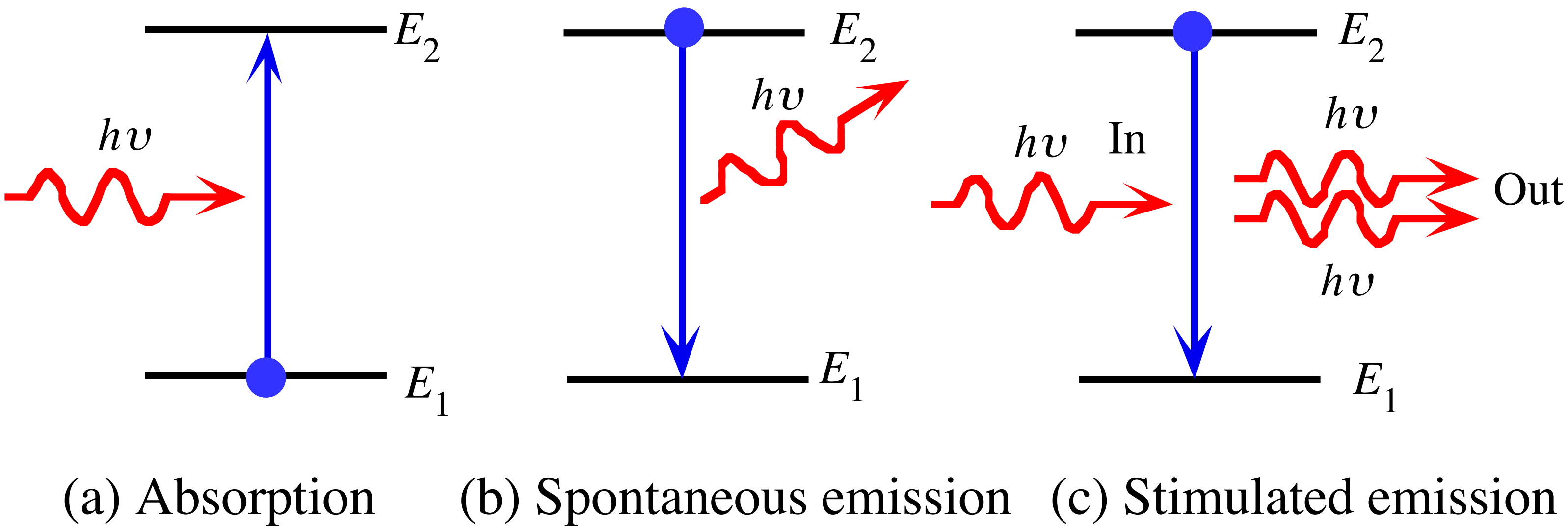
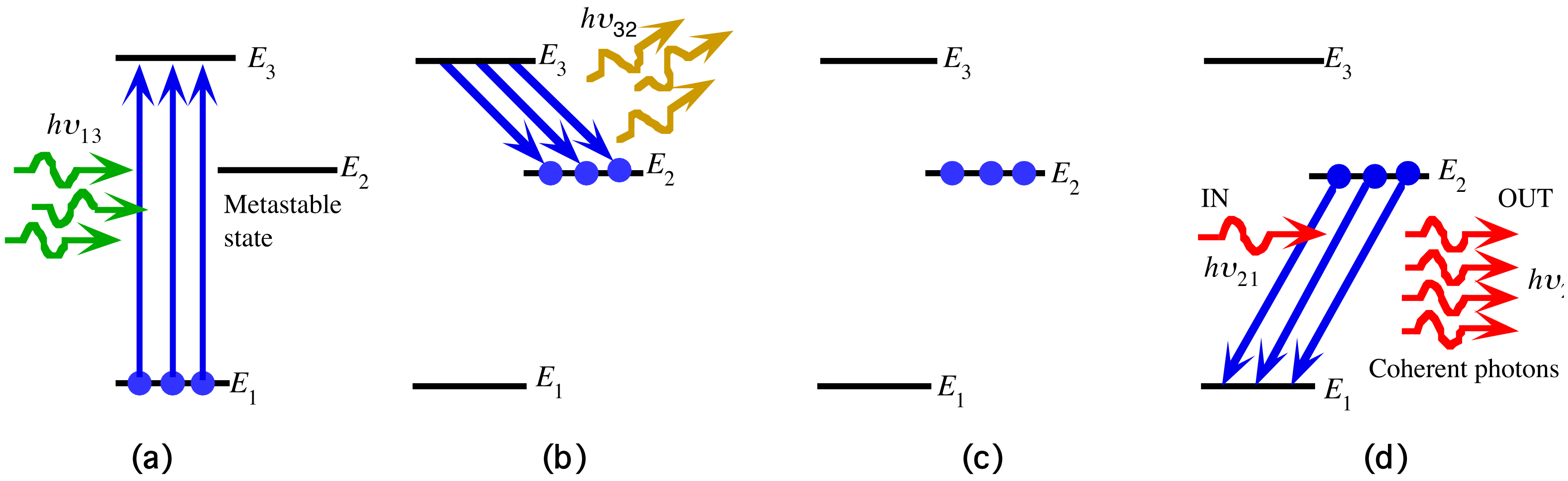
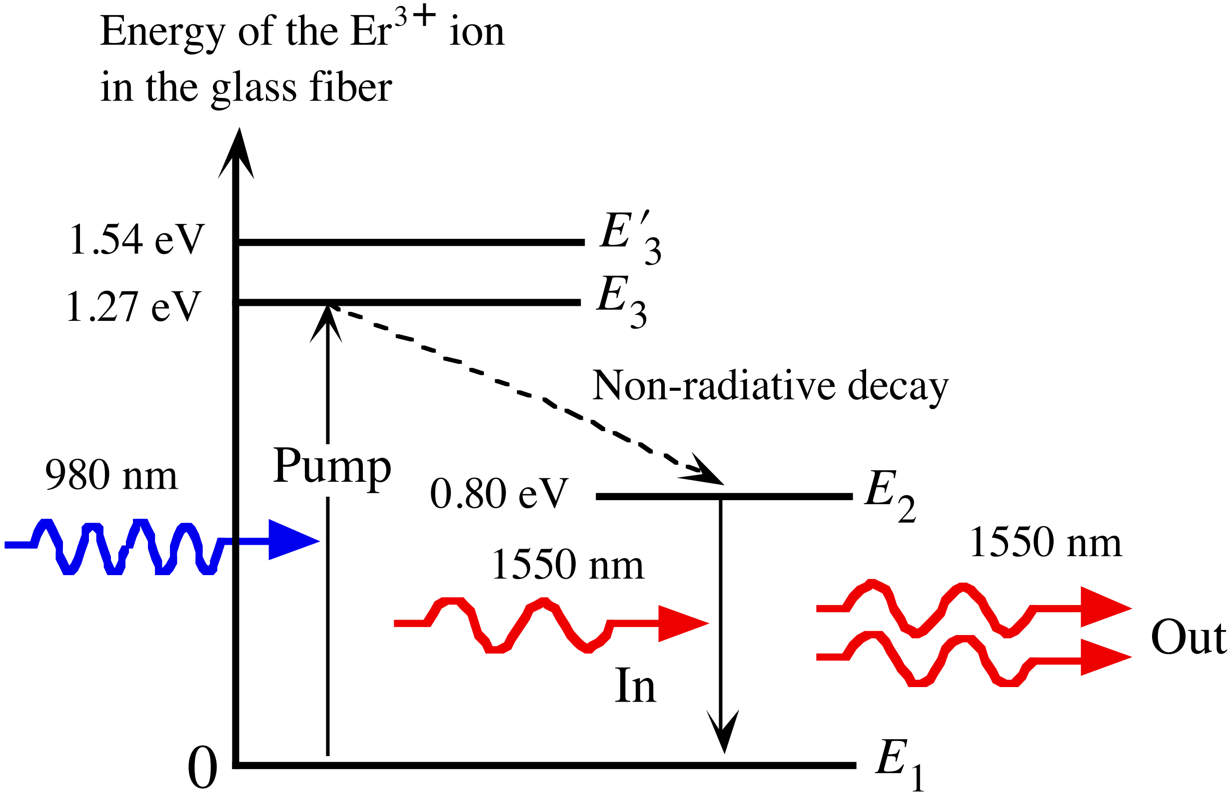


Absorption, spontaneous (random photon) emission and stimulated emission.



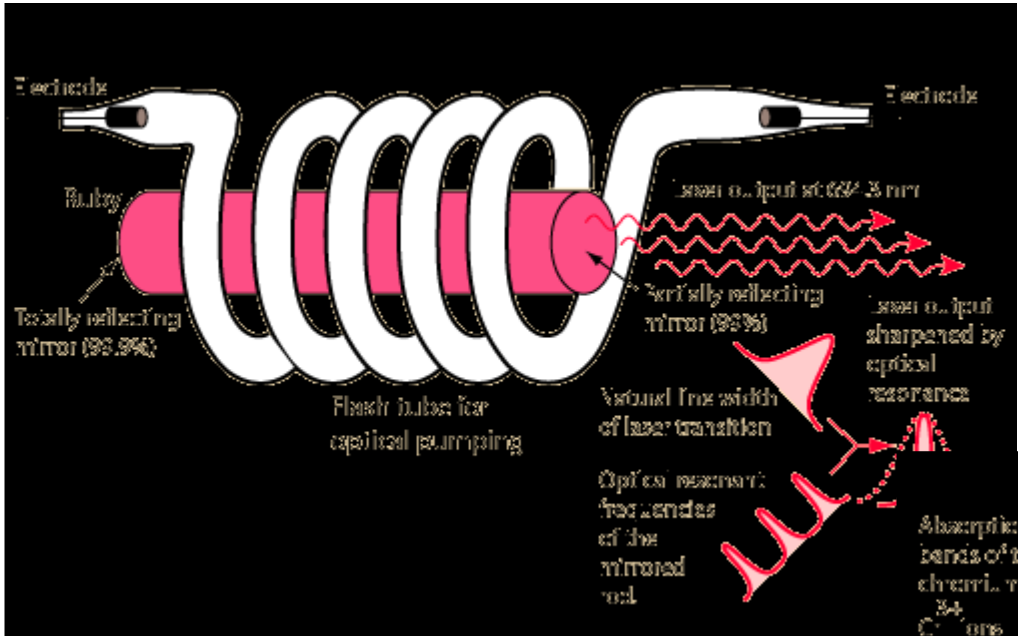
The principle of the LASER. (a) Atoms in the ground state are pumped up to the energy level E_3 by incoming photons of energy $h\upsilon_{13} = E_3 – E_1$. (b) Atoms at E_3 rapidly decay to the metastable state at energy level E_2 by emitting photons or emitting lattice vibrations; $h\upsilon_{32} = E_3 – E_2$. (c) As the states at E_2 are long-lived, they quickly become populated and there is a population inversion between E_2 and E_1.

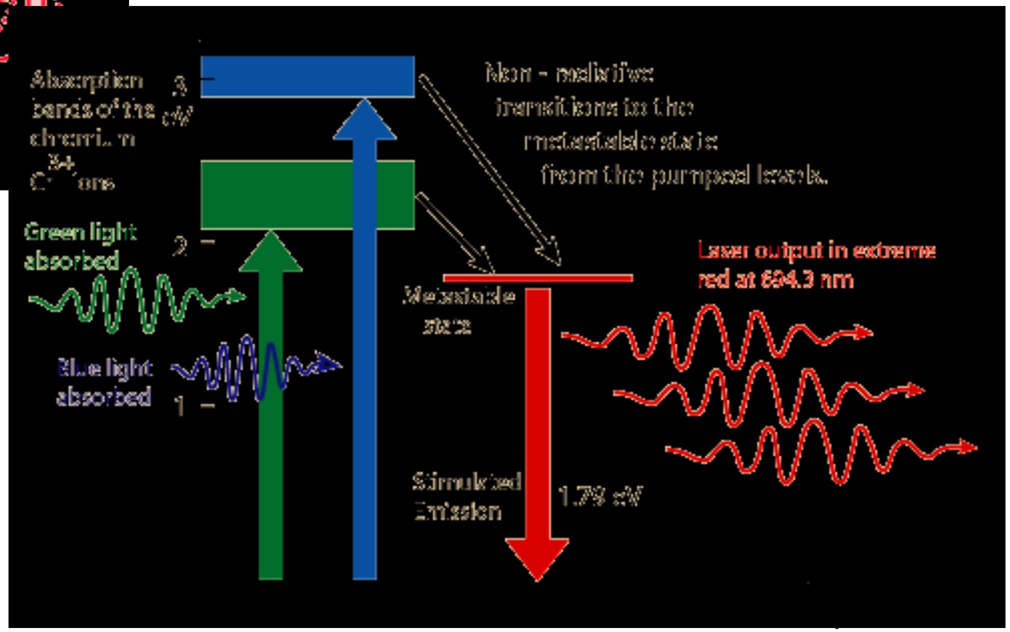
(d) A random photon (from a spontaneous decay) of energy $h\upsilon_{21} = E_2 – E_1$ can initiate stimulated emission. Photons from this stimulated emission can themselves further stimulate emissions leading to an avalanche of stimulated emissions and coherent photons being emitted.

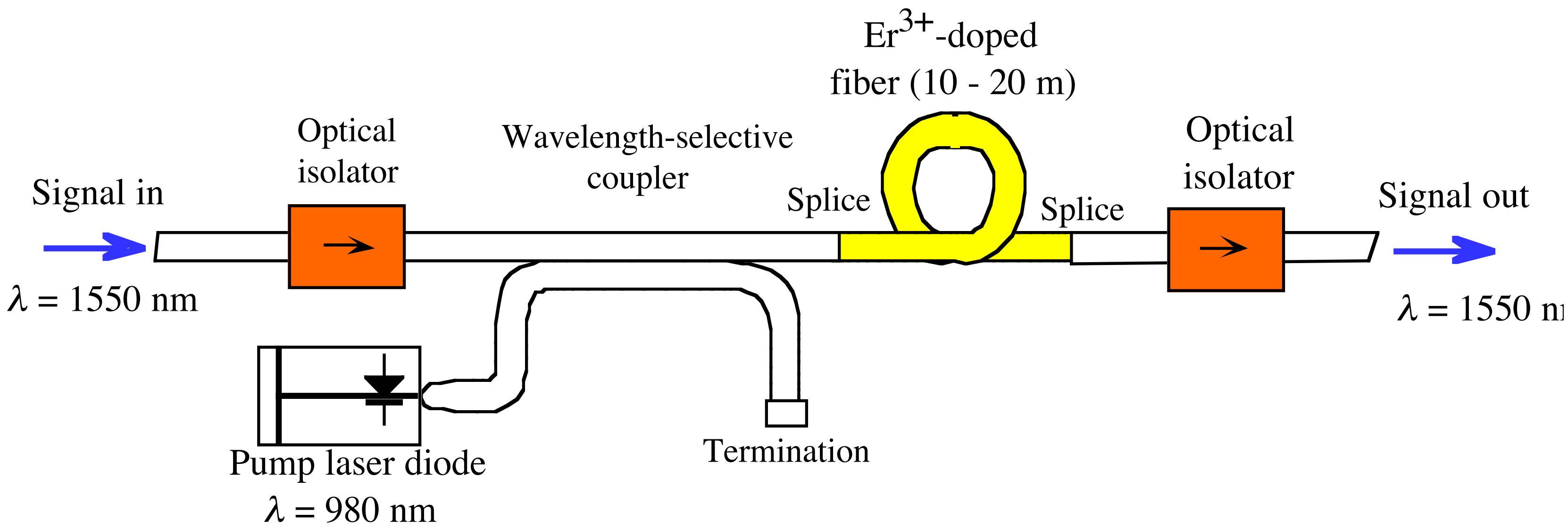


Energy diagram for the Er^{3+} ion in the glass fiber medium and light amplification by stimulated emission from E_2 to E_1. Dashed arrows indicate radiationless transitions (energy emission by lattice vibrations)

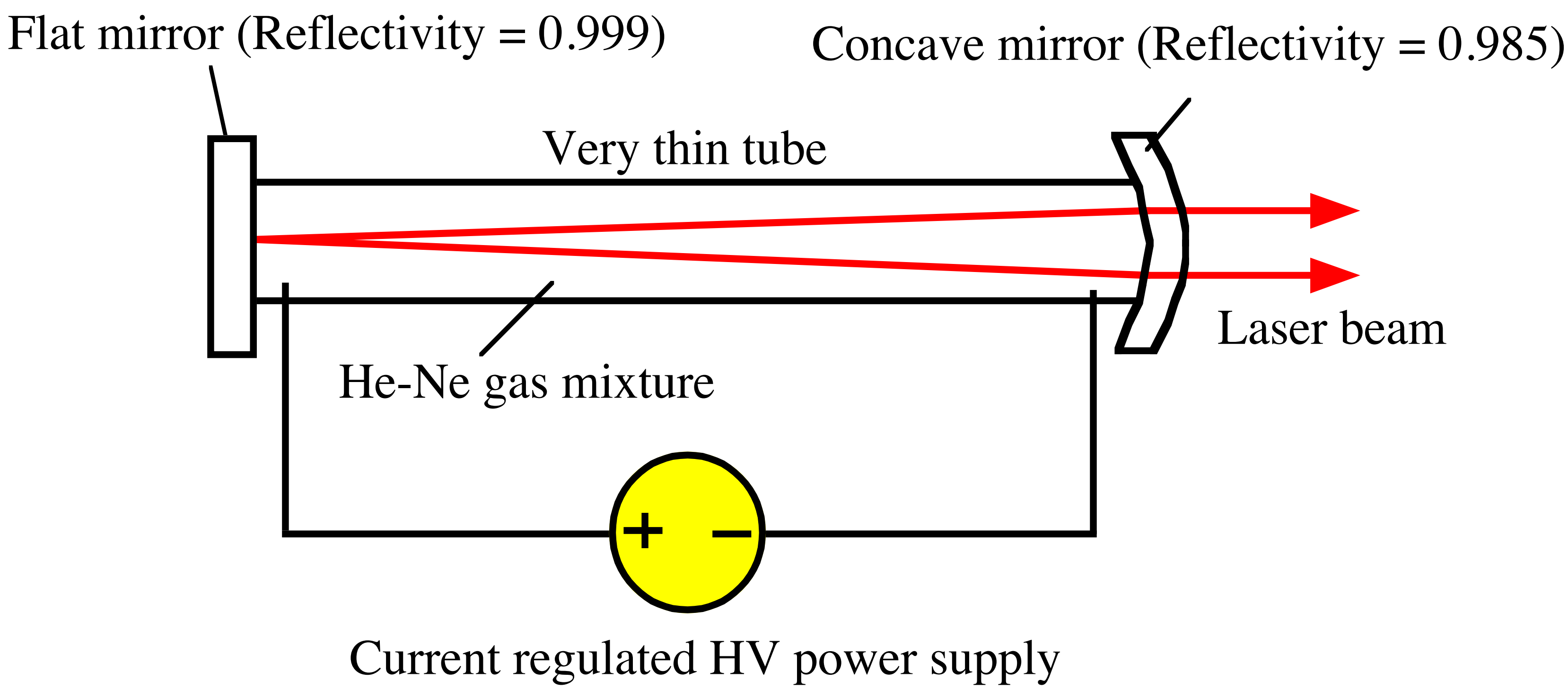
Ruby Laser


Electrode
Electrode
Ruby
Laser output at 694.3 nm
Partially reflecting mirror (98%)
Totally reflecting mirror (99.9%)
Laser output sharpened by optical resonance
Flash tube for optical pumping
Natural line width of laser transition
Optical resonant frequencies of the mirrored rod

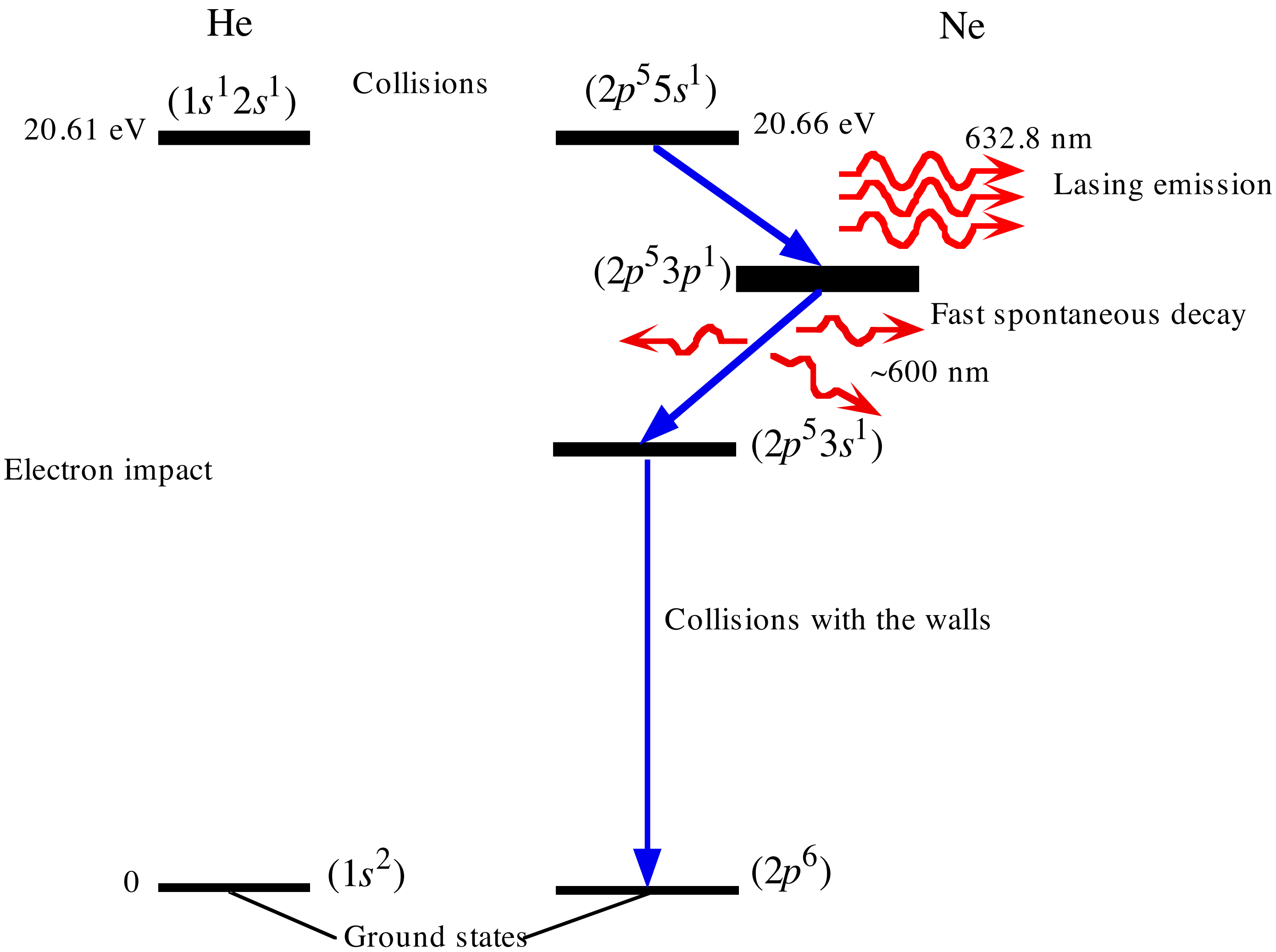

Absorption bands of the chromium Cr^{3+} ions
3 eV
2
1
Non - radiative transitions to the metastable state from the pumped levels.
Green light absorbed
Blue light absorbed
Metastable state
Laser output in extreme red at 694.3 nm
Stimulated Emission
1.79 eV



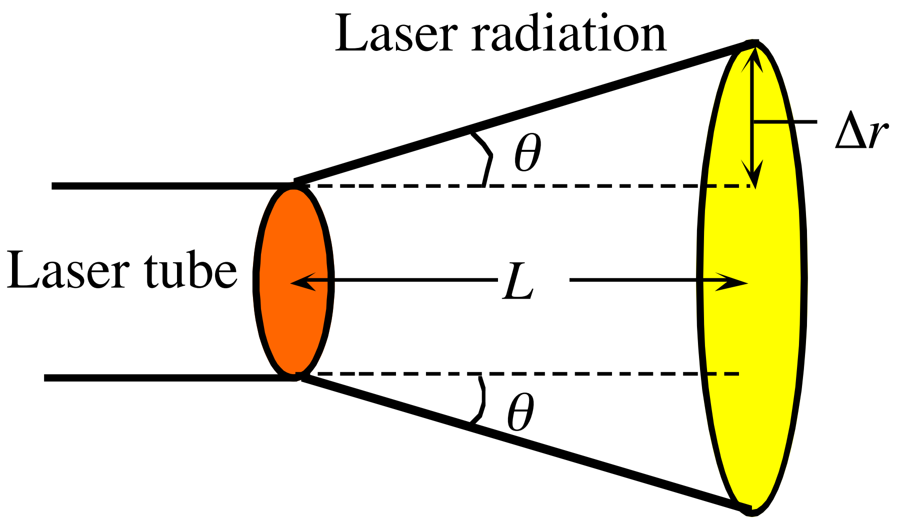
A simplified schematic illustration of an EDFA (optical amplifier). The erbium-ion doped fiber is pumped by feeding the light from a laser pump diode, through a coupler, into the erbium ion doped fiber.



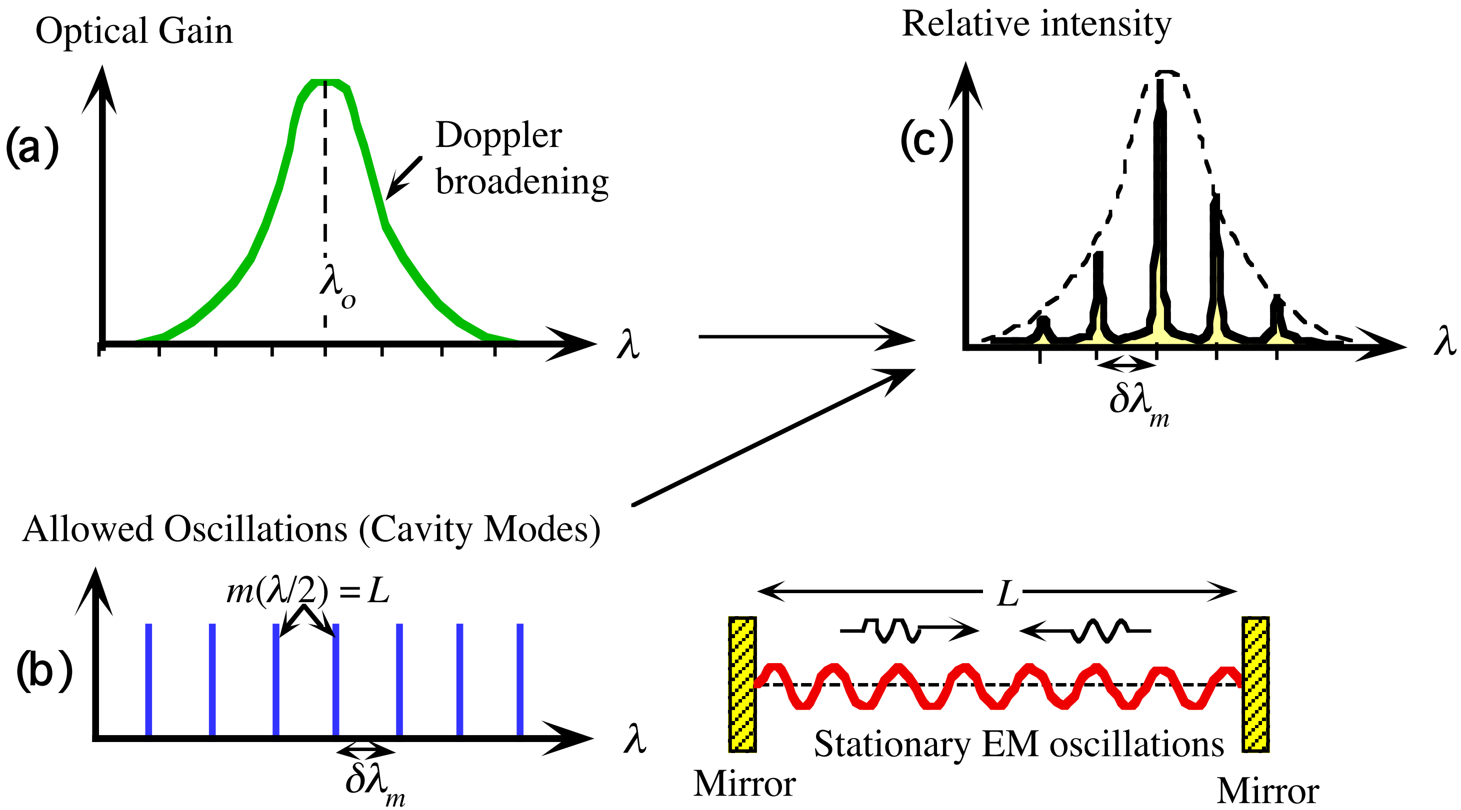
A schematic illustration of the He-Ne laser



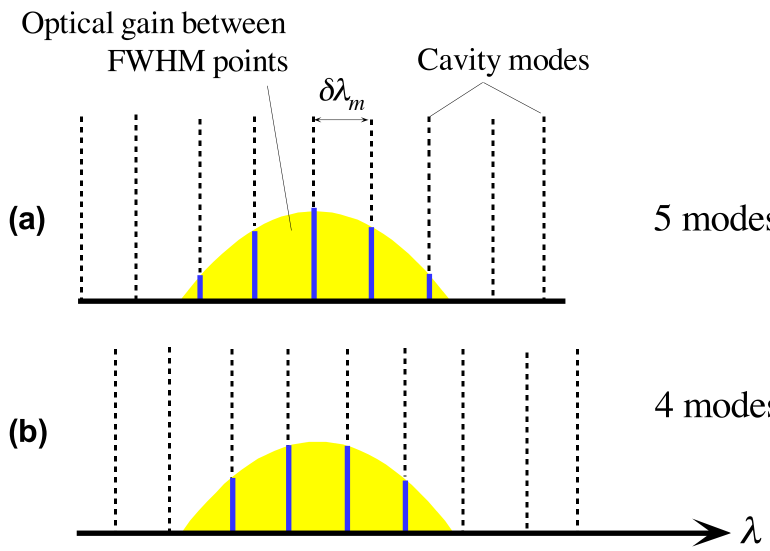
The principle of operation of the He-Ne laser. He-Ne laser energy levels (for 632.8 nm emission).



The output laser beam has a divergence characterized by the angle 2θ (highly exaggerated in the figure)



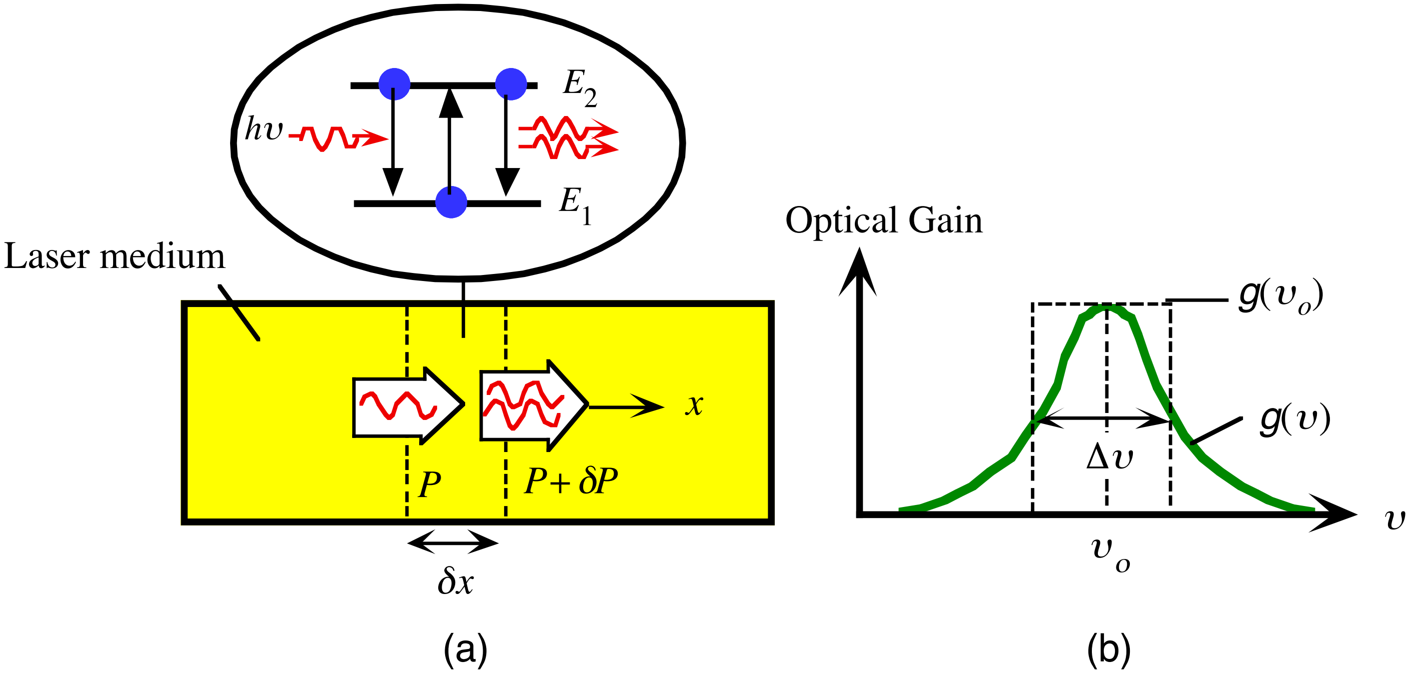
(a) Optical gain vs. wavelength characteristics (called the optical gain curve) of the lasing medium. (b) Allowed modes and their wavelengths due to stationary EM waves within the optical cavity. (c) The output spectrum (relative intensity vs. wavelength) is determined by satisfying (a) and (b) simultaneously, assuming no cavity losses.



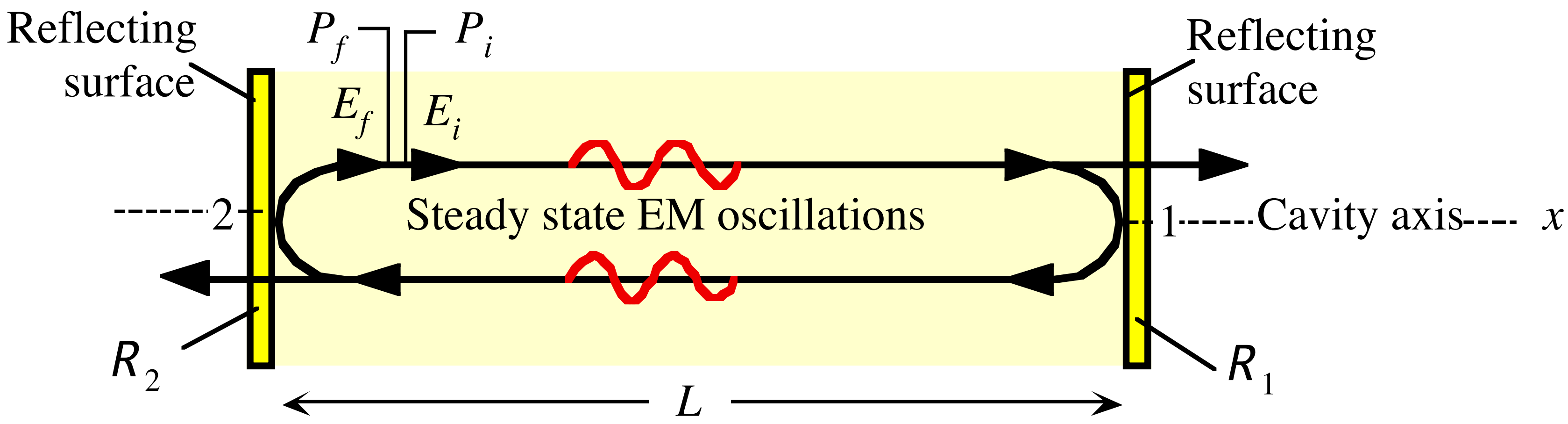
5 modes

4 modes

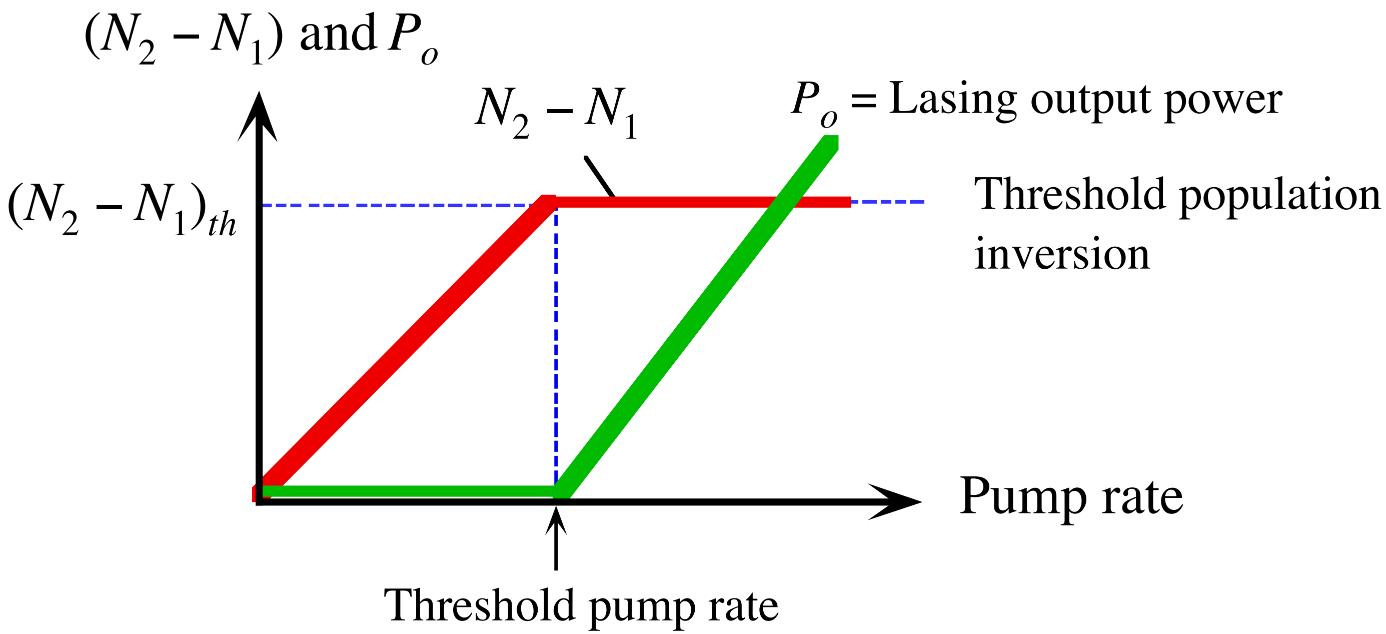
Number of laser modes depends on how the cavity modes intersect the optical gain curve. In this case we are looking at modes within the linewidth $\Delta\lambda_{1/2}$.



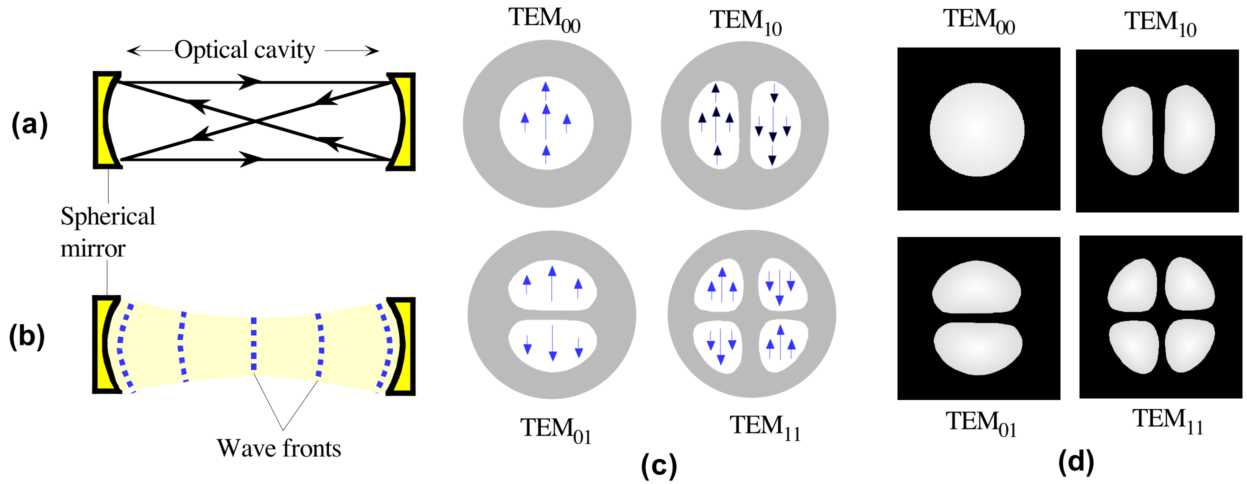
(a) A laser medium with an optical gain (b) The optical gain curve of the medium. The dashed line is the approximate derivation in the text.



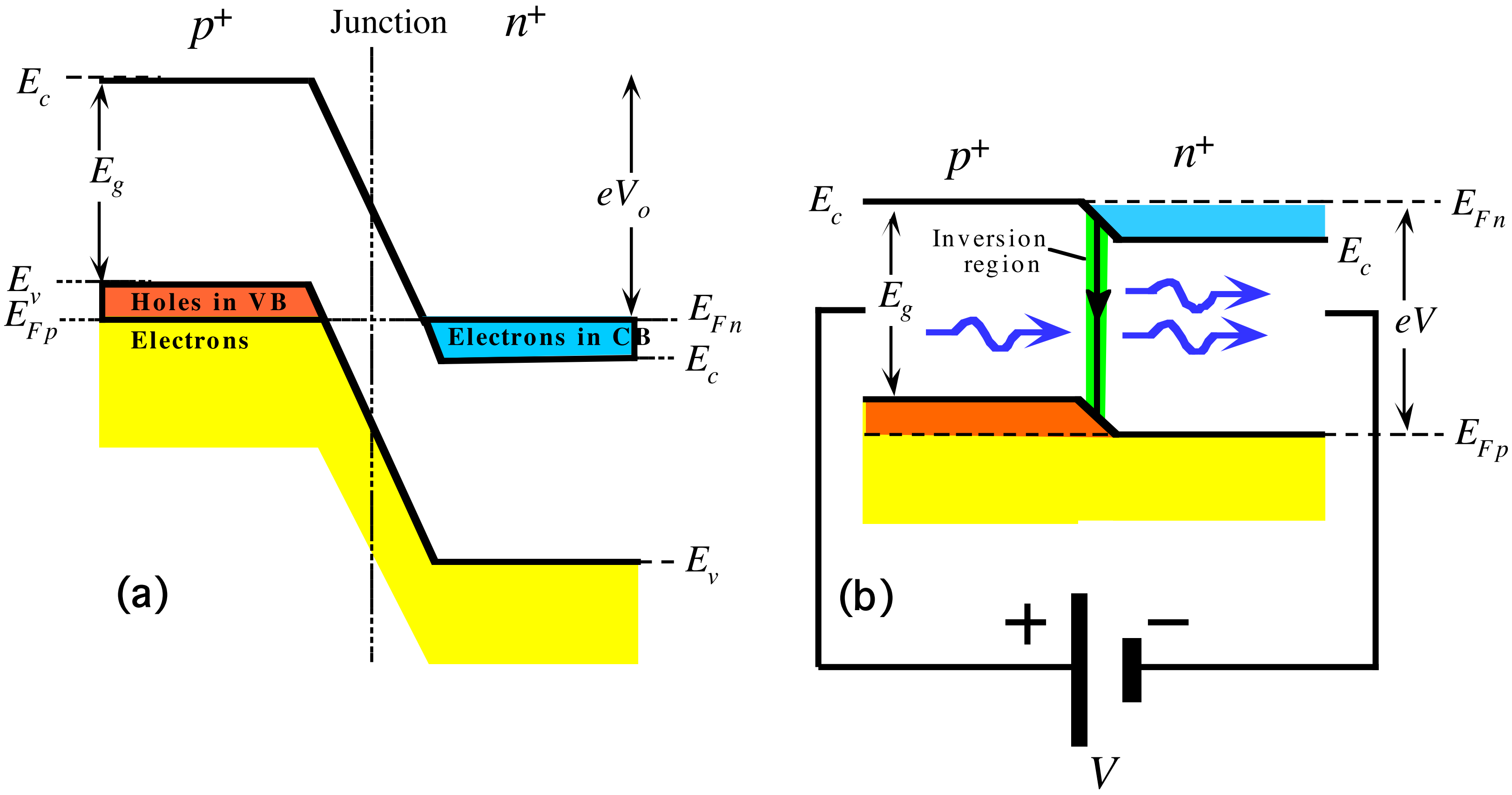
Optical cavity resonator



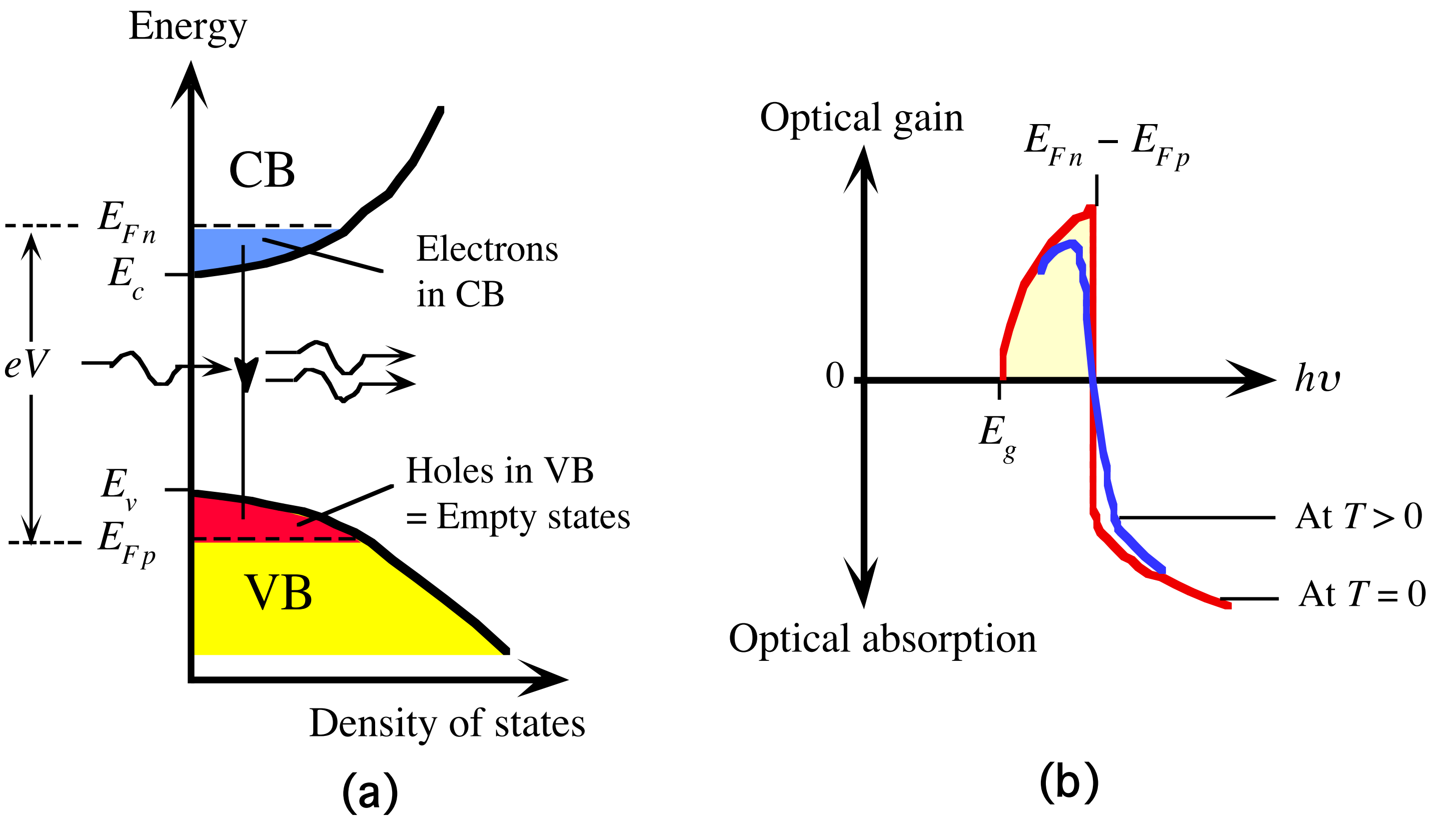
Simplified description of a laser oscillator. $(N_2 - N_1)$ and coherent output power (P_o) vs. pump rate under continuous wave steady state operation.



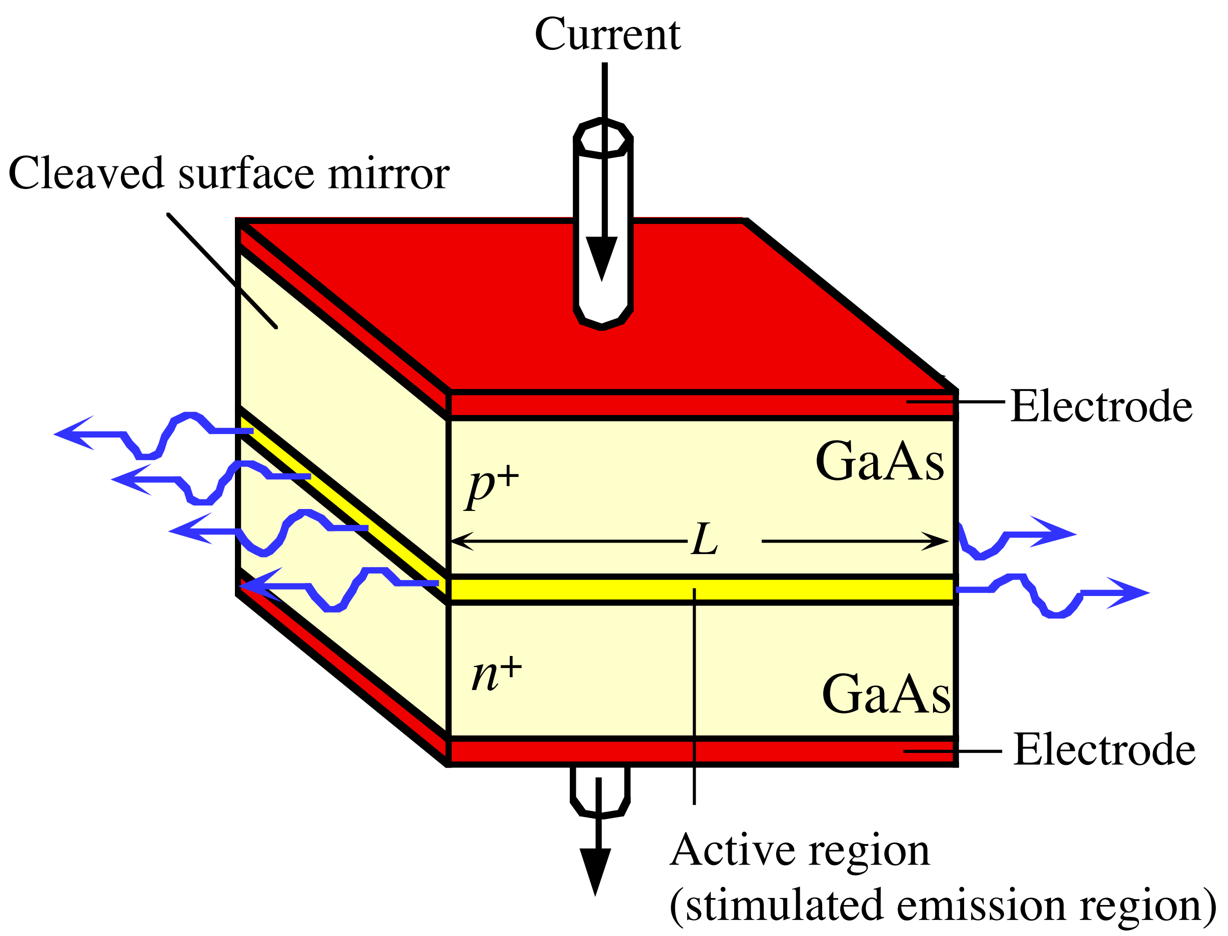
Laser Modes (a) An off-axis transverse mode is able to self-replicate after one round trip. (b) Wavefronts in a self-replicating wave (c) Four low order transverse cavity modes and their fields. (d) Intensity patterns in the modes of (c).



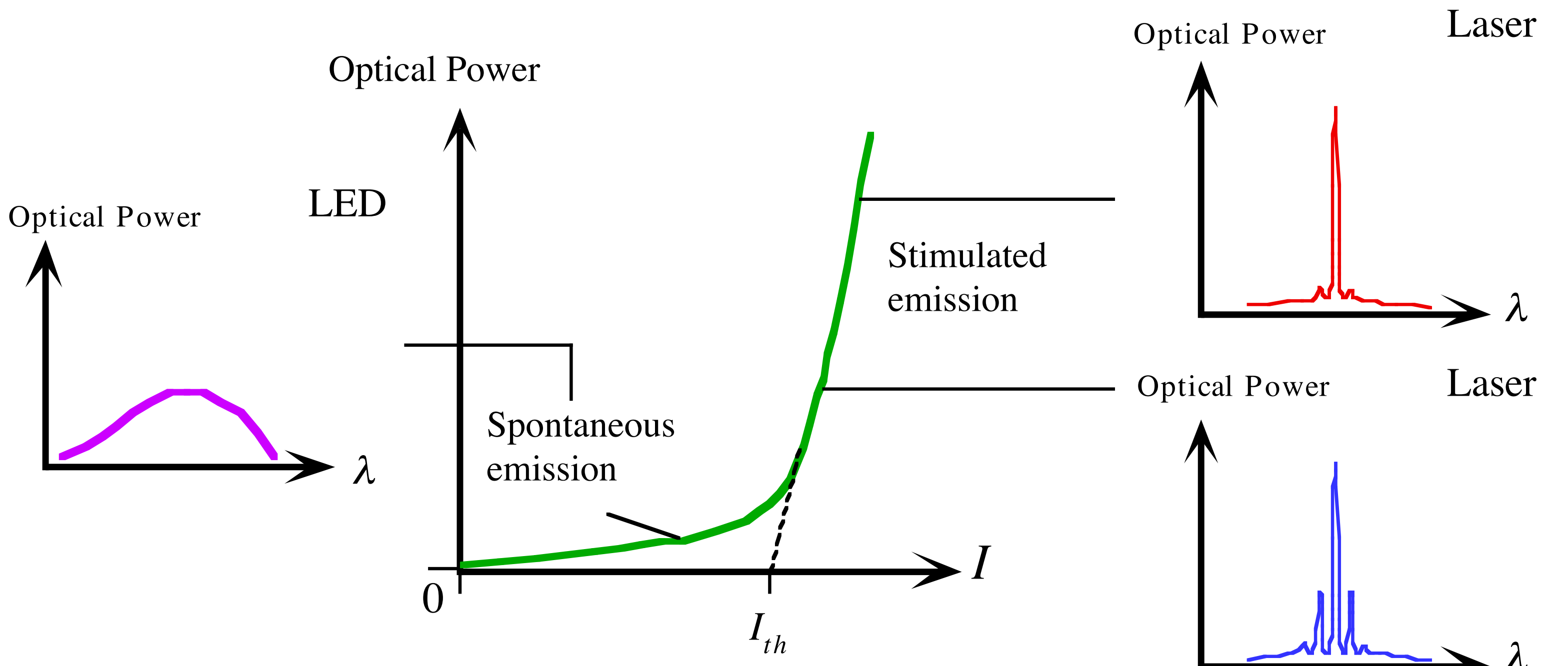
The energy band diagram of a degenerately doped *p-n* with no bias. (b) Band diagram with a sufficiently large forward bias to cause population inversion and hence stimulated emission.



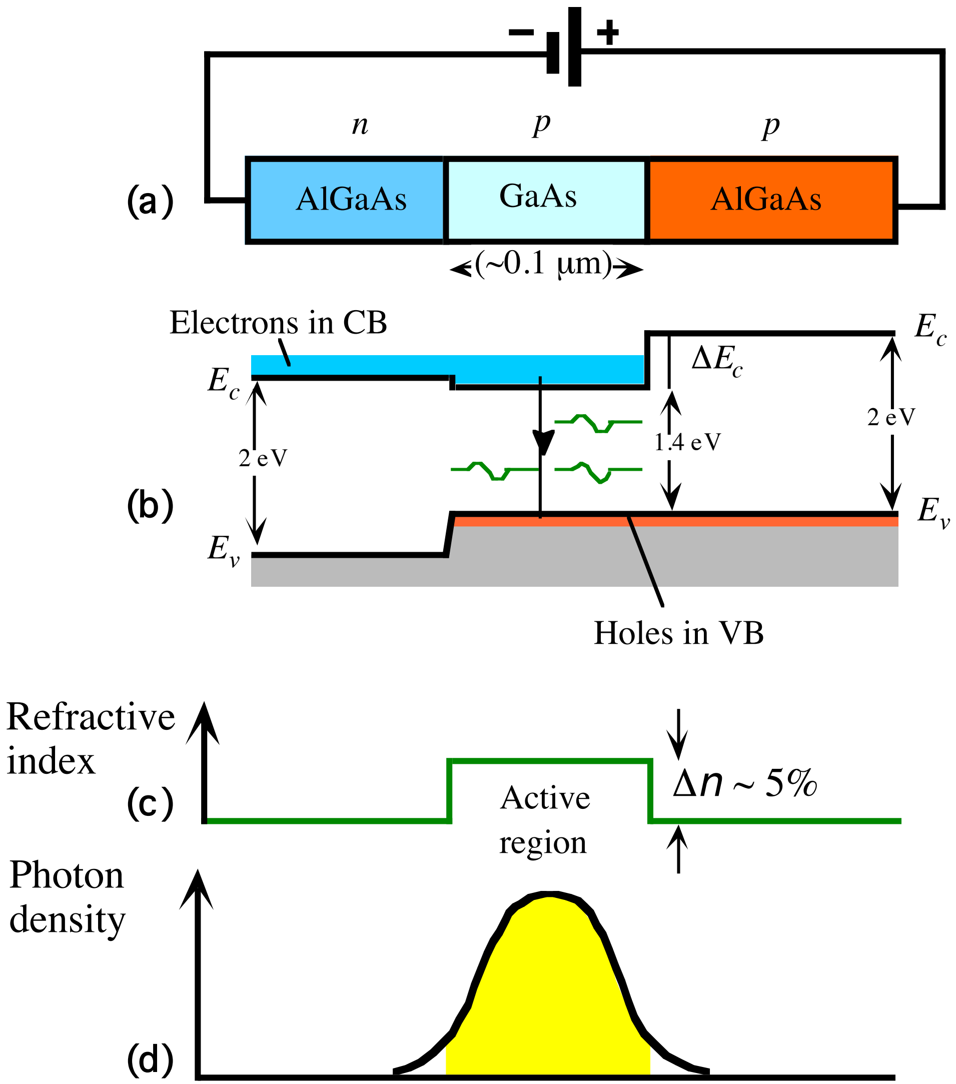
(a) The density of states and energy distribution of electrons and holes in the conduction and valence bands respectively at T ∪0 in the SCL under forward bias such that $E_{Fn} - E_{Fp} > E_g$. Holes in the VB are empty states. (b) Gain vs. photon energy.



A schematic illustration of a GaAs homojunction laser diode. The cleaved surfaces act as reflecting mirrors.



Typical output optical power vs. diode current (I) characteristics and the corresponding output spectrum of a laser diode.

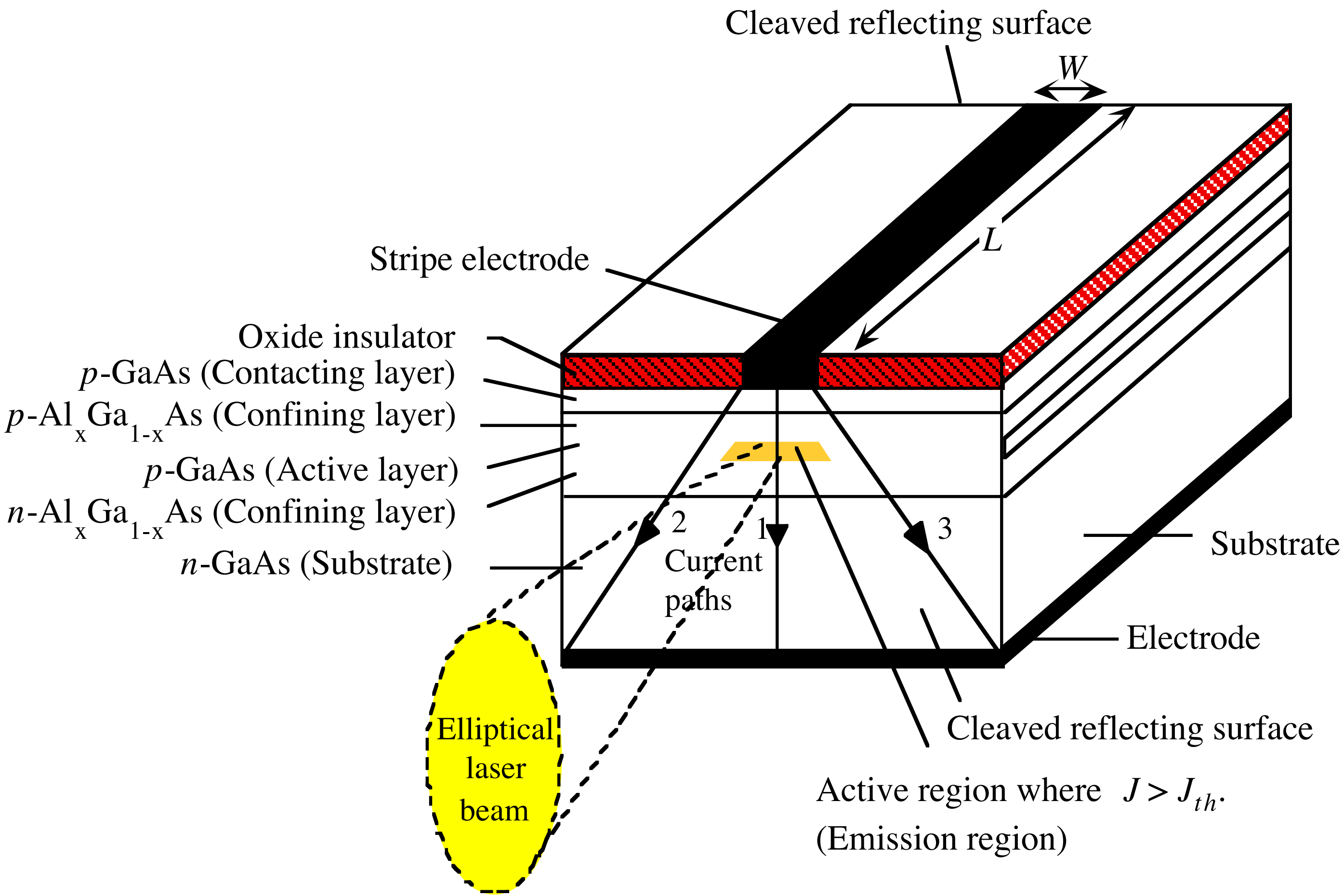


(a) A double heterostructure diode has two junctions which are between two different bandgap semiconductors (GaAs and AlGaAs).

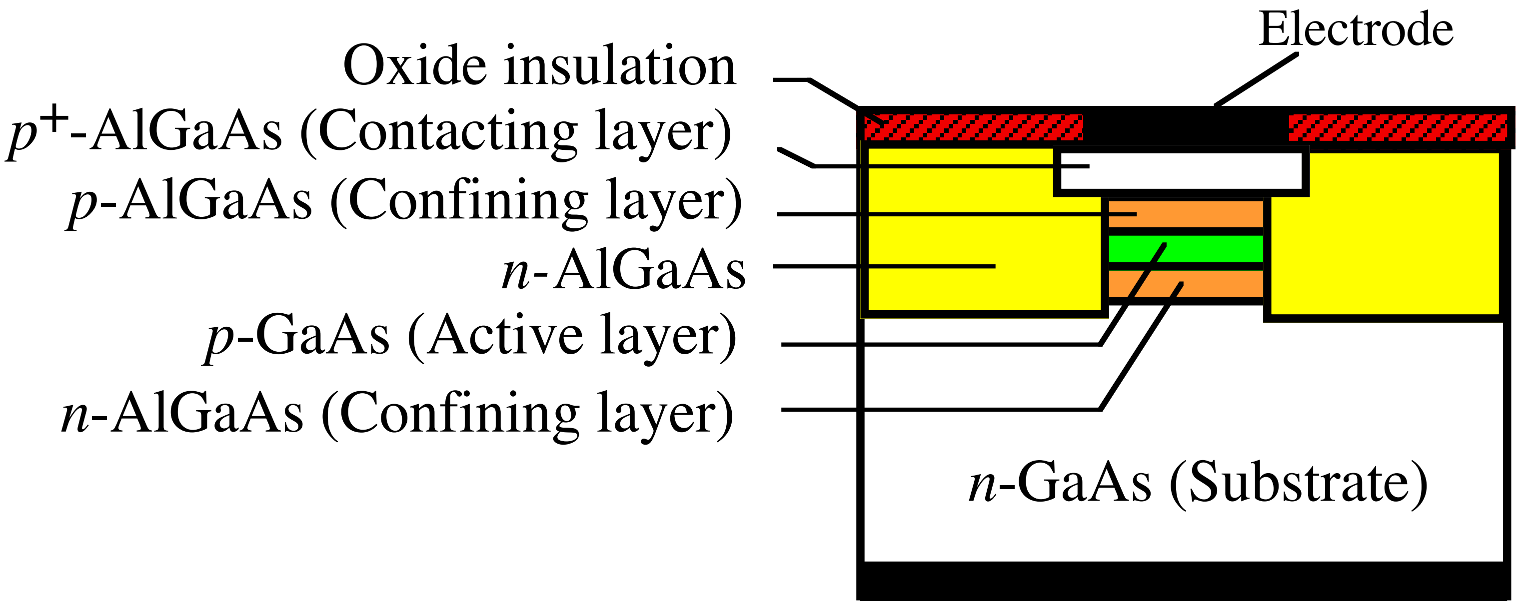
(b) Simplified energy band diagram under a large forward bias. Lasing recombination takes place in the *p*-GaAs layer, the *active layer*

(c) Higher bandgap materials have a lower refractive index

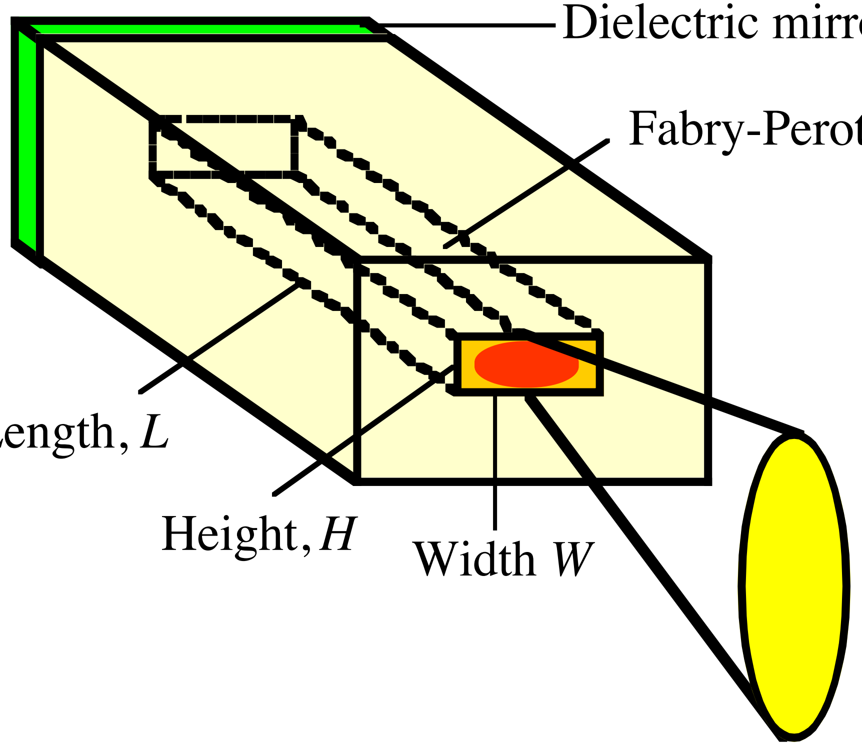
(d) AlGaAs layers provide lateral optical confinement.



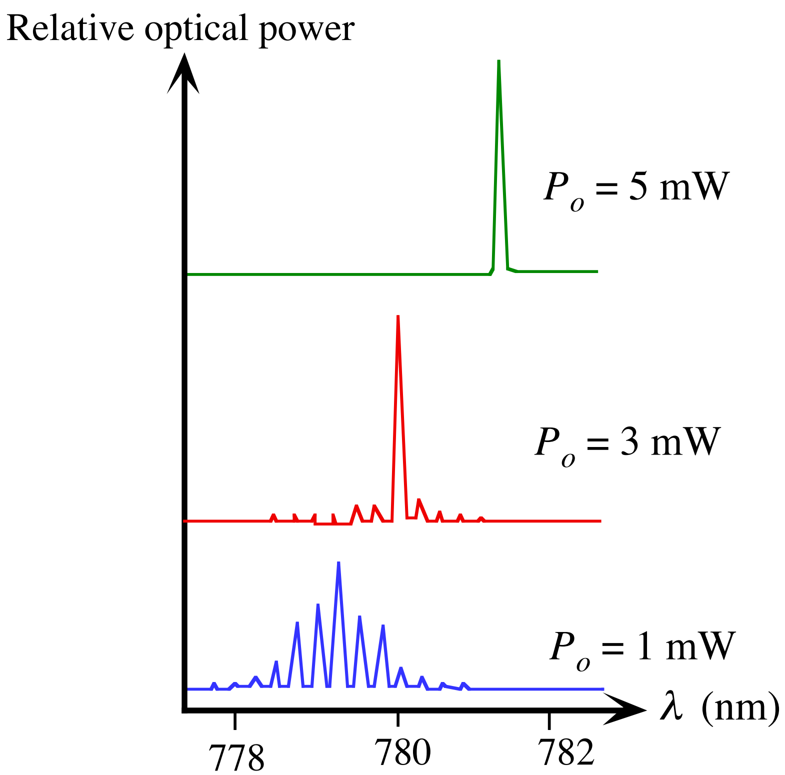
Schematic illustration of the the structure of a double heterojunction stripe contact laser diode



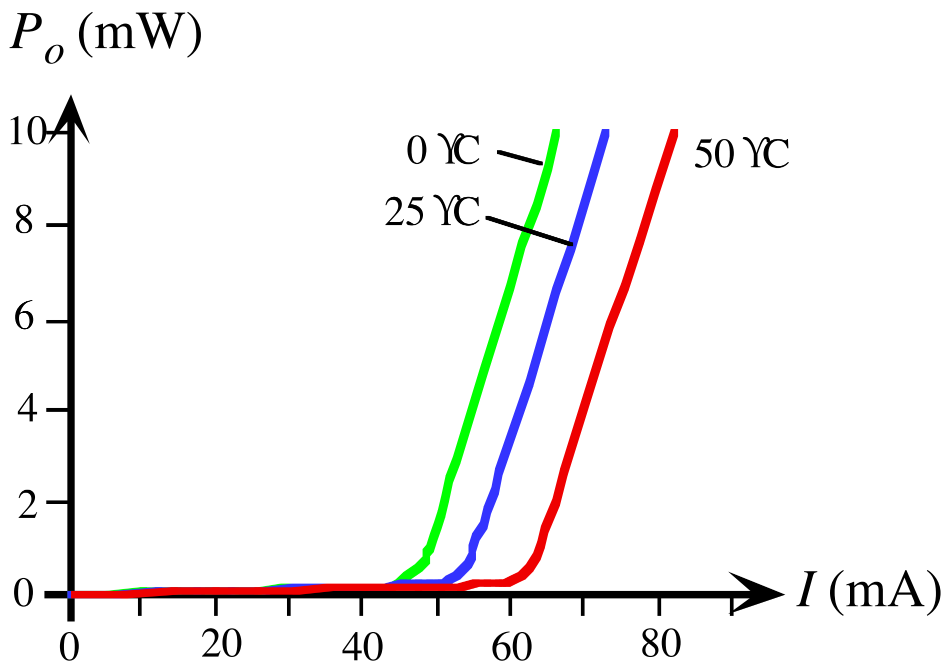
Schematic illustration of the cross sectional structure of a buried heterostructure laser diode.



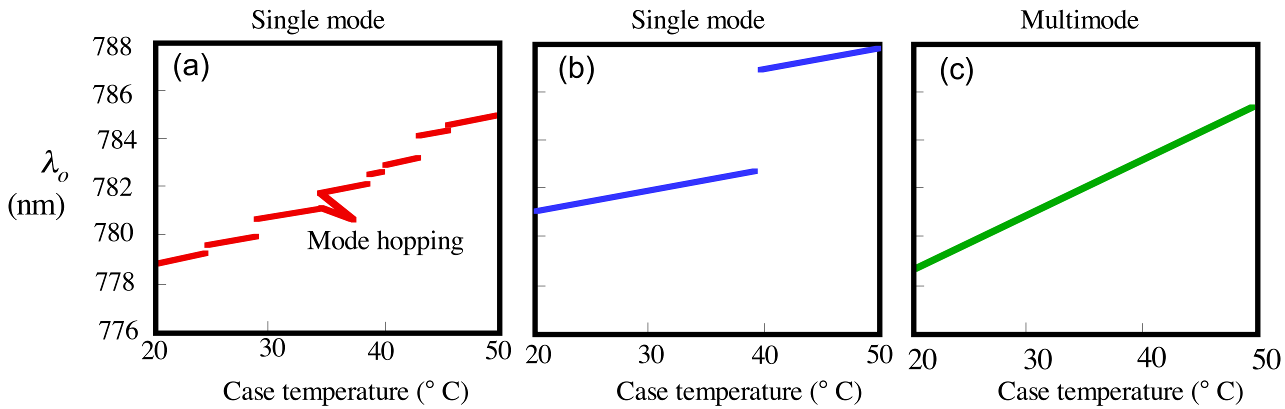
The laser cavity definitions and the output laser beam characteristics.



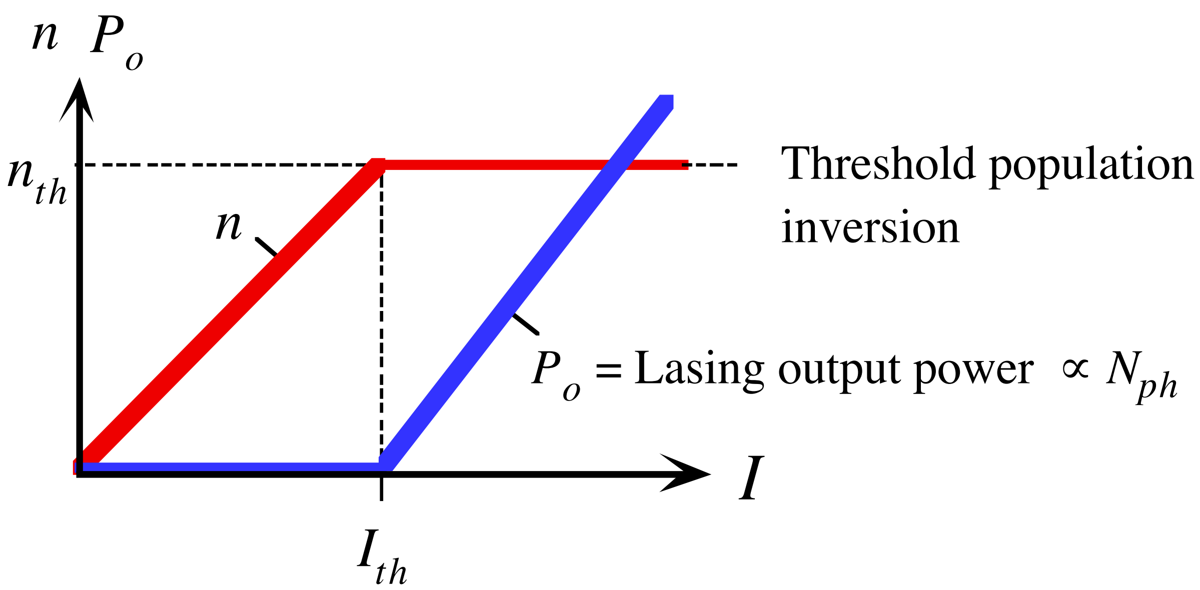
Output spectra of lasing emission from an index guided LD. At sufficiently high diode currents corresponding to high optical power, the operation becomes single mode. (Note: Relative power scale applies to each spectrum individually and not between spectra)



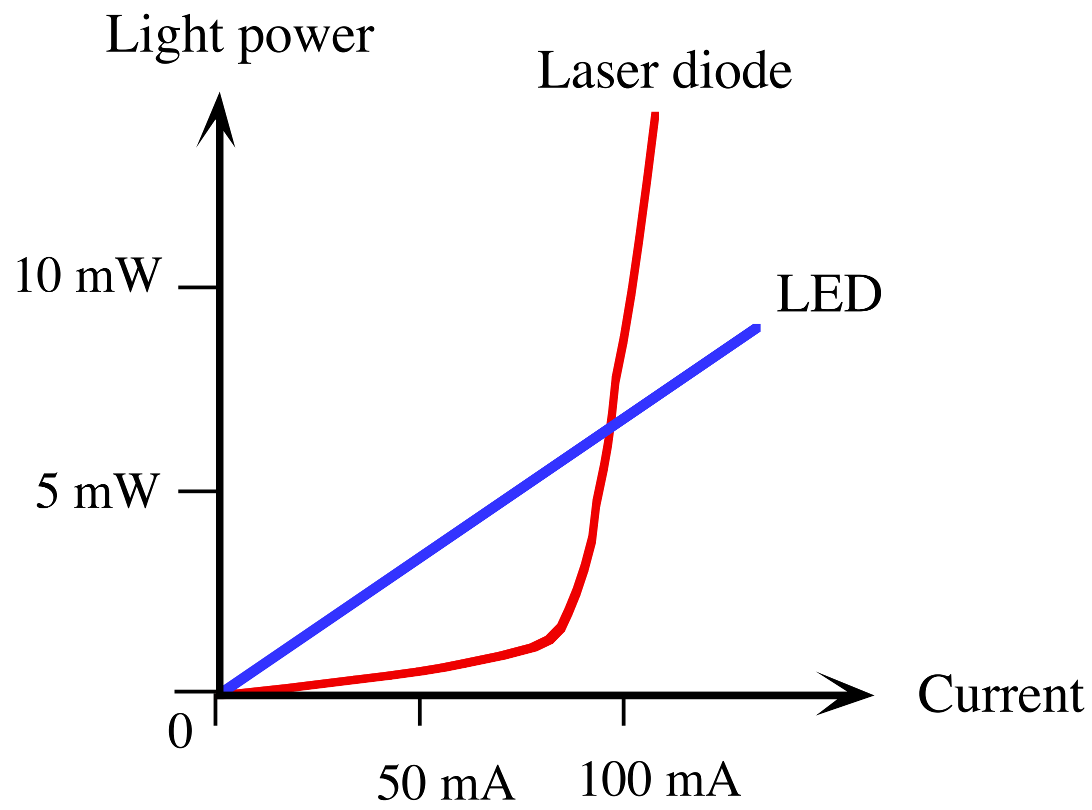
Output optical power vs. diode current as three different temperatures. The threshold current shifts to higher temperatures.



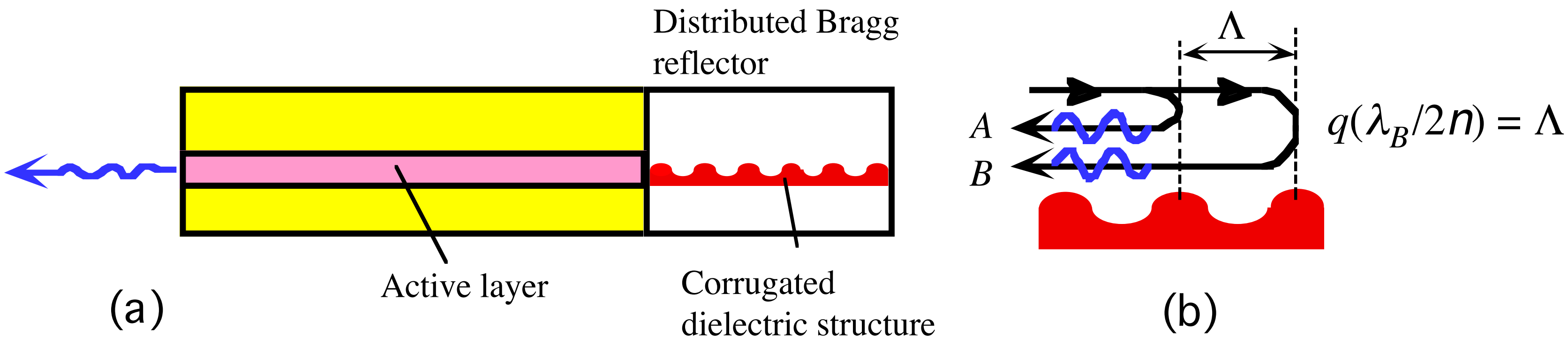
Peak wavelength vs. case temperature characteristics. (a) Mode hops in the output spectrum of a single mode LD. (b) Restricted mode hops and none over the temperature range of interest (20 - 40 °C). (c) Output spectrum from a multimode LD.



Simplified and idealized description of a semiconductor laser diode based on rate equations. Injected electron concentration n and coherent radiation output power P_o vs. diode current I.

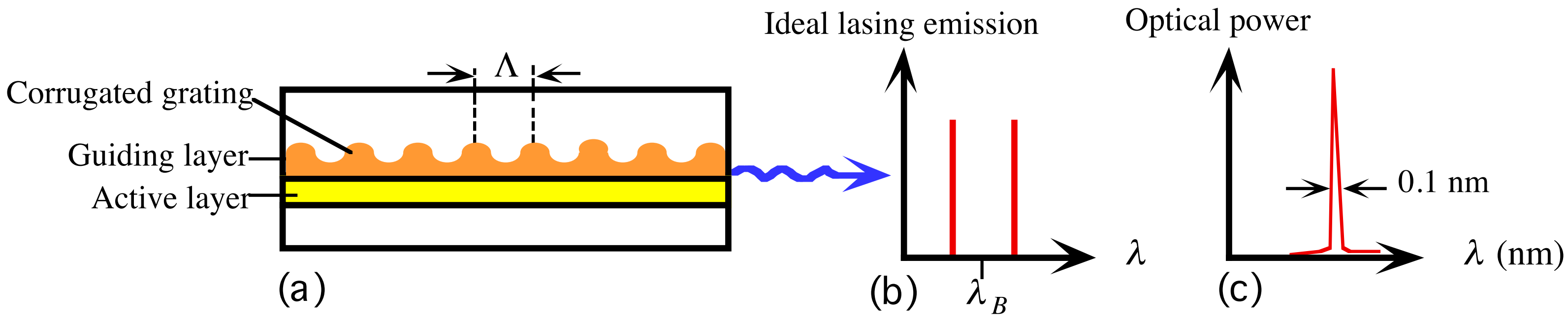


Typical optical power output vs. forward current for a LED and a laser diode.

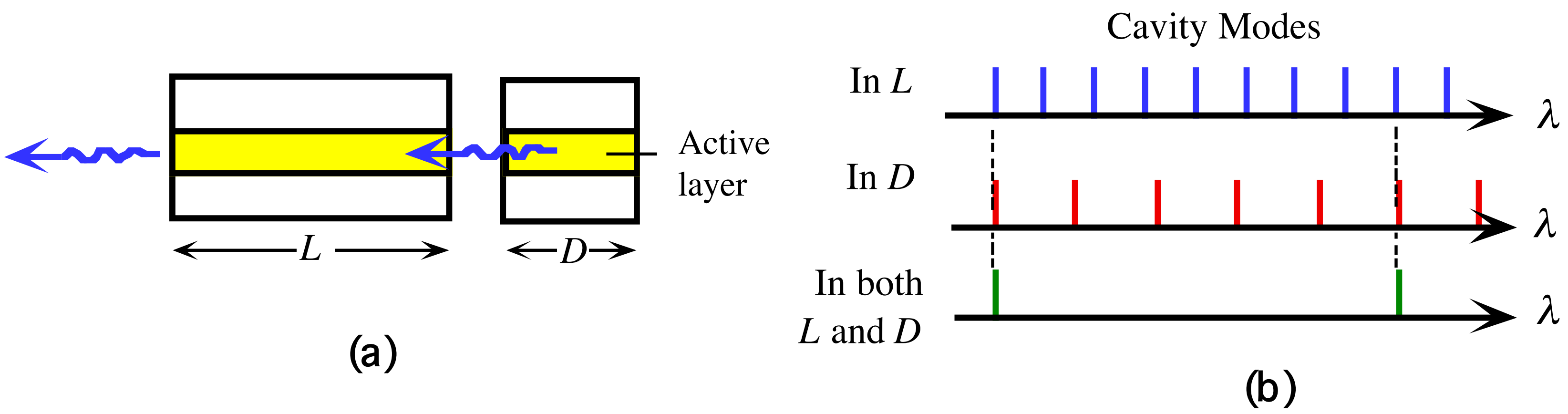


(a) Distributed Bragg reflection (DBR) laser principle. (b) Partially reflected waves at the corrugations can only constitute a reflected wave when the wavelength satisfies the Bragg condition. Reflected waves A and B interfere constructive when $q(\lambda_B/2n) = \Lambda$.

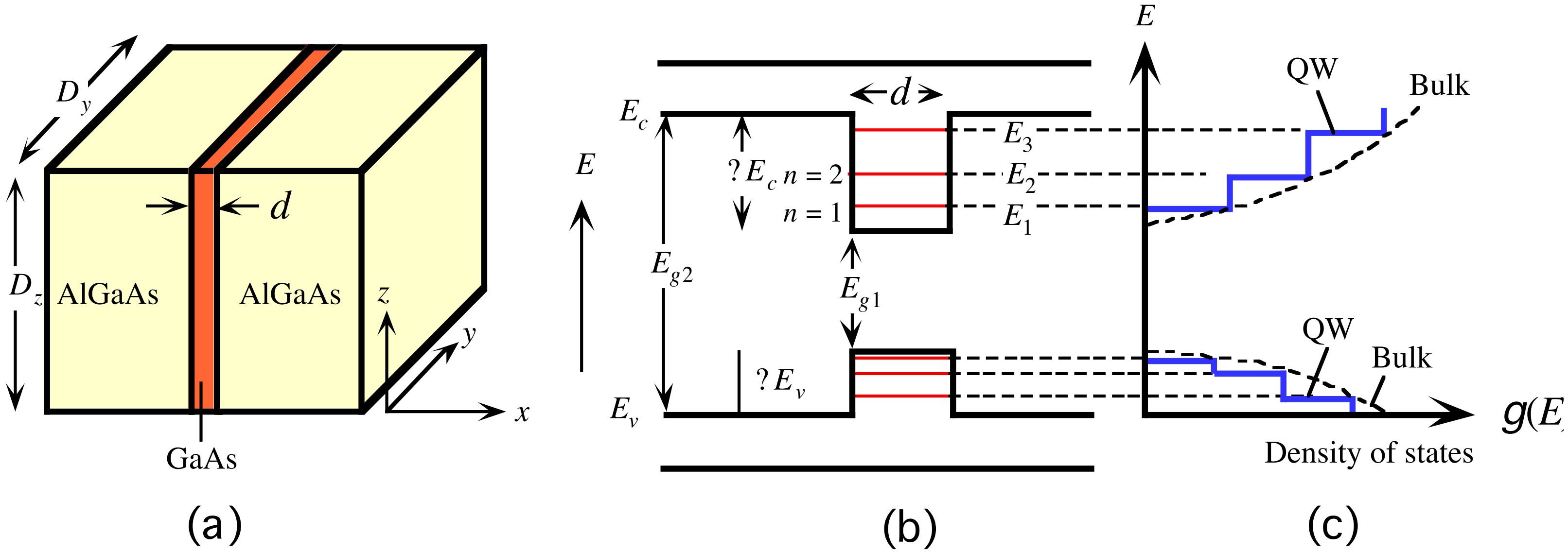
-



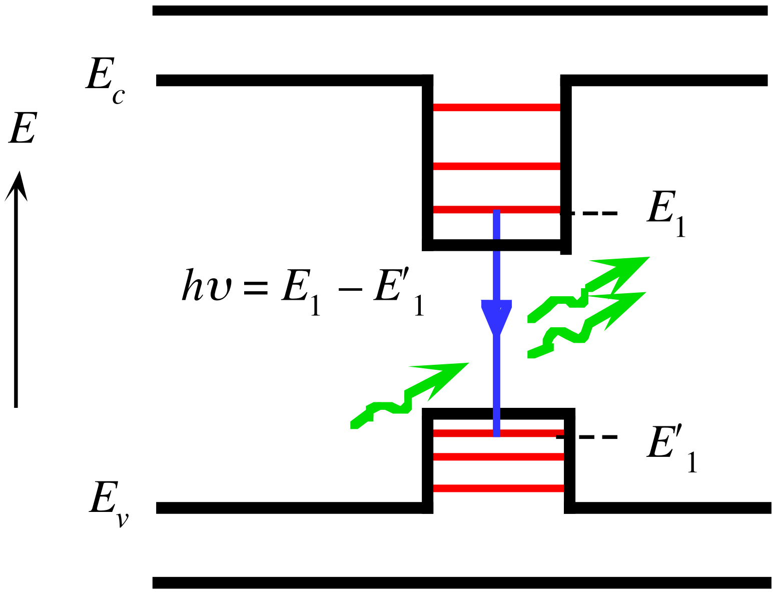
(a) Distributed feedback (DFB) laser structure. (b) Ideal lasing emission output. (c) Typical output spectrum from a DFB laser.



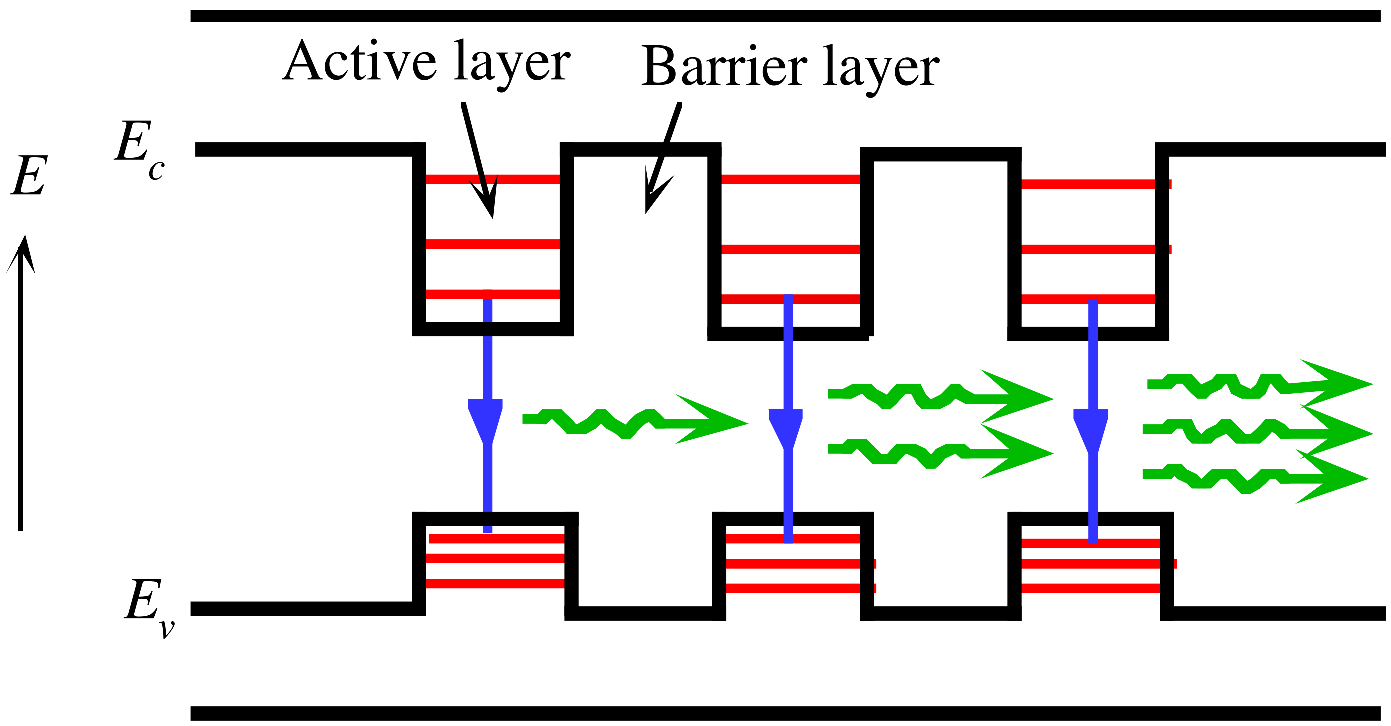
Cleaved-coupled-cavity (C^3) laser



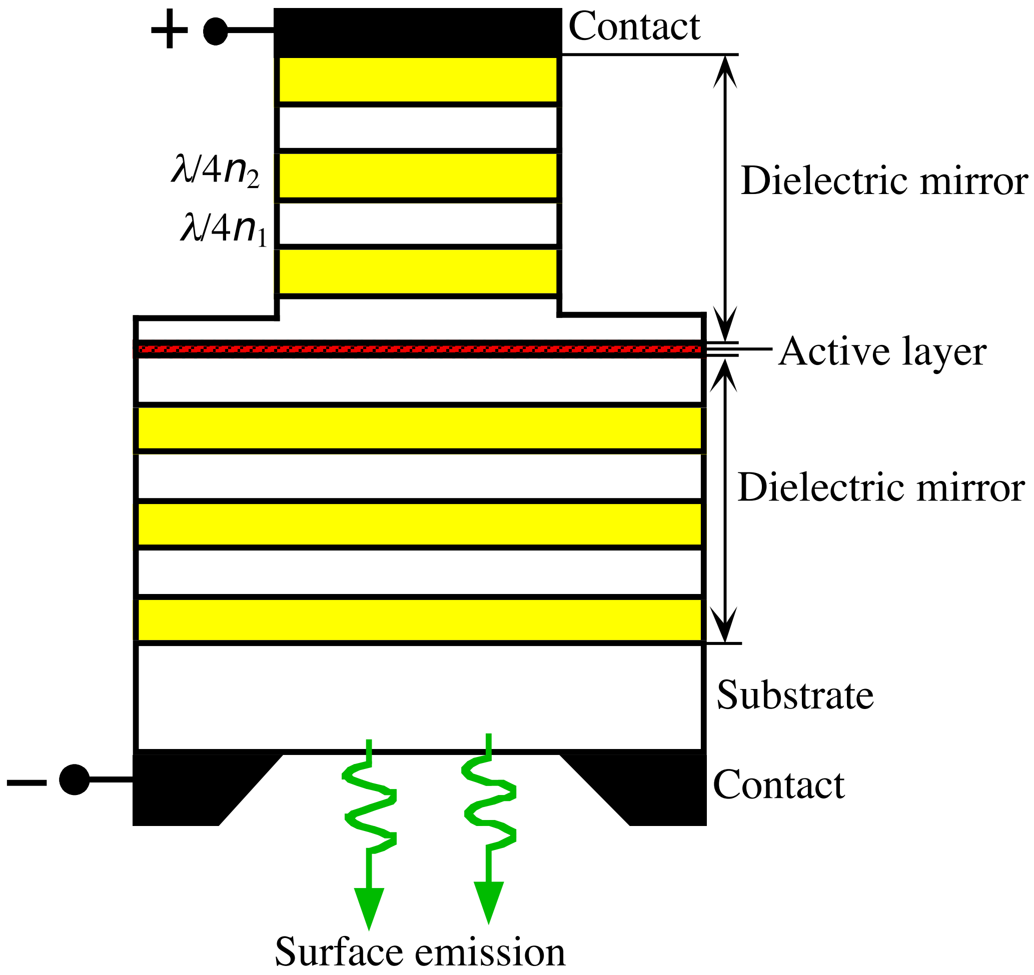
A quantum well (QW) device. (a) Schematic illustration of a quantum well (QW) structure in which a thin layer of GaAs is sandwiched between two wider bandgap semiconductors (AlGaAs). (b) The conduction electrons in the GaAs layer are confined (by ? E_c) in the *x*-direction to a small length *d* so that their energy is quantized. (c) The density of states of a two-dimensional QW. The density of states is constant at each quantized energy level.



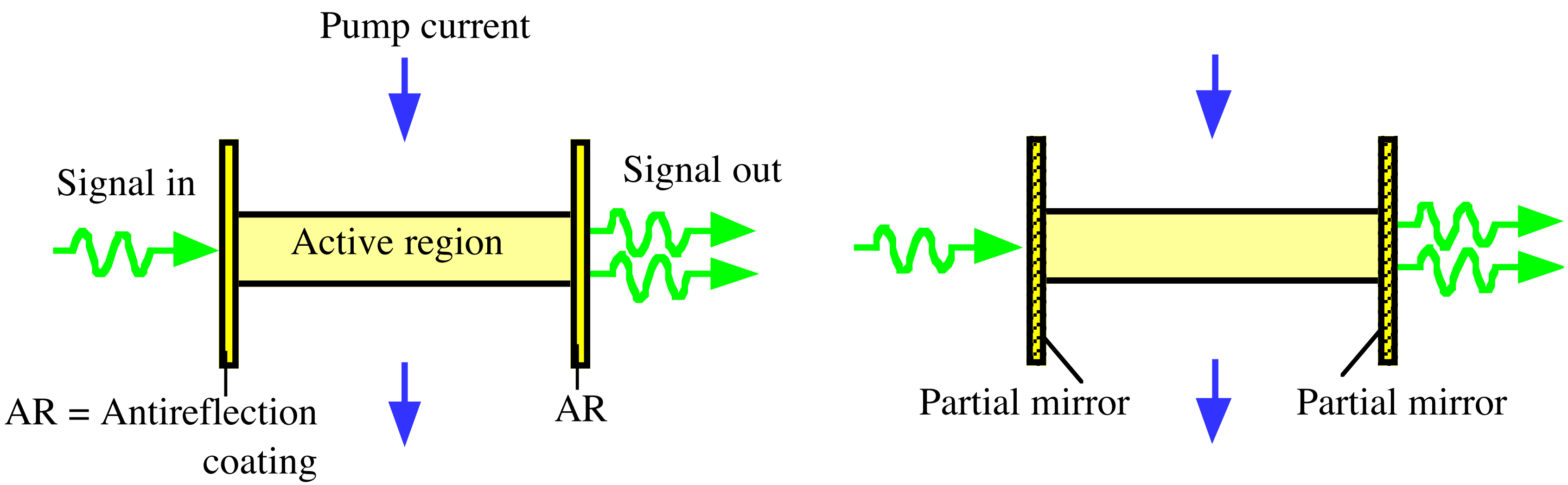
In single quantum well (SQW) lasers electrons are injected by the forward current into the thin GaAs layer which serves as the active layer. Population inversion between E_1 and E'_1 is reached even with a small forward current which results in stimulated emissions.



A multiple quantum well (MQW) structure. Electrons are injected by the forward current into active layers which are quantum wells.



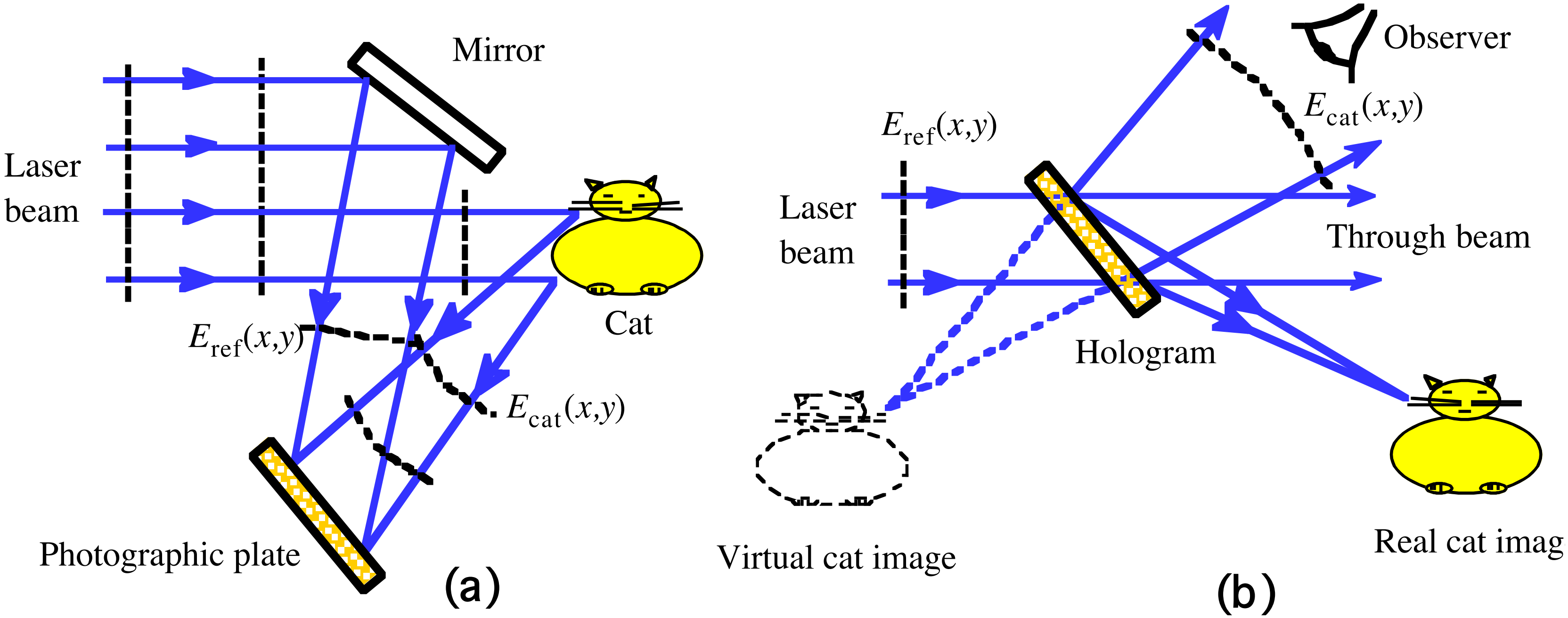
A simplified schematic illustration of a vertical cavity surface emitting laser (VCSEL).



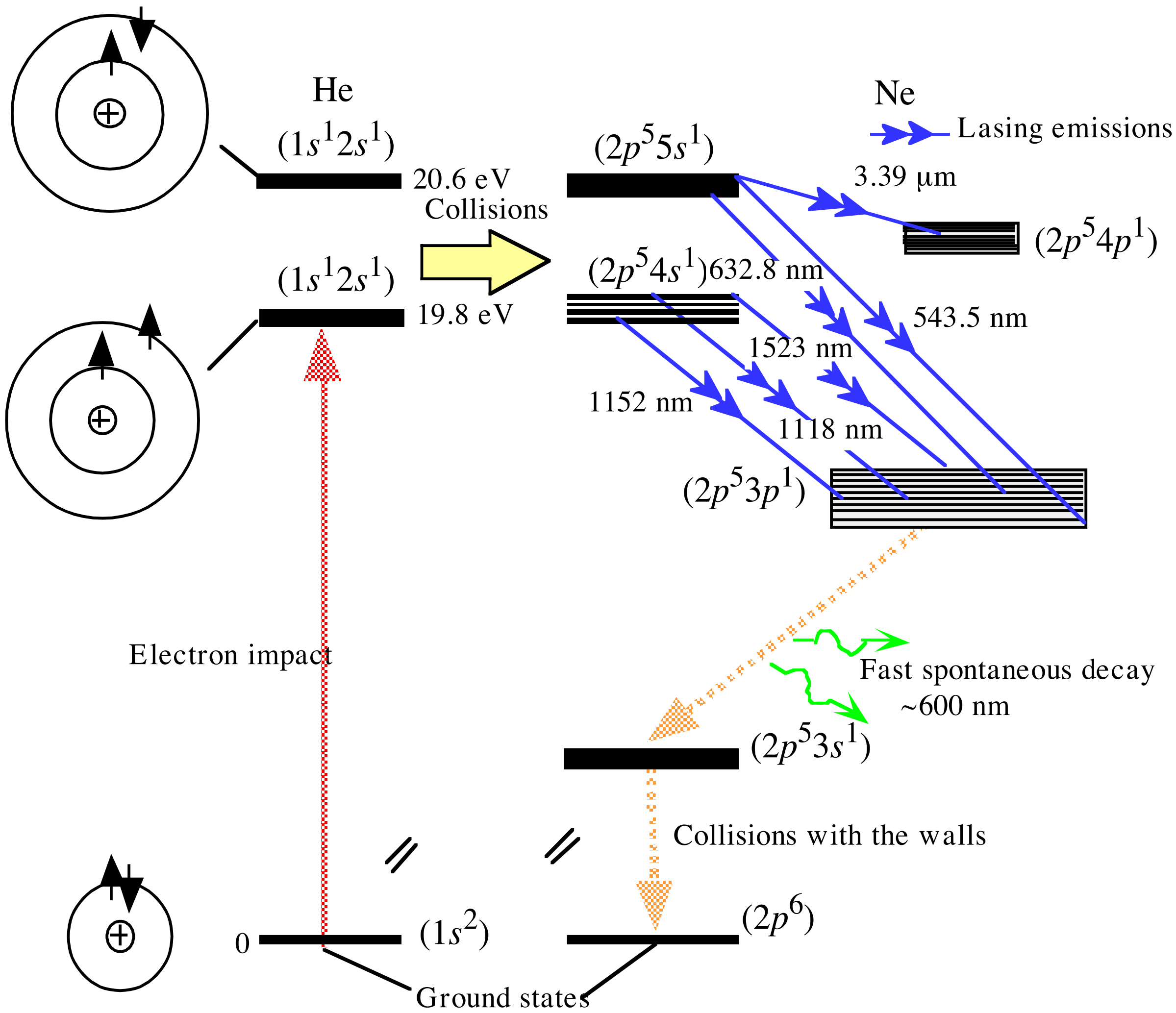
(a) Traveling wave amplifier

(a) Fabry-Perot amplifier

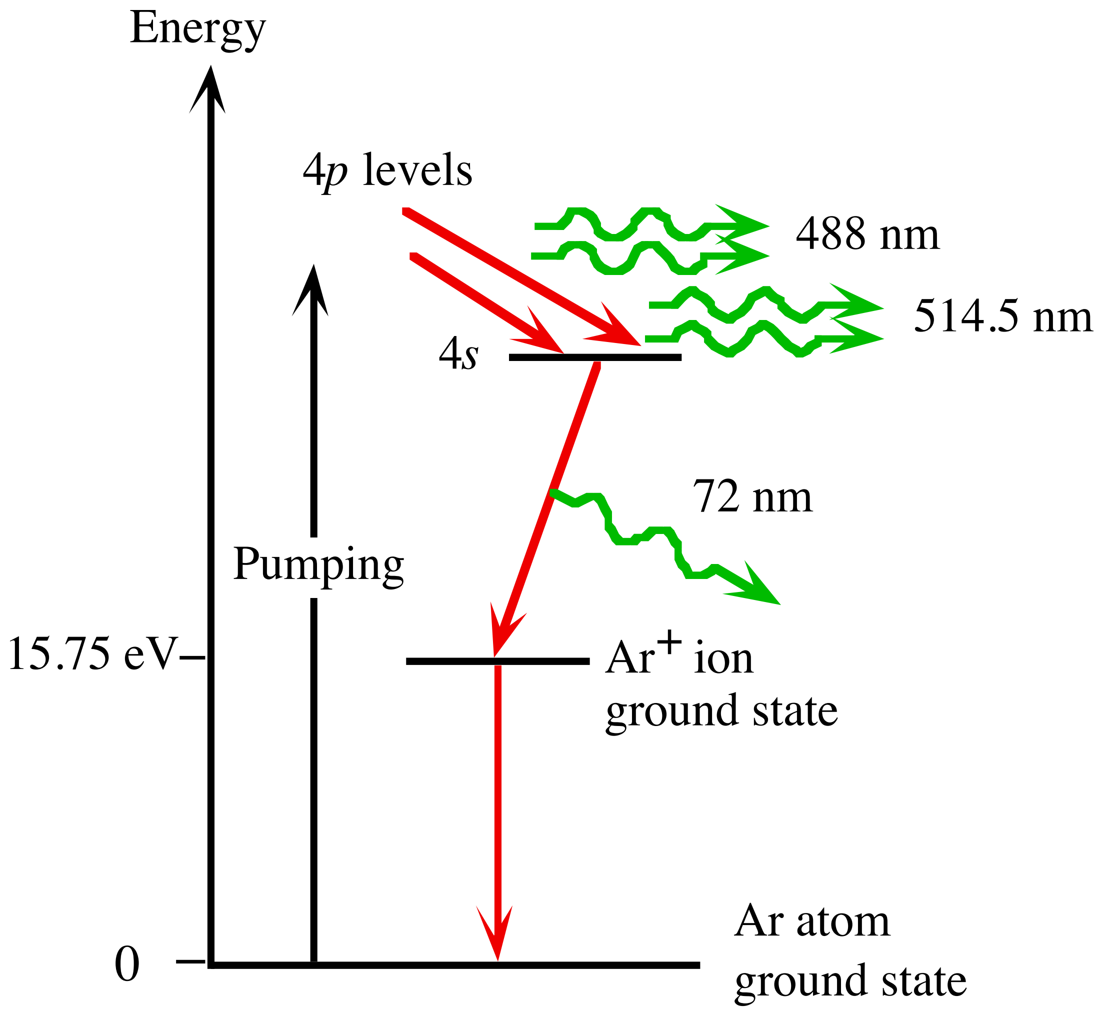
Simplified schematic illustrations of two types of laser amplifiers



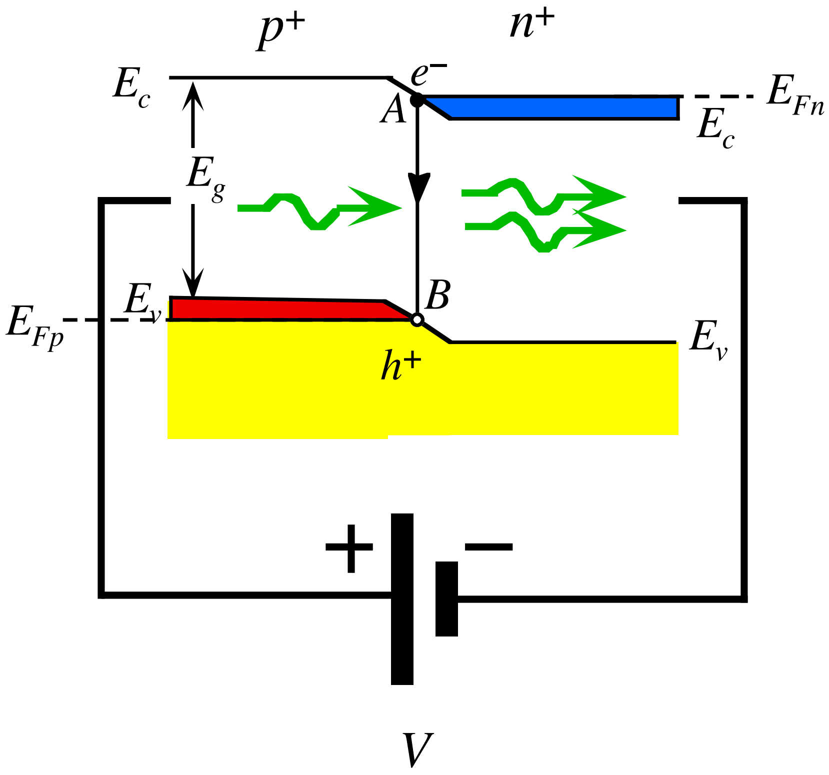
A highly simplified illustration of holography. (a) A laser beam is made to interfere with the diffracted beam from the subject to produce a hologram. (b) Shining the laser beam through the hologram generates a real and a virtual image.



Various lasing transitions in the He-Ne laser



The Ar-ion laser energy diagram



The energy band diagram of a degenerately doped *p-n* with with a sufficientl large forward bias to just cause population inversion where *A* and *B* overlap.