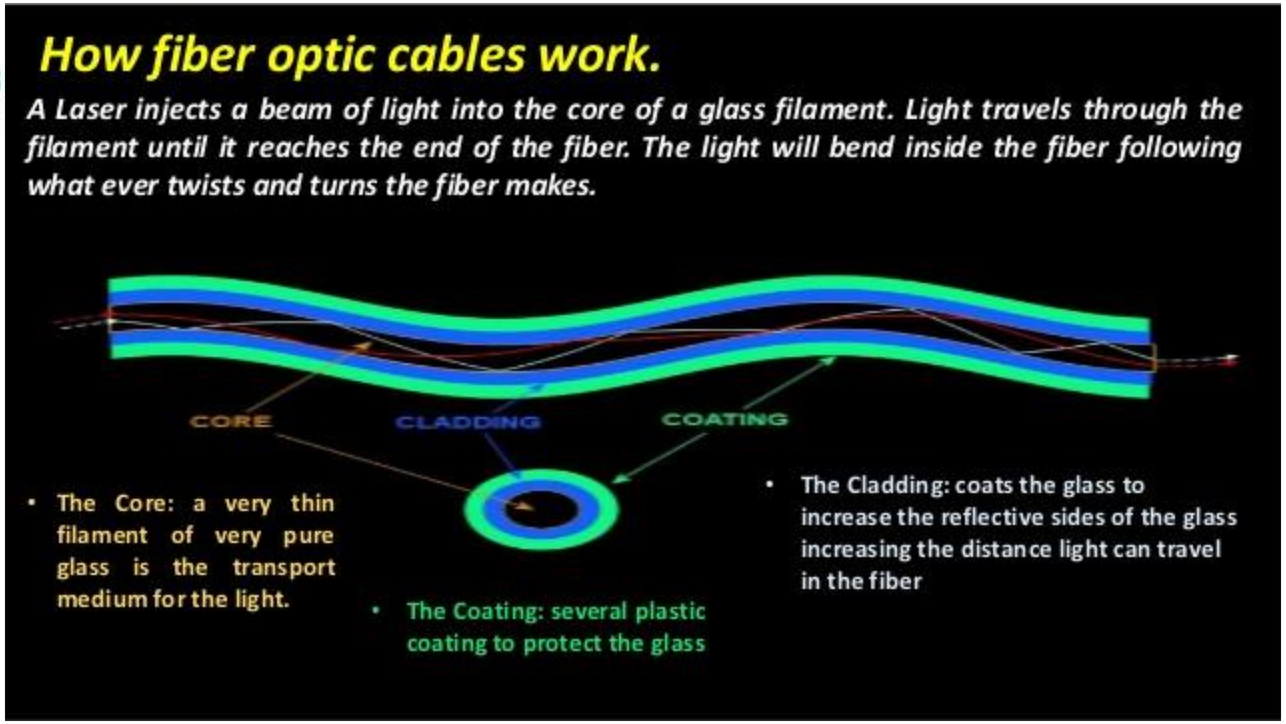
$$\frac{n_1}{n_2} = \frac{\sin\theta_2}{\sin\theta_1}$$

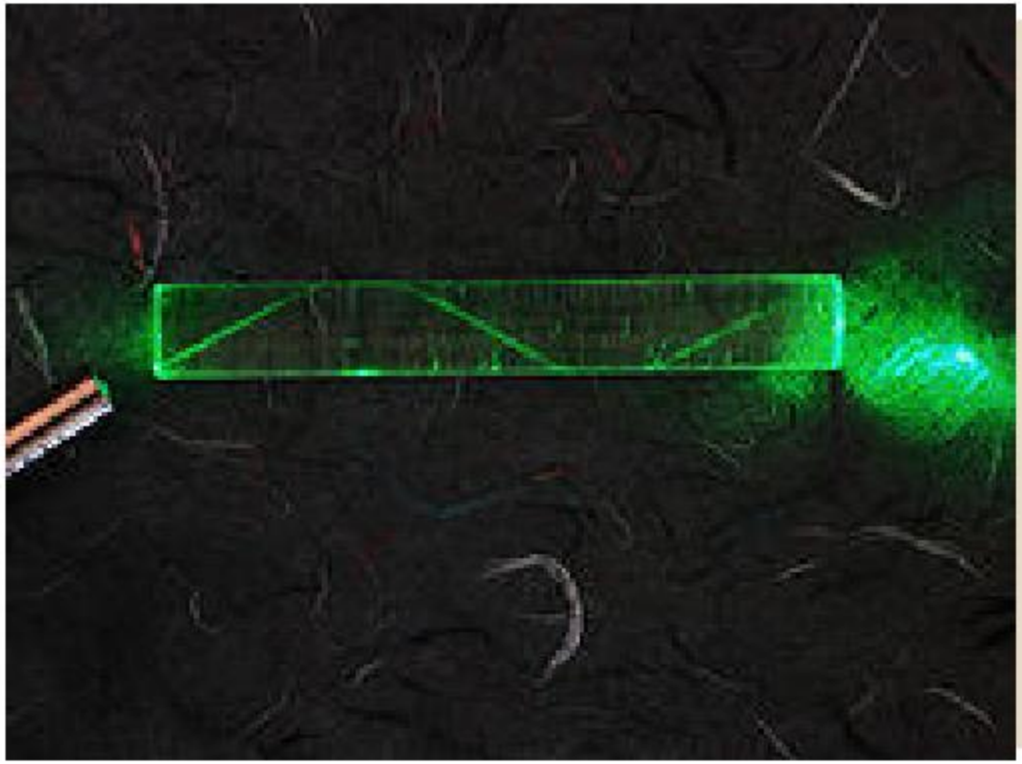


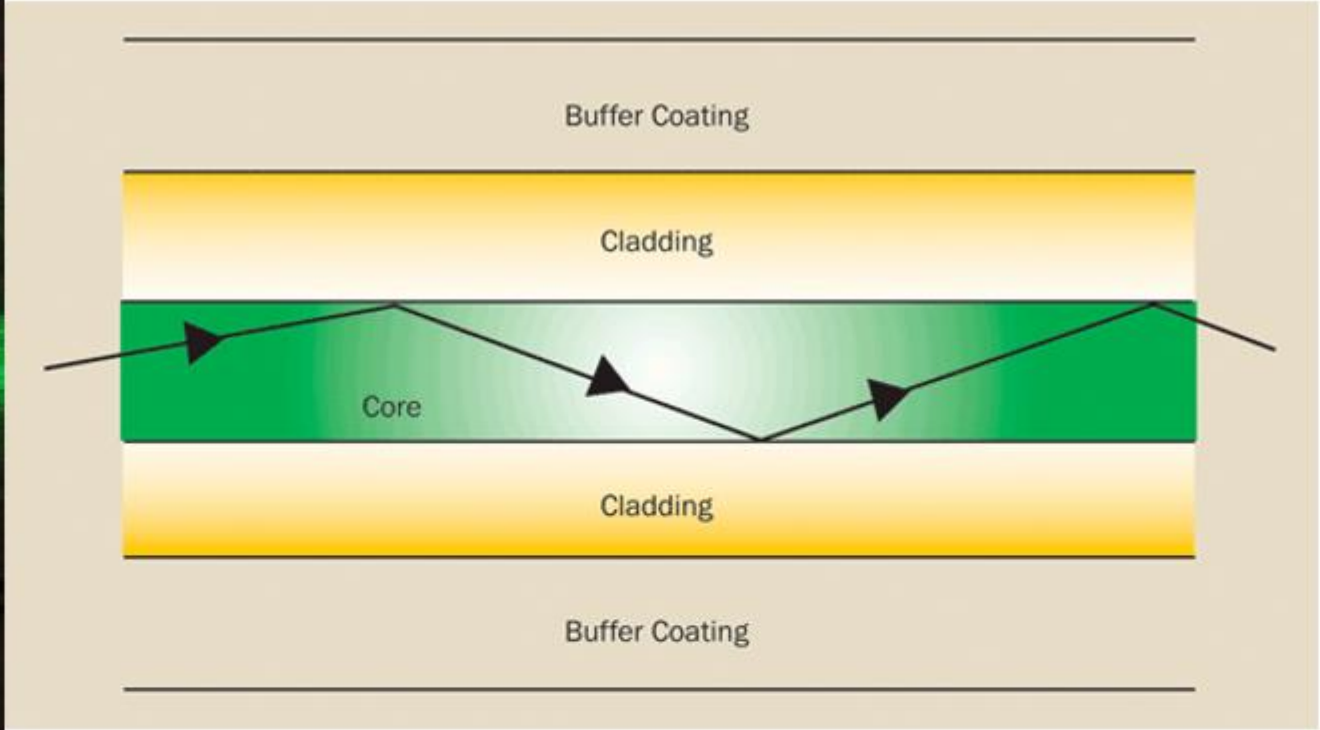
Total Internal Reflection

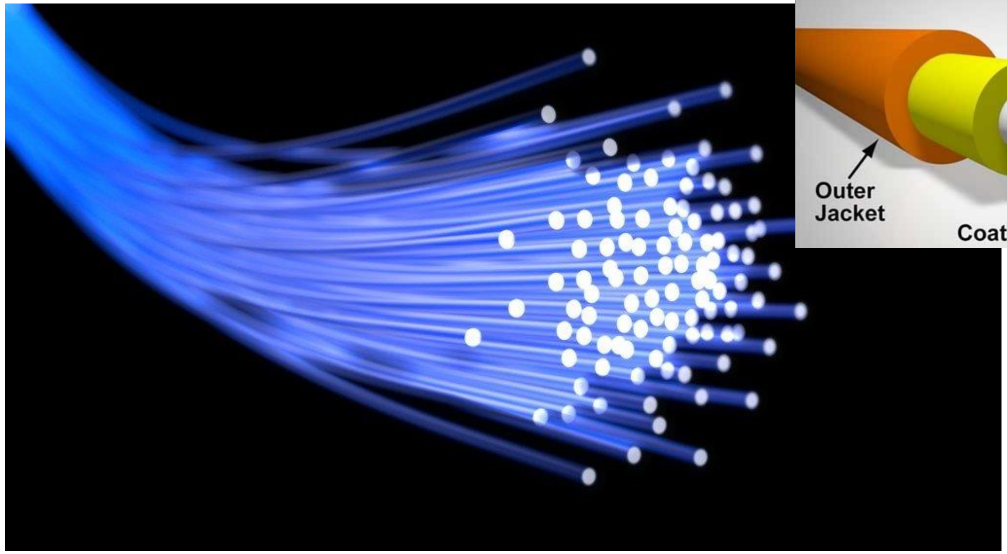


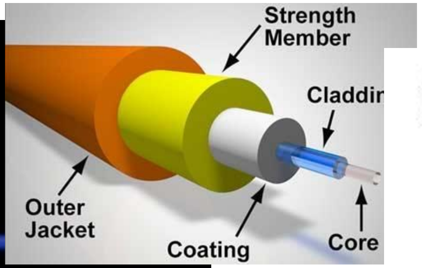

THE MOST POPULAR USES OF FIBER OPTIC CABLES
Great to know the most popular uses of fiber optic cables
Nexus-net
www.nexus-net.info
COMPUTER NETWORKING
Decreased time to transfer files and information across networks
INTERNET
This technology is widely used in Internet cables because of its very high speed transmission
MILITARY AND SPACE APPLICATIONS
To protect extremely high level of data security needed in military and aerospace applications
CABLE TV
Ideal for transmitting signals for high def televisions because of greater bandwidth and speed
MECHANICAL CHECKS
It is widely used in checking hard-to-reach places like on-site inspections
TELEPHONE
Connect faster and talk to your friends without any lag on either side
LIGHTING AND DECORATIONS
Fiber optic cables provide an easy, economical and attractive solution to lighting projects
SURGERY AND DENTISTRY
Fiber optics are commonly used in microscopy and biomedical research

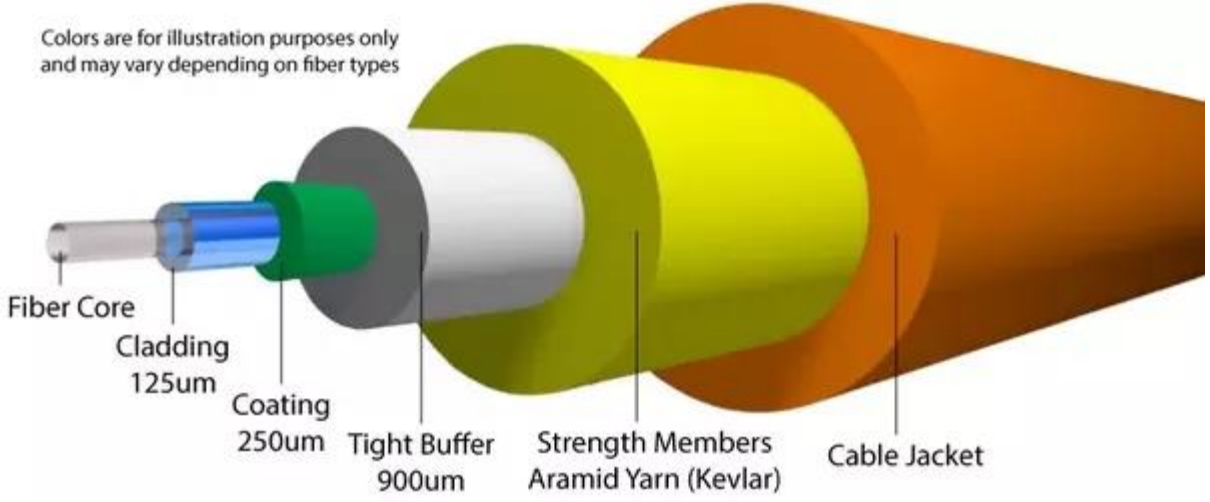

How fiber optic cables work.
A Laser injects a beam of light into the core of a glass filament. Light travels through the filament until it reaches the end of the fiber. The light will bend inside the fiber following what ever twists and turns the fiber makes.
CORE
CLADDING
COATING
• The Core: a very thin filament of very pure glass is the transport medium for the light.
• The Coating: several plastic coating to protect the glass
• The Cladding: coats the glass to increase the reflective sides of the glass increasing the distance light can travel in the fiber




Buffer Coating
Cladding
Core
Cladding
Buffer Coating




Strength Member
Outer Jacket
Coating
Core


Colors are for illustration purposes only and may vary depending on fiber types
Fiber Core
Cladding 125um
Coating 250um
Tight Buffer 900um
Strength Members Aramid Yarn (Kevlar)
Cable Jacket

Please see the AIM Photonics Videos here

- https://aimphotonics.academy/videos
- https://www.youtube.com/watch?v=er3v4PVNQqE

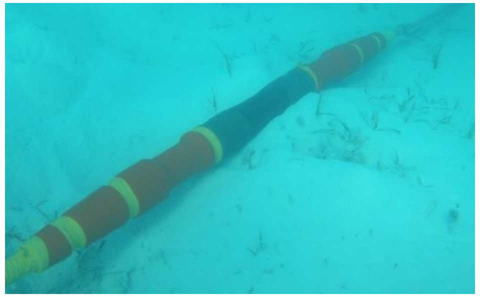


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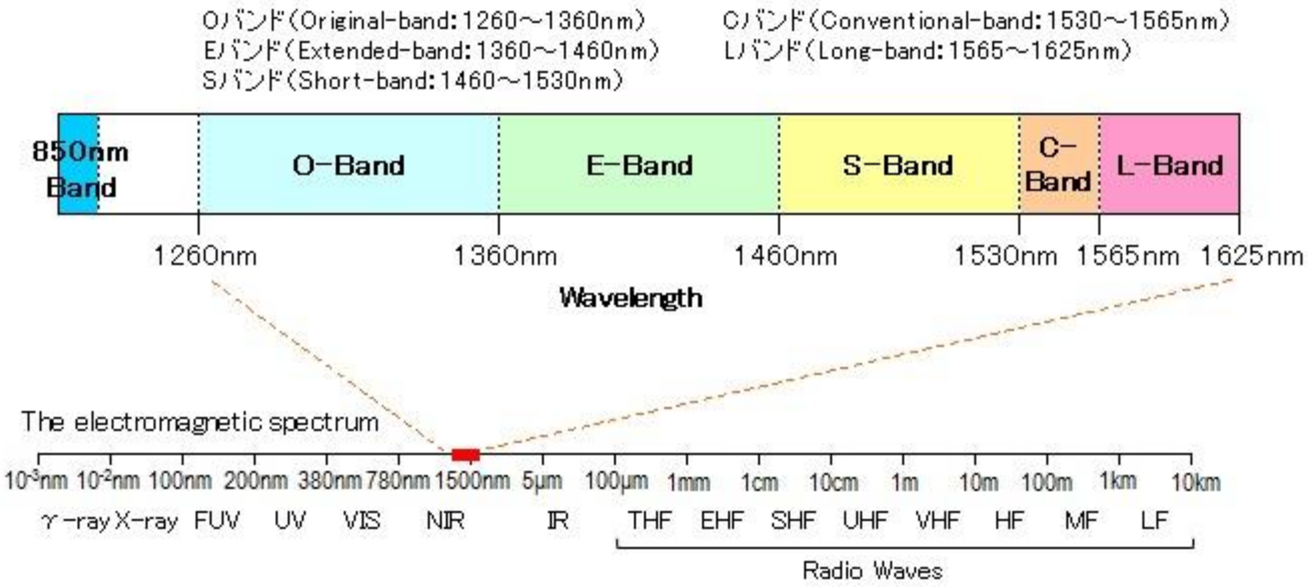
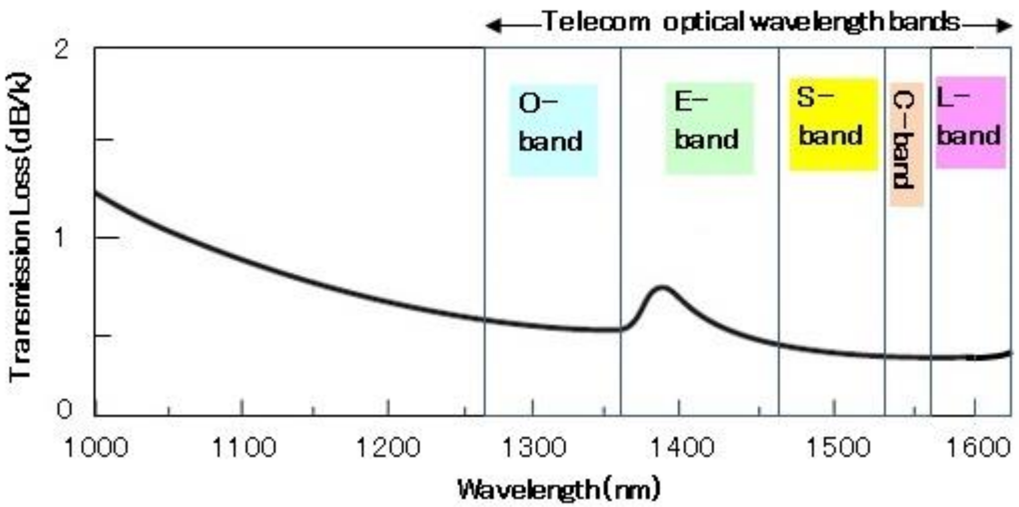
Figure 1 Transmission loss of silica fiber and optical communication wavelength bands





- Among these five bands, the O-band (orignal band: 1260-1360 nm) was historically the first wavelength band used for optical communication, because signal distortion (due to chromatic dispersion) is minimum. It was also because optical fibers produced in the mid 1970s showed its lowest loss near the O-band.
- Today optical fibers show its lowest loss in the C-band (conventional band: 1530-1565 nm), and thus is commonly used in many metro, long-haul, ultra-long-haul, and submarine optical transmission systems combined with the WDM and EDFA technologies.
- The L-band (long-wavelength band: 1565-1625 nm) is the second lowest-loss wavelength band, and is a popular choice when the use of the C-band is not sufficient to meet the bandwidth demand. The same WDM and EDFA technologies can be applied to the L-band.
- The loss of optical fiber in the S-band (short-wavelength band: 1460-1530 nm) is lower than that of the O-band, and the S-band is used for many PON (Passive-Optical Network) systems as the downstream wavelength.
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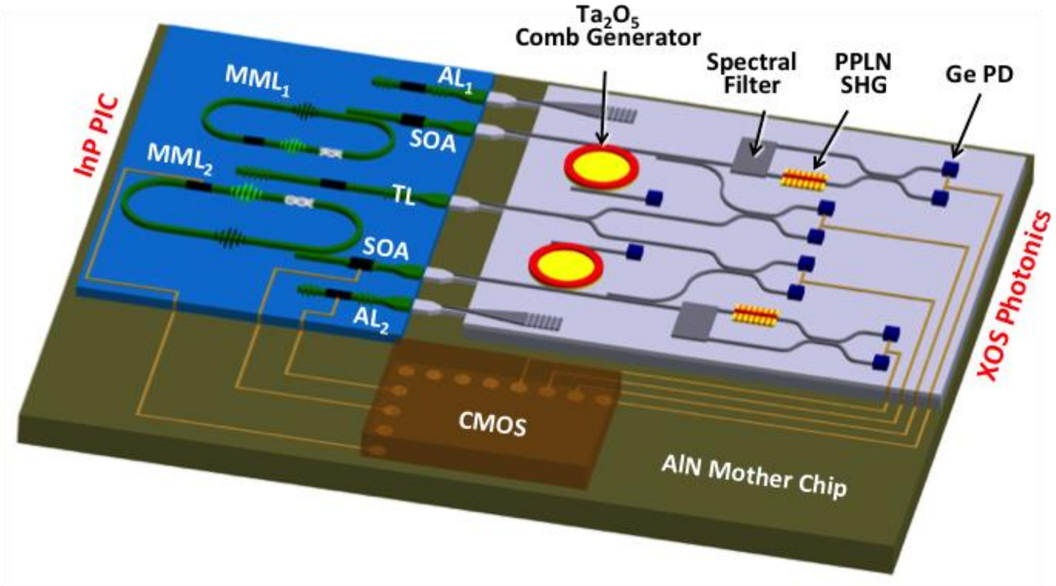
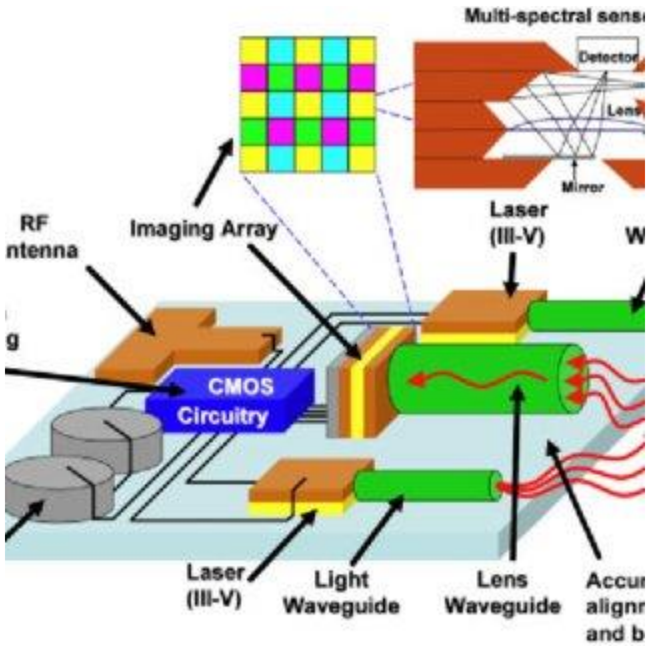
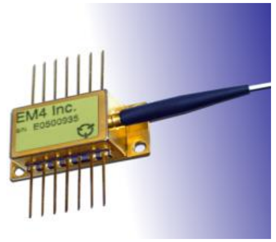
- In addition to the O- to L-bands, there are two more wavelength bands, namely the 850-nm-band and U-band (ultra-long-wavelength band: 1625-1675 nm). The 850-nm-band is the primary wavelength for multimode fiber optical communication systems, combined with VCSEL (Vertical-Cavity Surface Emitting Laser). The U-band is mainly used for network monitoring purposes.





Photonic Components in Optical Communication Systems

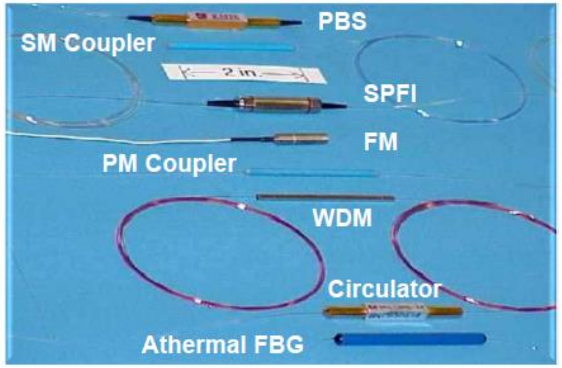
Optical Sources



Optical Modulators

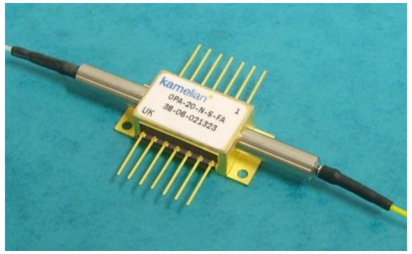
Photodiodes

Passive Components



Optical Amplifiers (Fiber)

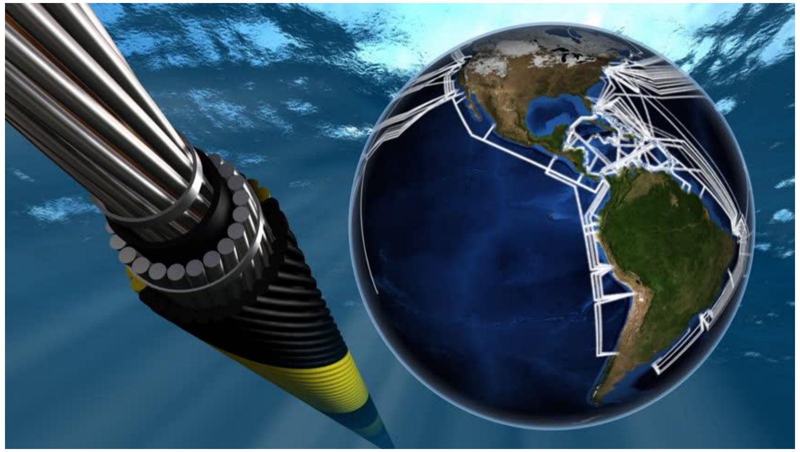
Optical Amplifiers (Semiconductor)

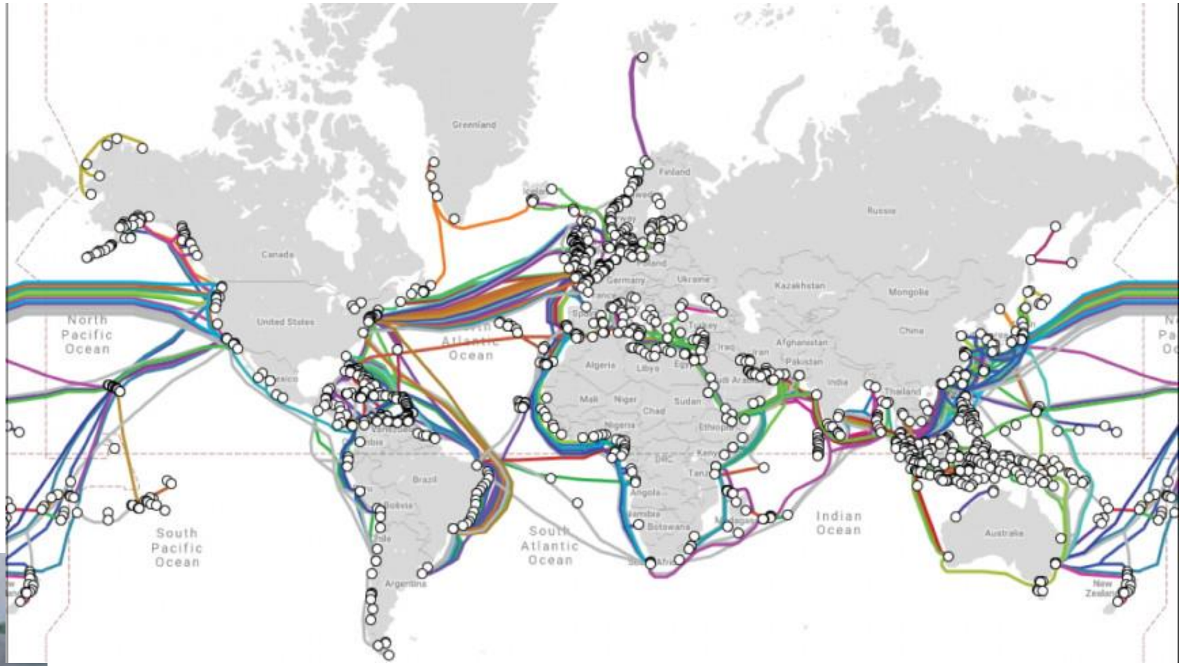


Tunable Optical Filters

Optical Switches

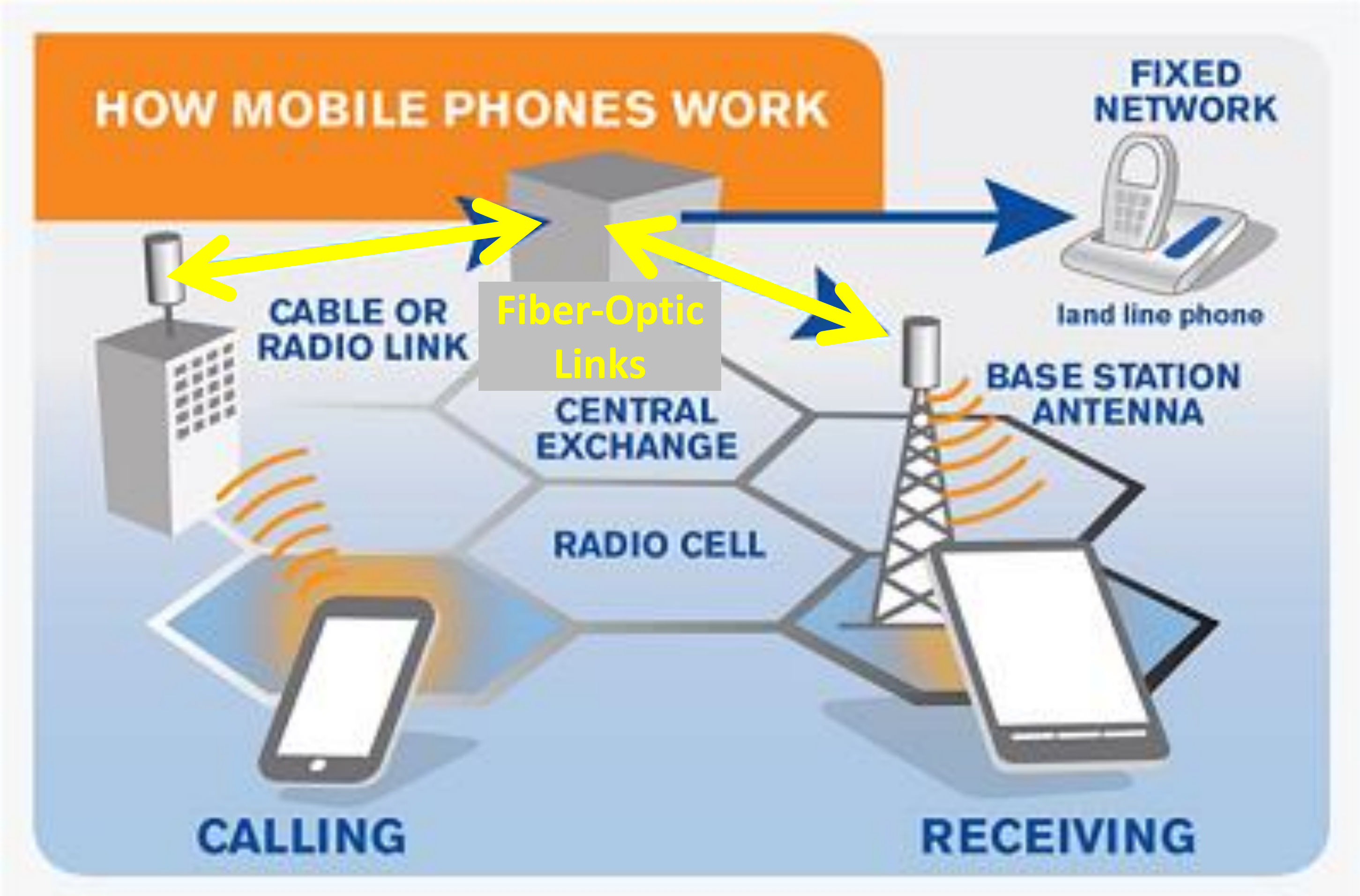
WDM Mux/Demux




Greenland
Finland
Russia
Canada
Kazakhstan
Mongolia
United States
China
North Pacific Ocean
Algeria
Libya
Mali
Niger
Chad
Sudan
India
Thailand
Brazil
Angola
Australia
South Pacific Ocean
South Atlantic Ocean
Indian Ocean

Devices Using Semiconductors Chips, Lasers and Photonic Chips

How Do Cell Phones Communicate Voice and Data Information?

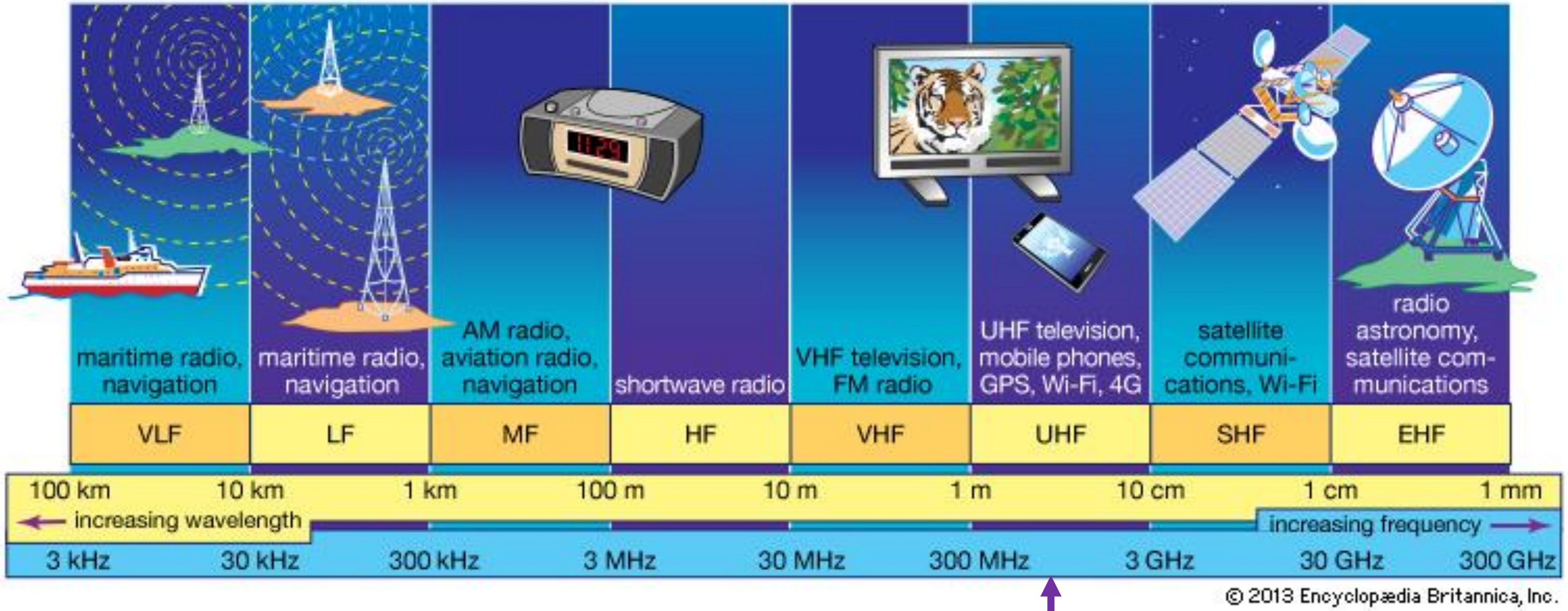


Almost all information traveling some distance is transmitted over optical fiber

Reference: https://eliptech.com/mobile-phones-work/

It's All About the Bandwidth…

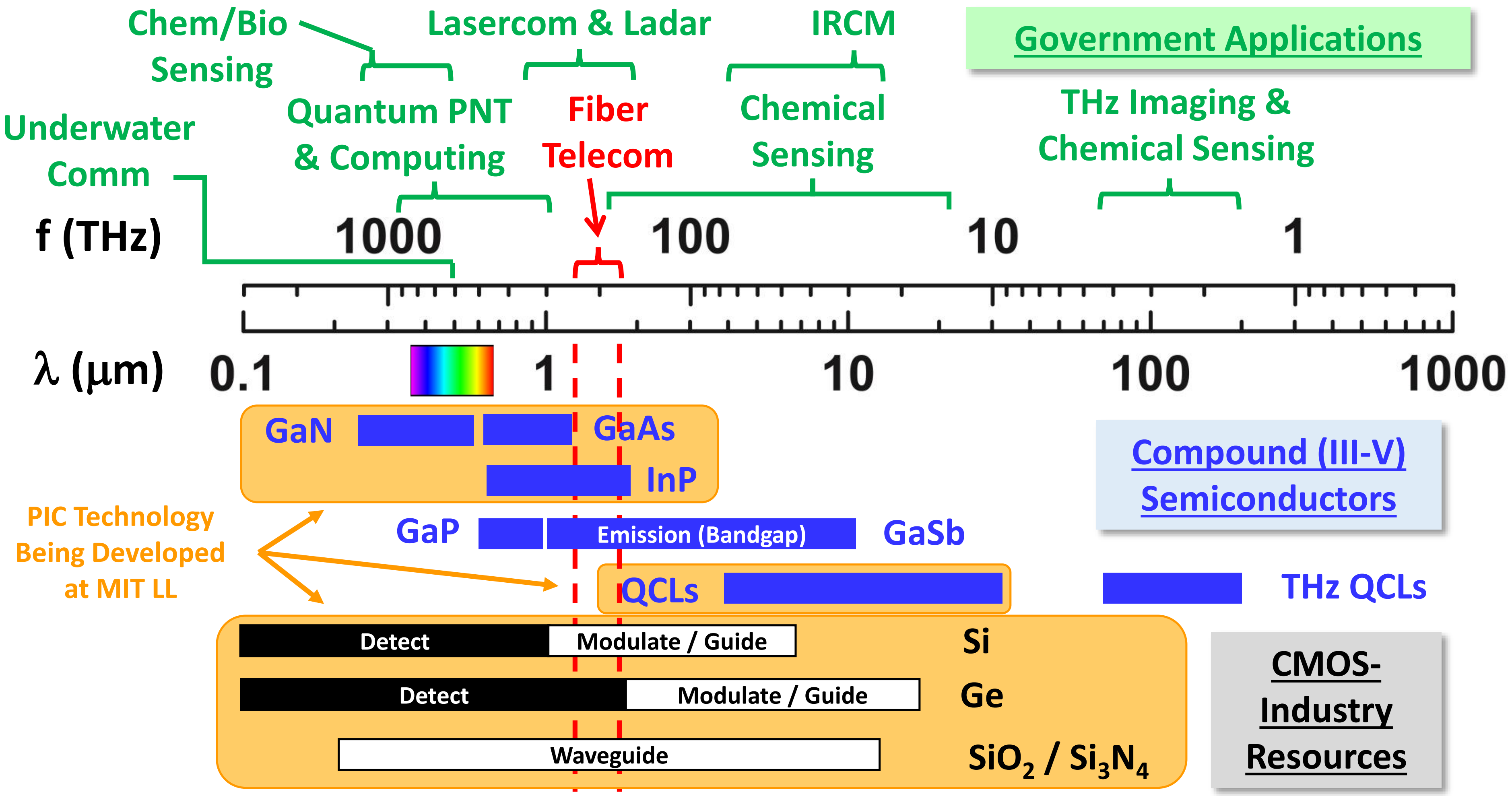
Radio and Microwave Frequency Spectrum



- **Cell Phone Channel Bandwidth ~ 30 kHz**
- **4G Wireless UltraHD Video Bandwidth ~ 6 MHz**

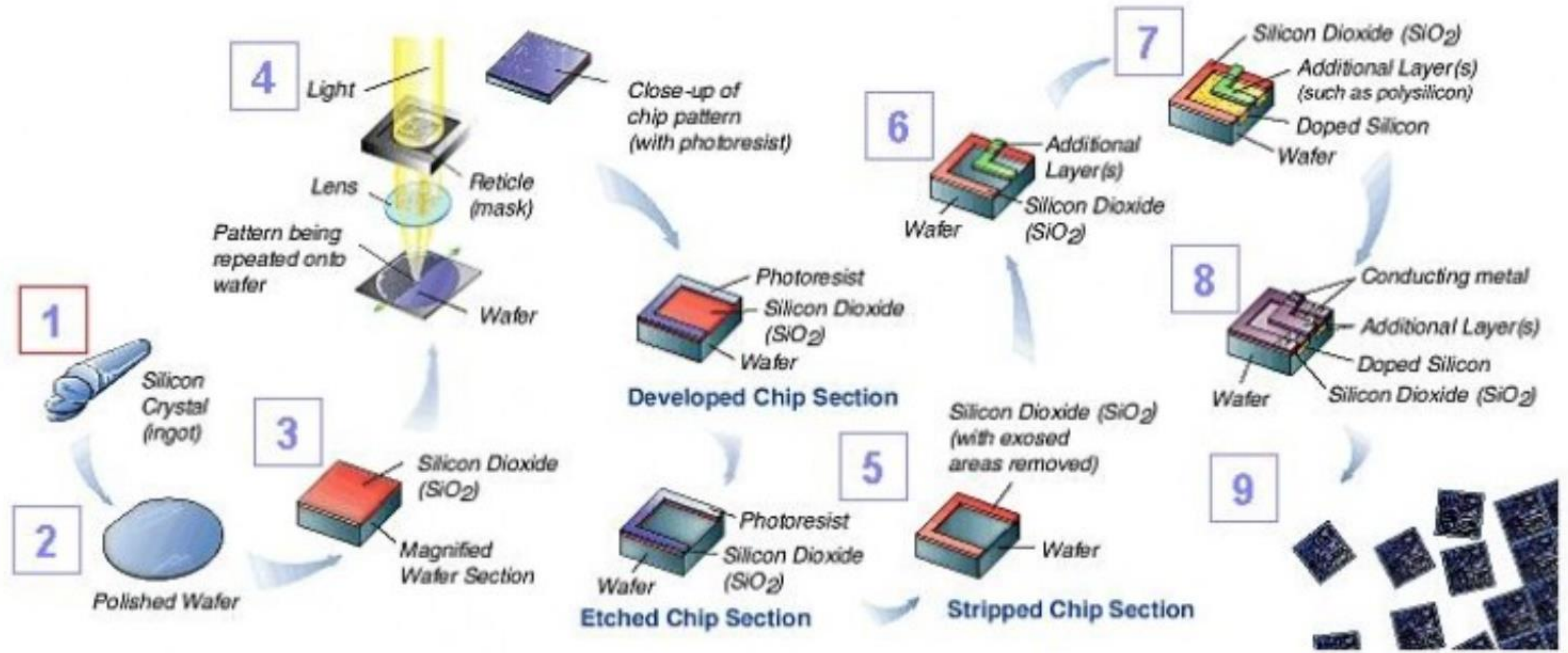
Total RF and microwave spectral bandwidth (B_{RF}) ~ 300 GHz

Integrated Photonics
Application and Technology Spectrum

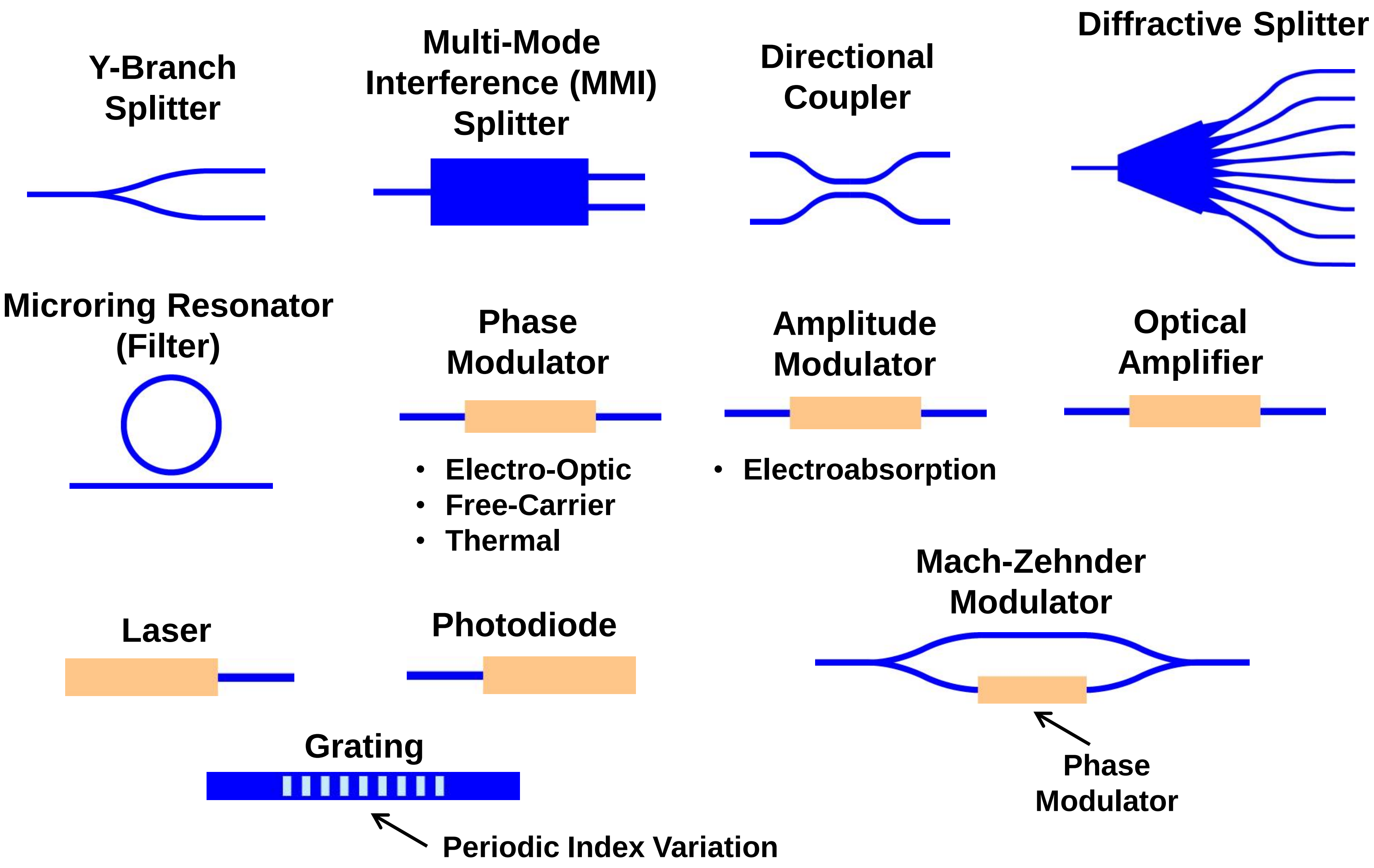


Government applications require combination of III-V, Si and hybrid technologies

Chip Fabrication Process: Schematic



Integrated Photonic Component Schematics (Top View)

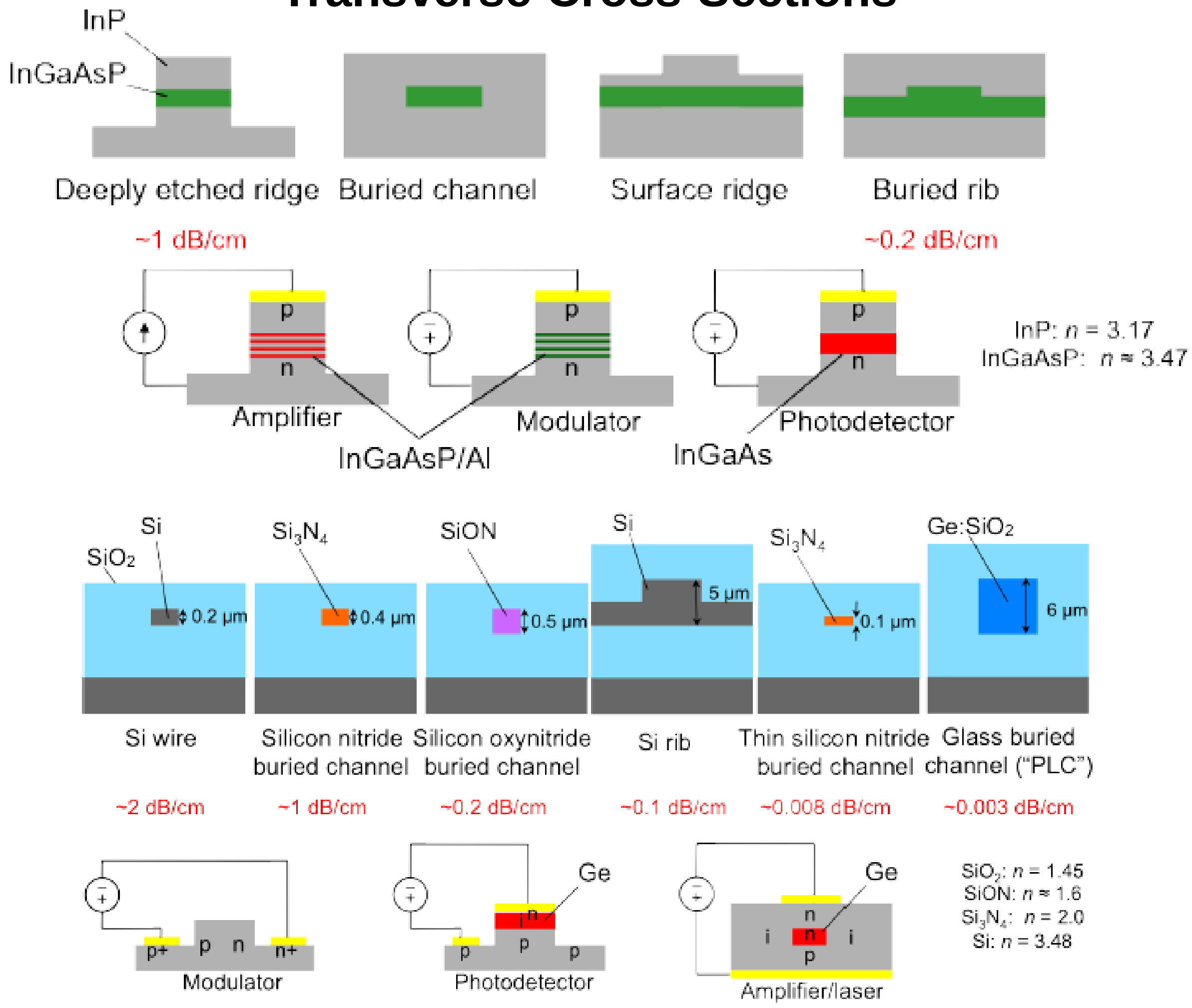


Example Waveguide Devices

Transverse Cross-Sections

Compound Semiconductor (III-V) Photonic Components

Silicon/Germanium (Group IV) Photonic Components



C. R. Doerr, *IEICE Trans. Electron.*, 2013

Electrons Vs Photons

	Electrons	Photons
Flavor	Single entity	Many entities (wavelengths/colors)
Properties that are controllable/measurable	R,C,L,V,I	Polarization, Phase, Intensity, Wavelength
Transport depends on	Conductivity	Index contrast, absorption, scattering, geometry of waveguide, proximity to other waveguides
Transport to nearby devices?	Cannot move from one wire to another without direct contact	Can move evanescently from one waveguide to another (no need for direct contact),
Multiple signal transmission possible?	Need one wire for every signal. Coax bundle	Multiple signals (wavelengths) can be transmitted through a single waveguide
Coupling and contacting	Simple	Needs careful alignment

PHOTONIC IC VS ELECTRONIC IC

FEATURES	PIC	EIC
❖Data Carrier	Photons	Electrons
❖Type of components	Functional optical devices	Transistors
❖No. of components integrated	Limited to a few hundred	Range into millions
❖ Substrate materials	Many different materials in a single chip	Fits nicely onto Silicon

UNDISTURBED SUPER-POSITION

Dozens of data signals can be coupled into one single optical fiber and be separated again at the receiver's end. The signals can be very finely distinguished based on their wavelength (spectral color), polarization, and phase.

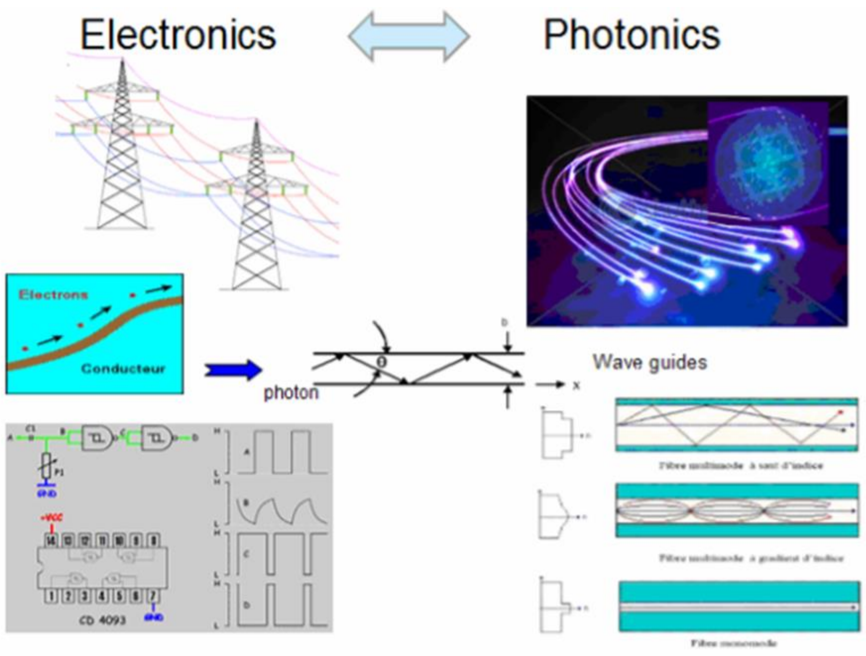
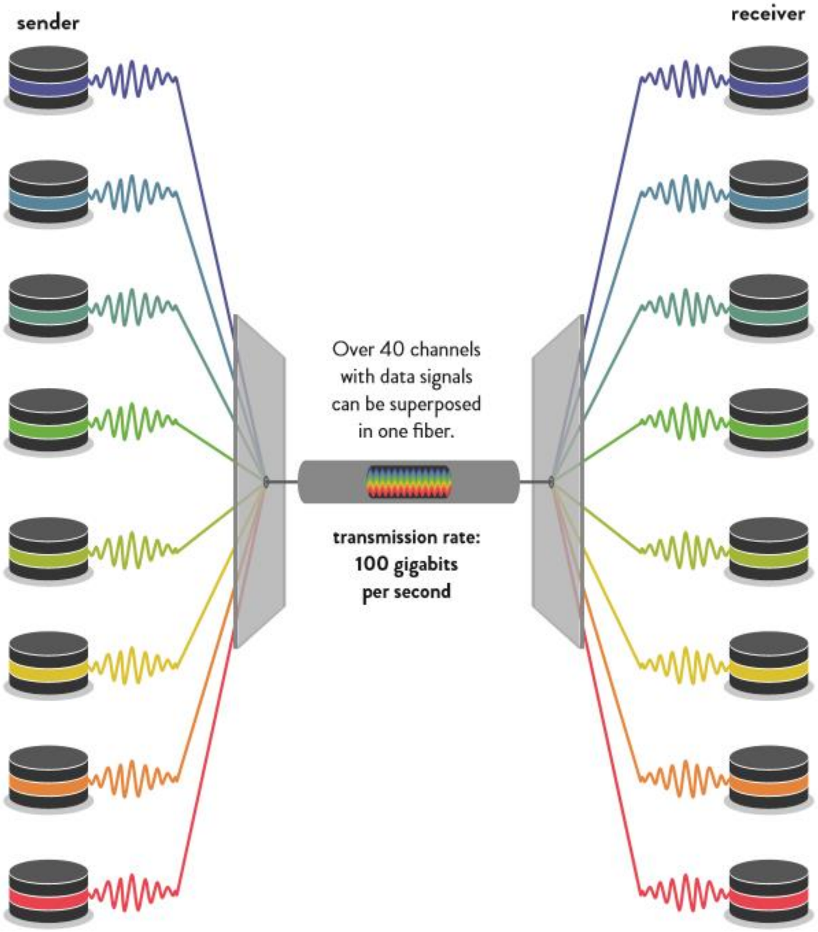


Fig.2. Information carrier vectors and the transports ways of the carriers in electronics and photonics



Reference for photonics and electronics comparison

Nature **556**, 316-318 (2018)

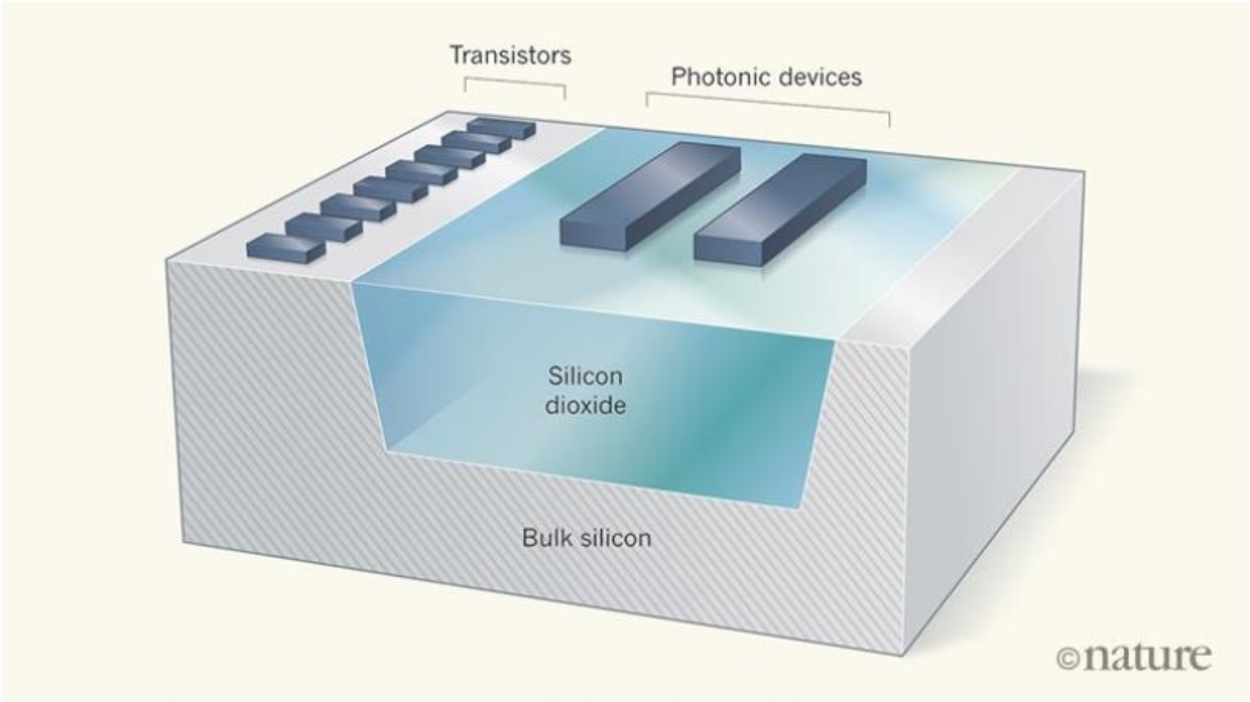
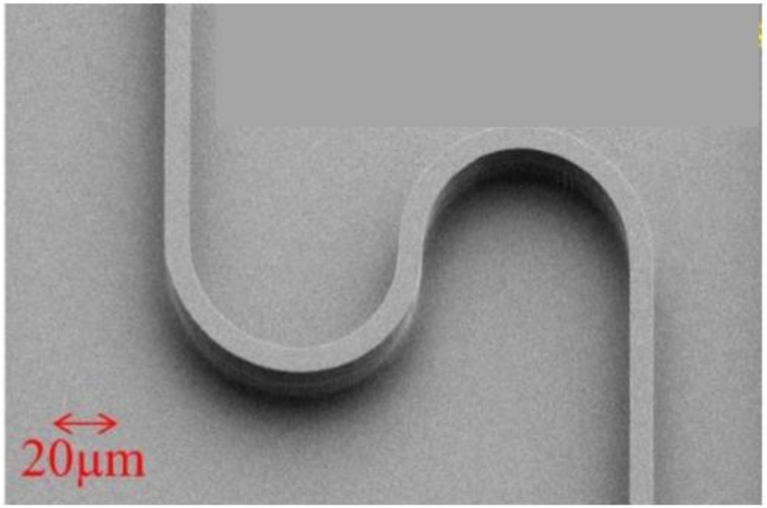
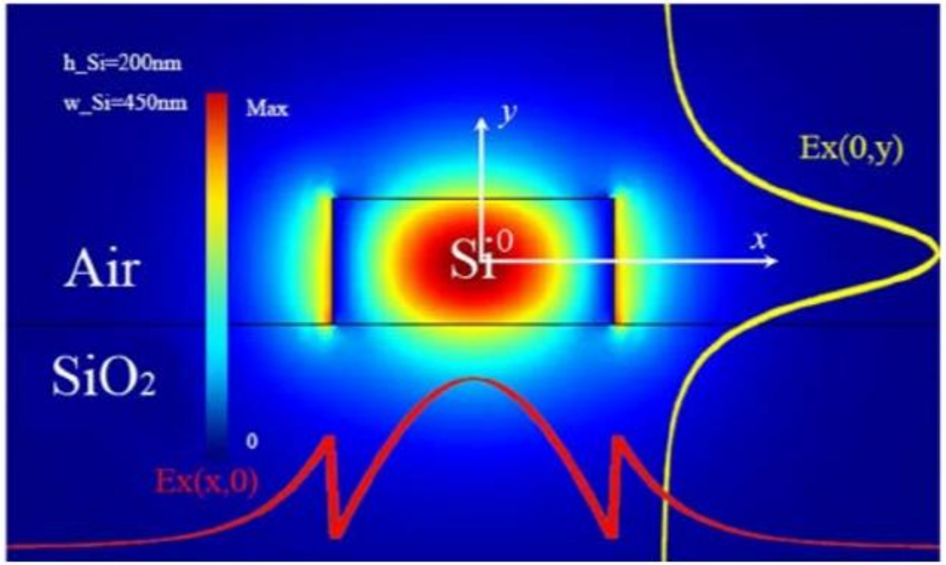


Figure 1 | Optoelectronic integration. Atabaki *et al.*[1] report a technique for integrating electronic and photonic devices on a single silicon microchip. The authors added isolated patches (islands) of the insulator material silicon dioxide to a bulk silicon substrate — for simplicity, a single island is shown here. They then deposited a thin film of polycrystalline silicon on top. Photonic devices and electronic devices known as transistors were fabricated from this film; the former in the silicon-on-insulator region and the latter in the bulk silicon. (Adapted from Fig. 1b of ref. 1.)

Integrated Photonics: Optical fiber on a chip



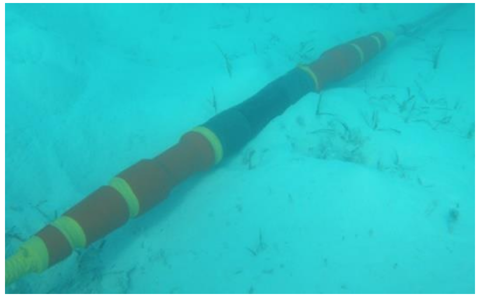


Integrated photonics in the 21st century
March 2014 Photonics Research 2(2)
Lars Thylén and L. Wosinski

λ = 1550 nm for low loss within SOI waveguides

Advantages and Challenges of Integrated Photonics

- Advantages of Integrated Photonics
  - Smaller size and weight
  - Reduced number of optical interfaces
  - Reduced packaging cost and time
  - Improved performance (smaller loop delays, increased stability)
  - Novel functionality (optical phased array)
- Integrated Photonics Challenges
  - System size, weight and power (SWaP) limited by factors other than photonics
  - Need higher material and fabrication control to achieve high yield
  - Reduced performance (monolithic device trade-offs, hybrid coupling)
  - Thermal management
  - Implementing tight integration with electronics
  - Lack of a high-performance integrated optical isolator
  - Limited capability of present design automation tools



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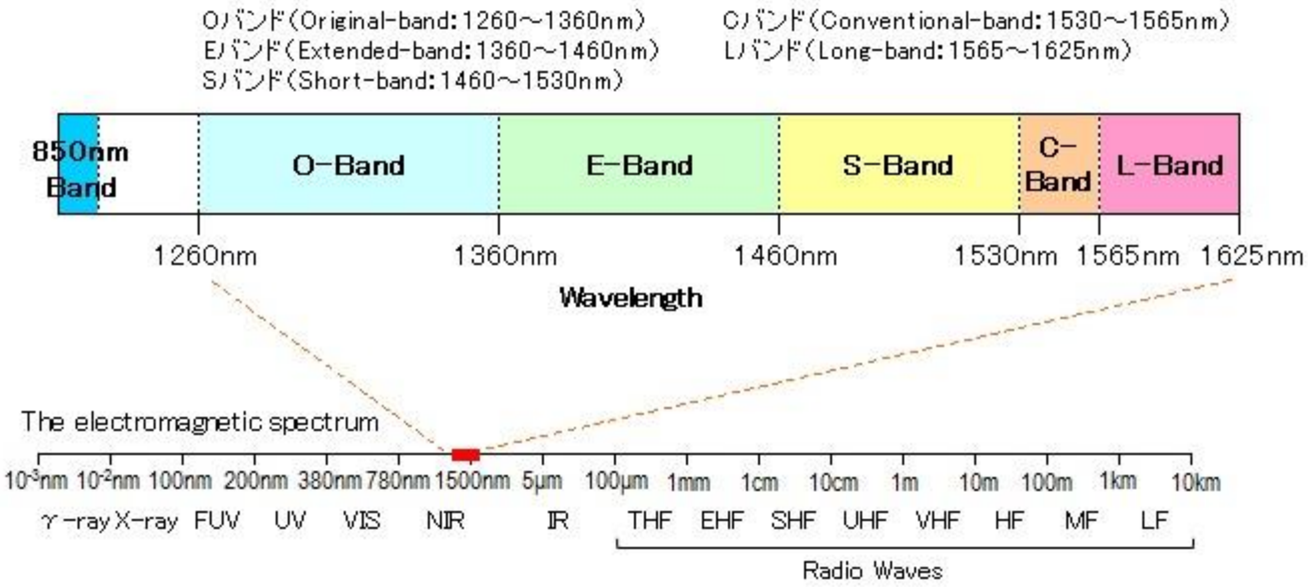

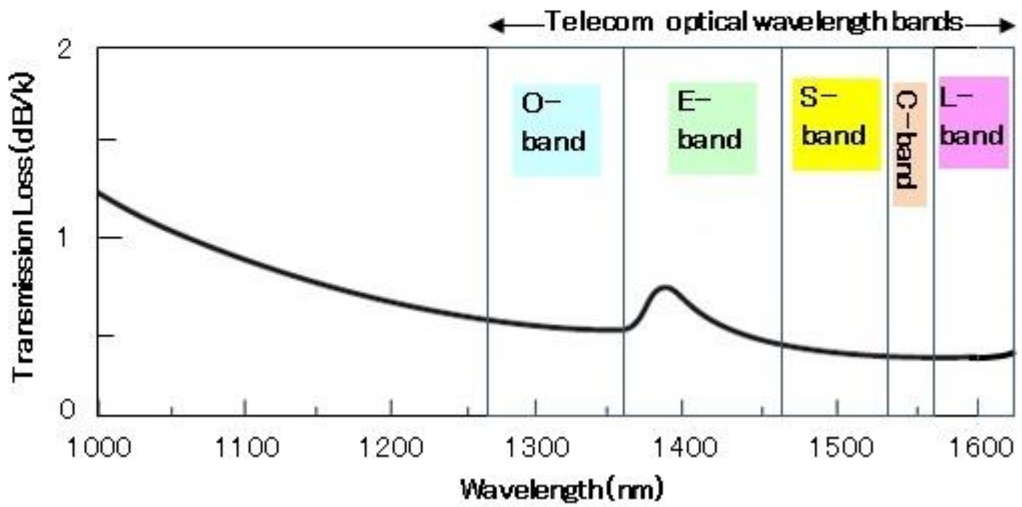

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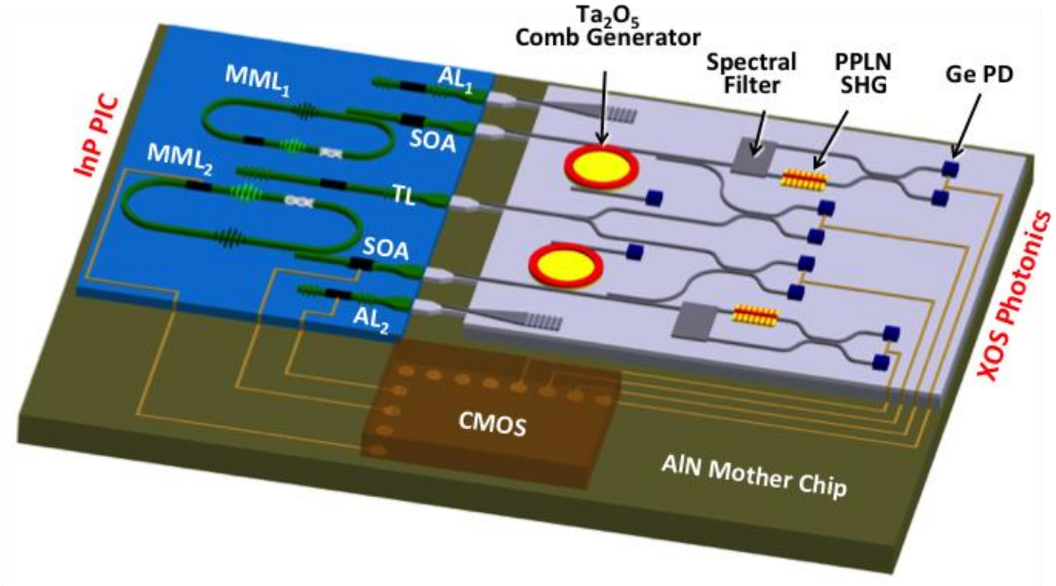
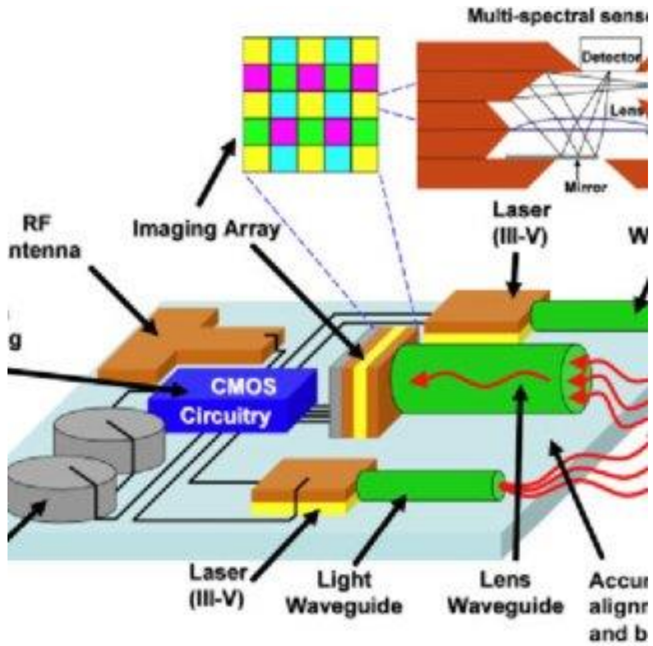
- The E-band (extended-wavelength band: 1360-1460 nm) is the least common wavelength band among the five. This is because the attenuation of early optical fiber in the E-band was highest among the five bands, due to residual water (OH group) impurity remained in the glass. After the invention of dehydration technique during glass production, the attenuation of most commonly used optical fiber (ITU-T G.652.D) in the E-band has become lower than that in the O-band. The use of the E-band in optical communication is, nevertheless, still limited as many existing fiber optic cables installed before 2000 show high attenuation in the E-band.
- In addition to the O- to L-bands, there are two more wavelength bands, namely the 850-nm-band and U-band (ultra-long-wavelength band: 1625-1675 nm). The 850-nm-band is the primary wavelength for multimode fiber optical communication systems, combined with VCSEL (Vertical-Cavity Surface Emitting Laser). The U-band is mainly used for network monitoring purposes.





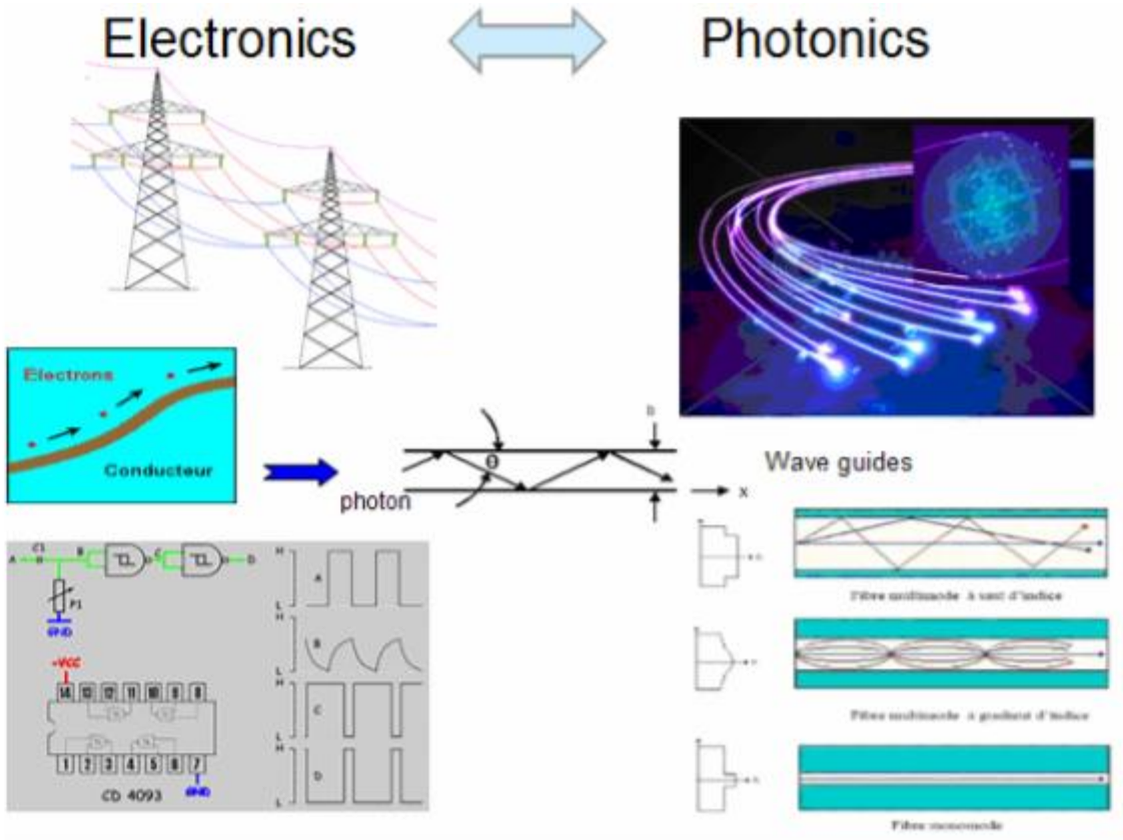
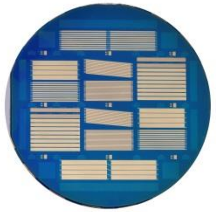


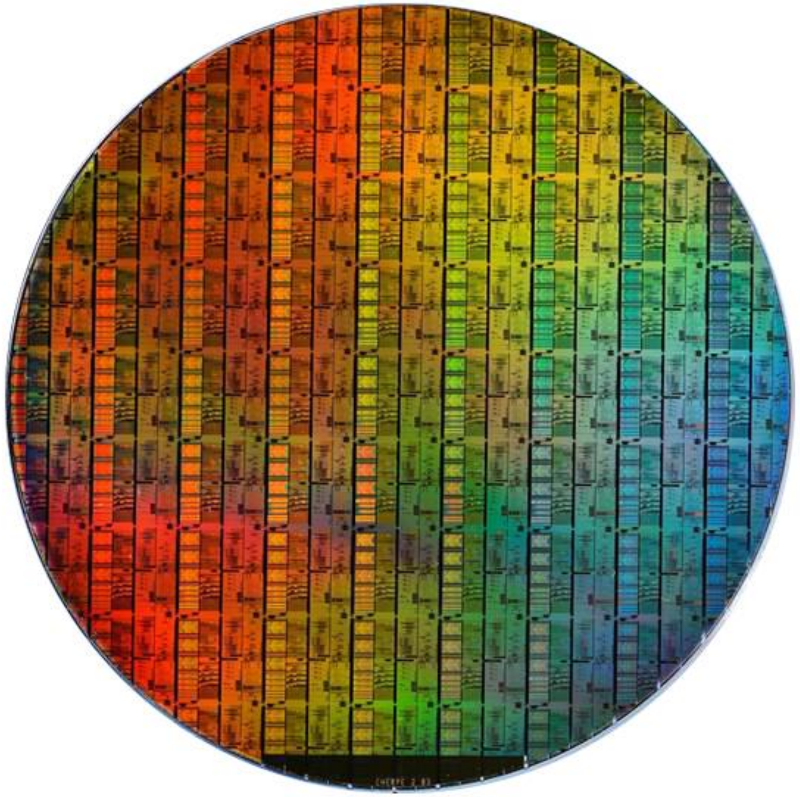
Fig.2. Information carrier vectors and the transports ways of the carriers in electronics and photonics

Fabrication of Photonic Components and Integrated Circuits (PICs)

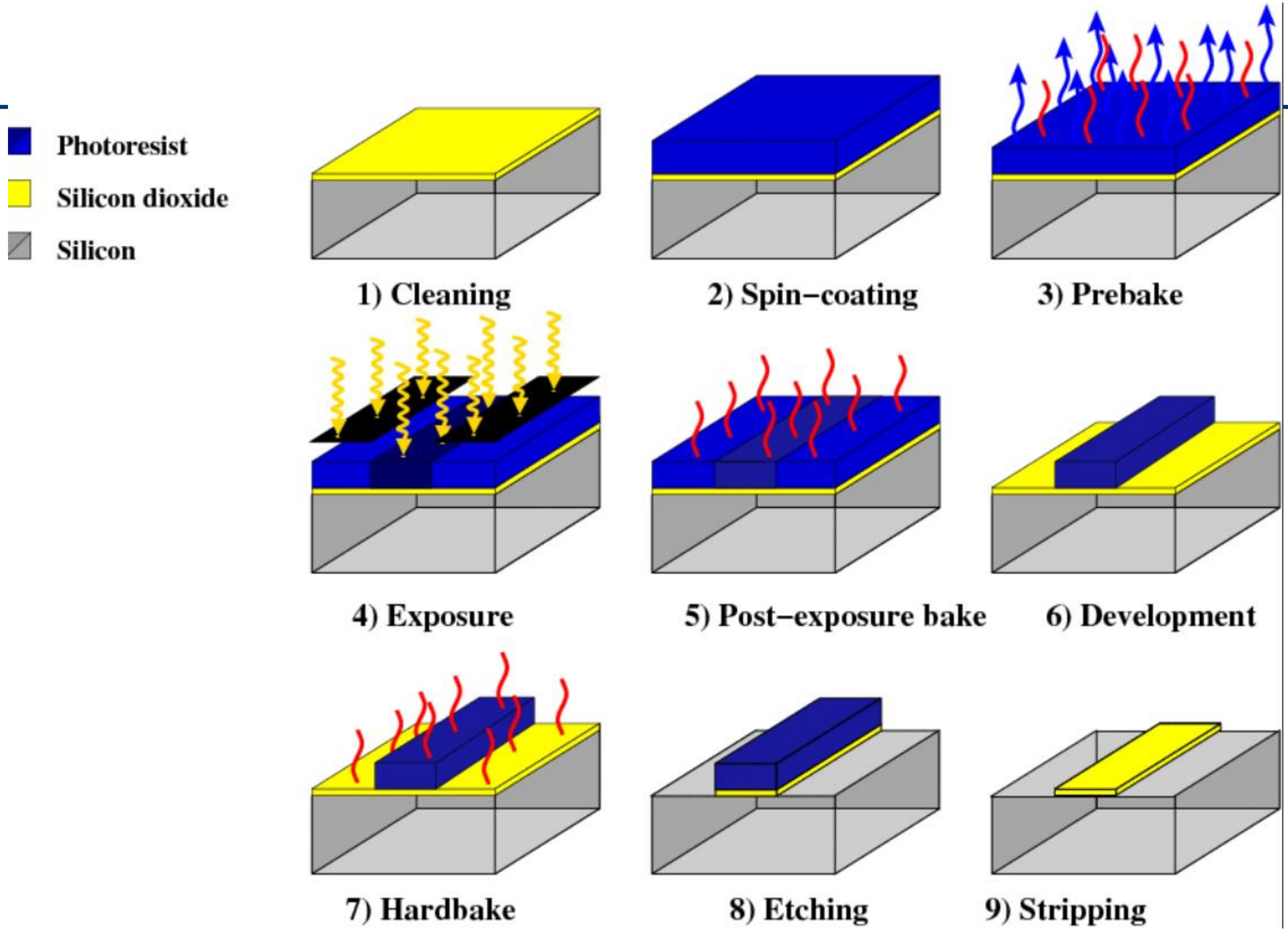
InP Laser/SOA Wafer
(50-mm Diameter)



Silicon PIC Wafer
(200-mm Diameter)



InP-based and silicon-based photonics fabricated at Lincoln Laboratory


Photoresist
Silicon dioxide
Silicon
1) Cleaning
2) Spin−coating
3) Prebake
4) Exposure
5) Post−exposure bake
6) Development
7) Hardbake
8) Etching
9) Stripping

Simple InP Device Process Flow: Strip-Loaded Rib Waveguide