Introduction to Optoelectronic Devices

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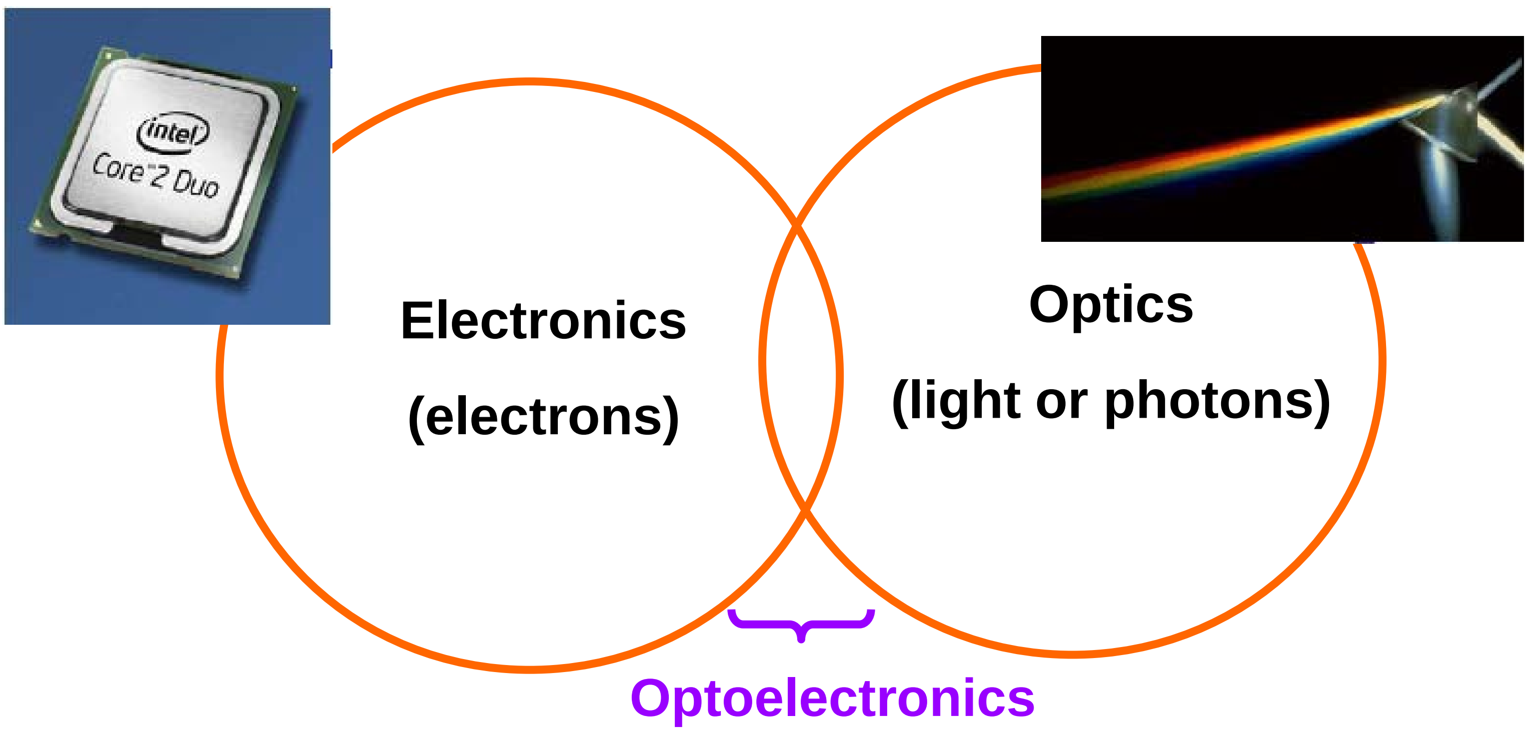
Outline

- What is the optoelectronics?
- Major optoelectronic devices
- Current trend on optoelectronic devices
- Nanoscale optoelectronic devices

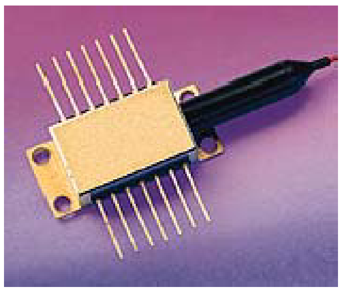
What Did the Word "Opto-Electronics" Mean?

- **Optoelectronics** is the study and application of electronic devices that interact with light



Examples of Optoelectronic Devices

Telecommunication laser



Newport.com

Blue laser

TDK

Optical fiber

Corning

LED traffic lights

Rsc.org

Photodiodes

Hamamatsu

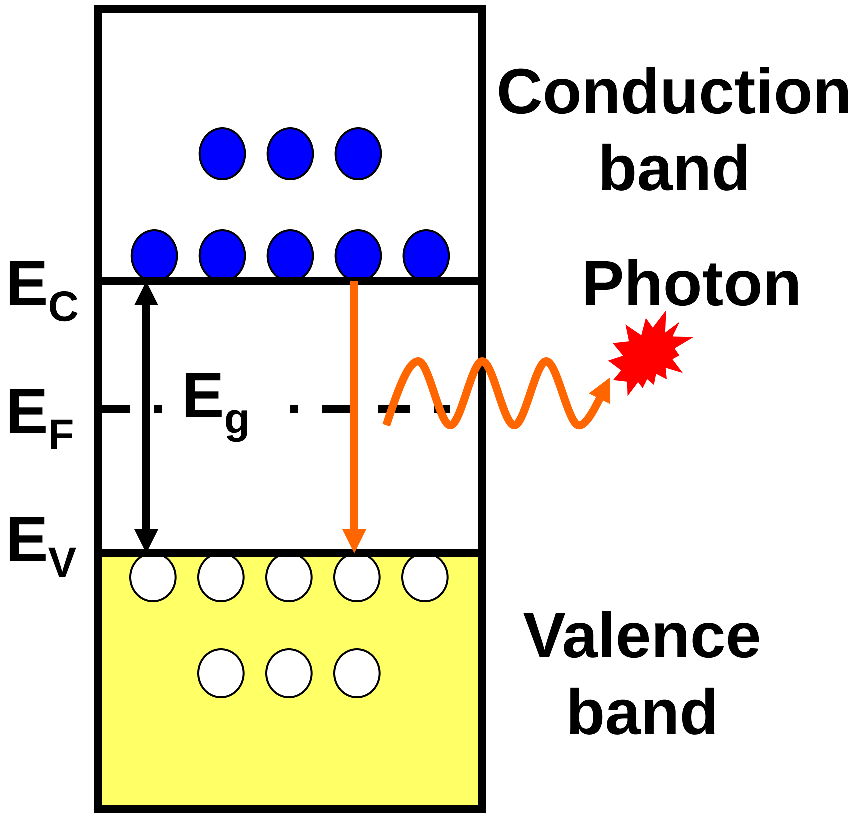
Solar cells

Wikipedia

Light-Emitting Diodes (LEDs)

Light-emitting diode (LED) is a semiconductor diode that emits incoherent light over relatively wide spectral range when electrically biased in the forward direction of the p-n junction.

Photon Emission in Semiconductor

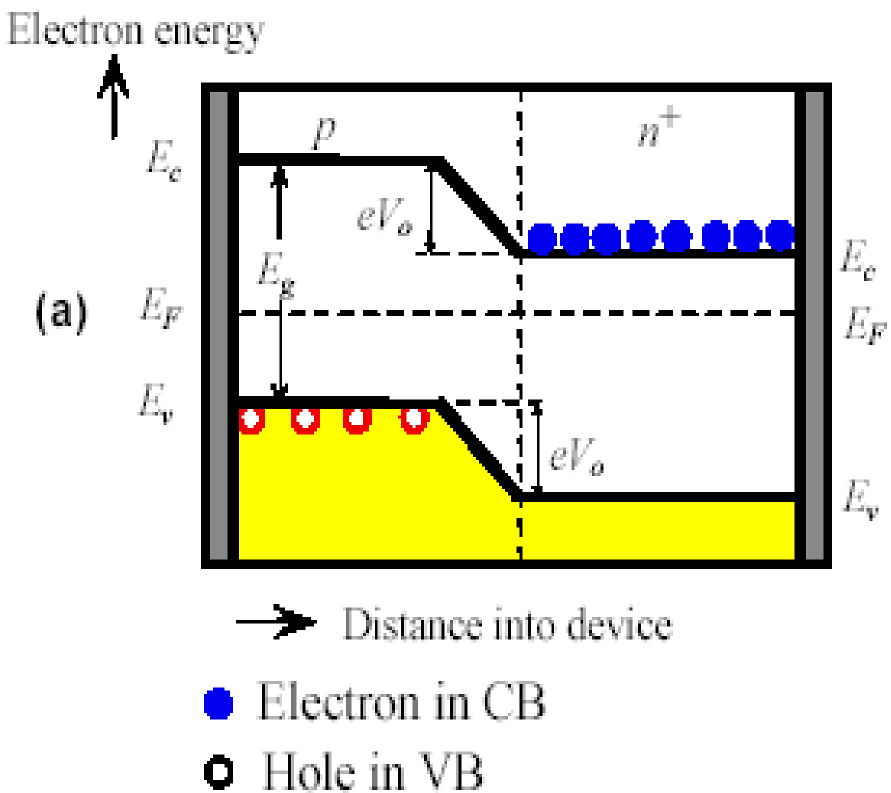


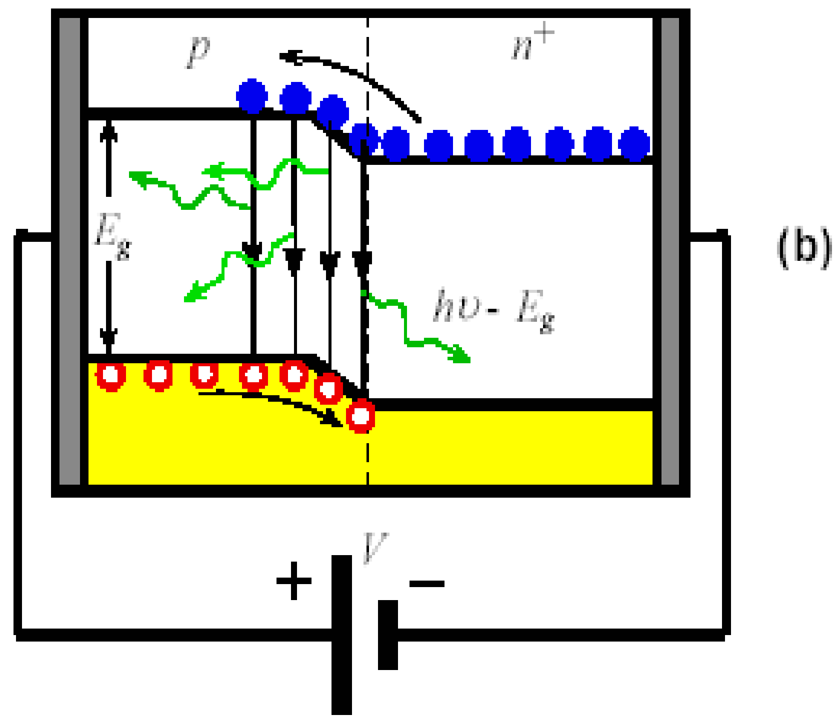
When an electron meets a hole, it falls into a lower energy level, and releases energy in the form of a photon.

The wavelength of the light depends on the band gap of the semiconductor material

Semiconductor materials: Si, Ge, GaAs, InGaAs, AlGaAs, InP, SiGe, *etc*

Operation Principle of LED

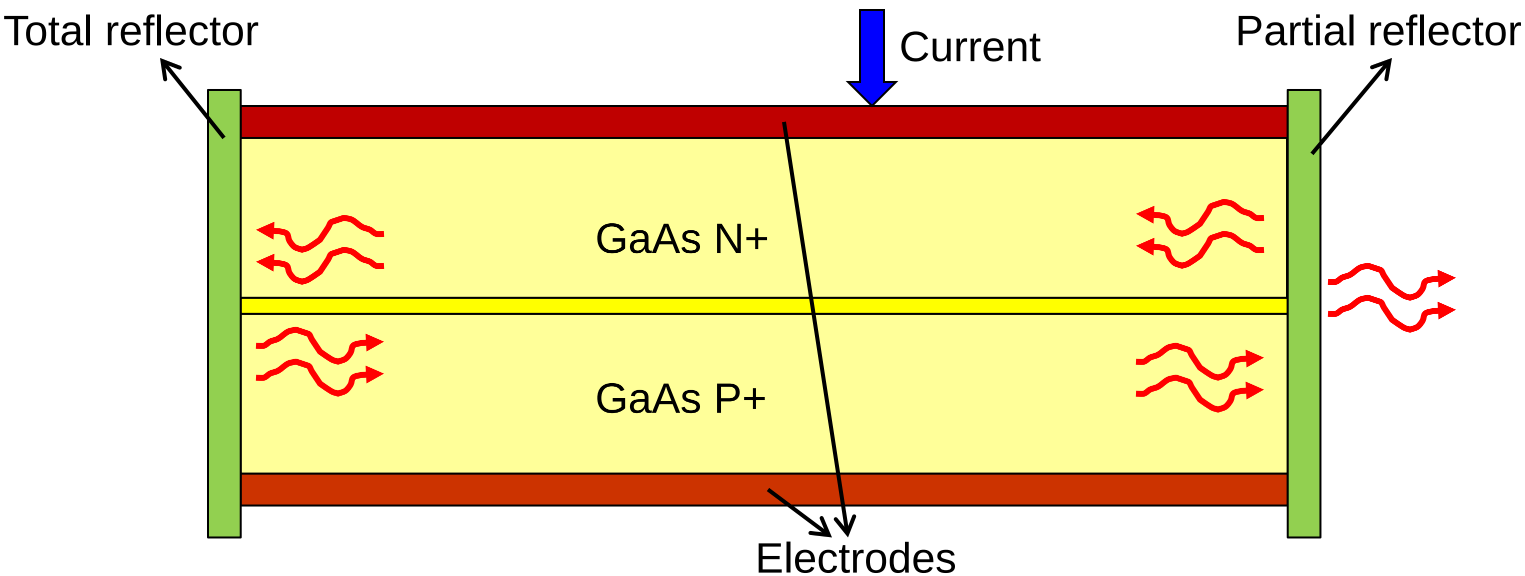


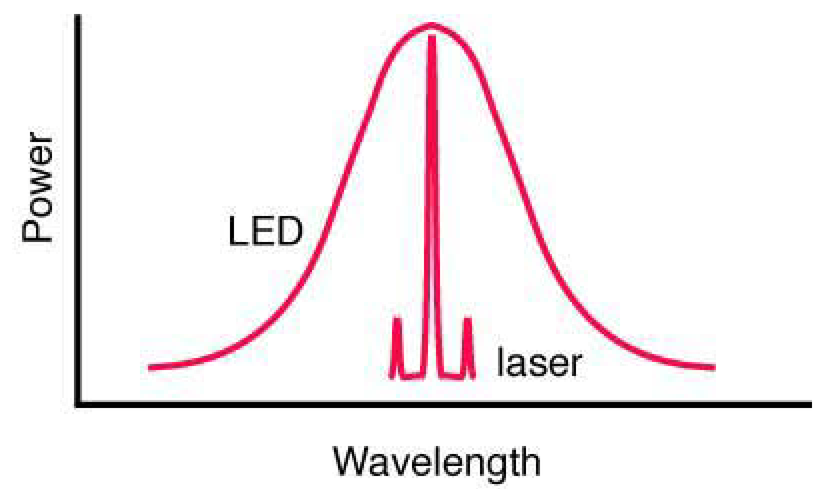


Semiconductor Materials vs. LED Color

General Brightness				
GaP	**GaN**	**GaAs**	**GaAlAs**	**--**
Green, Red	**Blue**	**Red, Infrared**	**Red, Infrared**	**--**
Super Brightness				
GaAlAs	**GaAsP**	**GaN**	**InGaN**	**GaP**
Red	**Red, Yellow**	**Blue**	**Green**	**Green**
Ultra Brightness				
GaAlAs	**InGaAlP**	**GaN**	**InGaN**	**--**
Red	**Red, Yellow, Orange**	**Blue**	**Green**	**--**

Laser Cavity Design





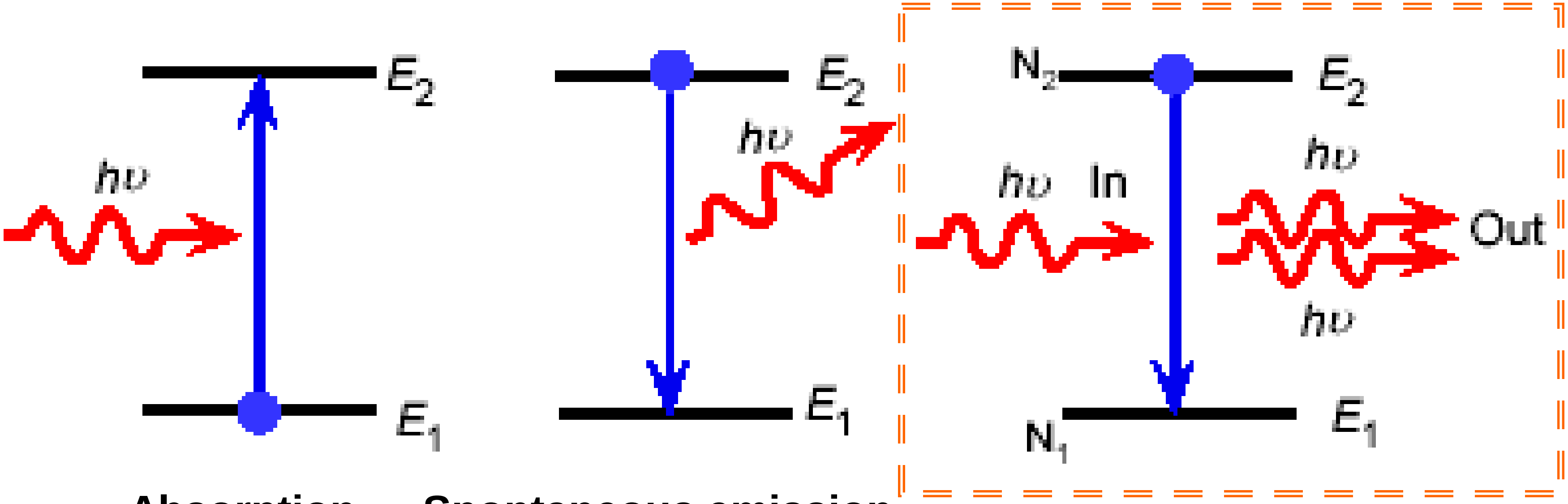
Laser cavity design:

- Laser medium is similar to LEDs,
- Extra components a in laser cavity are the mirrors at two facing planes (facets) for lasing mode selection.
- The laser light is monochromatic and coherent due to the mode selection in the cavity design

Laser Diodes

Lasers (Light Amplification by Stimulated Emission)

Photon emission processes:

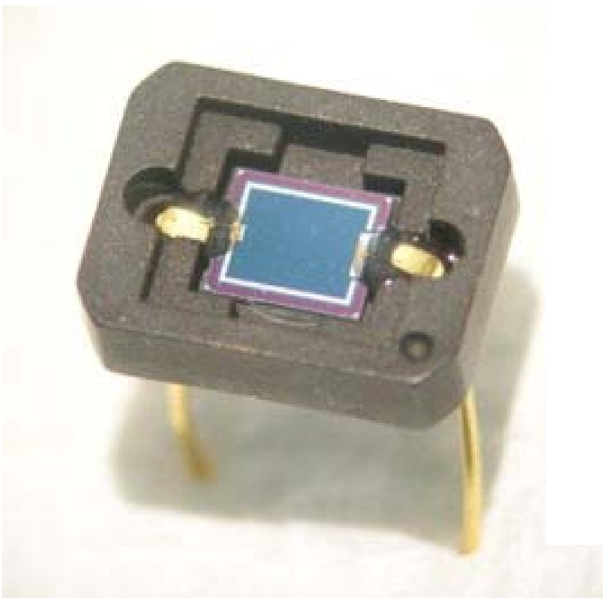


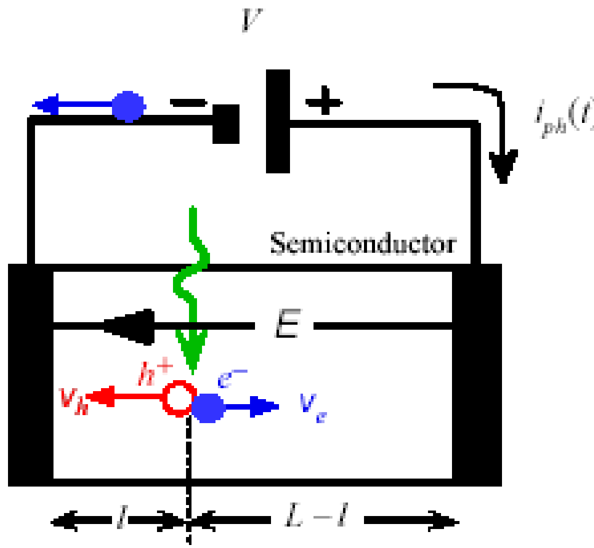
Absorption
Photodetectors

Spontaneous emission
LEDs

Stimulated emission
Lasers

Photo Diodes (PDs)

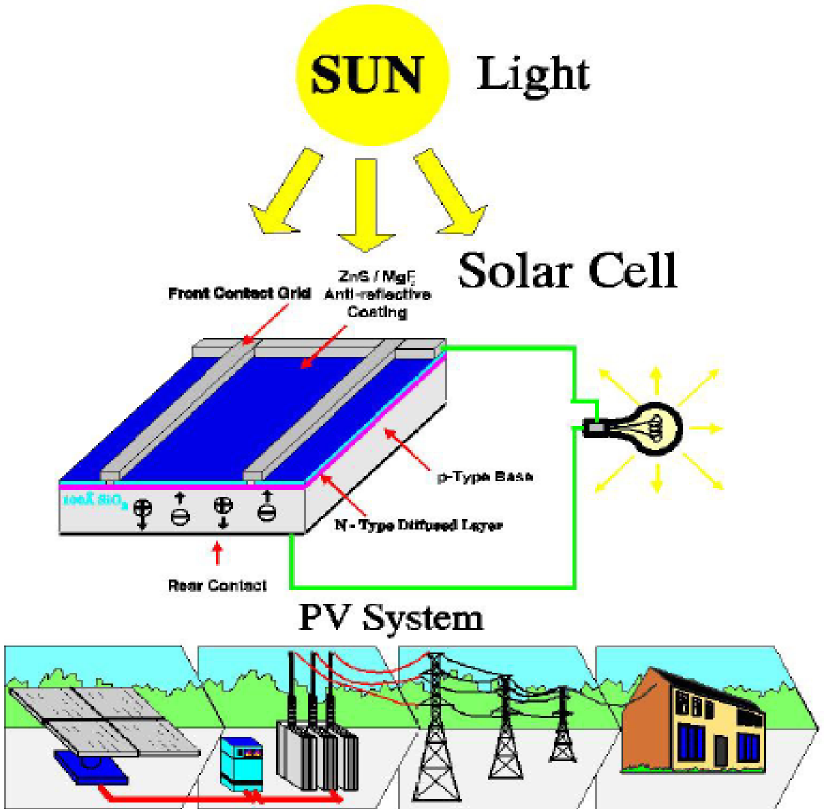




PD symbol:

A **photodiode** **is a semiconductor diode that functions as a photodetector. It is a p-n junction or p-i-n structure. When a photon of sufficient energy strikes the diode, it excites an electron thereby creating a mobile electron and a positively charged electron hole**

Solar Cells (Photovoltaics)



Why solar cells?

Solar Energy

- **Free**
- **Essentially Unlimited**
- **Not Localized**

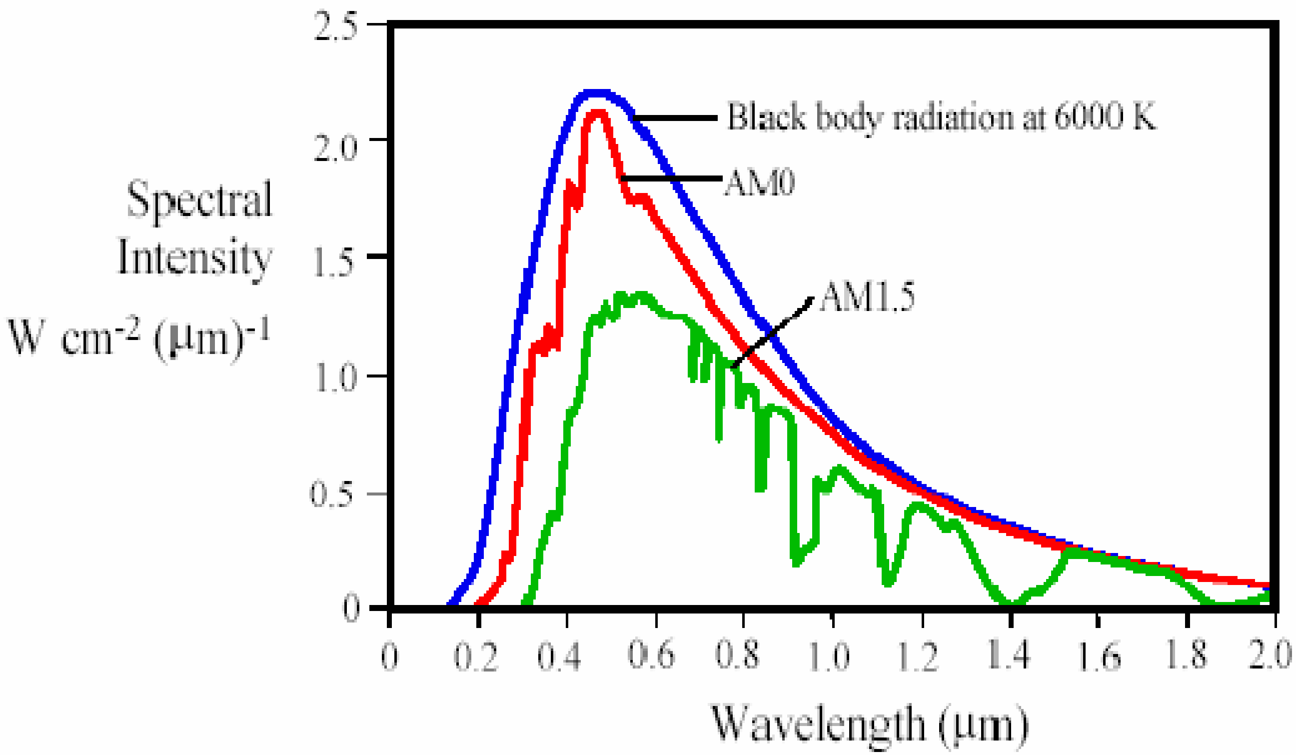
Solar Cells

- **Direct Conversion of Sunlight → Electricity**
- **No Pollution**
- **No Release of Greenhouse-effect Gases**
- **No Waste or Heat Disposal Problems**
- **No Noise Pollution — very few or no moving parts**
- **No transmission losses — on-Site Installation**

Residential and Commercial Applications

Challenges:
cost reduction via: a) economy of scales b) building integration and
c) high efficiency cells

Solar Energy Spectrum

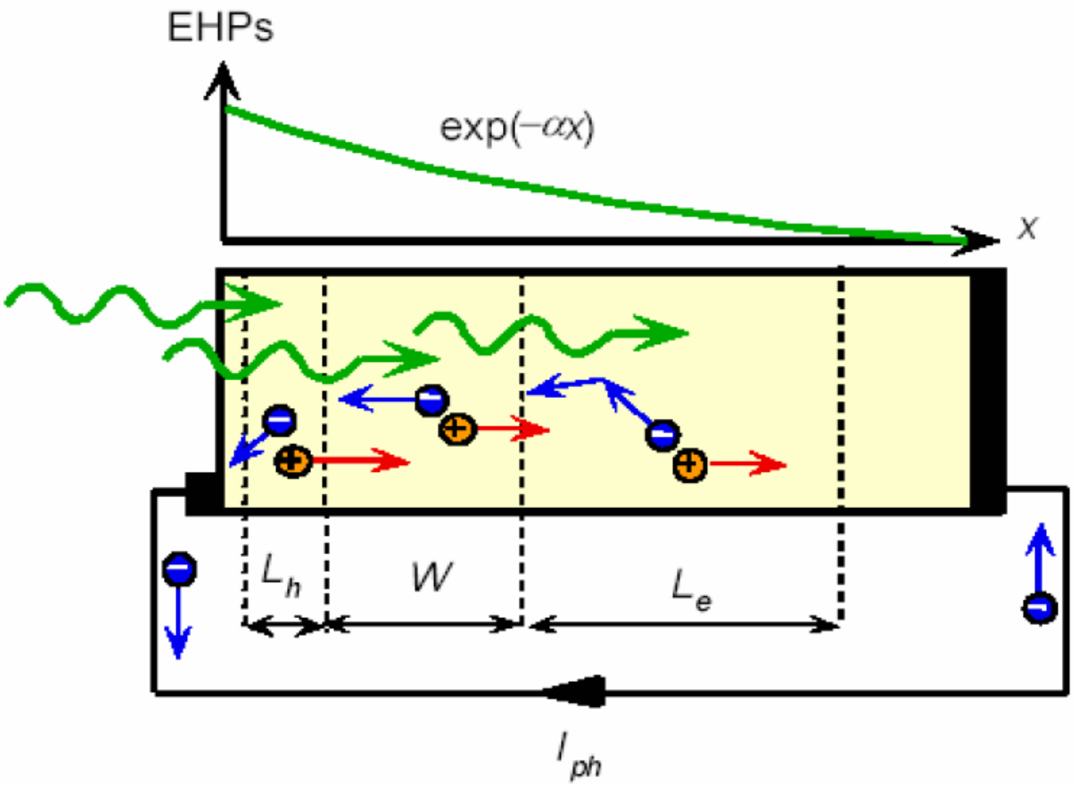


Spectrum of the solar energy

Solar radiation outside the earth's surface: 1.35 kW/m^2, 6500 times larger than world's energy demand

AM0: radiation above the earth's atmosphere
AM1.5: radiation at the earth's surface
Blackbody radiation: ideal radiation

Operation Principle of Solar Cells



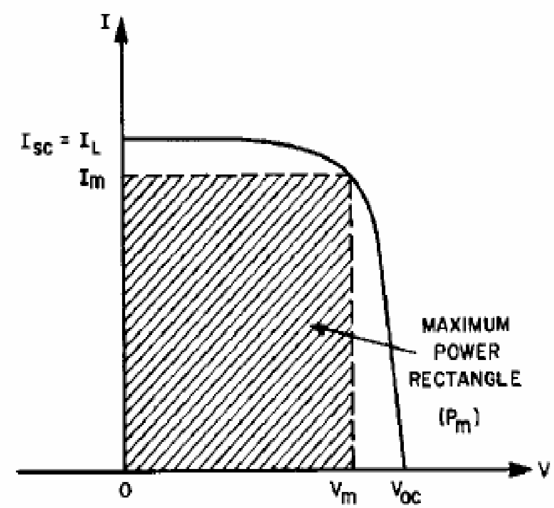


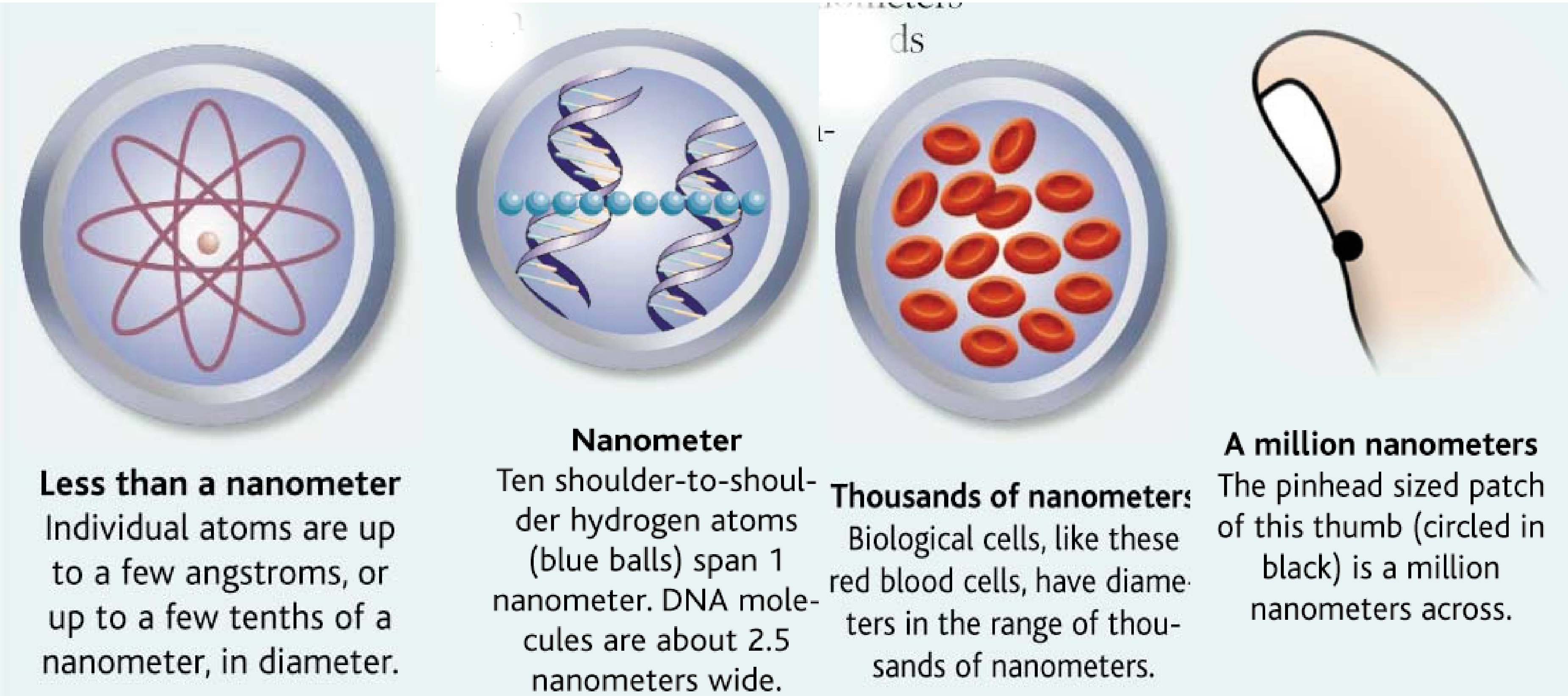
Photo generated carriers within the volume, $L_h + W + L_e$

Trends in optoelectronic devices

- Ultra-short, high power mid-infrared light sources
- Low cost, easy fabricated materials
- Compact multi-wavelength laser sources
- Less expensive and high efficiency photovoltaic devices
- Molecular and biomedical optoelectronics

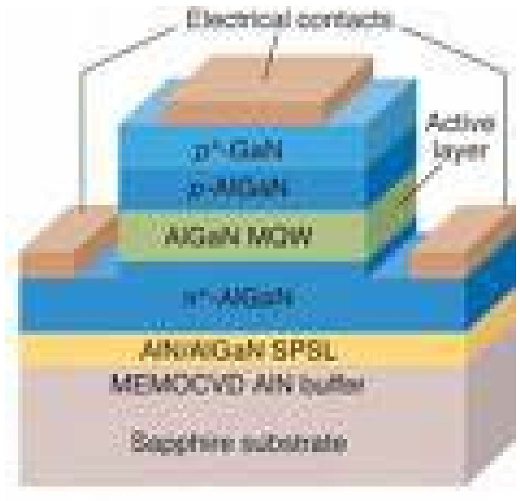
— nanoscale optoelectronic devices

How Small Is The Nano-Scale?

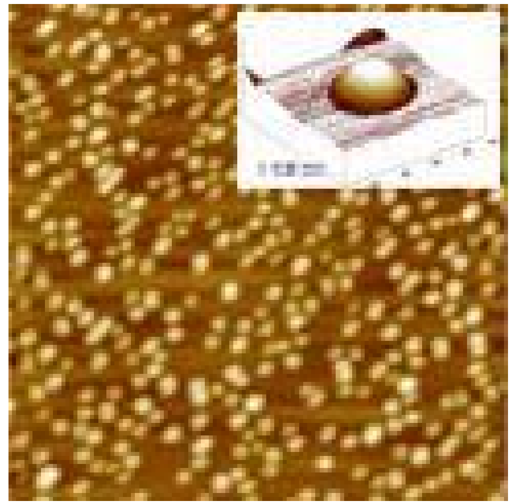


A human hair is 50,000 – 80,000 nanometers wide and grows ~10 nm every second (~600 nm every minute)

Semiconductor Nanostructures

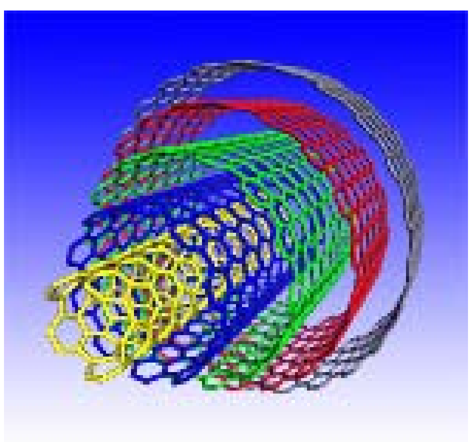


Quantum wells

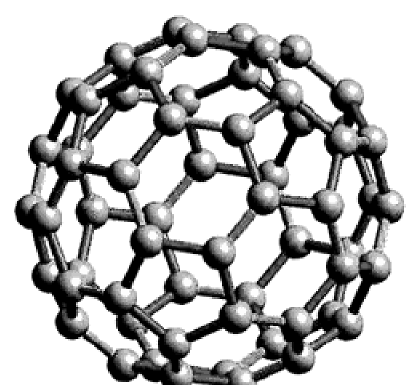


Quantum dots

Nanowire

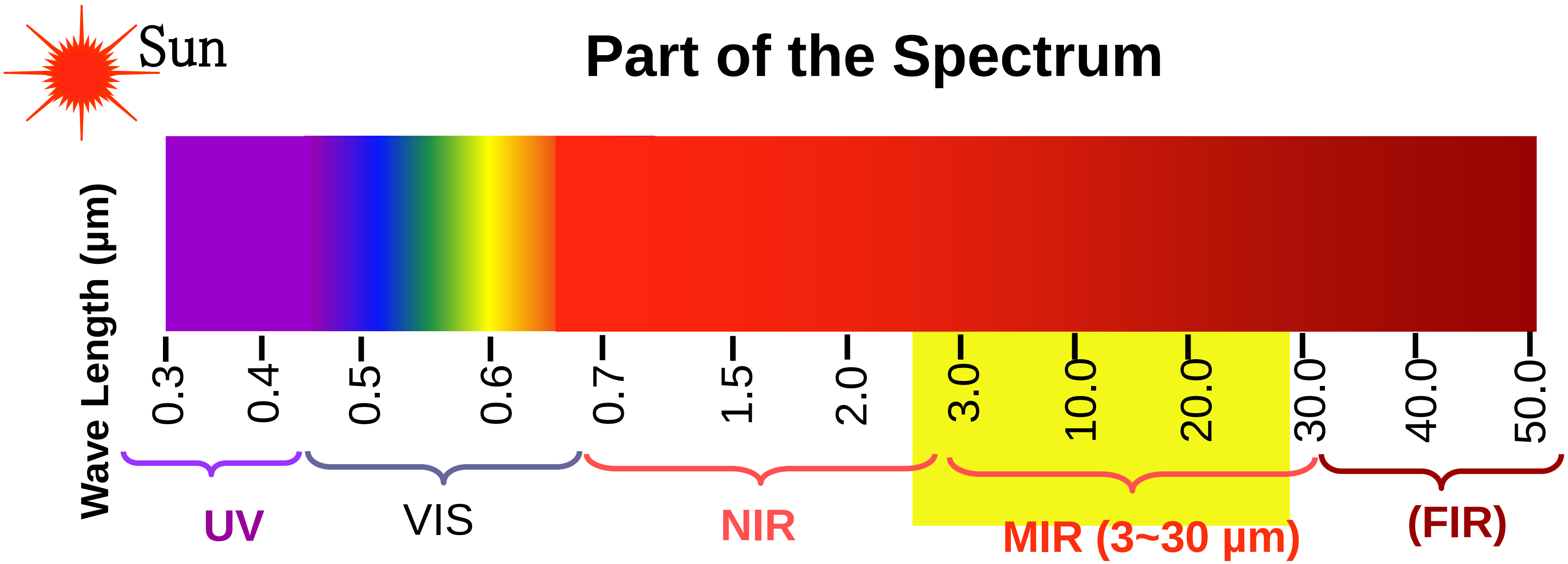


Carbon Nanotubes (CNT)



Buckyball

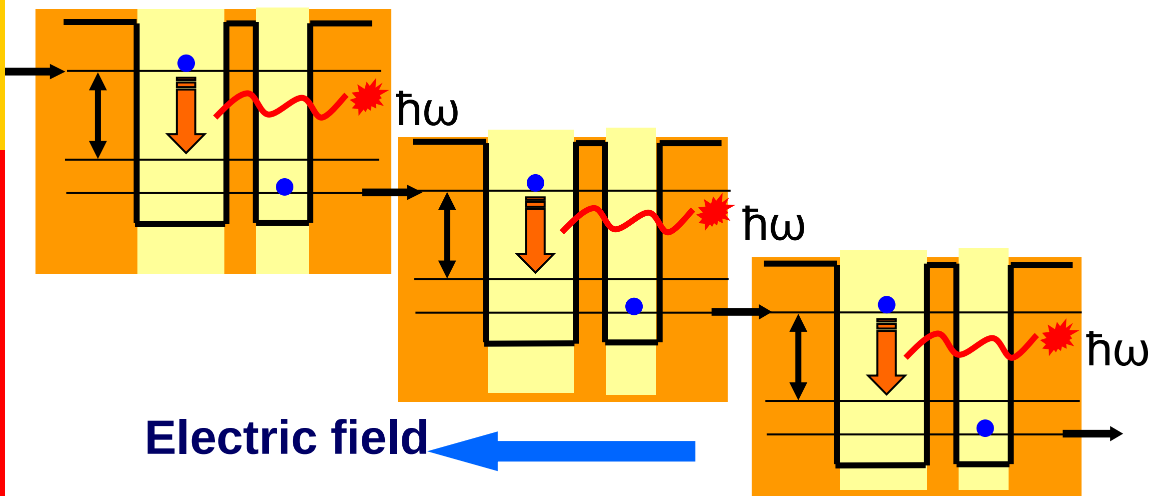
Quantum Cascade Lasers — MIR Light Emission



The wavelength of quantum cascades laser lies in the mid-Infrared (MIR) region (3~30 μm)

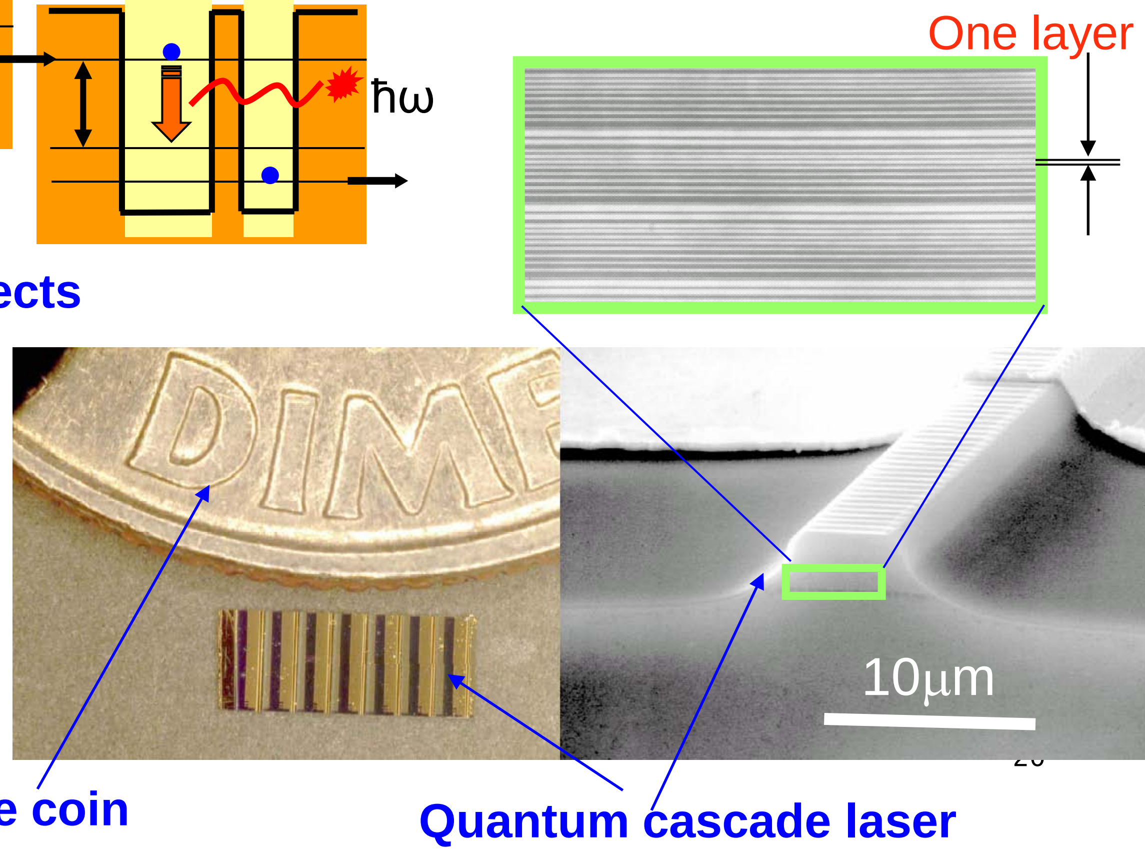
Many chemical gases have strong absorption in mid-infrared region, such as CO,NH_3,, NO, SO_2,, *etc*.

Quantum-Cascade Laser (QCL)



Cascade effects

Cross Section of a QCL: Note that the layer thickness is smaller than the wavelength

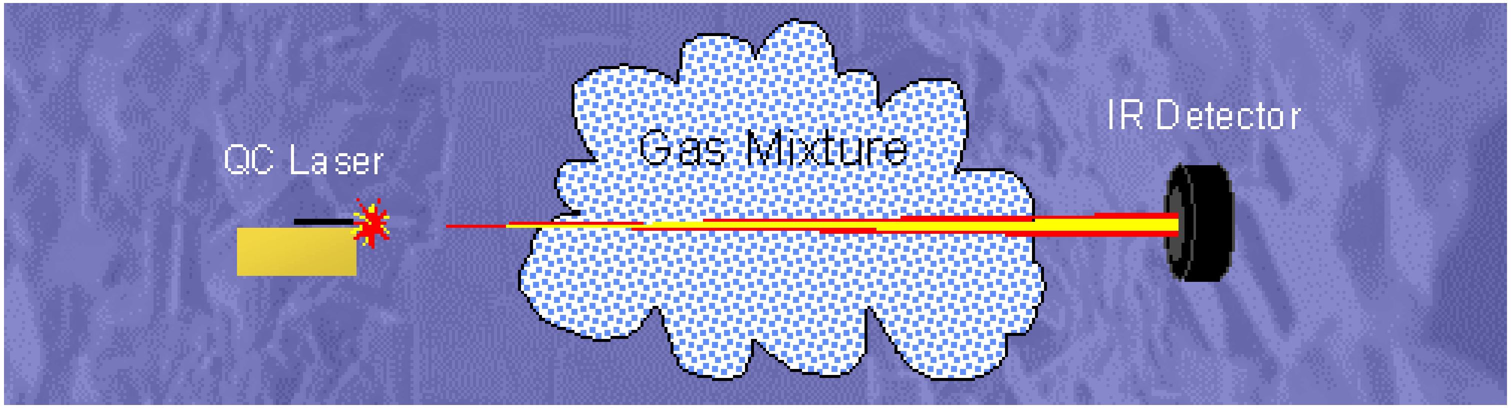


One electron emits N photons to generate high output power

Typically 20-50 stages make up a single quantum cascade laser

Applications of QCL

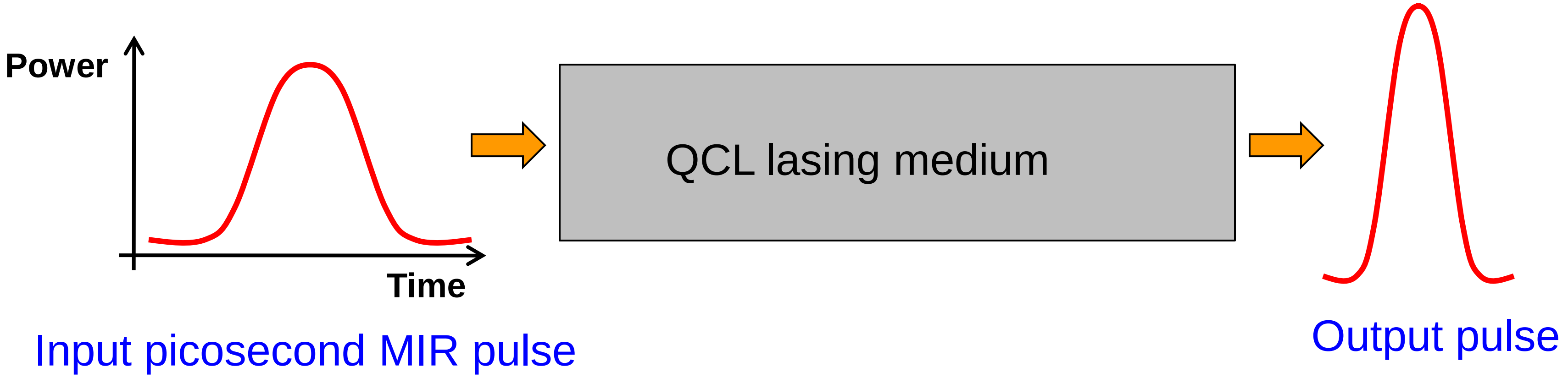
- Environmental sensing and pollution monitoring
- Automotive
  - Combustion control, catalytic converter diagnostics
  - Collision avoidance radar, cruise control
- Medical applications
  - Breath analysis; early detection of ulcers, lung cancer, etc



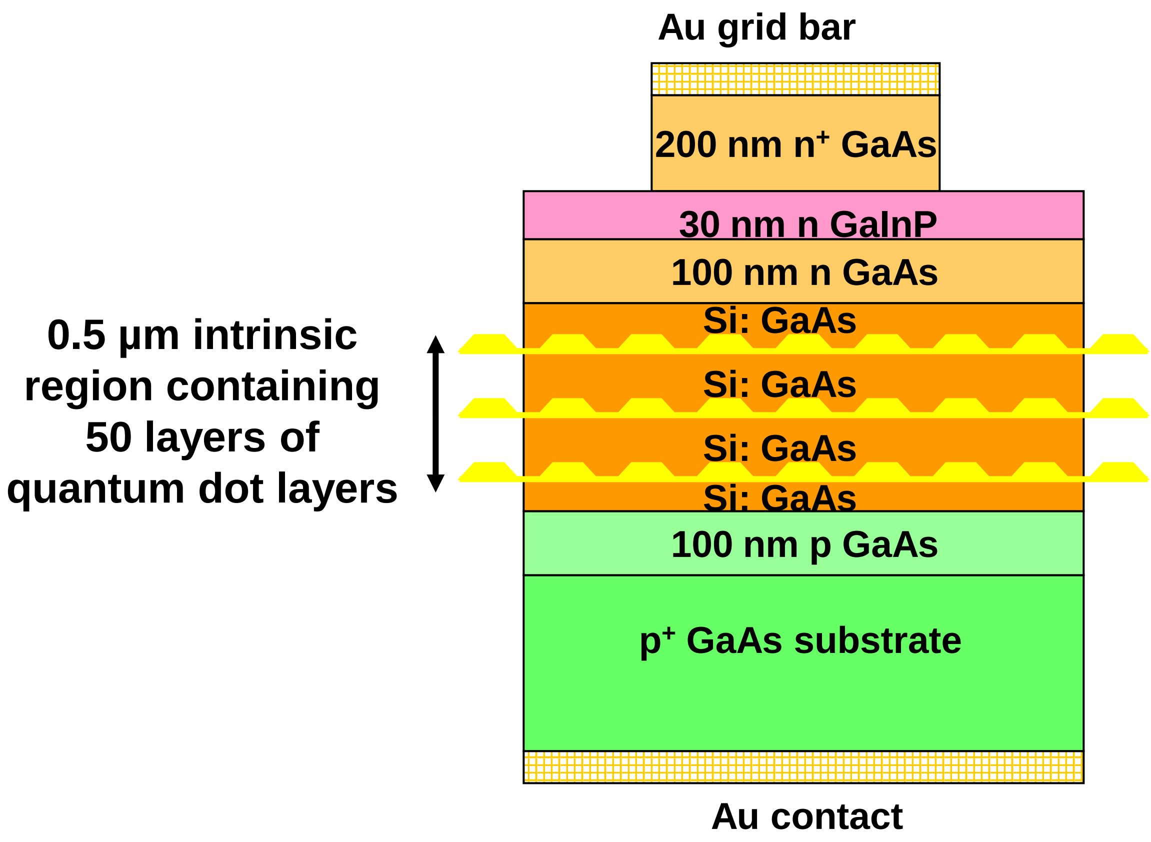
QCL for gas detection

Challenges in QCL design

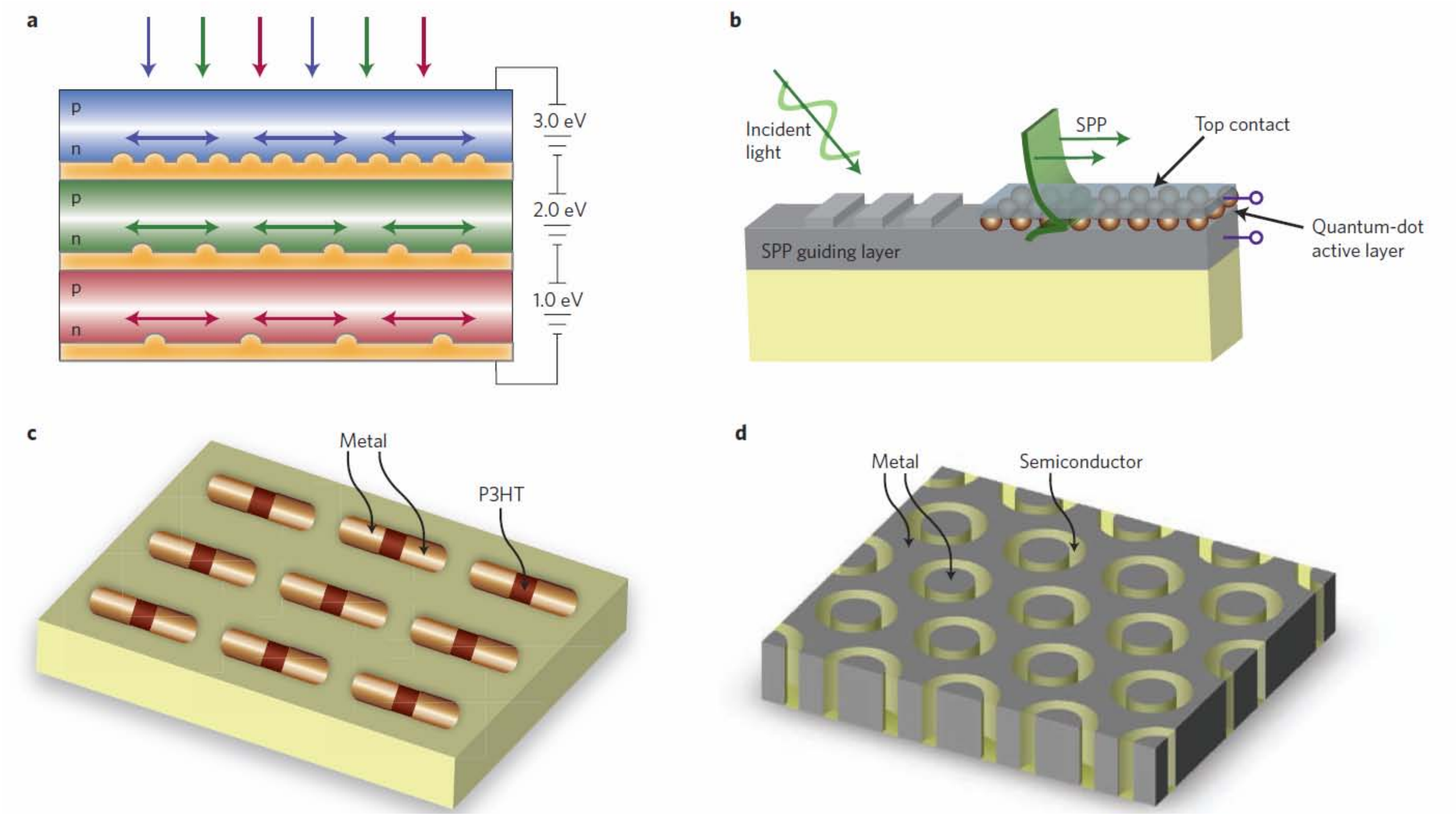
- Identify various physics interplaying in the QCL cavity and their effects on pulse propagation
- Design Lasing medium for ultra-short, stable, high power MIR pulse generation for environmental control and biomedical sensing



Quantum-Dot Solar Cells



Plasmonic Solar Cells



H. A. Atwater and A. Polman, Nature Materials, Vol 9, March 2010

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