19a. Lasers

Definitions

Coherent: Light waves which are in phase with each other.
Collimated: Light emitted travels in the same direction (highly directional). It can be focused into a tiny spot, achieving very high intensity.
Monochromatic: Light consists of only one wavelength.
Population inversion: When there are more atoms in the excited state than in the ground state.
Metastable state: Atoms stay in the excited state for a longer time of 10^{-3} seconds as compared to the usual 10^{-8} seconds, before falling to a lower energy level.

Stimulated emission: Stimulated emission is the process whereby an incident photon of appropriate energy triggers the emission of another photon of the same energy from excited atoms. The emitted photon has the exact same frequency, energy, amplitude, direction and polarisation as the incident photon.

- In the **2 level laser system**, it will not work with optical pumping as it is not possible to pump more than half of the population of atoms to the excited state for stimulated emissions. The energy being used to excite the atoms has an equal probability of stimulating them back down to the ground state, therefore population inversion is not possible.
- In the **4 level laser system**, a modest amount of pumping is enough to create population inversion as there are very few atoms in the lower laser level (the one just above the ground level, i.e. the level which is involved in stimulated emission) and hence greatly decreases **the loss of triggering photons by absorption processes**, i.e. there are not many atoms in the lower laser level to absorb the triggering photons (laser photons).
- Stimulated emission helps to achieve coherence, but collimation and monochromatic property is achieved by using the appropriate lasing medium and the use of 2 mirrors fixed at the ends of the lasing medium.
- Spontaneous emission: Photon emitted spontaneously and in a random direction.
- Stimulated emission: Photon emitted has the same phase, energy (frequency and wavelength), polarization and direction of travel as the incoming photon.
- Optical pumping: the excitation of atoms from a lower energy level to a higher energy level using light of the correct frequency such that the energy difference between the two levels is equal to hf.
- Electrical pumping: colliding atoms with energetic electrons.

Questions

1. Explain why a laser can cut metals but normal light can't.
Ans: Laser light is unidirectional and highly collimated, where the intensity of light is concentrated in a smaller area, thus delivering more power per unit area and hence is more penetrating.

2. Explain how stimulated emission results in the laser properties.
Ans: Stimulated emission causes emission of photons that are identical in frequency, wavelength, phase, direction and polarisation. The resultant beam is thus highly **coherent**, **collimated**, **monochromatic** and **intense**.

3. Using the band theory, explain how doping changes the conductivity of silicon for n-type semiconductors.
Ans: In an n-type semiconductor, a small amount of element with 5 outer electrons is added to semiconductor silicon. In silicon atoms doped with arsenic atoms, the extra electrons do not fit into the crystal lattice, are loosely bounded and so are free to move about. This semiconductor is called n-type as the majority charge carriers are electrons. The impurity energy level is just below the conduction band and hence electrons in this level need only about 0.05eV of energy to reach the conduction level; hence this transition occurs readily at r.t.p.

4. Explain what is meant by population inversion and why it is important in laser production.
Ans: Population inversion is a situation in which a system of atoms has more of its atom in a higher energy state than in a lower energy state. When this happens, the probability that a single photon will cause stimulated emission is higher than the probability that the photon will be absorbed. Hence, stimulated emission dominates, resulting in amplification of identical photons and lasing happens.

5. Explain why it is important to excite atoms to the metastable state.
Ans: With atoms in the metastable state, they can remain in the excited state longer, allowing sufficient time for population inversion to be achieved. During population inversion, a photon with an energy equals to the difference between the 2 energy levels can cause stimulated emission to take place, rather than absorption/The probability that a single photon will cause stimulated emission is higher than the probability that the photon will be absorbed.

6. State and explain the conditions required for lasing.
Ans:
- Atoms must be excited to a metastable state to bring about stimulated emission of coherent photons of the same energy.
- Population inversion must be attained by atoms in order to cause amplification of the lasing photons through stimulated emission.
- Emitted photons must be confined in the system long enough by means of reflection from 2 parallel mirrors to allow them to stimulate further emissions from the excited atoms of the lasing medium.

7. Explain why a 4 level lasing system is better than a 3 level lasing system.
- 4 level ensures that there is always population inversion
- Lower energy undergoes rapid spontaneous emission to ground state, therefore reducing the loss of photons to stimulated absorption between the lower and upper level.

19b. Semiconductors
Valence band: Highest energy band completely filled by electrons.
Conduction band: The next highest band which is empty/not completely filled.
- Bands of lower energy are narrower than those of higher energy because electrons that occupy the lower energy bands spend most of their time deep within the atom's electron cloud. The wave functions of these core electrons at lower energy bands do

not overlap as much as the wave functions of the outer electrons at higher energy band and hence splitting of the lower energy levels are less.

- At higher temperatures, more electrons can be promoted to the conduction band in semiconductors hence increasing the number density of charge carriers and thus increasing the conductivity of the semiconductor.
- Note that energy bands only applies for solids! (lattice solids) for gases, on a energy against interatomic separation graph, will be two distinct straight line.

<u>Questions</u>

1. Explaining the origins of the depletion region.

Ans: In the narrow region near the p-n junction, electrons diffuse from the n-type side through the junction into the p-type side while holes diffuse from the p-type side to the n-type side. The electrons and holes in the region then tend to recombine, forming a region virtually free of mobile charge carriers. Since electrons move from the n-type side to the p-type side and holes in the opposite direction, the n-type side becomes positively charged and the p-type side becomes negatively charged. These immobile charge ions set up a contact potential difference, forming an electric field in the depletion region. At equilibrium, the electric field is strong enough to prevent further diffusion of electrons from the n-type side to the p-type side. The potential difference can be seen as a potential energy barrier, preventing further migration of mobile charge carriers.

2. Explain how forward/reverse bias works.

Ans: (say which is made more/less positive/negative) In forward bias, the height of the contact potential is decreased. During forward bias holes from the p-type side and electrons from the n-type side are pushed into the depletion layer from both sides, resulting in the narrowing of the depletion layer and hence smaller space charge. In reverse bias, the height of the potential barrier is increased and the width is also widened. This is because holes in the p-type and electrons in the n-type near the depletion region are pulled away, thus creating more space charge.