PH 201

OPTICS & LASERS

Lecture_Lasers_14

Ref.: William T. Silfvast, *Laser Fundamentals*, 2nd ed., Cambridge Univ. Press (2004)

Types of Lasers

Based on lasing levels

Three-level system

Four-level system

Based on medium

Gas lasers

He-Ne, He-Cd, Ar^+

Solid-state lasers

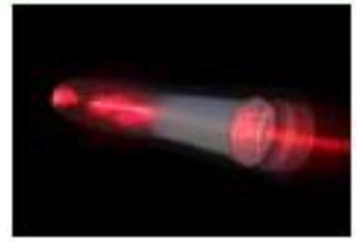
Nd:YAG, Nd:YLF, Nd:YVO_4

Semiconductor lasers

GaAs, GaN, InSb

- Edge emitting
- Surface emitting (VCSEL)

Types of Lasers



Gas Lasers

Solid State Lasers

Semiconductor Lasers

Excimer Lasers

etc etc

Gaseous (low-density) gain media are used in approx. half of the existing commercial lasers.

For very short wavelength lasers, gaseous or plasma media remains a dominant media.

Solid state lasers are compact & have increased reliability.

Atomic Gas Lasers

Atomic gas lasers, including lasers in low-ionization-stage ions, were some of very first lasers discovered.

They characteristically have narrow discrete laser wavelengths over a wide range from 200 nm to 5 μm. There are some 1,500 – 2,000 reported atomic laser transitions.

Semiconductor lasers are rapidly becoming more available in visible spectral region & are thus being used in many applications.

Many atomic gas laser species exist normally as gases at room temp, yet many others must be ionized to produce lasers in ionized energy levels of atoms.

There are many atomic & ionic gas lasers in which species must be vaporized to produce gaseous state within which electric current produces laser excitation.
He-Cd: Cd must be heated to 300°C to vaporize.

- Atomic gas lasers are produced by applying a voltage between two electrodes at opposite ends of laser gain medium that are installed within a long cylindrical tube containing atomic species in form of low pressure gas of order of 1/1,000 to 1/100 of an atmosphere.

- Reason for low pressure is that electron temp is inversely proportional to gas pressure & directly proportional to applied voltage between electrodes.

- When voltage is applied to electrodes of laser gain medium, discharge begins to conduct through gas, which causes an electrical current to flow within discharge tube.

- This current is established by ionizing some of the atoms to produce free electrons within discharge tube that travel from cathode (-ve electrode) to anode (+ve electrode).

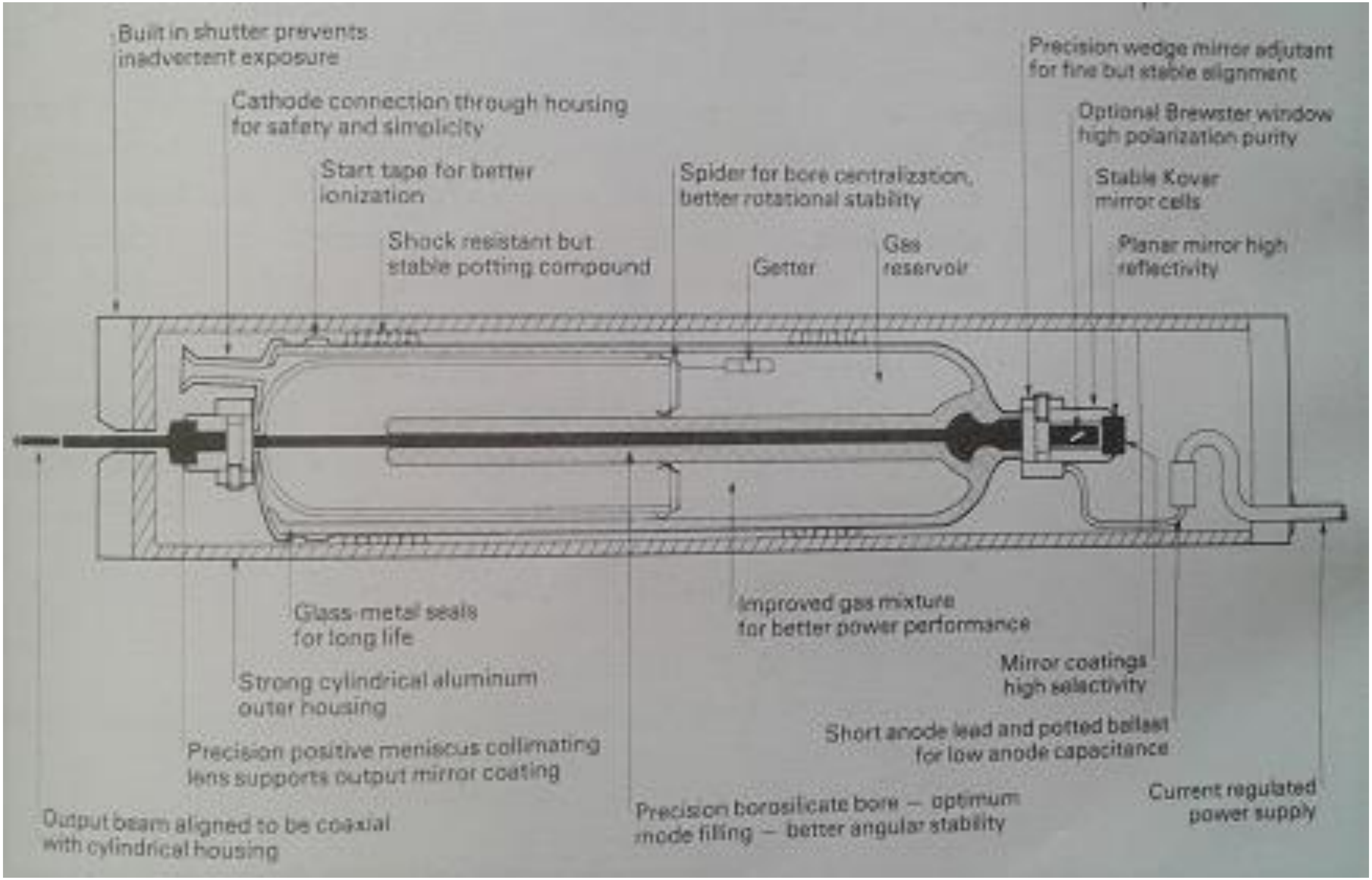
- As electrons travel through tube, they collide with atoms & sometimes excite those atoms to higher energy levels, from which they radiate back to lower levels.

HELIUM-NEON LASER

- Trouble-free & extremely long operating lifetime (~ 50,000 hours).
- Operates in a low-pressure mixture of He & Ne gases (approx. 15% Ne).
- Wavelengths: 632.8 nm, 543.5 nm, 594 nm, 612 nm, 1.523 μm, 3.39 μm.
- Power: 0.5 mW – 100 mW in red but lower on other wavelengths.
- Continuous wave (cw) & have a very stable low-noise output.
- FWHM: 1.5 GHz
- Assembly: 0.15 m – 0.5 m length

$$He(1s2s\,^1S)^* + Ne(2p^6) \rightarrow He(1s^2) + Ne(2p^5 3s)^*$$

(*) indicates an excited state.



Helium-Neon Laser

- Mixture of Ne & Ne gases (approx. 15% Ne) are introduced into a glass laser enclosure consisting of narrow-bore tube that comprises gain region: an anode region where high-voltage electrode exists & a cathode region where a large aluminium cathode is located.

- Optimum gas pressure is determined by product of pressure & tube-bore diameter, so that optimum product is 3.6 – 4.9 Torr-mm with a He:Ne pressure ratio of 5:1.

- For a discharge-bore diameter of 1.5 mm, optimum total gas pressure would be 2.5 Torr (2.5/760 = 0.0033 of an atmosphere).

- Optical cavity comprises internally mounted laser mirrors.

- If a polarized output is desired, then a Brewster angle window is inserted into laser cavity within either anode or cathode region of tube.

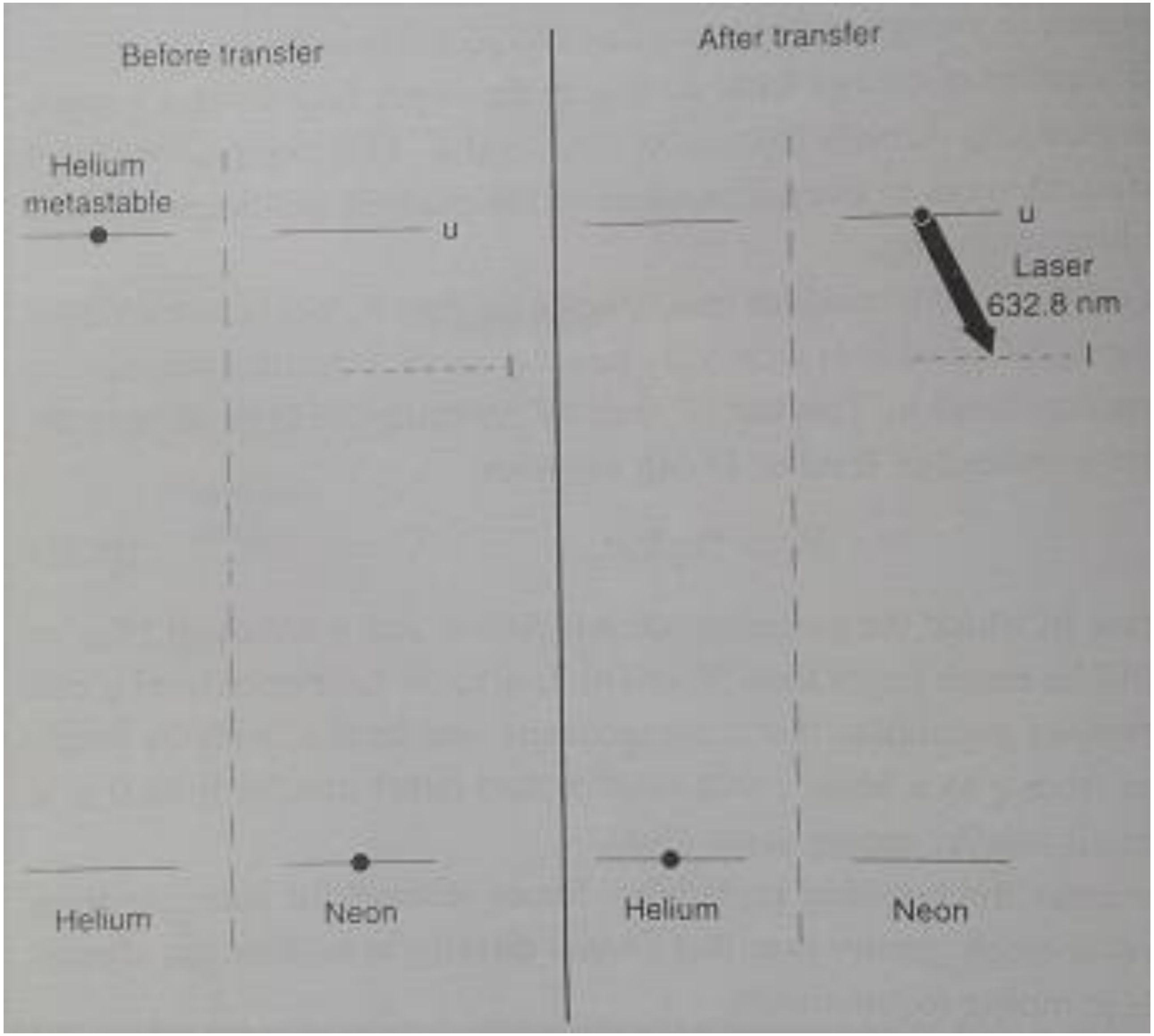
- **Power supply generally requires a high voltage of up to 1,000 V & a discharge current of a few to tens of milliamps.**

- **A higher starting voltage is used to produce initial ionization within discharge; this starting voltage is typically applied to discharge tube for only a few microseconds (or less) after starting switch is turned on.**

- **He-Ne laser operates via transfer of energy from He metastable energy levels to specific excited neutral Ne energy levels that are energetically close to He metastable levels.**

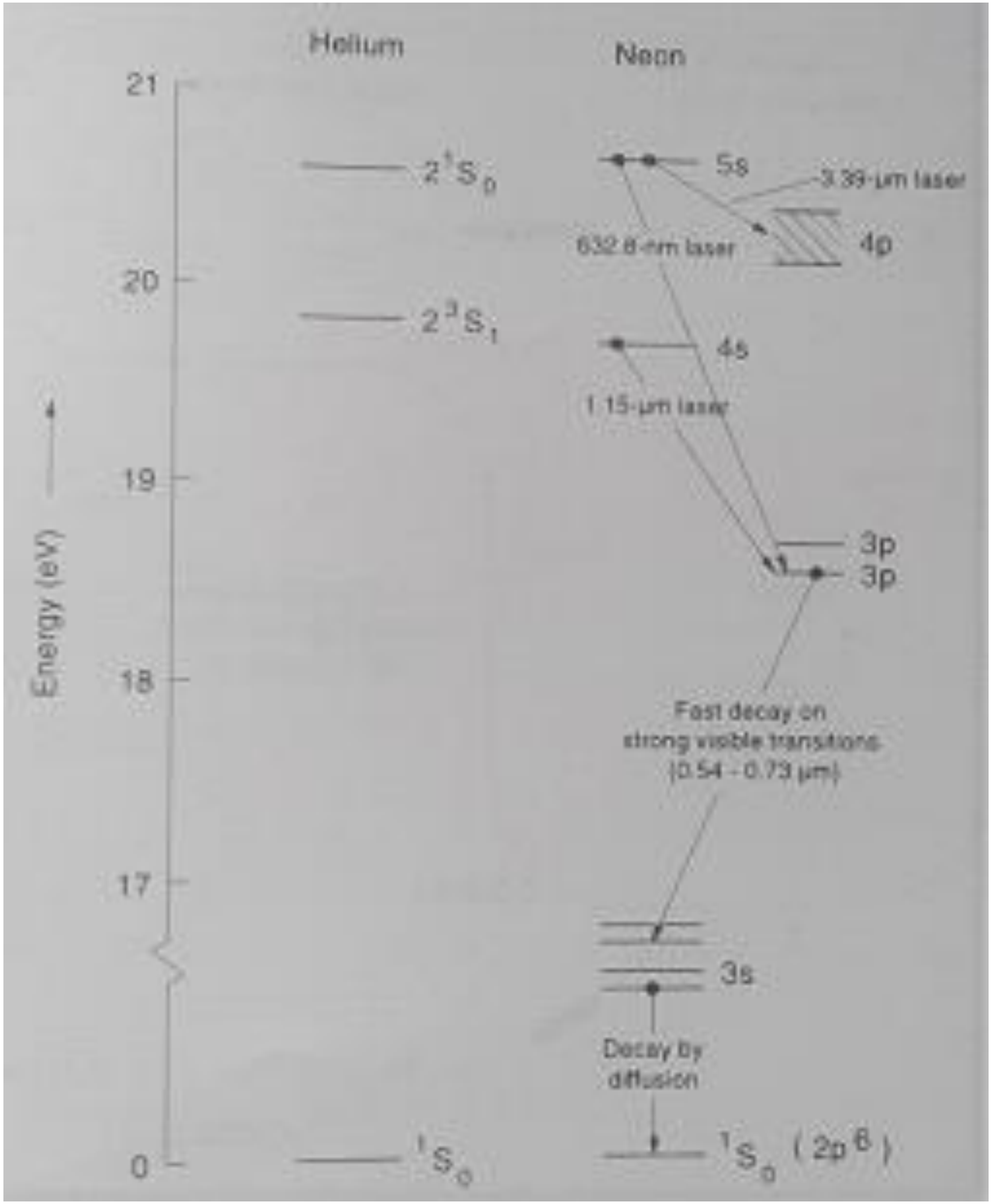
- **When discharge is initiated within laser bore region, discharge electrons, which comprise discharge current, collide with both He-Ne atoms & provide excitation to excited levels of both He & Ne.**

- **He metastable levels acquire population densities of order of $10^{17}/m^3$, which is approx. 3 orders of magnitude higher than that of other excited energy levels of atoms within discharge.**

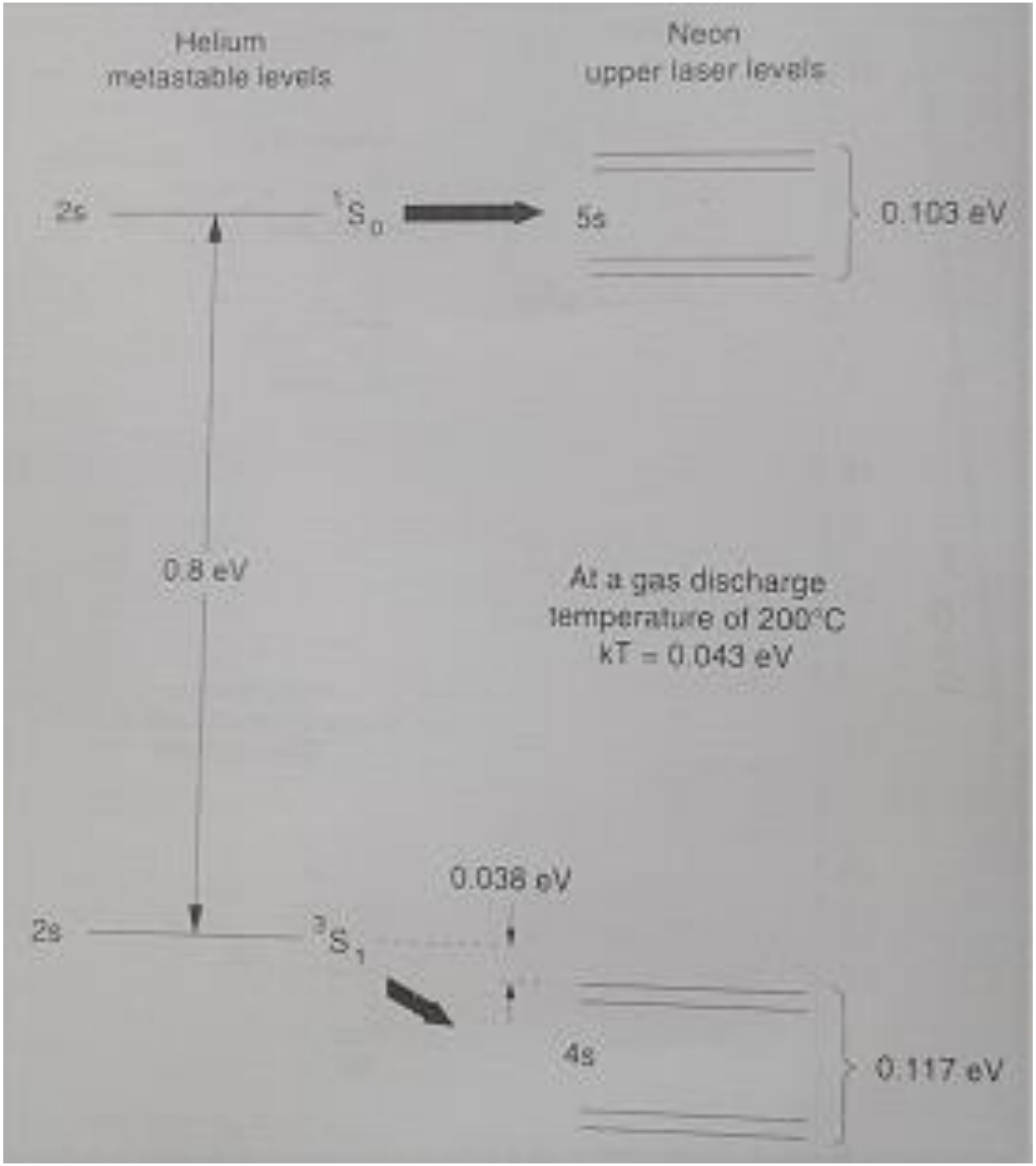


General energy level diagram for He-Ne laser

Relevant energy levels of He-Ne laser in which transfer-across process is used.



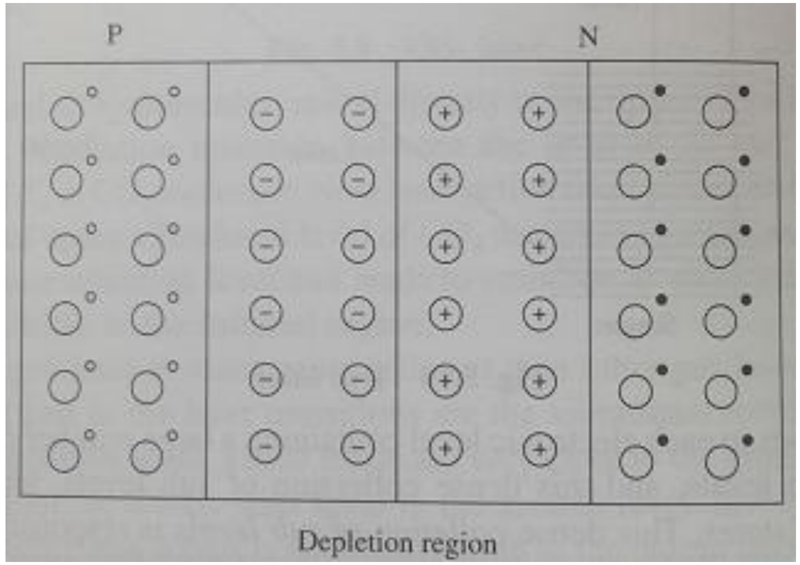
Collisional transfer of energy illustrated by relationship to Helium metastable levels in a He-Ne laser



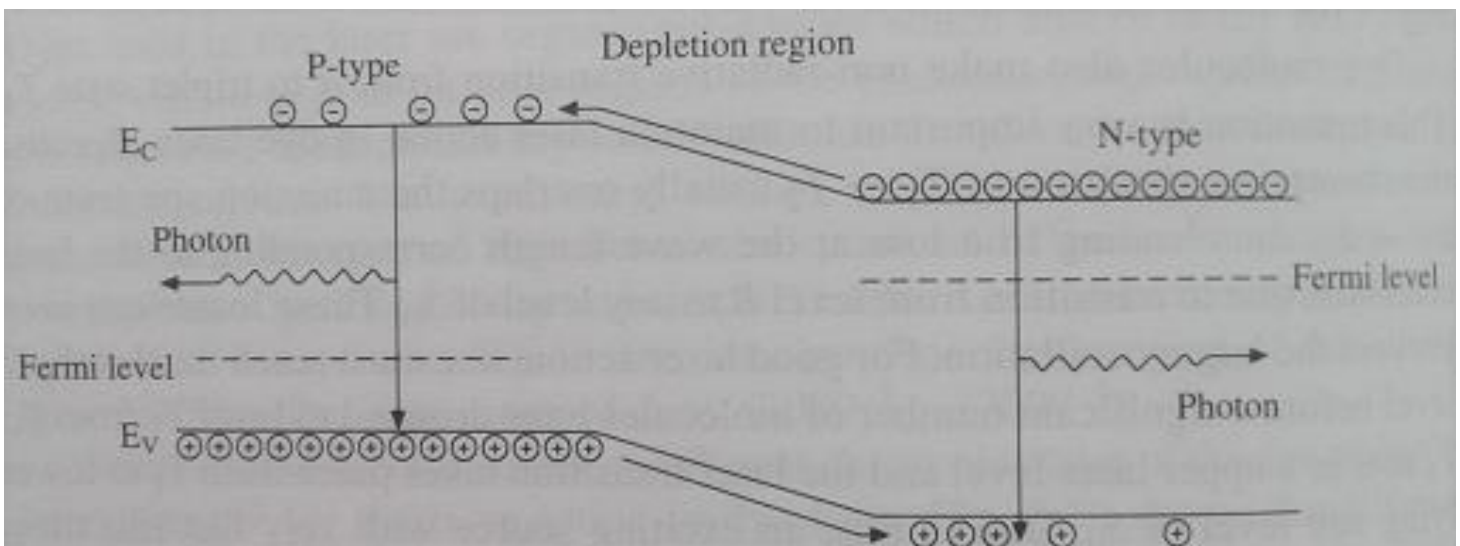
Typical He-Ne Laser parameters

Laser wavelengths (λ_{ul})	632.8 nm	543.5 nm
Laser transition probability (A_{ul})	3.4×10^6/s	2.83×10^5/s
Upper laser level lifetime (τ_u)	3×10^{-8} s	
Stimulated emission cross section (σ_{ul})	3×10^{-17} m^2	2×10^{-18} m^2
Spontaneous emission linewidth and gain bandwidth, FWHM ($\Delta\nu_{ul}$)	1.5×10^9 Hz (Doppler)	1.5×10^9 Hz
Inversion density (ΔN_{ul})	5×10^{15}/m^3	
Small-signal gain coefficient (g_0)	0.15/m	
Laser gain-medium length (L)	0.1–1.0 m	
Single-pass gain ($e^{\sigma_{ul} \Delta N_{ul} L}$)	1.015–1.16	
Gas pressure	2.5 Torr	
Gas mixture	He : Ne at 5 : 1	
Index of refraction of gain medium	≈1.0	
Pumping method	electrical discharge	
Electron temperature	15,000–20,000 K	
Gas temperature	400 K	
Mode of operation	cw	
Output power	0.5–100 mW	
Mode	TEM$_{00}$	

Semiconductor Diode Lasers



Formation of depletion region in P-N junction



Recombination of carriers under forward bias in P-N junction

Semiconductor Diode Lasers

- **Very small, operate with low power input, & very efficient.**

- **Require merging of two different materials & laser action occurs in interface between those two materials.**

- **One of the materials has an excess of electrons (*n*-type) & other has material (*p*-type). [*p*-type has a deficit of electrons or an excess of holes (missing electrons)]**

- **When a forward bias voltage is placed across this junction, electrons are forced into region from *n*-type material & holes are forced into junction from *p*-type material.**

- **These electrons (-ve) & holes (+ve) are attracted to each other, & when they collide, they neutralize each other & in the process emit recombination radiation.**

- **Electrons in *n*-type material exist (at normal operating temp) at a higher energy (conduction band) than holes (valence band).**

- **Energy difference is designated as *bandgap* of material; amount of energy that is released when recombination radiative process occurs.**

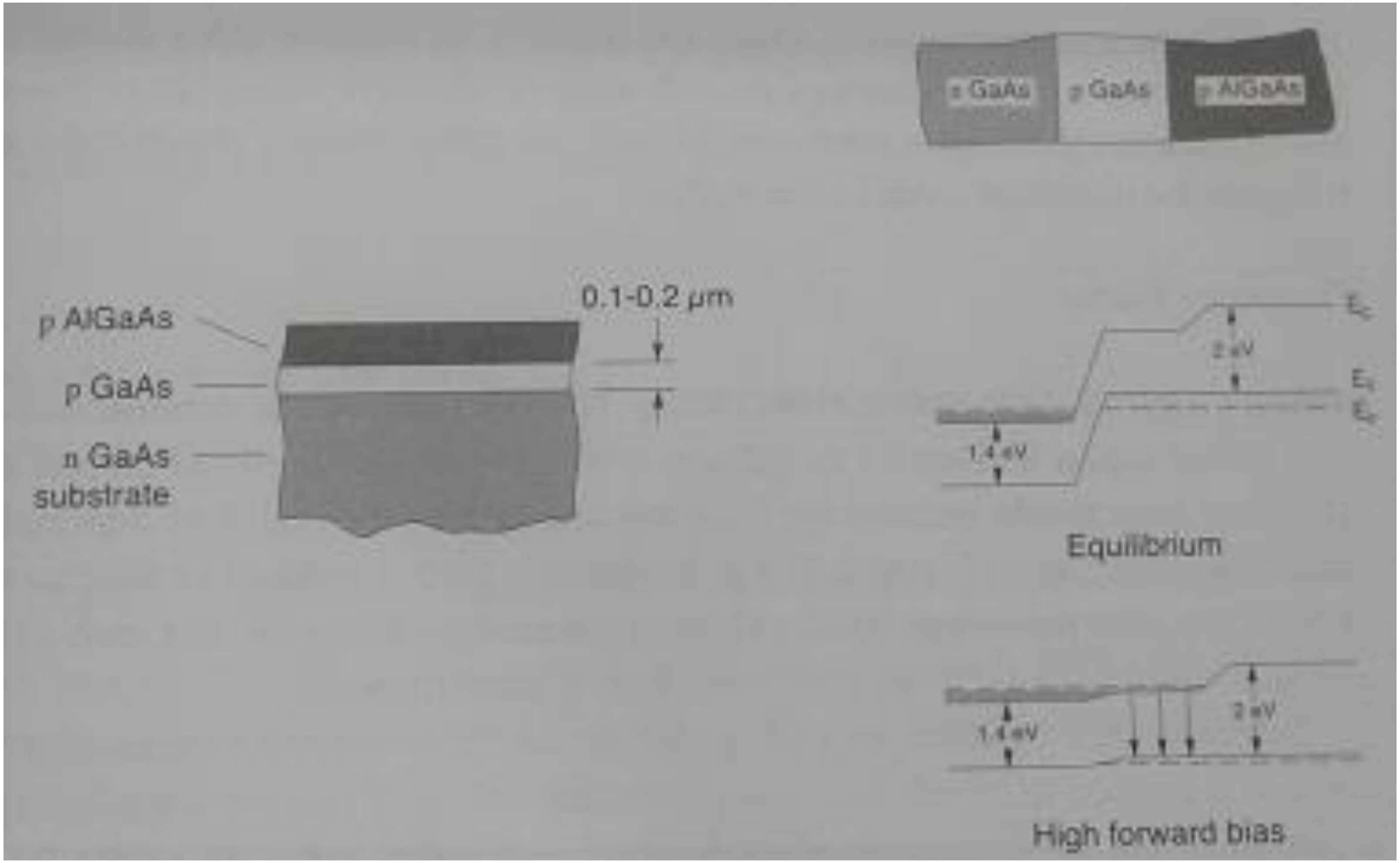
- **Different material combinations have different bandgaps & thus emit different wavelengths of light.**

- **When forward bias voltage is applied across the junction, it produces a current flow in the form of electrons (& holes) flowing into junction. If current is low, incoherent light is emitted from the junction when recombination process occurs – <u>Light Emitting Diode</u> (LED).**

- **If current is high enough that there are more electrons in conduction band at a given energy than in valence band, then a population inversion exists & gain is produced.**

- **Gain coefficient (g_0) is between 5,000 & 10,000 m^{-1}.**

- **Gain bandwidth: 10^{13} Hz or 20 nm.**



A simple heterojunction semiconductor laser material, showing critical dimensions & energy levels both at equilibrium & with an applied forward bias

Bandgap energies of several semiconductor laser compounds

Material	Abbreviation	Bandgap energy (in eV at 300 K)
III–V Compounds		
Aluminum arsenide	AlAs	2.16
Aluminum phosphide	AlP	2.45
Aluminum antimonide	AlSb	1.58
Boron nitride	BN	7.5
Boron phosphide	BP	2.0
Gallium arsenide	GaAs	1.42
Gallium nitride	GaN	3.36
Gallium phosphide	GaP	2.26
Gallium antimonide	GaSb	0.72
Indium arsenide	InAs	0.36
Indium phosphide	InP	1.35
Indium antimonide	InSb	0.17
II–VI Compounds		
Cadmium sulfide	CdS	2.42
Cadmium selenide	CdSe	1.70
Cadmium telluride	CdTe	1.56
Zinc sulfide	ZnS	3.68
Zinc selenide	ZnSe	2.71
Zinc telluride	ZnTe	2.393

Semiconductor Lasers

Edge emitting lasers

Surface emitting lasers

<u>Edge emitting lasers</u> have laser beam parallel to surface of junction region. Mirrors are produced by using cleaved surfaces at ends of laser crystal or by distributed feedback within crystal or distributed Bragg reflecting structures at ends of crystal.

<u>Surface emitting lasers</u> have laser beam emitting in a direction perpendicular to junction region with multilayer Bragg reflecting mirrors incorporated into crystal.

Four Basic Types of Laser Materials

1. **Gallium Arsenide-based lasers (Red & IR region: 635 nm – 870 nm)** **GaAs-based, AlGaInP: CD-ROM, DVD-ROM, Plastic optical fiber (short distance communication)**

2. **Indium Phosphide-based lasers (1.55 µm) InGaAs/InP (long distance communication)**

3. **Zinc Selenide-based lasers (460 nm – 520 nm) ZnCdSe, ZnSSe (problem with long term operation)**

4. **Gallium Nitride-based lasers (Blue & UV: 405 nm) GaN: CD or DVD**