Chapter 21: Optical Properties

ISSUES TO ADDRESS...

- What is optoelectronics?
- What optical properties are important for electrical engineers?
- What sort of materials?

- Optical applications:
  - -- luminescence
  - -- photoconductivity
  - -- solar cell
  - -- optical communications fibers

Designing for Optoelectronics

- Creep resistant solders for *dimensional stability*

- Non-brittle intermetallics and smooth bonding interfaces for *long term reliability*

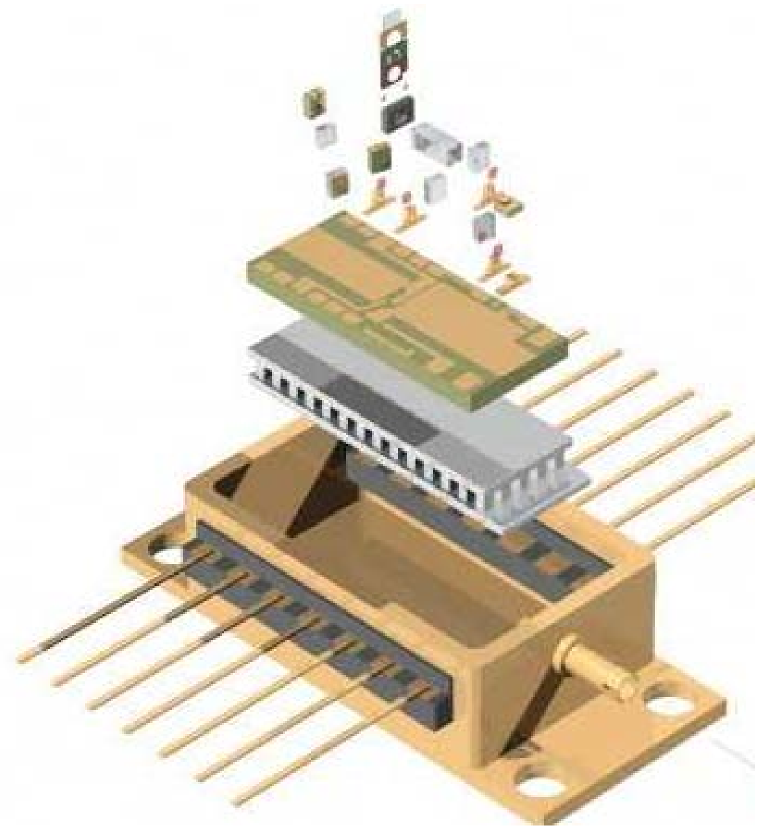
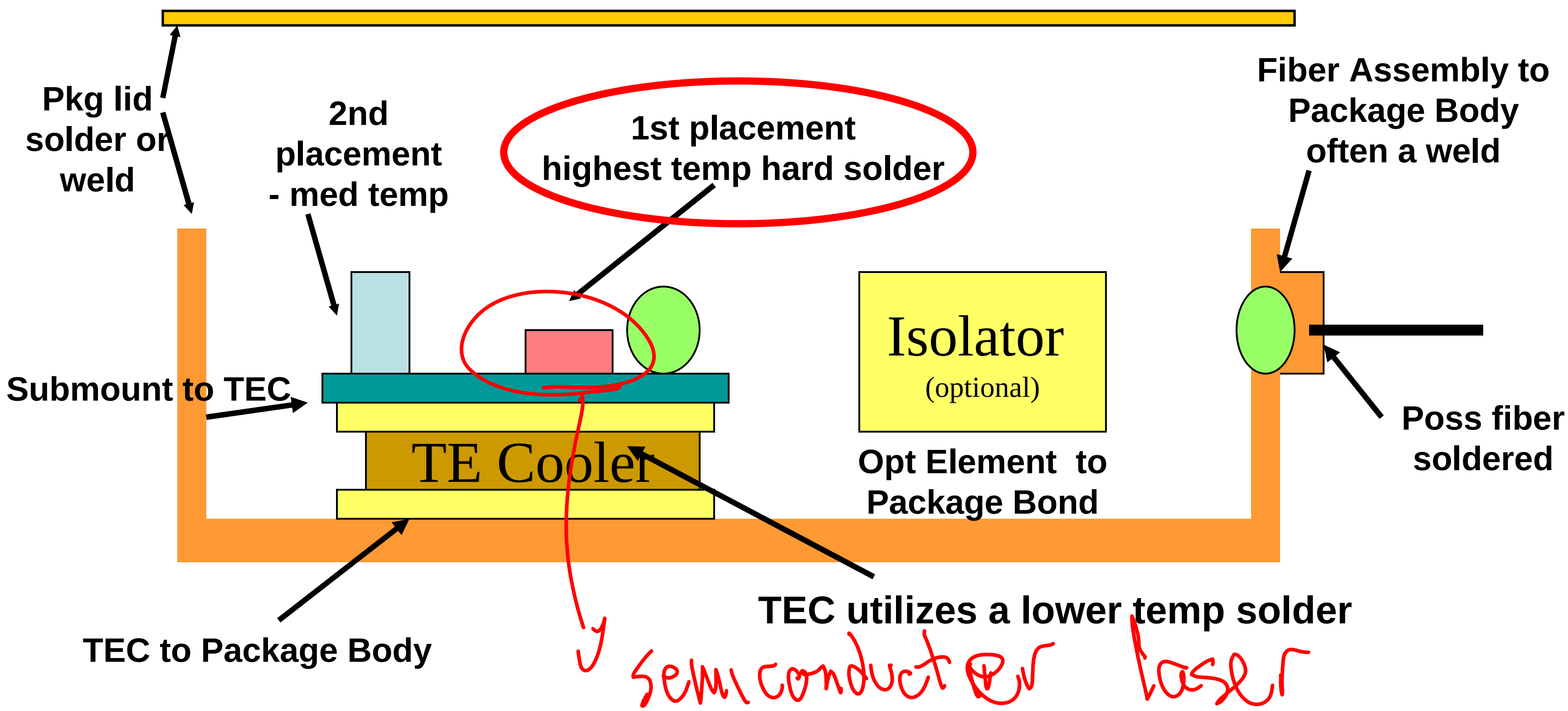


Image courtesy of Axsun, Inc.

Solders & Solder Hierarchy



Need a series of solders melting at successively lower temps

Optical Properties

Light has both ***particulate*** and ***wavelike*** properties

– Photons - with mass

$$\Delta E = h\nu = \frac{hc}{\lambda}$$

ΔE = energy

λ = wavelength

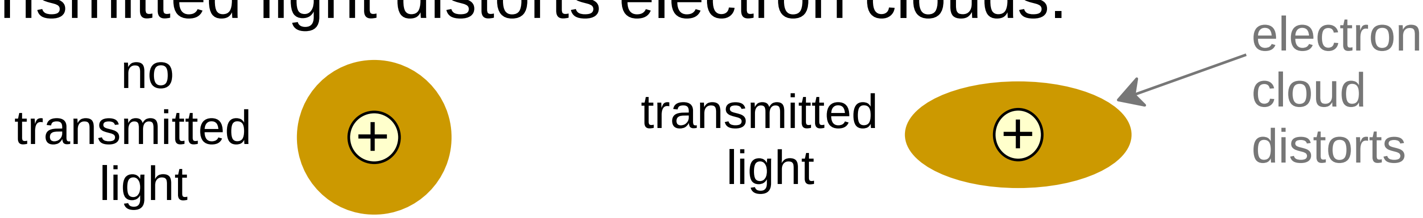
ν = frequency

h = Planck's constant ($6.62 x 10^{-34}$ J·s)

c = speed of light ($3.00 \text{ x } 10^{8}$ m/s)

Refractive Index, n

- Transmitted light distorts electron clouds.

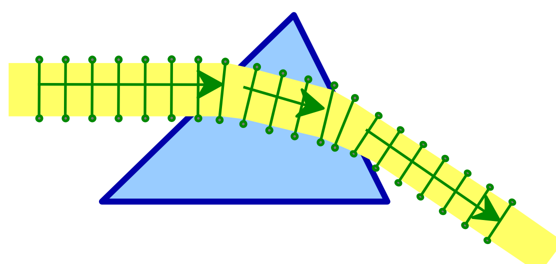


- Light is slower in a material vs vacuum.

$$n = \text{refractive index} \equiv \frac{c \text{ (velocity of light in vacuum)}}{v \text{ (velocity of light in medium)}}$$

--Adding large, heavy ions (e.g., lead can decrease the speed of light.

--Light can be "bent"



- Note: $n = f(\lambda)$

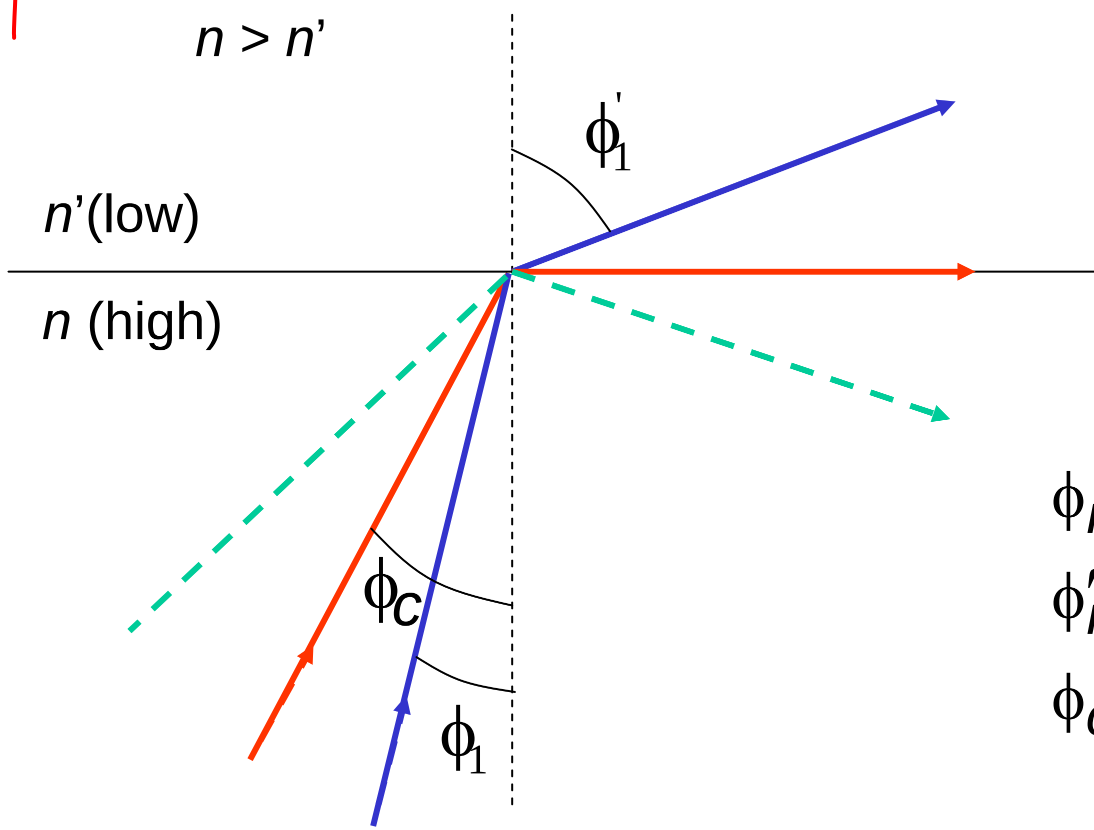
Typical glasses ca.	1.5 -1.7
Plastics	1.3 -1.6
PbO (Litharge)	2.67
Diamond	2.41

Selected values from Table 21.1, *Callister 7e*.

Total Internal Reflectance

$\sin\phi = n'/n$

Snell's Law



$$\frac{n}{n'} = \frac{\sin\phi'}{\sin\phi}$$

ϕ_i = incident angle

ϕ_i' = refracted angle

ϕ_c = critical angle

ϕ_c occurs when $\phi_i' = 90°$

for $\phi_i > \phi_c$ light is internally reflected

Optical Fibers

- prepare preform as indicated in Chapter 13
- preform drawn to 125 μm or less capillary fibers
- plastic cladding applied 60 μm

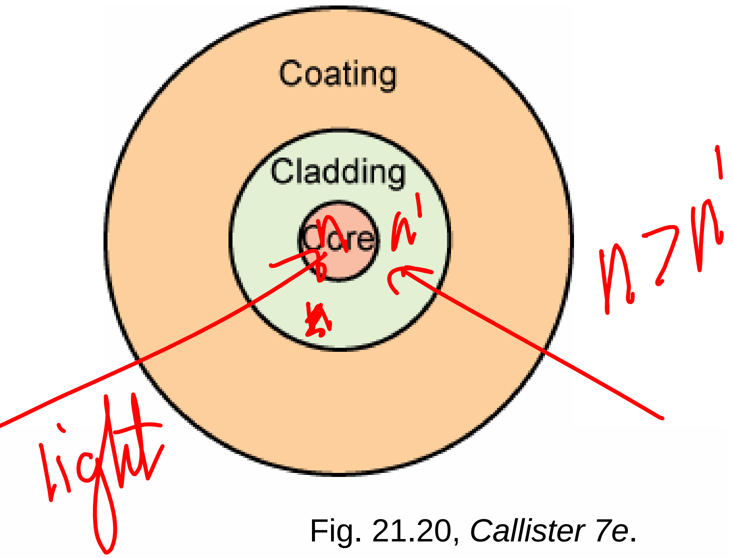


Fig. 21.20, *Callister 7e*.

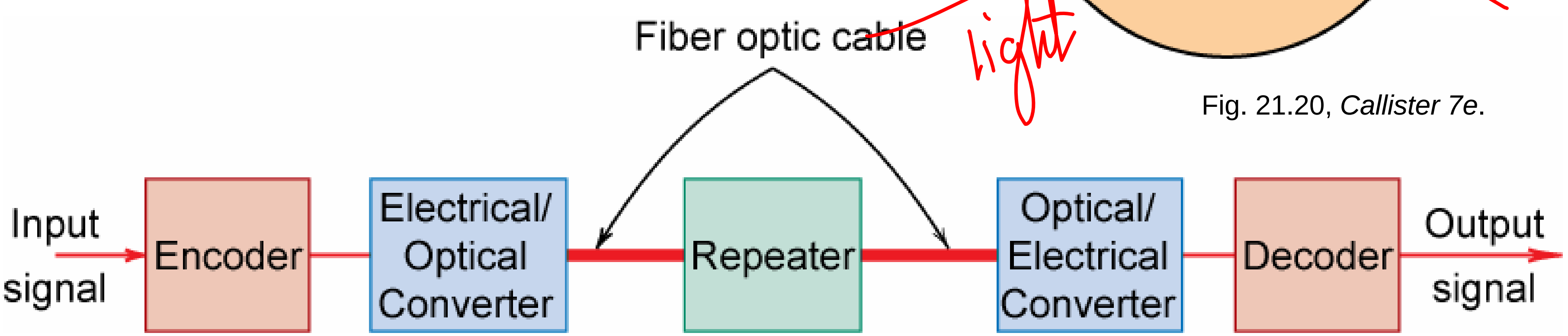


Fig. 21.18, *Callister 7e*.

Optical Fiber Profiles

Step-index Optical Fiber

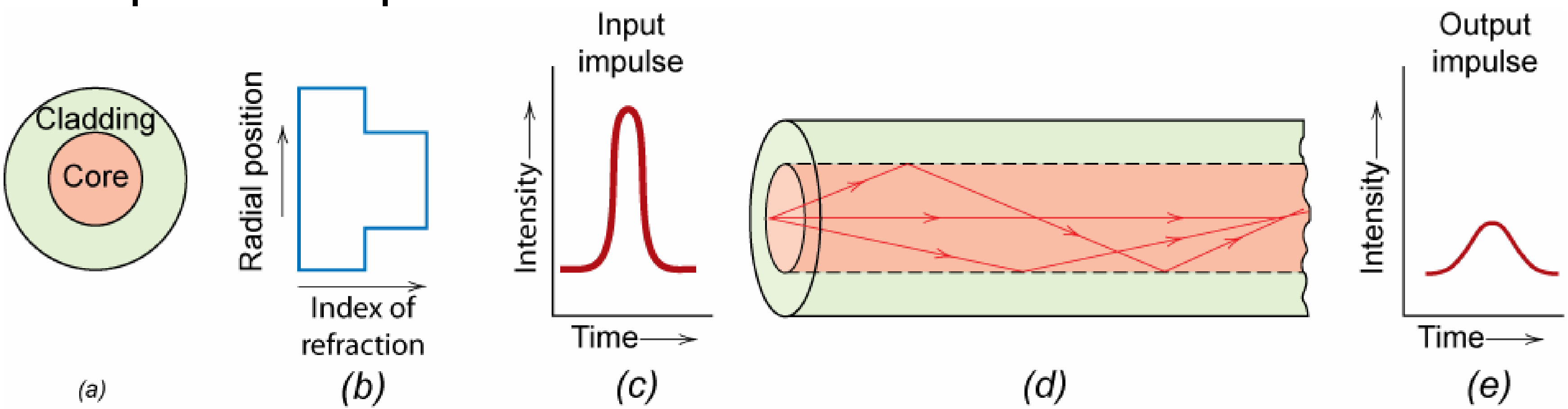


Fig. 21.21, *Callister 7e*.

Graded-index Optical Fiber

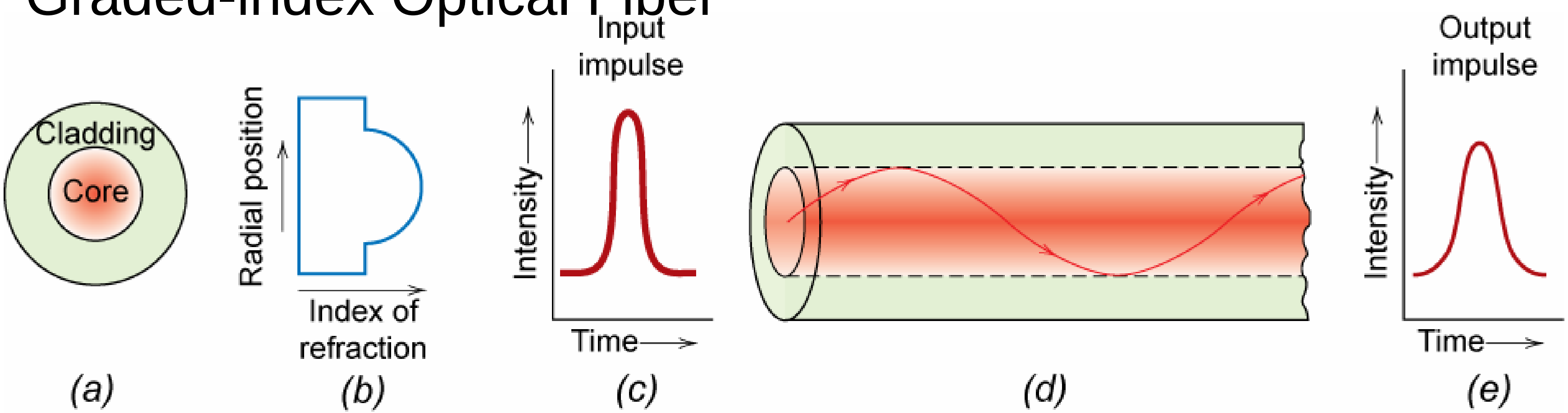
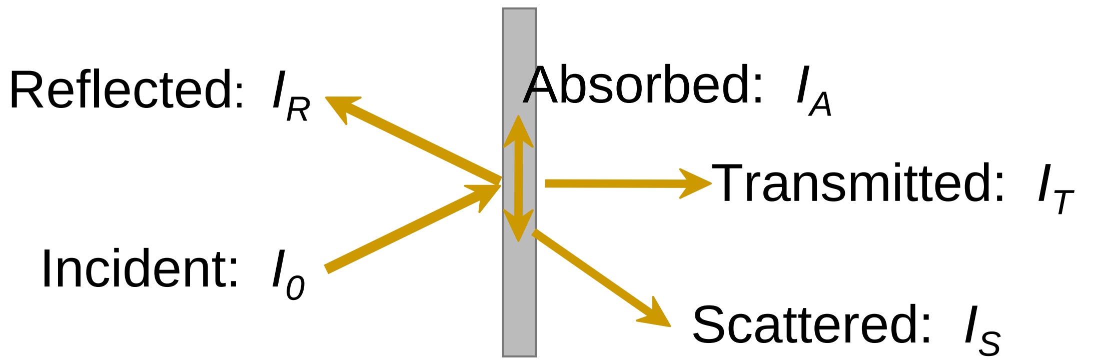


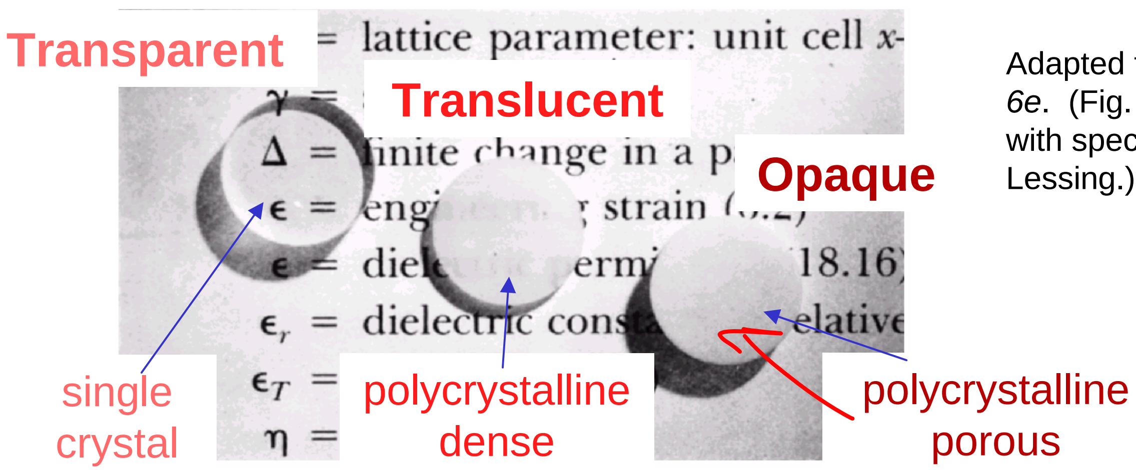
Fig. 21.22, *Callister 7e*.

Light Interaction with Solids

- Incident light is either reflected, absorbed, or transmitted: $I_o = I_T + I_A + I_R + I_S$



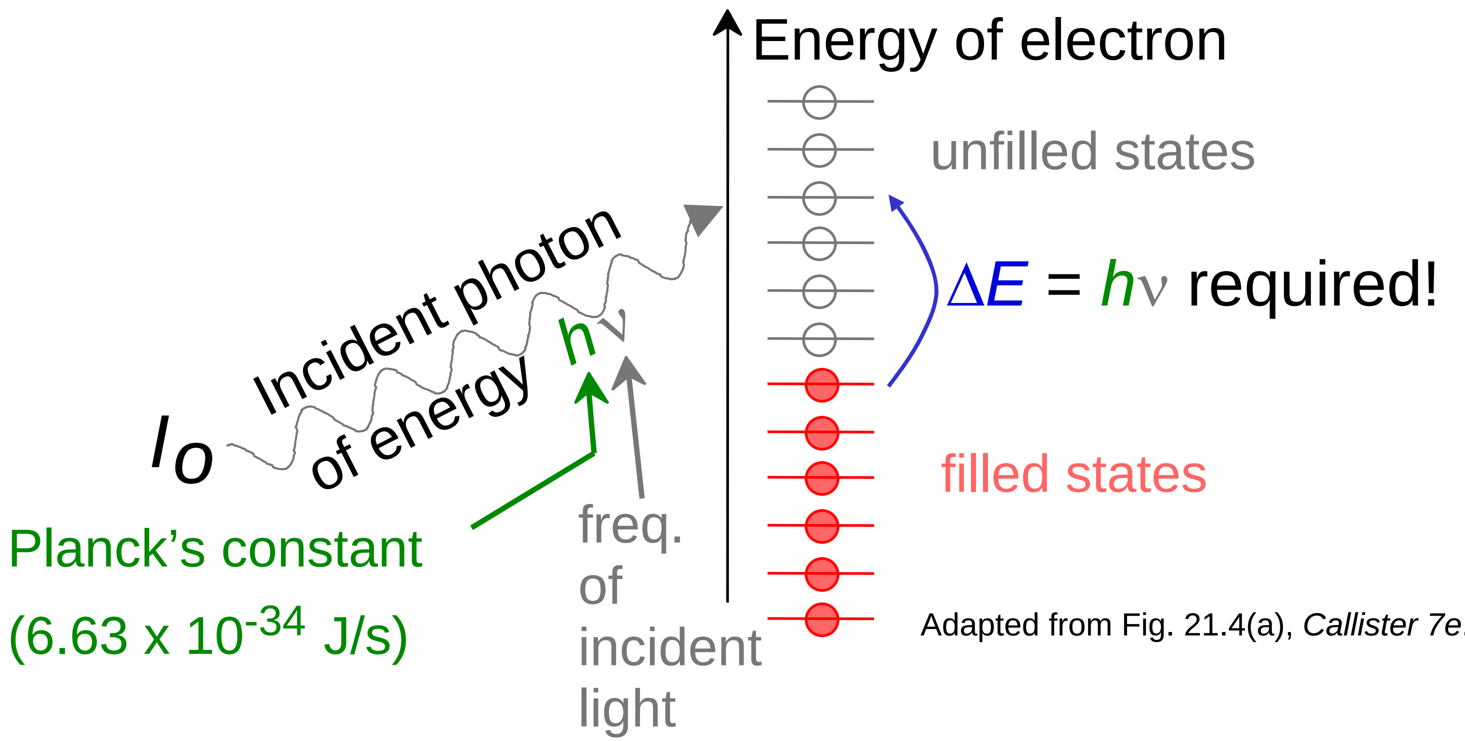
- Optical classification of materials:



Adapted from Fig. 21.10, *Callister 6e*. (Fig. 21.10 is by J. Telford, with specimen preparation by P.A. Lessing.)

Optical Properties of Metals: Absorption

- Absorption of photons by electron transition:

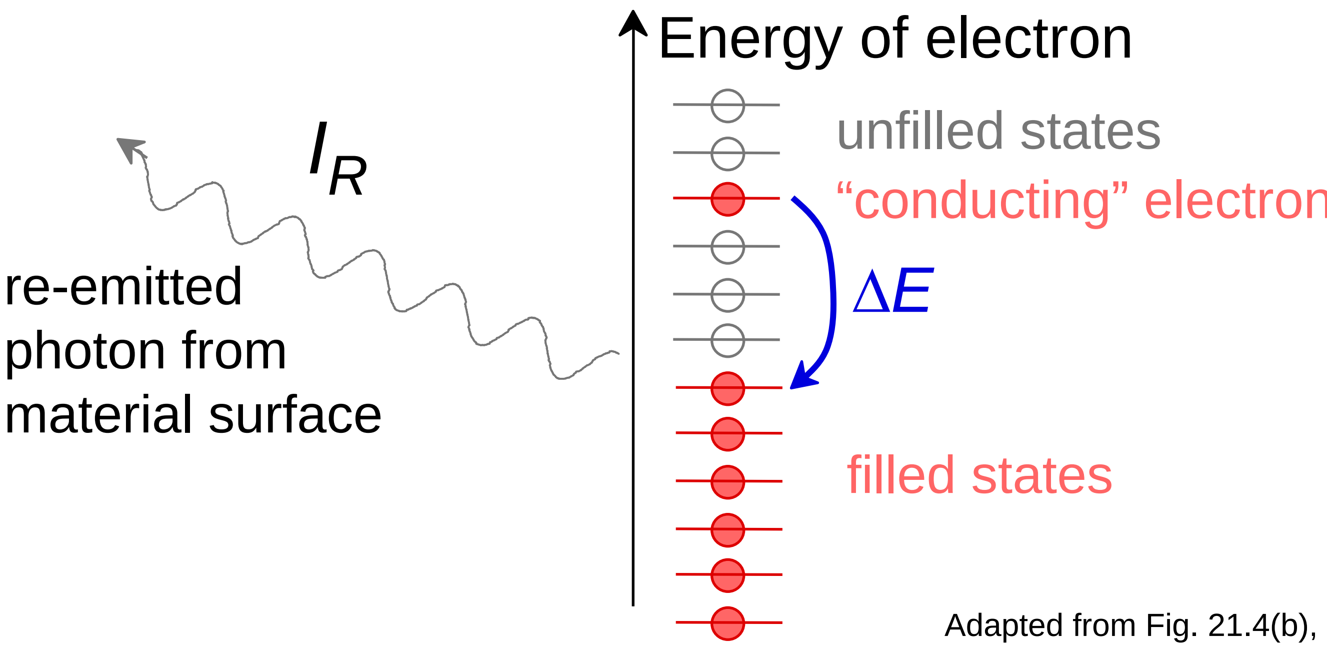


Adapted from Fig. 21.4(a), *Callister 7e*.

- Metals have a fine succession of energy states.
- Near-surface electrons absorb visible light.

Optical Properties of Metals: Reflection

- Electron transition emits a photon.



Adapted from Fig. 21.4(b), *Callister 7e*.

- Reflectivity = I_R/I_o is between 0.90 and 0.95.
- Reflected light is same frequency as incident.
- Metals appear reflective (shiny)!

Reflectivity, R

- Reflection
  - Metals reflect almost all light
  - Copper & gold absorb in blue & green => gold color

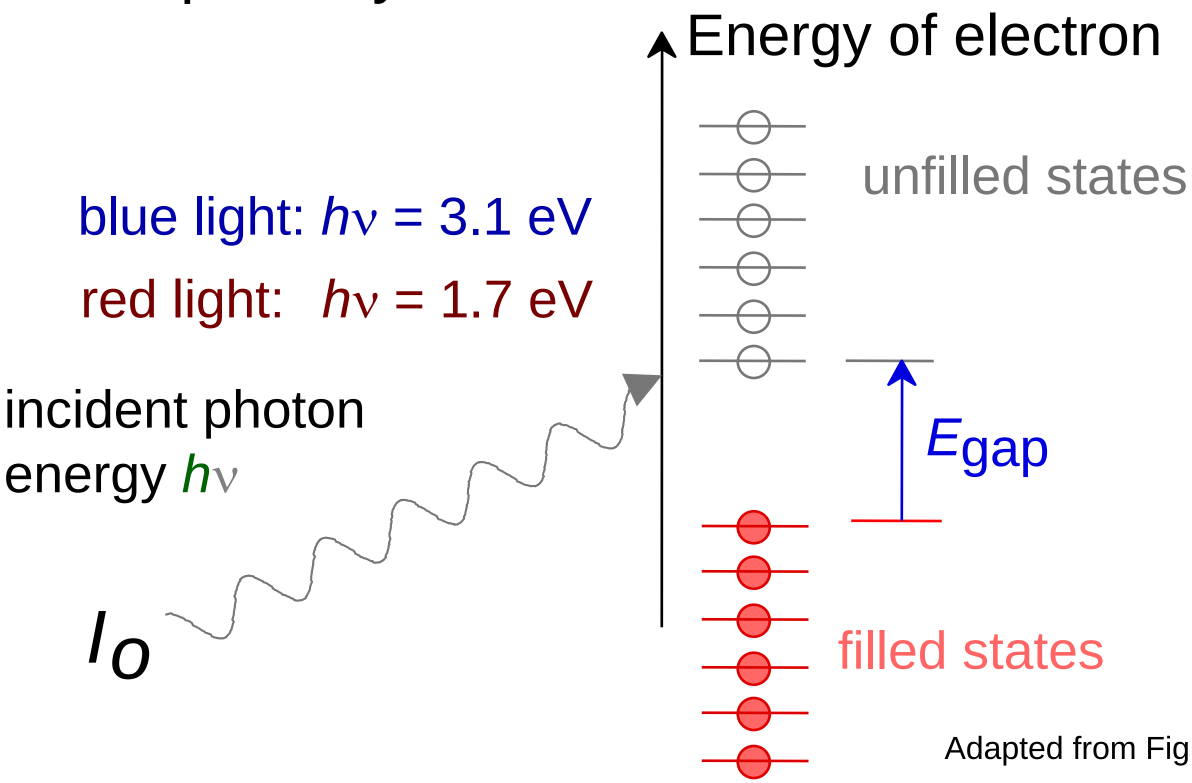
$$R = \left(\frac{n-1}{n+1}\right)^2 = \text{reflectivity}$$

- Example: Diamond $R = \left(\frac{2.41-1}{2.41+1}\right)^2 = 0.17$

$$\therefore \text{ 17\% of light is reflected}$$

Selected Absorption: Semiconductors

- Absorption by electron transition occurs if $h\nu > E_{gap}$



Adapted from Fig. 21.5(a), *Callister 7e*.

- If E_{gap} < 1.8 eV, full absorption; color is “black” (Si, GaAs)
- If E_{gap} > 3.1 eV, no absorption; colorless (diamond)
- If E_{gap} in between, partial absorption; material has a color.

Wavelength vs. Band Gap

Example: What is the minimum wavelength absorbed by Ge?

$$E = h\nu = \frac{hc}{\lambda}$$

$E_g = 0.67$ eV

$$\lambda_c = \frac{hc}{E_g} = \frac{(6.62 \times 10^{-34}\ \text{J}\cdot\text{s})(3 \times 10^{8}\ \text{m/s})}{(0.67\text{eV})(1.60 \times 10^{-19}\ \text{J/eV})} \leq 1.85\ \mu m$$

note : for Si $\quad E_g = 1.1\,\text{eV} \qquad \lambda_c \leq 1.13\ \mu m$

If donor (or acceptor) states also available this provides other absorption frequencies

LASER Light

- Is non-coherent light a problem? – diverges
  - can't keep tightly columnated

- How could we get all the light in phase? (coherent)
  - LASERS
    - Light
    - Amplification by
    - Stimulated
    - Emission of
    - Radiation
- Involves a process called population inversion of energy states

Population Inversion

- What if we could increase most species to the excited state?

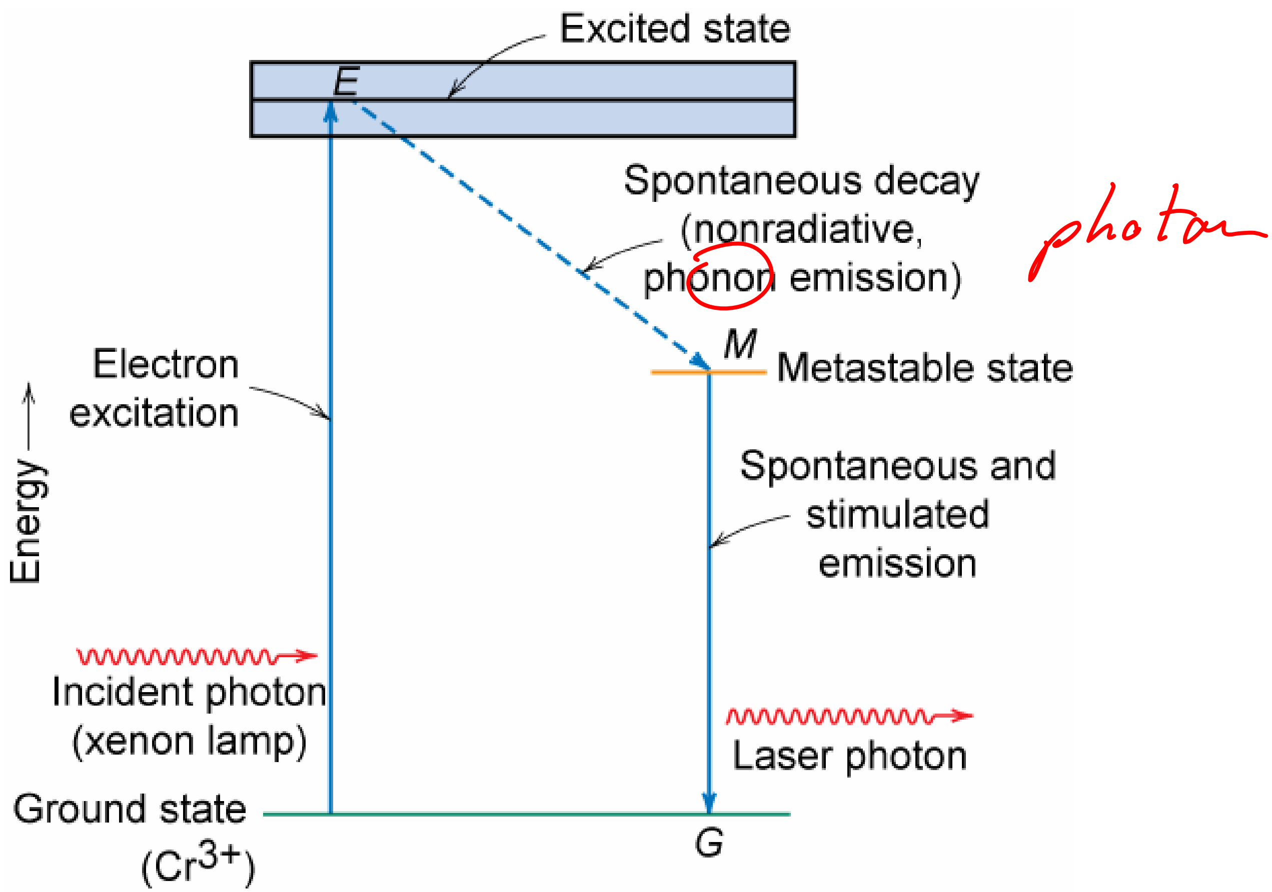


Fig. 21.14, *Callister 7e*.

LASER Light Production

- "pump" the lasing material to the excited state
  - e.g., by flash lamp (non-coherent lamp).

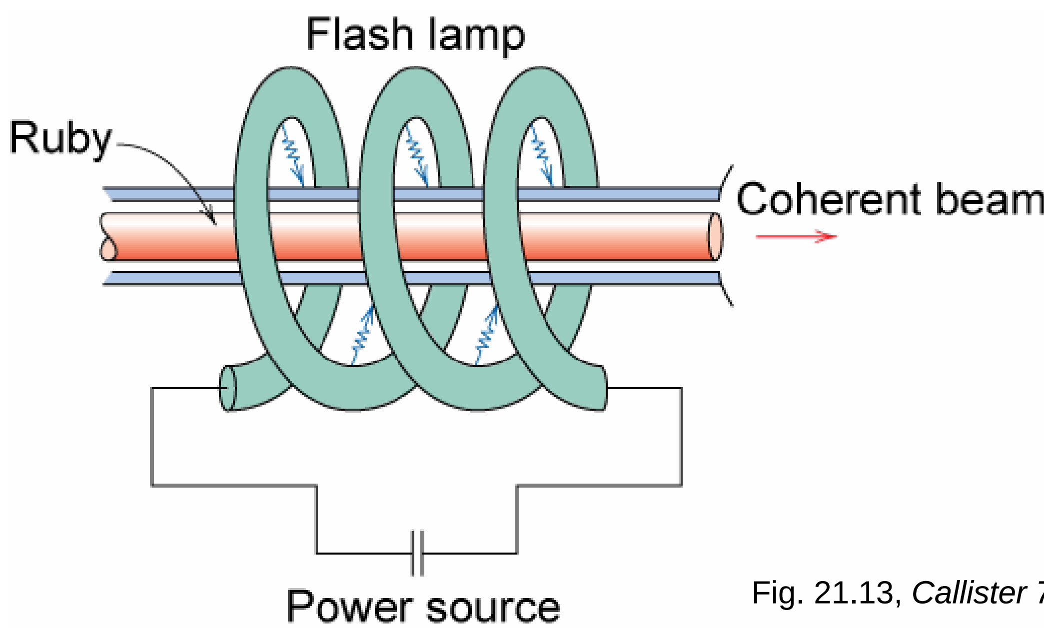


Fig. 21.13, *Callister 7e*.

- If we let this just decay we get no coherence.

LASER Cavity

"Tuned" cavity:

- Stimulated Emission
  - One photon induces the emission of another photon, in phase with the first.
  - cascades producing very intense burst of coherent radiation.
- i.e., Pulsed laser

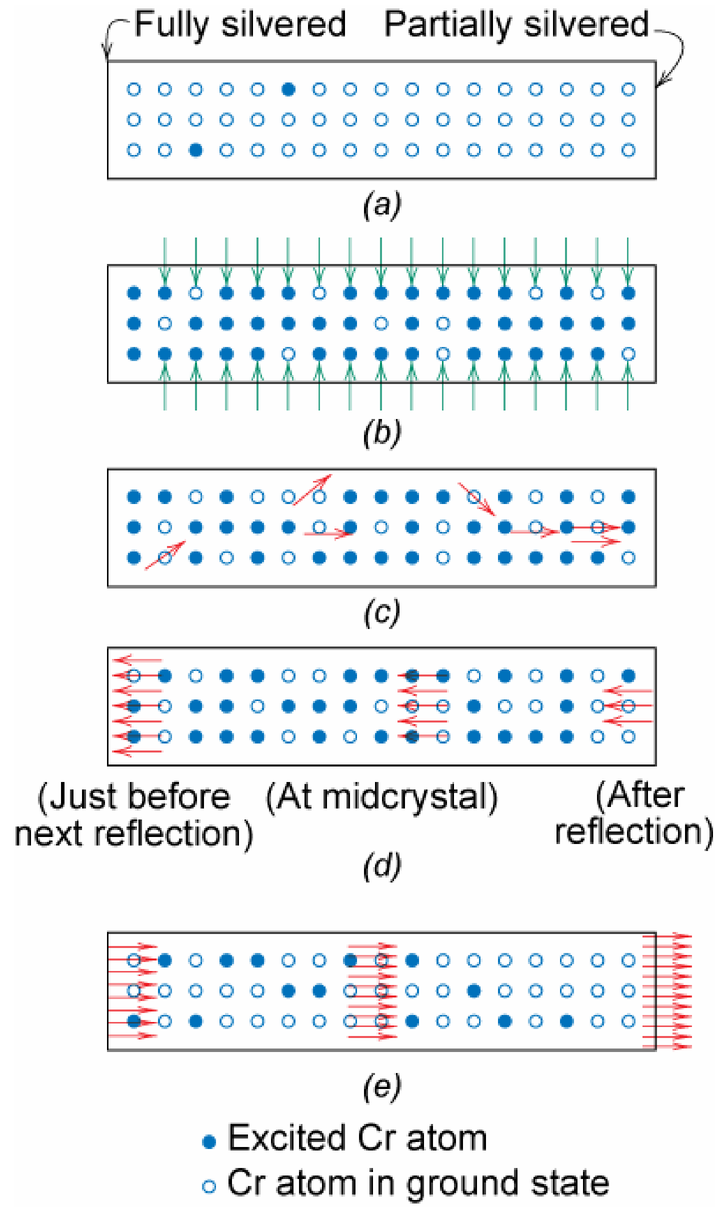
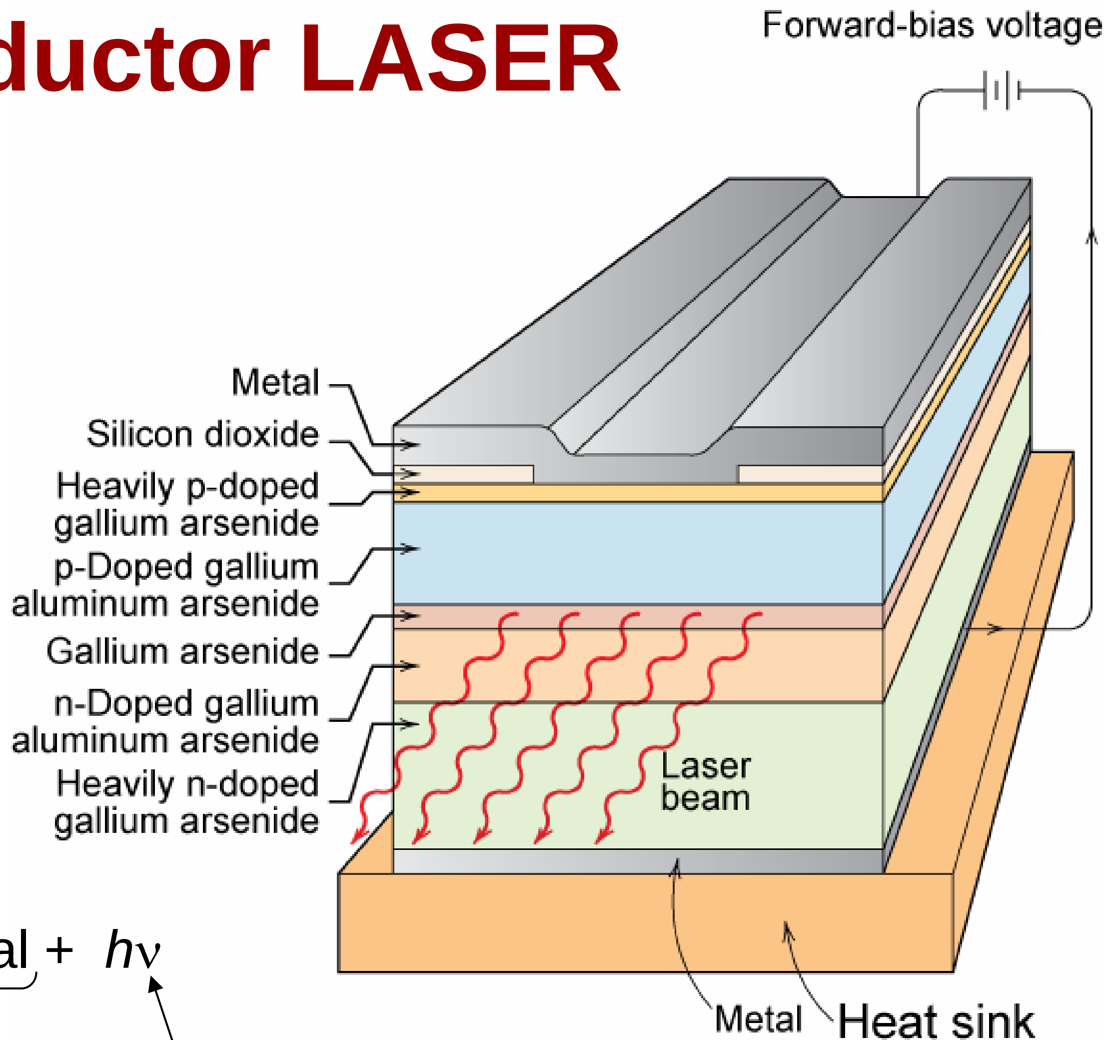


Fig. 21.15, *Callister 7e*.

Semiconductor LASER

- Apply strong forward bias to junction. Creates excited state by pumping electrons across the gap- creating electron-hole pairs.



$$\underbrace{\text{electron} + \text{hole}}_{\text{excited state}} \rightarrow \underbrace{\text{neutral}}_{\text{ground state}} + h\nu$$

$h\nu$: photon of light

Adapted from Fig. 21.17, *Callister 7e*.

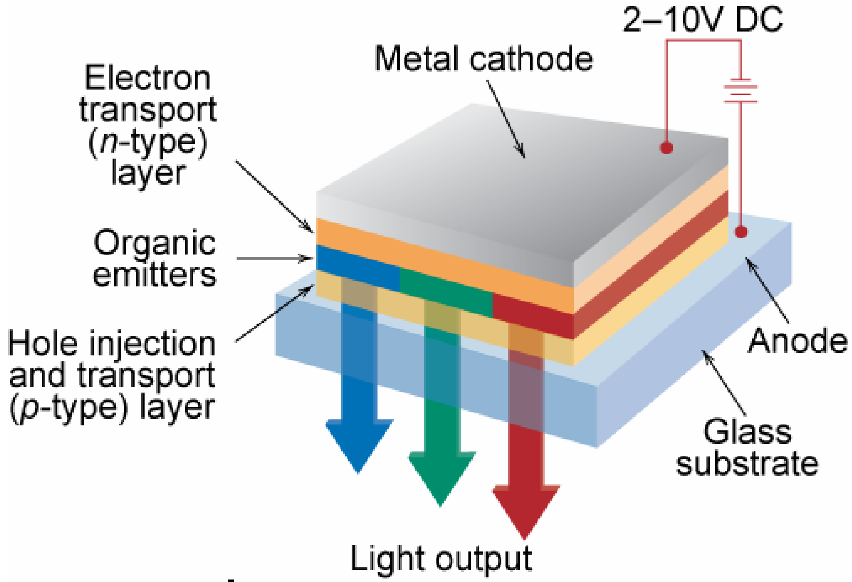
Uses of Semiconductor LASERs

- #1 use = compact disk player
  - Color? - red
- Banks of these semiconductor lasers are used as flash lamps to pump other lasers
- Communications
  - Fibers often turned to a specific frequency (typically in the blue)
  - only recently was this a attainable

Applications of Materials Science

- New materials must be developed to make new & improved optical devices.
  - Organic Light Emitting Diodes (OLEDs)
  - White light semiconductor sources

Fig. 21.12, *Callister 7e*. Reproduced by arrangement with *Silicon Chip* magazine.)

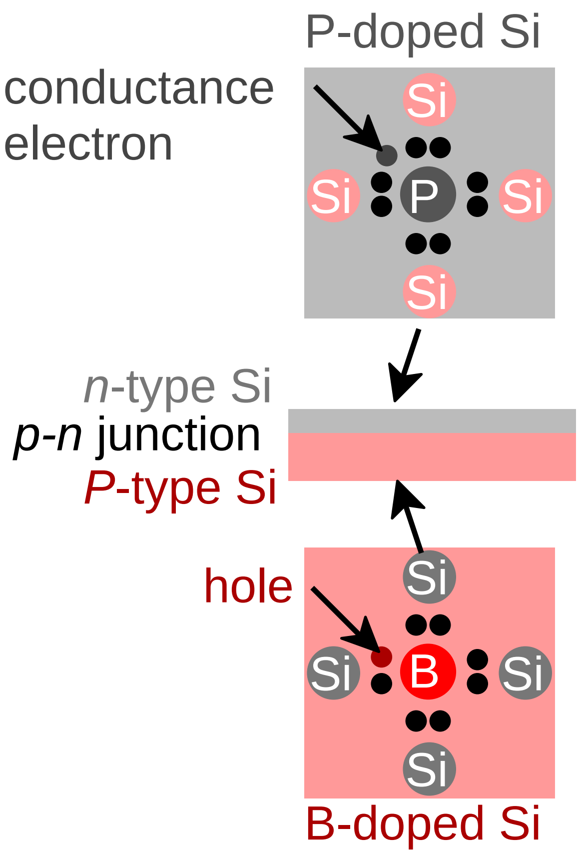


- New semiconductors
- Materials scientists

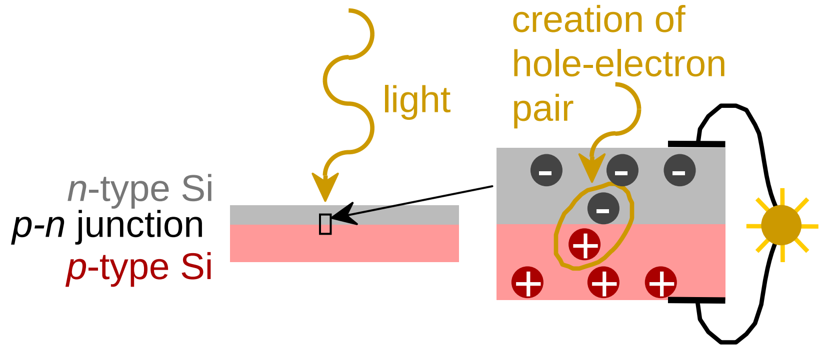
  (& many others) use lasers as tools.
- Solar cells

Solar Cells

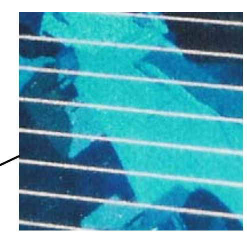
- *p-n* junction:



- Operation:
  - -- incident photon produces hole-elec. pair.
  - -- typically 0.5 V potential.
  - -- current increases w/light intensity.



- Solar powered weather station:



polycrystalline Si

Los Alamos High School weather station (photo courtesy P.M. Anderson)

From study guide…

21.4, 21.5, 21.7, 21.12, LEDs, 21.13, 21.14

- **How do we describe the energy of a photon?**
- **What is index of refraction?**
- **What is total internal reflection?**
- **What is an optical fiber? How does it work?**
- **What is a laser? How does it work? What is a semiconducting laser? How does it work?**
- **What is a light-emitting diode? How does it work?**

Update on final exam (I will add this info to the study guide on WebCT)

- **20 questions total**
- **3 of the questions contain calculations**
- **4 of the 20 are "very short" answer**

STUDY RECOMMENDATIONS

- ***Don't forget what you learned in the first half. Some concept questions will require knowledge of the first half of the course.***
- ***For the second half, it is important that you know what equations mean. Work out (or review) problems using the equations you think are important based on this study guide.***
- ***Don't forget the lecture on Si device technology and microelectronics packaging (some of which is in Ch. 22 of Callister).***
- ***For the problems, units and dimensional analysis are important. A table of converting electromagnetic units to SI equivalents will be given in the appendix of the exam.***
- ***MOST IMPORTANTLY: Consider the concept map and the learning objectives during your preparation. They describe the overall picture of learning goals for the course.***

FINAL WORDS

- **Office hours between now and 24Apr are by appointment (TAs as well)**
- **Best of luck on all your final exams**
- **Best of luck in your future careers.**
- **Please evaluate the course on Mercury.**