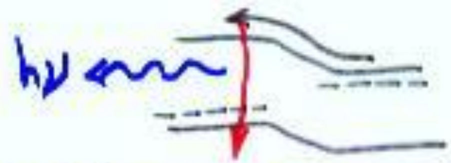
6.3 Diodes for Light Emitters

- LEDs (light emitting diodes)
- lasers (light amplification by stimulated emission of radiation)

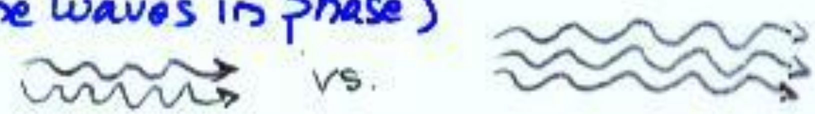
Forward bias injection: Electroluminescence



Laser → Narrower linewidth emission ("monochromatic")

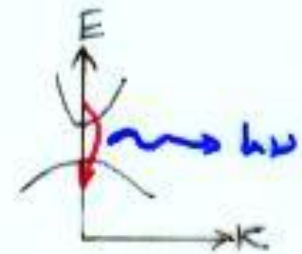
→ Directional

→ Coherent (plane waves in phase)

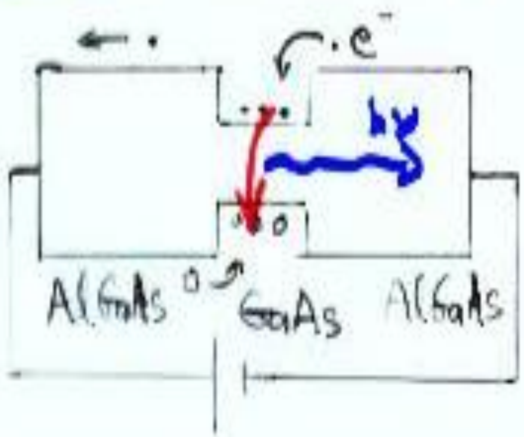


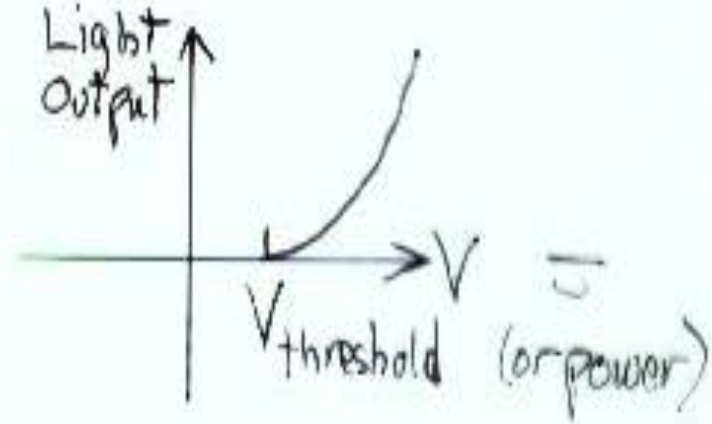
Semiconductors for lasers need:

- Direct gap (efficient recombination)



· Match λ to low absorption for fibers.



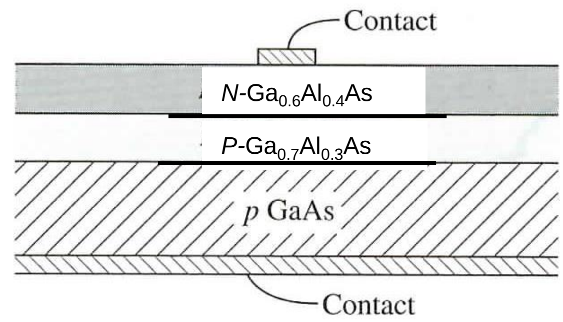


Reduce $V_{Threshold}$ or $J_{threshold}$

to shrink power supply required

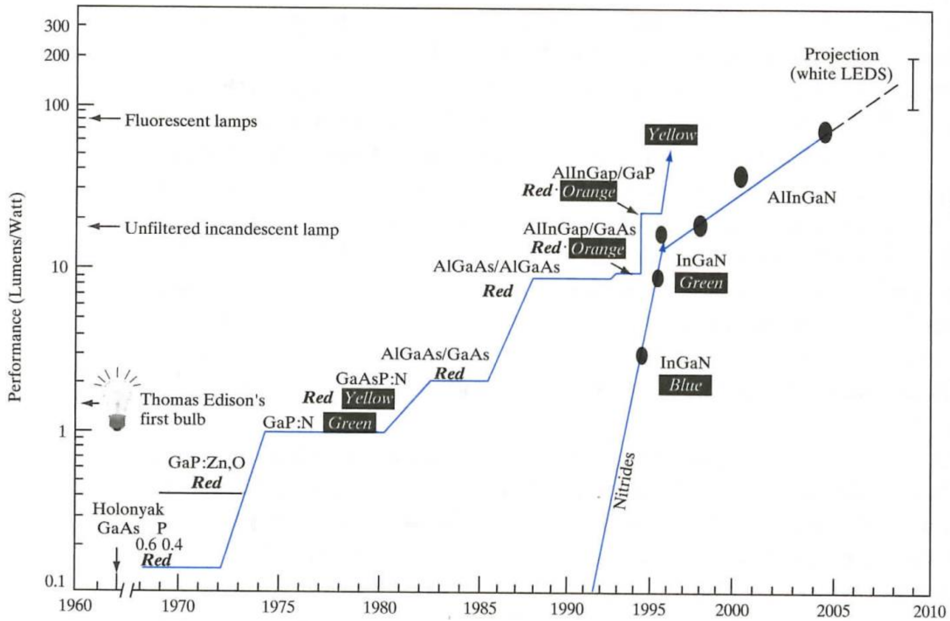
Light Emitting Diode - Heterostructures

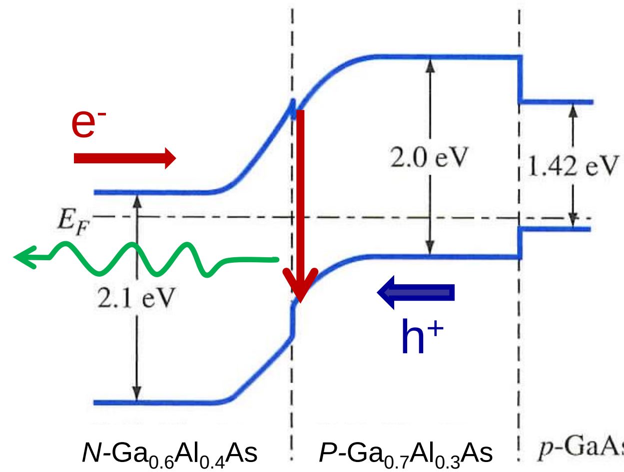
Electrons inserted from wide band gap N-$Ga_{0.6}Al_{0.4}As$ in narrower bandgap p-$Ga_{0.7}Al_{0.3}As$



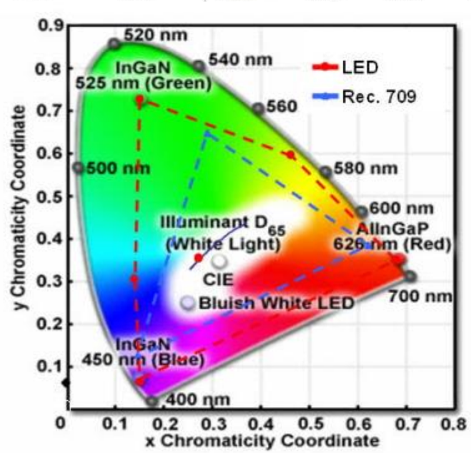
(a)

LED efficiency near fluorescent lamps



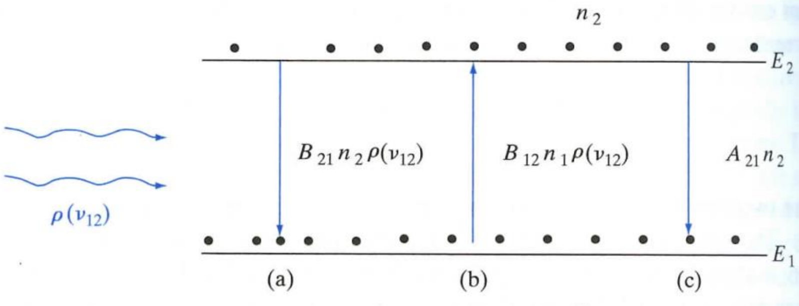


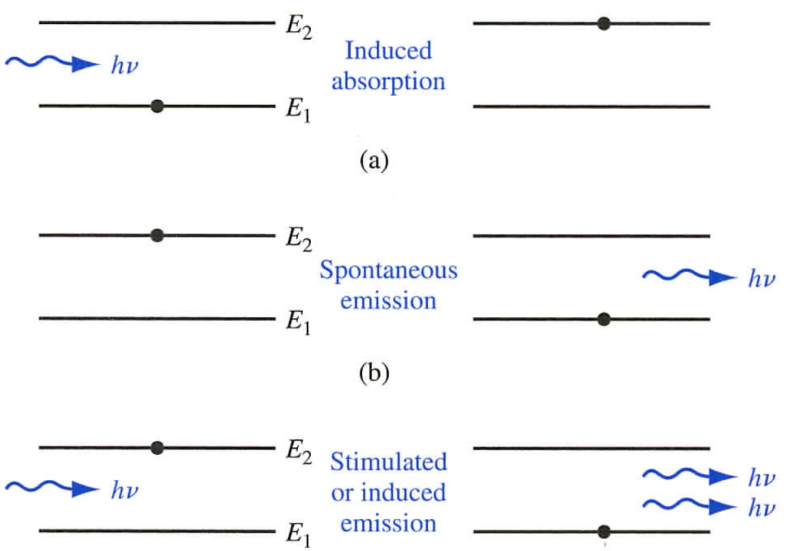
(b)



GaN extends LED color gamut to blue
→ produce white light illumination

Stimulated Emission - Lasers





Spontaneous emission proportional to upper level population

$B_{12}\, n_1\, p(\upsilon_{12}) = A_{21}\, n_2 + B_{21} n_2 \rho(\upsilon_{12})$ → Einstein Coefficients

Absorption = spontaneous emission + stimulated emission (rates balance)

$$\frac{\text{Stimulated emission rate}}{\text{Spontaneous emission rate}} = \frac{B_{21}n_2\rho(v_{12})}{A_{21}n_2} = \frac{B_{21}}{A_{21}}\rho(v_{12})$$

$$\frac{\text{Stimulated emission rate}}{\text{Absorption rate}} = \frac{B_{21}n_2\rho(v_{12})}{B_{12}n_1\rho(v_{12})} = \frac{B_{21}}{B_{12}}\frac{n_2}{n_1}$$

To get stimulated emission > absorption, need $n_2 > n_1$

But $n_2/n_1 < 1$ in equilibrium → For $n_2/n_1 > 1$, need "population inversion"

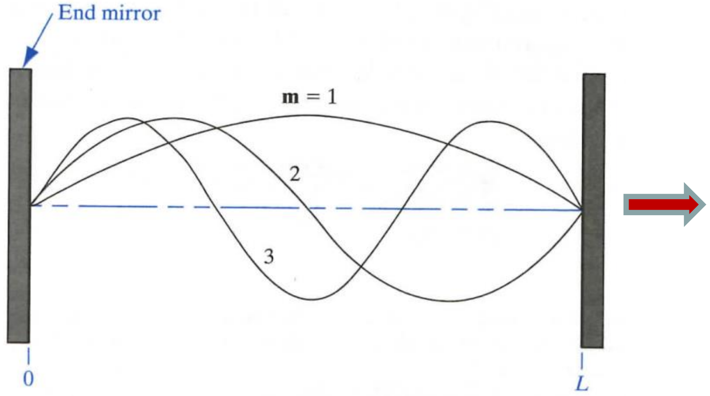
(1) Optical resonant cavity to build up photon field

(2) Means to obtain population inversion

Stimulated Emission – Build Up Photon Field

Resonant modes in a laser cavity: Cavity length L = mλ/2; Reflecting mirrors – partially transmitting (small)

→ Build up $\rho_{12}(\upsilon_{12})$



Stimulated Emission – Maintain Population Inversion

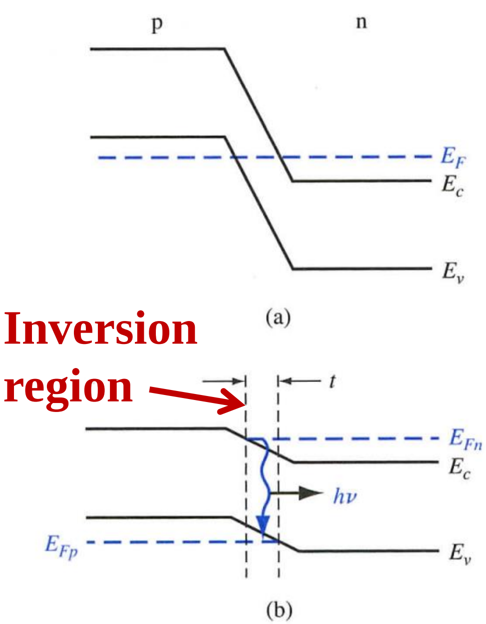


Figure 14.33 | (a) Degenerately doped pn junction at zero bias. (b) Degenerately doped pn junction under forward bias with photon emission.

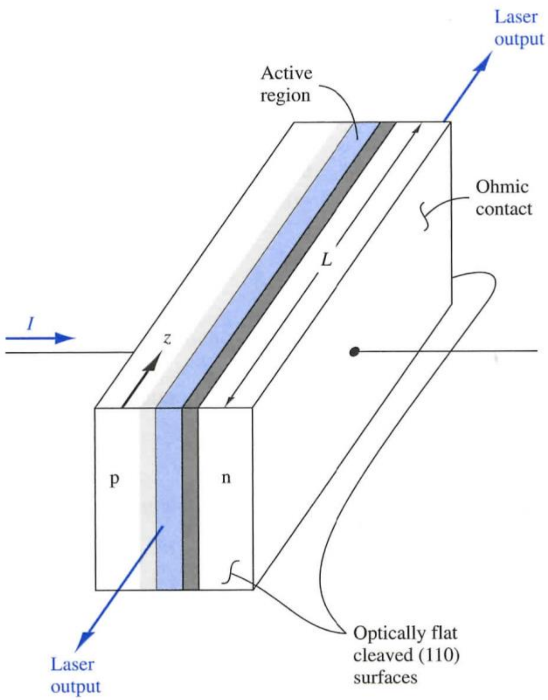


Figure 14.34 | A pn junction laser diode with cleaved (110) planes forming the Fabry-Perot cavity. *(After Yang [22].)*

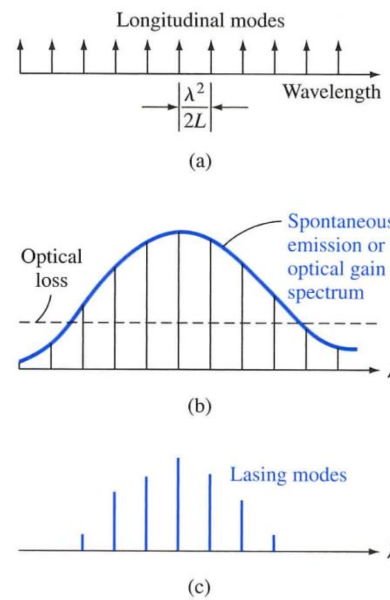
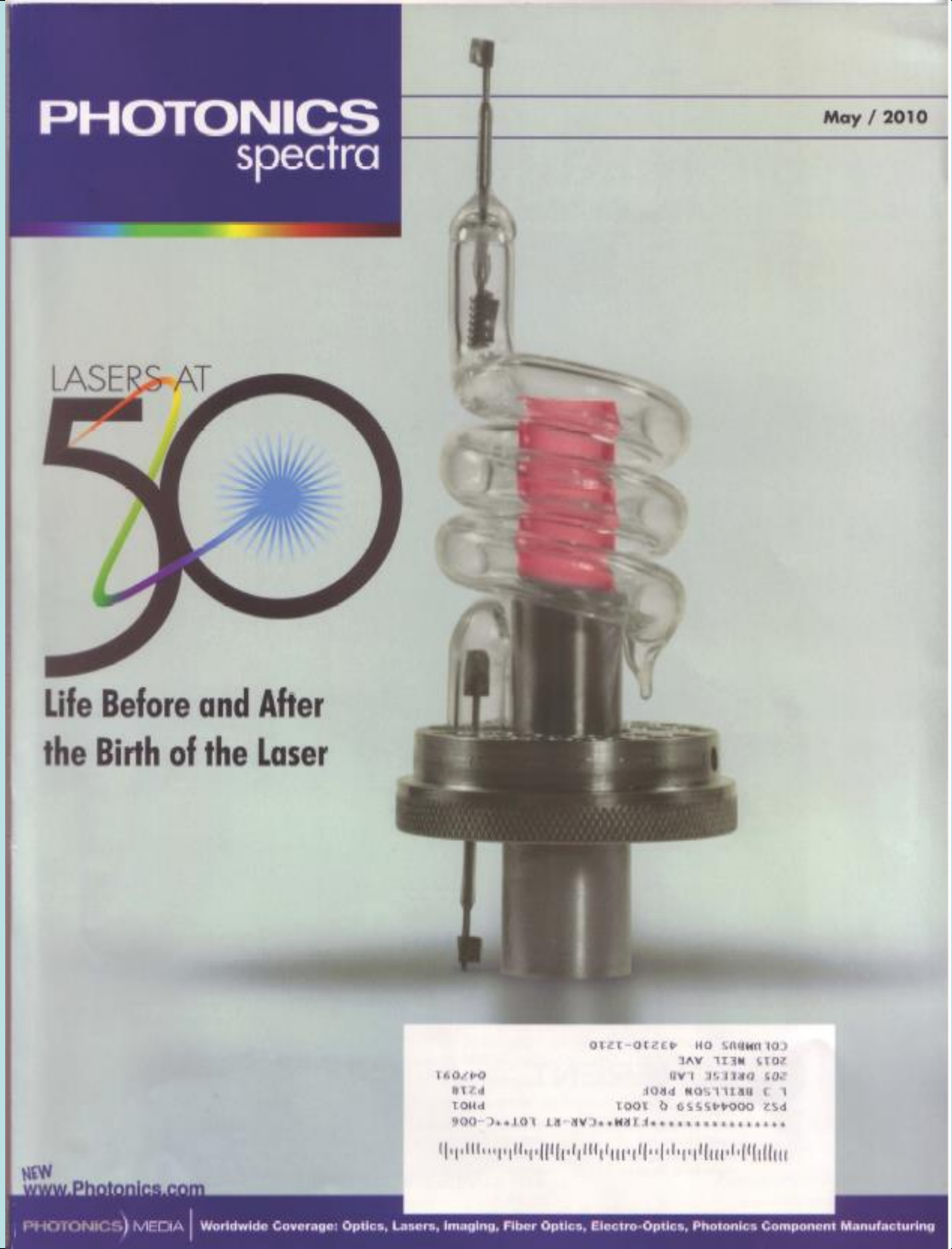


Figure 14.35 | Schematic diagram showing (a) resonant modes of a cavity with length L, (b) spontaneous emission curve, and (c) actual emission modes of a laser diode. *(After Yang [22].)*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LASERS AT 50
Life Before and After the Birth of the Laser
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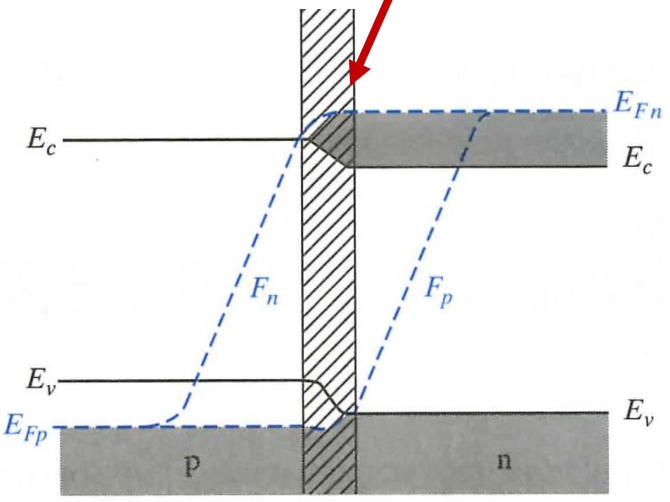
Population Inversion at a Junction

Recall quasi-Fermi levels:
Measure of departure from equilibrium

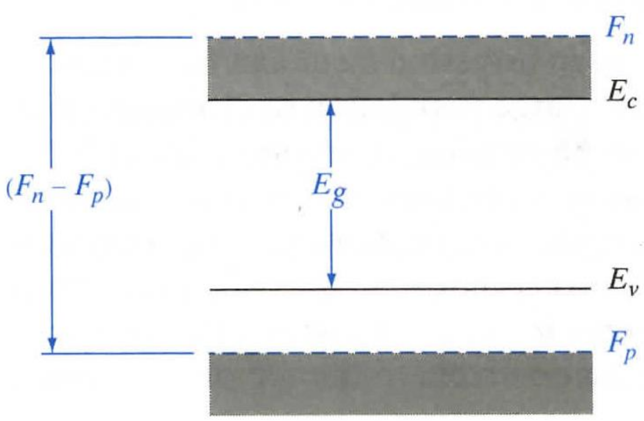
$n = N_c e^{-(Ec - Fn)/kT} = n_i e^{(Fn - Ei)/kT}$

$p = N_v e^{-(Fp - Ev)/kT} = n_i e^{(Ei - Fp)/kT}$

Forward bias: inversion region

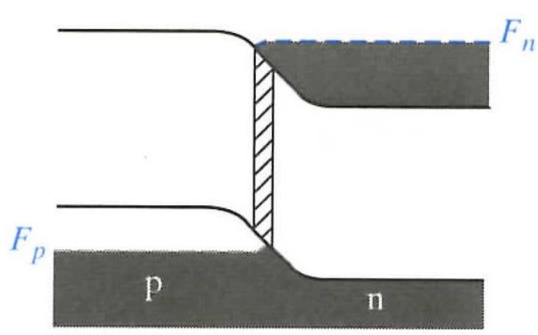


Inversion region expanded

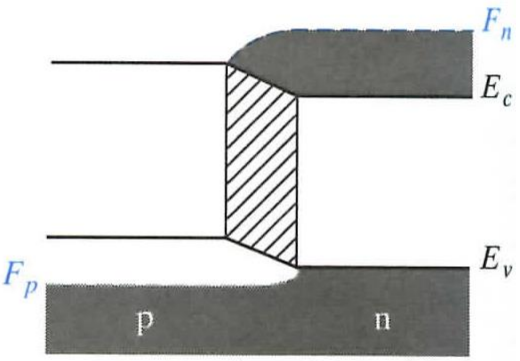


Population inversion exists when $F_n - F_p > h\upsilon$
Minimum requirement: $F_n - F_p > E_g$

- **Inversion region width varies with forward bias**
- **Range of stimulated emission energies**
- **Dominant laser transitions determined by resonant cavity & band edge**



(a)

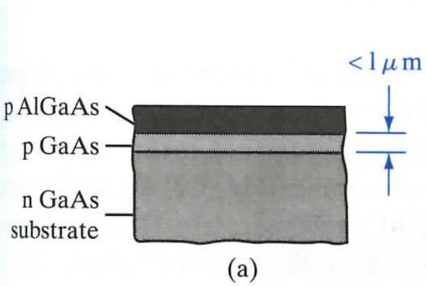


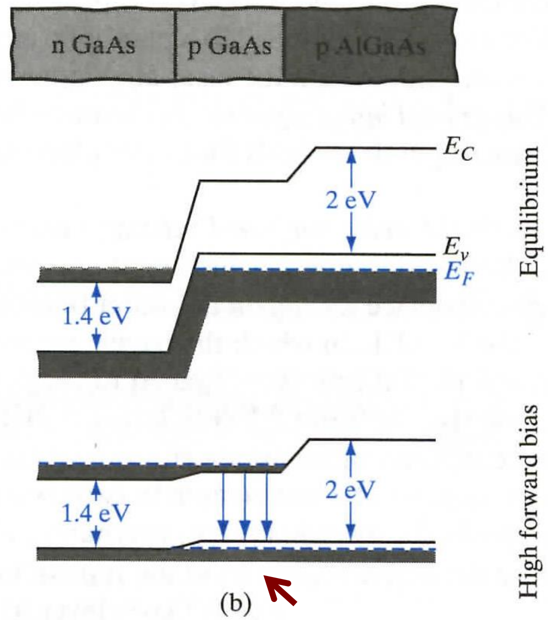
(b)

Heterojunction Lasers

Single Heterojunction Laser

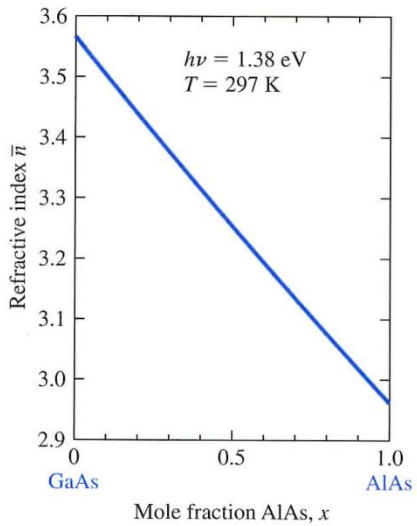
Electrons confined to thin p-GaAs region under bias





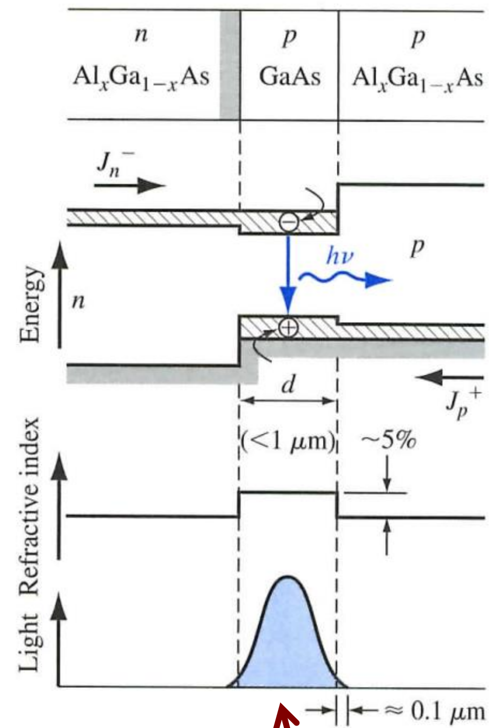
Inversion layer

AlGaAs Index of Refraction



Use AlGaAs for total internal reflection: optical confinement

Double Heterojunction Laser



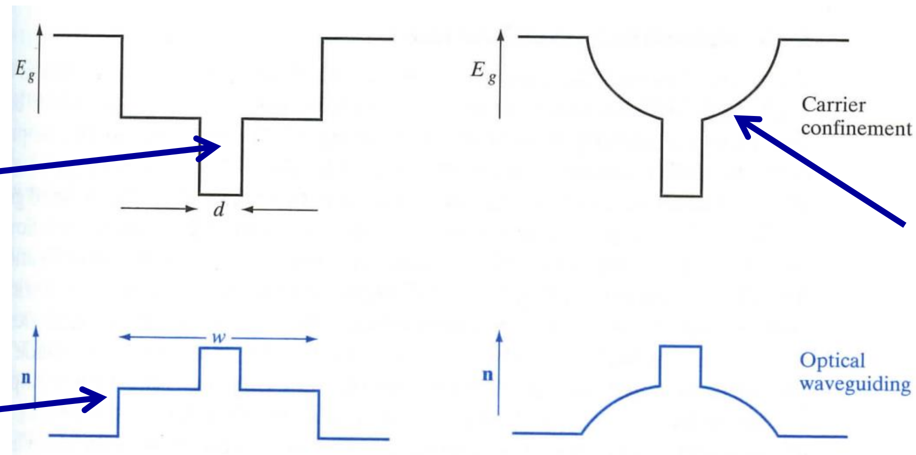
Light confined in dielectric waveguide

Multilayer Heterostructure Lasers

Separate confinement and graded index channels

Confine recombination in narrow region → low threshold current

Separate optical confinement

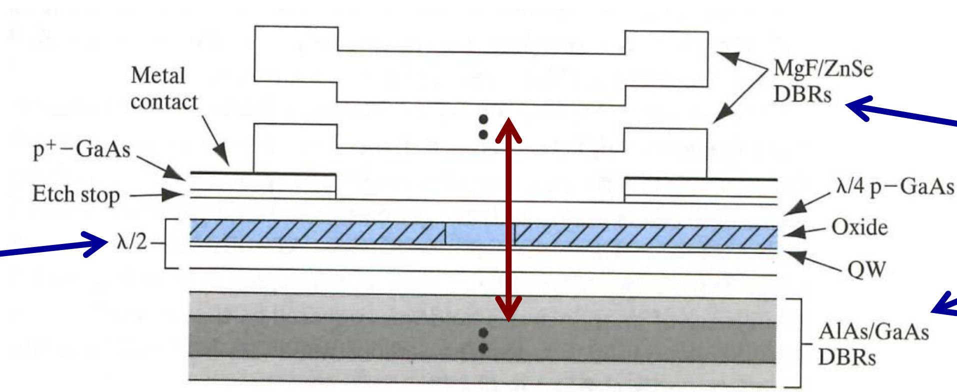


Even better optical confinement

Graded index separate confinement heterostructure (GRINSCH) laser

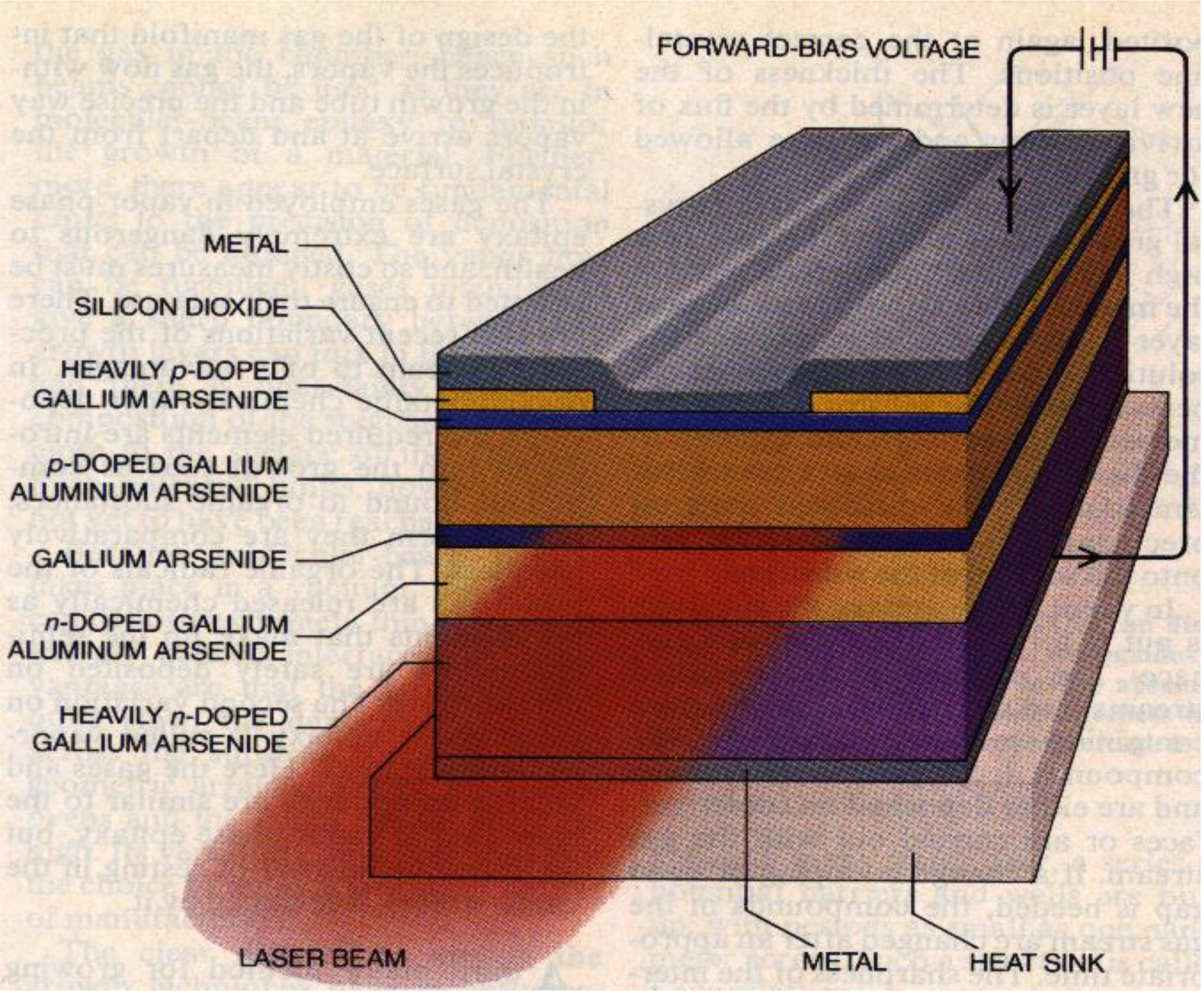
Oxide-confined vertical cavity surface-emitting laser (VCSEL) diode

InGaAs-GaAs quantum wells



Distributed Bragg reflectors (DBRs) : Constructive interference → Cavity mirrors

Distance between DBRs = λ



Man-Made Structure of Atomically-Ordered Layers
Based on Quantum Mechanical Principles

A History Of The Laser A Trip Through The Light Fantastic

Melinda Rose, Senior Editor, melinda.rose@photonics.com

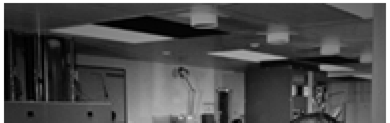
A HISTORY OF THE LASER

In honor of the laser turning 50, here is a timeline of some of the more notable scientific accomplishments related to light amplification by stimulated emission of radiation (laser). An interactive version is available at www.lasertimeline.com. The laser would not have been possible without an understanding that light is a form of electromagnetic radiation. Max Planck received the Nobel Prize in physics in 1918 for his discovery of elementary energy quanta. Planck was working in thermodynamics, trying to explain why “blackbody” radiation, something that absorbs all wavelengths of light, didn’t radiate all frequencies of light equally when heated.

Max Planck

In his most important work, published in 1900, Planck deduced the relationship between energy and the frequency of radiation, essentially saying that energy could be emitted or absorbed only in discrete chunks - which he called quanta - even if the chunks were very small. His theory marked a turning point in physics and inspired up-and-coming physicists such as Albert Einstein. In 1905, Einstein released his paper on the photoelectric effect, which proposed that light also delivers its energy in chunks, in this case discrete quantum particles now called photons.

Physicists John L. Emmett (left) and John H. Nuckolls were the key Lawrence Livermore National Laboratory pioneers in laser and fusion science and technology. Emmett co-invented the multipass laser architecture still in use



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First LED Replacement Bulb Unveiled
New Cell Phone App: Night Vision
Long-Lost Lunar Reflector Located
Images of Atomic Spin Captured
Tabletop 3-D System to Print in Glass


Some rough calculations on the feasibility of a LASER: Light Amplification by Stimulated Emission of Radiation.

Conceive a tube terminated by optically flat

1 mm

L

partially reflecting parallel mirrors. The mirrors might be silvered or multilayer interference reflectors. The latter are lossless and may have an arbitrarily high reflectance depending on the number of layers. A practical achievement is 98% in the visible for a 7-layer reflector. Flats with closer tolerance than 1/100 λ are not available so if a resonant system is desired, higher reflectance would not be useful. However for a nonresonant system, the 99.9% reflectors which are possible might be useful.

Consider a plane standing wave in the tube. There is the effect of a closed cavity, since the wavelength is small the diffraction and hence the lateral loss is negligible.

① O.S. Heavens, "Optical Properties of Thin Solid Films" (Butterworths Scientific Publications, London, 1955) P.158


2,929,922

THE UNITED STATES OF AMERICA

TO ALL TO WHOM THESE PRESENTS SHALL COME:

Whereas Arthur L. Schawlow, of Madison, New Jersey, and Charles H. Townes, of New York, N. Y., assignors to Bell Telephone Laboratories, Incorporated, of New York, N. Y., a corporation of New York,

presented to the Commissioner of Patents a petition praying for the grant of Letters Patent ...

Whereas ...

Now therefore these Letters Patent ... Bell Telephone Laboratories, Incorporated, its successors or assigns for the term of SEVENTEEN years from the date of this grant ... throughout the United States.

In testimony whereof I have hereunto set my hand and caused the seal of the Patent Office to be affixed at the City of Washington this twenty-second day of March, in the year of our Lord one thousand nine hundred and sixty, and of the Independence of the United States of America the one hundred and eighty-fourth.

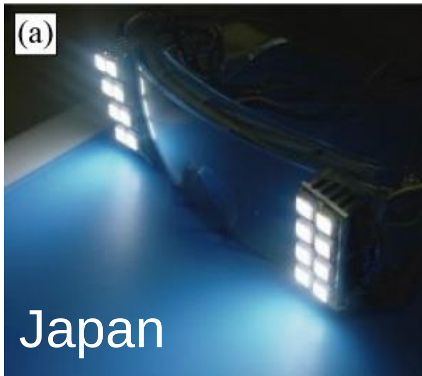
Robert C. Watson

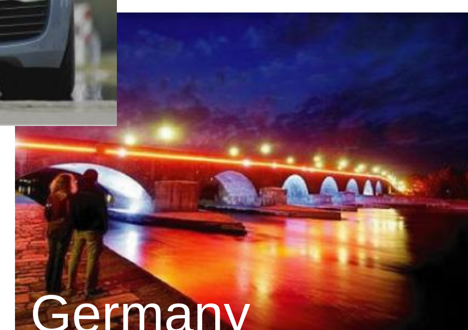
Nov. 13, 1957: Columbia University graduate student Gordon Gould jots his ideas for building a laser in his notebook and has it notarized at a candy store in the Bronx. It is considered the first use of the acronym laser. Gould leaves the university a few months later to join private research company TRG (Technical Research Group).

March 22, 1960: Townes and Schawlow, under Bell Labs, are granted US patent number 2,929,922 for the optical maser, now called a laser. With their application denied, Gould and TRG launch what would become a 30-year patent dispute related to laser invention.

Light Peak module close-up with laser light added for illustration (actual infrared light is invisible to the eye).

Recent applications **(not all of them are saving power)**





Courtesy: Prof. F. Schubert, RPI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From Black Box to Physics of electrons and holes at interfaces.

From μ, n, p, τ's to equivalent circuit diagrams.

<u>The</u> <u>End</u>

" 'LOOK', I WOULD SAY TO LEONARDO. 'SEE HOW FAR OUR TECHNOLOGY HAS TAKEN US'. LEONARDO WOULD ANSWER, 'YOU MUST EXPLAIN TO ME HOW EVERYTHING WORKS.' AT THAT POINT, MY FANTASY ENDS."