9.3 Summary

9.3.1 Summary to: 9. Optoelectronics

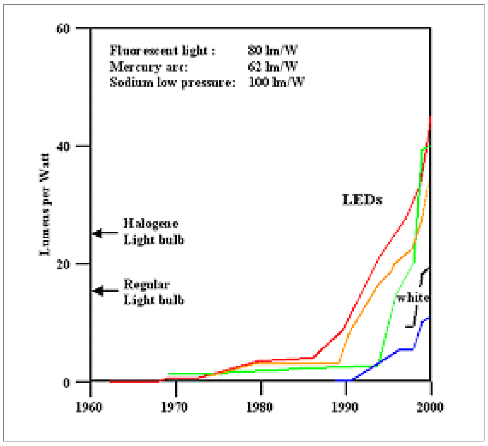
- Optoelectronics has *two* basic branches:
  - **1.** Light in ⇒ electrical signal out:
    - **Optical sensors** as single elements
    - "**CCD**" chips in "megapixel" matrices.
  - **2.** Electricity in ⇒ light out; in two paradigmatic versions:
    - **LED's**
    - **Laser** diodes
- Here we only look at the second branch.
  - The semiconductors of choice are mostly the **III-V's**, usually in single-crystalline perfect thin films.
  - The present day (**2008**) range of wavelength covers the **IR** to near **UV**.
  - Indirect semiconductors like **GaP** can be used too, if some "tricks" are used.

	Wavelength (nm)	Typical Semiconductor
Infrared	**880**	**GaAlAs/GaAs**
Red	**660 - 633**	**GaAlAs/GaAs**
Orange to **Yellow**	**612 - 585**	**AlGaInP** **GaAsP/GaP** **GaAsP/GaP**
Green	**555**	**GaP**
Blue to **Ultraviolet**	**470 - 395**	**GaN/SiC** **GaN/SiC** **InGaN/SiC**

- The index of refraction $n = (\epsilon)^{1/2}$ and thus the dielectric constant ϵ become important
  - Semiconductors have a relatively large index of refraction at photon energies below the bandgap of $n \approx$ **3 - 4**.
  - Diamond has the highest n in the visible region
- The *thermal conductivity* becomes important because for generating light one needs *power* (which we avoided as much as possible for signal processing with **Si**!)
  - Again, diamond has the highest thermal conductivity of all known materials - **5** times better than **Cu**!

Typical Semiconductor	Dielectric constant	Thermal conductivity [W/cm · K]
Si	11.9	1.5
GaAs	13.1	0,45
GaP	11.1	1.1
GaN	8.9	1.3
SiC	10	5
C (Diamond)	5.8	22

- **LED's** come as cheap little "indicator" lights and recently also as replacement for "light bulbs".
  - Intense white light from **LED's** becomes possible, Advantages: High efficiencies and long life time
  - The key was the "taming" of the **GaN** material system for blue and **UV LED's**.

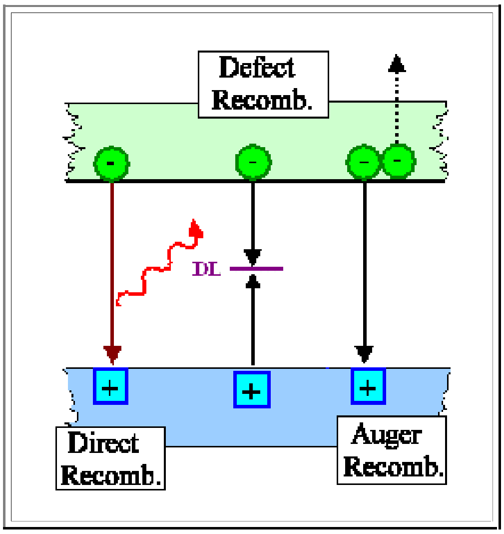


- **LED's** based on organic semiconductors (**OLED**) are rapidly appearing in **OLED** based displays.
  - *Advantage:* High efficiencies because of active light generation.
    Problem: Product life time; sensitivity to air.
- Semiconductor "Diode" **Lasers** are high-power" **LED's** plus "mirrors"
  - *Advantage:* Small and cheap.
    Problems: Low power, "Quality".

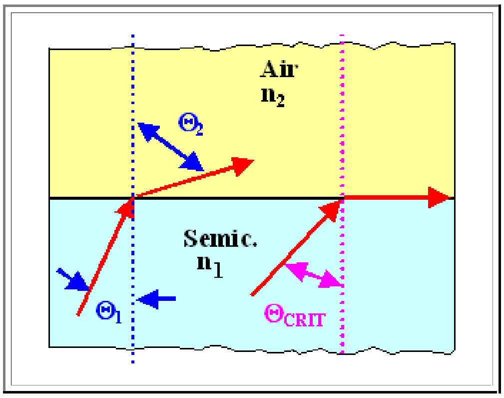
Enabling technology for CD / DVD / Blue ray / ... memory technologies!

- There are always several recombination channels active in parallel
  - Direct **band-band recombination**; *producing light*.
  - **Defect recombination**; *not* producing light.
  - **Auger recombination**; *not* producing light.
  - "Exotic" mechanisms like **exciton recombination**; producing light in *indirect* semiconductors like **GaP**

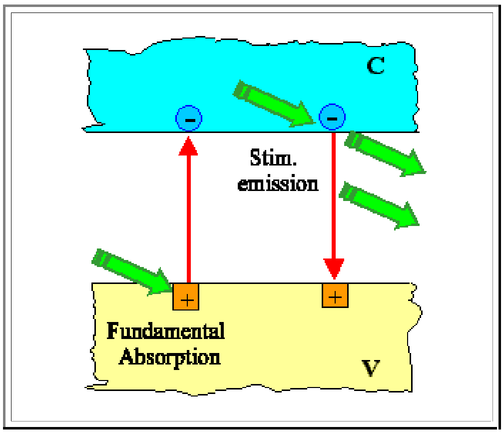
  - High efficiency **LED's** need optimized recombination.

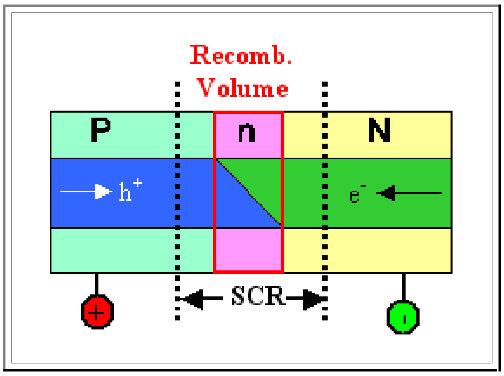


- Without "tricks" only a fraction of the light produced gets out of the semiconductor
  - Index grating is essential
  - Avoiding re-absorption is essential
  - Defined recombination volumes are important
- Hetero junctions of the **NnP** or **NpP** type are the solution, but create problems of their own
  - Hetero-interfaces must be defect free ⇒ Avoid misfit dislocations!



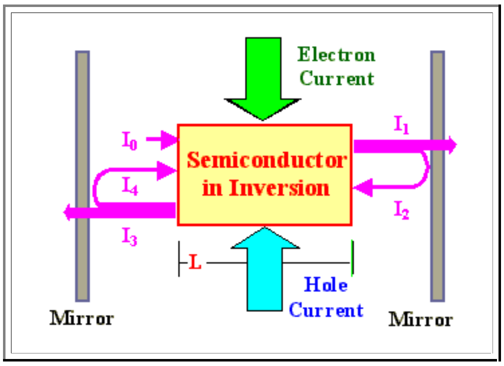
- **Laser** diodes are similar to **LED's** but need to meet two additional conditions
- **1.** The rate of **Stimulated emission**, a new process predicted by A. Einstein concerning the interaction of light and electrons in the conduction band, must be at least as large as the rate of **fundamental absorption**
  - *Stimulated emission*results in *two* **fully coherent** photons for *one* incoming photon and thus allows optical *amplification*.
  - Strong stimulated emission his requires large non-equilibrium electron concentrations in the conduction band. ⇒strong "pumping" is necessary, moving electrons up to the conduction band just as fast as they disappear by recombination.
  - In semiconductor junctions pumping can be "easily" achieved by very large injection currents across a forwardly biased (hetero) junction.⇒ cooling problem!
- **2.** There must be some feed-back that turns an (optical) amplifier into an oscillator for one frequency
  - *Feed-back* is achieved by partially transparent mirrors.





- Monochromatic output is achieved by the optical resonator forme by two exactly plan-parallel mirrors

- Only wavelengths **λ=2*L*/i** (*i*=integer) that "fit" into the cavity will be able to exist. Together with the condition
  $h\nu = hc/\lambda = E_g$
  the Laser wavelength is given



- Semiconductor Lasers now span the range from **IR** to **UV**; essential materials are all **III-V's**, in particular the **GaN** family.

- **Molecular beam epitaxy** is the deposition method of choice for epitaxial multilayer structures

Exercise 9.3-1
All Quick Questions to 9.